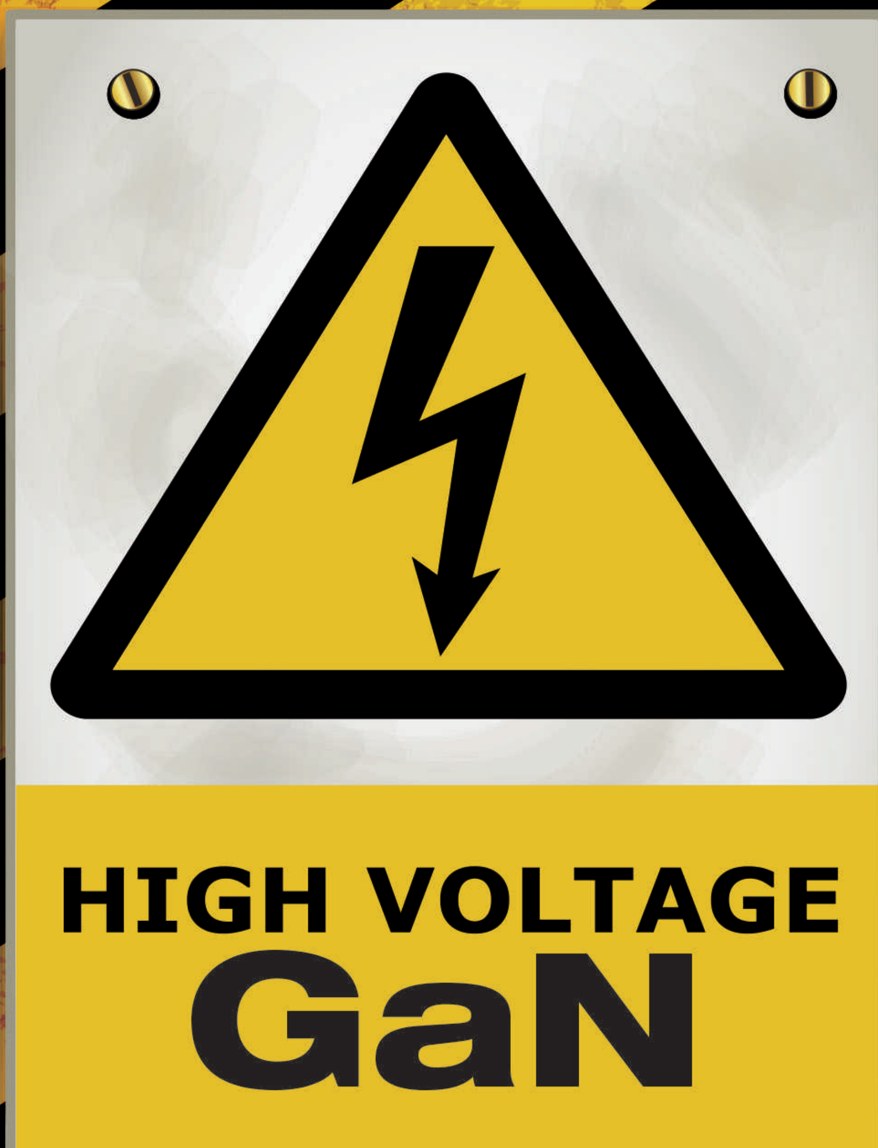
Vol. 62 • No. 9
September 2019

Microwave Journal



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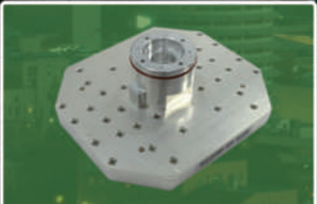
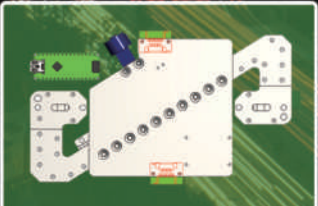


Diplexer with Built in OMT

5G Millimeter Wave Patch Antenna



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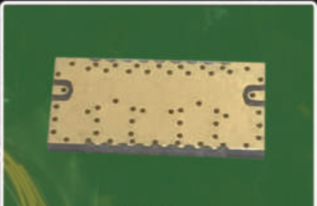
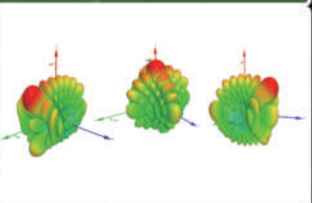
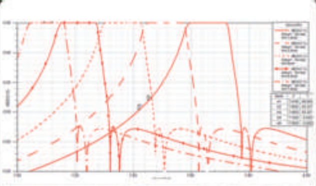


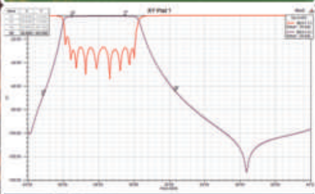
5G Millimeter Wave Filter



Pattern of 5G Millimeter Wave Patch Antenna



Test Curve of Tunable Filter



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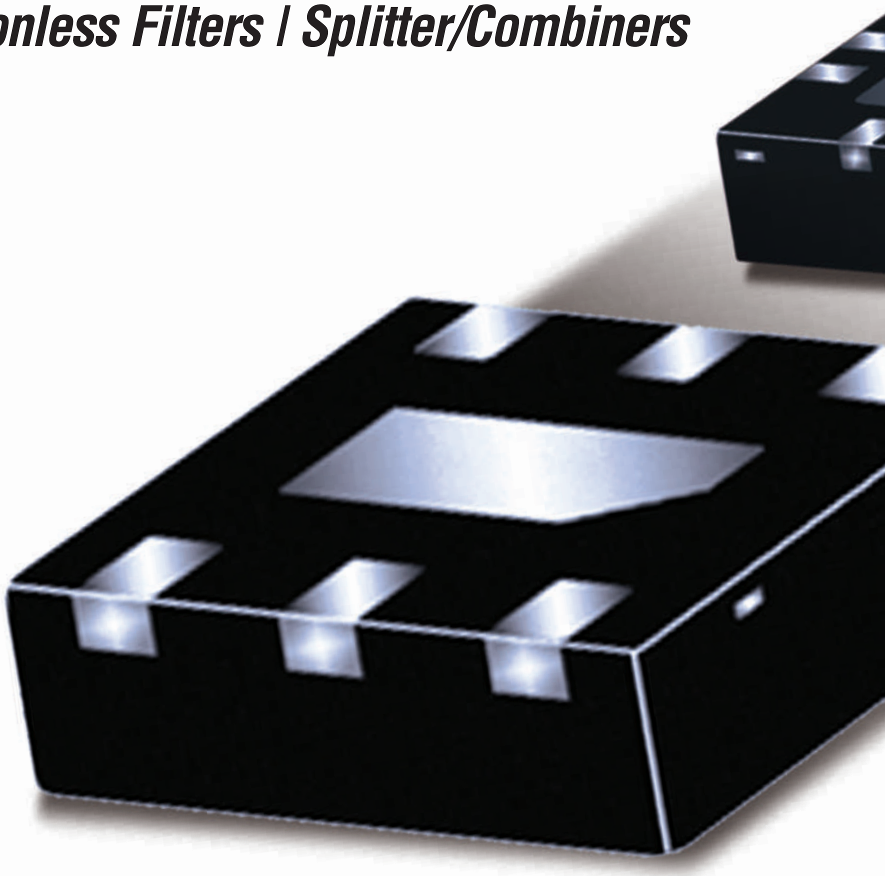

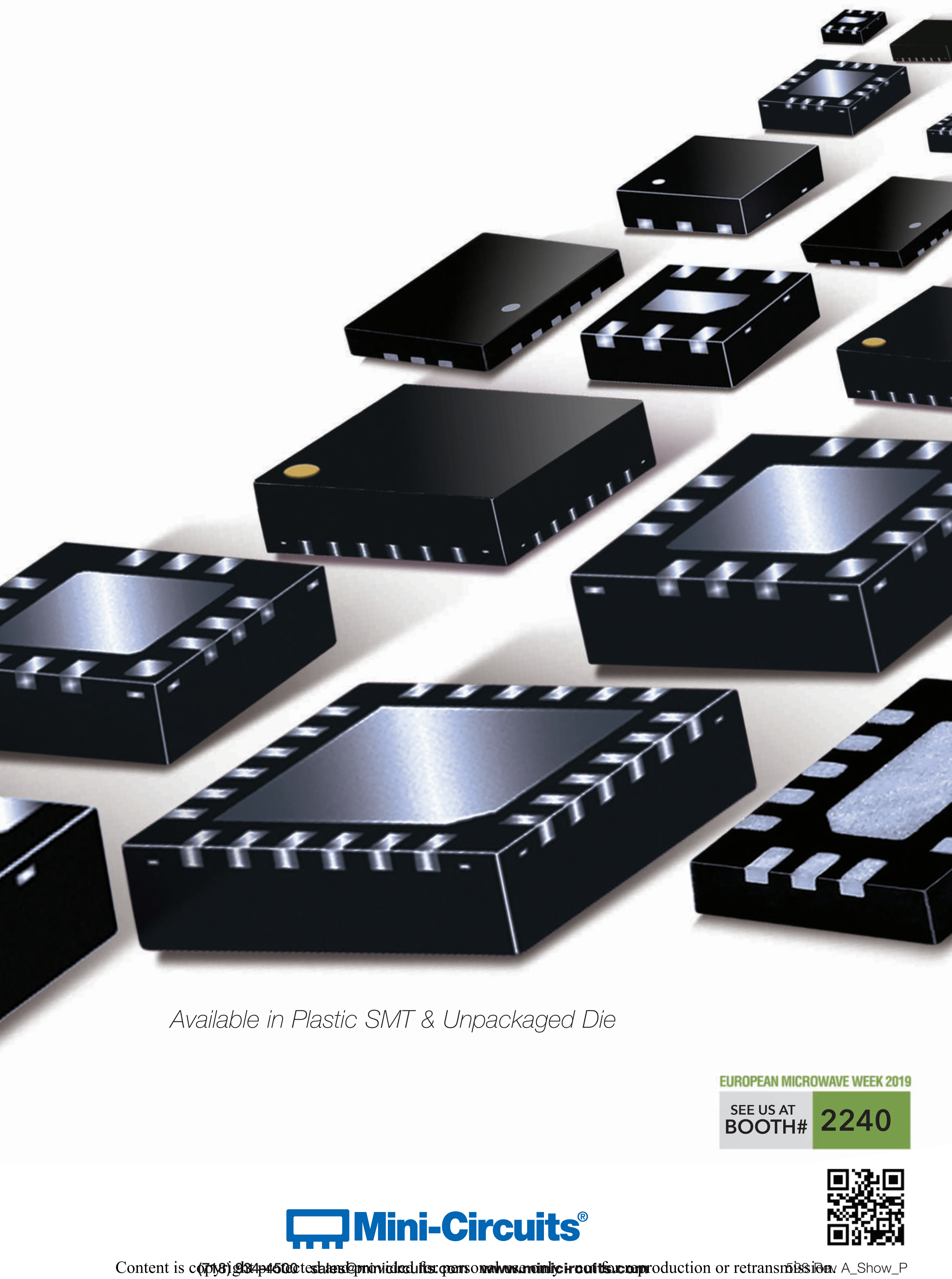
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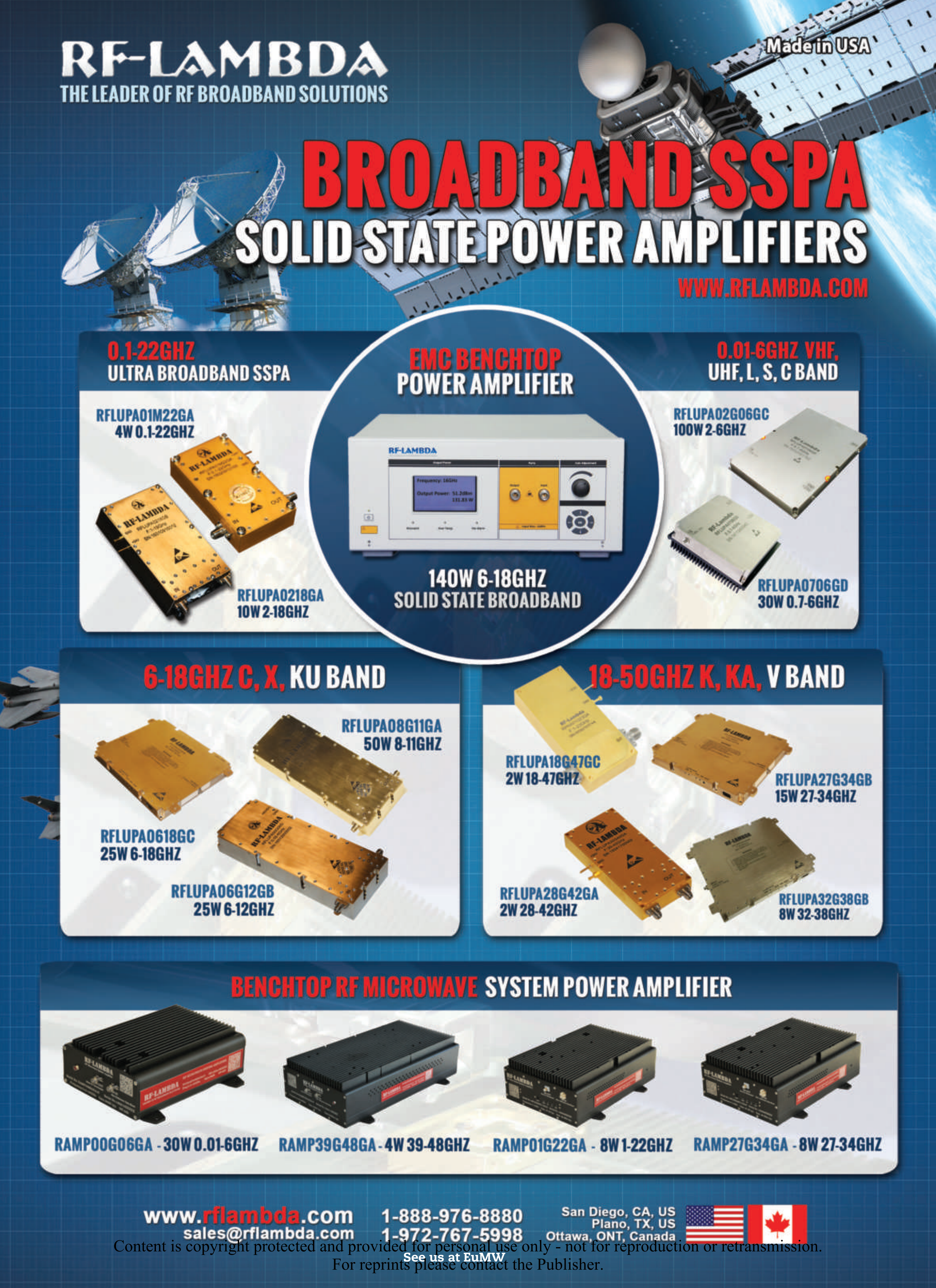

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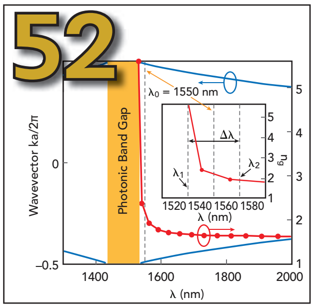

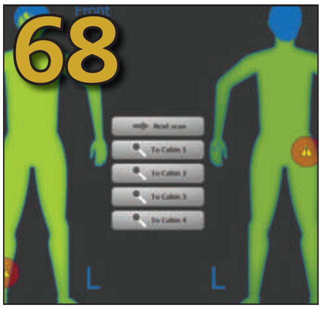

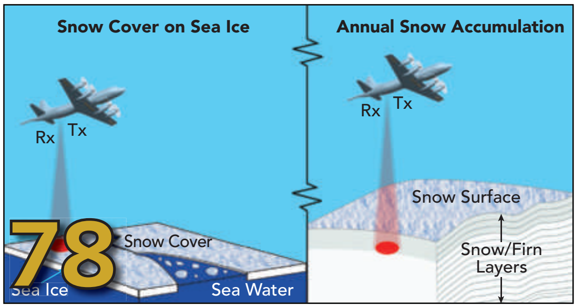

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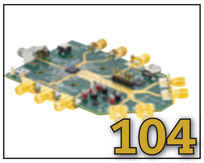

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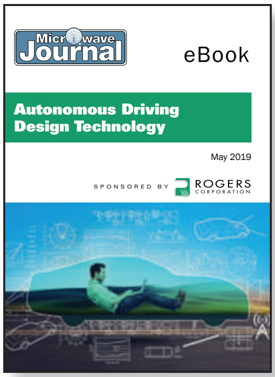

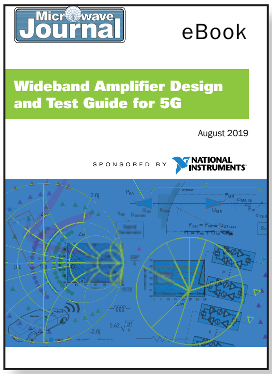

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15-18

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21-24

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22-24

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https://antennasonline.com/

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November 5–7 • London, U.K.
www.smi-online.co.uk/defence/uk/global-milsatcom

MILCOM 2019
November 12–14 • Norfolk, Va.
https://events.afcea.org/MILCOM19/Public/enter.aspx

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www.spacetechexpo.eu/

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https://imarc-ieee.org/

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https://apmc2019.miceapps.com/client/sites/view/SP8f993

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www.arftg.org

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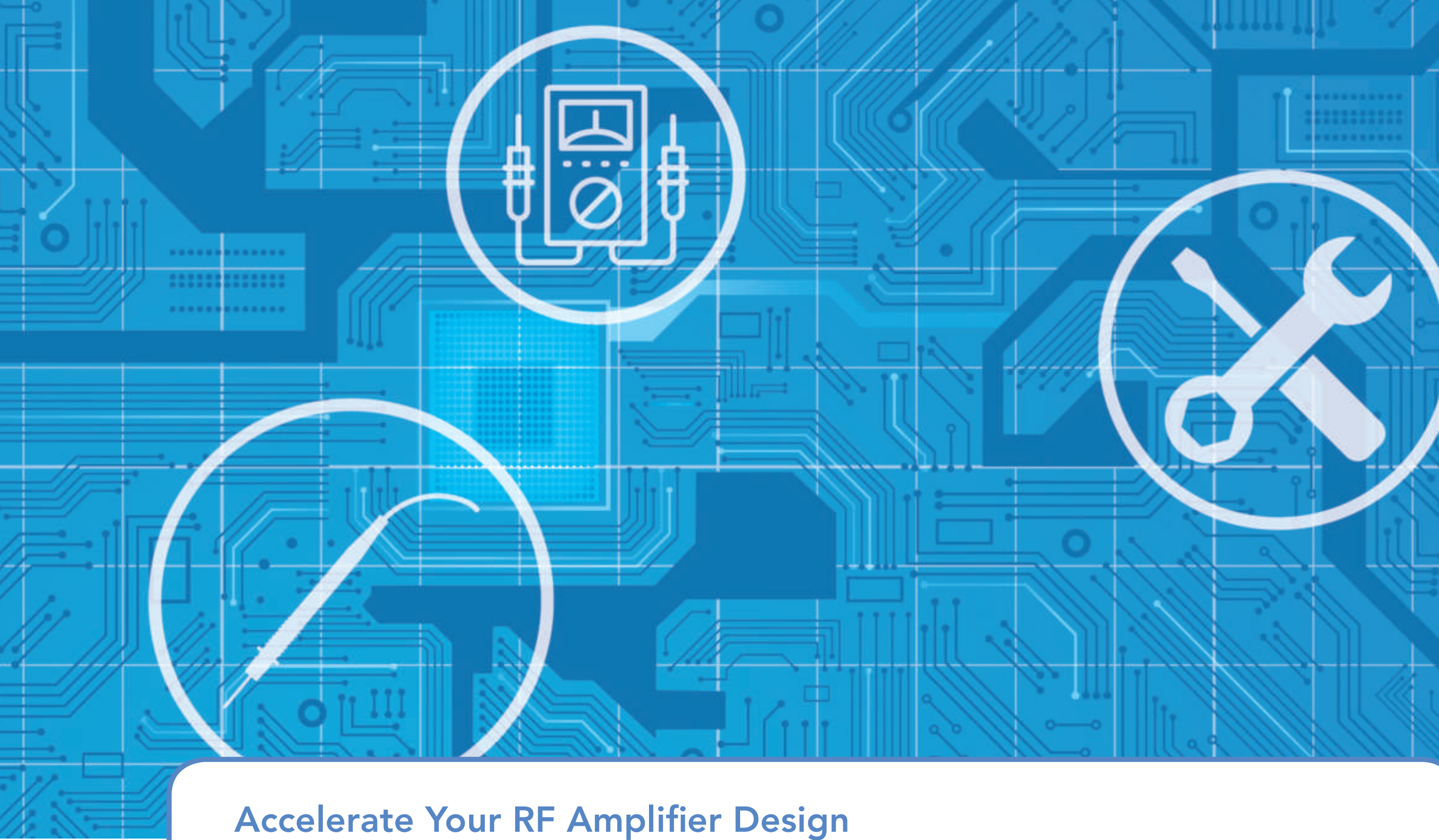

Extremely High-Power GaN Devices

Patrick Hindle
Microwave Journal *Editor*

Most GaN devices commercially available in the market today have either 28 or 50 V operating voltages. The 28 V devices are more common, but several manufacturers offer 50 V devices for even higher power circuits. The 50 V devices seem to be about the limit at which most GaN device processes can support today in order to provide long-term, reliable operation. However, a few companies have been working on much higher operating voltage GaN devices for extremely high-power applications and are pursuing better thermal solutions in conjunction with these efforts. I reached out to several companies for some examples of their work with 65+ V devices and received inputs from Integra Technologies and Qorvo, which are summarized here, along with an overview of some of the thermal solutions I have seen in the market.

PIONEERING HIGH VOLTAGE GaN TO REPLACE VACUUM ELECTRON DEVICES

Integra Technologies

Many aerospace and defense radar, SATCOM and industrial, scientific and medical (ISM) systems require highly reliable, rugged components with RF output power levels of several kilowatts. These systems have historically relied on vacuum electron devices (VED) such as traveling wave tubes (TWT) to generate multi-kW power levels. To address the increasing complexity and cost of VED based systems, semiconductor-based, solid-state power amplifiers (SSPA) have overtaken lower frequency and lower power applications, first with silicon LDMOS, then GaAs and now GaN. However, the high-power mar-

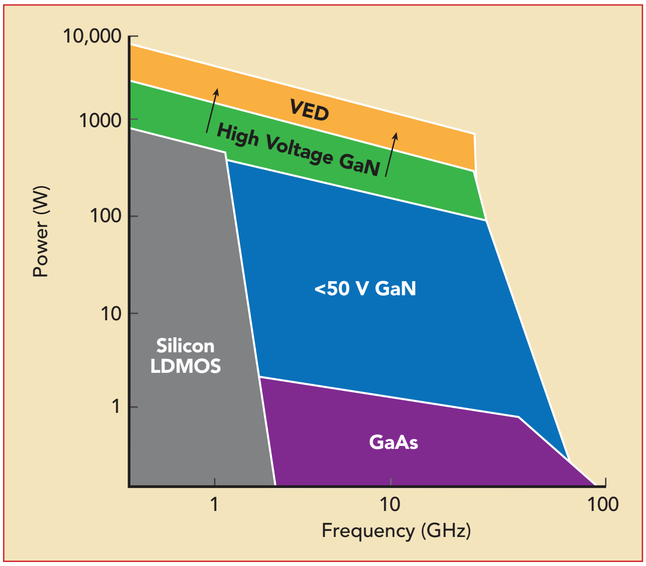

Fig. 1 Performance comparison of technologies for high-power amplifiers.

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ket is still predominantly addressed with VEDs.

In radar applications, LDMOS technology has made minimal inroads for high RF power due to its low frequency limitations. While GaAs technology is capable of operation above 100 GHz, its low thermal conductivity and operating voltage limit its output power levels. To achieve high-power, GaAs amplifiers require paralleling of multiple devices at the expense of loss in efficiency and cost resulting from multiple devices. Today's 50 V GaN/SiC technology offers hundreds of W of output power at high frequencies, and provides the ruggedness and reliability required by radar systems (see ***Figure 1***) but struggles to go beyond that.

Since 2014, Integra Technologies has been pioneering research and development in the area of high voltage (HV) GaN/SiC to further extend the technology to achieve multi-kW power levels for next generation radar systems. As system designers are challenged with increasing complexity of radars while needing to reduce lifetime operational costs, the push for a solid-state solution leveraging commercial manufacturing platforms is more imperative than ever. Integra's HV GaN/SiC has demonstrated very high-power densities in the order of 10 W/mm for 100 V CW operation and 20 W/mm for 150 V pulsed operation and efficiencies exceeding 80 percent.

HV GaN TECHNOLOGY

Higher voltage operation at the transistor level opens up new degrees of freedom for the design of high-power RF amplifiers. The technology allows for more trade off space between higher power density and higher impedance. This flexibility results in the ability to match up to 10 kW single ended transistors into a 50 Ω load and achieve 80 percent efficiency at UHF frequencies with proper harmonic tuning optimization. Integra has successfully demonstrated such performance at higher frequencies from L- through X-Band.

One of the challenges of operating at high power densities of 10 to 20 W/mm is pulling the heat away

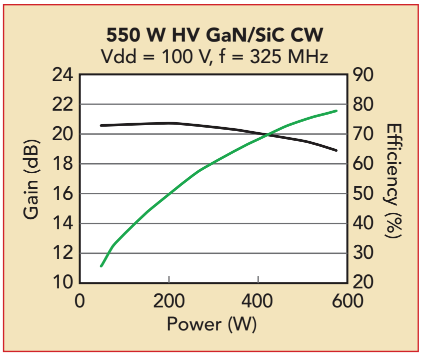

Fig. 2 **550 W high voltage GaN/SiC single die transistor performance.**

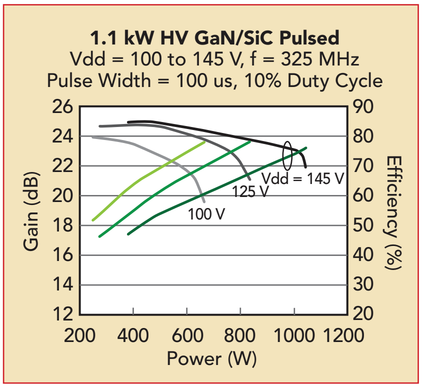

Fig. 3 **1.1 kW high voltage GaN/SiC single die transistor performance.**

from the active region of the semiconductor device. Integra has addressed this thermal management challenge through a combination of leveraging Integra thermal patents and proprietary HV GaN/SiC epitaxial material, device design and packaging.

Figure 2 shows a single 50 mm HV GaN transistor operated at 100 V in CW at 325 MHz and achieving >10 W/mm with 77 percent efficiency. By incorporating Integra's thermally enhanced technology, the device operates at a junction temperature of 160°C for 10 million hours operating lifetime. These devices can also operate at 150 V bias in pulsed conditions to achieve 20 W/mm or 1 kW single device at 325 MHz (see ***Figure 3***) and 650 MHz, with 80 percent efficiency. Similar performance has been achieved from L- up to X-Band. Integra continues to innovate on the next generation of HV GaN/SiC technology with the goal to further improve efficiencies, increase power levels and extend frequency range of operation.


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Delivery Stalled Your Program?
Noise Figure In Select Frequency Bands
Noise Figure (dB)
Frequency (GHz)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
4.5dB
4.0dB
2.8dB
2.8dB
2.5dB
1.8dB
1.5dB
1.3dB
1.2dB
1.2dB
0.9dB
0.7dB
0.7dB
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BENEFITS OF HV GaN

For high-power systems in the 100 kW range, system designers have been limited to VED technology or 50 V GaN/SiC SSPA. For solid-state designs, a large number of power devices are required to achieve the required multi-kW target power levels. Integra's HV GaN/SiC is capable of realizing significantly higher power levels while dramatically reducing RF power transistor count, system complexity and overall cost.

For example, a 200 kW system architected with 50 V, 1 kW transistors would require over 200 transistors to reach the target power level with complex power combining and associated losses in efficiency. Utilizing 10 kW HV GaN/SiC transistors, the same 200 kW system would require around 20 transistors. This eliminates a significant number of components and complex power combining of those components plus results in the system running at significantly higher efficiency. This allows the radar systems engineers to design a more competitive, lower cost radar with lower operating expenses over its lifetime.

The HV GaN/SiC technology has been developed utilizing high volume, production grade SiC substrates rather than more exotic substrate materials such as diamond which are expensive and limited in supply. The HV GaN process is built on mainstream, commercially available materials and manufacturing platforms to reduce cost and service volume applications (see ***Table 1***).

TABLE 1

COMPARISON OF HIGH-POWER RF TECHNOLOGIES

Technology	TWTA	50 V GaN/SiC	HV GaN/SiC	GaN/Diamond
Performance	High	Medium	High	High
Reliability	Low	High	High	High
Cost	$$$	$$	$$	$$$
Availability	Production	Production	Sampling	Sampling

Integra's HV GaN/SiC offers a solid-state replacement path for VEDs today with technology that utilizes a mainstream, commercially available supply chain. By leveraging Integra's patented thermally enhanced technology, the platform has solved the heat management challenges resulting from high current density operation to develop a more reliable and robust technology capable of addressing the needs of next-generation radars.

160 W GaN PA CONQUERS THE THERMAL CHALLENGES OF SMT PACKAGING

Qorvo

Innovations in GaN technology are enabling operation at higher

Fig. 4 One of the fully assembled power amplifiers. The hole in the front of the aluminum carrier allows a thermocouple to be placed directly below the QPD1013 transistor.

powers, supply voltages and frequencies—all critical elements for advanced L-Band radar and other wideband communications. GaN is capable of higher power densities than either LDMOS or GaAs. But with higher RF power levels, thermal performance must be optimized to keep the junction temperature adequately low, minimize power dissipation and ensure a long transistor lifetime. When the transistor is a surface-mount technology (SMT) component, careful design of the PCB is required in order to optimize thermal performance.

One PA that is addressing this HV and thermal challenge is a reference design using the Qorvo QPD1013—a high-power, wide-bandwidth high electron mobility transistor (HEMT). Housed in an industry-standard 7.2 mm × 6.6 mm surface-mount, dual flat no leads (DFN) package, the device allows for simpler PCB assembly compared to traditional metal-ceramic packages as shown in ***Figure 4***.

The QPD1013 utilizes Qorvo's 0.5 μm GaN/SiC technology, which enables operation at 65 V. This delivers improved efficiency and wide bandwidths suitable for many applications from DC to 2.7 GHz, including military radar, and land-mobile and military radio communications. The example PA covers the 1.2 to 1.8 GHz band and delivers an RF output power of around 160 W with an efficiency of around 55 percent

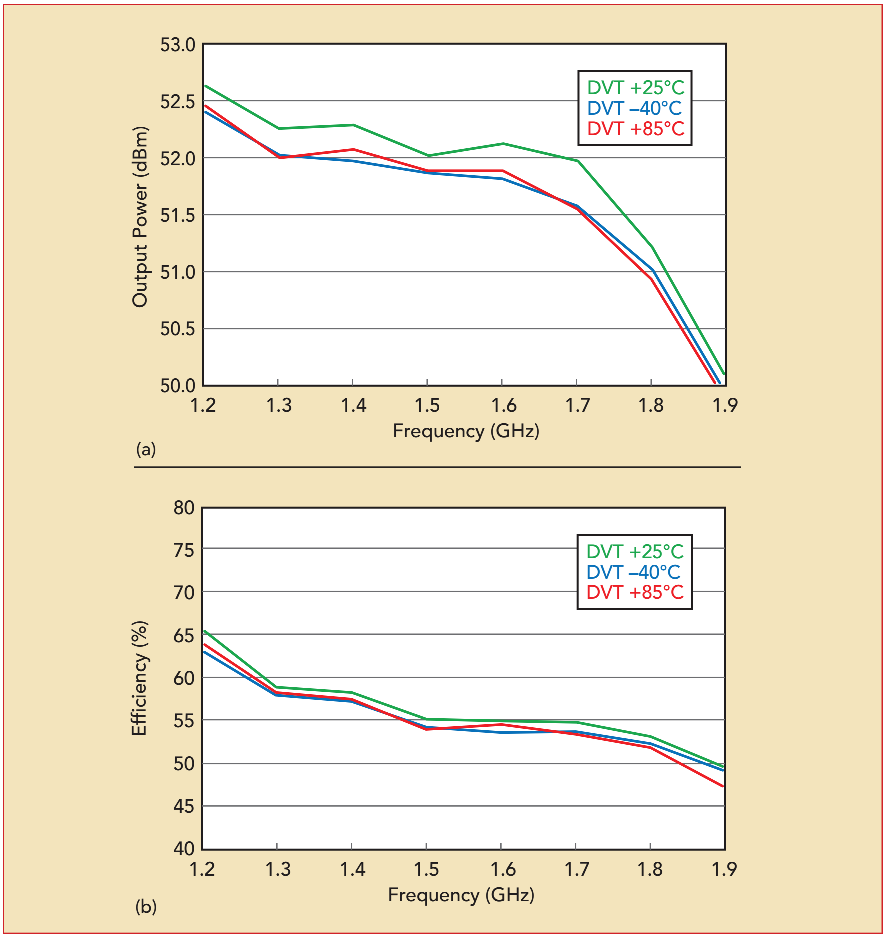

Fig. 5 Typical output power (a) and efficiency at the output of the PA of 55 percent (b) which includes output matching network and connector losses.

as shown in ***Figure 5***. While the efficiency of the PA is impressive, the dissipated power can still exceed 100 W, highlighting the need for an effective thermal solution.

To optimize thermal performance, the reference design PA uses copper coin technology. A copper coin is a solid piece of copper, or slug, embedded into the PCB during fabrication to allow efficient heat transfer from the transistor to the carrier on which the PCB is mounted. While the use of copper-filled via technology is common and the most cost effective, use of copper-coin techniques provides better thermal transfer.

As shown in ***Figure 6***, the copper coin has a minor effect on the RF performance of the amplifier and must be taken into consideration in the design. Although the improved thermal impedance of the copper coin is attractive, great care must be taken to ensure that the surface of the PCB remains planar and that good contact is made between the copper coin and the ground paddle of the DFN. Any air gaps or solder voids can mitigate the inherent advantages of the copper coin approach.

As with all power transistors, careful thermal design is essential to reliable operation. In the QPD1013, use of a copper coin PCB delivers an operating temperature 10°C cooler compared to copper-filled via PCB. The PAs high-power and broad bandwidth, supported by its thermally efficient design, is helping to

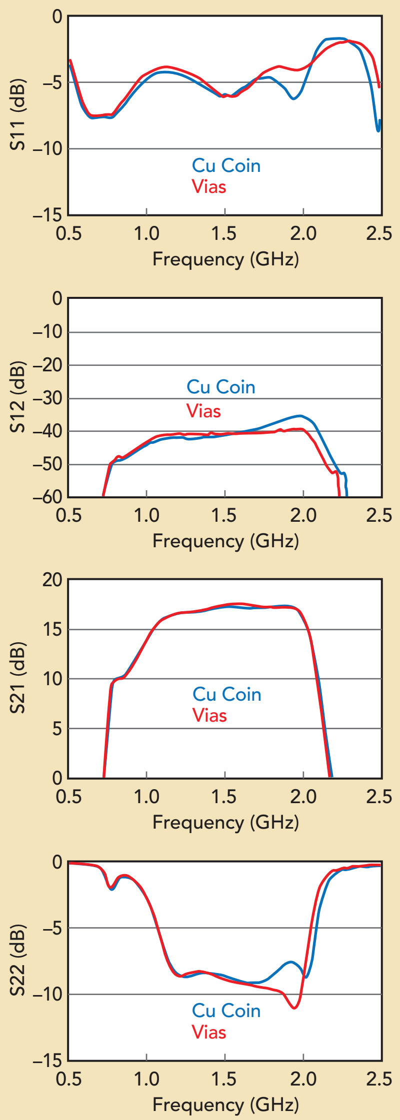

Fig. 6 S-parameter comparison for using copper vias vs. copper coin for QPD1013 transistor.

drive mission superiority in military and commercial radar, land mobile and military radio communications, active antennas, test instrumentation, wideband and narrowband amplifiers and jammers.

IMPROVED THERMAL SOLUTIONS

One key to HV operation and higher efficiency is getting the heat out of the device to keep the junction temperature in an acceptable range for reliable operation. One method that many manufacturers have researched is GaN on diamond since it has the highest thermal conductivity of any material while others are pursuing better heat sinking or liquid cooling options.

As we covered in our June issue last year, TriQuint (now Qorvo) announced the production of the first GaN on Diamond wafers producing HEMT in April 2013, in conjunction with partners at the University of Bristol, Group4 Labs and Lockheed Martin under the Defense Advanced Research Projects Agency's (DARPA) Near Junction Thermal Transport (NJTT) program. NJTT focused on device thermal resistance near the junction of the transistor using various cooling techniques. The results of this effort showed a three-fold improvement in heat dissipation, while preserving RF capabilities.

Raytheon also did work under the same DARPA program and developed a way to etch cooling channels in a diamond substrate and attach it to the wafer, avoiding some of the manufacturability issues with growing the GaN on the diamond substrate, and added liquid cooling. Raytheon used a glycol/water coolant to flow through the channels within 100 microns of the active HEMT area. Raytheon demonstrated a wideband continuous-wave (CW) amplifier with 3.1× the power output and 4.8× the power density of the baseline amplifier currently designed into a next-generation electronic warfare (EW) system.

More recently, Fujitsu Ltd. and Fujitsu Laboratories Ltd. announced development of the first technology for bonding single-crystal diamond to a SiC substrate at room temperature. This overcame one of the biggest challenges to previous GaN on Diamond bonding that took place at very high temperatures causing bowing of the wafers due to mismatch of coefficient of thermal expansion (CTE). This technology promises GaN PAs that can operate at higher power by about 1.5× when applied to systems such as weather radar.

RFHIC acquired GaN on Diamond technology from Element Six and in their 2017 announcement, the company stated that "RFHIC will work closely with Element Six and foundry partners for the capability of manufacturing 10,000 6-in. GaN on Diamond wafers per year in the foreseeable future." The technology has taken a little longer to launch than they projected but seem ready to sample the product soon.

JETCOOL Technologies unveiled a new approach to cooling high-power electronics at IMS2019 in


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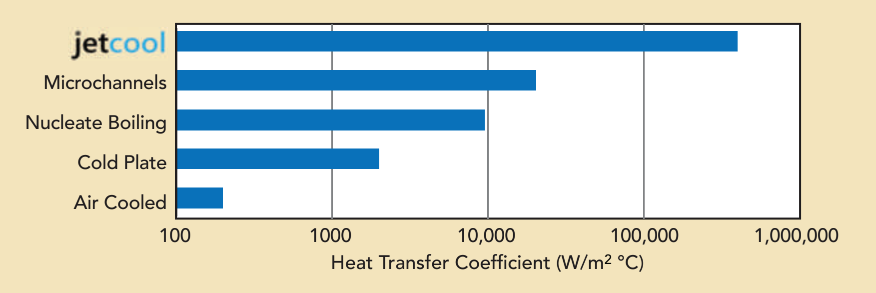

▲ Fig. 7 Comparison of thermal performance of various cooling methods (from JETCOOL website).

Boston, winning the MIT spin-off of the title of Next Top Startup in the new Startup Pavilion. The company is trying to change the way electronics are cooled by using micro-convective cooling that uses small fluid jets that can be built within the electronic device. The result according to the company is 10× better cooling than other cooling technologies used today as shown in ***Figure 7***. CEO Bernie Malouin said in a press release that the technology can build the heat sink into the silicon substrate, integrating cooling into the processor chip and other devices.

Their patent-pending process on microjet cooling uses small jets of high velocity fluid to cool the device. Instead of passing fluid over a surface like in typical heat sinks or cold plates, microjets are aimed directly at the surface. The high flow effectively cools the bottom of the chip providing better cooling than previous methods. Their solution provides cooling without a need for large metal heat sinks, eliminating the metal makes tower-based systems smaller and lighter.

JETCOOL discusses GaN/SiC devices specifically in one of their blog postings making the point that the thermal conductivity of a GaN device operating up to 225°C is about 50 percent of what it would be at the reference temperature of 25°C. As the underlying SiC layer warms, its thermal conductivity is also reduced. "This turns into a cascade effect where lower conductivity means higher temperature, which further lowers conductivity until equilibrium is reached. Therefore, if temperature dependence is not incorporated into the material properties, computed peak temperatures would be artificially low due to the inappropriately high thermal conductivity."

GaN devices are continuing to improve their performance every year, and we have not come close to the ceiling of their performance yet as manufacturers find better epi processes, transistor configurations and packaging solutions to improve heat dissipation.■

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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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Advanced Phased Array for Air Force Satellite Control Network

Lockheed Martin (LM), Ball Aerospace and Kratos Defense & Security Solutions Inc. were awarded a $7.2 million prototype agreement by the Defense Innovation Unit to develop a new multi-band, multi-mission (MBMM) prototype phased array as part of a broader initiative to modernize the existing Air Force Satellite Control Network and bring new technology faster to warfighters. MBMM enables multiple satellites to simultaneously connect with a single array antenna over multiple frequencies, a significant performance improvement compared to traditional single contact parabolic dishes.

MBMM Antenna (Credit: Lockheed Martin Corp.)

The LM team is building prototype transmit and receive electronically steerable arrays (ESA). Each array uses Ball's advanced phased array technologies and supports L- and S-Band frequencies initially. Signal processing is accomplished with Kratos' digital intermediate frequency (IF) technology and cloud-enabled quantumRadio.

Future operational MBMM systems will offer new cyber resilience while reducing long-term sustainment costs for the Air Force. MBMM may eventually support multiple orbits from LEO to GEO and can perform multiple missions at the same time, including command & control (C2), launch pad and ascent operations, radar and mission data transmission.

Air Force Releases Request for Proposals for New ICBM System

The Air Force recently released a request for proposals for its Ground Based Strategic Deterrent (GBSD) intercontinental ballistic missile weapon system program July 16.

The request is for the weapon system's Engineering and Manufacturing Development phase and includes five production lot options to produce and deploy the weapon system. The two contractors for GBSD's current Technology Maturation and Risk Reduction phase, Boeing and Northrop Grumman, will compete for the EMD contract. The Air Force Nuclear Weapons Center expects to award the contract in the fourth quarter of fiscal year 2020.

The GBSD is the follow-on to the aging LGM-30G Minuteman III ICBM, which first became operational in the mid-1960s. While some components and subsystems have been upgraded over the years, most have supported over 50 years of continuous operation.

In May, Under Secretary of Defense for Acquisition and Sustainment Ellen M. Lord expressed the need to upgrade nuclear capability and modernization to maintain a deterrence edge. She said it no longer makes financial sense to continue to upgrade or extend the life of existing Minuteman III ICBMs and the new GBSD weapon system must be brought online.

"There is no margin to do another service life extension program on Minuteman III, because not only would it be more expensive than developing GBSD, but you would not have the resiliency in the capability because you would not have the modern equipment, you would not have the actual capabilities from a functional range point of view (or) warhead capability," Lord said. "So we need to, by 2028, start replacing ICBMs."

"If you look at the threat that we face, Russia just completed modernization of their triad this year…because they know they cannot defeat us—and certainly can't defeat NATO—conventionally," said Air Force Chief of Staff Gen. David L. Goldfein at a congressional committee hearing in April. "So, our modernization and recap of the triad is just in time because in the missile leg, key parts of that program expire right about the time that we bring on the new GBSD to replace it."

The GBSD program office is part of Air Force Nuclear Weapons Center's ICBM Systems Directorate at Hill Air Force Base, Utah. The center is responsible for synchronizing all aspects of nuclear materiel management on behalf of Air Force Materiel Command in direct support of Air Force Global Strike Command.

What Do Dragonflies Teach US About Missile Defense?

Be grateful you are not on a dragonfly's diet. You might be a fruit fly or maybe a mosquito, but it really would not matter the moment you look back and see four powerful wings pounding through the air after you. You fly for your life, weaving evasively, but the dragonfly somehow tracks you with seemingly instant reflexes. For a moment, you think you have gotten away, just as it closes in swiftly from below for the kill. Then, as the dinosaur-era predator claws into you with its spiny legs and drags you into its jaws midair, you might wonder to yourself, "How did it catch me with such a tiny brain and no depth perception?"

Sandia National Laboratories is homing in on the answer, with research showing how dragonfly brains might be wired to be extremely efficient at calculating complex trajectories. In recent computer simulations, faux

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dragonflies in a simplified virtual environment successfully caught their prey using computer algorithms designed to mimic the way a dragonfly processes visual information while hunting. The positive test results show the programming is fundamentally a sound model.

The Sandia research is examining whether dragonfly-inspired computing could improve missile defense systems, which have the similar task of intercepting an object in flight, by making on-board computers smaller without sacrificing speed or accuracy. Dragonflies catch 95 percent of their prey, crowning them one of the top predators in the world.

Computational neuroscientist Frances Chance, who developed the algorithms, is presenting her research at the International Conference on Neuromorphic Systems in Knoxville, Tenn. Earlier, she presented at the Annual Meeting of the Organization for Computational Neurosciences in Barcelona. Chance specializes in replicating biological neural networks—brains, basically—which require less energy and are better at learning and adapting than computers. Her studies focus on neurons, which are cells that send information through the nervous system.

"I try to predict how neurons are wired in the brain and understand what kinds of computations those neurons are doing, based on what we know about the behavior of the animal or what we know about the neural responses," Chance said. For example, a dragonfly's reaction time to a maneuvering prey is a mere 50 ms. A human blink takes about 300 ms. Fifty ms is only enough time for information to cross about three neurons. In other words, to keep up with a dragonfly, an artificial neural network needs to be done processing information after only three steps—though, because brains fire lots of signals at once, each step may involve many calculations running at the same time.

Missile defense systems rely on established intercept techniques that are, relatively speaking, computation-heavy. But rethinking those strategies using highly efficient dragonflies as a model could potentially:

- Shrink the SWaP needs of onboard computers. This would allow interceptors to be smaller and lighter, and therefore more maneuverable.
- Reveal new ways to intercept maneuvering targets such as hypersonic weapons, which follow less-predictable trajectories than ballistic missiles.
- Reveal new ways to home in on a target with less sophisticated sensors than are currently used.

Dragonflies and missiles move at vastly different speeds, so it is unknown how well this research will ultimately translate to missile defense. But developing a computational model of a dragonfly brain also could have long-term benefits for machine learning and AI.

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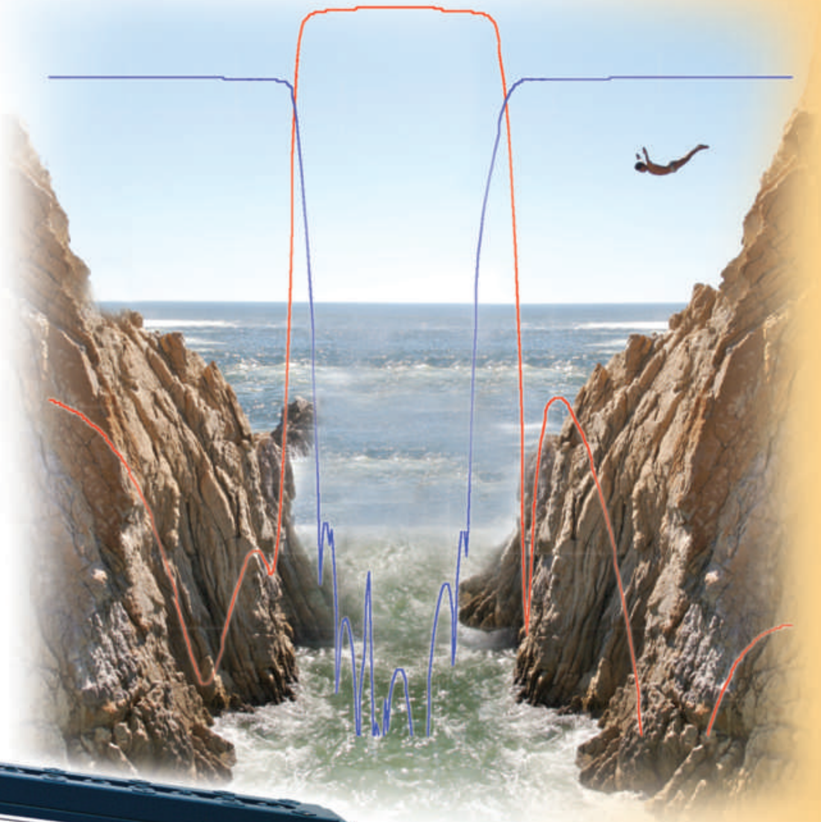

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5G RF Power Semiconductor Device Sales for Wireless Infrastructure Take Off

Just when the industry thought that things were pretty good for 4G/LTE wireless RF power semiconductors, devices for 5G new radio (NR) low- and mid-band took off as the overall market grew to $1 billion in 2018. The market will continue to climb nearly $2 billion by 2024, according to global tech market advisory firm, ABI Research.

> The increasing and critical need for wireless data remains an important driver...

China and the Asia-Pacific region, in general, continue to be the main driver for the RF power semiconductor devices sold into the mobile wireless infrastructure segment. "Once again, for the foreseeable future, the Asia-Pacific region, especially China, will dominate this market and remain the most important region and focus for high-power RF semiconductor devices for wireless infrastructure," says Lance Wilson, research director, ABI Research.

The 4G/LTE air interface will continue to be a technology engine of revenue for the next five years, but the industry is now seeing major shipments of Si LDMOS for 5G. Although, GaN devices had meaningful share, the 2018 story was still about Si LDMOS, which continues to dominate this segment by a large margin.

New Satellite Networks Will Enable 24M IoT Connections, Provide Seamless Global Connectivity By 2024

A new report by ABI Research unveils the long-term opportunity within the satellite space for the growth of IoT deployments, particularly in application verticals, such as agriculture and asset tracking that are dealing with the unreliability of terrestrial infrastructures.

"Terrestrial cellular networks only cover 20 percent of the Earth's surface, while satellite networks can cover the entire surface of the globe, from pole to pole," says Harriet Sumnall, research analyst. "The expansion of the satellite constellations that are currently in orbit and those due to take place will allow for connectivity to be more global. While the market using satellite connection is still immature, it shows great opportunities for growth."

The application segments that are expected to see significant growth include agriculture, asset tracking, maritime tracking and aviation tracking. Maritime and aviation tracking are two important markets for the satellite space due to the lack of terrestrial infrastructures available. Vendors such as Aerial & Maritime (A&M) provide cost-effective aircraft ADS-B surveillance and ship AIS tracking from constellations of nano-satellites.

This technology is a game-changer in this industry space, and recent initiatives demonstrate the high-end tracking capabilities from large satellites in multi-constellations. Though this is yet to be considered a cost-efficient process, it is expected to become more so with upcoming software-defined radio (SDR) technology, as it is possible to use nano-satellites for these actions.

> Large satellite providers face competition from new nano-satellite LEO constellation

The larger and more traditional satellite providers, such as Inmarsat and GlobalStar, are facing new competition with many new start-up constellations from vendors like Amazon and SpaceX, which are launching low Earth orbit (LEO) satellites. LEO satellites, however, are costly in set-up as many are required to provide the coverage that vendors are offering. However, in the long run, they are more cost-effective than larger traditional satellites for these applications. Conventional satellite providers will have to consider driving their prices down to become more competitive in order to stay relevant.

"Once the market becomes more successful and has matured, pricing strategies will drop overall, allowing the satellite IoT connectivity options to compete against terrestrial connectivity options," Sumnall concludes.

Drone Market in Full Flight with Commercial and Industrial Use-Cases

Small unmanned aerial systems (sUAS) have been in the public eye for well over this decade and a hype cycle developed around its applications for the consumer and commercial space. The high-profile failure of major drone manufacturers and software providers, such as U.S. firm Airware in 2018, somewhat tempered initial enthusiasm, causing early projections from industry organizations such as the Association for Unmanned Vehicle Systems International (AUVSI) to look overly optimistic. However, according to a new report from global tech market advisory, ABI Research, commercial drone usage, especially in the industrial space, will be a source of accelerating growth throughout the next decade with $101 billion in revenue being created annually by 2030 across the commercial, military, civil and consumer sectors.

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"The consumer drone market has become heavily commoditized through the advancements and price point advantages pushed through by Chinese giant DJI, which has taken a commanding majority of all consumer-related drone hardware. With interest in the consumer space somewhat deflating, value continues to shift away from the drone toward value-added services for the enterprise," says Rian Whitton, senior analyst, ABI Research. Services like analytics, unmanned traffic management (UTM), flight management and repair are all increasing as the use of drones is scaled up to provide affordable and ubiquitous aerial imagery for verticals like construction, energy and industrial inspection.

"Delivery by sUAS is going to become one of the larger opportunities for the market, but do not expect immediate returns inside five years," Whitton points out. "While Amazon thinks it can get a 15-mile drone delivery going within 2019, there are still certificates needed from the FAA, including Part 135, authorization to operate an airline. They have so far cleared one regulatory hurdle, however, receiving a certificate of airworthiness from the FAA. "Overall, their ambition to make a drone delivery service in 2019 will be likely delayed by months. But with successfully tested drone-deliveries in the U.S., U.K., Iceland, China, Indonesia and Africa (for emergency aid), the use-cases have value. So much so that drone-deliveries are expected to reach global revenues of up to $10 billion by 2030, accounting for 14 percent of all commercial sUAS revenue."

> **Delivery market preparing for takeoff.**

Before any of this is likely to occur, serious challenges facing the development of UTM need to be addressed. One is simply tracking and applying registration numbers to the multitude of drones that are already in the air. Another is the deficiency in effective communication link technology for long-range BVLOS operations. Even ignoring these technical hurdles, there is a fractured ecosystem of app developers and drone solution providers offering some UTM solutions, but they are not effectively coordinating with major government institutions like NASA to develop comprehensive coverage.

"We are not likely to see ubiquitous drone delivery, flying taxi services or a massive consumer market for drones in the way people perhaps thought in 2015," says Whitton. "Instead, the growth in the drone industry will be dependent providing cost-effective, three-dimensional aerial imagery and indices to industries and verticals that previously had no access to it, namely construction, mining, high-value energy assets and infrastructure."

Around the Circuit

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Taoglas has acquired **Firmwave**, an IoT product design, and engineering company based in Ireland, to deliver next-generation IoT to best-in-class IoT applications such as healthcare, energy and utilities, supply chain and logistics, transportation, agriculture and construction. Many companies struggle with design engineering for complex next-generation IoT applications because they require a high level of integration. Many companies want to take advantage of advances in imaging like facial recognition; centimeter-level positioning (cm versus accuracy); audio like speech recognition; and AI for motion sensing and analysis. Advancements in these four areas promise to open a world of next-generation IoT applications.

Communications & Power Industries (CPI) has entered into an agreement to purchase **SATCOM Technologies**, the antenna systems business of **General Dynamics Mission Systems**, a business unit of **General Dynamics**. SATCOM Technologies designs, manufactures and installs SATCOM antenna systems used in commercial, defense and scientific applications, as well as provides related RF products and electronics, including feed components, amplifiers, converters, antenna control systems and engineering and installation services. This business will complement CPI's existing portfolio of communications products for government, military and commercial applications.

U.S. private equity firm **Advent International** has agreed to pay £4 billion ($5 billion) to buy **Cobham**, the British aerospace and defense and group known for its pioneering air-to-air refueling technology. In the latest of a series of buyouts in Europe, with private equity firms seeking new targets for their bumper cash balances, Advent is offering 165 pence in cash for each Cobham share representing a 50 percent premium to the three-month average price. Shares in Cobham, whose technology is found on F-35 fighters and Airbus jets, jumped 35 percent to just above the offer price, the highest they have been since March 2016. The deal will be part funded by about £2.5 billion of debt.

Ontic has acquired the manufacturing and aftermarket rights for **Thales** in the U.K.'s Doppler Velocity Sensors. The sensors are used by a range of civil and military customers across several rotary and fixed wing platforms. The companies have now entered a transition period where the Doppler technology and associated products transfer will take place. The aim to complete the transition by early 2020. This will be the 14th product line introduced to Ontic's Cheltenham facility since its foundation in 2012, and the company's first agreement with Thales in the U.K. The products complement Ontic's existing capabilities and customer base.

COLLABORATIONS

TowerJazz, **Cadence Design Systems Inc.** and **Lumerica Inc.** announced the availability of a complete custom design silicon photonics (SiPho) and silicon germanium (SiGe) integrated process design kit (PDK). The differentiated PDK is based on the Cadence® Virtuoso® custom IC design platform, providing native synthesis using the Cadence CurvyCore engine and electrical-optical co-simulation capability in Lumerical's photonic integrated circuit simulator INTERCONNECT. The complete, photonics-optimized solution provides SiPho designers with a single, streamlined design environment for developing complex multi-fabric systems, while enabling them to collaborate in a shared IC design environment to leverage the electro-optical interface that is critical for enabling 400GB optical transceivers.

Cree and **ON Semiconductor** have signed a multi-year agreement where Cree will produce and supply its Wolfspeed SiC wafers to ON Semiconductor. The agreement, valued at more than $85 million, provides for the supply of Cree's advanced 150 mm SiC bare and epitaxial wafers to ON Semiconductor for use in high-growth markets, such as electric vehicle and industrial applications.

Egide USA announced the signature of a manufacturing and supply contract with its customer **Crane Aerospace & Electronics (A&E)**, based in Lynnwood, Wash., for a renewable 18-month period. This will strengthen the historic business partnership between Crane A&E and Egide USA, and both are looking forward to continuing the excellent business relationship based on this agreement. In the framework of the new long-term agreement, Egide USA will continue to manufacture key components in Crane A&E's various high-reliability businesses.

NEW STARTS

Custom MMIC commemorated its recent office and lab expansion with a ribbon cutting ceremony. U.S. Congresswoman Lori Trahan, who represents the third congressional district of Massachusetts and serves on the House Armed Services Committee (HASC), cut the ribbon and congratulated Paul Blount, founder, and company employees on the success of the 13-year-old firm. Blount gave Trahan a brief history of the company, saying the defense market is a focus, and noted awards received from leading defense firms such as Raytheon and BAE Systems.

Antenom Antenna Technologies was established in 2018 for developing a new concept in antenna training and antenna design. Their main product is Anten'it Antenna Design and Training Kit which includes metal, dielectric, ground plane cells in brick form. Cells are able to connect to each other and create different types of antennas at different frequencies. This new concept provides its users to use the same cells for building many different antennas.

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Arralis Technologies announced at the International Paris Air Show the expansion into the U.S. It was announced by Dr. P. Barry Butler that Arralis Technologies would be opening a new office at the John Mica Engineering and Aerospace Innovation Complex at Embry-Riddle Aeronautical University Research Park, Daytona Beach, Fla. Arralis Technologies officially opened their new office in August 2019.

ACHIEVEMENTS

Microlease, a part of **Electro Rent Corp.**, has made several significant investments in test equipment for the emerging 5G mobile communications standard. The company has increased its entire 5G testing inventory with an investment of $30 million ($10 million in the past 12 months), to serve the growing demand from equipment manufacturers and mobile network operators. Interest in 5G is being driven by its ability to deliver much greater bandwidths to mobile terminals, the reduced latency of its data transfers and support for many more terminals per unit area.

Designed for 5G NR signaling test in sub-6 GHz (FR1) and mmWave (FR2) frequency bands, the R&S CMX500 radio communication tester seamlessly integrates into Intertek's existing **Rohde & Schwarz** test systems. Network operators are driving LTE-A Pro features to boost 5G NR data rates in non-standalone (NSA) mode and to ensure that LTE provides "4.9G" performance if 5G service is unavailable. Existing test solutions built upon the R&S CMW500 by Rohde & Schwarz can be cost-effectively extended to support 5G NR FR1 standalone (SA) and NSA, TDD and FDD modes, with the simple addition of an R&S CMX500.

3D Glass Solutions Inc. (3DGS) announced it has closed $12 million in Series B equity funding, bringing the company's total equity funding to more than $19 million. Led by Nagase & Co. Ltd., a Japanese conglomerate specializing in next-generation chemistries and technologies across multiple market sectors, Series B investment participants also include Sun Mountain Capital, Murata Manufacturing Co. Ltd. and Lockheed Martin Ventures. With the successful close of this round of equity funding, 3DGS is now well-positioned for continued manufacturing expansion and acceleration of its technology roadmap.

Optenni Ltd. celebrates 10 years of continuous innovation in matching circuit synthesis and RF design automation. In 10 years, Optenni Lab RF Design Automation Platform has become the leading tool for matching circuit synthesis for broadband, multiband, multiport and tunable matching circuits, utilizing their extensive component library of inductors and capacitors and accurate microstrip models. Optenni Lab is used worldwide by leading wireless companies in the telecommunication, automotive and medical sec-

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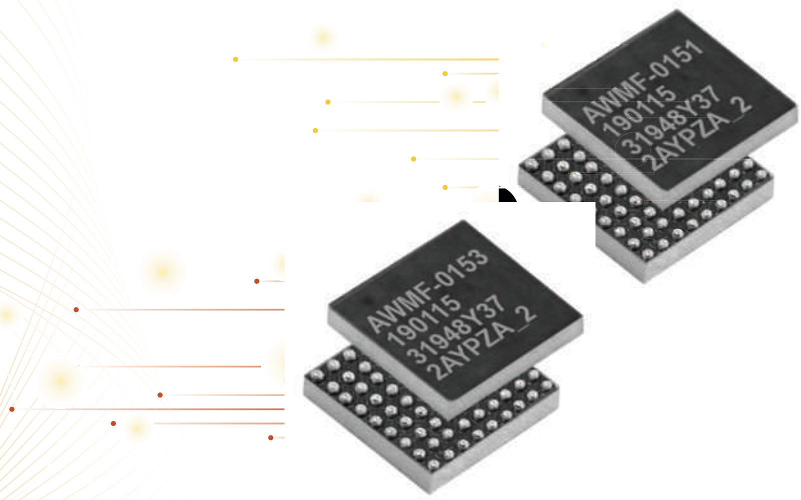

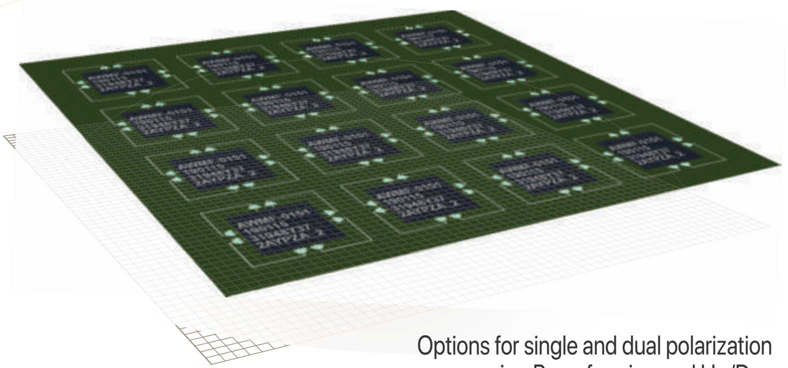

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Quectel Wireless Solutions has announced that its NB-IoT modules BC95-G and BC68 are now certified to operate on SoftBank's network in Japan. The two modules will give IoT integrators, developers and OEMs the ability to deploy fixed and mobile IoT applications on SoftBank's stable network in Japan. Designed for global markets, BC95-G and BC68 are multi-band NB-IoT modules, both of which work on LTE FDD bands of B1/B8 on the carrier's network. They provide ideal solutions for a wide range of IoT applications such as smart metering, bike sharing, smart parking, smart city, security and asset tracking, smoking detectors, home appliances, agricultural and environmental monitoring, etc.

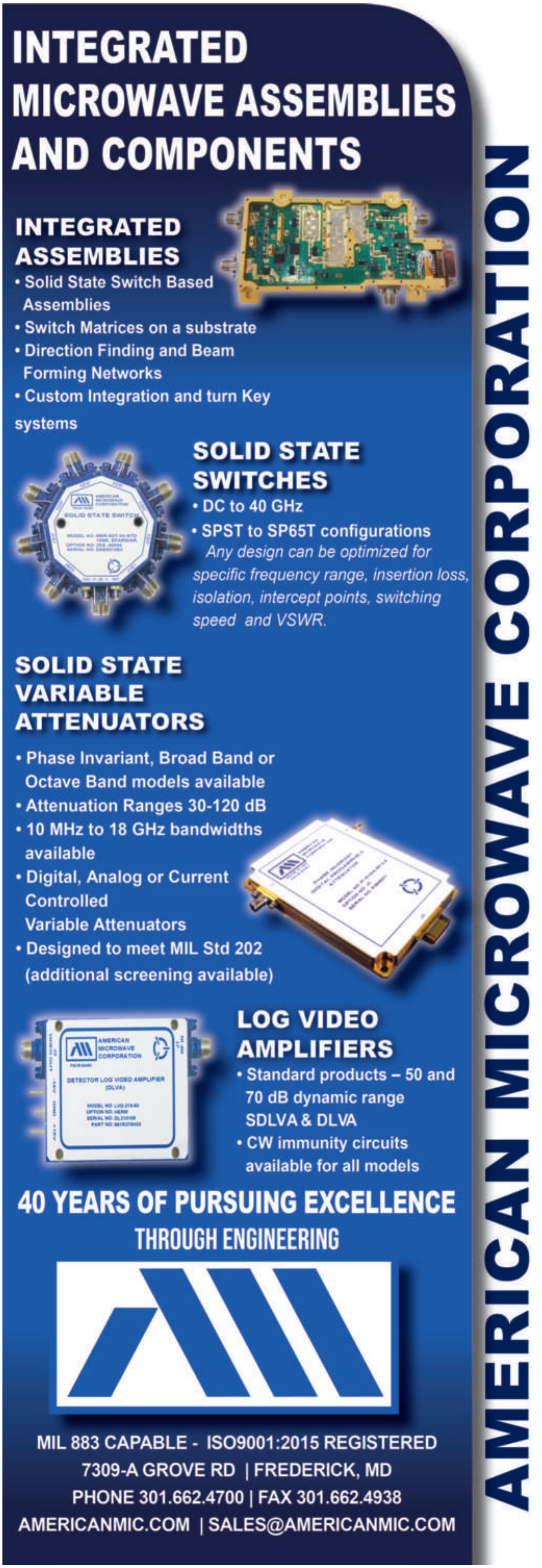
CONTRACTS

Affinity Innovations LLC announced the award of **Defense Information Systems Agency's System Engineering, Technology, and Innovation (SETI)** contract. SETI is a $7.5 billion multiple-award task order contract with IDIQ put in place to streamline critical engineering expertise, and to research, design, develop, integrate and optimize DoD information technology capabilities.

Transphorm Inc. announced that the **DoD Office of Naval Research (ONR)** has exercised a three-year $15.9 million option on an existing $2.6 million base contract with the company. This contract, N68335-19-C-0107, administered by Naval Air Warfare Center Aircraft Division, Lakehurst establishes Transphorm as a U.S.-based dedicated production source and supplier of GaN epiwafers for DoD and commercial RF/mmWave and power electronics applications. The award comprises a base program for key technology development/transfer and an option program to establish production scale capability.

Sivers IMA has received a design-in order for SEK1.3 million (approximately $135,000) for 60 GHz RFICs and support services for two broadband applications in China. The order was placed by Sivers' Chinese reseller **Matrix Electronic Co. Ltd.**, which will provide the products and support services to an end customer in mainland China. According to a Sivers IMA press release, this is the company's first Chinese order for a 60 GHz unlicensed application. If successful, the design-in could lead to "significant volumes" for high speed transportation and Gbps fixed wireless access applications.

Lockheed Martin (LM) has received three contracts from the **U.S. Army** to produce additional Q-53 systems and outfit the radar with enhanced capabilities, including extended range and counter unmanned aerial system (CUAS) surveillance. The flexible architecture



Around the **Circuit**

of the Army's most modern radar allows for these upgrades, which support adaptable growth of the system to address aircraft, drone and other threats in the future. The Army awarded LM a contract for the third lot of 15 Full-Rate Production systems. Once this contract is delivered the Army will own 189 Q-53 systems.

The **U.S. Navy** has awarded **BAE Systems** a prime contractor position on a new IDIQ contract to enhance maritime operations and flight safety systems aboard new construction aircraft carriers and large deck amphibious ships, to include refueling and complex overhaul ships. BAE Systems was one of three contractors awarded the opportunity to bid on future integration, engineering, assembly, testing and installation focused task orders awarded throughout an eight-year ordering period. The work will be performed to enhance a variety of distributed systems that provide network capabilities, communications, command and control, intelligence and non-tactical data management.

The sensor solutions provider **HENSOLDT** is equipping the second batch of the **German Navy**'s K130 corvettes with its TRS-4D Rotator naval radar and its MSSR 2000 ID friend-or-foe identification system (IFF). Only six months after the order was placed, the company has now successfully passed the factory acceptance test by the German procurement authority BAAINBw for the second system. HENSOLDT has received orders for seven radars which are intended for five ships and two land-based systems and are to be delivered by 2022. The company had previously equipped the first K130 batch with its proven TRS-3D radar.

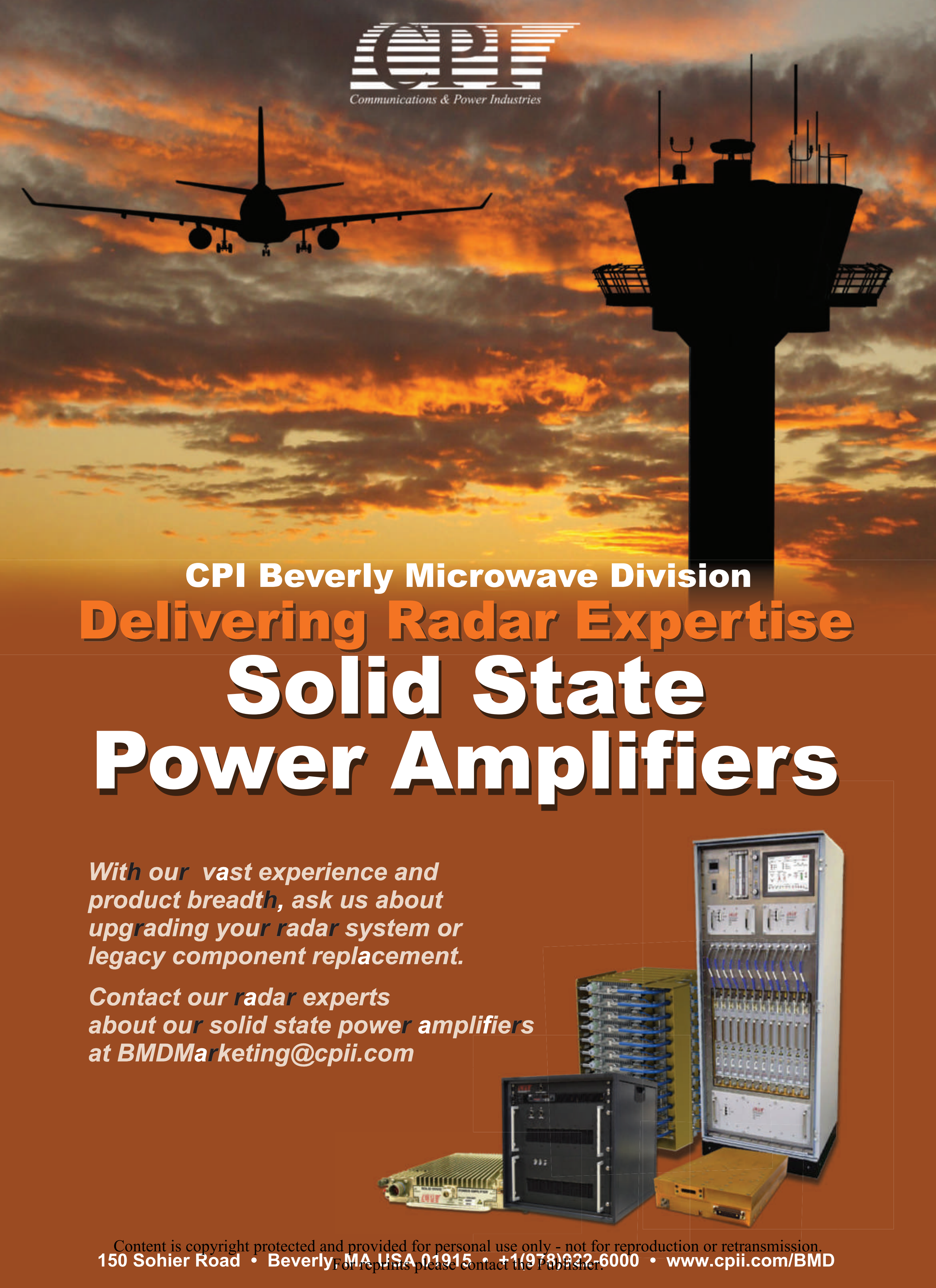
PEOPLE


▲ *Nazzic S. Keene*

Science Applications International Corp. (SAIC) and its board of directors have announced **Nazzic S. Keene** as CEO effective immediately. Keene, who most recently served as COO of SAIC, succeeds Tony Moraco who has retired after serving as CEO since 2013. Keene is a well-respected industry leader with three decades of experience in information systems and technology services, and more than 20 years in executive management. Prior to serving as SAIC's COO, she was the president of the company's Global Markets and Missions sector and led Corporate Strategy.


▲ *Ritu Favre*

National Instruments (NI) announced the appointment of **Ritu Favre** as SVP and GM of the semiconductor business. In this role, she will set the strategic direction to grow the semiconductor business at NI, building on the company's momentum in this industry. Favre brings to NI her experience in general management and executive leadership roles in the RF



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and semiconductor industries, including CEO of NEXT Biometrics and a member of Cohu board of directors. Before NEXT Biometrics, Favre was SVP and GM at Synaptics, a biometrics firm. Earlier, she led the RF power business segment at Freescale, after a long career beginning at Motorola in 1988.

▲ ***Theodore S. Rappaport***

Theodore S. Rappaport, a NYU professor and founding director of the research center NYU WIRELESS, will be inducted into the **Wireless History Foundation (WHF) Wireless Hall of Fame** at the Foundation's Awards Dinner in Los Angeles on October 23. Rappaport also recently became the recipient of the IEEE 2020 Eric E. Sumner Award, named in honor of the late IEEE President Eric E. Sumner, who was instrumental in developing early switching systems. Rappaport will receive the Sumner medal at the 2019 IEEE Global Communications Conference in Hawaii in early December.

REP APPOINTMENTS

Hirose has expanded its distribution network to better serve customers in the RF and microwave market. Hirose will work with **RFMW** to enhance customer resources and provide best-in-class RF design solutions. RFMW will support Hirose's extensive product offering with a focus on RF and microwave components portfolio including attenuators, terminators, dividers, directional couplers equipped with SMA/BNC/N standard coaxial connectors.

KP Performance Antennas has announced a partnership with global equipment distributor **Winncom Technologies**, to offer its products to a worldwide customer base. As an authorized stocking distributor of KP Performance Antennas, Winncom can now offer their customers a wide range of antennas to address a myriad of wireless networking applications. Through Winncom, customers will have immediate access to KP's broad antenna offering, which includes complete solutions covering the tower to the subscriber. By partnering with Winncom, the company will now be able to reach even more customers, providing them with the latest antenna designs and technologies along with Winncom's best-in-class technical, engineering, logistics and sales support.

PLACES

Altum RF announced the opening of its Sydney R&D office. The lab and office space is ideally situated in the area of Ultimo, adjacent to the Sydney Innovation and Technology Precinct, and a short walk from Sydney University, University of Technology Sydney and Central Station.

INVITED PAPER

Computer-Controlled K-Band Frequency Synthesizer Using Self-Injection-Locked Phase-Locked Optoelectronic Oscillator: Part 2

Afshin S. Daryoush, Tianchi Sun, Kai Wei and Francis T. Pantano
Drexel University, Philadelphia, Pa.

Ajay K. Poddar and Ulrich L. Rohde
Synergy Microwave Corp., Paterson, N.J.

In Part 1, a highly stable computer-controlled K-Band frequency synthesizer is demonstrated using a tunable optoelectronics oscillator (OEO). LabVIEW software control of a modular rack-mountable frequency synthesizer is achieved from 16 to 24 GHz. A narrowband computer-controlled filter is realized using a broadband YIG filter combined with a narrowband, optically-tuned transversal filter. A forced self-injection-locked phase-locked loop (SILPLL) technique is employed to suppress side-modes generated in OEOs, caused by the long fiber delay lines, and further reduce the oscillator phase noise, reaching an estimated 12 fs timing jitter. Computer control of this SILPLL OEO is demonstrated by achieving both linear chirp (FMCW) and pseudo-random frequency hopping. In Part 2, future generations of the forced SILPLL-based OEO are introduced based on integrated optoelectronics. A Si photonics OEO design is presented using an optical phase modulator in place of the conventional optical intensity modulator, by employing a Sagnac loop as a phase modulation (PM) to intensity modulation (IM) convertor. One hundred percent PM sensitivity improvement is achieved by using a 1D photonic crystal superstrate to lateral electro-optic (EO) polymer-based PM. A forced SILPLL K-Band synthesizer using this improved PM is modeled with estimated phase noise of –148 dBc/Hz at an offset frequency of 10 kHz from a 20 GHz signal. A compact multi-mode laser is also developed, where forced oscillation achieves a clean intermodal oscillation frequency at X-Band, with a phase noise of –98 dBc/Hz at 10 kHz offset. This can be extended to K-Band.

High frequency oscillators are important for high speed data transmission. Forced oscillation has been used as a technique[1-3] to stabilize oscillators, and various optical distribution techniques have been reported for stabilization of remotely located oscillators using an external frequency reference.[4-8] The OEO is a new category of oscillator, based on energy storage using long optical delay lines to achieve high frequency stability.[9] This structure has been widely employed for high frequency oscillators because of its high spectral purity,[10] and it has been extended to 50 GHz.[11] One of the challenges encountered with OEOs is the temperature sensitivity of long fiber-optic delay lines,[12] which can be improved


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TABLE 1

X- AND K-BAND FREQUENCY SYNTHESIZERS BASED ON THE SILPLL OEO

Frequency Tuning Range (GHz)	8 to 12	16 to 24
Computer Control Accuracy (kHz)	<10	<20
Manual Control Accuracy (Hz)	<35	<70
RF Output Power (dBm)	>14	>10
SSB Phase Noise (dBc/Hz)		
1 kHz Offset	−109.97	−102.30
10 kHz Offset	−136.45	−127.37
100 kHz Offset	−141.91	−133.16
10 MHz Offset	−143.66	−140.67
Timing Jitter, 300 Hz to 10 MHz (fs)	8.5	11
Side-Mode Levels, 300 Hz to 10 MHz (dBc)	<−100	<−100
Short-Term Stability Over 60 min (ppm)	±0.15	±0.15
Prime Power Consumption (W)	20	20
Package Size (in.)	19 x 14 x 9	19 x 14 x 9
Package Weight (lb.)	<30	<30
Output Connector	SMA (F)	SMA (F)

by employing passive temperature compensation using special hollow-core photonic crystal fibers (HC-PhC),[13] resulting in both short- and long-term frequency stability.[14] Forced oscillation techniques help to reduce the oscillation side-modes.[15] Using an injection-locked phase-locked loop (ILPLL) improves phase noise close to the carrier, reduces pull-in time, enhances the locking and tracking ranges over the standard IL or PLL and reduces prime power and reduces space compared to a multiplier chain.[16]

Self-forced oscillation is an approach employed in X- and K-Band frequency synthesizers[17-19] without any external frequency reference, using integrated concepts of self-IL[20] (SIL) or self-PLL[21] (SPLL) for improvement in phase noise, both close to and far from the carrier. Oscillation side-modes are also suppressed using multiple loops with anharmonic or non-harmonic delays. The concept of SIL and SPLL are combined as SILPLL for demonstrated improvement in close-in phase noise of dielectric resonator oscillators[22] and its significant side-mode suppression, which has led to low timing jitter.[23] Part 1 of this article[24] reviewed the design implementation and testing of a 19 in. rack-mountable, computer-controlled K-Band frequency synthesizer with high frequency resolution, using a Mach Zehnder modulator (MZM) SILPLL OEO with a YIG filter combined with an optical transversal filter. The synthesizer achieved extremely narrowband frequency selection, with operation at either X- or K-Band using bias voltage control. The performance of the X- and K-Band OEO synthesizers is summarized in ***Table 1***.

Part 2 of this article discusses straightforward changes that reduce the size and cost, which also improve the environmental sensitivity of the synthesizer. Building on these, innovations are explored using custom integration of the SILPLL in various degrees to implement the OEO. The first step to reduce the size of the frequency synthesizer is to use alternative commercial computer-controlled power supplies and integrate the fiber laser and fiber amplifier modules. The innovations adopts Si photonics integration to convert the optical IM to a PM that is DC bias free and less sensitive to the pyroelectric and piezoelectric properties of the optical modulator. The design

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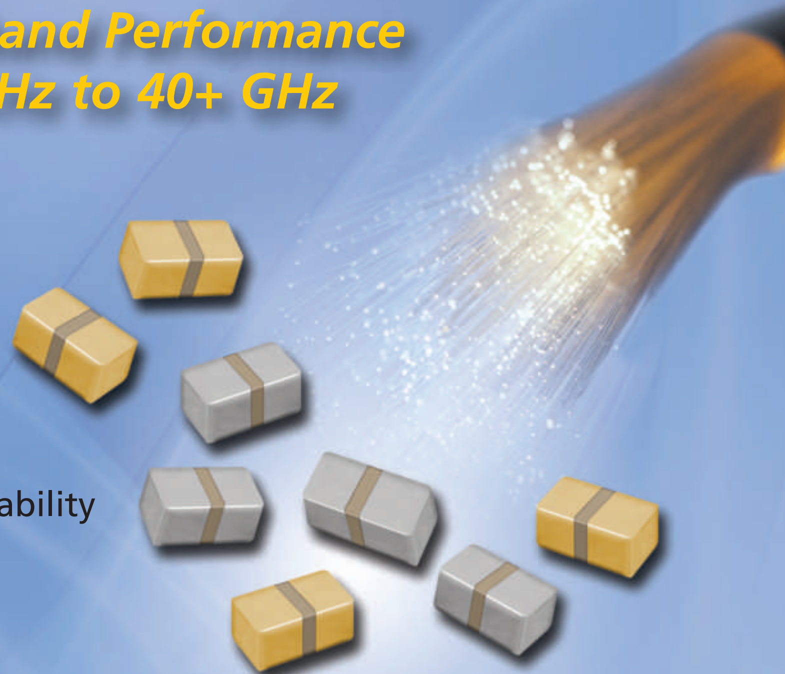

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- Broadband Test Equipment
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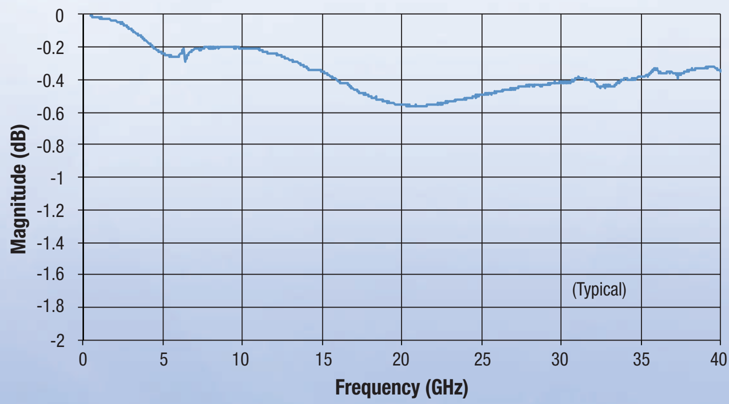
† Receive and Transmit Optical Sub-Assembly
†† Synchronous Optical Network

560L Insertion Loss (S21)



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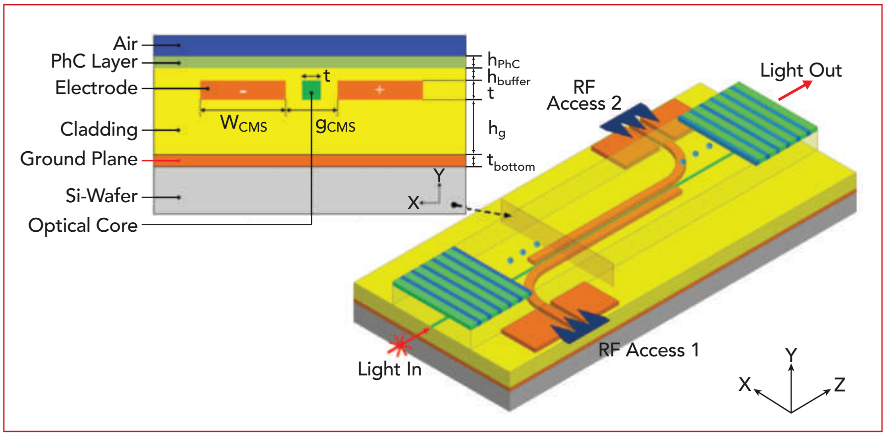


▲ **Fig. 1** **Electro-optic PM with integrated 1D PhC driven by in-plane CMS electrodes.**

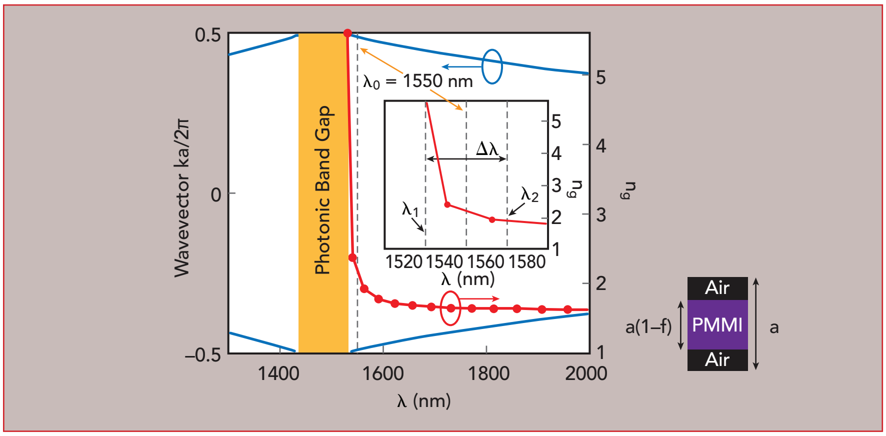
employs EO polymer-based phase modulators[24-26] implemented with a Si photonics Si BiCMOS topology. Incorporating a photonic crystal (PhC) slow light structure to the PM[25-26] leads to a nonlinear dispersive group velocity that enhances modulation sensitivity. Realization of the PM-based OEO employs PM to IM using a Sagnac loop.[27-29]

The simulated results for a future generation K-Band synthesizer using a SILPLL OEO show improved phase noise. The improved modulation efficiency reduces the noise figure of the fiber-optic delay lines, which in turn reduces the close-in phase noise of the OEO. A low cost, compact and stable OEO system is proposed using the intermodal oscillation output of an integrated multi-mode laser.[30-32] Experimental results of this chip-level intermodal oscillator demonstrate the forced oscillation performance. The roadmap to a fully integrated IC using high Q-factor annular resonators as optical delay elements is discussed.

SIZE REDUCTION AND FREQUENCY EXPANSION

In Part 1 of this article,[24] the design and implementation of a K-Band frequency synthesizer using OEO techniques were reported. Even though the prototype synthesizer shows great frequency stability, size, weight and frequency coverage compared to other commercially available electronic or optoelectronic synthesizers, the design can be further improved. In the implementation described, most of the physical space and weight in the box were from the Agilent power supply. This supply can be replaced with a compact AC-DC convertor module from XP Power (PBM200PQ05-C), with the size of the new supply only 10 in. × 6 in. × 2.25 in.—only a quarter of the size of the Agilent supply. The weight of the new unit is 1.83 lbs, a reduction of 90 percent.

The erbium-doped fiber amplifier (EDFA) can be integrated and placed inside the OEO box. In the initial design, the EDFA from Shandong Wanshuo Optoelectronic Equipment Co. contained two power supply modules for redundancy, one a backup to ensure reliable performance. An EDFA with only a single supply, a mother board for control and the other components would reduce the size to approximately half of the original Agilent power supply. This new EDFA would easily fit with the compact power supply module, yielding a total weight saving of about 18 percent and a size reduction of 20 percent. The revised system using modular components would occupy a total volume of 1200 cubic in., with the computer-controlled power supply and EDFA consuming 470 cubic in. The overall weight of the new design will be under 25 lbs, and the system can be integrated in a single housing compatible with 19 in. rack mounting.



▲ Fig. 2 Photonic band structure and group index vs. wavelength for lattice constant a = 470 nm and filling fraction f = 0.1, with λ_1 = 1530 nm, λ_2 = 1570 nm and $\Delta\lambda$ = 40 nm.

TABLE 2

SIMULATED SSB PHASE NOISE OF SAGNAC LOOP SILPLL OEO AT 20 GHz (dBc/Hz)

Offset	Vπ = 1.38 V IL = 5 dB	Vπ = 5 V IL = 3 dB	Vπ = 3 IL = 3 dB
1 kHz	−120.7	−120.2	−120.5
10 kHz	−148.2	−145.0	−147.0

Extending the frequency coverage of the synthesizer is also feasible. The first design covers 16 to 24 GHz. Because of the advantages of the OEO system and using the half-wave voltage (Vπ) of the intensity modulator, only a few components need to be updated to extend the upper frequency to 40 GHz: the photodiode, intensity modulator and RF amplifiers. For the optical modulator, the T.DEH 1.5-40-ADC from Sumitomo[33] or the OC-768 from EOSPACE[27] are options to extend the bandwidth to 40 GHz. An ultra-high speed photodetector from Discovery Semiconductors (DSC30S) will be suitable for 40 GHz, and low noise amplifiers from B&Z (e.g., BZ-30005000-550820-152020) covers the additional required bandwidth. With little system engineering and component replacement, the new synthesizer will operate to 40 GHz.

Si PHOTONICS SYNTHESIZER

Even though simple revisions can significantly reduce the size of the synthesizer, the sizes of the optical fiber mandrills and complex circuits limit further reduction; an integrated solution is necessary to go further. Also, the performance of the modular RF components will affect the performance above 60 GHz. An ideal realization of a high frequency synthesizer covering above 24 GHz requires integration of the optoelectronics circuitry using Si photonics.

The first step is a hybrid integrated SILPLL system[33] using EO polymer-based optical modulators. To avoid the bias dependent characteristics of the MZM, an optical phase modulator design[27] is considered using a Si photonics technique compatible with SiGe BiCMOS fabrication. The structure of the proposed phase modulator with 1 cm interaction length is shown in ***Figure 1***. PMMI-CPO-1 is chosen as the optical core material (20 wt%), which has a refractive index of 1.63 and a conservative EO coefficient of 70 pm/V at 1550 nm. Norland Optical Adhesive 65 (NOA65) is selected as the cladding material; it has a refractive

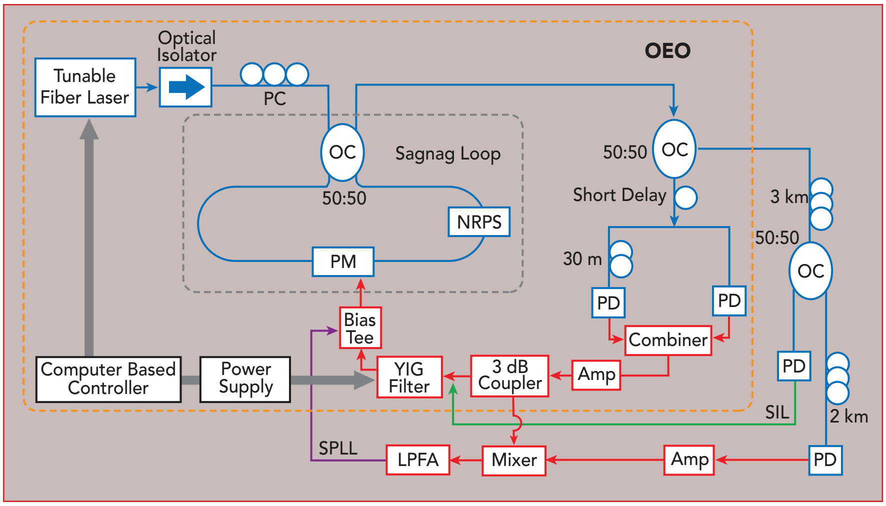


Fig. 3 **PM-based SILPLL K-Band OEO synthesizers (outer dashed box) with Sagnac loop, optical/RF paths (blue and red) and SPLL/SIL (purple and green).**

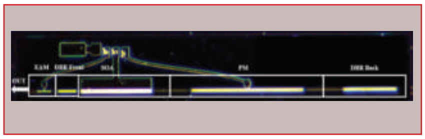


Fig. 4 **Photograph of DBR multi-mode laser to generate inter-modal oscillation.**

index of 1.51 and a loss tangent of 2.2×10^{-2}. The geometrical dimensions of the in-plane coupled microstrip (CMS) electrodes are calculated to achieve a 50 Ω characteristic impedance: t = 1.6 μm, W_{CMS} = 94 μm, g_{CMS} = 10 μm, h_g = 40 μm, t_{bottom} = 0.2 μm, h_{PhC} = 0.6 μm and h_{buffer} = 0.2 μm.[27]

To enhance modulation efficiency, a slow light 1D PhC structure with lattice constant of 470 nm, consisting of a base material of PMMI and a substrate with 47 nm of air gaps is placed close to the optical core as a superstrate. The dispersive characteristic of the propagating light inside the optical core is affected by the slow light effect, as depicted in ***Figure 2***. The effect is maximized when the PhC layer touches the optical core, with the optical loss a significant side-effect. The dispersive effect gets stronger as the PhC layer thickens, at the cost of increased optical loss. A combination of h_{buffer} of 0.6 μm and h_{PhC} of 0.2 μm represents a compromise between the thickness of the buffer layer and height of the PhC layer. The modulator figure of merit $V\pi \times L$ and optical loss were modeled at approximately 3 Vcm and 3 dB/cm, respectively, using a commercial optical simulator, OptiBPM. Compared to a $V\pi \times L$ of 7.2 Vcm for a phase modulator without the PhC layer, the half-voltage magnitude is more than 100 percent improved.

The realization of the SILPLL-based OEO is based on a Sagnac loop[28] (see ***Figure 3***), where the input light coming from the tunable laser source is fed into an optical coupler and equally divided into clockwise (CW) and counter-clockwise (CCW) paths around the loop. Both CW and CCW signals propagate through the phase modulator and travel around the other half of the loop, where only the CCW propagating signal is phase shifted by a non-reciprocal phase shifter, because of the polarization controller. The simulated phase noise performance is better than −148 dBc/Hz at 10 kHz offset using this SILPLL architecture[29-30] (see ***Table 2***).

InP SYNTHESIZER

The second innovation is a monolithically integrated design, where the whole synthesizer is realized as a single InP IC, which will operate beyond K-Band. RF oscillation is achieved using the inter-modal oscillation output of a long multi-section, multi-quantum well DBR semiconductor laser (see ***Figure 4***), which provides the laser realization for the synthesizer.[31-33]

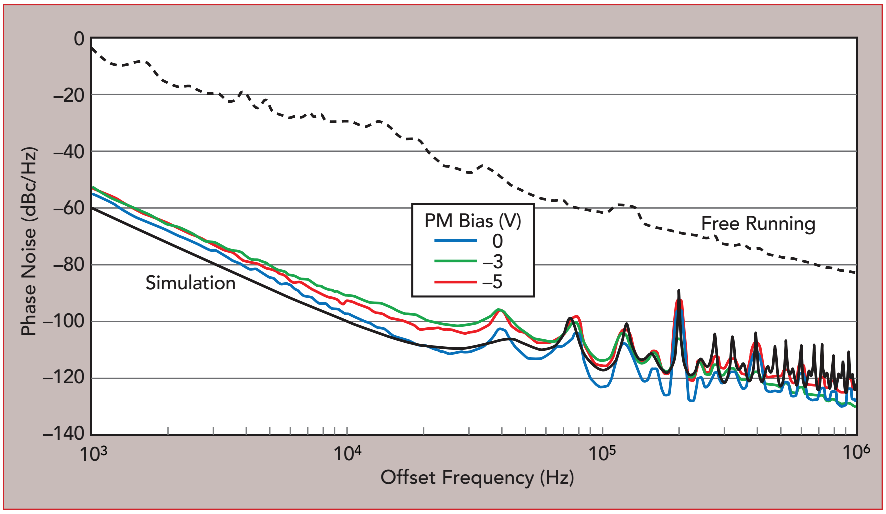


Fig. 5 SILTPLL-based inter-modal RF phase noise vs. PM bias using SIL of 3 km, STPLL of 500 m, 1 km and 5 km. PM bias of 0 V, –3 V and –5 V are for RF frequency tuning of ~800 MHz from 11.549, 11.938 and 12.272 GHz, respectively.

The laser consists of four major sections,[34] the distributed Bragg reflector (DBR), gain medium, phase tuning section and electro-absorption modulator. The DBR is used as a filter to select the laser output frequency,[35] and the phase section tunes the intermodal output to achieve the desired RF output. With this technique, the whole system can be realized within a 5 mm × 2 mm chip without an outside circuit, which is significantly smaller than any conventional RF synthesizer. The performance of the intermodal output at 11.6 GHz is shown in ***Figure 5***. Free running, the output phase noise is around −30 dBc/Hz at 10 kHz offset. With SILTSPLL[23] applied, the phase noise drops to −98 dBc/Hz at 10 kHz offset with an offset phase modulator bias of 0 V, yielding a 68 dB phase noise reduction from the free-running case.

CONCLUSION

The first article in this two-part series demonstrated a computer-controlled K-Band synthesizer using a MZM-based OEO architecture. Suppression of intermodal oscillation from the long fiber-optic delay lines reduced the close-in phase noise,[23] with measured results about −130 dBc/Hz at 10 kHz offset over the full frequency range from 16 to 24 GHz. This second article discusses approaches for reducing the size and cost of the OEO synthesizer by using a PhC-PM device and a Sagnac loop phase modulator to intensity modulator convertor.[28-29] Using the PhC-PM instead of the MZM OEO requires forced SILPLL techniques and achieves an estimated −148 dBc/Hz phase noise at 10 kHz offset. PhC-PM design concepts compatible with Si photonics could be integrated with SiGe BiCMOS technology for a full monolithic integration of the photonic and electronic circuits. Forced-oscillation control of an InP based DBR semiconductor laser is another alternative to full monolithic integration. Various high quality factor, low loss optical resonators (e.g., Si_3N_4 and SiO_2) could be employed in place of km-long fiber-optic delay lines to further reduce the size of the optical components used in the SILPLL structure. For example, whispering gallery mode resonators with Q-factors to 10^8 and optical ring resonators with Q-factors to 10^5 have been demonstrated,[36] which could be integrated using a Si photonics process. These proposed solutions make the realization of OEOs very attractive for future generations of instrumentation, communications and sensing.

References

1. R. Adler, "A Study of Locking Phenomena In Oscillators," *Proceedings of the IRE 34*, No. 6, 1946, pp. 351–357.

2. U. L. Rohde, "Digital PLL Frequency Synthesizers: Theory and Design," *Prentice Hall*, New York, 1983.
3. A. S. Daryoush, "Optical Synchronization of Millimeter-Wave Oscillators for Distributed Millimeter-wave Systems," *IEEE Trans. on Microwave Theory and Techniques*, Vol. 38, No. 5, May 1990, pp. 1371–1373.
4. P. R. Herczfeld, A. S. Daryoush, A. Rosen, A. K. Sharma and V. M. Contarino, "Indirect Subharmonic Optical Injection Locking of a Millimeter Wave IMPATT Oscillator," *IEEE Trans. on Microwave Theory and Techniques*, Vol. 34, No. 12, December 1986, pp. 1371–1376.
5. A. S. Daryoush, P. R. Herczfeld, P. Wahi and Z. Turski, "Comparison of Indirect Optical Injection Locking Techniques of Multiple X-Band Oscillators," *IEEE Trans. on Microwave Theory and Techniques*, Vol. 34, No. 12, December 1986, pp. 1363–1370.
6. S. Lipsky and A. S. Daryoush, "Fiber Optic Methods for Injection-Locked Oscillators," *Microwave Journal*, Vol. 35, No. 1, January 1992, pp. 80–88.
7. E. C. Niehenke and P. Herczfeld, "An Optical Link for W-Band Transmit/Receive Applications," *1997 IEEE International Microwave Symposium Digest*, Vol. 1, pp. 35–38.
8. A. S. Daryoush, "Phase Noise Degradation in Nonlinear Fiber Optic Links Distribution Networks for Communication Satellites," *Microwave Photonics from Components to Applications and Systems*, Kluwer Academic Publishers, May 2003.
9. X. S. Yao and L. Maleki, "Optoelectronic Microwave Oscillator," *J. Opt. Soc. Am.*, B 13, 1996, pp. 1725–1735.
10. A. S. Daryoush, A. K. Poddar, T. Sun and U. L. Rohde, "Optoelectronic Oscillators: Recent and Emerging Trends," *Microwave Journal*, October 2018, pp. 58–76.
11. S. Fedderwitz, A. Stohr, S. Babiel, V. Rymanov and D. Jager, "Opto-Electronic Dual-Loop 50 GHz Oscillator With Wide Tunability and Low Phase Noise," *Proc. of 2010 IEEE Microwave Photonics*, pp. 224–226.
12. M. Kaba et al., "Improving Thermal Stability of Opto-Electronic Oscillators," *IEEE Microwave Magazine*, Vol. 7, No. 4, August 2006, pp. 38–47.
13. A. S. Daryoush, H. W. Li, M. Kaba, G. Bouwmans, D. Decoster, J. Chazelas and F. Deborgies, "Passively Temperature Stable Opto-Electronic Oscillators Employing Photonic Crystal Fibers?," *Proc. of the European Microwave Association*, Vol. 3, No. 3, September 2007, pp. 201–209.
14. L. Zhang, V. Madhavan, R. Patel, A. K. Poddar, U. L. Rohde and A. S. Daryoush, "Ultra Low FM Noise In Passively Temperature Compensated Microwave Opto-Electronic Oscillators," *Proc. IEEE International Microwave and RF Conference*, December 2013.
15. T. Sun, Li. Zhang, A. K. Poddar, U. L. Rohde and A. S. Daryoush, "Frequency Synthesis of Forced Opto-Electronic Oscillators at the X-Band," *Chin. Opt. Lett.*, Vol. 15, No. 1, January 10, 2017, p. 010009.
16. A. S. Daryoush, "Phase Noise Degradation in Nonlinear Fiber Optic Links Distribution Networks for Communication Satellites," *Microwave Photonics from Components to Applications and Systems*, Kluwer Academic Publishers, May 2003.
17. A. K. Poddar, U. L. Rohde and A. S. Daryoush, "Self-Injection Locked Phase Locked Loop Optoelectronic Oscillator," *U.S. Patent 20140186045*, July 3, 2014.
18. T. Sun, A. S. Daryoush, A. Poddar, L. Zhang and U. Rohde, "High-Resolution Frequency Synthesizers Over X-Band Using SILPLL Opto-Electronic Oscillators," *2017 IEEE International Frequency Control Symposium*, 2017.
19. T. Sun, A. S. Daryoush, A. Poddar, L. Zhang and U. Rohde, "High-Resolution X-Band Frequency Synthesizer Using SILPLL Opto-Electronic Oscillators," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*.
20. L. Zhang et al., "Analytical and Experimental Evaluation of SSB Phase Noise Reduction in Self-Injection Locked Oscillators Using Optical Delay Loops," *IEEE Photonics J.*, Vol. 5, No. 6, December 2013.
21. L. Zhang et al., "Comparison of Optical Self-Phase Locked Loop Techniques for Frequency Stabilization of Oscillators," *IEEE Photonics J.*, Vol. 6, No. 5, October 2014, pp. 1–15.
22. L. Zhang et al., "Self-ILPLL Using Optical Feedback for Phase Noise Reduction in Microwave Oscillators," *IEEE Photonics Technology Letters*, Vol. 27, No. 6, 2015, pp. 624–627.
23. T. Sun et al., "Limits in Timing Jitters of Forced Microwave Oscillator Using Optical Self-ILPLL," *IEEE Photonics Technology Letters*, Vol. 29, No. 2, January 15, 2017, pp. 181–184.
24. A. S. Daryoush, T. Sun, N. Bromhead, A. K. Poddar and U. L. Rohde, "Computer Control of Self Injection Locked Phase Locked Opto-Electronic Oscillator Based K-Band Frequency Synthesizers: Part 1," *Microwave Journal*, Vol. 62, No. 8, August 2019, pp. 90–104.
25. M. Hadjloum, M. El Gibari, H. W. Li and A. S. Daryoush, "Design Challenges of EO Polymer Based Leaky Waveguide Deflector for 40 Gs/s All Optical Analog-To-Digital Converters," *Opt. Commun.*, Vol. 373, 2016, pp. 82–90.
26. K. Receveur, K. Wei, M. Hadjloum, M. El Gibari, A. De Rossi, H. Li and A. Daryoush, "Sensitivity Improvement of Broadband Electro-Optic Polymer-Based Optical Phase Modulator Using 1D and 2D Photonic Crystal Struc-

tures," *Chin. Opt. Lett. 15*, Vol. 15, No. 1, January 10, 2017, p. 010003.

27. K. Wei and A. S. Daryoush, "Broadband and Sensitive Lateral Optical Phase Modulators Using 1D-PhC for Integrated Si-Photonics," *2018 International Meeting on Microwave Photonics*.
28. S. E. Hosseini et al., "Low-Drift Opto-electronic Oscillator Based on A Phase Modulator in A Sagnac Loop," *IEEE Transactions on Microwave Theory & Techn.*, Vol. 65, No. 7, July 2017, pp. 2617–2624.
29. F. Pantano et al., "Forced Opto-Electronic Oscillators Using Efficient PBG Based Phase Modulators," *2018 IEEE International Frequency Control Symposium*, pp. 1–3.
30. F. T. Pantano, K. Wei, T. Sun and A. S. Daryoush, "SILPLL Based Forced Opto-Electronic Oscillator Using A Phase Modulator in A Sagnac Loop," *2018 IEEE Topical Conference on Wireless Sensors and Sensor Networks*, pp. 66–69.
31. T. Sun and A. S. Daryoush, "Ultra-Stable RF Signal Generator Using Beat-Notes Output of DBR Based Multi-Modes Lasers," *2017 International Topical Meeting on Microwave Photonics*, pp. 1–3.
32. A. S. Daryoush and T. Sun, "Compact Highly Stable Synthesized RF Sources Using Self Mode-Locked Beat-Notes of Multimodes of Multimode Lasers," *U.S. Patent Application No. 62/576,398*, October 24, 2017.
33. A. K. Poddar, U. L. Rohde and A. S. Daryoush, "Optoelectronic Oscillator using Monolithically Integrated Multi-Quantum Well Laser and Phase Modulator," *U.S. Patent Application No. 63/702,970* July 25, 2018.
34. L. A. Johansson, Y. A. Akulova, G. A. Fish and L. A. Coldren, "Sampled-Grating DBR Laser Integrated with SOA and Tandem Electroabsorption Modulator for Chirp-Control," *Electronics Lett.*, Vol. 40, No. 1, January 8, 2004, pp. 70–71.
35. S. Joshi, C. Calò, N. Chimot, M. Radziunas, R. Arkhipov, S. Barbet, A. Accard, A. Ramdane and F. Lelarge, "Quantum Dash Based Single Section Mode Locked Lasers for Photonic Integrated Circuits," *Opt. Express 22*, 2014, pp. 11254–11266.
36. A. A. Savchenkov et al., "Whispering-Gallery Mode Based Opto-Electronic Oscillators," *2010 IEEE International Frequency Control Symposium*, pp. 554–557.

INVITED PAPER

mmWave Technology Enables Faster, Safer, Privacy-Conscious Travel

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The security checks passengers undergo before boarding flights are changing, the aim being to scan more passengers while reducing waiting times—and, of course, improving threat detection to ensure safety and security. Walk-through metal detectors (WTMD) are a familiar preflight security check. Although familiar, they are far from ideal: frequent "false positives" oblige security staff to perform many manual checks that are labor-intensive and detract from the traveler's experience. Of more concern, the equipment cannot detect plastic or liquid explosives or ceramic blades.

As threats are evolving, so must the security techniques, while achieving important practical and privacy goals:

- Privacy is a key concern. New equipment and procedures must respect the privacy and dignity of travelers and not place security staff in awkward or stressful situations.
- Safety is critical. Scanners cannot use radiation harmful to passengers or security staff.
- Checks need to be completed quickly, as the average time from front door to departure lounge is an important metric for airports.
- Cost is always an issue. The equipment must be affordable and not require additional staff.
- A less obvious concern is size; space in busy airports is scarce and a premium. A security system involving large or power-hungry equipment, extra rooms or dedicated security areas is impractical.

mmWAVE SCANNERS

mmWave scanners meeting these requirements offer a better alternative to the traditional WTMD and are already being introduced at leading airports around the world. From the passenger's perspective, the difference between the new scanner and the familiar metal-detector gate is the requirement to stand still for a few seconds inside the machine, facing the scanner with the arms away from the body. In addition to detecting a wider range of threats involving

non-metallic objects or substances, the new scanners reduce the rate of "false positives," which shortens the average time to screen each passenger.

To protect the privacy and comfort of airline customers and ensure a stress-free working environment for security staff, the new scanners take advantage of advanced machine-learning techniques to avoid inspecting actual body images. They use several technical innovations to meet the goals for scan time, equipment size and cost.

THE OPTIMUM mmWAVE BAND

Scanning with mmWave is intrinsically well-suited to airport security. They have no ionizing effect on the body's cells and are considered harmless to staff and passengers. In comparison, ultrasonic scanning, although harmless, has a very short range; a coupling medium—usually a gel—is required to ensure image quality. This is obviously impractical in an airport.

Wavelengths in the 1 to 10 mm range are suitable for non-contactless scanning and allow a suitable combination of penetration depth and spatial resolution to detect objects airline passengers may seek to conceal beneath clothing. In choosing the best wavelength, there is a trade-off between penetration and spatial resolution. A spatial resolution of about 2 mm is considered adequate for security applications, so E-Band (60 to 90 GHz with wavelengths of 5 to 3.3 mm) provide reliable object recognition and adequate penetration to reach the surface of the skin. Within this band, working in the 70 to 80 GHz range allows equipment designers to use existing components and knowledge from automotive radar applications, which shortens the development time.

PASSIVE VS. ACTIVE SCANNING

mmWave images can be captured passively by detecting the characteristic radiation of an object and the natural background radiation. This is suitable for equipment used outdoors, where the background radiation temperature is typically below 100°K. Indoors, however, the radiometric contrast between the object and background is much lower. Although this can be addressed using cooled detectors, passively detected radiation can be confused with thermal noise, resulting in a lack of depth information about the object. Obviously, this is not ideal when the goal is to classify objects quickly and accurately and identify concealed weapons, while reliably avoiding false positives.

For this reason, active scanning is preferred for security systems. This involves illuminating the subject by transmitting low-power mmWave radiation. With the high water content of human tissue, the body acts as a strong reflector. Accurately characterizing the reflections enables the system to identify vari-


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ous objects concealed against the skin. With active scanning, antenna positioning is critical to minimize the effects of unwanted reflections. Where conventional industrial applications using active mmWave imaging operate at far-field distances, long-range imaging is impractical to find small threats in security applications. Hence, airport security scanners operate at close range.

3D FROM 2D

To reconstruct an accurate 3D image of a scanned object requires sampling a 2D aperture with a broadband measurement signal at each selected transmitter-receiver combination. The transmitter/receiver design must be optimized both for depth and spatial resolution. For example, the high range resolution needed to identify thin objects, such as plastic explosives formed in sheets, requires a large signal bandwidth and corresponding short pulse duration.

There are several ways to achieve the required spatial resolution. Conventional mechanical scanning is not well-suited to the fast cycle times needed for the mass screening of airline passengers. The typical alternative involves dense monostatic antenna arrays that require large numbers of transmitter/receiver units, resulting in equipment that is extremely expensive. Rohde & Schwarz overcame this challenge by combining synthetic aperture algorithms from radio astronomy with virtual aperture techniques to create a new form of multistatic 2D array. Such arrays comprise multiple clusters of transmit and receive antennas in a novel array architecture. Digital beamforming algorithms are applied to weight each antenna with suitable phase and amplitude factors to create an electronically optimized aperture. Using a cost-effective sparse antenna array, the resulting system can achieve good image quality at close range, with minimal ambiguities.

In the multistatic array, each transmitter sequentially illuminates the volume in front of the system, with all receive antennas activated simultaneously to ensure coherent sampling of the reflected field. Subsequent processing calculates the reflections and applies the necessary error correction. Compared to a monostatic array, multistatic imaging requires significantly fewer channels, while parallelizing the data acquisition to allow near real-time performance. The resolution of the Rohde & Schwarz scanning system is approximately a half-wavelength, namely 2 mm. For a given image resolution, the speed of a digital beamforming system depends mainly on the number of measurements and the complexity of the image formation algorithms. This enables system performance to be improved by leveraging successive generations of DSP ICs with higher clock speeds and greater computational parallelism.

TRANSMITTER/RECEIVER DESIGN

To realize the system, Rohde & Schwarz developed signal sources that generate coherent RF and receiver local oscillator (LO) signals, which are needed to coherently operate the transmitters and receivers. The signal source uses direct digital synthesis (DDS) and a highly stable oven-controlled crystal oscillator (OCXO) to achieve accurate phase stability. After the DDS, the transmit signal frequency is multiplied to the 20 GHz range and distributed to the clusters. At each chip, the RF and LO signals are quadrupled to the operating frequency and distributed to each of the four channels. The antenna design is optimized to ensure a small footprint and high bandwidth. ***Figure 1*** shows a transmit/receive panel which integrates approximately 100 transmit and 100 receive antennas.

Based on the innovative sparse-array design, a full-size body scanner can be realized with about 12,000 channels. Although this is far less than would be required to achieve a similar system using conventional antenna array and imaging knowhow, many discrete front-ends would be needed using current commercial RFICs, which have been developed for systems with few channels. Practical space constraints demand higher integration, and the RF front-end must be closely integrated with the RF signal source and antenna to minimize interface losses at mmWave frequencies. As suitable modules were not available commercially, Rohde & Schwarz worked with Infineon to produce a custom RF front-end chipset comprising a four-channel transmitter/receiver MMIC fabricated with Infineon's SiGe:C bipolar process. The MMICs are carefully packaged to maintain the bandwidth and reduce production cost (see ***Figure 2***).

PROTECTING PRIVACY WITH AI

The security system can image features as small as a few millimeters and can show depth variations down to 50 microns. The reconstruction block automatically analyzes the image data using dedicated and optimized machine-learning algorithms, tailored for security

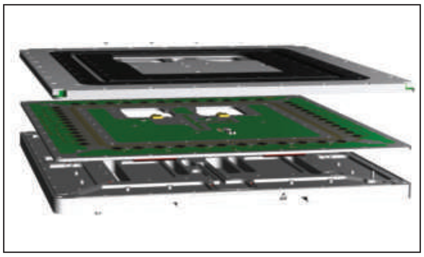


Fig. 1 Transmit/receive panel.

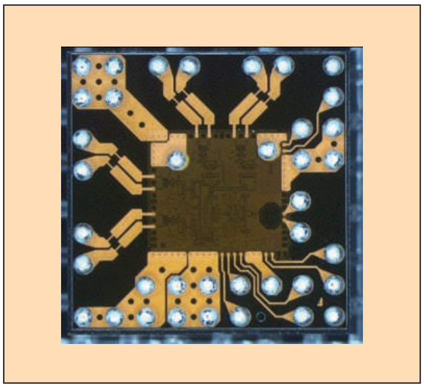
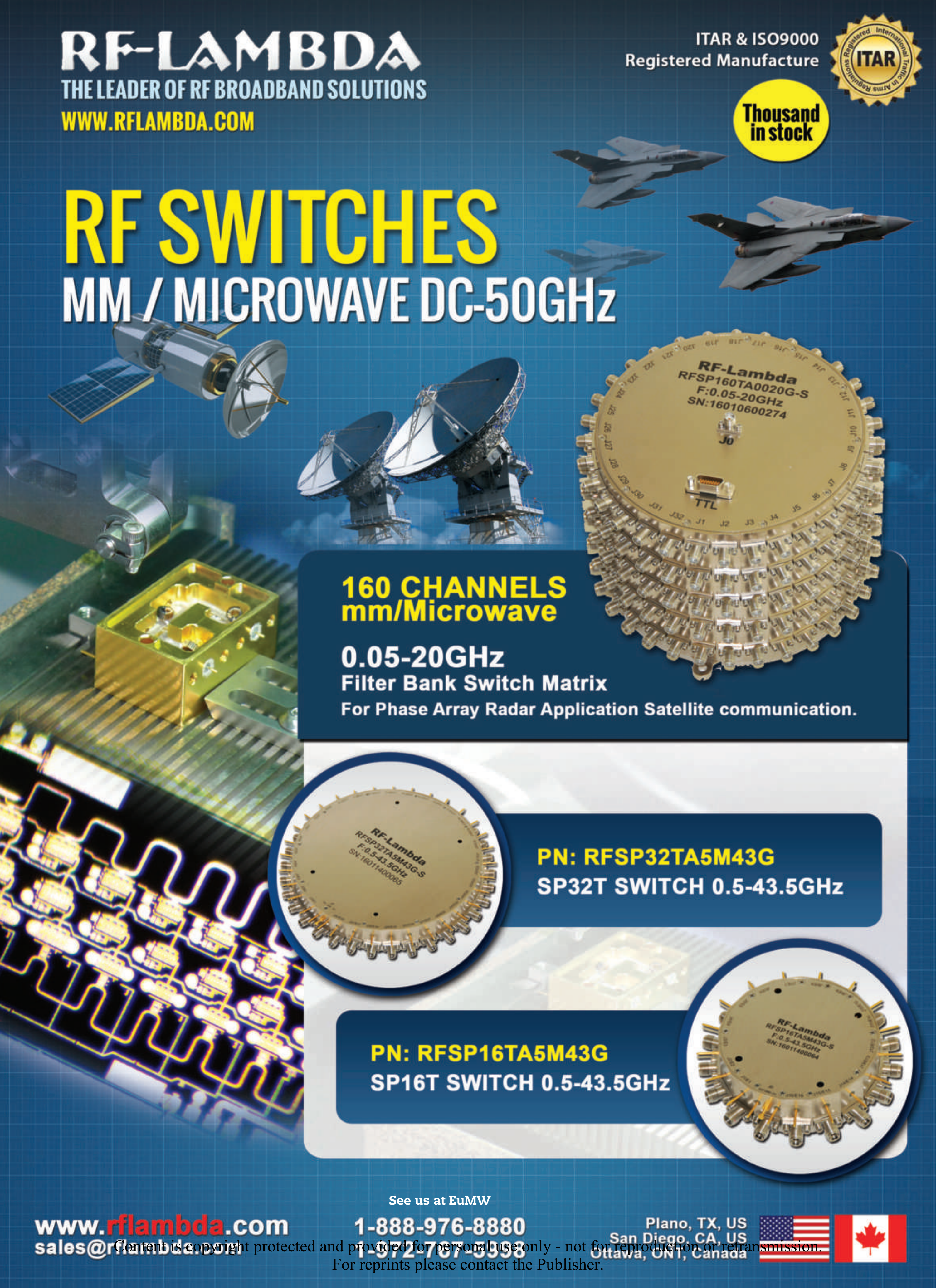


Fig. 2 SiGe RFIC packaging.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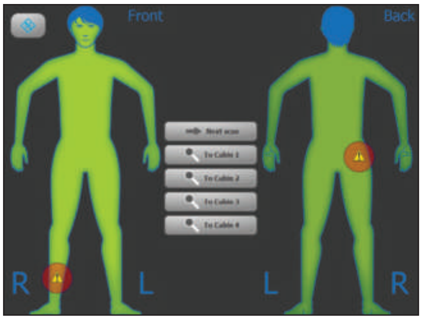
scanning. Each part of the 3D image is analyzed and observed to decide if any location looks anomalous to usual conditions. The algorithms are also trained to be more accurate finding relevant threats, including but not limited to explosives, guns and knives.

The accuracy of these machine-learning algorithms enables the system to reliably identify prohibited items based solely on the data analysis, and no visible body image is created at any point in the system. Any detected threat or unusual object is highlighted on-screen to security staff by indicating the location on an avatar (see ***Figure 3***). While protecting privacy, this also provides a reliable guide for security staff to quickly deal with a situation appropriately. The captured mmWave data is discarded as soon as the analysis is complete.



▲ Fig. 3 Detecting the exact location of a threat without compromising privacy.


▲ Fig. 4 R&S QPS201 design.

SUMMARY

mmWave scanning is an effective threat detection technology. To realize a practical and cost-effective solution for airport security, Rohde & Schwarz has addressed the technical and privacy challenges. The resulting scanner uses innovations such as multistatic imaging with sparse antenna arrays, advanced multi-channel MMICs and RF modules, high performance parallel processing and machine-learning techniques.

The Rohde & Schwarz QPS family are the first commercial security scanners to achieve these exceptional technical advances, quickly receiving praise from airport security agencies worldwide (see ***Figure 4***). Advanced mmWave technology will provide passengers with shorter security queues, less intervention by security staff and safe flights.■

Prototyping an UWB Airborne Radar for Snow Probing Using Modular Building Blocks

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A set of compact ultra-wideband (UWB) radar transmit/receive modules has been developed using rapid prototyping. The modules are based on tailored microwave filters, off-the-shelf building blocks from a commercial supplier and custom DC biasing circuits. As an intermediate step toward full system miniaturization, the integration of microwave components using this technique enables evaluation of different configurations to improve radar performance with a reduced form factor. The modular transmitter and receiver provide a loop sensitivity of 160 dB with 1 W transmit power and low range sidelobes. These modules are intended for airborne snow probing applications requiring multi-GHz bandwidths to achieve cm-scale vertical resolution. Laboratory test results indicate an overall performance improvement compared to larger connectorized assemblies, and radar images demonstrate the utility of the modules for measuring snow layers on terrestrial and marine ice from long-range aircraft. *This work was funded by the Department of Energy's Kansas City National Security Campus, operated by Honeywell Federal Manufacturing & Technologies LLC, under contract number DE-NA0002839 and the National Aeronautics and Space Administration (grant NNX10AT68G).*

UWB microwave radars are widely used for a variety of applications ranging from medical imaging and detection of concealed objects to airborne geophysical surveys and mapping of infrastructure.[1-4] Because of their broad operating bandwidths, such instruments are able to resolve closely spaced targets and media interfaces, making them ideal for measurements of snow thickness and mapping of seasonal snowpack changes (see ***Figure 1***).[5] The University of Kansas' UWB snow radar is a 2 to 18 GHz, frequency modulated continuous wave (FMCW) system, originally developed for gauging snow depth on sea ice and mapping nival accumulation with cm resolution.[6] Previous versions of this instrument employed either a connectorized or a hybrid connectorized/printed circuit board (PCB) assembly in the RF section and were used to demonstrate UWB performance onboard large fixed-wing aircraft for wide coverage retrieval of snow thickness information.[6-7]

Future applications, such as operation on unmanned aerial vehicles, require reduction of the radar's SWaP. As an intermediate step toward complete system miniaturization, modular components from a commercial supplier, X-Microwave,[8] were used to evaluate different receiver and transmitter configurations. The technique uses passive

and active components mounted on discrete PCB carriers arranged in a grid pattern and connected by flexible ground-signal-ground (GSG) jumpers. Such an approach is convenient for optimizing the radar's RF performance—linearity, receiver sensitivity, transmit power and overall performance—before committing to a final design. It also enables suitable chipsets, available in both packaged and discrete die formats, to be identified for future miniaturization.

A 2 to 18 GHz radar reference system using commercial connectorized parts was first built to establish a performance baseline. This radar testbed was characterized in the laboratory and used to collect extensive snow cover data flying on NASA aircraft over the Arctic and Antarctic, supporting Operation IceBridge in 2017.[9] Transmitter and receiver modules were subsequently developed using the X-Microwave framework and integrated in an improved radar demonstrator.

This article describes the modular receiver, transmitter and upgraded 2 to 18 GHz radar system. Careful selection and close integration of these components improved radar performance and demonstrated the utility of the new modules for airborne radar systems measuring the thickness of snow layers.

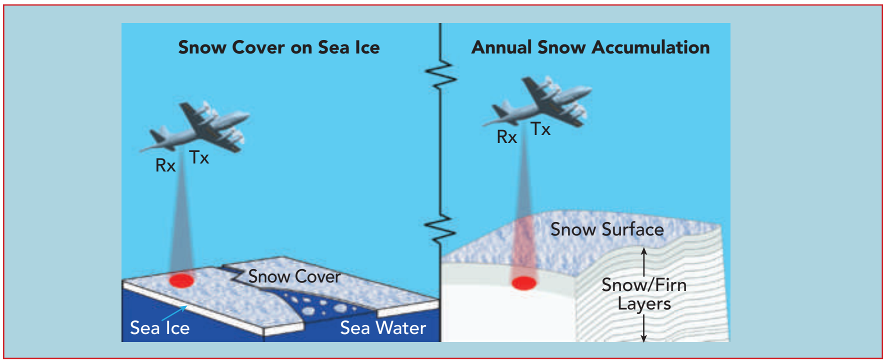

Fig. 1 UWB radar can measure snow thickness and map seasonal changes in the snowpack.

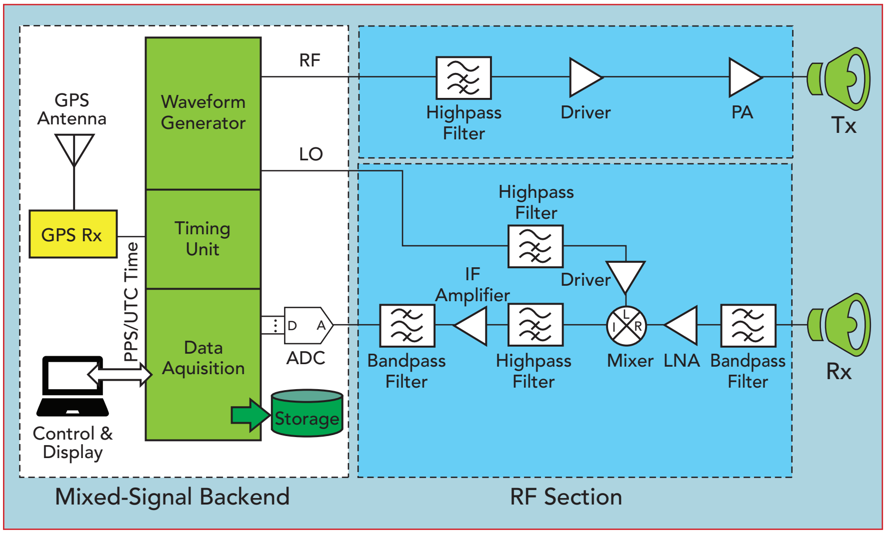

Fig. 2 UWB radar block diagram.

SYSTEM OVERVIEW

Figure 2 shows a simplified block diagram of the radar system. The waveform generator produces a linear frequency modulated signal (chirp) in the 2 to 18 GHz spectral range. The chirp signal is filtered and amplified by the transmitter before feeding the transmit antenna.

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The scattered signal from the observed scene is captured by a second antenna and conditioned by the filter and low noise amplifier in the receiver front-end. A replica of the transmit signal is injected into the local oscillator port of the mixer to de-chirp the amplified received signal. The intermediate frequency (IF) at the output of the mixer is highpass filtered to reject spectral content produced by direct coupling between the transmit and receive antennas. The IF signal is amplified and bandpass filtered before being converted by the analog-to-digital converter (ADC) in the data acquisition (DAQ) system, which stores GPS time-stamped range profiles.

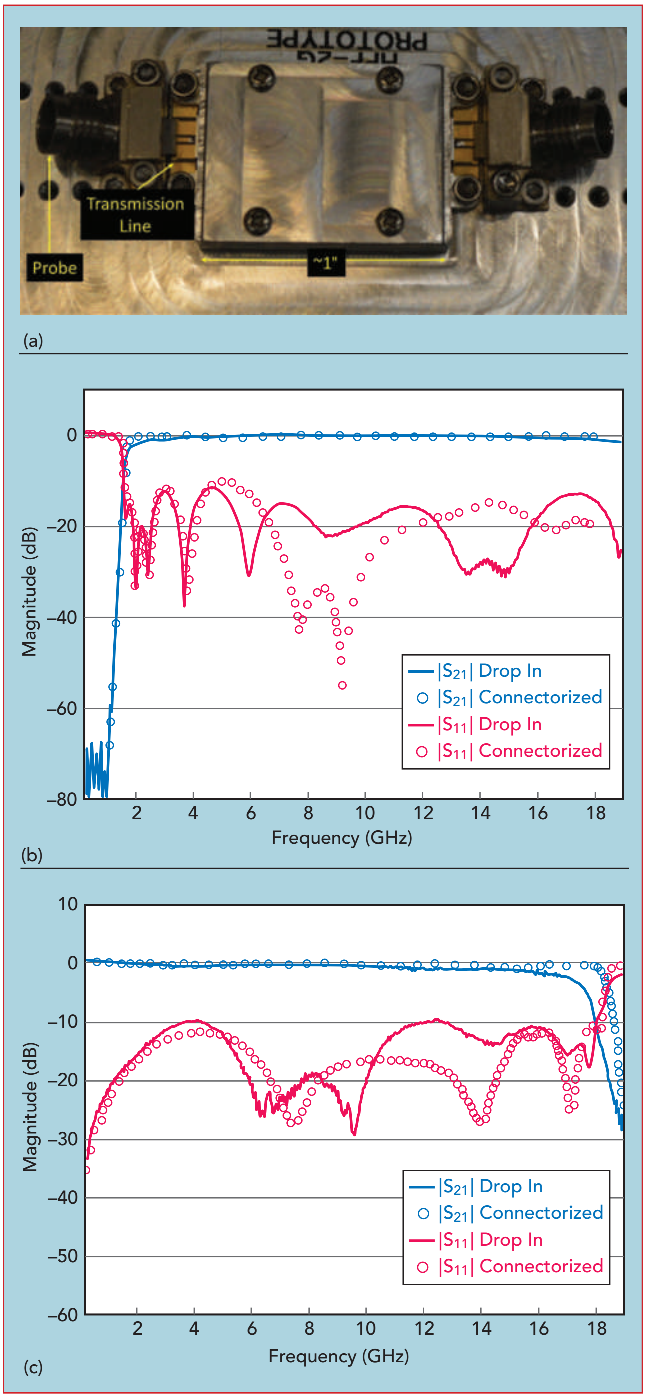

Fig. 3 Drop-in highpass filter in a test vehicle (a). Measured drop-in vs. connectorized highpass (b) and lowpass (c) filters.

The radar is carried onboard an airborne platform with the antennas mounted under the fuselage. The fine resolution of the system, due to its UWB operation, is advantageous for the detection of thin snow cover on sea ice and mapping seasonal accumulation of snow on glacial ice or the ground (see Figure 1).[6-7]

Filter Development

Microwave filters provide frequency selectivity within the radar, specifically at the receiver input, to eliminate interference from other onboard radar systems operating at VHF (180 to 210 MHz), UHF (600 to 900 MHz) and Ka-Band (32 to 38 GHz). Yan, McDaniel et al.[6,10] developed a set of tailored highpass and lowpass filters on suspended substrate stripline, operating from 2 to 18 GHz. The coaxial launch structure of these filters was modified to create a drop-in component compatible with the X-Microwave building block architecture.

The filters installed on a test vehicle (see ***Figure 3a***) enable the transition to planar transmission lines attached to coaxial probes. ***Figures 3b*** and ***3c*** show the measured responses for both filters, compensated for probe losses and compared to the discrete implementations. The highpass filter response is comparable to that of its connectorized counterpart, with an overall improvement in return loss over 6.5 to 16 GHz. Return loss for the two implementations is generally comparable up to 8 and beyond 15 GHz, with some differences versus frequency. Roll-off of the drop-in lowpass filter is slightly faster than that of the connectorized implementation. Similar effects in other samples of the same batch, accompanied by good return loss to 18 GHz, indicates differences in filter responses, not an issue with the coaxial launch.

Module Assembly

Multiple chipsets for the receiver and transmitter designs were tested to achieve the best overall performance; in particular, different mixer devices were evaluated to minimize short-range leakage[11] or "coherent noise" in the receiver. Coherent noise is an artifact inherent in FMCW radars caused by coupling between the transmitter and receiver through various paths and mechanisms, including the antennas and mixer ports. The main contributors to coherent noise include the chirp's own phase noise and in-band harmonics, as well as self-mixing products of the main chirp signal with internal reflections. Mixer impedance match and interport isolation are critical to minimize coherent noise. Of the wideband mixers evaluated, the best was a connectorized component with field-replaceable connectors, which was used as a drop-in block. Using LO driver amplifiers with low phase noise also improves performance. To achieve at least 1 W output power (versus the 0.1 W in the connectorized reference system), a 4 W capable amplifier under-driven to 1 W was chosen to lower the in-band harmonics and reduce coherent noise.

One of the requirements using the X-Microwave building blocks is precise alignment between the adjacent carriers in a component chain with their corresponding GSG jumpers. Full-wave electromagnetic simulation was used to better understand and predict the effect of misalignment in interconnect performance,

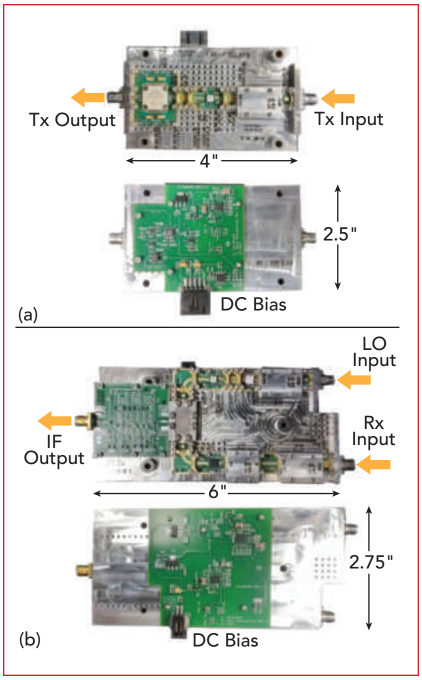

Fig. 4 Tx (a) and Rx (b) modules.

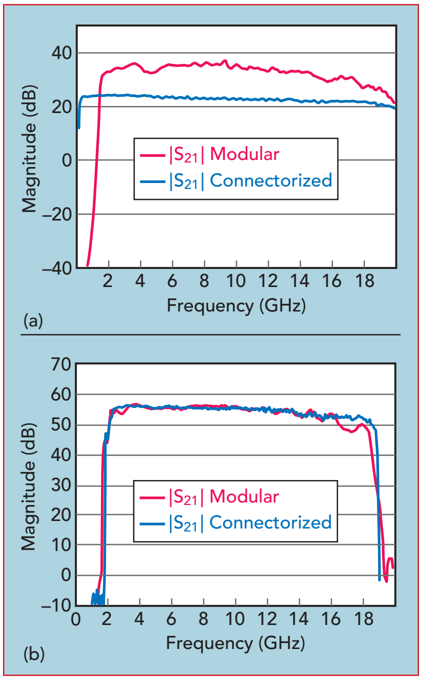

Fig. 5 Measured Tx insertion gain (a) and Rx conversion gain (b).

including a parametric analysis in which the GSG jumper's horizontal position was varied from 0 (perfectly aligned) to 6 mils (severely misaligned). Both the transmission and reflection coefficients were satisfactory well beyond 20 GHz when the alignment was within 3 mils from nominal. In practice, alignment of the interconnects is achieved by using registration marks built into the carrier boards and installing them under a high magnification microscope. Blocks are assembled in custom fixtures with the DC power circuitry mounted on the back. Active biasing chips ensure proper power sequencing of the GaN amplifiers. Passive gain equalizers and surface-mount attenuators improve overall the gain and return loss as a function of frequency. ***Figure 4*** shows the assembled transmitter and receiver modules.

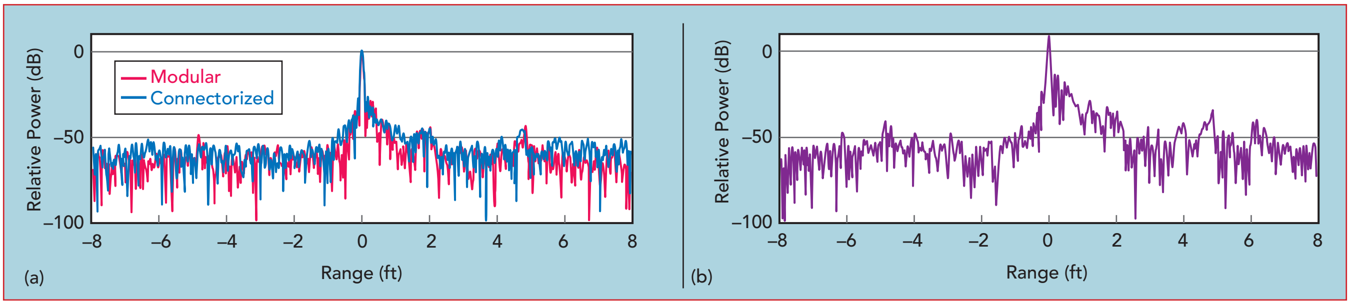

Fig. 6 Measured radar responses for modular and connectorized receivers with the same low-power transmitter (a) and modular receiver with a higher power modular transmitter (b).

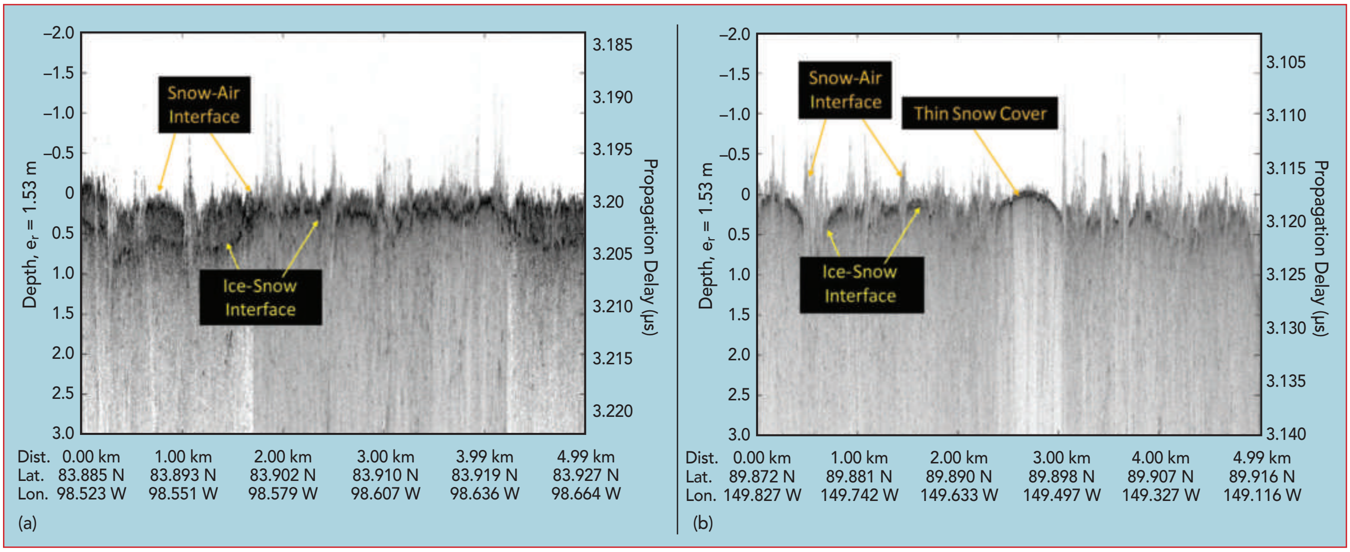

Fig. 7 Field results with fine vertical resolution from a flight over the North Pole, showing thick (a) and thin (b) snow cover on Arctic sea ice.

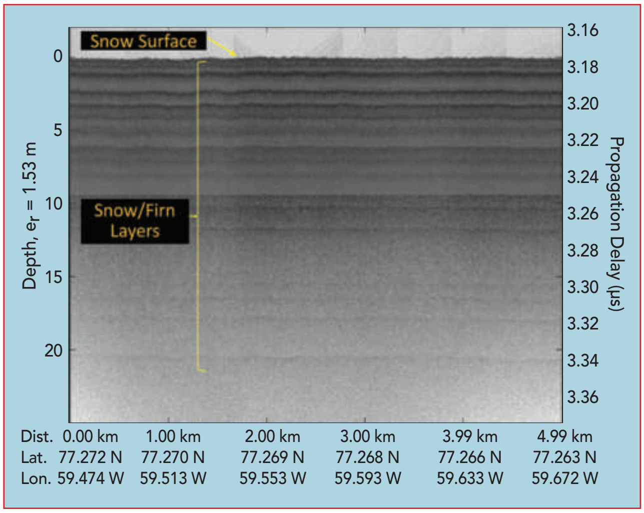

Fig. 8 Echogram data from the Greenland ice sheet, showing snow buildup to 20 m below the surface.

PERFORMANCE

A multi-port vector network analyzer was used to test the transmitter and receiver. Transmitter performance was verified by measuring its scattering parameters. ***Figure 5a*** shows the measured transmitter gain, indicating an increase of about 10 dB compared to the connectorized system. This was expected, because the modular transmitter was designed to have 10× more output power for the same input drive. The gain variations across the band were also expected, largely due to the power amplifier's frequency response.

For the receiver, a frequency offset mode with a fixed IF was used to simulate FMCW operation. The RF range was set to cover 1 to 19 GHz with four different IF frequencies within the four bands supported by the radar's digitizer: DC to 125, 125 to 250, 250 to 375 and 375 to 500 MHz. ***Figure 5b*** shows the measured conversion gain of the receiver with an IF frequency of 100 MHz. Responses for the other

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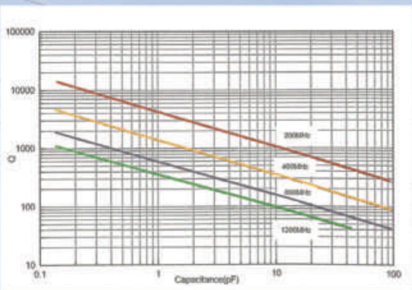
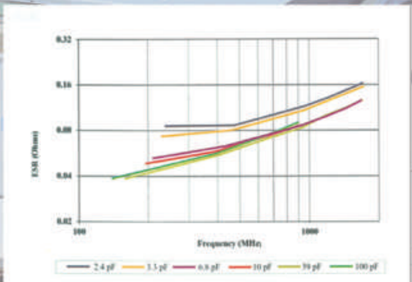


DLC70A(0505) Q Value and Capacitance Curve



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IF frequencies are nearly identical. The response of the connectorized testbed receiver is included for reference. Slight differences in roll-off at the lower and upper ends of the band are due to the marginally different filter responses; the impact of these variations on radar performance is negligible.

Bench Top Performance

The modules integrated into the radar system were tested using an electro-optical transceiver with a 1.72 µs fiber-optic delay line. The delay line between the transmitter and receiver simulates a single target at a fixed range of 850 ft., used to assess the radar's impulse response and sensitivity. Coaxial attenuators in the signal path emulate the large power loss experienced by a long-range signal, totaling 90 dB. The receiver's IF output, after onboard coherent averaging, was digitized by the radar's data acquisition system, and a Hanning windowing function was applied to the recorded time-domain samples before the FFT to obtain a set of power versus range profiles (see ***Figure 6***).

The two traces in Figure 6a show the modular and connectorized receivers with the same low power transmitter. The range profiles were normalized both in range and amplitude to facilitate comparisons. The radar echoes in both cases were detected approximately 60 dB above the noise, achieving a loop sensitivity of 150 dB. The main lobe widths in the responses correspond to approximately 0.55 in. (1.4 cm) in both cases and agree with the range resolution expected from a 16 GHz bandwidth with windowing. The range sidelobes were low in both cases, as expected using Hanning smoothing. Note the improvement in the "skirt" around the main response of the modular receiver, which indicates outstanding linearity and phase noise performance. This is expected with a higher level of integration and using an ultra-linear chirp generator and LO driver amplifier with low phase noise.

Figure 6b shows the performance with a higher power modular transmitter. Here, the system had a 10 dB improvement in signal-to-noise ratio, resulting in a total loop sensitivity of 160 dB. The width of the main lobe—and, thus, the range resolution—and low leading-edge sidelobes was preserved. The asymmetry in the response and the slightly larger trailing edge sidelobes are attributed to the transmitter gain variations previously noted. While such variations have an adverse effect on the radar's system response, this is outweighed by the benefit of having additional sensitivity from the increased transmit power. Systematic gain fluctuations can typically be corrected in post-processing.

FIELD TESTS

Field tests with the complete system onboard a NASA P-3 were conducted in 2018, as part of NASA Operation IceBridge. The transmitter and receiver modules were installed inside a small rack-mounted enclosure and operated with the rest

of the system, covering 2 to 18 GHz. Antennas in the aircraft's "bomb bay" were connected to the radar via low loss coaxial cables. Range profiles were recorded at a nominal altitude of 1500 ft. above ground level. ***Figure 7*** shows sample radar images from data collected over two 5 km flight segments at different sea ice transects near the North Pole, demonstrating the radar's capability to resolve the air-snow and snow-ice interfaces on thick (greater than 50 cm) and thin (less than 5 cm) snow-covered sea ice, respectively. ***Figure 8*** is an echogram produced from data collected over the Greenland ice sheet, showing the yearly snow buildup.■

ACKNOWLEDGMENTS

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References

1. T. Barret, "History of Ultra Wideband Communications and Radar: Part II, UWB Radars and Sensors," *Microwave Journal*, Vol. 44, No. 2, February 2001, pp. 22–52.
2. A. D. Pitcher, J. J. McCombe, E. A. Eveleigh and N. K. Nikolova, "Compact Transmitter for Pulsed-Radar Detection of On-Body Concealed Weapons," *IEEE International Microwave Symposium Proceedings*, June 2018, pp. 919–922.
3. M. Oyan, S. E. Hamran, L. Damsgård and T. Berg, "Compact Airborne C-Band Radar Sounder," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 52, No. 10, October 2014, pp. 6323–6332.
4. C. Wamsley, D. Draper, T. Pett and S. Roark, "Synthetic Aperture Radar for Pipeline Right-of-Way Monitoring," *Remote Sensing and Modeling of Ecosystems for Sustainability XV*, September 2018.
5. Y. Kim, T. J. Reck, M. Alonso-delPino, T. Painter, H. P. Marshall, E. H. Bair, J. Dozier, G. Chattopadhyay, K. N. Liou, M. C. F. Chang and A. Tang, "A Ku-Band CMOS FMCW Radar Transceiver for Snowpack Remote Sensing," *IEEE Transactions on Microwave Theory Techniques*, Vol. 66, No. 5, May 2018, pp. 2480–2494.
6. J. B. Yan, S. Gogineni, F. Rodriguez-Morales, D. Gomez-Garcia, J. Paden, C. J. Leuschen, D. A Braaten, J. A Richter-Menge, S. L. Farrell, J. Brozena and R. D. Hale, "Airborne Measurements of Snow Thickness Using Ultrawide-Band Frequency-Modulated-Continuous-Wave Radars," *IEEE Geoscience Remote Sensing Magazine*, Vol. 5, No. 2, June 2017, pp. 57–76.
7. J. McDaniel, J. B. Yan and S. Gogineni, "Design, Integration and Miniaturization of a Multichannel UWB Snow Radar Receiver," *Microwave Journal*, Vol. 59, No. 5, May 2016.
8. X-Microwave LLC, www.xmicrowave.com/.
9. F. R. Morales, C. Leuschen, C. Carabajal, A. Wolf and S. Garrison, "Measurements of Snow Cover Using An Improved UWB 2-18 GHz Airborne Radar Testbed," *Proceedings of the IEEE Radar Conference*, April 2018.
10. J. McDaniel, "Design, Integration, and Miniaturization of Multichannel Ultra-Wideband Snow Radar Receiver and Passive Microwave Components, Master's Thesis," *The University of Kansas, Lawrence*, 2015.
11. A. Melzer, A. Onic, F. Starzer and M. Huemer, "Short-Range Leakage Cancelation in FMCW Radar Transceivers Using an Artificial On-Chip Target," *IEEE Journal of Selected Topics in Signal Processing*, Vol. 9, No. 8, December 2015, pp. 1650–1660.

A Paradigm Shift in VNA Calibration and Validation Enables Better Decisions

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Since their introduction in the 1980s, vector network analyzers (VNA) and S-parameters have become so common they are used in nearly all aspects of an RF device's life cycle, from research and development to design validation test to production test. It is not uncommon to walk into an RF lab and see VNAs from various suppliers, spanning multiple generations, being used interchangeably, from the original HP 8510 and Wiltron 360 to the latest Keysight PNA-X, R&S ZNA, Anritsu VectorStar or Copper Mountain Cobalt. Several challenges come from using so many different VNAs, each with different interfaces and capabilities: ensuring VNA users are properly trained on every model in their labs; eliminating simple mistakes caused by differences in VNA

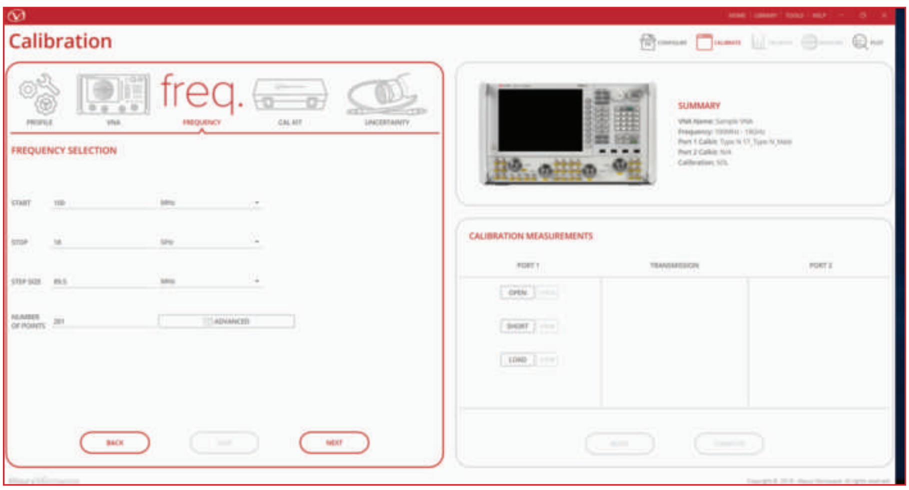

Fig. 1 Insight VNA calibration wizard.

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P2T-0R5G8G-45-R-SFF-50W-SM https://www.pmi-rf.com/product-details/p2t-0r5g8g-45-r-sff-50w-sm	0.5 - 8	3.0	30 Min	100 ns	50 W CW	+5 VDC @ 32 mA	1.20" x1.0" x 0.5" SP2T Reflective SMA Female
P2T-500M10G-60-R-515-SFF-10WCW https://www.pmi-rf.com/product-details/p2t-500m10g-60-r-515-sff-10wcw	0.5 - 10	2.5	60 Min	100 ns	10 W CW Max	+ 5 VDC @ 38 mA -15 VDC @ 43 mA	1.20" x 1.00" x 0.5" SP2T Reflective SMA Female
P2T-1G1R1G-25-R-SFF-100W-SM https://www.pmi-rf.com/product-details/p2t-1g1r1g-25-r-sff-100w-sm	1 - 1.1	0.8	25 Min	250 ns	100 W CW, 5 kW Peak	+50 VDC @ 10 mA +5 VDC @ 128 mA	3.25" x 2.75" x 0.7" SP2T Reflective TNC Female
P2T-1G18G-10-R-528-SFF-HIP10W https://www.pmi-rf.com/product-details/p2t-1g18g-10-r-528-sff-hip10w	1 - 18	4.0	10 Min	100 ns	10 W CW	+5 VDC @ 2.19 mA, -28 VDC @ 2.5 mA	1.2" x 1.0" x 0.5" SP2T Reflective SMA Female
P2T-1R2G1R4G-25-R-SFF-250W https://www.pmi-rf.com/product-details/p2t-1r2g1r4g-25-r-sff-250w	1.2 -1.4	0.8	25 Min	250 ns	250 W Peak	+30 V @ 50 mA, +5 V @ 200 mA	4.22" x 2.98" x 0.7" SP2T Reflective SMA Female
P2T-6G18G-40-R-570-TFF-1D6KW https://www.pmi-rf.com/product-details/p2t-6g18g-40-r-570-tff-1d6kw	6 - 18	2.2	40	1.1 µs	1.6 kW Peak - Tested to 125.89 W CW	+ 5 VDC @ 300 mA -70 VDC @ 60 mA	2.0" x 2.0" x 0.75" SP2T Reflective TNC Female
PDT-8G12G-40-515-SFF https://www.pmi-rf.com/product-details/pdt-8g12g-40-515-sff	8 - 12	2.0	40 Min	200 ns Max	40 dBm CW, 57 dBm, 1 µs, 1% DC	+5 VDC @ 100 mA -15 VDC @ 60 mA	1.25" x 1.25" x 0.3" SP2T Reflective SMA Female
P2T-8G18G-50-R-SFFF https://www.pmi-rf.com/product-details/p2t-8g18g-50-r-sfff	8 - 18	3.0	50 Min	200 ns	40 W Max, 300 W Peak	+5 VDC @ 150 mA, -28 VDC @ 80 mA	1.55" x 2.3" x 0.5" SP2T Reflective SMA Female

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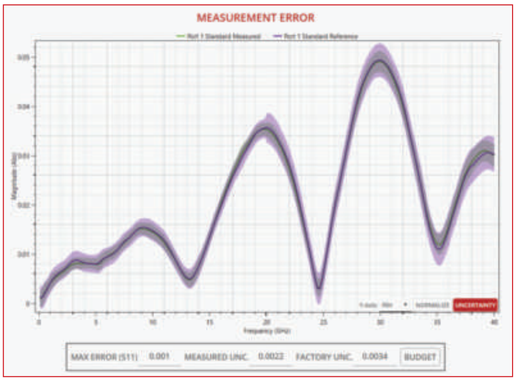

Fig. 2 Calibration validation with overlapping uncertainty boundaries.

terminologies, calibration standards definitions and calibration flows; and validating VNA calibrations so users have confidence in their measurements.

Additionally, it is not enough to think about a single lab; today's global organizations have multiple labs in various countries, with multinational teams collaborating on projects. This global scale introduces another set of challenges, such as saving important settings and measurement data in sharable formats and improving visualization and analysis so better decisions are made more efficiently. Finally, as organizations strive to understand more about device performance and face more stringent specifications, challenges arise related to data accuracy. It is crucial to understand and include all sources of error in a measurement setup and be able to quantify the uncertainty contribution and impact to device performance.

INSIGHT VNA SOFTWARE

Insight, Maury Microwave's VNA calibration and measurement software platform, is designed to empower VNA users, helping them make better decisions. Insight represents a paradigm shift in the way users approach VNA calibration, validation, measurement, visualization and analysis. With Insight, users can

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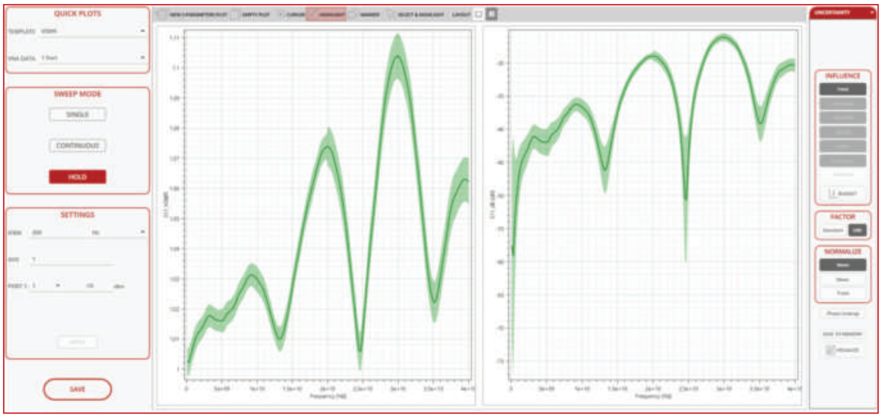

Fig. 3 Real-time device measurements with uncertainty boundaries.

the calibration method and calibrating by connecting and measuring each standard and computing the error terms (see ***Figure 1***).

Validate the VNA Calibration

The calibration validation wizard guides users through the validation process. This includes selecting the VNA calibration verification

To provide the best experience, Insight guides users through five simple steps:

Define the System Library

The system library is the database of instruments and accessories used to calibrate, validate and measure S-parameters. The database of VNAs comprises VNA drivers and the GPIB or network address; VNA calibration kits, which define connector type and gender and whether the kit uses polynomial definitions or individually characterized standards; and calibration verification kits.

When calibrating and measuring with uncertainty, the system library identifies and quantifies the uncertainty contribution of each component in a measurement setup, including VNA drift and noise floor, calibration kit factory uncertainty, the transmission and reflection uncertainty of cable assemblies (related to amplitude and phase stability with flexure) and the repeatability of connectors (related to the impact of pin depth, concentricity and user etiquette).

Use the Calibration Wizard

The calibration wizard guides users through the calibration process. This includes selecting the VNA from the database and defining the VNA properties (port numbers, power, averaging, IF bandwidth, etc.), defining the frequencies for calibration (linear step or custom list), selecting the calibration kit from the dataset, defining kit from the database, validating the source match using beadless airlines and a short and validating the calibration by using a characterized device verification kit that compares a user's measured data with factory-measured data and calculates the error vector.

Calibration validation can be expanded to take advantage of uncertainty when used with a characterized device calibration kit and characterized device verification kit. Validating with uncertainty compares the uncertainty boundaries measured on a verification device by the user with the uncertainty boundaries measured on the same verification device at the factory and defines a passing validation as one where the uncertainty boundaries overlap (see ***Figure 2***).

Measure Using the Real-Time Measurement Interface

The real-time measurement interface enables users to take live measurements. This includes setting VNA options (IF bandwidth, averaging, port power), defining plots to visualize measurement data, setting the sweep mode (single, continuous, hold), saving measurement data to memory or as S2P files, comparing and normalizing data sets for analysis and creating specifications files for comparison and analysis.

When calibrating and measuring with uncertainty, individual uncertainty contributors can be activated, and measurement data can be plotted with uncertainty boundaries (see ***Figure 3***). The uncertainty budget tool reports the individual uncertainty contributions of the VNA, calibration kit, cable and connector as a percentage of the total at each frequency, enabling users to concentrate on improving the largest contributors for more accurate measurement results.

Visualize and Analyze Measurement Data

To ensure consistent and repeatable measurement analysis, the visualization and data analysis tool empowers users to visualize and analyze measurement data by creating, saving and sharing visualization templates or using a quick plot. It also allows user to create sessions (template and measurements data) to share among collaborators, load and compare multiple saved data sets, create custom expressions from measured S-parameters and export data as CSV and image files.

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New Coax Connector: Excellent Performance for Confined Spaces

Telegärtner Karl Gärtner GmbH
Steinenbronn, Germany

Increasingly sophisticated services at ever faster data rates are being transmitted by high performance mobile radio networks, reflecting the modern mobile community's unwillingness to put up with slow internet connections and poor quality voice, picture and video services. Today, everything must be fast—no matter what, no matter where. "Any service, anywhere, anytime" is the mantra. Service availability is no longer seen as a privilege, rather a right. Added to consumer expectations, fully or partially automated applications such as intelligent traffic control and autonomous driving require fast, secure and reliable connectivity. 5G is enabling these applications, unimagined just a few years ago, and 5G is driving dense, picocell networks. Space restrictions for these small cells are hampering the build-out of the infrastructure, which adds to the pressure on installers and operators. Limited space is problematic for anten-

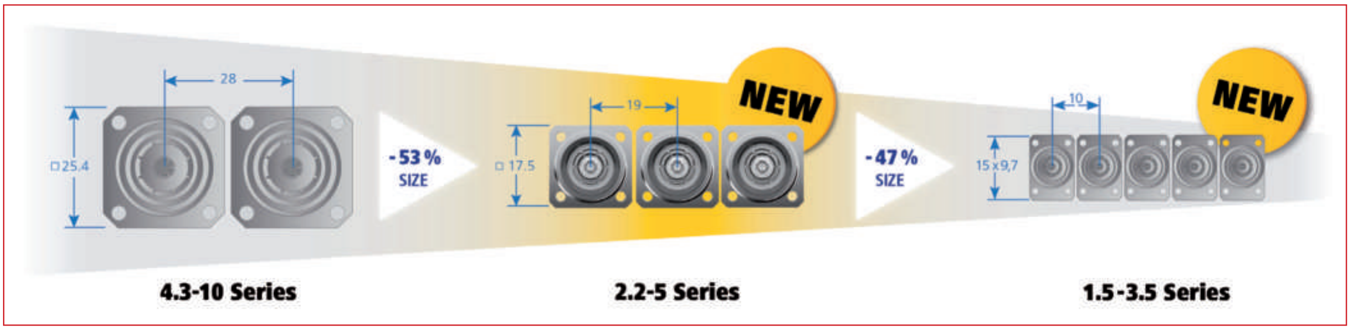

Fig. 1 The 1.5-3.5 is significantly smaller than the 2.2-5 and 4.3-10 connectors, making it well suited for small cells.

PHASE ADJUSTERS 2019

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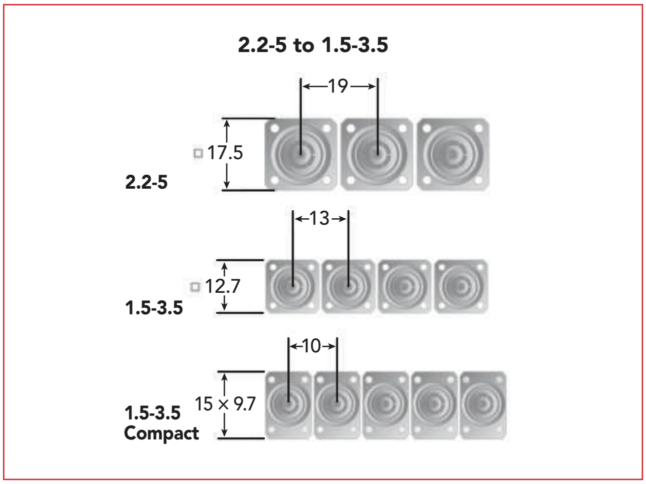

Fig. 2 **Two versions of the jack are available, with center-to-center spacing of 13 mm or, for tighter spaces, 10 mm.**

na masts at the wireless access points and the cables connecting them.

1.5-3.5: PERFORMANCE IN CONFINED SPACES

To address this challenge of achieving performance in a small space, the new 1.5-3.5 generation of connectors offers an elegant and reliable solution. The 1.5-3.5 type delivers the performance of larger connectors in a significantly reduced size. Building on the success of the trendsetting 4.3-10 and 2.2-5 connectors, Telegärtner has developed the compact, high performance 1.5-3.5 connector for tomorrow's mobile networks. This innovative connector achieves performance that, until recently, was not possible for such compact connectors. A typical 1.5-3.5 jack reduces the required mounting space by 47 percent compared to the compact 2.2-5 and an even more impressive 75 percent versus the 4.3-10 connector (see ***Figure 1***). The 1.5-3.5 jack is available in two versions: either center-to-center spacing of 13 mm or a more compact 10 mm (see ***Figure 2***).

Borrowing from its two "bigger brothers," the 1.5-3.5 uses the popular and field-proven hexagon nut screw for extreme environmental conditions, and a quick, push-pull, self-locking mechanism for frequent plugging and unplugging—all usable on the same universal jack. The screw and hand screw versions are combined in one plug, allowing an installer to decide whether to tighten the connector by hand or with a torque wrench on site.

With the standard version, reliable signal transmission is guaranteed by a particularly low passive intermodulation of –166 dBc up to 6 GHz, measured with the standard two-tone 43 dBm signals. The response of the special version of the connector extends to 30 GHz. Despite its small dimensions, the 1.5-3.5 can transmit considerable power: up to 100 W at 2 GHz. The connectors have been engineered for more than 100 mating cycles, and the reliable design protects the plug contact against damage, even when unmated.

The plugs, available in straight and angled versions, are optimized for 0.25 in. corrugated cables, the jacks for UT 85, UT 141 and UT 250 Semiflex cables (see

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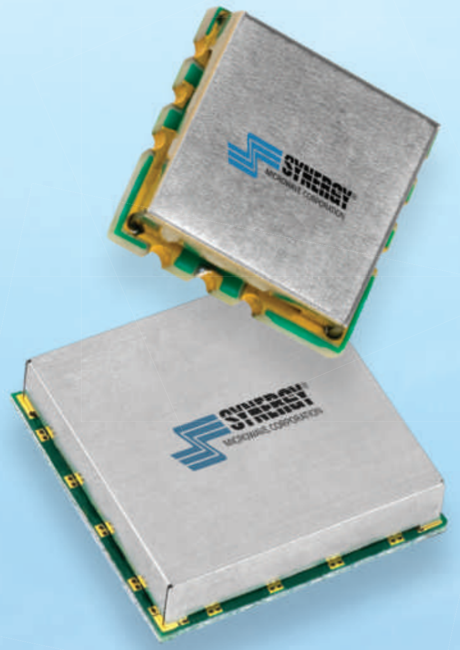
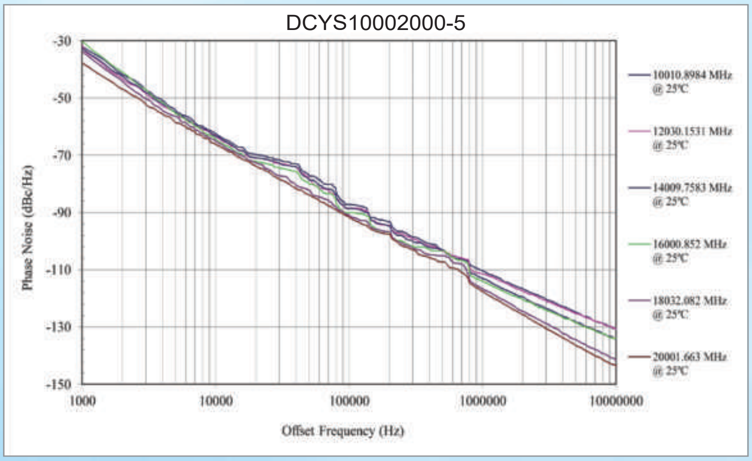
Model Number	Frequency	Phase Noise @ 10 kHz offset	Phase Noise @ 100 kHz offset	Tuning Voltage	Output Power
	(GHz)	(dBc/Hz)	(dBc/Hz)	(V)	(dBm)
DCO100200-5	1 - 2	-95	-117	0 - 24	+1
DCYS100200-12	1 - 2	-105	-125	0 - 28	+4
DCO200400-5	2 - 4	-90	-110	0 - 18	-2
DCYS200400P-5	2 - 4	-93	-115	0 - 18	0
DCO300600-5	3 - 6	-75	-104	0 - 16	-3
DCYS300600P-5	3 - 6	-78	-109	0 - 16	+2
DCO400800-5	4 - 8	-75	-98	0 - 15	-4
DCO5001000-5	5 - 10	-80	-106	0 - 18	-2
DCYS6001200-5	6 -12	-70	-94	0 - 15	> +10
DCYS8001600-5	8 - 16	-68	-93	0 - 15	> +10
DCYS10002000-5	10 - 20	-65	-91	0 - 18	> +10





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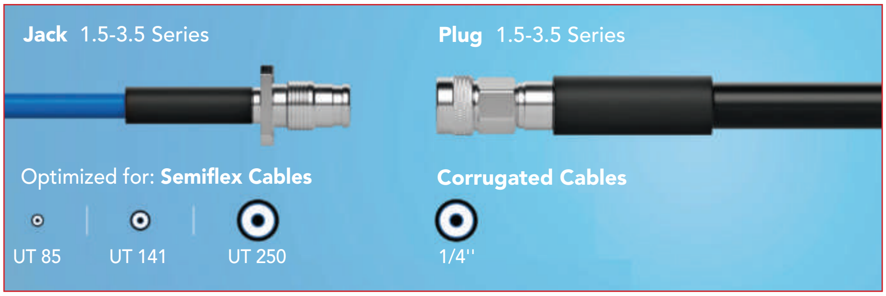


Fig. 3 The plugs are optimized for 0.25 in. corrugated cables; the jacks for UT 85, UT 141 and UT 250 semiflex cables.

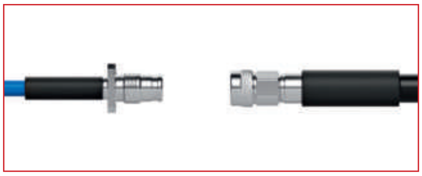


Fig. 4 Off-the-shelf cable assemblies are available and can be made in custom lengths.

Figure 3). In addition to offering plugs and jacks as individual parts, off-the-shelf cables are available in standard and custom lengths for simple and time-saving installations (see ***Figure 4***). A variety of adapters are also available for other connector series, such as the 4.3-10, 7-16, PC3.5 and N.

Whether screw, hand screw or push-pull, both connector variants offer IP68 protection and are suitable for harsh indoor and outdoor environments. An extended temperature range from −40°C to +85°C and a dielectric strength of 1.5 kV at 50 Hz makes the resilient high performance connector ideal for a wide range of applications needing a compact size. These include mobile radio networks, small cells, picocells, low power remote radio units and in-building wireless and distributed antenna systems. Installers, often working to tight schedules, will appreciate the many cable entry and locking possibilities. They can choose the best one for the project or application, whether the installation is in a compact space, at great height or facing rugged weather.

The new 1.5-3.5 connector has been developed for applications where high quality transmission is required and cabling and installation space is limited. Despite being comparable in size to SMA connectors, the 1.5-3.5 connector is PIM-stable and suitable for outdoor use. The straight and angled cable outlet variants and the screw and push-pull locking mechanisms enable trouble-free installation in locations where no other connector can be used.

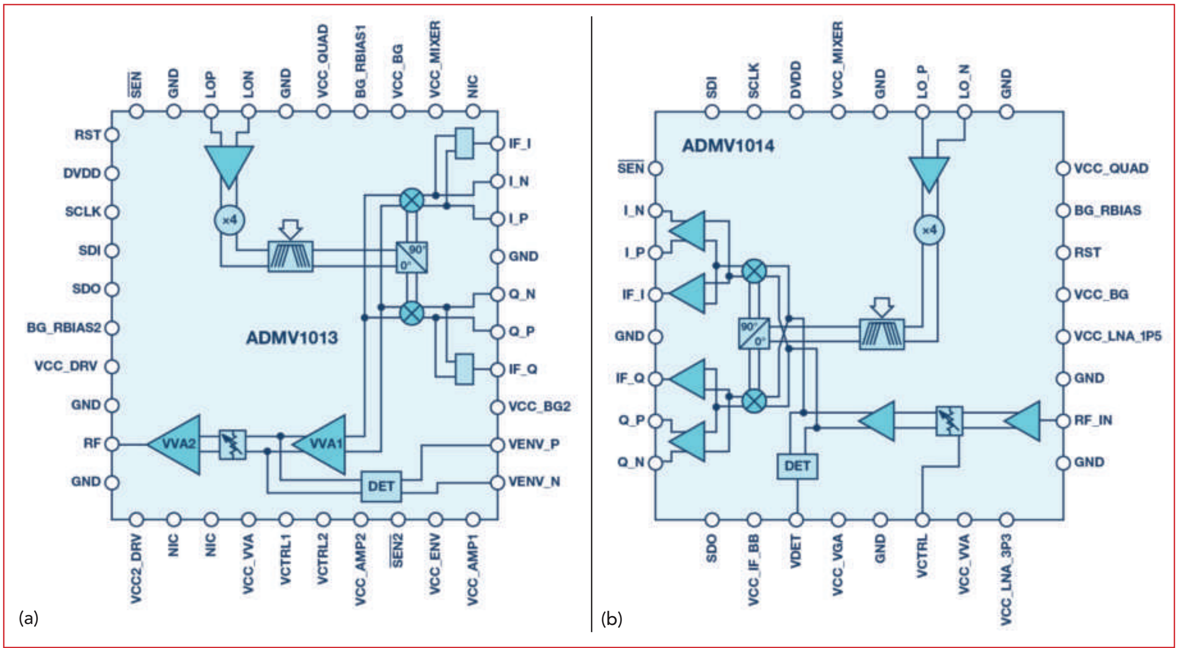
Telegärtner Karl Gärtner GmbH
Steinenbronn, Germany
www.telegaertner.com

24 to 44 GHz Up- & Down-Converters Boost Radio Performance, Reduce Size

Analog Devices
Norwood, Mass.

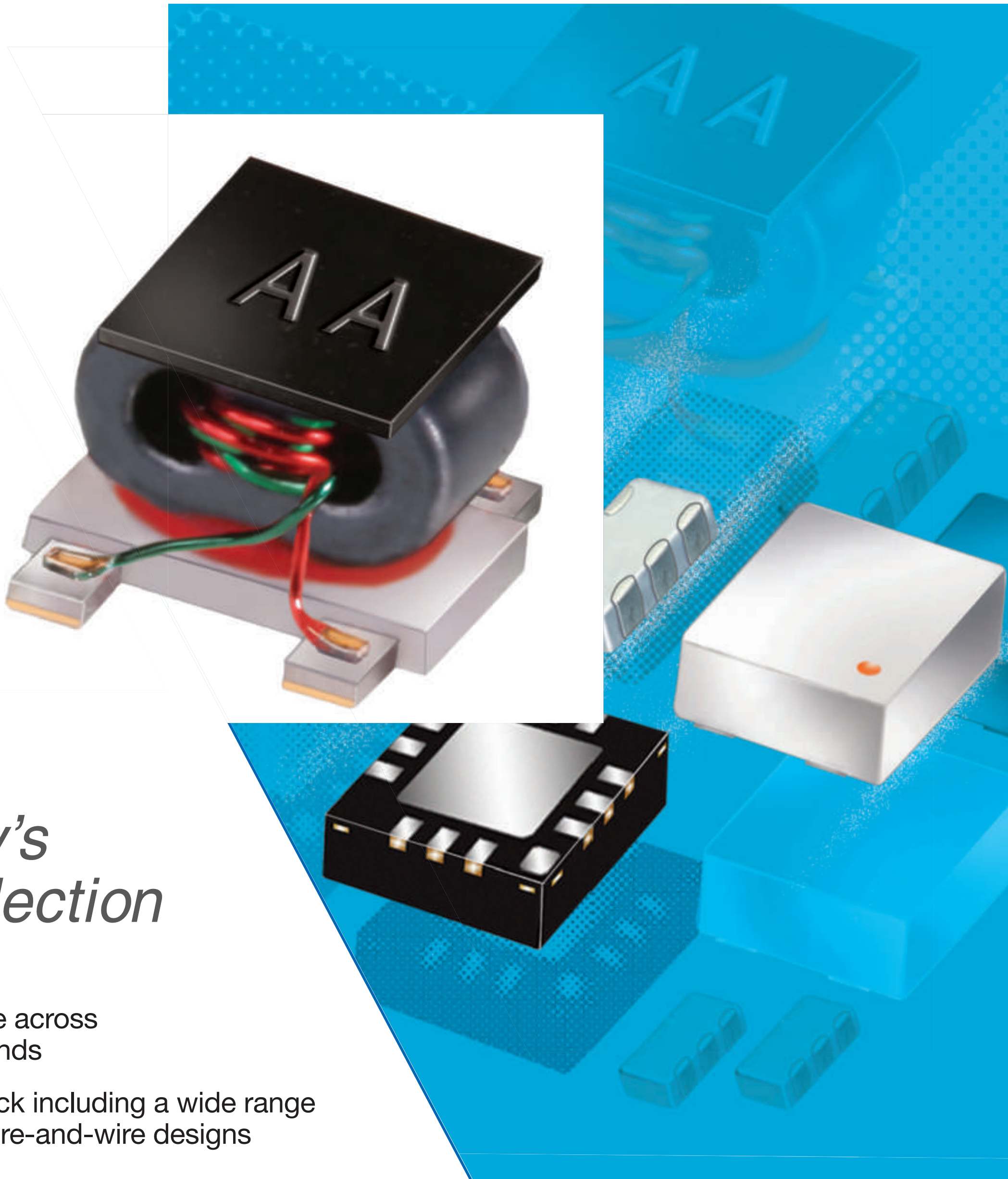
Analog Devices has developed a pair of highly integrated up-converter (ADMV1013) and down-converter (ADMV1014) ICs covering 24 to 44 GHz with greater than 1 GHz instantaneous bandwidth. Matched to 50 Ω, the ADMV1013 and ADMV1014 simplify the design and implementation of mmWave platforms for the popular 28 and 39 GHz 5G bands, whether backhaul, fronthaul or other wide bandwidth transmitter and receiver applications.

The up- and down-converter ICs are highly integrated (see ***Figure 1***), comprising I/Q mixers with on-chip quadrature phase shifters. The converters are configurable for direct conversion to or from baseband (DC to 6 GHz) or an IF (800 MHz to 6 GHz). The up-converter RF output has an on-chip driver amplifier with a voltage variable attenuator (VVA), while the down-converter's RF input starts with a low noise amplifier (LNA), followed by a VVA and gain stage. Each local oscillator (LO) chain contains an integrated



▲ Fig. 1 Block diagrams of the ADMV1013 up-converter (a) and ADMV1014 down-converter (b).

[redacted]and [redacted]formers & Baluns!



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LO buffer, frequency quadrupler and programmable bandpass filter. Most of the programmability and calibration are controlled with a serial peripheral interface (SPI), making the ICs easily configurable via software.

ADMV1013 UP-CONVERTER

The ADMV1013 has two modes of frequency translation: direct from baseband and single sideband up-conversion from IF. With direct up-conversion, the baseband I and Q differential inputs accept signals from DC to 6 GHz and are compatible with high speed digital-to-analog converters (DAC). The inputs have a configurable common-mode range from 0 to 2.6 V, which accommodates the interface requirements of most DACs, simplifying the interface design. The second mode is typically for signals generated by a quadrature digital up-converter.

Unique to the ADMV1013 is the capability to allow digital correction of the I and Q mixers' DC offset error in the I/Q mode, which reduces the LO leakage to the RF output. After calibration, the LO leakage can be as low as –45 dBm at the RF output at maximum gain. An even more difficult challenge that plagues direct conversion radio design is I/Q phase imbalance, which causes poor sideband suppression. An added challenge with direct conversion: the sideband is usually too close to the microwave carrier, making filtering impractical. The ADMV1013 solves this problem by enabling users to digitally correct for the I/Q phase imbalance with register tuning. In normal operation, the up-converter exhibits an uncalibrated sideband suppression of 26 dBc. Using the on-chip registers, the sideband suppression after calibration can be improved to about 36 dBc. Both correction features are accessed via the SPI and do not require extra circuitry. Additional suppression can be achieved in the I/Q mode by adjusting the phase balance of the I and Q baseband DACs. These performance capabilities improve microwave radio performance while minimizing external filtering.

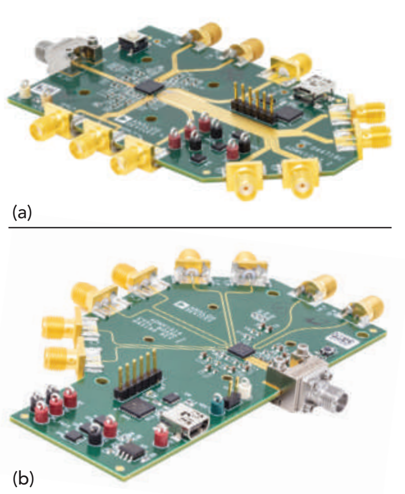


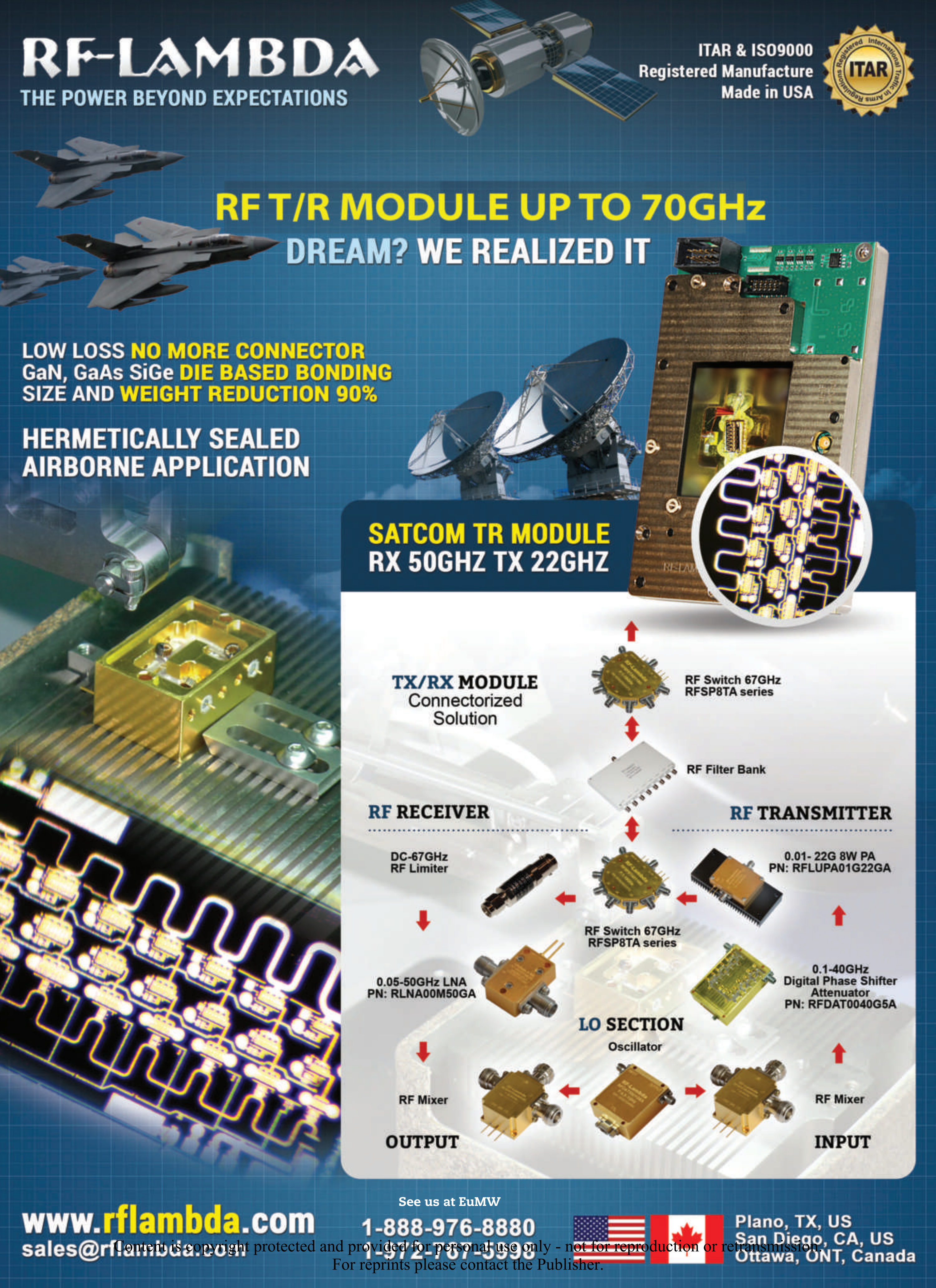
Fig. 2 Evaluation boards showing the 6 mm x 6 mm surface-mount ADMV1013 up-converter (a) and 5 mm x 5 mm ADMV1014 down-converter (b).

With the LO buffer amplifier integrated on-chip, the up-converter only requires 0 dBm drive, enabling the IC to be driven directly from a synthesizer with an integrated voltage-controlled oscillator (VCO), such as the ADF4372 or ADF5610, reducing the external components. The on-chip frequency quadrupler multiplies the LO frequency to the desired carrier frequency, and the signal is passed through a programmable bandpass filter to reduce the undesired multiplier harmonics, prior to feeding the mixers' quadrature phase generator stage. This reduces spurious injection into the mixers and allows the IC to work with an external low cost and low frequency synthesizer or VCO.

The modulated RF output from the mixer is amplified through a pair of amplifier stages with a VVA between them, providing an adjustable gain range of 35 dB and a maximum cascaded conversion gain of 23 dB. The ADMV1013 is packaged in a 6 mm × 6 mm, 40-pin land grid array (see ***Figure 2a***).

ADMV1014 DOWN-CONVERTER

Similar to the up-converter, the ADMV1014 has the LO buffer, frequency quadrupler, programmable bandpass filter and quadrature phase shifter in the LO path. However, as a down-converter, the ADMV1014's RF signal chain has an LNA followed by a VVA and amplifier (see Figure 1b). Controlled by a DC voltage applied to the VCTRL pin, the down-converter's gain has a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continuous adjustment range of 19 dB.

The ADMV1014 also has two modes of frequency translation: direct down-conversion and as an image-reject down-converter to single-ended I and Q IF ports. Configured as a direct conversion demodulator from microwave to baseband, the demodulated I and Q signals are amplified at the respective differential outputs, with the gain and DC common-mode voltage set by registers via the SPI. This enables the output to be DC coupled to a pair of baseband analog-to-digital converters (ADC). In either mode, the I and Q phase and amplitude imbalance can be corrected via the SPI, improving the down-converter's image rejection whether it demodulates to baseband or IF.

Overall, the down-converter provides a cascaded noise figure of 5.5 dB with a maximum conversion gain of 17 dB from 24 to 42 GHz. Near the band edge of 44 GHz, the cascaded noise figure remains respectable: 6 dB. The ADMV1014 is slightly smaller than the up-converter IC, measuring 5 mm × 5 mm (see *Figure 2b*).

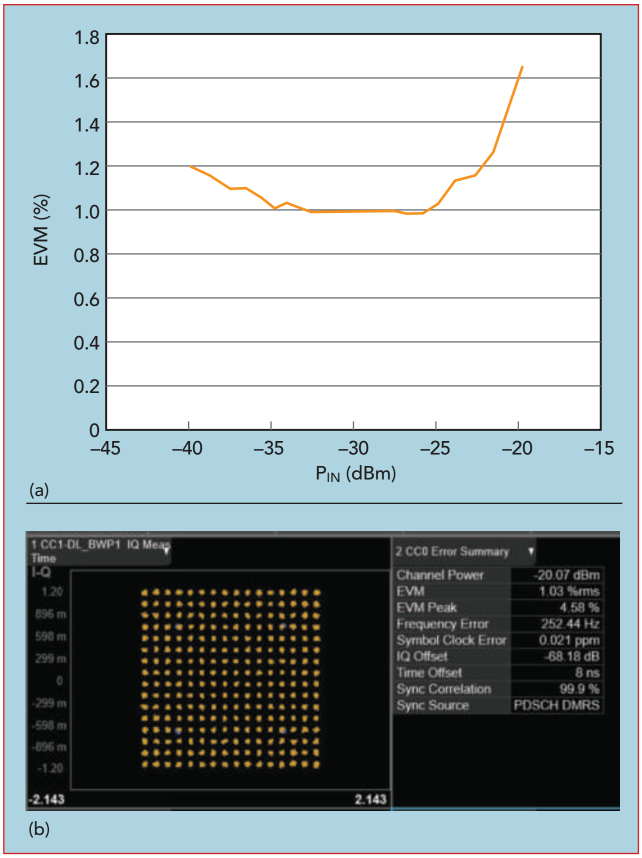


Fig. 3 Measured RMS EVM vs. input power (a) and corresponding 256-QAM constellation (b) of the down-converter at 28 GHz.

BOOSTING RADIO PERFORMANCE

Figure 3 shows the measured performance of the down-converter at 28 GHz with a 5G NR 256-QAM waveform composite of four independent 100 MHz channels at −20 dBm input power per channel. The resulting error vector magnitude (EVM) measured −40 dB (1 percent RMS), which supports demodulating the higher-order modulation that mmWave 5G systems require.

With greater than 1 GHz bandwidth and 23 dBm output third-order intercept (OIP3) for the up-converter and 0 dBm input IP3 for the down-converter, the two devices support high-order QAM, enabling high data throughput. These capabilities offer designers flexibility and ease of design, while requiring minimal external components. The small size combined with high linearity and image rejection are compelling, supporting high performance and small form factor microwave links and broadband base stations. In addition to 5G, the up- and down-converters will serve applications such as satellite and Earth station broadband communication links, secured communication radios, RF test equipment and radar systems.

VENDORVIEW

Analog Devices
Norwood, Mass.
www.analog.com

Waveguide Antenna Family Covers 40 to 220 GHz

Pasternack has released a line of waveguide antennas covering 40 to 220 GHz, with 85 new models in waveguide sizes from WR5 to WR19. The antennas are available in standard gain horn, conical gain horn, wide angle scalar feed horn, horn lens and omnidirectional types, with nominal gains from 2 to 40 dBi depending on the antenna type. The standard gain and conical gain horn antennas are available with maximum frequency coverage to 220 GHz, while the wide angle scalar feed, horn lens and omnidirectional antennas cover up to 99 GHz.

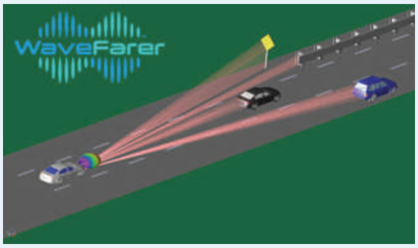
As examples, the PEWAN1068 conical gain horn antenna with a WR5 interface covers 140 to 220 GHz and has 25 dBi nominal gain and a 3 dB beamwidth of 10 degrees vertical and 9 degrees horizontal. The typical input VSWR is 1.15:1. The PEWAN1086 horn lens antenna, with WR10 interface, covers 89 to 99 GHz with 40 dBi gain and a 3 dB beamwidth of 1 degree vertical and horizontal. The typical input VSWR is 1.5:1.

These waveguide antennas were developed to address a wide range of mmWave applications, including aerospace, defense, experimental radar, test & measurement, point-to-point and point-to-multipoint wireless, scientific and general R&D. All antennas in the series are constructed with the highest quality materials and workmanship standards and are RoHS and REACH compliant. Pasternack's mmWave waveguide antennas are all in stock, available for immediate shipment with no minimum order quantity.

VENDORVIEW

Pasternack
Irvine, Calif.
www.pasternack.com

TechBrief



Ray-Tracing EM Simulation Speeds Auto Radar Design

Remcom has developed a software product for automotive radar design and placement, a targeted niche application for sensor designers at automotive manufacturers and their Tier 1 suppliers. WaveFarer® is a highly accurate simulator for drive scenario modeling, allowing engineers to set up virtual track testing and use the results to refine their designs early in the development process. This makes physical testing more successful, as the prototypes more closely meet requirements. WaveFarer is a more efficient simulation tool for teams focusing on target detection signal processing and sensor placement, because it was created specifically for simulating radar sensors. Drive scenarios and sensor locations can be iterated in WaveFarer, reducing the cost and time to build prototypes and improving sensor placement and the resulting performance.

To predict the scattered returns from a drive test, WaveFarer uses ray-tracing algorithms adapted for radar. Employing near-field propagation and scattering methods, the raw radar returns from target objects are computed, including the multipath interactions from ground reflections and other structures. The software supports the global automotive bands to frequencies above 100 GHz.

WaveFarer is integrated into Remcom's electromagnetic—simulation platform, working seamlessly with XFdtd® EM Simulation Software. This streamlines radar returns incorporating high fidelity radar antenna and sensor simulations to be calculated in end-to-end drive scenarios. A common user interface between XFdtd and WaveFarer simplifies the design process, with CAD import, geometry editing, visualization, definitions and results analysis sharing similar controls and a unified workflow. This consistent user experience will help RF engineers who need full-wave simulation for antenna design and ray-tracing analysis for drive test modeling.

VENDORVIEW

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State College, Pa.
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Website Relaunch

AnaPico is proud to announce the relaunch of their company website. It offers improved usability and a better navigation for all users. AnaPico's product categories "Signal Generators, Frequency Synthesizers and Signal Source Analyzers" can be found more easily right at the navigation bar. Visitors can now make requests for a quote and select options more efficiently. The revised design of the website gives better access to product information and manuals, inquiries and contact.

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50th Anniversary Video

VENDORVIEW

2019 marks the 50th Anniversary of the inception of AR RF/Microwave Instrumentation. What began as two men designing power amplifiers in the basement of a small home is now a multi-national family of companies that includes AR RF/Microwave Instrumentation, AR Modular RF, SunAR RF Motion and AR Europe. Watch their new video "50 Years: What Have We Got To Show For It?" to learn more.

AR RF/Microwave Instrumentation
www.arworld.us/html/video-ar-50th-anniversary-video.asp

New Website Launched

Comtech PST has launched a new updated website. The new website contains information about solid-state power amplifiers and high-power control components available as standard or custom products. Datasheets and product information can be downloaded directly from the website. Customers can request quotes by completing information on the site and clicking the link to send it in. Comtech PST serves the military, commercial, aviation, datalink and medical markets with a wide array of narrow and broadband product offerings, for both amplifiers and control components.

Comtech PST
www.comtechpst.com

New Video: Raw Data Injection

Watch this new video to gain a sneak peek at one of the latest dSPACE labs innovations: By injecting simulated raw data directly into a LIDAR sensor, you can test all processing stages behind the sensor's front-end—allowing validation of the entire LIDAR signal processing chain at a very early stage in development.

dSPACE
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New Website Update

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

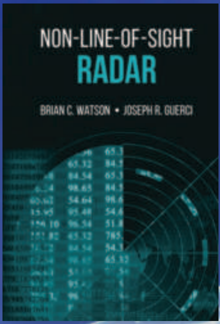
K&L Microwave
www.klmicrowave.com

New Website Update

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

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

Hot New 2019 Titles



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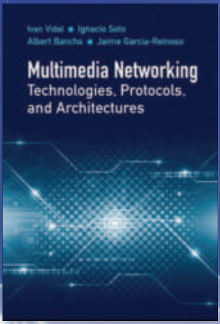

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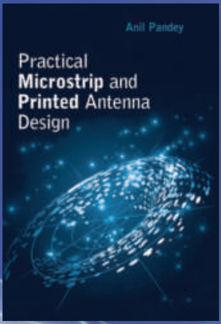

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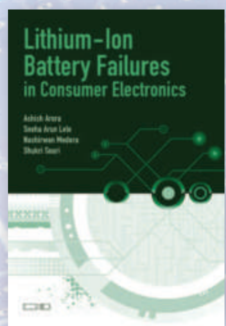

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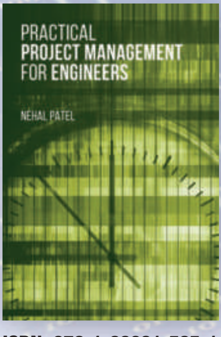

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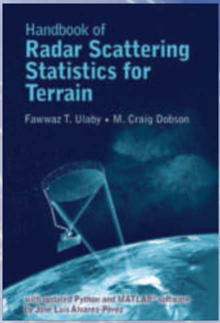

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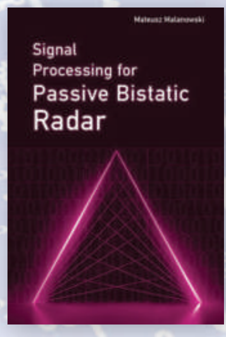

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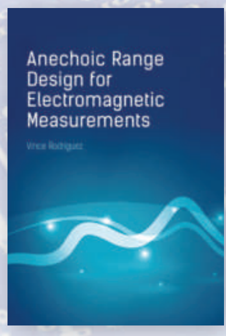

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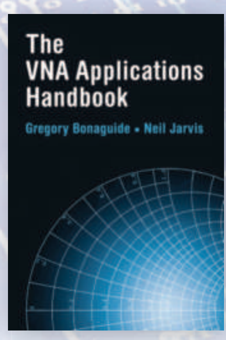

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PRACTICAL BOOKS FOR ENGINEERING PROFESSIONALS

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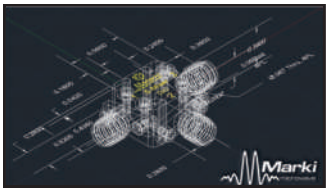
3D CAD Models Now Featured



By popular demand, Marki Microwave now provides downloadable 3D CAD models for many of their products, available for free on their website (found under Engineering > Package & Layout). Available in STP, DXF and DWG formats, these files are compatible with AutoCAD, SOLIDWORKS and other 3D CAD software and include accurate package dimensions and connector locations. For all other products, including the company's legacy components, they have 2D models in DXF and DWG file formats available upon request.

Marki Microwave

www.markimicrowave.com

Updated Website

Millennium Microwave Corp. is located in Fruitland, Md. and has been in operation since 1999. Their standard and custom design products serve the defense electronics, SATCOM and commercial industry, and you will find Millennium Microwave products on ground, naval and airborne platforms as well as test labs and commercial communications systems. Millennium Microwave has registration to AS9100D and ISO 9001:2015. They offer four major product lines which include filters, pin diode switches, switch filter banks and integrated assemblies.

Millennium Microwave Corp.

www.microwave2000.com

DIY Vector Network Analyzer Kit

VENDORVIEW

The first of the Univeristy 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

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Web&Video Update

Updated Website

NuWaves Engineering, a veteran-owned company founded in 2000, provides advanced RF expertise and microwave solutions for military, government and industrial customers. NuWaves Engineering provides off-the-shelf RF products, as well as quick-tempo design and engineering services that address today's most demanding RF challenges, especially with regard to hardware SWaP reduction, cost and—oftentimes equally important—schedule. NuWaves Engineering is an undisputed leader in the research, design, development, manufacturing, integration, sustainment and modernization of complex RF systems.

NuWaves Engineering

https://nuwaves.com

New Website Launched

VENDORVIEW

Passive Plus Inc. (PPI) has launched a brand-new website with a sleeker design and a more user-friendly interface. The newly designed website showcases PPI's product offering and technical information. The new website also coincides with new product offerings from PPI, including Trimmer (Variable) Capacitors; Broadband Resistors; Single Layer Capacitors; and Thin Film Products. PPI is a manufacturer of high performance RF/microwave passive components for the medical, semiconductor, military, broadcast and telecommunications industries.

Passive Plus Inc.

www.passiveplus.com

Test Equipment Rentals

When it comes to RF test & measurement gear, you need to have the right equipment at the right price. Try before you buy with Signal Hound Equipment Rentals. Every rental comes with Signal Hound's powerful, free Spike™ software giving you the full experience. All Signal Hound RF analyzers and signal generators are available for rent, allowing you to put them to the test for a fraction of the cost of the device. Learn more on their website.

Signal Hound

www.signalhound.com/rent

NEW PRODUCTS

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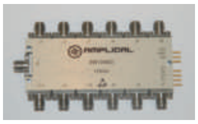
COMPONENTS

PIN Diode Switch



Amplical's SW12A003 SP12T broadband coaxial absorptive PIN diode switch features 2 to 18 GHz bandwidth with low insertion loss, low VSWR, high isolation and fast switching speed. J1 through J12 ports are terminated in 50 Ω when switched in the isolation (off) state. A 4-bit coded TTL-compatible driver is incorporated for convenient logic control. The switch operates from +5 VDC and a negative DC supply ranging from −12 to −20 V. The compact design incorporates field-replaceable SMA female connectors.

Amplical
www.amplical.com

Coaxial Power Divider/Combiner

VENDORVIEW

Cernexwave's model CDPU5180608T coaxial power divider/combiner has a frequency range of 0.5 to 18 GHz, an isolation greater than 16 dB, a VSWR of less than 1.5:1 with one SMA and female input and 8 SMA female output connectors. It features low insertion loss, low VSWR and high isolation in 2- to 32-way configurations.

Cernexwave
www.cernexwave.com

Switch Cycler

Ducommun's switch cycler is designed to automate switch cycling and allow users to "plug-and-play" versus having to design a custom instrument themselves. The CAT-001 allows users to perform a "burn-in" function for switches that have sat in inventory for long periods of time. The CAT-001 also features an optional strip chart counter to record data for each switch, GUI remote control for automation and a keypad for local control.

Ducommun
www.ducommun.com

Microstrip Filter Designs

VENDORVIEW

Free microstrip filter designs are available in Exceed Microwave's Microstrip Filter Library for number of sections that are four or less. When you do not have time to design your own planar filters, choose from the company's library and they will send you the .step file for the design.

Exceed Microwave
www.exceedmicrowave.com

18 to 40 GHz mmWave 4-Way Power Divider

VENDORVIEW

MECA expanded offering of 5G mmWave products. Featuring 4-way power dividers covering 18 to 40 GHz with 2.92 mm interfaces. Specifications of 1.2:1 typical/1.80:1 max VSWR, 19 dB typical/13 dB min. isolation, 2 dB typical/2.6 dB max insertion loss and 1 dB max amplitude balance. Also available are attenuators, terminations, bias tees, DC blocks and adapters. Additionally octave and mulit-octave models covering up to 50 GHz built by J-Standard certified assemblers and technicians. Made in U.S. with 36-month warranty.

MECA Electronics Inc.
www.e-MECA.com

Broadband 1.8 GHz Couplers

VENDORVIEW

These 75 Ω couplers are designed for next-gen CATV systems. The MRFCP6762 16 dB coupler is flat to 1.8 GHz and provides 20 dB return loss. Uniquely the 6762 also provides max throughput power with low loss and nearly 30 dB isolation with MiniRF repeatability and reliability.

MiniRF
www.minirf.com

5G Interference Solution

VENDORVIEW

Norsat's latest 5G interference solution consists of a C-Band interference suppression LNB and bandpass filter. With the rollout of 5G infrastructure, new cellular base station signals will be powerful enough to saturate sensitive C-Band satellite receiving systems. Norsat's advanced LNB with internal filtering can mitigate 5G signals and is the perfect solution for broadcasters, media houses and other C-Band operators. For additional filtering, the bandpass filter can be used to reject terrestrial interference within the C-Band.

Norsat
www.norsat.com

RF Limiters

VENDORVIEW

Pasternack, an Infinite Electronics brand, has expanded its line of broadband, high-power coaxial limiters that are designed to help protect sensitive components in the receive chain and other microwave circuits in close proximity to high-power signals. The typical applications for these RF limiters include EW, military communications, instrumentation, fiber optic communication systems, SATCOM, radar, point-to-point wireless, telecom and R&D applications.

Pasternack
www.pasternack.com

8-Bit Digitally Tuned Attenuator

VENDORVIEW

PMI Model No. DTA-200M18G-100-CD-1 is a 0.2 to 18 GHz, 8-bit digitally tuned attenuator. This unit has a min. attenuation range of 100 dB and a min. attenuation step of 0.5 dB. It is supplied with SMA female connectors and a 15-Pin Micro-D female connector in a housing measuring 4 × 1.8 × 0.5 in.

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

Terminated (Absorptive) SPDT Switch

RLC Electronics announced the addition of a miniature terminated (absorptive) SPDT switch. The switch provides proven reliability, long life and excellent electrical performance. It features extremely low insertion loss (< 0.3 dB at 18 GHz) and VSWR (1.5:1 max at 18 GHz) while maintaining high isolation (> 60 dB at 18 GHz). This miniature terminated SPDT switch measures 1.2 × 2.09 × 0.52 in. (standard unit is 2.25 × 2.25 in.).

RLC Electronics Inc.
www.rlcelectronics.com

RF Switches, Filters and Measuring Chambers

The current economy is developing faster and faster. Those who cannot react flexibly and at short notice to new technologies and ideas miss the pulse of time. These demands are also passed on to the entire supply chain. Telemeter Electronic GmbH, which as a strong link in this chain, is proud to be able to act Europe-wide now. The company will now present new products in the field of RF switches, filters and measuring chambers.These products convince by fast availability, customized adaptation and reliability.

Telemeter Electronic GmbH
www.telemeter.info

CABLES & CONNECTORS

RF Cable Assemblies

Fairview Microwave Inc. has released a new series of high-reliability, temperature conditioned RF cable assemblies that are ideal for military electronics, avionics, SATCOM, ECM, IFF and other mission critical applications. Fairview's new low loss, pre-conditioned, high-reliability cables cover operating frequencies to 18 GHz and deliver VSWR as low as 1.35:1. This product line is made up of 128 configurations built from three different types of cable, totaling more than 1,400 parts all available with same-day shipping.

Fairview Microwave Inc.
www.fairviewmicrowave.com

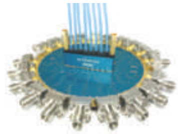
Plenum-Rated Twinaxial Cable Assemblies

MilesTek's plenum-rated cable assemblies are available in both 78 Ω (0.150 in. O.D. and 0.242 in. O.D.) and 124 Ω (0.242 in. O.D.) versions. The cables are offered off-the-shelf in standard lengths or they can be ordered in custom lengths. They feature TRB plugs and jacks, insulated and non-insulated bulkhead connectors and blunt end combinations. Plenum cable jackets reduce the amount of smoke and flame emitted during combustion, when compared to PVC jacketed cables.

MilesTek
www.milestek.com

NewProducts

Multicoax Cable Assemblies



withwave's high speed and high-density multicoax cable assemblies (WMX Series) provides a wide range of multiple coax connectors and flexible cable assemblies with a choice of 20, 40, 50 and 67 GHz configurations based on precision array design and superior high frequency cabling solutions. WMX Series are excellent signal integrity solutions for benchtop testing and automated test equipment to meet increasing demands of semiconductor test equipment and optical testing industries. These products consist of high performance flexible assemblies which can be bundled in housings (8 and 16 channels).

withwave Co. Ltd.
www.with-wave.com

AMPLIFIERS

AR Catalog, 50th Anniversary Edition

VENDORVIEW

This 50th Anniversary edition includes state-of-the-art amplifiers and other products for EMC, wireless, medical and military markets. Look at the timeline on the inside cover to see impressive industry firsts AR has accomplished over the last half a century. Find details of the company's new shielded enclosure leak detection system, new RF solid-state and microwave amplifiers and new ampwebwARe software so you can control your AR amplifier remotely.

AR RF/Microwave Instrumentation
www.arworld.us

Discrete Ultra Low Noise Transistors

Diramics' pH-100 series of discrete InP PHEMT transistors offers the best available noise figure for hybrid LNA fabrication. These bare die transistors excel at

cryogenic as well as room temperatures and are available in various sizes. This allows the pH-100 series to cover frequencies from below 1 GHz to above 50 GHz. The combination of these features make it suitable for a broad range of applications including radio astronomy, quantum computing, SATCOM, radar, mmWave imaging and mmWave 5G.

Diramics AG
www.diramics.com

Solid-State High-Power Ka-Band Outdoor Amplifier

VENDORVIEW

Exodus Advanced Communications' outdoor Ka-Band series is designed for 5G mobile and fixed SATCOM terminals. This series features high linear power and long-term reliability in a lightweight and small outdoor form factor. The new AMP4069-ODT covers 26.5 to 40 GHz, produces 5 W, 3 W P1dB, with 37 dB min. gain. The unit has excellent band flatness. The nominal weight is 22 lbs, and dimensions of 8.43 × 13.15 × 5.7 in.

Exodus Advanced Communications
www.exoduscomm.com

RFA 300K3G—RF Amplifier 300 kHz to 3 GHz

HUBER Signal Processing extends its precision amplifier series with the RFA 300K3G. Besides the DC-coupled amplifiers RFA 300 and RFA 600, the RFA 300K3G is ideal for RF applications. Typical applications are radar, SATCOM, avionics, space, defense, etc. Products of HUBER Signal Processing are made in Germany and may be individually modified to the customer's specification.

HUBER Signal Processing
www.huber-signal.com

SGA/SGN Series SSPA

KRATOS General Microwave's SGA/SGN Series SSPA's offer GaAs/GaN technology reliability that can be customized to meet specific pulse or CW output powers. The product line supports both X- and Ku-Band applications with bandwidths up to 10 percent and offers peak power outputs up to 400 W. Designed for demanding aerospace, defense and SATCOM applications. General Microwave SSPAs have excellent power efficiency with demonstrated field proven performance and reliability. General Microwave's vertical integration process affords flexible layouts and architectures to meet individual specifications for electrical, mechanical and environmental parameters.

KRATOS General Microwave
www.kratosmed.com

Low Current, Wideband, Ceramic Monolithic Amplifier

VENDORVIEW

The CMA-183L+ is a low current, wideband gain block that operates up to 20 GHz fabricated using highly reliable GaAs HBT process. This Darlington pair amplifier delivers excellent gain flatness, good return

loss, low current with acceptable P1dB and OIP3 across a wide bandwidth without the need of external matching network. It has highly repeatable performance from lot to lot and it is packaged in an LTCC hermetic package utilizing fully automated and highly reliable manufacturing processes. CMA-series amplifiers are capable of meeting MIL requirements for gross leak, fine leak, thermal shock, vibration, acceleration, mechanical shock and HTOL. The tests can be performed if requested.
Mini-Circuits
www.minicircuits.com

Ultra-Low Noise Amplifier

Richardson RFPD Inc. announced the availability and full design support capabilities for an ultra-low noise amplifier from WanTcom. At +12 VDC operation, the unconditionally-stable WBA0180210A offers 0.27 dB noise figure, with 27 dB of gain and +10 dBm P1dB. Available in a standard SMA-connectorized gold plated package, it benefits from WanTcom's proprietary LNA technologies, high frequency microelectronics assembly techniques and longstanding reputation for high-reliability.
Richardson RFPD
www.richardsonrfpd.com

SYSTEMS

RF Down-Converters

NuWave's ConvertaWave™ series of RF down-converters offer unmatched precision with 100 kHz or 1 Hz tuning resolution with superior rejection of out-of-band interference. These down-converters are robust, providing high dynamic performance and featuring both automatic gain control (AGC) and manual gain control (MGC). ConvertaWave's combination of power efficiency, miniaturization and ruggedized packaging is ideal, but not limited to SIGINT, COMINT, ELINT and RF down-conversion.
NuWaves
www.NuWaves.com

W-Band Receiver

SAGE Millimeter's Model SSR-9330634030-10-M1-I is a W-Band image rejected receiver. The receiver has a typical conversion gain of 30 dB with a typical RF input power of –60 dBm in the frequency range of 90 to 96 GHz and an IF output frequency range of 5 to 11 GHz. The receiver has a built-in ×8 multiplier which requires a typical input LO power and frequency of +5 dBm and 10.625 GHz, respectively.
SAGE Millimeter
www.sagemillimeter.com

NewProducts

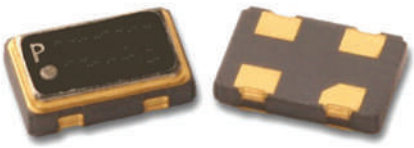
SOURCES

Precision CNG Generator

The NoiseWave NW-CNG instrument improves the speed and accuracy of BER testing by automatically setting precise, stable SNR, CNR and Eb/No ratios, replacing cumbersome alternatives and reducing test time. High accuracy is achieved due to NoiseWave's proprietary noise generator, broadband amplifier and solid-state variable attenuator and switch technology. Utilizing NoiseWave's true AWGN noise modules with a minimum noise crest factor of 18 dB allows the user to rapidly and accurately test very low bit error rates.

NoiseWave
www.noisewave.com

New Ultra-Ultra Low Jitter Crystal Oscillators



Announcing the expanded offering of the Pletronics SM77J, HC77J, LV77J and PE77J Series boasting ultra-ultra low jitter and is, produced on an AEC Q-200 manufacturing line. The J series oscillator family is ideal for use applications where an improved signal to noise ratio and bit error rate are required. Digital communications infrastructure, 5G head-end & data, 100G to 400G optical transport networks, full speed GbE, PCI express. This full line of high precision quartz crystal are available in 1.25 to 175 MHz in CMOS logic and 25 to 175 MHz in differential output logic.

Pletronics
www.pletronics.com

Fixed Frequency Phase Locked Loop

VENDORVIEW

Z-Communications announces a RoHS compliant fixed frequency phase locked loop model RFS1090A-LF in the L-Band. RFS1090A-LF is a fully integrated synthesizer operating at 1090 MHz.

Z-Communications
www.zcomm.com

ANTENNAS

Anten'it Antenna Design and Training Kit

Antenom Antenna Technologies announced four different products in Anten'it product family. Anten'it is a new concept in antenna design and antenna training. There are metal cells, three different types of dielectric cells with 2.6, 4.4 and 10 dielectric constants, ground planes and connectors. These cells are in brick form which allows connecting them to build an antenna and disconnecting them to re-use for another antenna. Anten'it antenna training kit has the ability of teaching antenna design in antenna laboratory lectures at the universities.

Antenom Antenna Technologies Inc.
www.antenit.com

Triband (26/28/39 GHz) 5G Antenna

Sensorview Co. Ltd., a manufacturer of test antennas and cables for 5G and mmWave industry, has released ASV0051, Triband (26/28/39 GHz, Circularly Polarized) antenna with 11 dBic gain, ≤ 3 axial ratio, miniature size 22 × 42 × 42 mm, and 2.92 mm connector for test & measurement solutions. It is an optimized solution for 5G AUT in test & measurement and will minimize your chamber sizes, decrease budgets and maximize your test performances.

Sensorview Co. Ltd.
www.sensor-view.com

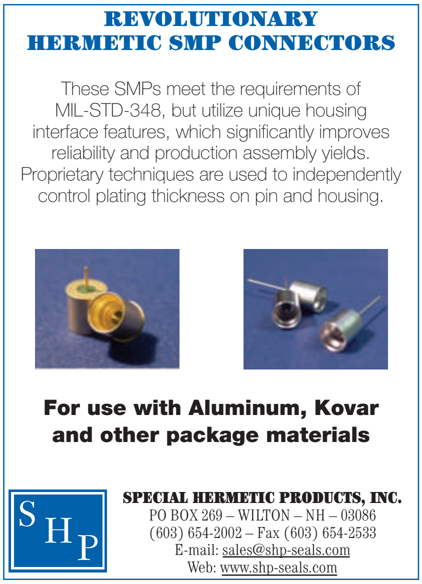
MATERIALS

Bondjet BJ855—Fine Wire & Ribbon Bonder

The high speed and fully automated fine wire bonder Bondjet BJ855 of Hesse Mechatronics meets with its wedge-wedge and ball-wedge bondheads the increasing demands of bonding. On the large working area of 305 × 410 mm fine wires from 12, 5 to 75 µm are processed. Typical applications are components in RF technology, COB, MCM, hybrids, optical and automotive electronics. In addition to standard configurations, Hesse offers individually adapted automation concepts.

Hesse GmbH
www.hesse-mechatronics.com

MICRO-ADS



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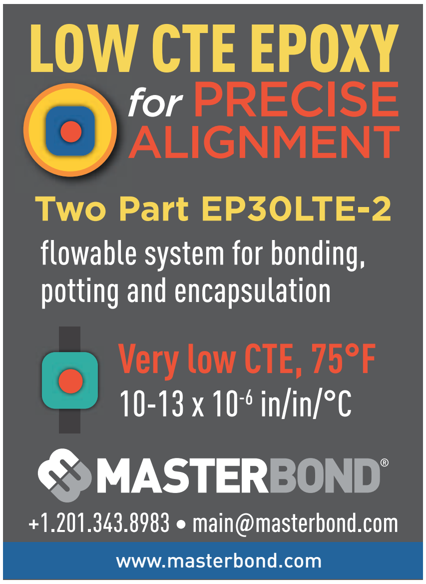

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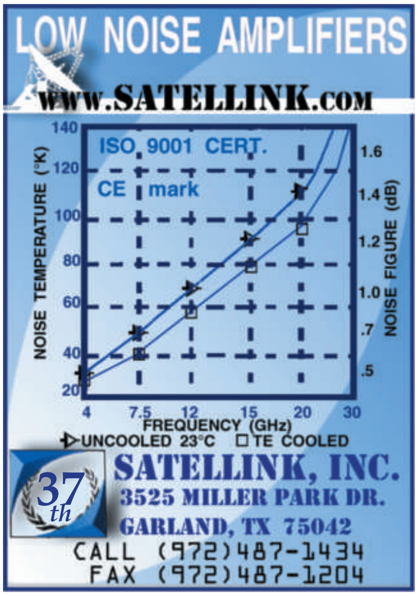

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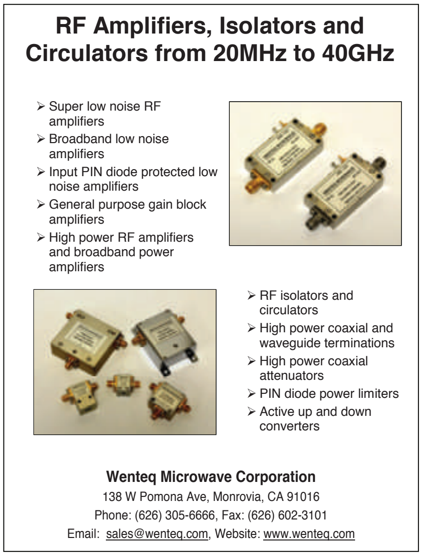

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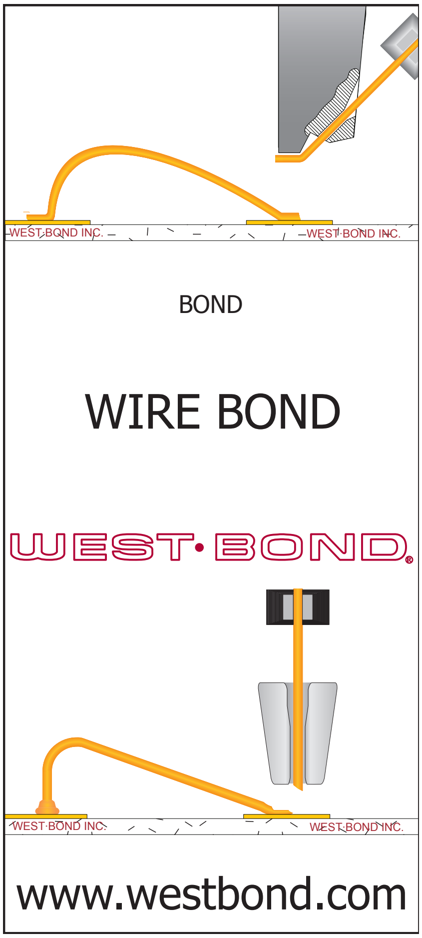

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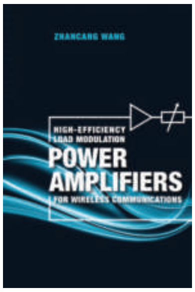

High-Efficiency Load Modulation Power Amplifiers for Wireless Communications

Zhancang Wang

This cutting-edge resource presents a complete and systematic overview of the practical design considerations of RF high efficiency load modulation power amplifiers (PA) for modern wireless communications for 4G and beyond. It provides comprehensive insight into all aspects of load modulation PA design and optimization, not only covering design approaches specifically for passive and active load modulation operation but also hybrid with dynamic supply modulation and digital signal processing algorithms required for performance enhancement.

Passive load impedance tuner design, dynamic load modulation PA, active load modulation PA and Doherty PA design for efficiently enhancement are explained. Readers find practical guidance into load modulation PA design for bandwidth extension, including video bandwidth enhancement techniques, broadband dynamic load amplifiers, topology selection, design procedures and network output. This book presents the evolution and integration of classical load modulation PA topologies in order to meet new challenges in the field.

To order this book, contact:

Artech House
www.artechhouse.com
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Northeastern University Expeditionary Cyber and Unmanned Aerial System Facility: *One of the most advanced wireless evaluation centers in the world*

Back in the 1990s, I completed an MBA night program at Northeastern University's suburban campus in Burlington, just north of Boston. On my recent visit to the campus, I was stunned to find a completely transformed facility that used to only house a few classrooms and small library. Now it is the state-of-the-art Northeastern University Innovation Campus at Burlington MA (ICBM) that hosts the Kostas Research Institute and Northeastern University Expeditionary Cyber and Unmanned Aerial System (ECUAS) Research and Development Facility along with labs and startup incubator facilities.

The ECUAS facility provides a suite of capabilities for science, engineering, technology development, test and evaluation on advanced systems across all readiness levels. It is a platform to spur innovation in cyber systems, electromagnetic systems, navigation and timing systems, autonomous systems and flight systems for ground and air autonomous vehicles. The facility consists of both indoor and outdoor test ranges for evaluating autonomous aerial and ground systems, antennas, cyber, radio, network, navigation and communications equipment.

This unique facility has one of the largest anechoic chambers on the East Coast that attaches through a tunnel to a large netted outdoor testing area with the goal of being flexible and configurable to support current and future R&D activities. The Indoor Wireless Test Range includes a 50 ft. × 50 ft. × 22 ft. Faraday Cage/Anechoic Chamber for operation of unmanned and autonomous systems as well as testing of wireless devices in a fully controlled RF environment. The chamber has state-of-the-art software-defined radios and 64 antenna array to transmit/receive arbitrary waveforms for jamming, interference, spoofing, communications and control; multi-axis antenna positioner with ±0.5 degree accuracy for antenna testing/analysis; accommodation for testing up to 1300+ lbs large drones with integrated tether points; RF testing from 300 MHz to 18+ GHz; 24 cameras with 360 degree HD optical tracking system for precise indoor positioning in the 50,000 cu. ft. volume; and state-of-the-art RF measurement equipment.

The outdoor facility is a 150 ft. × 200 ft. × 60 ft. netted enclosure for unobstructed GPS enabled flight testing. Flight in the netted enclosure eliminates need for FAA approval and is large enough to support multiple simultaneous test events. It is outfitted with various UAS obstacles for setting up a wide range of flight tests and has a paved surface for testing air and ground systems, including UAS/UGS teaming exercises. It is equipped with enhanced kinematic GPS for extremely precise centimeter positioning, has steady state/gust wind test capability for small drones (<150 g), an interconnected flight path between outdoor and indoor test ranges for seamless transition and 60 ft. observation deck in adjacent building for flight test viewing.

The facility can perform navigation testing (with jamming, spoofing, interference) using a Global Navigation Satellite System (GNSS) simulator, cyber security testing of wireless devices for vulnerability/exploitation analysis, EMP testing (RS105) for radiated susceptibility of small devices/systems, characterization of emissions of wireless devices to enable things such as UAS/UGS Detection/Tracking and networking for autonomy, swarms and massive MIMO.

The ICBM facility recently won the right to host DARPA's Colosseum testbed, which is the largest and most powerful channel emulator in the world. The Colosseum is supporting the Spectrum Collaboration Challenge to evaluate teams entering their AI-based wireless algorithms into the contest to see who has the best performance for autonomous systems. This ECUAS facility is one of the most advanced and unique wireless facilities in the world and will be enabling new RF and microwave innovation for years to come.

Patrick Hindle,
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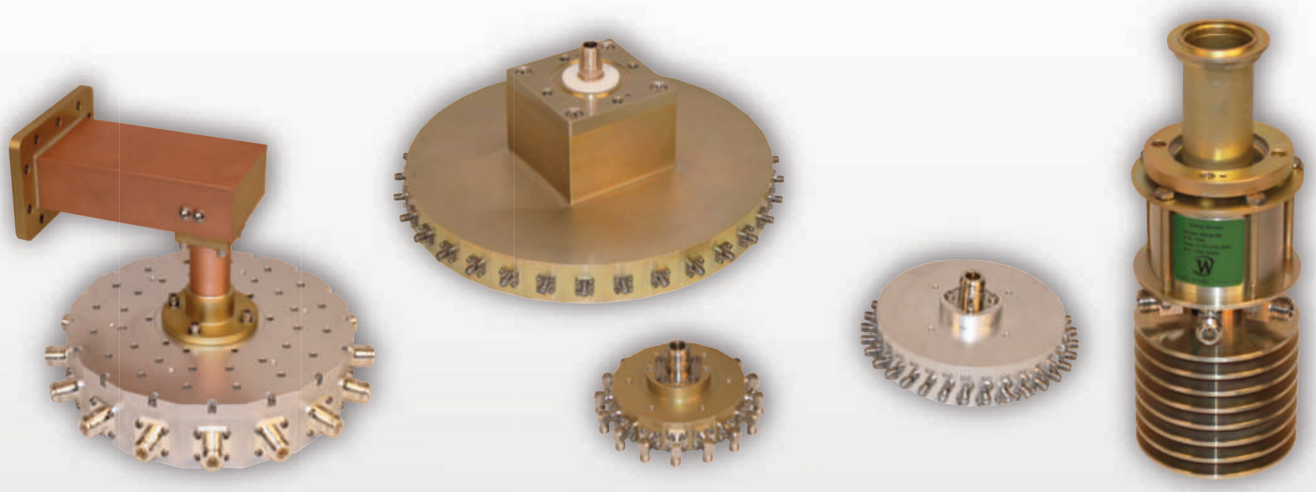
D5320	12-Way	470-860	500	5,000	0.3	1.30	All N-Female
D10119	4-Way	700-4200	2,000	15,000	0.3	1.35	13-30 DIN-Female, N-F
D10603	32-Way	900-925	50,000	150,000	0.15	1.25	WR975, 7/16-Female
D10795	32-Way	900-930	25,000	150,000	0.25	1.20	WR975, 4.3-10-F
D9710	8-Way	1000-2500	2,000	10,000	0.3	1.40	1 5/8” EIA, N-Female
D8182	5-Way	1175-1375	1,500	25,000	0.4	1.35	1 5/8” EIA, N-Female
D6857	32-Way	1200-1400	4,000	16,000	0.5	1.35	1 5/8” EIA, N-Female
D9529	8-Way	2305-2360	1,000	6,000	0.2	1.15	7/16-Female, N-Female
D9528	8-Way	2305-2360	2,000	12,000	0.2	1.15	7/8” EIA, N-Female
D11028	16-Way	2305-2360	2,000	20,000	0.2	1.15	1 5/8” EIA, N-Female
D10851	8-Way	2400-2500	8,000	50,000	0.2	1.25	WR340, 7/16-Female
D11433	16-Way	2700-3500	2,000	20,000	0.3	1.35	WR284, N-Female
D11815	16-Way	2700-3500	6,000	40,000	0.3	1.35	WR284, N-Female
D9582	16-Way	3100-3500	2,000	16,000	0.25	1.50	WR284, N-Female
D11839	16-Way	5300-5900	8,000	50,000	0.15	1.40	WR159, 7/16-Male



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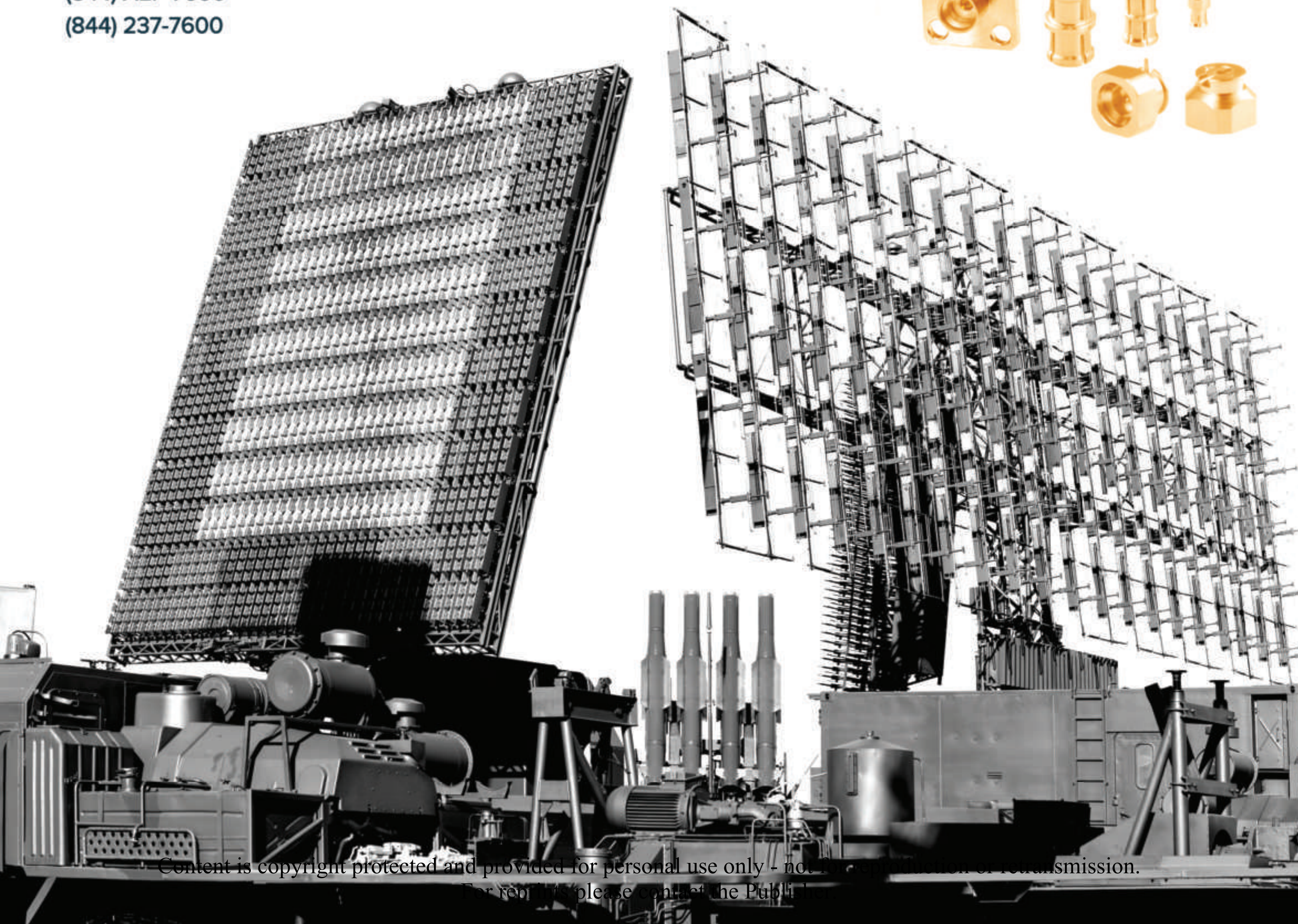

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Executive Interview

Shawn Black, the new president of **Cobham's Advanced Electronic Solutions (CAES)** sector, discusses the trends in defense and space and how CAES is positioning to provide components and subsystems that enable new system capabilities.

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INVITED PAPER

Agile IF Architectures Enable Flexible EW and ELINT Systems

Mario LaMarche
Mercury Systems, Andover, Mass.

About one century ago, Armstrong and Levy independently filed patents for receivers incorporating the superheterodyne principle. This revolutionary idea used a variable frequency oscillator to tune the RF input, allowing a range of RF frequencies to be converted to a fixed intermediate frequency (IF). By fixing the IF output of the down-converter, it became much easier to design and build the rest of the system—since low frequency, narrowband components performed better and were less expensive. This simple idea set the groundwork for modern wireless systems.

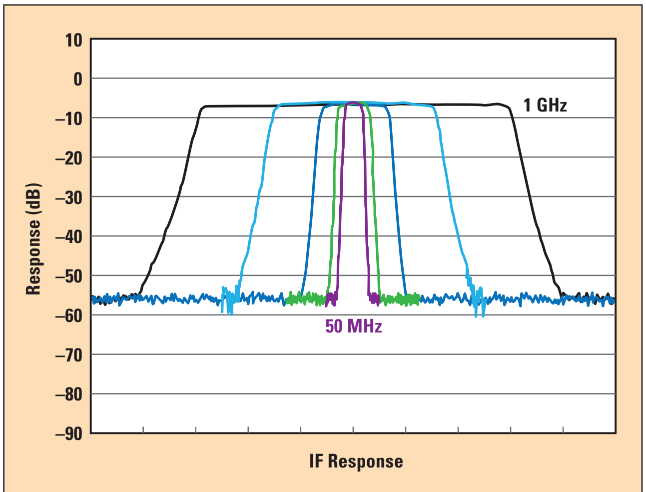

Fig. 1 Agile IF bandwidths from 50 MHz to 1 GHz.

Relying on a fixed IF does compromise frequency planning. Some applications require a wide IF bandwidth to digitize a wideband signal; others are better suited to a narrower IF with better sensitivity. Since different microwave converters use different IF bands, matching them with digitizers is challenging. To address this, Mercury Systems has implemented a novel, agile IF architecture that maintains the benefits of the classical superheterodyne system while providing flexibility to dynamically adjust the IF band, enabling optimization from mission to mission and easy integration with various digitizers (see ***Figure 1***).

AGILE EW AND ELINT SYSTEMS

While an agile IF architecture can be used in various applications, the benefits are critical for electronic warfare (EW) and electronic intelligence (ELINT). Unlike most communication and radar systems, where both the transmit and receive sides of the link are defined, EW and ELINT systems process an adversary's signal. Since they span a wide range of frequencies and bandwidths, modern EW and ELINT systems must be highly flexible. This is one of the primary challenges designing such systems and is also the key reason EW and ELINT systems typically have wide bandwidths. With an agile IF architecture, they can be dynamically optimized for a specific mission, ensuring their capabilities stay ahead of new threats.

As adversaries harness readily available commercial technology, the U.S. and its allies must


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have the ability to rapidly update existing systems to control the electromagnetic spectrum. As upgrading system elements is both costly and time consuming, hardware with the capability to reduce the scope of system changes provides a strategic advantage. Here, the agile IF architecture provides an additional benefit: by adjusting the IF band, the user can adapt a single microwave converter to operate with various components, which both reduces the cost to upgrade and enables the latest EW and ELINT technology to be deployed rapidly. Adopting this architecture, system hardware can be dynamically optimized for specific missions. The following sections describe these differentiators.

MISSION-TO-MISSION OPTIMIZATION

Imagine you are the EW officer on an aircraft, scanning the spectrum for threats and other signals of interest. You use a microwave tuner to down-convert a portion of the band to IF, which is digitized and processed. The scanning continues as the microwave tuner is re-tuned to the next RF frequency range. The amount of spectrum down-converted in a single pass is known as the instantaneous bandwidth (IBW). For scanning large spans of spectrum, it should be as large as possible. By maximizing the IBW, the system can observe more of the spectrum simultaneously and capture signals with a wide bandwidth. For example, a 2 GHz IBW covers the 6 to 18 GHz band in six steps, while a 1 GHz IBW requires 12.

A narrower IBW is preferred for other applications, such as collecting a specific signal rather than scanning the spectrum for signals of interest. If a signal is only 200 MHz wide, for example, there is no need to capture 2 GHz of spectrum. Capturing an unnecessarily wide band results in the digitization and collection of noise, causing the storage medium to fill quickly. Also, optimizing for a wide bandwidth requires a trade-off in the performance of the converter. Typically, maximum sensitivity and dynamic range are achieved with a narrower bandwidth. A low level signal compared to the background noise requires a high sensitivity receiver, which is much easier to implement with a narrow IBW.

By dynamically adjusting the IF band, the IBW can be optimized for a specific application, enabling a single microwave converter to be used without sacrificing performance. Previously, multiple converters were required. This multi-IBW solution reduces cost and helps minimize total system size.

DIGITIZER COMPATIBILITY

Turning to the digitizer following the microwave converter, in receive, the RF signal is down-converted to IF, then feeds an analog-to-digital (ADC) converter, where it is digitized for processing. In transmit, the processed digital signal is converted back to IF by a digital-to-analog converter (DAC) and up-converted to RF. To maximize system performance, the IF frequency from the microwave converter must be compatible with the digitizer. Often, this requires a custom microwave front-end; however, an off-the-shelf front-end with an agile IF architecture operates with many ADCs and DACs, reducing cost and supply chain complexity.

Returning to the example from the previous section, assume that optimizing system performance requires dedicated digitizers for each scenario: 1) scanning the spectrum for signals and 2) analyzing a specific, narrowband signal. While the scanning system might use a 12-bit digitizer, the narrowband system will perform better with a higher resolution, 16-bit digitizer, enabling detection down into the noise. However, these digitizers likely require different microwave frequency converters. While it is possible for each system

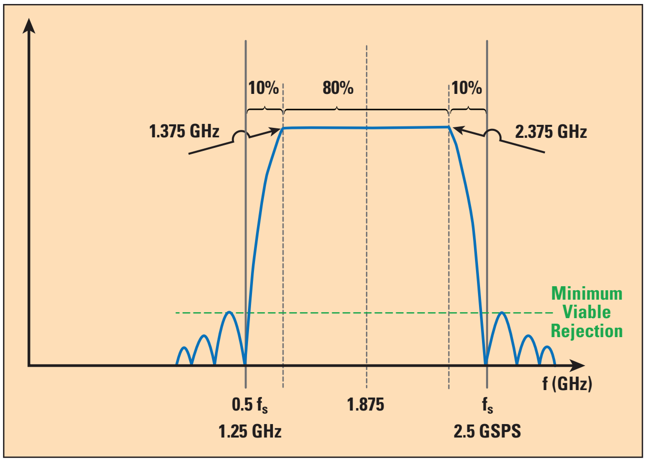

Fig. 2 1 GHz IBW IF centered in the second Nyquist zone.

to have its own custom-designed frequency converter, it will increase the development cost and supply chain complexity. Also, with separate frequency converters, it is not possible to reconfigure a system in the field. However, as noted, an agile IF architecture enables a single frequency converter to support both wideband and narrowband applications.

The agile IF architecture simplifies system updates. In an environment of rapidly emerging electronic threats, EW and ELINT systems must be regularly updated to incorporate the latest technology. Unfortunately, these updates are time consuming and costly. Using an agile IF architecture makes it possible to reuse the same microwave frequency converter through multiple system upgrades, which extends the operational life of the converter and significantly reduces cost. Of the types of technology improvements that drive system updates, most of the changes are on the digital side, due to pace of processor and software technology driven by Moore's Law. While the performance of the microwave converter will likely support multiple upgrades, the system needs the latest generation of ADCs and DACs. With a traditional system, updating the digitizer requires changing the microwave converter.

NYQUIST ZONES

The microwave converter is dependent on the specific digitizer because the IF from the converter must be restricted to a single Nyquist zone. The digitizer's Nyquist zones are defined by its data rate and the number of samples per frequency component. For example, if an ADC has a data rate of 2 GSPS, the first Nyquist zone extends from DC through 1 GHz, and the second Nyquist zone starts at 1 GHz and extends to 2 GHz. A signal spanning two Nyquist zones causes aliasing, i.e., signals from all the Nyquist zones are mapped into the first zone. To prevent this, anti-aliasing filters are used to limit the input frequency range; however, this requires the input signal to be constrained to a single Nyquist zone. With a fixed IF architecture, modifying the data rate of the digitizer results in a new frequency plan and requires a new microwave converter. With an agile IF architecture, the frequency plan can be modified and the existing microwave converter will support multiple updates to the digitizer.

CASE STUDY

To illustrate, assume an EW system with a broadband microwave front-end and a digitizer designed to process signals from 6 to 18 GHz. For this application, a digitizer with a

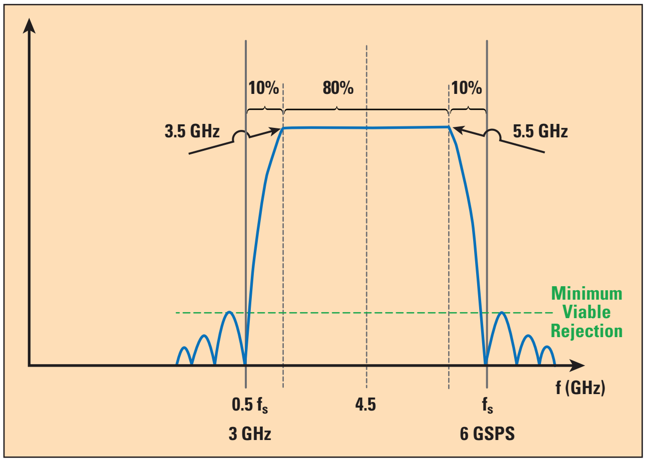

Fig. 3 2 GHz IBW IF centered in the second Nyquist zone.

sample rate of 2.5 GSPS is selected, using the second Nyquist zone, i.e., from 1.25 to 2.5 GHz. However, the roll-off of the anti-aliasing filter makes the usable bandwidth closer to 1.375 to 2.375 GHz. Hence, to use this specific digitizer requires a microwave transceiver with RF coverage from 6 to 18 GHz and 1 GHz IBW, from 1.375 to 2.375 GHz (see ***Figure 2***).

After developing and fielding this system, assume new threats emerge that require a 2 GHz IBW. To update the system, a new digitizer with a sample rate of 6 GSPS is chosen. Accounting for the anti-aliasing filter, the second Nyquist

Fig. 4 Mercury Systems agile IF microwave frequency converter.

zone for this digitizer is from 3.5 to 5.5 GHz, which meets the 2 GHz bandwidth but might possibly require a new microwave transceiver (see ***Figure 3***). With an agile IF architecture, however, the original transceiver can simply be programmed for a different IF band.

SUMMARY

This article and case study show the benefits of agile IF technology: instead of designing a new microwave transceiver, a costly and time intense effort, the original transceiver can simply be programmed to a different IF band and IBW. This ability to optimize the IF from mission to mission, as well as configure the converter to operate with a range of digitizers, enables a flexible and more future-proof approach to EW and ELINT system design. As new threats emerge, this capability is critical to maintaining spectrum superiority.

Mercury Systems is employing this architecture with its portfolio of microwave tuners and high performance digitizers (see ***Figure 4***).■

INVITED PAPER

Product Development for the Defense Market—Do Not Forget ITAR and EAR

Mark Andres and Heatherly Bucher
Arena Solutions, Foster City, Calif.

The defense market offers commercial electronics suppliers compelling reasons to expand focus: additional revenue from same or variant products, longer customer contracts and diversification to cushion against commercial market swings. However, commercial companies should consider the added complexity of regulatory compliance and product lifecycle differences from the commercial market when considering how to adjust their product development processes for the defense market.

ITAR AND EAR COMPLIANCE

Most product design and manufacturing companies in the defense market provide products subject to export regulations (see ***Figure 1***), the International Traffic in Arms Regulations (ITAR) and Export Administration Regulations (EAR). This article provides an overview of the basic requirements for compliance, with the caveat that ITAR and EAR regulations are complex, and Arena Solutions is not offering legal advice or counsel for any reader. This article is not intended to supersede a company's or individual's responsibilities to understand and comply with the regulations.

The ITAR and EAR regulations govern the export of products to foreign countries and, perhaps more complex, they govern the technical data associated with the products, requiring an export license prior to disclosure to a foreign national. The full list of products governed by ITAR and EAR ranges from fabrics, tactical uniform gear and mechanical components to RF arrays, wireless platforms, antennas, radars, avionics systems and all things aerospace. If a product falls into the regulated space, processes, people and systems need to be in place to ensure regulatory compliance—regardless of the industry space, product volumes, timelines and product complexity.

▲ Fig. 1 The ITAR is administered by the Directorate of Defense Trade Controls in the Department of State; the EAR by the Bureau of Industry and Security in the Department of Commerce.

Beyond export licenses for products, the regulations stipulate that any technical data controlled by ITAR or EAR be under export control, meaning technical data must not be exported at any point during design, production or any sustaining activities unless authorized by an export license. Practically, this means ITAR and EAR-regulated data must remain in the U.S. and only be accessible by U.S. persons. Data in transit or "at rest" must be encrypted, and access to any platform containing regulated product data must be controlled and restricted to U.S. persons.

These regulations ensure companies control all regulated technical data, including what is referred to as controlled unclassified information. The registered manufacturer defines what technical data in the product record is under export control, based on the product, how the government classifies the product and the particulars of the product of interest to the U.S. government. Depending on the circumstances, technical data can include file names, component descriptions, engineering drawings, specifications, test procedures and bills of materials. All restricted data must be controlled, including the standard policies and procedures for access, audit history and incident reporting. Access includes any method of access: via any operating system and any application, including access by IT to assist and maintain the systems where restricted data is stored. It specifies that all methods of sharing information be controlled, such as email, faxes and physical delivery.

Clearly, complying with these stringent regulations without sacrificing business agility can be an unwanted challenge for manufacturers.

PRODUCT DEVELOPMENT

The product development processes for commercial and defense products share much in common. Conceptually, teams take an idea from concept through design and test to validation, followed by new product introduction, production and support. Irrespective of the market, business concerns include cost, quality, time to market and supply chain logistics. For defense systems, the product development process needs to consider the following four areas and how they impact product development decisions: accountability, product lifecycle timing, product priorities and supplier qualification and management.

Accountability—The defense industry's accountability burdens include ITAR or EAR export controls and the compliance programs and underlying policies to meet the regulations. Not everyone knows this also means customer audits for products, processes and systems, as well as financial aspects and supplier investigation. Some manufacturers pursue ISO 9001 and AS9100 certifications for competitive advantage or to gain customer contracts, which require additional audits. The environment is constantly changing, and programs, contracts and processes need to change to ensure compliance. Most companies entering the defense market find they need to expand team resources, which includes adding compliance specialists to help ensure the company meets regulatory and contractual customer requirements.

Product Lifecycle Timing—In the defense industry, the overall product lifecycle is longer than in commercial markets, largely due to the size and complexity of the end product. Prod-


CMD241

Fig. 2 Global supply chains complicate export compliance. An IC may be designed in Europe, fabricated in Taiwan, assembled and tested in the Philippines and shipped to a customer in the U.S.

Fig. 3 All manufacturers of defense articles defined by the U.S. Munitions List are required to be ITAR registered.

ucts may fit into a much larger system or platform, such as an aircraft, navigation system, satellite, ground station or launch platform. Negotiations and design review approvals with the customer are typically slower. For export-controlled products, attention should be paid to the length of the product development, testing and production schedule, with obsolescence and serviceability top concerns. Teams should plan for the "natural" obsolescence of components during the longer life of the product, building in flexibility and tactics to address serviceability.

Product Priorities—As noted, defense products tend to be in service far longer than commercial products. Therefore, teams may need to weigh product design priorities differently than in a purely commercial business. Quality and serviceability become more important, as well as integration with any subsystems. With controlled technical data, expect more design review boards and more back and forth—not only with the customer and supply chain, but also subassembly suppliers and, potentially, the end customer.

If products are intended for dual markets, consider how to allow for these differences within the product development timelines for the defense market deliverables. Depending on the extent of both product and process variances for defense customers, the dual market product might be better split into separate product lines, one for each market.

Supplier Qualification and Management—With the long serviceability and planned part obsolescence, coupled with the export control requirements of the product and controlled technical data, supplier qualification requires attention (see ***Figure 2***). Regulated requirements need to flow down to supply chain partners that may not be regulated, so closed-loop quality and change processes with security are required. Potential supply chain vulnerabilities occur every time designs or parts change hands. Plan for this in the company's standard operating procedures (SOP) and ensure the systems and tools support compliance to these SOPs.

TOOLS FOR DEFENSE PRODUCT LIFECYCLE MANAGEMENT

Those new to the defense market will likely establish teams and processes to address these four concerns. Equally important, companies should consider the systems used to manage product data throughout the product lifecycle. Remember, export-controlled data requires secure handling. ITAR and EAR regulations are complex and often contain cross-references to other regulations and standards, which may not be applicable for certain situations. As such, company management should confer with compliance officers and legal counsel to determine:

- If registration is required for ITAR, EAR or both (see ***Figure 3***).
- What specific product data is under export control.
- Which requirements above and beyond specific regulations must also be met.

With any system solution, companies must determine how the regulations are being met, with a responsible owner assigned for each regulation re-

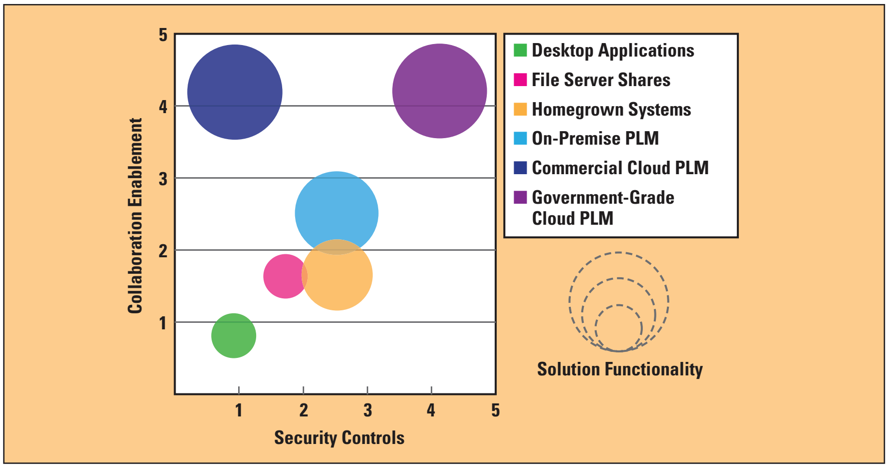

Fig. 4 PLM options for the defense industry.

quirement. This is critical, as solutions vary in approach and extent of meeting requirements. Tools which are used to support defense product development processes include (see ***Figure 4***):

- Desktop applications, such as spreadsheets.
- Local or shared file servers and FTP sites.
- Homegrown databases.
- Industry-provided, on-premise product lifecycle management (PLM) systems.
- Commercial cloud (SaaS) PLM systems.
- Government-grade, secure cloud (SaaS) PLM systems.

While homegrown solutions such as desktop apps, spreadsheets and local file servers can suffice for a time, none of these enable scaling the business or optimizing processes across a business. Most were not designed to adequately address security and the location-based restrictions imposed by federal regulations; they create compliance risks with cost implications following a problem.

A dangerous assumption is if information is stored, accessed and collaborated on-site—within a LAN, WAN or VPN network—the company is complying with most ITAR and EAR regulations, because everything is "local." This is not true. Regulations require demonstration of compliance regardless of where the solution resides.

The list of security elements to consider and evaluate is lengthy: handling printed drawings sitting on an engineer's desk to digital files on an internal file server to uploaded data in an on-site system or a cloud application. Exporting controlled technical data can still occur within the U.S. if the data is transmitted or shared with foreign nationals in any form or format, whether oral, written, physical observation, paper, email, phone, fax or application.

SUPPORTING DESIGN COLLABORATION

Everyone working in product development talks about the importance of collaboration, as it is one of the primary ways to improve quality. Industry analysts, customer surveys and institutional research indicate that the opportunity for the most quality improvement occurs in design, the first part of the product's life,[1] and poor design quality most often occurs due to lack of collaboration on design requirements and issues found during product development.[2]

Given the longer lifecycle of most defense products, communication among the teams, availability and transparency of product data and a complete and auditable history of the product record are all necessary. Most defense products will outlast the individual team participants and any partner relationships.

When considering a solution for defense PLM, security controls must take the highest priority. However, do not stop there. Evaluate options to get the most collaboration capability and functional scope possible. Modern systems can provide more capability to support compliance with regulations, while producing the best products for customers—whether commercial or defense.■

References

1. S. Dowlatshahi, "Purchasing's Role in a Concurrent Engineering Environment," *International Journal of Purchasing and Material Management*, Vol. 28, No. 2, 1992, pp. 21–25.
2. Y. Zhu, R. Alard, J. You and P. Schönsleben, "Collaboration in the Design-Manufacturing Chain: A Key to Improve Product Quality," 2011, 10.5772/18694.

INVITED PAPER

TWTAs Still Dominate High-Power and mmWave Applications

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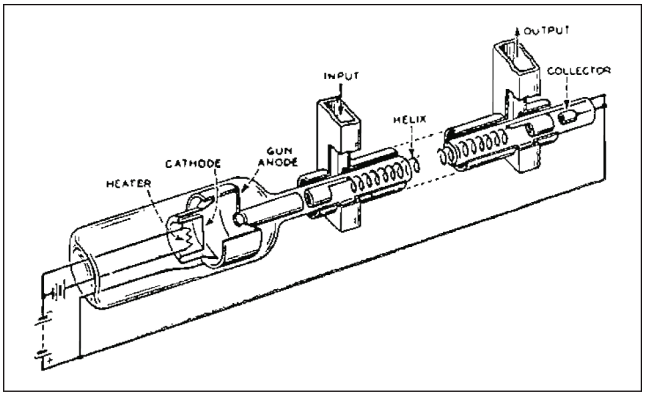
There has been a long-standing argument that microwave and mmWave vacuum electron devices (VED)—known as traveling wave tubes (TWT), TWT amplifiers (TWTA) or microwave tubes (MWT)—are an obsolete technology almost completely superseded by solid-state power amplifiers (SSPA). Throughout the larger electronics industry, tube transistors have, for the most part, been replaced by solid-state transistors. However, within the microwave and mmWave industries, the extremely high-power capability at higher frequencies, relatively compact size and steadily increasing reliability of VEDs has maintained a nearly $1 billion market despite the opinion that VEDs are large, cumbersome, complex, expensive and unreliable solutions.[1]

VEDs are essential devices in many space, aerospace, military, electromagnetic interference (EMI), electromagnetic compatibility (EMC), weather and radar applications. Though the common opinion may be that VEDs are obsolete devices, now only used in legacy applications and long-standing contracts, this is far from true. SSPA technology essentially replaced VEDs in commercial, low power and low frequency applications decades ago. However, even with the advent of "high-power" GaN power amplifiers (PA), SSPA technologies have yet to supersede TWTAs for extremely high-power levels and at high frequencies (i.e., mmWave). This article provides an update on the current state of VEDs, specifically TWTAs, how they compare with available SSPA solutions and why this "legacy" technology is still being actively developed and deployed.



▲ Fig. 1 Traveling wave tube cutaway. Source: Tele-Tech magazine.[2]

TWTA OVERVIEW

A TWT operates by generating an electron beam from an electro-optical system consisting of an electron gun, electrodes, delay line and a collector of the electron beam (see ***Figure 1***). The electrodes act to focus and accelerate the electron beam. A heater is used to ensure that the electron beam cathode reaches the desired operational temperature to generate electrons. There are two RF ports: an input port, at the start of the delay line near the beam generator, and an output port, at the end of the delay before the collector. With reflections within the TWT from the RF input and output ports, a microwave absorber is added to reduce the reflections and mitigate self-excitation. Hence, it is important to ensure that the RF ports are terminated with a matched load.

A driver amplifier and attenuator combination are often used to ensure that the RF input to the TWTA is at the desired signal level. Several additional inputs are needed for it to operate, including a high voltage power supply, heater, low voltage power supply, driver amplifier power supply

and a control and monitoring circuit to prevent failure (see ***Figure 2***). Given the system complexity and number of critical inputs, many consider TWTAs to be large, cumbersome and expensive, with a low lifespan and high maintenance. Though this may be true in the most extreme applications at the edge of TWTA technology and performance, this is not true for most applications that use TWTAs, which have been improving for decades.

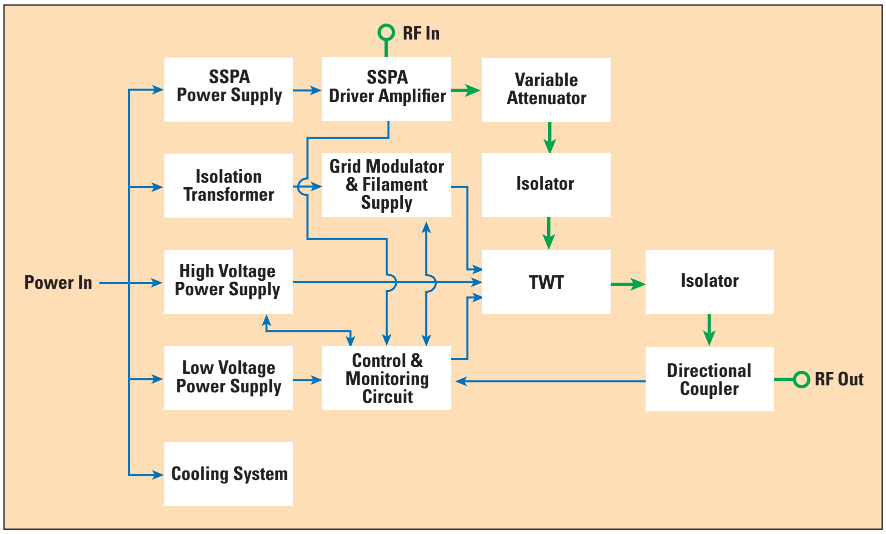
MODERN TWTAs VS. SSPAs

SSPAs have steadily been integrated into more system designs, yet there are still regions of power and frequency where TWTAs dominate and likely will for some time (see ***Figure 3***). The benefits of SSPA technology are derived from its small footprint, high-power density, large process technology and ability to be integrated into compact assemblies. However, these factors create additional cooling challenges at higher power levels and frequencies, where the resistive losses of the lower operating voltage and higher current of the semiconductors, with the associated resistive losses in the conductors, are much higher than at lower frequencies. Hence, there is a practical power versus frequency limit for SSPAs, where the cost benefit of using SSPAs diminishes compared to TWTAs. This region is typically toward the hundreds of Watts of output power at microwave frequencies and beyond several Watts at mmWave.

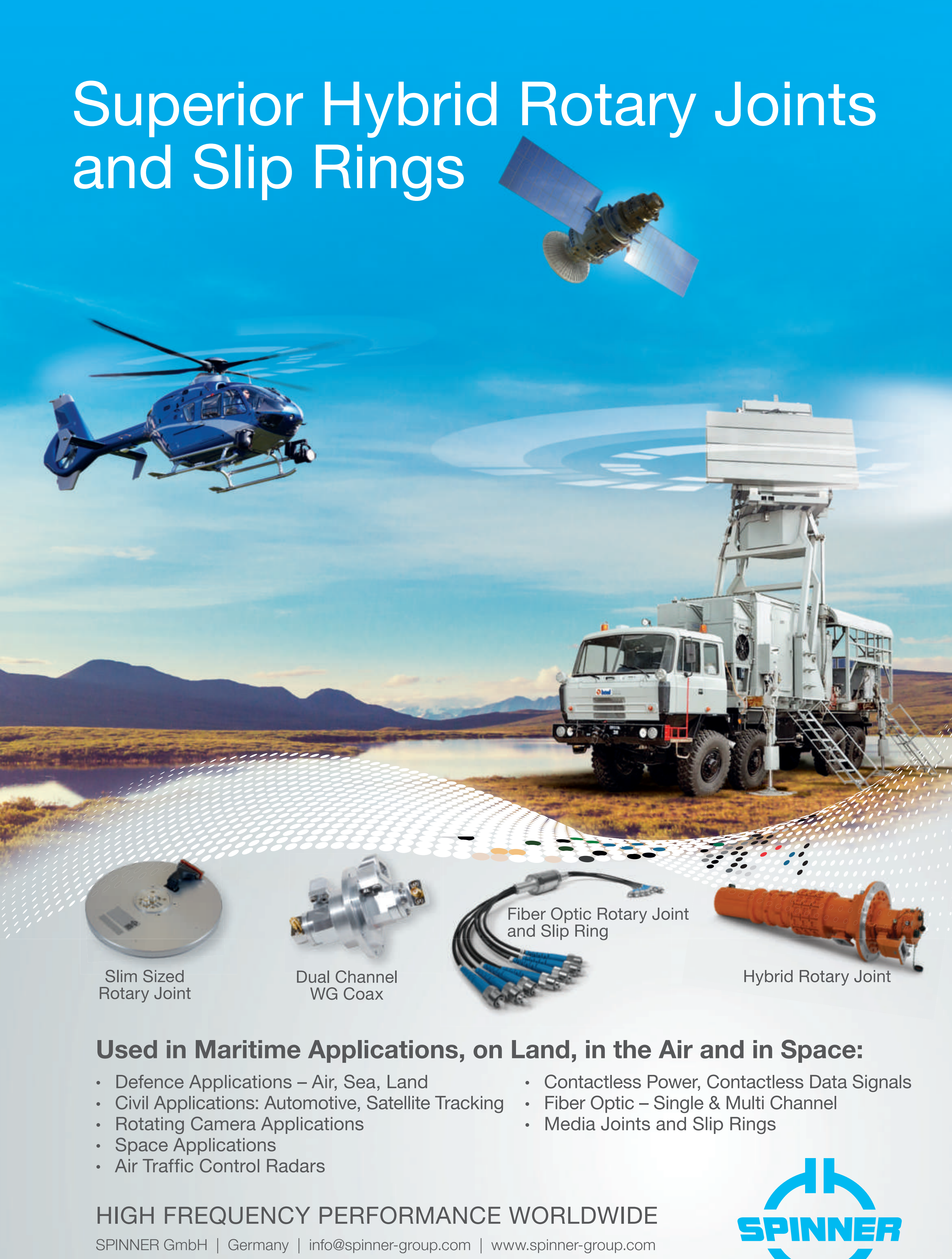
TWTAs typically have higher operating voltage, which mitigates the resistive losses at higher frequencies. Therefore, TWTAs can deliver much higher pulsed peak and continuous wave (CW) power. In these higher power regimes, it is also likely that TWTAs are comparable, if not superior, in power efficiency, due to the increased power combining losses for the more complex SSPA assemblies.

To reach higher power, it is common to combine several SSPAs. ***Figure 4*** shows a block diagram of an N-way combined SSPA, with the accompanying interconnect, power combining and accessory components. These complex assemblies, though viable in some cases, introduce greater system complexity and additional failure modes. They typically reduce overall efficiency (from power combining insertion loss and matching the individual PAs), degrade noise figure and create a substantial cooling challenge. As each of the components in a compound SSPA are not broadband, designing and fabricating a high-power SSPA with wide bandwidth may require substantial engineering and custom solutions.

Compared to TWTAs, the reliability of SSPAs is commonly considered to favor SSPAs; however, this is not necessarily the case at high-power levels and high frequencies. In the past, largely due to the state of fabrication technology and poor operating practices, it was rare yet common enough for the tubes in TWTAs to only last a couple of years. Recently, advances in fabrication technology, tooling and materials—which also benefit SSPAs—have led to tubes rated to nearly 20,000 hours of operation, yielding a usable lifespan of 8 to 10 years. This lifespan is comparable to SSPA technology, although SSPAs



▲ Fig. 2 Generic TWT amplifier block diagram showing RF signal path (green).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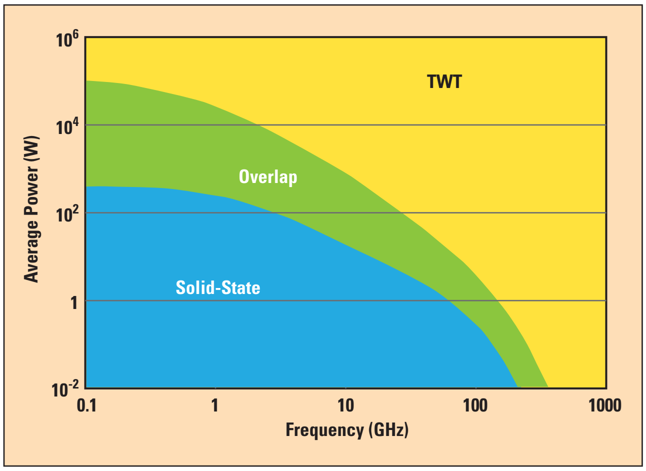

Fig. 3 Power/frequency trade space between TWT and solid-state power amplifiers.[3]

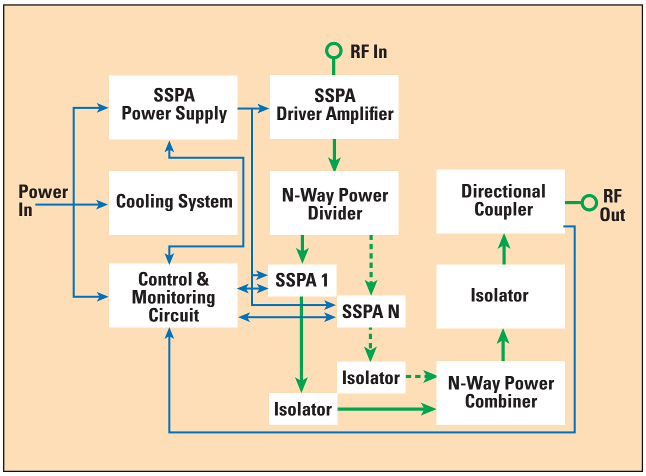

Fig. 4 Generic solid-state power amplifier block diagram showing RF signal path (green).

typically do not require maintenance throughout their lifespan. This benefit could be offset in a highly integrated SSPA, where replacing a failed internal amplifier may be impractical; however, replacing a failing tube in a TWTA is a procedure accounted for in the maintenance plan. Regardless of the technology, SSPA or TWTA, for the system to be reliable, backup units are needed.

SSPA technology has advanced over the years, yielding amplifiers that reach tens of kW of output power and operate over 100 GHz. However, SSPA solutions reaching these extremes are generally expensive, custom and may not meet the reliability or performance standards required by legacy and emerging applications. VEDs such as TWTAs are often the only viable solution for high-power, high frequency and ultra-wideband applications.

SSPA technology typically uses mass produced solid-state devices that are not readily customizable. Some customization can be done on the amplifier pallet and with additional circuitry, but the performance limits of the amplifier are constrained by the solid-state transistors and the underlying fabrication processes. With TWTAs, a significant amount of customization is available with the design and tuning of the amplifier system. Applications that require very specific performance criteria rely on TWTAs, especially for use cases that require extreme CW power, frequency, bandwidth, pulse repetition frequency (e.g., MHz PRFs), long duty cycle pulses and high peak pulse power.

The health of the MWT in a TWTA amplifier is the greatest liability of the system. Poor design, care and use of a TWTA can dramatically reduce the lifespan of a MWT and lead to accelerated degradation. This is a common challenge with VEDs and MWTs, as matching MWTs is difficult, and each MWT requires slightly different input characteristics for optimal operation. Hence, an area of ongoing development is more intelligent high voltage power supplies that can adjust performance over time to optimize the output power of the TWTA as a tube ages. With intelligent heater systems, a TWTA may become easier to use with lower maintenance.

Table 1 compares the characteristics of TWTAs and SSPAs.

TRENDS DRIVING TWTA GROWTH

Several industries rely on VEDs for high-power microwave and mmWave

applications, such as radar, aerospace, weather and SATCOM. As well as having legacy applications that require upgrades, new applications demand advancements in the design and performance of TWTAs. Though some may believe that TWTAs only serve legacy applications, several key trends in microwave and mmWave applications are driving new use cases and demands of TWTA technology. These include terrestrial communications, such as 5G testing and mmWave backhaul, and SATCOM, moving to upper microwave and mmWave frequencies. This growing communications market is creating interest in moving radar systems to higher frequencies to avoid interference.

With more applications moving to higher frequencies, EMI and EMC testing requires instruments that can operate at high-power with high quality over very broad bandwidths. Most of these new applications require microwave and mmWave power sources, high-power test equipment—even high-power amplifiers in the end product. The recent opening of additional license-free spectrum at V-Band (57 to 71 GHz) has created the need to test these new applications at frequencies and power levels typically beyond the capability of SSPAs. Outside of the usual markets, the availability and understanding of microwave and mmWave technology is providing new opportunities for scientific research, such as linear accelerators and RF propulsion for spacecraft.

TABLE 1

TWTS AND MWTS VS. SOLID-STATE AMPLIFIERS FOR HIGH-POWER

Factor	TWT/MWT	Solid-State
High Voltage Power Supply	Yes	No
Periodic Maintenance	Yes	No
Warm-Up Delay	Long	Short
Device Footprint, Volume	Larger	Smaller
Power Efficiency at Extreme Power Levels	Better	Lower
Noise Figure	Better	Lower
Power Density	Lower	Higher
Design & Fabrication Complexity	Less	Higher
Operating Temperature	Higher	Lower
Direct Heat Zone Cooling	Yes	No
Radiation Hardness	Better	Lower
Environmental Ruggedness	Better	Less
>3 Octave Bandwidth at High-Power	Yes	Uncommon
Peak Pulsed Power	Higher	Lower
Power Device Count	Lower	Higher
Breakdown Voltage	Higher	Lower

SUMMARY

VEDs, such as TWTAs, are still very much in use for applications with extreme power and frequency demands. Though often considered outdated, TWTAs are being used in new and leading technology applications, including 5G, mmWave backhaul, SATCOM, high-power and high frequency testing and scientific research. It is likely that tubes will continue to be the only solution that provides high-power at microwave and mmWave frequencies with GHz of bandwidth for many years.■

References

1. "ABI Research Finds Microwave Tube Market Still Strong at Over $1B for 2018," *Microwave Journal*, January 16, 2019, www.microwavejournal.com/articles/31649.
2. F. Loomis, "Bell System Plans for Broadband Network Facilities," *Tele-Tech Magazine*, Caldwell-Clements Inc., Bristol, CT, Vol. 12, No. 4, April 1953.
3. V. Kesari and B. N. Basu, "High Power Microwave Tubes: Basics and Trends, Volumes 1 and 2," January 2018, *Morgan & Claypool Publishers.*

INVITED PAPER

Selecting Phase-Locked Oscillators for Frequency Synthesis

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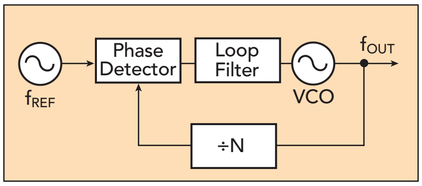
Phase-locked oscillators (PLO) are stable frequency sources with inherently low phase noise and spurious signals. They are widely used for frequency generation in radar, communications and other applications. This article reviews the background, architectures and pertinent parameters of PLOs.

Much RF/microwave literature covers the design and application of the phase-locked loop (PLL), a feedback system designed to closely track and match the phase of two RF sources: a reference oscillator and voltage-controlled oscillator (VCO). A PLO is meant to function as a stable microwave source or local oscillator (LO) and often leverages an analog or digital PLL to impart onto the VCO the frequency stability and phase noise of a crystal oscillator or other low noise reference.

In a simple PLL (see ***Figure 1***), the output of a VCO is fed in a feedback loop through a divider, where the divider generates one output pulse for every N input pulses. The output of the divider is fed to a phase or error detector that detects the phase between the output of the divider and the output of the reference. The phase detector produces a pulsed error signal representing the phase difference between the reference and the frequency divided VCO. This error is filtered in a lowpass filter, also known as the loop filter, and controls the VCO, ultimately locking it to a specific frequency, which is related to the phase.

In a radar or communications system, a LO with poor short-term stability rapidly changes its output level and phase, and adjacent frequency components or sidebands appear due to the amplitude and phase modulation. The sidebands of this noisy LO are present at the IF and compromise receiver sensitivity. A weak received signal buried in the phase noise would be undetected. The frequency generation process often results in a poor signal-to-noise ratio due to the phase noise sidebands. For a VCO, this process integrates the PLL, frequency multipliers, dividers and other components used in generating the LO frequency output, with the phase noise profile shaped by these components. A PLO leverages the good short-term stability and close-to-carrier performance (high Q) of a crystal oscillator or other stable source by using it as a reference for the VCO, which has comparatively poor short-term stability, yet a good noise floor far from the carrier.



▲ Fig. 1 Phase-locked loop.

DIRECT SYNTHESIS, INDIRECT SYNTHESIS AND DIGITAL SYNTHESIS

A frequency synthesizer is generally defined as a device that can generate multiple frequencies from a single frequency reference. A PLO can be considered a fixed frequency synthesizer that generates a stable output frequency regardless of temperature drift, vibration and aging. Frequency synthesizers can be implemented using one of three topologies: direct synthesis, indirect synthesis or direct digital synthesis.

Some systems generate an LO frequency using direct synthesis. In one implementation, the reference oscillator frequency (typically from a crystal) is multiplied in several stages (see ***Figure 2***), where each multiplier stage requires an amplifier and filter to reach the required drive level and minimize spurious signals. This architecture can become cumbersome, with many components and potential failure modes, and multipliers often use step recovery diodes, which are prone to instability and difficult to tune.[1] In direct synthesis, filter design and alignment are crucial to minimize spurious signals.

More often, indirect synthesis is employed, typically in the form of a PLL oscillator (PLLO), where the output frequency is divided and compared directly with the phase of a reference oscillator. This way, the output frequency is a rational multiple of the reference frequency. A common topology (see ***Figure 3***) includes a temperature compensated crystal oscillator (TCXO) or oven controlled crystal oscillator (OCXO) as a reference, with a VCO such as a dielectric resonator oscillator (DRO) or coaxial resonator oscillator (CRO). This architecture is far less complex than direct synthesis and provides low phase noise and spurious signals.

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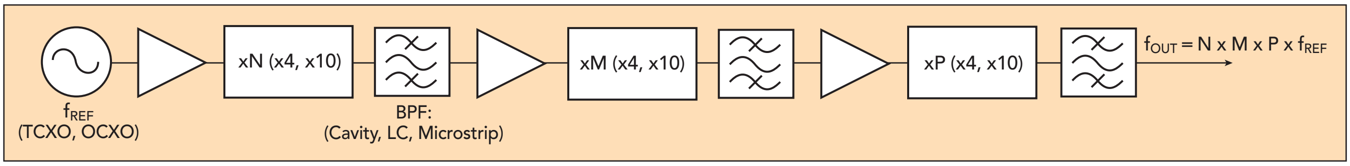

Fig. 2 Direct frequency synthesis.

With direct digital synthesis (DDS), an analog reference signal determines an invariant sampling interval, from which a sequence of signal amplitudes are calculated and output as digital codes (see ***Figure 4***). The digital signal is sent to a digital-to-analog converter (DAC) and the output is filtered to generate an analog signal at the desired frequency. While this method is more frequency agile than the previous approaches, it generally operates only at lower frequencies due to increasing power consumption with increasing frequency. The DDS also produces more spurious emissions than its analog counterparts, caused by numerical truncation and DAC errors.

INDIRECT SYNTHESIS: DIGITAL VS. ANALOG PLL

A PLLO can use either a digital PLL (DPLL) or analog PLL (APLL). The analog implementation includes all the conventional PLL components with one major difference: the phase detector is an analog multiplier (mixer) instead of a digital phase frequency detector (PFD). The analog approach involves several frequency multiplication stages (e.g., ×4, ×10) to generate the required frequency to compare with the output frequency of the microwave oscillator (see ***Figures 5a*** and ***5b***). Phase comparison uses an analog phase detector (e.g., a four quadrant multiplier or diode ring mixer). This topology may have an advantage for space applications, where analog components have an inherent immunity to radiation effects or signal events that may affect digital components (e.g., latch up).[1]

The main issue with this approach is the potentially large multiplication ratio required for high frequencies, i.e., X-Band and above. Each multiplication stage requires amplification and filtering to minimize spurious signals, and the added sub-circuits introduce potential failure modes, such that these PLOs are less reliable in many circumstances. Another disadvantage is the phase noise of the reference source is multiplied by the analog PLL.

A digital PLL (DPLL) uses a digital frequency divider (either integer- or fractional-N) for the main and reference signals (see ***Figures 5c*** and ***5d***). Digital phase detectors such as PFDs are used with active and passive filtering to achieve the desired phase noise and spurious performance. This implementation lends itself to greater inherent reliability, due to its relative simplicity, and offers a cost benefit from the ease of manufacturing. The main issue is a relatively higher noise floor. Multi-loop architectures are often used to mitigate this limitation.

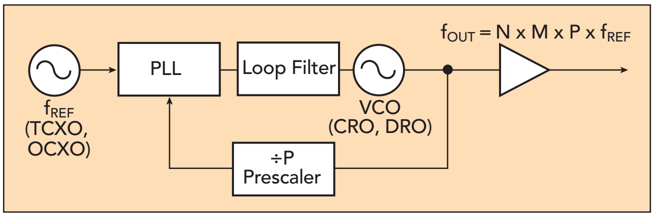

Fig. 3 Indirect frequency synthesis.

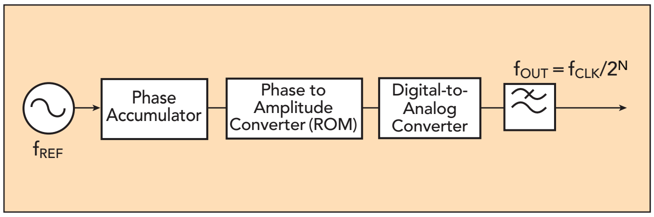

Fig. 4 Direct digital synthesis.

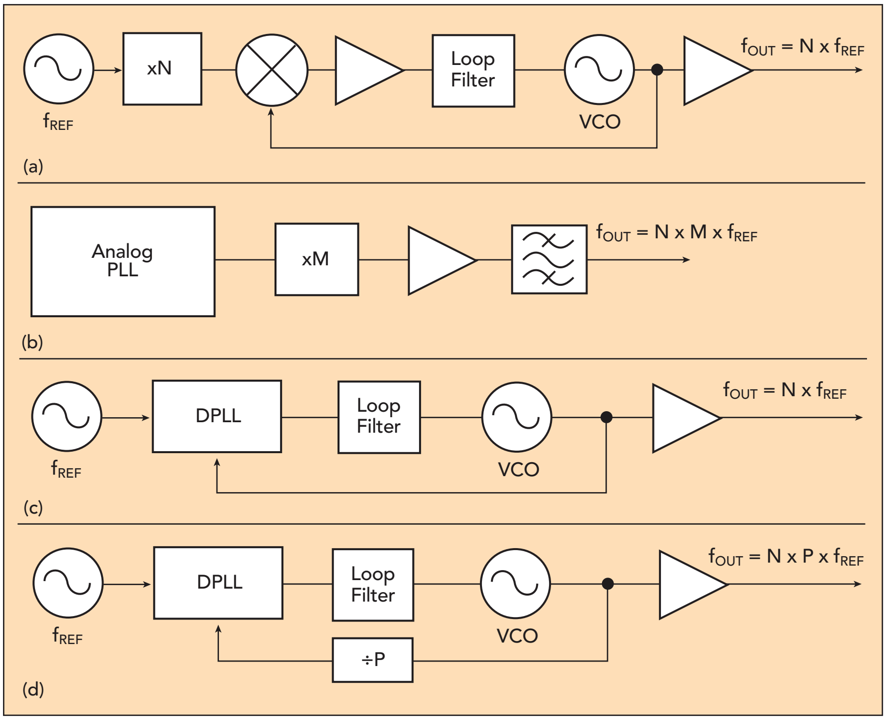

Fig. 5 PLO architectures: analog PLL (a), analog PLL with multiplier (b), digital PLL (c) and digital PLL with prescaler and multiplier (d).

The DPLL should not be confused with the all-digital PLL (ADPLL), which can include a DDS. The ADPLL eliminates all analog circuitry, comprising a digital loop filter and digitally controlled oscillator. Some PLOs can incorporate an ADPLL or a DDS to provide high frequency resolution.

DUAL-LOOP ARCHITECTURES

Dual-loop PLOs contain two PLLs, where the first stage provides the reference frequency for the second stage (see ***Figure 6***). The signal output from the first stage is divided down to an appropriate frequency to be the second stage reference. Most PLO designs assume a 10 or 100 MHz reference. This architecture is particularly useful when the input reference is an unknown quantity that must be manipulated to obtain a precise output frequency. Another benefit is the ability to mitigate the spurs generated by the digital dividers, where the frequencies of the spurs are based on the division. With the dual-loop architecture, the division number is reduced due to the fixed offset frequency. This approach is also helpful for high frequency

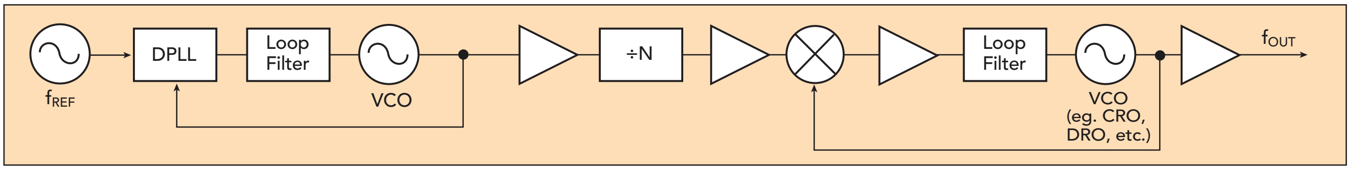

Fig. 6 Dual-loop PLO with both digital and analog PLLs.

loops, which tend to require a narrower loop bandwidth to limit the phase noise at the output. With a dual-loop PLO, the loop bandwidth can be larger to increase the locking speed of the PLO, while suppressing the VCO output phase noise close to the carrier.

FUNDAMENTAL OSCILLATOR CHOICE

The choice of the fundamental oscillator depends on the output frequency and required noise performance. Up to S-Band, a crystal oscillator offers excellent phase noise performance close to the carrier. This, however, does not suffice at higher frequencies. Here, a CRO up to C-Band or DRO up to X-Band can be used. A VCO can be used up to Ka-Band with the trade-off of poorer phase noise. As stated earlier, this can be mitigated in a multi-loop design. A DDS can generate the output frequency with much higher frequency resolution and lower phase noise than a VCO; still, spurious emissions and power consumption must be considered.

The selection of the fundamental oscillator may also depend on size constraints. A DRO, for example, may be unreasonably large at lower frequencies. A DDS can be implemented with CMOS technology, achieving low cost and a small form factor. However, the size benefit generally diminishes above 500 MHz, due to the increasing power consumption and need to dissipate the heat. A VCO can be implemented as a MMIC, including the PFD and digital divider. A PLO will typically be built as a microwave integrated circuit on a thin film substrate; this allows for greater output power at moderate frequencies.

CONCLUSION

A PLO supplies an RF signal with the high spectral purity required for many applications, from LOs in radar and communications systems to high speed clock signals to clean sources in test and measurement equipment. PLOs can be implemented with many architectures, and the choice will impact the output frequency, phase noise, spurious, harmonics and output power. Each has its respective pros and cons.■

References

1. B. Hitch and T. Holden, "Phase-Locked DRO/CRO for Space Use," *Proceedings of the International Frequency Control Symposium*, May 1997.
2. T. J. Rouphael, "RF and Digital Signal Processing for Software-Defined Radio: A Multi-Standard Multi-Mode Approach", *Elsevier Newnes*, 2009.

INVITED PAPER

Using Additive Manufacturing for Aerospace and Defense Applications

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In a recent head-to-head test, defense contractor Harris Corp. created 3D printed RF amplifier and antenna circuits and compared them with the same designs fabricated with traditional printed circuit board (PCB) methods. Both circuits printed by additive manufacturing worked just as well as those created using traditional PCB manufacturing and were printed days faster than with the conventional method. This demonstration was intended to show the feasibility of precision 3D printed electronics for defense and aerospace applications.

Engineers at Harris partnered with Nano Dimension, a manufacturer of 3D printers for printed electronics, to see how RF circuits created with additive manufacturing (3D printing) compare with those made using conventional manufacturing processes. The study comprised circuit design and simulation, fabrication and testing. The goals set by the Harris team were to study the use of 3D printing for functional RF circuits by demonstrating how the 3D printed circuits compare with those made by conventional manufacturing. The proof-of-concept test vehicles were a 2 GHz amplifier and an RF antenna designed to operate at 5.2 GHz. The details and experimental results of the study follow, with a discussion of the implications for RF manufacturing.

From the ocean to orbit, Harris provides mission-critical systems to connect, inform and protect the world. The company is a leader in tactical communications, EW, avionics, air traffic management, space and intelligence and weather solutions. Developing circuits and systems for conveying data, video and voice across long distances, Harris has focused on improving system mobility and performance while working to reduce development time and cost—particularly important for complex defense and space systems. Hence, the company's interest in additive manufacturing.

This study on using additive manufacturing to develop RF circuits for wireless systems is part of a joint project with the Israel Innovation Authority and Space Florida Foundation, a partnership promoting research, development and the commercialization of aerospace and technology projects. In June 2017, Nano Dimension received an Israel Innovation Authority grant to collaborate with Harris to apply 3D printing to electronic modules. The project was designed to demonstrate 3D printing of double-sided, multilayer circuits integrating digital, power and RF signals could reduce the SWaP-C of space systems.

BUILDING THE RF CIRCUIT

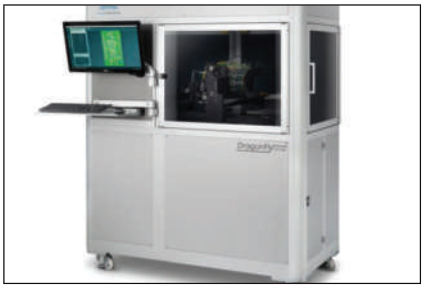
Creating RF components for complex systems is typically a complex, multi-stage process. Achieving the optimum component and system performance is iterative: create a design, produce a prototype circuit, test its performance to identify shortfalls, change the design, build and test another prototype and repeat until the optimum design is achieved. This process has long lead times and is expensive. With electronic components the heart of automotive, defense, consumer and medical devices, the capability of 3D printing to prototype PCBs and other components in just hours and onsite—regardless of the circuit's complexity—yields time and cost savings and supports rapid innovation.

To fabricate the 3D printed circuits for this study, Harris used Nano Dimension's DragonFly printer (see ***Figure 1***), the first commercial additive manufacturing system for printed electronics. DragonFly provides essentially unlimited possibilities for creating densely packed electronic prototypes and rapid design iterations. The high-resolution system prints metal and polymer simultaneously, for PCBs and precision elec-

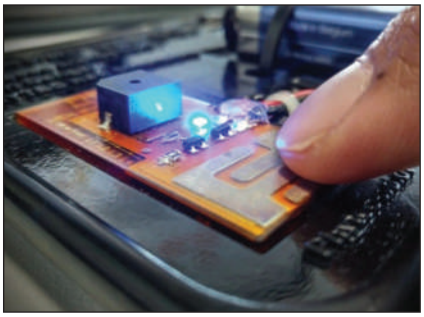
tronics such as sensors, RF circuits, antennas, molded interconnects and customized parts such as smart cards, RFID circuits and other ID products and arrays (see ***Figure 2***). With the DragonFly, circuits and systems that have rigid packaging integrated with flexible circuits can be produced in a single print, without the need for cables and connectors.

Harris selected Nano Dimension because the DragonFly 3D printer is designed to drastically reduce development time and cost, while enabling the fabrication of complex electronic systems that cannot be manufactured by conventional means. The printer uses conductive silver and dielectric inks tailored for use in 3D printed electronics. To assess the applicability of 3D printing for RF systems, Harris designed, simulated and tested a 3D printed RF amplifier and compared it with an amplifier fabricated using conventional manufacturing of a PCB using an FR4 substrate. Both the amplifier and antenna were designed using electromagnetic simulation software. Once the beam and radiation patterns of the antenna were simulated and set, the file was converted and uploaded to the DragonFly for 3D printing. The resulting circuit fabrication matched the original design nearly identically, demonstrating the expected functionality.

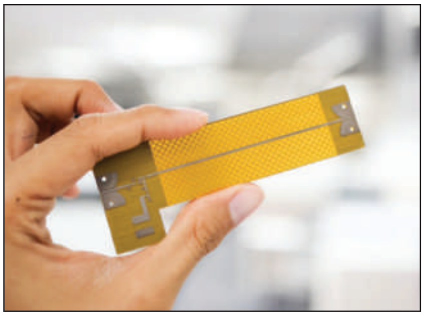
The RF amplifier (see ***Figure 3***) was built by Harris in a single print, with the fabrication taking about 10 hours using Nano Dimension's silver nanoparticle conductive and dielectric inks. Components were manually soldered to the PCB, which measured 101 mm × 38 mm × 3 mm. The traditionally manufactured circuits, in contrast, were sent to a prototyping facility to be manufactured, a process with cycle times that typically take days to weeks. The amplifier print-



▲ Fig. 1 DragonFly 3D printer.



▲ Fig. 2 Phytec touch sensor printed with the DragonFly 3D printer.



▲ Fig. 3 3D printed RF amplifier using the DragonFly Pro system.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ed using the DragonFly was designed for 2 GHz and performed close to the simulation out to 6 GHz. The frequency response was higher than anticipated and comparable to amplifiers fabricated on FR4 substrates using conventional PCB manufacturing steps.

TEST RESULTS

To assess the quality of the 3D printed RF circuit versus traditional PCBs, Harris measured small signal gain, input return loss and output return loss for each amplifier. Harris engineers determined the RF circuits printed with additive manufacturing performed the same as those fabricated using traditional methods, demonstrating the viability of 3D printing technology to produce functional RF circuits.

Figure 4 compares the gain of the 3D printed and conventional amplifiers, showing less than 1 dB difference to 4700 MHz and less than 1.3 dB to 6000 MHz. The lower gain with the 3D printed amplifier was attributed to higher losses in the dielectric and metal transmission lines. ***Figure 5*** compares the $|S_{11}|$ of the two prototypes, showing no material difference in the responses of the amplifiers from 10 MHz to 6000 MHz. Similarly, the $|S_{22}|$ of the two, shown in ***Figure 6***, reflects essentially the same responses over frequency. Harris presented these results and conclusions at the 2019 IEEE Radio & Wireless conference in Orlando.[1]

Given these performance results and the capability to rapidly and affordably manufacture prototypes, Harris plans to further develop 3D printing technology, including tests in actual field environments such as space. In addition to land-based reliability testing, hardware developed by Harris using the DragonFly will fly on the International Space Station, where it will be tested for communications capabilities with Harris' satellite tracking station in Florida. This project will provide a systematic analysis of 3D printed materials for space systems, which is especially applicable for nano-satellites.

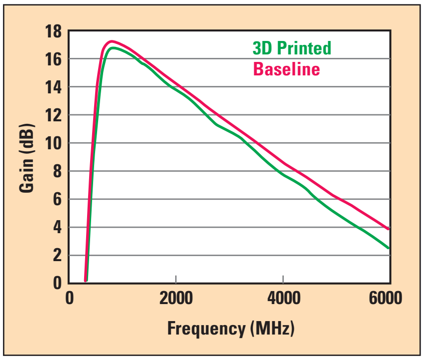


Fig. 4 Gain of the 3D printed and conventionally manufactured amplifiers.

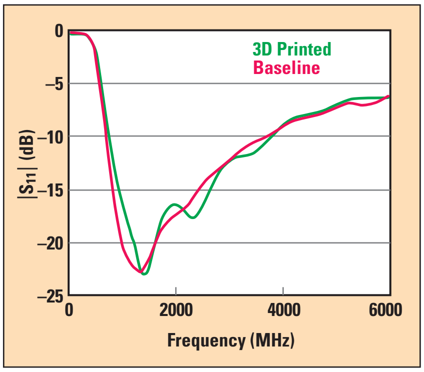
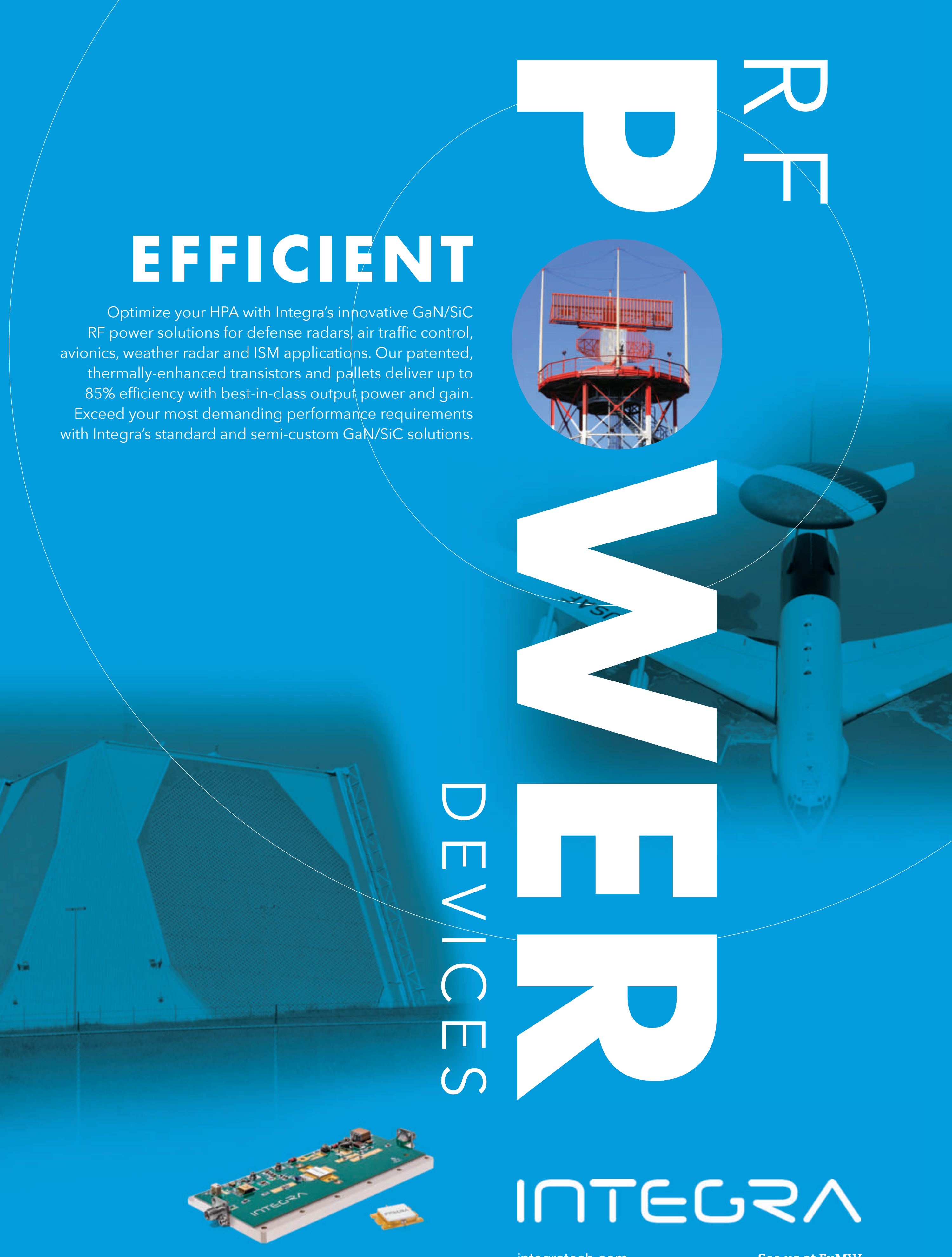


Fig. 5 $|S_{11}|$ of the 3D printed and conventionally manufactured amplifiers.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IMPLICATIONS FOR AEROSPACE AND DEFENSE

The results of this study are a significant milestone for the additive manufacturing of electronics in a variety of industries, including aerospace and defense. They demonstrate the viability of 3D printed electronics for RF circuits, showing the potential to play an important role advancing the small satellite and low Earth orbit (LEO) constellations. These satellites have many possible uses, from broadband internet access to IoT networks. 3D printing technology can play critical roles in nearly every aspect of research, design and manufacturing, offering significant advantages such as performance, rapid development and the ability to print complex shapes not achievable using traditional manufacturing processes.

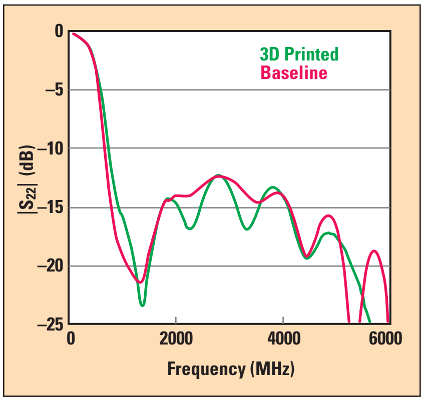
Harris and Nano Dimension plan to improve the high frequency performance of the 3D printed circuits, as well as fabricating more compact and denser circuitry. The capability to rethink circuit design—even considering flexible substrates and uniquely shaped circuits—is a major benefit of additive manufacturing, as it can create shapes not feasible using traditional fabrication.

SUMMARY

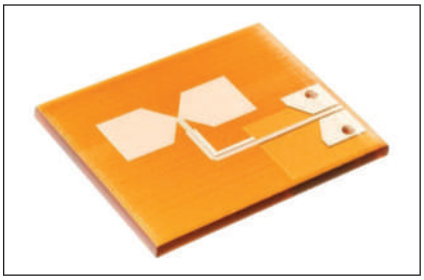
3D printed electronics offers a range of benefits: The capability to 3D print RF electronics and antennas in house significantly reduces the time and cost of prototyping and proving new concepts. Being able to 3D print antennas with similar performance to traditional antennas can be a catalyst for rapid advancements in radio communications (see ***Figure 7***). 3D printing enables even smaller and lighter antennas with rigid packaging integrated with flexible circuits, eliminating cables and connectors. Beyond reducing cost and cycle time and offering more flexible production, the capability reduces intellectual property risk.■

Reference

1. A. C. Paolella, "Directions in 3-D Printed RF Systems for Space Applications," *2019 IEEE Radio & Wireless Week*, Melbourne, Fla.



▲ Fig. 6 $|S_{22}|$ of the 3D printed and conventionally manufactured amplifiers.



▲ Fig. 7 Nano Dimension 3D printed 5G antenna.

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DC to 67 GHz GaAs MMIC Simplifies Broadband Designs

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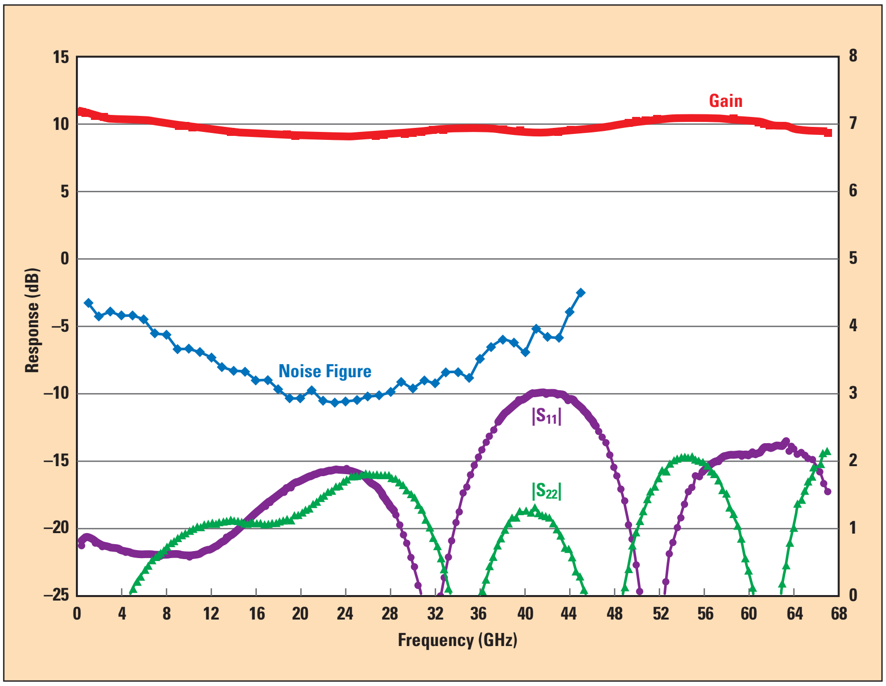

Fig. 1 Performance of the CMD304 at T = 25°C, with V_{dd} = 3 V and I_{dd} = 40 mA.

Broadband system designers are constantly pushing the envelope to get better performance, whether the design is a state-of-the-art microwave instrument or a robust electronic warfare (EW) system. The demand for consistently better performance across the required band makes the design task difficult, and the continued expansion of bandwidth only exacerbates the challenge. Not long ago, EW systems focused on DC to 20 GHz. Now, DC to 50 GHz—even higher—are becoming common. Instrumentation designers are challenged to enable the EW designers to test their designs, and the growth of mmWave 5G and 802.11ad add more markets challenging instrument capabilities.

Many microwave ICs have significant variation in performance over frequency, which is compounded by the operating voltage and temperature ranges. Variations in noise figure, gain, output power and linearity are all areas of focus for system designers, with the variation in gain over frequency often

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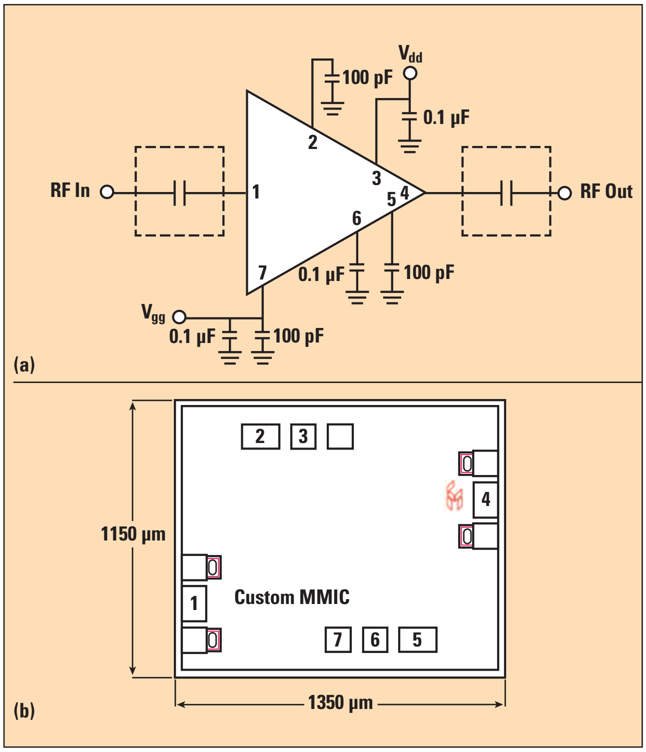
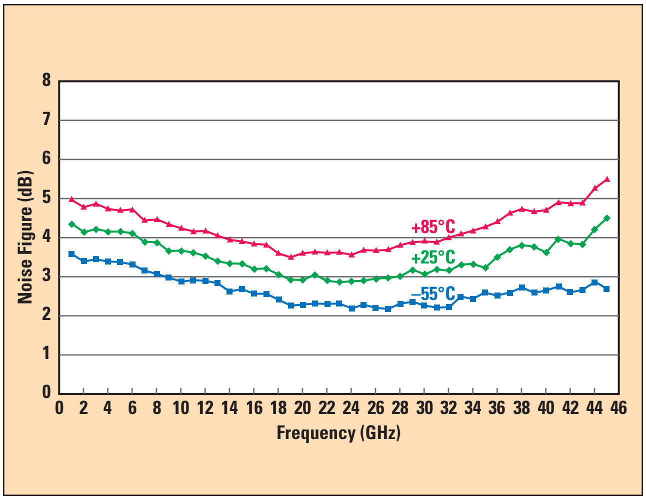


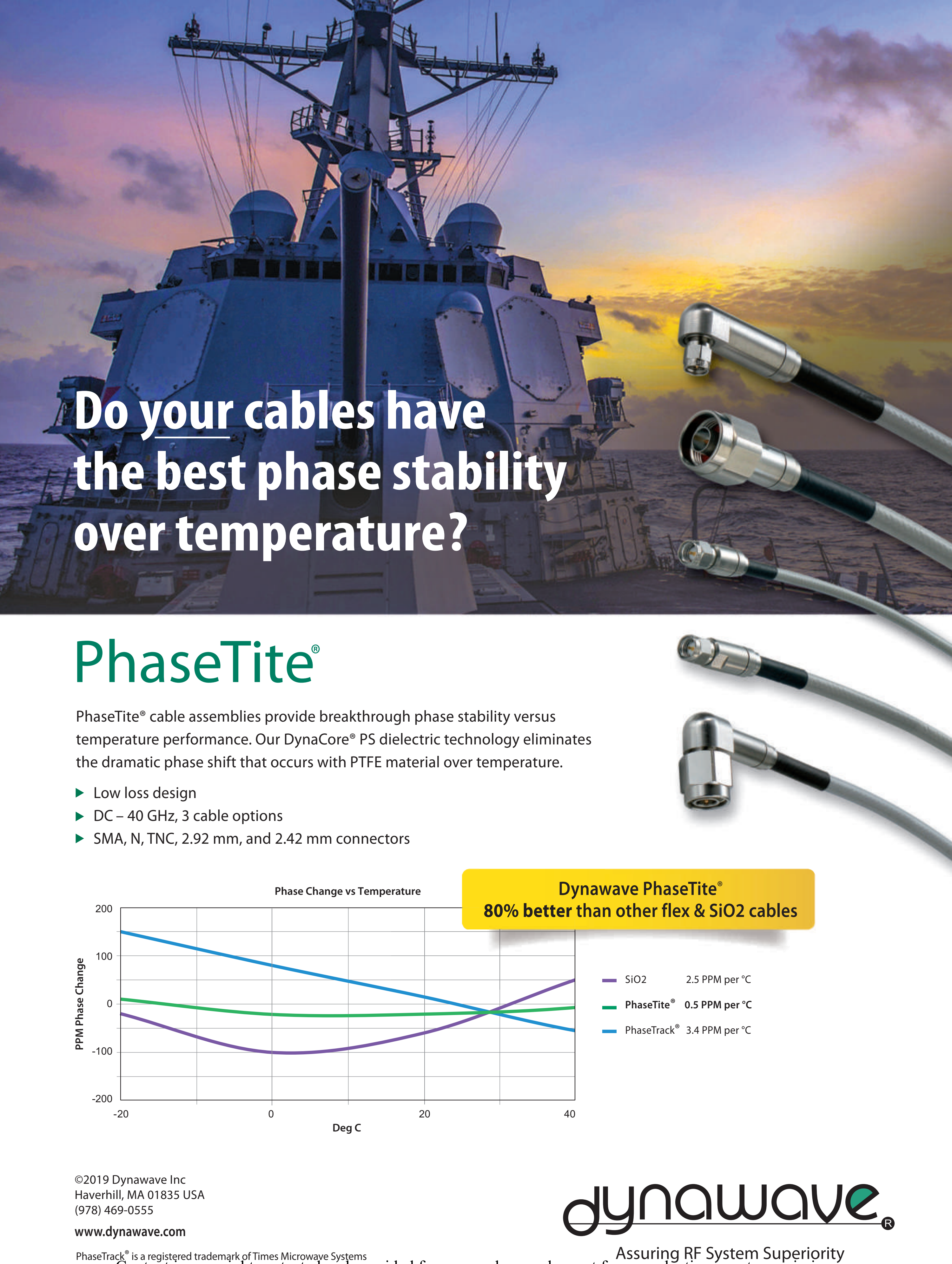
▲ Fig. 2 Using the CMD304 requires only a few external capacitors, keeping the amplifier's footprint small (a). Die layout (b).

the most challenging aspect of the design. The falloff in gain requires additional high frequency gain stages, with equalizers to maintain flatness. MMIC innovations have emerged to support these broadband requirements. Custom MMIC's GaAs amplifiers with attractive characteristics, such as flat or positive gain slope over a 30 GHz bandwidth, are examples. Now, the new > 50 GHz systems have pushed Custom MMIC's designers to further innovation, where achieving flat gain is the new requirement set by users.

To address this evolution, at the 2019 International Microwave Symposium, Custom MMIC introduced the CMD304



▲ Fig. 3 CMD304 noise figure vs. temperature. V_{dd} = 3 V.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DC to 67 GHz distributed driver amplifier to support the design of high performance, broadband systems. The amplifier features 9.5 dB gain and a 3 dB noise figure, with +11 dBm output power at 1 dB compression at 30 GHz. The GaAs MMIC is biased with a single positive 3 V supply, drawing a mere 40 mA. Importantly, the CMD304 has very flat gain characteristic across the full band (see ***Figure 1***), which eliminates the need for additional gain and equalization stages.

The single supply and simple layout of the CMD304 enables easy and cost-effective implementation in a system (see ***Figure 2***). The RF input and output are DC coupled, and the MMIC's performance is optimized down to DC. The CMD304 can be biased through an external bias tee at pin 4 or using the internal bias network at pin 3, which provides bias through an on-chip 50 Ω drain termination resistor. Using the internal bias network, as shown in Figure 2, provides the broadest performance, yet requires a 2 V higher bias voltage. Input and output coupling capacitors and bypass capacitors are the only external components used with the MMIC. The die size is 1.35 mm × 1.15 mm, yielding a compact footprint.

With its low noise figure, the CMD304 can be used at the receiver front-end for EW systems and test and measurement instruments. The room temperature noise figure is less than 5 dB from low frequency to at least 50 GHz (see ***Figure 3***). The noise figure above 50 GHz is being characterized, with the noise figure at 67 GHz expected to be under 7 dB. The noise figure over temperature falls within approximately ±1 dB (see Figure 3). Broadband designs that do not require the full 67 GHz bandwidth of the CMD304 will benefit from the MMIC's low noise figure up to 50 GHz—which is better than the noise figure of a 50 GHz distributed amplifier. This is because the noise figure of a distributed amplifier increases well below the high frequency cutoff, even though the gain and return losses remain flat. The CMD304 can also be used as a pre-driver at the output of an instrumentation signal source or in the chain of an EW jammer. The 1 dB compression point of +11 dBm is sufficient to drive the first stage of a power amplifier at these frequencies. This broadband amplifier can serve as a driver between the local oscillator and an up- or down-converting mixer.

The microwave industry remains robust. New systems and applications require improved capability to serve government, business and consumer users, challenging MMIC suppliers to continue meeting new requirements. Custom MMIC would not want it any other way.

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Simulating and testing multi-antenna systems such as phased arrays or beamforming antennas requires a test system capable of providing multiple signals with deterministic frequency and amplitude with stable, user-adjustable phase relationship among those signals. AnaPico's APMS multi-channel signal generators provide a well-designed solution for these applications, packing unique phase coherent signal features in a compact design. The APMS40G-ULN-PHS is a compact, four channel, 40 GHz signal generator that fulfills the demanding requirements for many new test applications cost-effectively.

TERMINOLOGY

When talking about signals and phase coherence, various terms are sometimes used interchangeably, although each term has a very specific meaning. Here are the important definitions used in this article.

Phase continuity and discontinuity—A signal is phase continuous if, after switching frequency, the phase of the signal is the same as before the switch occurred. If the phase changes after switching, the signal is phase discontinuous.

Phase coherence between two channels—If the phase relationship between two signals remains constant, the signals are considered to be phase coherent.

Phase coherent switching—Phase coherent switching defines the state of the signals' phase once frequency switching is complete. Two signals at frequency f and with relative phase ϕ are said to be phase coherently switched if the relative phase is again ϕ whenever they go back to frequency f.

Phase memory—A signal has phase memory if, when switched from frequency f_1 to frequency f_2 and back to frequency f_1, the signal's phase is the same as if it had run continuously at f_1.

Phase matched outputs — A multi-channel signal generator has phase matched signals if the outputs have 0 degree relative phase at all output frequencies.

APMS40G-ULN-PHS

AnaPico's APMS-ULN multi-channel synthesized signal generators are now available with frequency coverage to 40 GHz and with one to four channels in a compact 1U 19 in. rackmount enclosure. They provide tight stability, phase coherence and extremely fast tuning speeds, and each channel's frequency, phase, amplitude and modulation can be independently programmed. Other features include a compact design, excellent phase noise, high output power, accurately leveled output and simplicity of control.

The exceptionally low phase noise and high correlation of the independent channels yield outstanding phase coherence, both short- and long-term. The high stability synchronization circuit shared among all the channels of a single unit, with proprietary techniques for exact frequency synthesis, ensures little systematic phase drift between channels, even after hours or days of uninterrupted use. Some applications require more than four independent

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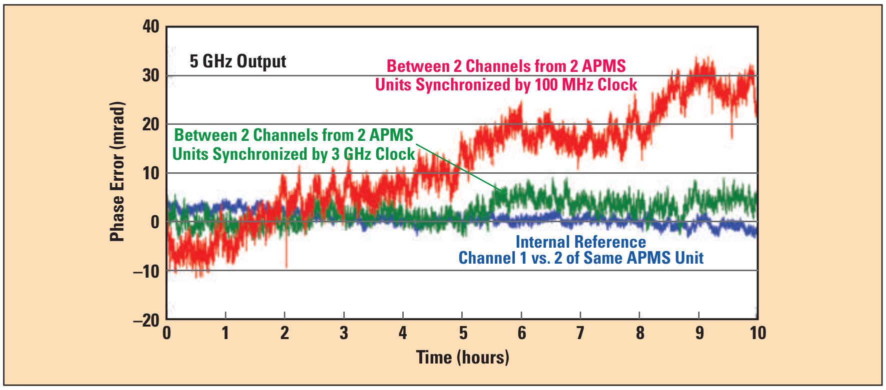
outputs maintaining phase stability over long time periods. The APMS-ULN offers a dedicated clock synchronization mode, using two ports on the rear panel to maintain phase coherence among a cascaded group of APMS-ULN sources. In this way, the unique features of the APMS can be scaled to virtually any number of channels.

To demonstrate the phase stability over time, ***Figure 1*** shows the measured phase difference between two 5 GHz output signals over 10 hours. The excellent phase stability between two individual channels of the APMS is shown by the blue trace. Similarly, the excellent stability when synchronizing two separate units is shown by the green trace. For comparison, phase locking two independent signal generators using an external, 100 MHz reference results in significant phase drift—several hundred milliradians—shown by the red trace. Synchronizing with a common 10 MHz reference yields even worse performance.



▲ Fig. 1 Phase stability measured over 10 hours.

In addition to the excellent channel-to-channel phase stability, the APMS supports both phase coherent switching and phase memory (see ***Figure 2***). Its channels can be synchronized to maintain a defined phase relationship at all times at any set frequency. As an example of phase coherent switching, consider two channels set to the same frequency f_1, with a phase offset of ϕ degrees. After switching both channels to any other frequency and then back to the initial frequency f_1, they will have the same phase offset ϕ. The APMS can also be programmed to phase match the outputs (ϕ = 0 degrees). Programming one channel does not affect the signal from the other channels; only the channel being programmed has a phase discontinuity. With phase memory, whenever a channel hops frequency, then goes back to a previous frequency, it behaves as if it had always been running at the first frequency. All these features can be extended beyond four channels by cascading and synchronizing multiple APMS units. ***Table 1*** summarizes the key specifications of the APMS40G.

AnaPico's APMS multi-channel signal generators support the requirements of a wide range of applications, such as testing phased arrays, beamforming antennas, satellite payloads and the implementation of quantum computing. With a unique design, the signal generators provide outstanding channel-to-channel phase coherence and are scalable to virtually any number of channels. The PHS option adds phase coherent switching, phase memory and phase matching features.

TABLE 1

APMS40G SPECIFICATIONS

Parameter	Min	Typical	Max	Note
Frequency Range	300 kHz		40 GHz	
Frequency Resolution		< 1 mHz		
Phase Resolution		0.1°		
Output Power Range	–30 dBm –50 dBm		+25 dBm +23 dBm	Option PE4
Output Power Resolution		0.01 dB		
Output Power Accuracy			< 1 dB	
Switching Speed			500 µs 25 µs	Option FS
SSB Phase Noise at 10 GHz	–80 dBc/Hz –100 dBc/Hz –112 dBc/Hz –128 dBc/Hz			10 Hz Offset 10 Hz Offset Option LN 1 kHz Offset 100 kHz Offset
Modulation	Pulse, Phase and Amplitude			Option Mod

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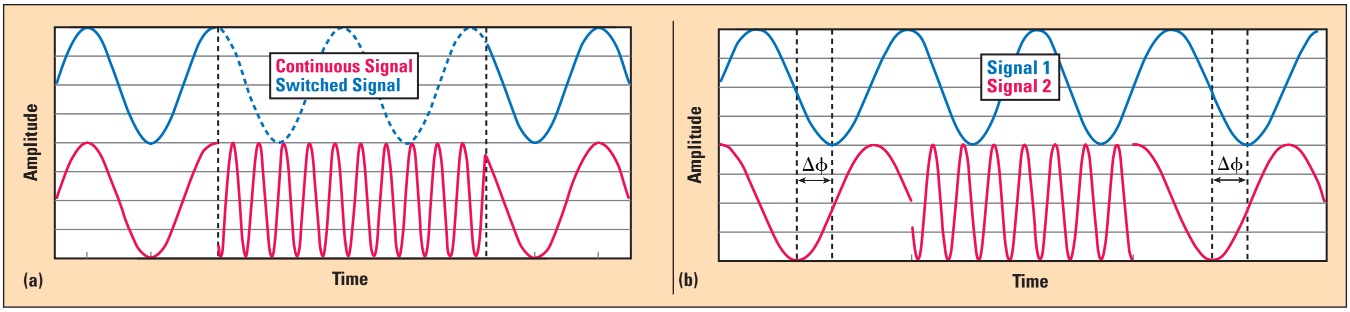

▲ Fig. 2 The signal generator has phase coherent switching (a) and phase memory (b).

Low-Cost 6 GHz Vector Signal Generator

Signal Hound has introduced a new 50 MHz to 6 GHz vector signal generator, model VSG60A, that offers the performance and agility of a serious vector signal generator at a fraction of the cost. A low phase noise, agile local oscillator with a 200 μs switching time enables frequency hopping spread spectrum testing, and a dual 14-bit DAC runs at 2 or 3× the I/Q symbol rate using digital oversampling to provide a flat, clean baseband. This results in baseband flatness of ±0.25 dB for 20 MHz and ±0.5 dB for 40 MHz (typical). Output power ranges from +10 to –55 dBm.

The VSG60A 6 GHz vector signal generator has 40 MHz streaming modulation bandwidth. It includes a variety of pre-programmed modulation types including Wi-Fi, QAM, PSK, CW, Pulse, Multi-tone and many more. Error vector magnitude is typically 0.3 percent (1 GHz carrier, 1 MSPS, 16-QAM, Alpha of 0.35, raised cosine) and typical phase noise is –114 dBc/Hz at 1 kHz offset and –135 dBc/Hz at 1 MHz offset.

A digitally adjustable internal VCTCXO ensures frequency errors are kept to a minimum over temperature, or an external 10 MHz input may be used for 0 ppm frequency error. Stability over temperature is ±0.28 ppm and aging is less than 1 ppm/year (typical). A trigger output is available to synchronize the VSG60A with other test equipment.

A custom API is available to continuously stream I/Q data to the VSG60A at an arbitrary sample rate up to 51.2 MSPS, or use the software to load a CSV, binary short int or binary floating point I/Q file. Corrections are automatically applied as the data is streamed to the instrument.

At a price of under $2,500, this VSG offers excellent value and rivals the performance of much more expensive instruments.

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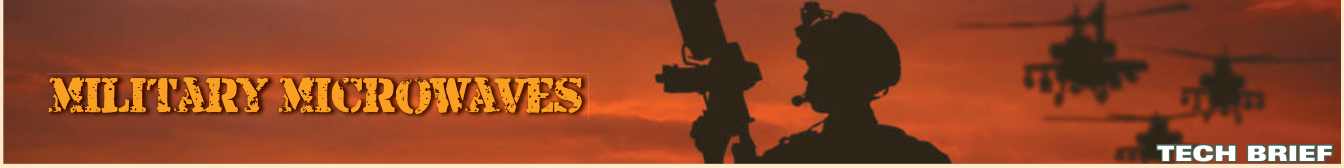

High-Reliability Amplifiers for Aerospace and Defense

Skyworks Solutions recently introduced its latest portfolio of high-reliability solutions for demanding military and space applications with stringent operating requirements. Skyworks' broadband low-noise and impedance-matched amplifiers function in harsh environments and can be leveraged in a multitude of communication platforms. With all peripheral components integrated into an optimized ceramic QFN package, these devices simplify the design process and reduce board space, while delivering robust performance for next-generation aerospace and defense applications such as satellites and avionics systems.

Skyworks provides upscreened and hermetically sealed high-reliability optocouplers, RF diodes and RFICs including multi-chip modules (MCM) as part of its portfolio. Product upscreening includes the equivalent of Class B and Class S of MIL-PRF-38535, Class H and Class K of MILPRF-38534, and JANS, JANTX and JANTXV level of MIL-PRF-19500.

SOME OF THEIR NEWEST SOLUTIONS INCLUDE:

- SKYH22001—a hermetically sealed, integrated broadband low-noise amplifier with –55°C to +125°C performance. Internally tuned for 700 MHz to 2.7 GHz and tunable up to 3.8 GHz, it has a typical low noise figure of 1.2 dB with high IP3 performance over voltage.
- SKYH22002—a hermetically sealed, integrated gain block amplifier with –55°C to +125°C performance. It is internally tuned for 700 MHz to 2.7 GHz and tunable from 0.1 to 6 GHz, it has a typical small signal gain of 20 dB at 2 GHz and a typical high OIP3 of 34 dBm.

Skyworks also offers a variety of RF diodes including Schottky for detection and mixing, Varactors for tuning and phase shifting, PIN for switching and attenuation and Limiter for receiver protection applications.

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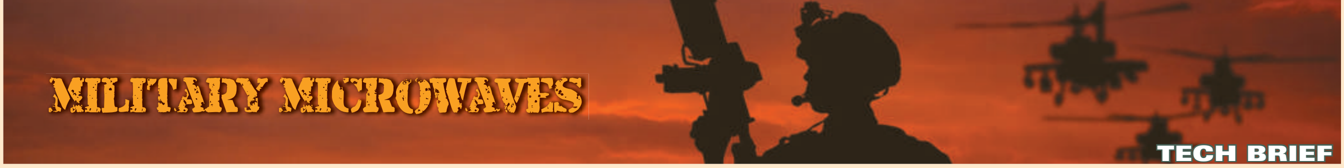

Pre-Configured Core Test Sets

In-Phase Technologies has introduced several new Core Test Sets, the first commercial test sets of this type available to the high frequency ATE market. Analog and digital test systems are already embracing the new concept of Core Test Sets that save money through their ease of configurability, and now the RF and microwave ATE community can do the same. The Core Test Sets provide a pre-engineered, integrated hardware framework to build a unique test set, and includes:

- Set of COTS test equipment in an enclosure, with power and wire management systems, proper air flow and coiling
- High density interface with pre-defined signal points
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With In-Phase Technologies' pre-configured Core Test Sets, test engineers can cut test set development time in half. They also save on development time, manufacturing and documentation costs. In-Phase assures total system signal integrity among all pre-configured building blocks.

THE NEW CORE TEST SETS INCLUDE:

- Analog/Digital Core Test Set tests avionics products, power supplies, LCR measurements, low frequency boards (< 1 GHz), electronic loads, etc.
- Full Transceiver Core Test Set tests digital or analog radios, radars, altimeters, frequency translators and components
- Amplifier Core Test Set tests high-power amplifiers, low noise amplifiers, medium power amplifiers, frequency translators and components
- Transmitter Core Test Set tests all types of transmitters from analog to digital modulation
- Receiver Core Test Set tests all types of receivers, including analog and digital modulation.

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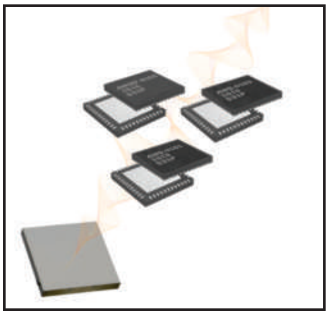

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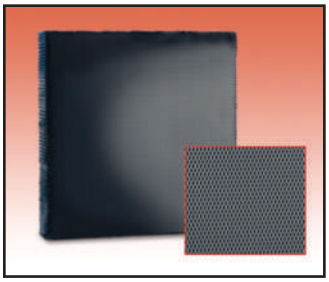

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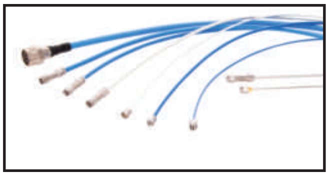
www.custommmic.com/cmd285c3-voltage-variable-attenuator/

NEW 40 GHz ARCTITE®

The ArcTite® series of cable assemblies is now available from DC to 40 GHz and provides ultra-low profile bends without the need for supplemental strain relief boots. Innovative connector designs conform to the MIL-STD-348 interface specification and utilize a 360 degree internal solder termination for high-reliability and enhanced shielding effectiveness. They are ideal for high density, internal module connections and provide a cost effective, higher performance alternative to SMA right angle connectors. They replace standard 0.086 and 0.141 custom semi-rigid cables eliminating the need for complex, pre-defined bends. Available in standard lengths and as hybrid assemblies.

Dynawave
www.dynawave.com/



PHASE-STABLE CABLE ASSEMBLIES

VENDORVIEW

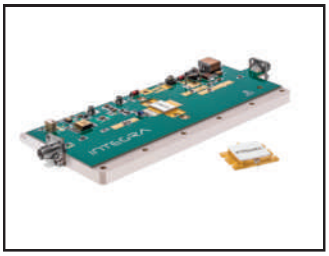
Opening a new door for phase critical applications in fluctuating temperatures, a steady and reliable interconnect solution to satisfy a huge range of applications where phase stability is key has been created—HUBER+SUHNER CT product family. Along with the industry-leading phase vs. temperature performance, as well as a unique range of cable constructions to fulfill any customer demands, HUBER+SUHNER CT cables and assemblies meet all requirements in aerospace & defense, test & measurement and industrial environments.

HUBER+SUHNER
www.hubersuhner.com/products/radio-frequency/assemblies/phase-invariant-cable-assemblies

HIGH-POWER PRODUCTS

To support emerging high-power requirements in both military and industrial applications at 13.56 MHz, 900 MHz and 2.45 GHz; IW's 4806 and 7506SP provide a flexible, low loss/phase stable alternative to solid wall cables and waveguide. Using Expanded PTFE dielectric for extremely low loss and greater heat dissipation, 4806 has been demonstrated to out-perform other manufacturer's products at equivalent line sizes. Customer testing has proven 4806 capable of handling 17 KW and 7506SP handling 30 KW at 13.56 MHz. Connector options include 7/16 DIN, LC, SC, C and 7/8, 1 5/8 and 3 1/8 EIA flange available.

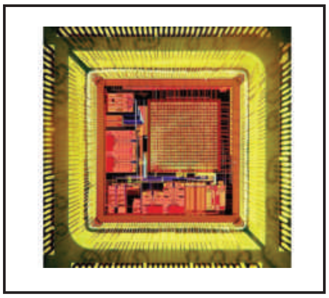
Insulated Wire Inc.
www.iw-microwave.com



X-BAND POWER SOLUTIONS

Integra Technologies Inc., a provider of RF and microwave power semiconductor and pallet solutions for state-of-the-art radar, EW and advanced communications systems, launched a new family of X-Band power solutions designed to meet the demanding needs of modern X-Band radar systems: higher sensitivity, improved resolution, superior detection and smaller form factor. Integra offers a full selection of the most advanced high-power GaN/SiC RF power solutions including standard, semi-custom and custom 50 Ω RF power transistors and modules for UHF through X-Band applications.

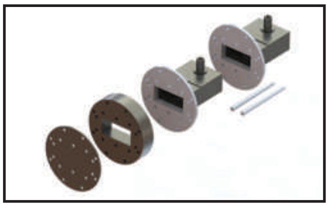
Integra Technologies Inc.
www.integratech.com



NEW ERA OF DIGITAL BEAMFORMING ANTENNA SYSTEMS

IQ-Analog's Antenna Processing Units (APU) bring digital processing advantages closer to the antenna and promise to revolutionize military communications, radar and EW systems with all new digital beamforming capabilities. Secure communications over wider and higher bandwidths in an increasingly complex spectrum environment is driving the need for software defined radios leveraging digital beamforming. Their state-of-the-art antenna processors offer Full Spectrum Conversion™ capabilities which enable limitless flexibility for software defined radios.

IQ-Analog
www.iqanalog.com



CALIBRATION KITS

MEGA Industries offers a complete line of precision calibration kits compatible with Vector Network Analyzer systems. Traditional, Short-Short Load (SSL) style calibration kits utilize three impedance standards and one transmission standard to create a full two-port calibration. Also offered by MEGA is the Thru Reflect Line (TRL) two-port calibration kit, utilizes three standards to define the calibrated reference plane. Both style calibration kits are available in various sizes from WR28 through WR2300. All kits include ultra-high performance waveguide to coax transitions.

MEGA Industries
www.megaind.com

A11/B10 SERIES CABLE ASSEMBLIES

MIcable A11/B10 series cable assemblies are specially designed for high-power, low loss, high shielding effectiveness applications. The maximum CW power handling is up to 3340 W at 1 GHz and 910 W at 10 GHz for A11 and 455 W at 18 GHz for B10, as well as typical insertion loss is 0.100 dB/m at 1 GHz and 0.361 dB/m at 10 GHz for A11 and 0.66 dB/m at 18 GHz for B10. They all have the shielding effectiveness less than –95 dB. Connectors A11: N, SC and 7/16 type; B10: N, TNC and 7/16 type.

MIcable
www.micable.cn

NEW PRODUCT GUIDE

VENDORVIEW

Mini-Circuits released over 400 models in 2018, and the company continues to develop new products at a rapid clip. Stay up to date with the latest additions to the company's lineup. Highlights in the Q2 2019 New Product Guide include new MMIC amplifiers, couplers and equalizers, waveguide bandpass filters, ultra-wideband connectorized passives and more.

Mini-Circuits
www.minicircuits.com

The 2019 Defence, Security & Space Forum

At European Microwave Week

EuMA — Microwave Journal

Wednesday 2 October – Porte De Versailles, Paris, France – 08:30 to 18:30, Room N01

A one-day focused Forum addressing New Radio Architectures: The Evolution of Satellite Constellations.

Programme:

08:30 – 10:10 **EuRAD Opening Session**

10:10 – 10:40 **Coffee Break**

10:40 – 13:00 **Challenges in Satellite Constellations and Impact on Communications Technologies**

13:00 – 14:00 **Strategy Analytics Lunch & Learn Session**
Global Satellite Market Outlook
Asif Anwar, Strategy Analytics, UK

14:10 – 15:50 ***Microwave Journal* Industry Session**

This session offers a perspective on how industry is aiming to design, develop and test radio architectures and the challenges that need to be addressed to implement them. Various tradeoffs in radio architectures will be covered along with solid state technologies, phased arrays and packaging concerns.

Company presentations include:

- High Throughput Satellites – Test & Measurement Challenges for the Next Generation Communication Satellites – Tobias Willuhn, **Rohde & Schwarz**
- Advanced GaN and GaAs Technologies Providing RF Capabilities for Satellite Systems Greg Clark, **Qorvo**
- New Generation of GaN MMICs for SATCOM and Electronic Warfare from X- to Ka-Band Cédric Corrége, **OMMIC**

15:50 – 16:20 **Coffee Break**

16:20 – 18:00 **Round Table: Concepts, Technologies and Systems Addressing Ultra-High Capacity and Data Traffic for Future Wireless Communications**

18:00 – 18:30 **Cocktail Reception**
The opportunity to network and discuss informally the issues raised throughout the Forum.

Registration and Programme Updates

Registration fee is €20 for those who registered for a conference and €60 for those not registered for a conference.
As information is formalized, the Conference Special Events section of the EuMW website will be updated on a regular basis.

Register online at www.eumweek.com

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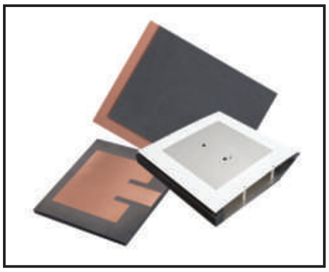


MAGTREX® HIGH IMPEDANCE LAMINATES

VENDORVIEW

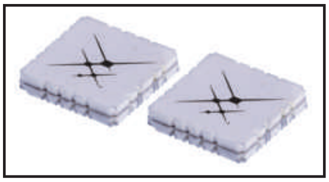
MAGTREX® 555 High Impedance Laminates are engineered PTFE composites intended for use at frequencies up to 500 MHz, primarily in antenna applications where they allow for substrate impedance match to free space. These laminates offer a miniaturization factor comparable to a material with a dielectric constant of 30, with an intrinsic impedance comparable to a material with dielectric constant of one. Designers now have the ability to produce electrically small antennas with bandwidth and efficiencies not previously possible.

Rogers Corp.
www.rogerscorp.com

LATEST SIGNAL GENERATOR

The VSG60A is an affordable and agile streaming vector signal generator capable of frequencies up to 6 GHz. Featuring a low phase noise local oscillator with 200 μs switch time, the VSG60A is ideal for frequency-hopping spread spectrum testing. Capable of continuously streaming waveforms of virtually any size from your PC or laptop—including arbitrary I/Q sample rates from 12.5 kSPS to 51.2 MSPS—the VSG60A offers an unrivaled value at $2,350.

Signal Hound
https://signalhound.com/test-equipment/vsg60a/



HIGH-RELIABILITY SOLUTIONS

VENDORVIEW

Skyworks recently announced new high-reliability solutions for demanding military and space applications with stringent operating requirements. These hermetically-sealed, broadband low-noise and impedance-matched amplifiers (SKYH22001 and SKYH22002) function in harsh environments and can be leveraged in a multitude of communication platforms. With all peripheral components integrated into an optimized ceramic QFN package, these devices simplify the design process and reduce board space while delivering robust performance for next-generation aerospace and defense applications such as satellites and avionics systems.

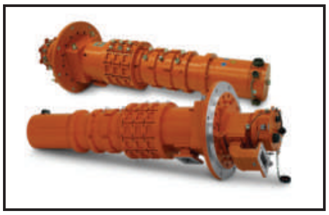
Skyworks Solutions Inc.
www.skyworksinc.com/Products/1186/LNAs_for_Radar_Applications_

2019 MULTIPORT HANDBOOK

VENDORVIEW

The new Handbook shows, at 126 pages, in detail the solution of using multipin connectors. They are available in circular and rectangular shells of different sizes with 4, 7, 8, 9, 10, 12, 19, 23 or 37 coaxial inserts, terminating the coaxial cable assemblies at the multipin end, connecting all the coaxial cable assemblies at once and in seconds with no need of a torque wrench, no need for safety wires and using only minimum space.

Spectrum Elektrotechnik GmbH
www.spectrum-et.com



NEW ATC ROTARY JOINT FAMILY

A new family of ATC rotary joints from SPINNER delivers superior performance, greater reliability and longer service. These products can be supplied as required with either contactless power modules for up to 300 W or conventional slip rings. An added benefit is that they are plug-and-play solutions, which dramatically reduces downtimes for maintenance: it takes only 10 minutes to replace the slip ring without the need to remove the entire rotary joint from the platform, thus increasing total on-air time.

SPINNER
www.spinner-group.com

NEW CLARITY SERIES

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

Times Microwave Systems
www.timesmicrowave.com

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