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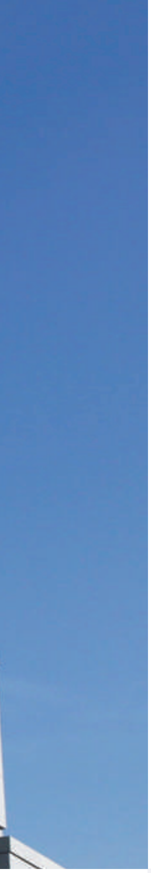

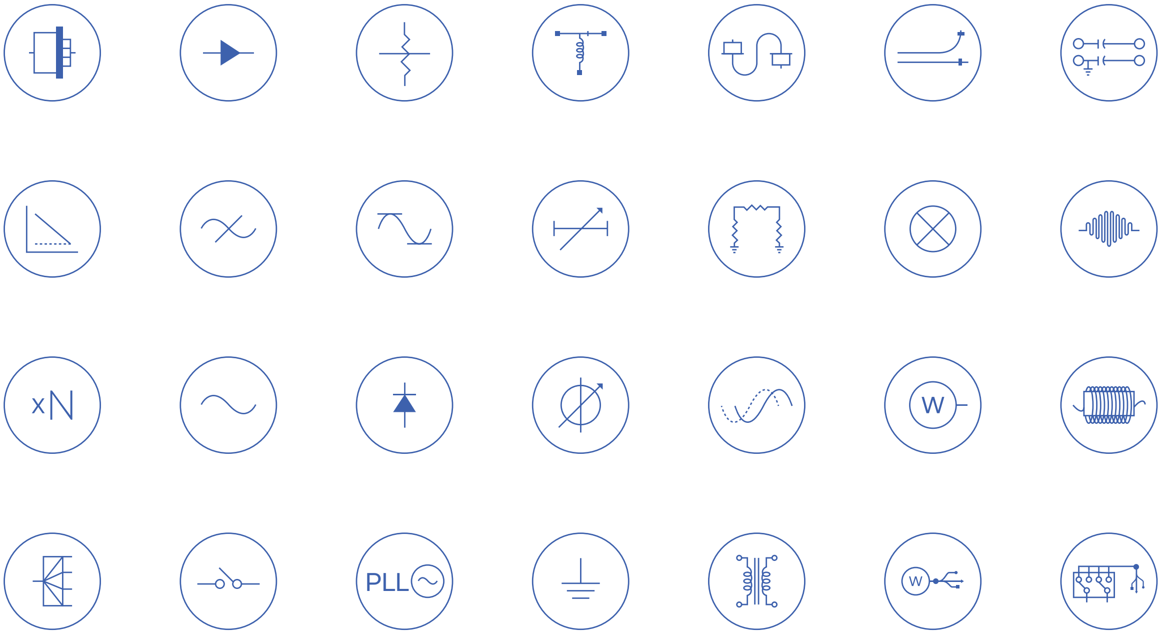

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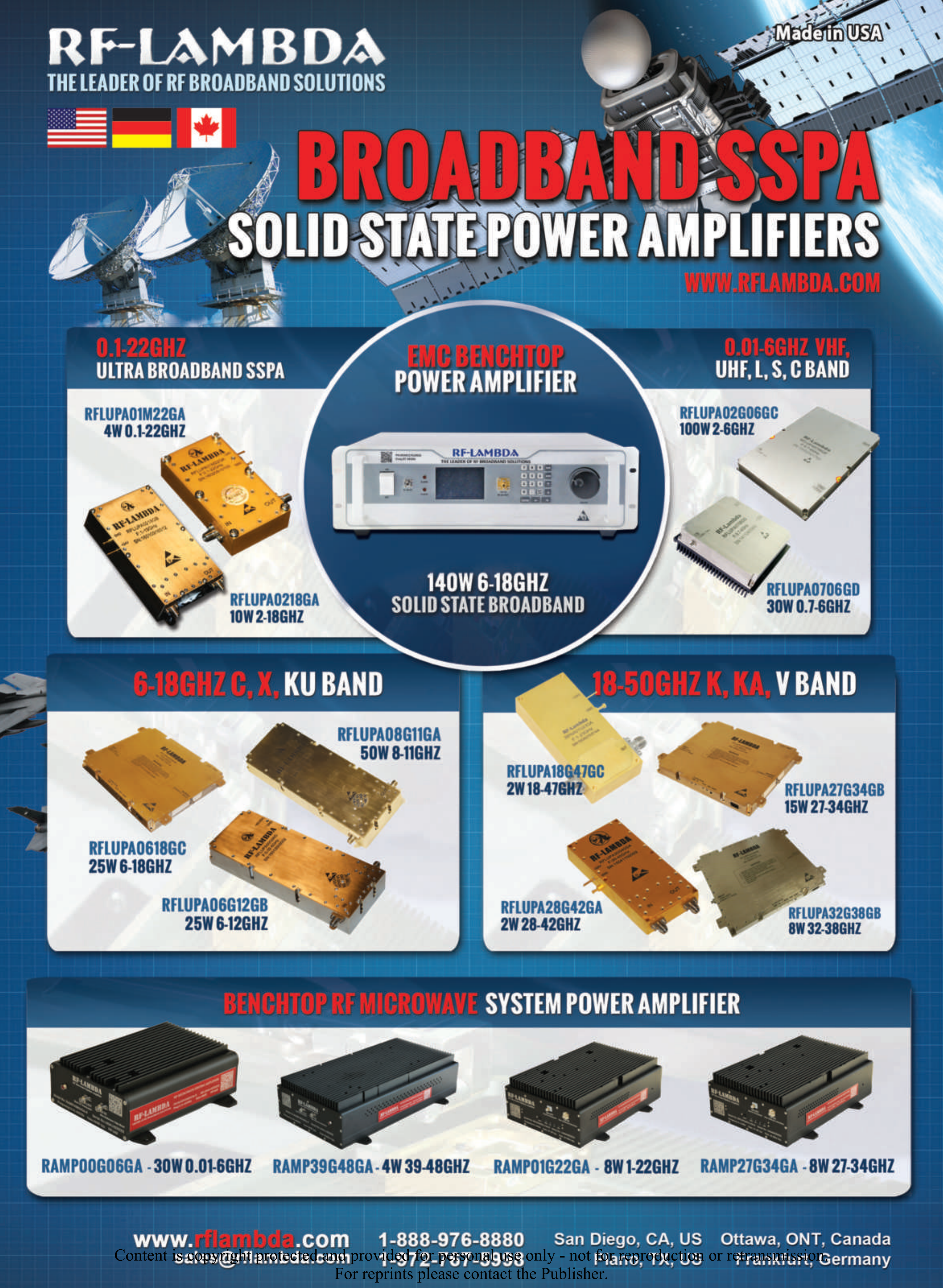
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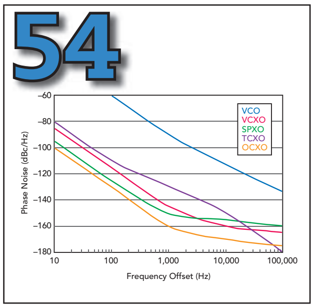

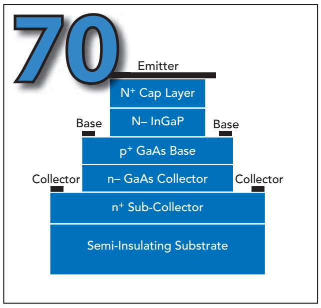

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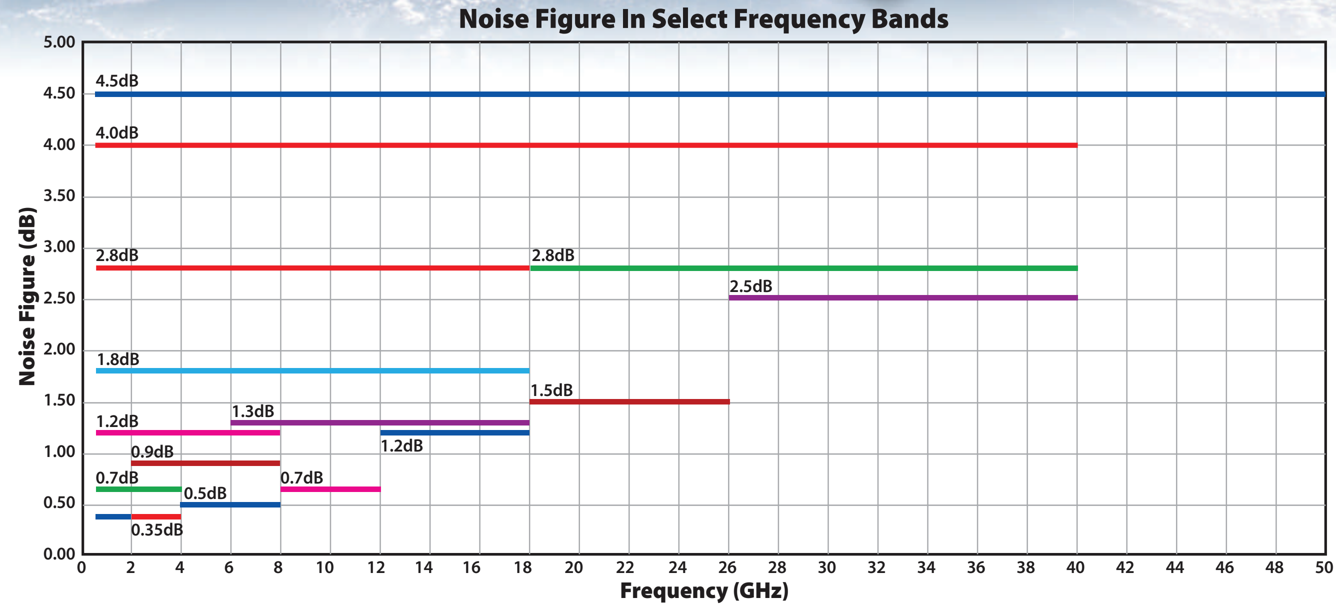

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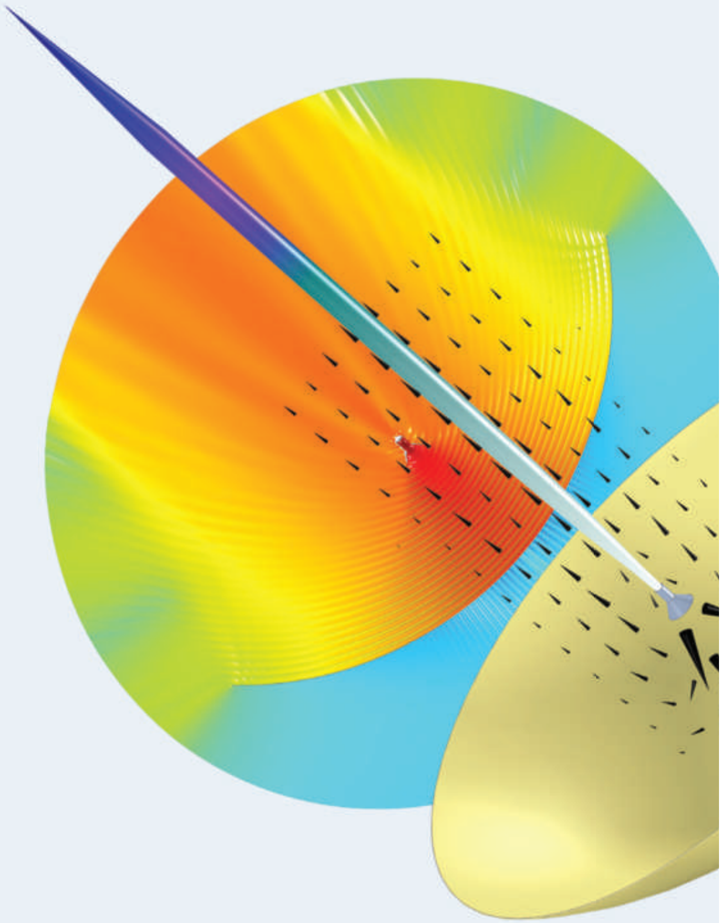

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E-Band mmWave Technology for HAPS and LEO Satellite Systems

Mike Geen
Filtronic, U.K.

Along with low earth orbit (LEO) satellite constellations, high-altitude platform station (HAPS) systems—or high-altitude pseudo-satellites—operating in the stratosphere, have the potential to address the challenge of providing ubiquitous connectivity. Although there has been great progress in rolling out high speed mobile networks to serve major centers of population, terrestrial connections will never realistically cover every part of earth's surface. To deliver the full promise of 5G and address the 'digital divide,' it is essential to provide coverage to low population areas where terrestrial mobile networks are not viable. This will be particularly important not only for improving personal communications, but also because many Internet of Things (IoT) sensors will need to be in these regions. This article gives an overview of the role of HAPS and satellites in forming "networks in the sky" and describes some of the RF challenges in designing the high data rate (10 Gbps-plus) communication links needed to backhaul data between earth and the satellite or HAPS, and between the platforms themselves.

CURRENT LANDSCAPE

Successive generations of mobile communications technologies have been effective in covering the most highly populated areas of the world, and modern life has come to depend on this ubiquitous connectivity. Mobile network operators in most developed countries have worked hard to meet their targets of connecting typically around 98 percent of the population in terms of where they live. However, the 5G goal of being able to connect everything—wherever it is on the planet—remains elusive for terrestrial mobile systems. A 'digital divide' has been created between populations who have a broadband connection, whether fixed or mobile, at an acceptable speed and those who do not. The FCC currently defines this benchmark as 25 Mbps, which

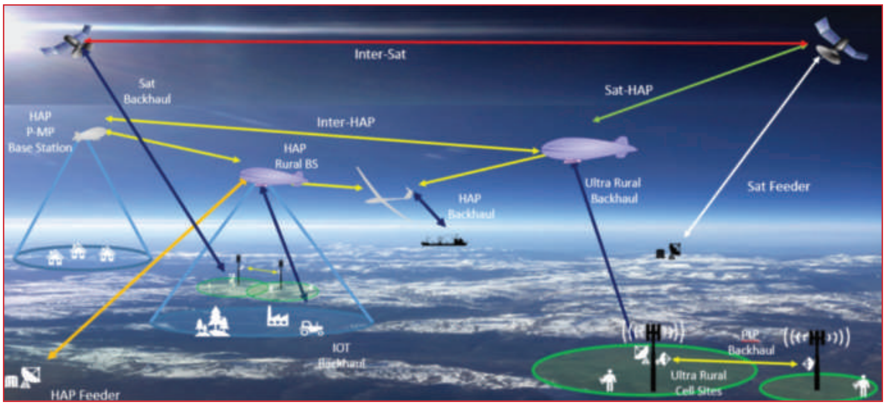

Fig. 1 Converged network of terrestrial mobile broadband and IoT services with HAPS and LEO satellites.

places some rural parts of the U.S. on the wrong side of the divide. Furthermore, mobile platforms such as aircraft and ships, along with many IoT devices located in isolated areas, will most likely fall outside the range of terrestrial 5G telecommunications systems.

This ambition to connect everyone and everything, wherever they are located, therefore cannot be fulfilled by ground-based communication networks alone. Therefore HAPS, operating in the stratosphere at an altitude of around 20 km, along with constellations of LEO satellites at an altitude of between 350 and 1,100 km, are beginning to be deployed to help address the challenge of providing ubiquitous connectivity. A HAPS station comprises an unmanned aerial vehicle —which may be either a gas-filled balloon, an airship structure or a fixed wing aircraft—and a payload that is essentially a moving 5G base station with onboard solar panels or fuel cells to provide power. As the technology evolves, we can expect to see non-terrestrial networks being converged with terrestrial infrastructure, as shown in ***Figure 1***. This introduces some interesting technical challenges in creating reliable links between each of the elements of these converged networks.

SPECTRUM ALLOCATIONS

As demand for broadband capacity from these space and airborne systems grows, additional spectrum will be needed to support it. The telecommunications industry has successfully lobbied for more spectrum for HAPS, and the allocation of new wider bands around 26 and 38 GHz was agreed to during the 2019 World Radio Conference. In addition, experimental licenses were granted for E-Band (71 to 86 GHz), supporting the growing interest. ***Figure 2*** summarizes the current and proposed bands, along with showing the geometry of the HAPS link to its ground station. There are commercial transceivers and high-power amplifiers available in these frequency ranges. Many have proven effective in XHaul (fronthaul, backhaul and midhaul) applications. Further development and qualification of these systems are exploited in the links that feed data between earth and the HAPS constellations.

While HAPS networks will mostly communicate directly with exist-

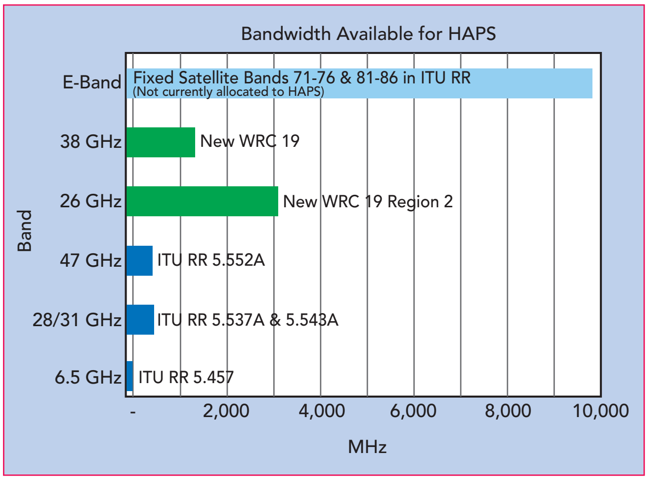

Fig. 2a Proposed bands for HAPS and LEO links (*Sources:* ITU RR and WRC-19).

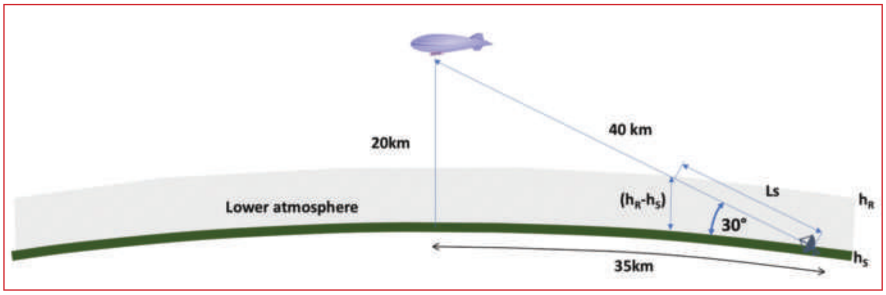

Fig. 2b Geometry of HAPS station and link to ground station.

ing mobile phones, LEO satellite constellations will also generate the need for huge numbers of new fixed consumer terminals. As a result, this will create a demand for high volumes of components operating at frequencies up to 55 GHz where production volumes are historically low. The increase in manufacturing volume presents a challenge not only for OEMs but also for test equipment manufacturers. Simultaneously, it also offers new opportunities for companies who design and manufacture mmWave components and subsystems.

INDUSTRY INITIATIVES

The HAPS Alliance was formed in February 2020 with the aim of creating an ecosystem to promote the use of high-altitude stratospheric vehicles to extend connectivity to more people and locations worldwide. The alliance is based on an earlier initiative by HAPSMobile (a joint venture between Softbank and AeroVironment) and Alphabet's Loon to work together to advance the use of HAPS.

In addition to these companies who are developing the high-altitude platforms themselves, the alliance now counts among its members: telecommunications providers, including AT&T, Bharti Airtel, China Telecom, Intelsat, T-Mobile and Telefónica; aviation and aerospace companies like Airbus Defense and Space and Raven; and technology providers, including Ericsson, Nokia and Filtronic.

Further evidence of the growing interest in HAPS technology has been demonstrated by the formation of a Non-Terrestrial Connectivity Solutions project group within the Telecom Infra Project, an engineering-focused collaboration sponsored by Facebook.

HAPS USE CASES

There are several use cases for which HAPS technology is uniquely well suited, mostly related to their potential for extending enhanced mobile broadband to areas that are difficult to reach or not served by terrestrial mobile for economic reasons. These can include mountainous terrain, remote islands, marine regions and developing countries. A further application is mobile cell connectivity for passengers on board vessels or aircraft, or hybrid connectivity to reach passengers on board public transport vehicles like high speed trains, buses or river boats. They can also deliver fixed wireless access for users in isolated villages or remote industrial premises that cannot be reached by fiber.

Yet another use case is to supplement the capacity of existing networks to meet accelerating demand, and to supply "instant infrastructure" in emergency situations or for disaster relief. This can ensure network resilience for critical network links that require high availability. They can be rapidly deployed to cover a footprint of approximately 100 to 140 km diameter, over any type of terrain, requiring only minimal ground infrastructure.

HAPS can potentially be used to rapidly deliver media and entertainment content in multicast mode to RAN equipment at the network edge, to reduce latency for 5G cellular users, or in Direct-To-Node broadcast, whereby TV or multimedia services are delivered direct to home premises or to users on board a moving platform.

Utilizing their capacity rather than bandwidth, HAPS can be exploited for Massive Machine Type communications, to communicate with both local area and wide area IoT services.

SATELLITE AND HAPS SYNERGY

While it may appear that HAPS and LEO satellites both perform the same function, they are complementary. LEOs move rapidly in orbit relative to the earth so are more difficult to coordinate but have a wider area coverage. HAPS, being closer to the earth's surface, are much easier and less costly to launch and deploy and give much lower latency. They feature "persistence"—the ability to remain stationary relative to the ground—and their transmissions are less affected by obstacles

Fig. 3 Loon HAPS (*Source:* Loon).

such as trees and buildings than terrestrial base stations. Unlike satellites, HAPS can be returned to earth for maintenance or payload re-configuration. They can quite literally be used as "base stations in the sky" providing additional capacity and wide cellular coverage in low density areas. They can also use the same frequency bands as terrestrial 3G, 4G or 5G networks, subject to regulatory approval, which means that the design of HAPS payloads should benefit from technology developments in 5G terrestrial base stations.

Experimental work with HAPS for communications relay has been taking place since the late 1960s,[1] but it is only since the growth of mobile Internet that their commercialization has accelerated. There are some differences between the two types of HAPS. For example, the solar-powered unmanned aircraft manufactured by AeroVironment and deployed by HAPSMobile are heavier than air and can only carry relatively small payloads. Another, fuel cell-powered fixed wing platforms, like those from Stratospheric Platforms, are emerging, which can carry much larger payloads. Finally, the airship-style platforms, along with the balloon platforms being used by Loon, are lighter than air and can usually carry a heavier payload as shown in ***Figure 3***. These airships have been deployed to extend mobile networks over some regions of Africa and South America. What the two styles of platforms have in common is the flexibility to be upgraded to newer technologies, and their multi-purpose capability, as they can be adapted for institutional, commercial communications or civil security applications. They are payload-agnostic and can readily be networked together and linked with other platforms.

HAPS LINK CHARACTERISTICS

Breaking the converged network down into its individual elements, the characteristics that will be required for each of the links between them can be examined. Rain attenuation is one of the key factors to consider. Looking more closely at the HAPS feeder link geometry in Figure 2, for a platform at 20 km of altitude, the footprint can reach 70 to 80 km in diameter, and the link length will typically be about 40 km at an elevation of 30 degrees. ***Figure 4*** shows the maximum rain attenuation per kilometer against frequency to permit 99.99 percent availability. For most of North America and Europe (Zone K), where rainfall is around 42 mm/hour, attenuation at 16 to 17 dB/km in E-Band is significantly higher than for the currently-used bands below 50 GHz. Nevertheless, as this service will be targeted at areas that have previously had no coverage at all, the demand for availability is likely to be lower than the 99.9 percent or 99.99 percent that is demanded of terrestrial networks, so some outage due to rain attenuation can be tolerated.

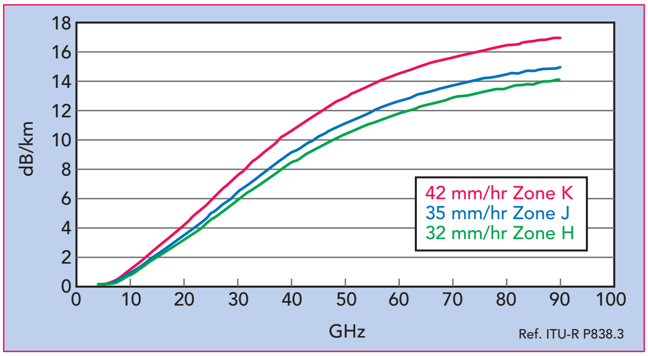

Fig. 4 Rain attenuation per kilometer versus frequency for different ITU rainfall zones.

Potential data rates for HAPS feeder links in the different frequency band allocations are shown in ***Table 1***, where they are compared for 256QAM and QPSK. Since antenna sizes are smaller at the higher fre-

quencies, fade margins at 48 and 86 GHz are similar for the same antenna size and channel bandwidth. It is also striking that the data rate of over 10 GB/s that is available at E-Band using 256QAM is substantially higher than for the lower bands, due to the higher available channel bandwidth. Even if forced to drop back to QPSK to improve the fade margin, 2.5 GB/s data rate can still be achieved. The key figures for comparison are highlighted. Availability could be improved by combining E-Band with either 31 or 39.5 GHz.

Figure 5 shows the formula for calculating the maximum distance between HAPS, showing the distances calculated for the different limitations. The distance normally used between HAPS is around 200 km. Rain and clouds have far less effect when the platforms are at this altitude, and the greatest limitation is the curvature of the earth's surface. ***Figure 6*** shows the transmitter power that would be required for inter-HAPS links in the different frequency bands, indicating that high-altitude atmospheric losses at E-Band are very similar to those in V-Band below 50 GHz. The higher antenna gain for a particular size helps to compensate for free space loss.

SATELLITE LINK LIMITATIONS

Performing a similar analysis of the limitations on the feeder links for LEO satellites, ***Figure 7*** shows the bands available and the geome-

TABLE 1

COMPARISON OF DATA RATES, RAIN PATH LENGTHS AND FADE MARGINS FOR HAPS LINKS IN DIFFERENT FREQUENCY BANDS

Modulation	Frequency Band (GHz)	31	39.5	48	E-Band	
					71 - 86	71 - 86
	Free space loss	154.4	156.5	158.2	162.2	162.2
	Channel bandwidth (MHz)	297	297	297	297	2000
256QAM	Data rate Mb/s	1520	1520	1520	1520	10240
	Minimum carrier - noise ratio (dB)	32.5	32.5	32.5	32.5	32.5
	Fade margin (dB)	38.6	37.8	35.6	33.6	25.3
	Maximum rain path length (km)	4.8	3.6	2.8	2.0	1.5
QPSK	Data rate Mb/s	380	380	380	380	2560
	Minimum carrier - noise ratio (dB)	13.5	13.5	13.5	13.5	13.5
	Fade margin (dB)	63.6	62.8	60.6	58.6	50.3
	Maximum rain path length (km)	8.0	6.0	4.8	3.6	3.0

Max Distance Between HAPS

Altitude	Cloud Limited	Rain Limited	Horizon Limited
18	505	815	959
20	598	875	1011
25	783	1011	1130

Typical inter HAP distance will be ~200 km.

$$d_{max} = 2\sqrt{(R+h)^2 - (R+c)^2}$$

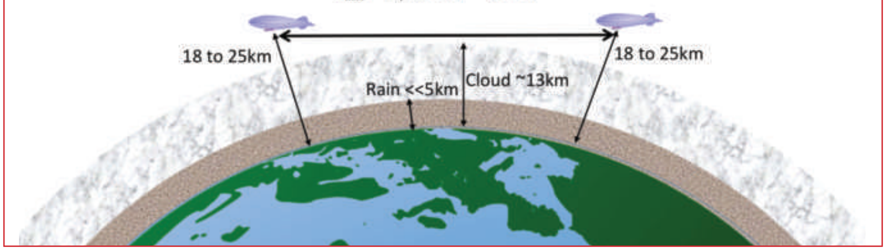

Fig. 5 Distance limitations for inter-HAPS links.


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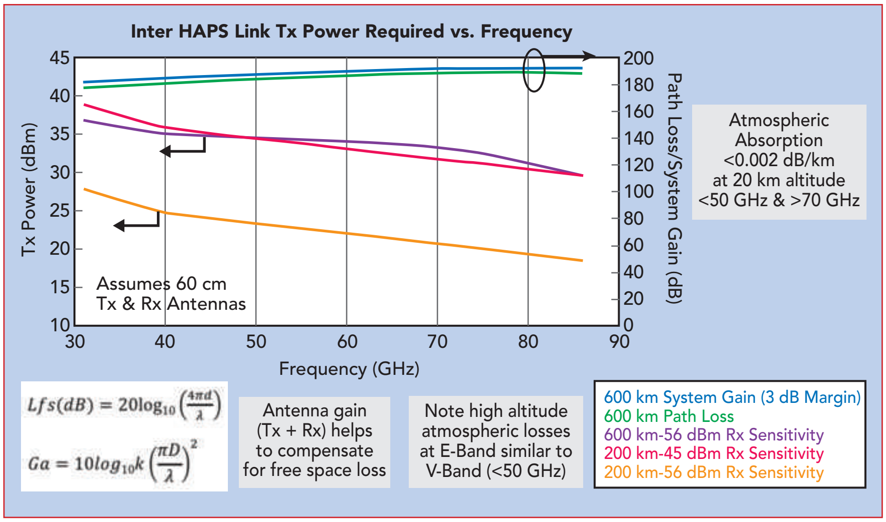


Fig. 6 Transmitter power requirements for inter-HAPS links.

try calculations involved. The orbits being used for SpaceX satellites are in the range of 350 to 1,100 km, and with an elevation of 35 degrees at the earth station this gives a link path length of between 600 and 1,700 km. Free space losses now become much more significant in comparison to atmospheric losses, as a higher proportion of the path is above the atmosphere. The free space loss is several tens of dB higher than the figures for HAPS feeder links—around 195 dB for a 1,700 km link length at 86 GHz.

When this is translated into system requirements, system gains between 180 and 200 dB are viable for mmWave satellite feed links in clear weather conditions, and this is achievable in E-Band with antenna gains of less than 58 dBi (equivalent to a 1 m parabolic antenna) and transmit powers less than +40 dBm. However, rain is a severe issue that can limit availability in both E-Band and V-Band, where increases in system gain of between 20 and 40 dB would be required to en-

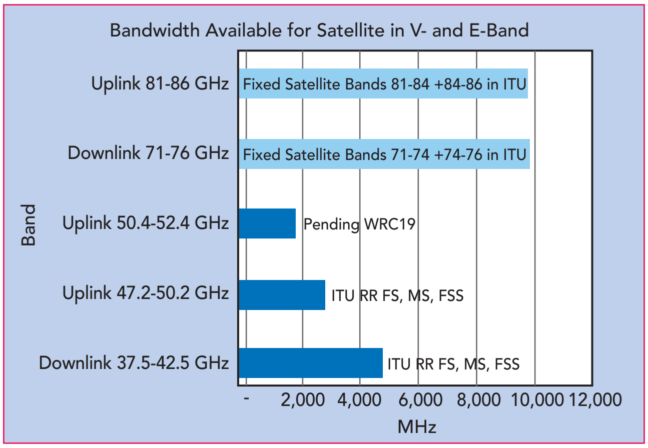


Fig. 7a LEO satellite feed link bands.

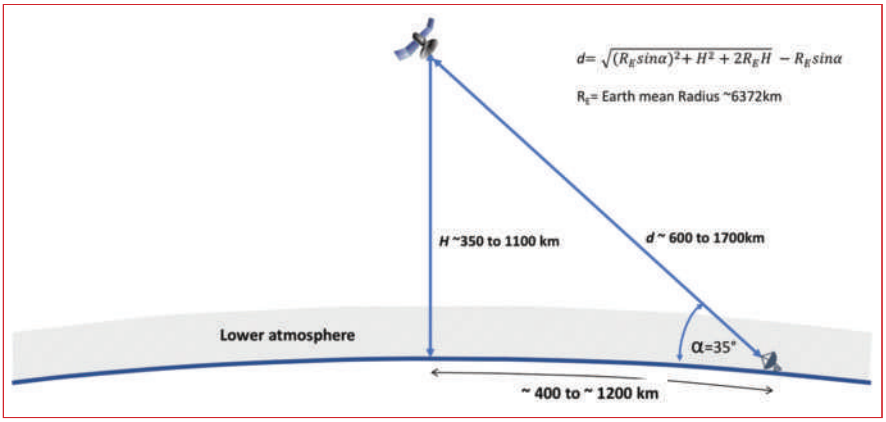
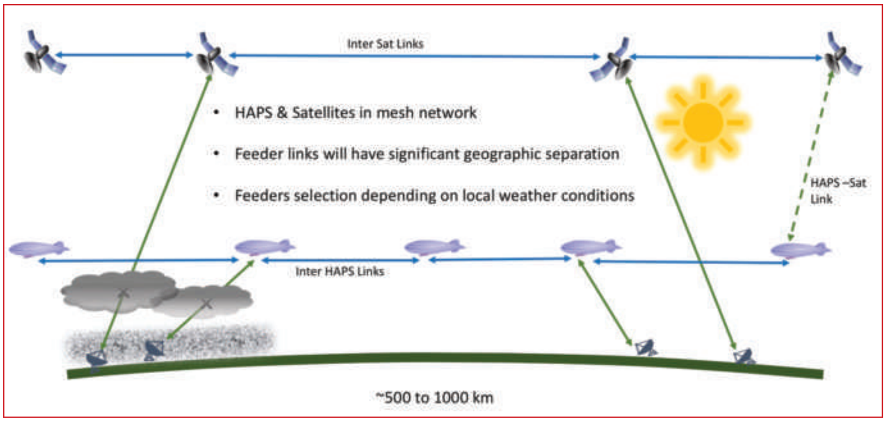


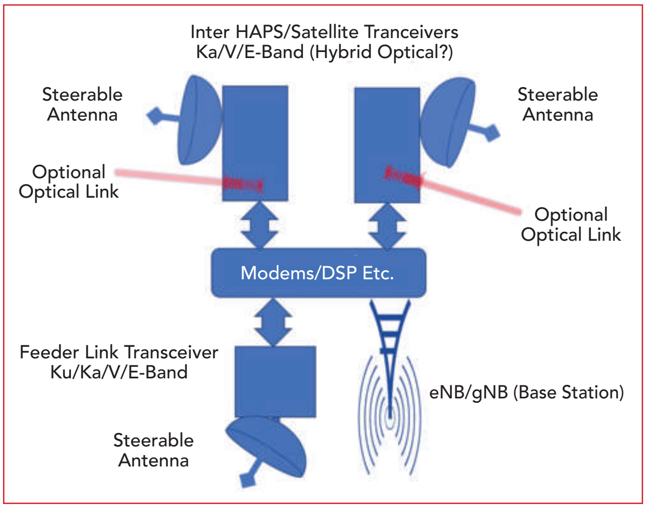
Fig. 7b LEO satellite geometry.



▲ Fig. 8 Mesh network combining HAPS and LEO satellites to avoid rain attenuation in feeder links.

sure acceptable availability. Inter-satellite links have no atmospheric limitations and fewer horizon issues, so LEOs can be many hundreds of kilometers apart.

Avoiding rain attenuation in feeder links is possible by using a mesh network that combines HAPS and satellites to form a resilient network, as shown in ***Figure 8***. Thus, if a platform in a certain area is subject to rain attenuation, then the signal can be routed using software-defined networking technology via a different path to avoid the region that is affected by the storm.



▲ Fig. 9 HAPS/satellite payload.

MMIC TECHNOLOGY AND ACTIVE ANTENNAS

Although many power amplifier technologies at microwave frequencies now use GaN technology for better efficiency and higher power, it is rare to find GaN devices that work in V- or E-Band. Some experimental GaN devices have shown promising results up to around 100 GHz, but have not been commercialized yet, and it is challenging to find commercially available GaN devices above 40 GHz. Also, although SiGe and CMOS devices can work at the higher frequencies, their power levels are low, and many more elements would be needed to reach the required EIRP of around +60 dBm.

While phased array and active antenna technology has proved effective at increasing the gain and EIRP of antennas, as well as providing beam-steering, as the frequency increases the half-wavelength dimension becomes smaller and they become difficult to fabricate. Increasing the number of elements also increases power consumption, so using high-power GaAs devices with fewer elements has become the optimum solution for E-Band links.

E-BAND TRANSCEIVER TECHNOLOGY

Figure 9 shows a typical payload for a satellite or HAPS. As well as the eNodeB (LTE) or gNodeB (5G) base station, there are transceivers for the inter-platform links and the ground link, meaning that each platform would require three links at Ka-, V- or E-Band.

Figure 10 shows a block diagram of the basic transceiver that is be-

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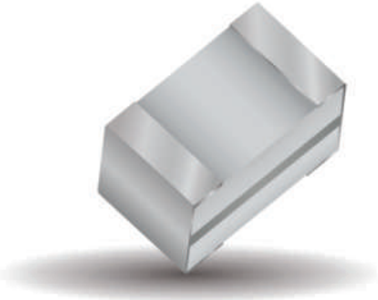

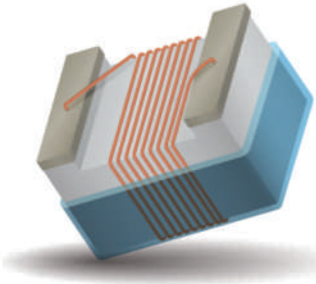

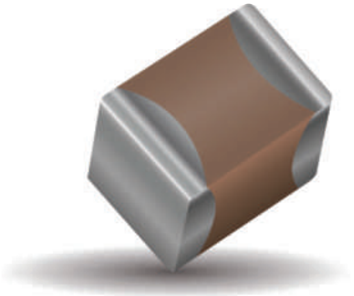

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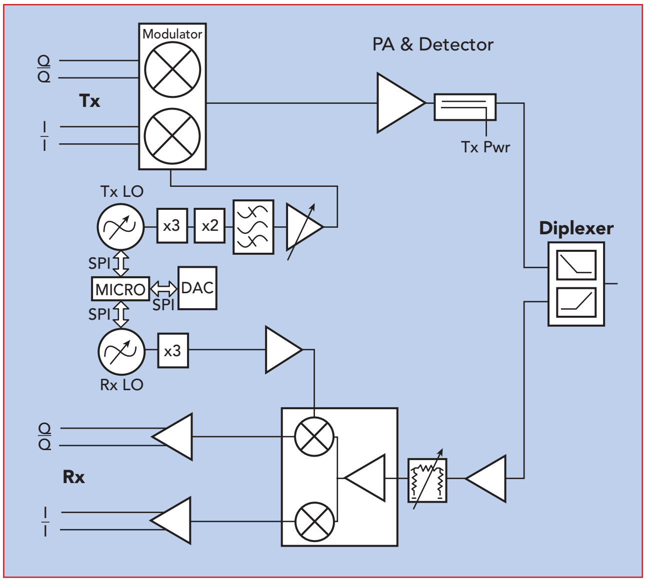

Fig. 10 Block diagram of basic E-Band transceiver.

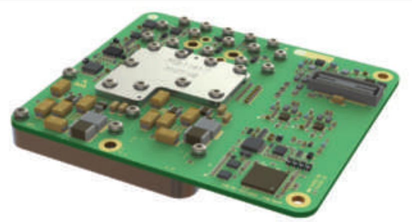

Fig. 11 Filtronic Morpheus II E-Band transceiver.

ing used for these E-Band links. It is fully integrated, for use in the 71 to 76 GHz and 81 to 86 GHz bands. It gives a highly linear transmitter output of more than 20 dBm and supports 256QAM modulation and above, along with a channel bandwidth more than 2 GHz. Phase noise is typically -112 dBc/Hz at 1 MHz. An integrated diplexer facilitates a single T/R port for the antenna interface, and there is also a single 50-way connector that supplies all communication between the module and the modem, as well as DC power, baseband data and control signals. A small, lightweight form factor is required, due to the number of elements to be accommodated and to optimize the overall weight of the payload. Morpheus II transceivers have a footprint of 90 × 80 mm and weigh only 110 g. For higher power levels, power combined amplifiers can be used—for example the Filtronic E-Band Cerus power amplifier can deliver output powers greater than 2 W. ***Figure 11*** shows an example transceiver module, which is being used in E-Band links for terrestrial applications and has also been customized for HAPS/LEO links.

CONCLUSION

Global mobile data usage is growing rapidly, and the new use cases enabled by 5G will create demand in areas that are underserved—and difficult to serve—by terrestrial cellular networks, such as more remote and sparsely-populated regions. Terrestrial networks will not be able to provide 100 percent coverage, and this creates a clear case for converged networks that will integrate satellites and HAPS with terrestrial mobile networks. Although hybrid satellite solutions are not expected before 2023 to 2024, the standardization work for integration of the satellite in 5G networks is underway. Following the finalization of 3GPP Release 16 at the end of 2019, it is expected that provisions for satellite and HAPS systems could form part of Release 17. Since spectrum is limited and is subject to many conflicting and sometimes overlapping demands, mmWave frequency bands are expected to form a key part of the solution for the links between satellites, HAPS and earth terminals. The FCC has approved several trials in V-, E- and W-Bands, confirming the growing role for mmWave bands in the future.

While the use of mmWave bands presents some technological challenges for semiconductor devices, RF systems, antennas and network architectures, some long range mmWave transceiver solutions with high data rates up to 40 Gb/s and above have been developed and successfully demonstrated in trial systems and will improve for future systems.■

Reference

1. D'Oliveira et al., "High-Altitude Platforms—Present Situation and Technology Trends," *Journal of Aerospace Technology and Management*, Vol. 8, No. 3, 2016, www.jatm.com.br/ojs/index.php/jatm/article/view/699.

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P2T-100M52G-100-T
P2T-100M56G-100-T


P4T-100M50G-100-T-RD
P4T-100M52G-100-T-RD
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Ultra Broadband Low Noise Amplifiers (https://www.pmi-rf.com/categories/ultra-broad-band-lna-s)

PMI Model No.	Frequency Range (GHz)	Gain (dB Typ)	Gain Flatness (dB Typ)	Noise Figure (dB Max)	OP1dB (dBm Typ)	Size (Inches) / Connectors
PEC-30-0R5G50G-22-12-24FF https://www.pmi-rf.com/product-details/ pec-30-0r5g50g-22-12-24ff	0.5 - 50	30	±2.5	9	+23	1.37" x 1.0" x 0.6" 2.4mm (F)

Digitally Controlled Attenuators (https://www.pmi-rf.com/categories/digitally-controlled-attenuators)

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DTA-100M50G-30-CD-1 https://www.pmi-rf.com/product-details/ dta-100m50g-30-cd-1	0.1 - 50	30	10 dB: ±0.95 20 dB: ±1.47 30 dB: ±2.13	±3.5 Typ	5.0 @ 20 GHz 8.0 @ 40 GHz 10.0 @ 50 GHz	5-BIT TTL 2.0" x 1.8" x 0.5" 2.4mm (F)

Limiters (https://www.pmi-rf.com/categories/limiters)

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LM-10M50G-18DBM-4W-24FF https://www.pmi-rf.com/product-details/ lm-10m50g-18dbm-4w-24ff	10 MHz - 50	1.2	4 W CW	+18	100 ns	0.9" x 0.38" x 0.38" 2.4mm (F) Removable
LM-10M62G-20DBM-1W-24FF https://www.pmi-rf.com/product-details/ lm-10m62g-20dbm-1w-24ff	10 MHz - 62	4.0		+22		

Solid-State Switches (https://www.pmi-rf.com/categories/switches)

PMI Model No.	Frequency Range (GHz)	Insertion Loss (dB Typ)	Isolation (dB Typ)	Switching Speed (Typ)	Power Supply	Configuration Size (Inches) Connectors
P2T-100M50G-100-T https://www.pmi-rf.com/product-details/ p2t-100m50g-100-t	0.1 - 50	6	100	50 ns	+5 V @ 100 mA -5 V @ 100 mA	SP2T, Absorptive 1.0" x 0.75" x 0.4" 2.4mm (F)
P2T-100M52G-100-T https://www.pmi-rf.com/product-details/ p2t-100m52g-100-t	0.1 - 52					
P2T-100M56G-100-T https://www.pmi-rf.com/product-details/ p2t-100m56g-100-t	0.1 - 56					
P4T-100M50G-100-T-RD https://www.pmi-rf.com/product-details/ p4t-100m50g-100-t-rd	0.1 - 50	7	100	50 ns	+5 V @ 154 mA -5 V @ 135 mA	SP4T, Absorptive 1.25" x 1.25" x 0.4" 2.4mm (F)
P4T-100M52G-100-T-RD https://www.pmi-rf.com/product-details/ p4t-100m52g-100-r-rd	0.1 - 52				+5 V @ 200 mA -5 V @ 200 mA	
P4T-100M53G-100-T-RD https://www.pmi-rf.com/product-details/ p4t-100m53g-100-t-rd	0.1 - 53				+5 V @ 200 mA -5 V @ 200 mA	
P8T-100M50G-90-T-RD https://www.pmi-rf.com/product-details/ p8t-100m50g-90-t-rd	0.1 - 50	9	90	50 ns	+5 V @ 400 mA -5 V @ 300 mA	SP8T, Absorptive 1.6" x 1.68" x 0.4" 2.4mm (F)
P8T-100M54G-90-T-RD https://www.pmi-rf.com/product-details/ p8t-100m54g-90-t-rd	0.1 - 54					
P16T-100M50G-100-T-DEC https://www.pmi-rf.com/product-details/ p16t-100m50g-100-t-dec	0.1 - 50	12.5	100	100 ns	+5 V @ 700 mA -5 V @ 680 mA	SP16T, Absorptive 8.0" x 3.0" x 0.67" 2.4mm (F)
P16T-100M52G-100-T-DEC https://www.pmi-rf.com/product-details/ p16t-100m52g-100-t-dec	0.1 - 52				+5 V @ 1100 mA -12 V @ 720 mA	


P8T-100M50G-90-T-RD


P8T-100M54G-90-T-RD


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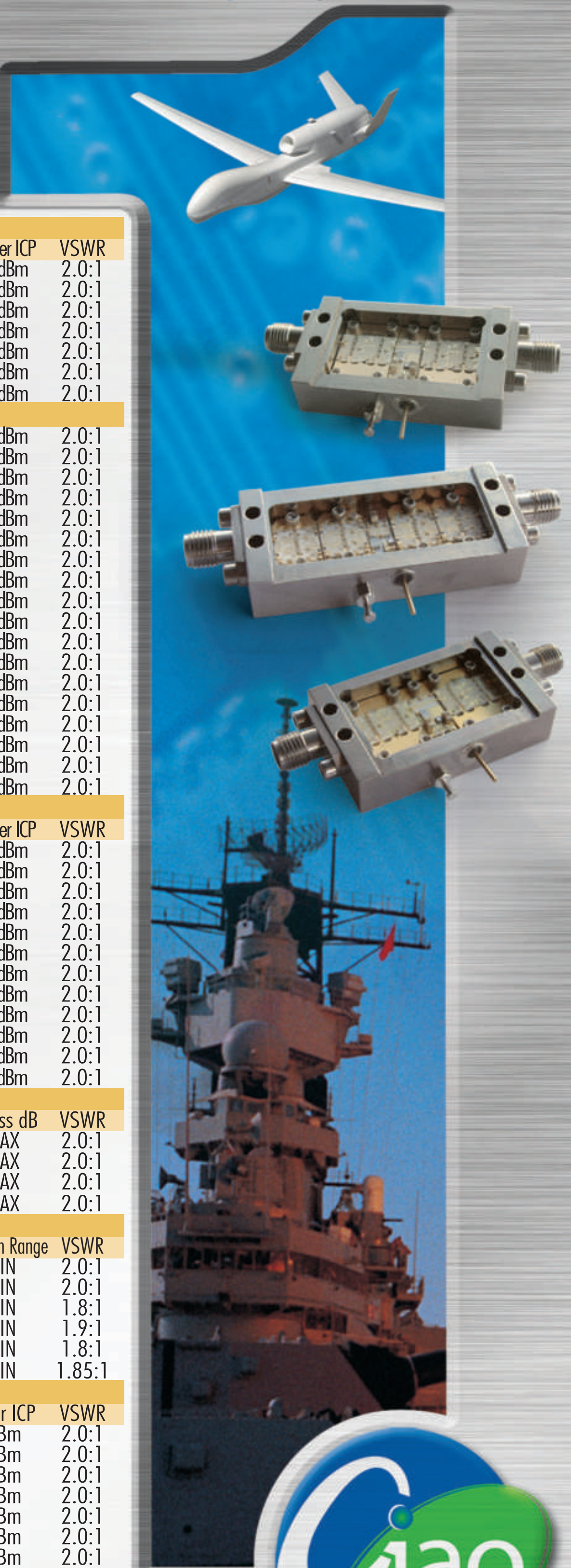

OCTAVE BAND LOW NOISE AMPLIFIERS

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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The IMDO and US MDA Successfully Complete Intercept Tests of an Advanced David's Sling Weapon System

The Israel Missile Defense Organization (IMDO), of the Directorate for Defense R&D in the Ministry of Defense, together with the U.S. Missile Defense Agency (MDA), have successfully completed a series of live-fire intercept tests of the David's Sling weapon system, against threat-representative cruise and ballistic missiles. The tests conducted were led by Rafael Advanced Defense Systems Ltd., from a testing site in central Israel, with the participation of the Israel Air Force and Navy.

"The series tested the capabilities of a new and advanced version of the David's Sling weapon system and included several scenarios simulating future threats. The results of this test will enable IMDO and industry engineers to evaluate and upgrade the system's capabilities.

David's Sling Weapon System (Source: Rafael Defense Systems Ltd)

In the framework of the series, the IMDO and Rafael also successfully demonstrated the capabilities of the Iron Dome in intercepting a variety of threats including UAVs and cruise missiles. The test also demonstrated the interoperability of the multi-layer air defense mechanism (Arrow, David's Sling and Iron Dome). This indicates that the systems will be capable of intercepting threats simultaneously during conflict.

Representatives of the MDA and Israeli defense industries, as well as IAF soldiers, participated in the test. Rafael is the prime contractor for the development of the David's Sling weapon system, in cooperation with U.S. Raytheon. IAI's Elta division developed the MMR radar and Elbit Systems developed the Golden Almond BMC.

David's Sling is a significant component of Israel's multi-layer air defense mechanism. The development of this mechanism is led by the IMDO and consists of four layers: Iron Dome, David's Sling, Arrow-2 and Arrow-3. These are all operational in the Israel Air Force.

Remain Well Clear – Drone Integration into European Airspace

Royal Netherlands Aerospace Center (NLR) and Information Systems Delft (ISD) are performing a multi-year study for General Atomics Aeronautical Systems, Inc. (GA-ASI) to develop the procedures needed to safely and efficiently integrate medium altitude, long endurance (MALE) remotely piloted aircraft systems (RPAS) into the European airspace. The partnership has recently completed a large-scale simulation experiment to test the application of a GA-ASI Detect and Avoid System in the European context.

"Shooting down a threat-representative ballistic missile target is the latest in a remarkable series of firsts that the government and industry team has achieved in demonstrating this leading-edge technology," said Doug Graham, Advanced Programs vice president, Lockheed Martin Space Systems Co. "This successful experiment validates the effectiveness of this revolutionary technology and makes it the most mature directed energy system in the world, opening the door to further new possibilities for the application of this technology."

The long-term goal of the partnership between NLR, ISD and GA-ASI is to develop the procedures needed to integrate MALE RPAS with civilian traffic in European airspace. For the purposes of this research, the MQ-9B SkyGuardian, designed and manufactured by GA-ASI, is used as an example case study. Enabling MALE RPAS to operate on a file-and-fly basis just like airliners would unlock numerous civilian applications of these new aircraft types including infrastructure inspection, search and rescue operations and quickly mapping events such as natural disasters.

MQ-9-Reaper-in-flight (Source: Royal NLR)

To develop and validate the required procedures meant for the real-life tests, large-scale simulation experiments are first carried out. To this end, NLR is using two simulators, namely the NLR ATM research simulator (NARSIM) and the NLR Multi unmanned aerial system supervision testbed (MUST). Here, NARSIM simulates air traffic and provides working positions for air traffic controllers and aircraft pilots. MUST functions as the RPAS simulator and as the ground control station the remote pilot uses to fly the RPAS. The combination of these two simulators is referred to as the MALE RPAS real-time simulation facility (MRRF).

In November 2020, NLR performed an experiment to investigate the procedures needed to use the "remain well clear," a functionality that enables the RPAS pilot to maintain a sufficient distance from other traffic, of DAA System in European airspace. The experiment involved real air traffic controllers, as well as licensed airliner and RPAS pilots. For this experiment, the MRRF simulation was equipped with GA-ASI's Conflict Prediction and Display System, which integrates DAA and traffic collision avoidance system functionality and is designed to meet the latest technical standards prescribed by the Radio Technical Commission for Aeronautics for these technologies.

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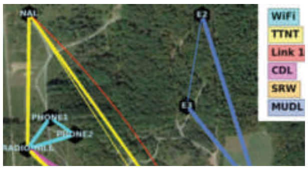
The results from the simulation will be fed back to regulators and standardization bodies on both sides of the Atlantic to accelerate the integration of MALE RPAS.

DARPA Successfully Demonstrates, Transitions Advanced RF Networking Program

A DARPA network technology program recently concluded field tests demonstrating novel software that bridges multiple disparate radio networks to enable communication between incompatible tactical radio data links—even in the presence of hostile jamming. The technology is transitioning to Naval Air Systems Command (NAVAIR) and the Marine Corps, which plans to put the software on a software reprogrammable multi-channel radio platform for use on aircraft and ground vehicles.

As a capstone event to conclude the program, DARPA recently demonstrated DyNAMO capabilities in over-the-air field tests at the Air Force Research Lab's experimentation and test facility near Rome, N.Y. Diverse military tactical data links, including LINK 16, tactical targeting networking technology, common data link and Wi-Fi networks were deployed to the test site. DyNAMO successfully provided uninterrupted network connectivity between all the data links under varying conditions in a simulated contested environment.

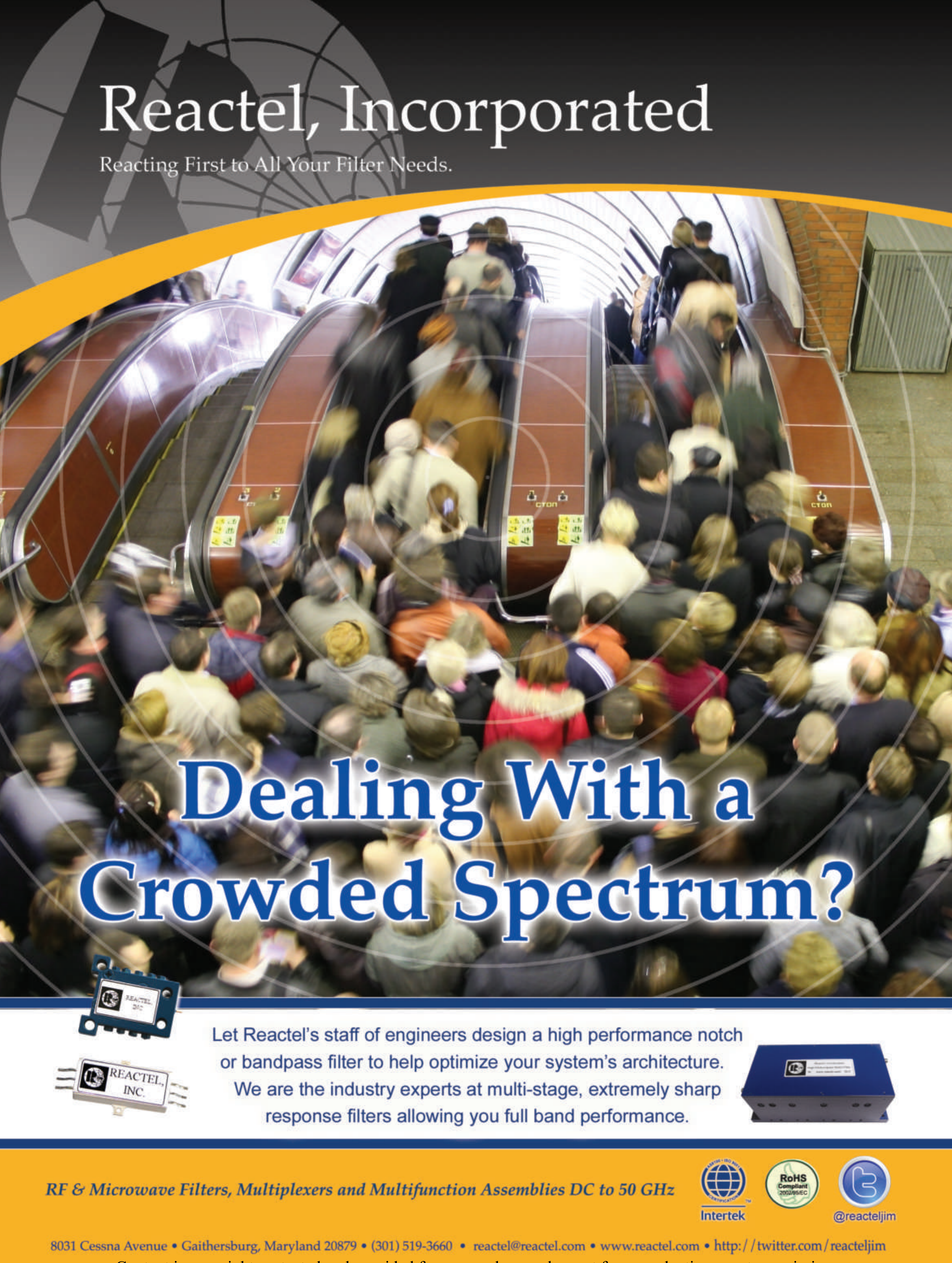


DyNAMO (Source: DARPA)

"Not only did we break the stovepipes and make the radios interoperable with each other, we showed that the network of networks DyNAMO creates has added resiliency," said Aaron Kofford, program manager in DARPA's Strategic Technology Office.

Current methods to bridge incompatible data links require deploying a large airborne platform housing the various radio datalinks on board. The airborne platform serves as a central gateway to interconnect the different links. Instead of this centralized model, DyNAMO employs a distributed gateway concept treating every node on the network as either a DyNAMO enabled node or a legacy, non-DyNAMO enabled node. DyNAMO software can interoperate with both types of nodes, so the DyNAMO enabled nodes serve as distributed gateways across the network eliminating a central gateway's single point of failure.

The field experimentation involved both static and mobile nodes. DyNAMO technology is slated for incorporation into NAVAIR/Marine aviation platforms through existing NAVAIR programs of record. Various Air Force representatives also observed the field tests.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The Far Future of Next Generation Wireless Communications

With 5G networks having just finished their second year in existence, wireless industry leaders are already exploring the path to future wireless networks beyond 5G. 5G Americas, recently announced the publication of a white paper "Mobile Communications Beyond 2020 – The Evolution of 5G Toward Next G," which details this global work from several academic and industry organizations and presents potential use cases and technologies integral to the evolution of 5G toward the "Next G."

Chris Pearson, president of 5G Americas said, "5G is in the second inning of a nine-inning baseball game with a huge roadmap of innovation ahead. Yet, the mobile wireless industry is going through a transformational change right now. Despite COVID, industries and societies are rapidly digitizing, so it is imperative that conversations around the next generation of mobile cellular wireless technologies begin to take place."

While 5G is still early in its lifecycle, it continues to be enhanced through continuous updates via 3GPP releases. These enhancements to networks, architecture, technologies and standards will continue through 3GPP Release 17 and beyond. However, it is expected over the next few years, that requirements for the next generation of mobile wireless will be outlined in the upcoming International Mobile Telecommunications 2030 (IMT-2030) update from the International Telecommunications Union.

Early thought leadership around next-generation wireless use cases may include scenarios involving tactile or haptic communications, high-resolution THz spectrum use for imaging and sensing, cyber-physical systems in manufacturing and enhanced public safety and national security applications.

The 5G Americas white paper covers the three main topics: a review of activities looking beyond 5G in both North America and globally; how communications will change beyond the 2020s, including several use cases; and how North America can establish and maintain technological leadership in future communications standards.

Brian Daly, assistant vice president, Standards & Industry Alliances at AT&T and leader of the working group in development of this white paper said, "Many projects identified as 'Next G' and '6G' are proceeding globally with some contribution from the Americas. There is a need for commercial entities, government agencies and academic bodies in the U.S. to be at forefront of these next-generation developments."

The white paper is available for free download on the 5G Americas website.

Geelong Proves Smart Cities Can Safely Integrate Drone Operations

In the skies over Geelong, a world-leading partnership has demonstrated the safe integration of manned and unmanned aircraft in low altitude airspace.

With support from the City of Greater Geelong, Thales and Telstra have jointly prototyped low altitude airspace management (LAAM), a technology that dynamically manages airspace, integrating manned and unmanned traffic while automating drone flight approvals.

Using the operational expertise of AUAV, a leading drone operator, Thales and Telstra combined their expertise to build a robust, safe and secure ecosystem, preparing the way for the integration of manned and unmanned traffic in Australian skies.

Thales Australia CEO Chris Jenkins said that this project has shown that the creation of a seamless sky is possible, where manned and unmanned traffic is safely integrated in the smart cities of the future.

Telstra's Group Owner, Incubation and Excellence, Gianpaolo Carraro said, "We're looking to solve aerial connectivity at lower altitudes than regular aviation, such as command and control and airspace awareness. Our ambition is to be an integral player for the industry, supporting safer and secure low altitude airspace equality."

The Thales UAS Airspace Management solution—at the heart of the LAAM—is operational in the U.S. to provide drone management services for the New York State Corridor, accredited by the FAA under the Low Altitude Authorization and Notification Capability initiative, and will soon be deployed in the State of North Dakota supporting safe airspace integration of unmanned aircraft. In Europe, the Thales UAS Airspace Management solution is managing the airspace for drones over two major cities, Rennes and Lille.

Over a six-month period, the Geelong Low Altitude Airspace Management Initiative demonstrated that drone operations can be conducted safely in a semi-urban environment and support the development of smart city concepts in Australia.

During this project, the objectives of the Geelong Smart City Office were to deliver technology solutions that put people first and provide benefit to the community. An unmanned aerial vehicle traffic management system will achieve a safer community by improving regulation, accountability and transparency of flights while mitigating privacy violations by ensuring pre-approvals for all flights including

Telstra Drone (Source: Thales)

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flight path, pilot and purpose.

The 'Smart City' of the future may include several drone platforms that have to be in operation and working together. Thales' UTM-FIMS system and its partners will manage and will integrate those drone platforms in an efficient and safe way.

Ultra-Wideband Emerges as a Key Wireless Connectivity Technology for Indoor Positioning

The foundation has been laid for ultra-wideband (UWB) to become a mainstream wireless connectivity technology across many consumer and IoT applications, enabling accurate indoor location and positioning with context-aware information and precise analytics in real-time. The year 2021 will be a critical juncture in UWB's rollout and increased adoption. ABI Research forecasts there will be 300 million UWB device shipments in 2021.

In its new white paper, "68 Technology Trends That Will Shape 2021," ABI Research's analysts identify 37 trends that will shape the technology market and 31 others that, although attracting huge amounts of speculation and commentary, are less likely to move the needle over the next eleven months.

UWB's rollout and increased adoption is due to wider chipset availability, adoption across multiple segments and the formation of a healthy UWB ecosystem across the entire supply chain. While historically, the technology has been used primarily within high-accuracy real-time location system applications, 2020 has propelled UWB into various new markets.

To date, arguably the biggest news was Apple's decision to develop and use its own UWB technology in its iPhone 11, iPhone 12 and iPhone SE devices. In addition, Samsung now supports the technology in its Galaxy Note 20 and Xiaomi added UWB to its Mi 10 series. Apple has also integrated the technology within its latest Apple Watch Series 6 and HomePod Mini speaker, demonstrating the importance of the technology going forward. Xiaomi also recently demonstrated UWB leveraged within a variety of smart home devices, such as fans, lamps and smart speakers, highlighting the growing potential of the UWB ecosystem.

Once embedded within a sizable installed base of smartphones, new opportunities will emerge within the mobile accessory space, alongside wider consumer electronics applications.

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

IN MEMORIAM

Arthur C. Nixon, chief executive officer of **Insulated Wire Inc. (IW)**, recently died unexpectedly at home on December 23, 2020 in Sayville, N.Y. The entire IW family mourns this loss. Arthur brought the experience and energy, passed on to him by his father Charles Nixon, to IW and the wire industry at-large. Peter Weigel, chairman of the IW Board of Directors, on behalf of the Board of Directors said, "With the passing of Arthur Nixon, IW has suffered a major loss. Notwithstanding that loss, the Board is confident that newly appointed Chief Executive Officer Michael Sarni, and the rest of the IW team will capitalize on the experience and expertise Arthur instilled in each team member. The Board will continue to consider in a deliberative way how best to maximize IW's performance over the long term."

MERGERS & ACQUISITIONS

iNRCORE announced that they have completed the acquisition of the **Gowanda Components Group** from Addison Capital Partners. For over 70 years, iNRCORE has deployed reliable and intelligent solutions to power the world's next-generation systems. From the frontlines of defense to the frontiers of space exploration, iNRCORE's power and signal magnetic components are utilized to help save lives, generate a powerful connection and further our knowledge of the cosmos. The Gowanda leadership team will continue to support the business reporting directly to iNRCORE President and CEO Sarah Harris. Additional terms of the transaction were not disclosed.

Fairbanks Morse, a portfolio company of Arcline Investment Management, has acquired **Ward Leonard Operating LLC**, a provider of motor and control solutions for military applications. This acquisition will expand the scope of power and propulsion equipment and aftermarket services that Fairbanks Morse provides to its core customers, including the U.S. Navy, U.S. Coast Guard and the Canadian Coast Guard. Ward Leonard has supplied the U.S. Navy for more than 125 years and today specializes in the provision of state-of-the-art motors, control components and systems integration solutions for surface, subsurface and land-based applications.

COLLABORATIONS

CEVA Inc. announced an open licensing agreement with the **U.S. Defense Advanced Research Projects Agency (DARPA)** to accelerate technology innovation for DARPA programs. The partnership, as part of the DARPA Toolbox initiative, establishes an access framework under which DARPA organizations can access all of CEVA's commercially available IPs, tools and support to expedite their programs. DARPA Toolbox is a new, agency-wide effort aimed at providing open licensing opportunities with commercial technology vendors to the researchers behind DARPA programs. Through DARPA Toolbox, successful proposers will receive greater access to commercial vendors' technologies and tools via pre-negotiated, low-cost, non-production access frameworks and simplified legal terms.

Nokia announced that they have been selected by **dtac**, a Thai mobile operator part of Telenor Group, as its first 5G radio access network (RAN) partner in a three-year deal covering the North and North Eastern regions of Thailand. With this deal, Nokia plays a key role in ensuring that dtac's network performance is fully 5G-ready and enabling a faster rollout of new 5G services as demand grows. Nokia has been in Thailand for over 30 years with the deployment of 2G, 3G and 4G networks and will now provide 5G connectivity that will support the country's efforts to digitize as part of its 'Thailand 4.0' economic strategy.

ACHIEVEMENTS

Keysight Technologies Inc. announced that **ArrayComm** will use the company's end-to-end portfolio of test solutions to speed development of network equipment based on the O-RAN standard. ArrayComm, a provider of physical layer software and hardware components for LTE and 5G base stations, selected Keysight's integrated test portfolio to validate O-RAN radio and distributed units. ArrayComm supports mobile operators deploying open, multi-vendor networks to deliver a wide range of advanced connectivity services. Keysight's test solutions enable ArrayComm to verify the performance of network components prior to deployment, leading to an optimized customer experience.

The Israel Missile Defense Organization, of the Directorate for Defense R&D in the Ministry of Defense, together with the **U.S. Missile Defense Agency**, have successfully completed a series of live-fire intercept tests of the David's Sling weapon system, against threat-representative cruise and ballistic missiles. The tests conducted were led by Rafael Advanced Defense Systems Ltd., from a testing site in central Israel, with the participation of the Israel Air Force and Navy. This successful series is a critical milestone in the augmentation of Israel's operational capabilities in defending itself against current and future threats.

CONTRACTS

The **U.S. Navy** has awarded **L3Harris Technologies** a five-year, $496 million contract to deliver prototype tactical jamming pods designed to extend U.S. Air superiority. The Next Generation Jammer Low Band (NGJ-

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LB) is a high-powered, high capacity airborne electronic warfare system. L3Harris' single-pod solution enables extended stand-off jamming capability, covers a broad spectrum and processes an increased number of threats. The system operates seamlessly with joint and allied forces and provides growth capacity for emerging threats. The company will deliver eight operational pods to NAVAIR for fleet assessment and additional test assets for airworthiness and design verification.

BAE Systems received a $4 million contract from the **U.S. Navy** to conduct a quick-turnaround demonstration of a new radio frequency countermeasure (RFCM) system for the P-8A Poseidon. The pod-mounted RFCM system is a leading-edge, lightweight, high-power system that will add a new self-protection capability to this next-generation U.S. Navy aircraft. The rapid response is the result of collaboration among small focus teams who developed an innovative approach to the design and fabrication of the system's mechanical parts. As a result, BAE Systems will design, build, integrate and ship the RFCM system in approximately five months, followed by two months of flight testing on the P-8A Poseidon platform. Testing will begin early in 2021.

Comtech Telecommunications Corp. announced that **Comtech Systems Inc.** was awarded a $2.7 million order from a major international oil and gas company to provide a troposcatter radio/modem. This will be the first over-the-horizon system for a floating liquefied natural gas facility, utilizing Comtech Systems' software-defined CS67PLUS radio/modem.

Leonardo DRS Inc. and **Rafael Advanced Defense Systems Ltd. of Israel** announced that they have completed the delivery of Trophy Active Protection Systems (APS) ordered by the **U.S. Army** for installation on Abrams main battle tanks. This marks a major milestone in the Army's efforts to outfit multiple brigades of tanks with APS to protect soldiers' lives against increasing anti-armor threats. Under contracts awarded on an urgent need basis by the Army's Program Executive Office for Ground Combat Systems, the companies delivered the first APS systems in September 2019 for both the U.S. Army and Marine Corps.

Altum RF announced a two-year contract with the **European Space Agency** to design and develop GaN Ka-Band high-power amplifiers for very small aperture terminals (VSATs), two-way ground stations that transmit and receive data from satellites. The ARTES Advanced Technology project designs Ka-Band high efficiency power amplifiers using a cost-effective package solution, well suited for the VSAT application.

PEOPLE

Qualcomm Inc. announced that its Board of Directors has unanimously selected **Cristiano Amon** to succeed **Steve Mollenkopf** as CEO, effective June 30, 2021.


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Around the **Circuit**

▲ *Cristiano Amon*

Mollenkopf informed the Board of his decision to retire as CEO following 26 years with the Company. Amon, who has worked at Qualcomm since 1995, is currently president of the company. Mollenkopf will continue his employment with the company as a strategic advisor for a period of time. Amon, 50, has served as president since January 2018. In this role, he is responsible for Qualcomm's semiconductor business, which includes mobile, RF front-end, automotive and IoT revenue streams and the company's global operations.

▲ *David Buhaenko*

Marki Microwave appointed **David Buhaenko** to serve as vice president of operations. The former senior director of product engineering at Renesas Electronics America (previously Integrated Device Technology) brings the company 30 years of global operations leadership in midsize and large organizations. In his new role, Buhaenko will lead Marki Microwave's operations organization as the company expands its U.S.-based manufacturing capacity and builds out its production, product engineering and test teams. A 30-year technology veteran, Buhaenko most recently served as the senior director of Renesas Electronics America's product engineering and program management team.

▲ *Ben Reed*

Times Microwave Systems announced the appointment of **Ben Reed** as the company's new general manager, effective immediately. Previously general manager for Amphenol Fiber Systems International, Reed succeeds Bill Callahan, who has been promoted to the role of group general manager of the Amphenol RF Optical and Broadband (ARFOB) division. Reed has served in management roles within Amphenol since 2013. Prior to joining Amphenol, he held engineering roles at Northrop Grumman Corporation. He has been working closely with Bill Callahan on the leadership transition for several months and both will continue to collaborate on opportunities for Times Microwave and the ARFOB division to expand and diversify into new markets.

▲ *David Kozlowski*

▲ *Rob Davies*

▲ *Jordan Klein*

NXT Communications Corp. announced key management appointments as the Georgia-based connectivity company continues to build out its team. **David Kozlowski** has been named vice president of Aero Structures and Certification, with responsibility for overseeing installation, testing and certification of NXT-

COMM's AeroMax® antenna on commercial aircraft, reporting to Co-founder and CEO Dave Horton. In addition, **Rob Davies** will serve as director, Product Engineering, reporting to CTO Carl Novello and **Jordan Klein** has been named creative director, reporting to Horton. With four decades of aircraft modification and maintenance experience, Kozlowski joins NXTCOMM from Panasonic Avionics, where he spent a decade holding key roles in installation and product management.

▲ *Glen Riley*

POET Technologies Inc. announced the appointment of **Glen Riley** to the Board of Directors. Riley's extensive and relevant experience includes more than 30 years in leadership roles spanning both the semiconductor and optoelectronics industries. He most recently served as general manager of the Filter Solutions Business Unit at Qorvo, where he was responsible for developing highly integrated RF modules used in flagship smartphones. Prior to the merger of RFMD and TriQuint that formed Qorvo, he held multiple leadership roles at TriQuint, including managing director of international headquarters in Singapore, general manager of the GaAs foundry business and general manager of Optoelectronics.

REP APPOINTMENTS

AR RF/Microwave Instrumentation has partnered with three new companies to serve as sales representatives throughout various regions of the U.S. The new companies that will be representing AR are **PSI Solutions Inc.** who partners with leading manufacturers of test instrumentation, imaging and embedded products, **ProTEQ Solutions Inc.** with headquarters in Nashua, N.H., who represents some of the best in-class manufacturers of electronic test equipment and **Dytec/Midwest**, an electronics manufacturers representative firm, with over 100 years of engineering and account management experience who has headquarters in the Chicago area and satellite offices in Minnesota and Indiana.

PLACES

NEC Corp. has opened an Open RAN laboratory in India to complement its Center of Excellence in the U.K. The facility will accelerate the development of NEC's 5G open ecosystem by pre-integrating partner Open RAN components to form end-to-end commercial-ready solutions according to customer-specific needs. The solutions will undergo end-to-end practical validations on functional/operational performance and quality assurance throughout all layers of the RAN, from network and cloud to service layers. The lab will also be responsible for post-deployment troubleshooting, life cycle management as well as continuous integration and continuous delivery of solutions.


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INVITED PAPER

Holographic Radar Development

Stephen Harman
Aveillant Ltd., Cambridge, U.K.

Holographic radar system architectures are less complex than conventional surveillance array radar architectures, yet holographic radars offer capabilities exceeding those of the most sophisticated active electronically scanned array radars. Holographic radars can therefore challenge conventional radars in both cost and performance.

Holographic radar is not constrained by the sampling nature of scanning radar and so (loosely) has the capability to provide information with higher dimensionality. Fundamentally, staring radars meet the requirements of the Electromagnetic Uniqueness Theorem and provide an analytical solution to all electromagnetic interactions within their coverage. Conversely, scanning radars heavily undersample so they cannot meet the same criteria. Some further benefits of staring radar are 1) the capability to provide very high Doppler frequency resolution by observation over dwell times unconstrained by the scan pattern or surveillance constraints and 2) contiguous measurement with high update rates, so fleeting, rapidly varying or complex returns can be sensed.

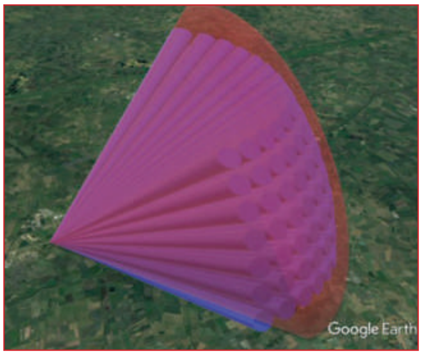

Fig. 1 **Holographic radar antenna patterns showing a broad transmit beam (red) and mesh of narrow receive beams (blue).**

These characteristics enable high-resolution clutter rejection (i.e., detection in the presence of complex background environments of complex target returns) and optimized recognition and tracking. The efficacy of staring operation has been demonstrated with both modeled and real targets and clutter, on both large and small scales and in different applications.

As a basic example, consider detection of a complex maneuvering target. A scanning radar with a 2-degree azimuth beamwidth might detect and report its position every second, with a Doppler frequency resolution of 200 Hz. A holographic radar, however, can divide its radar return into 2 Hz wide components, for retaining and reporting a fine-grain Doppler signature, and fully sample its varying position and velocity, to rapidly determine changes in trajectory for effective tracking and threat assessment. As such, holographic radars provide both highly flexible radar coverage and utility, offering a solution to provide ubiquitous radar sensing—the ultimate in flexibility.

HOLOGRAPHIC RADAR ARCHITECTURE

Fundamentally, the architecture of a holographic radar comprises a transmitter that constantly transmits over the entire field of view and an array receiver with a persistent mesh of narrow beams that fill the field of view, negating the need to scan to provide accurate angular measurements (see ***Figure 1***). As a design consequence, the transmitter and the receiver units do not share a common aperture or common RF modules, since a broad transmit pattern is not efficiently produced by the type of multibeam array antenna required by the receiver. Such separation of the transmit and receive circuitry reduces their respective complexities (see ***Figure 2***). The transmit antenna is usually a simple fixed planar array or a reflector

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antenna, and the receiver array is significantly simplified, since it does not contain high-power RF circuitry or complex transmit-receive switching elements.

Although staring radars have simplified RF, IF and control hardware and contain no moving parts, the consequence is increased processing complexity. The number of simultaneously processed beams is significantly increased. For example, a scanning radar typically processes only one beam at a time, while a staring radar processes many beams simultaneously. Also, the quantity of data processed in a single dwell is generally higher, to provide similar sensitivity to an equivalent scanning radar—since a scanning radar contains a high gain antenna on both transmit and receive—and to realize the benefits of a staring radar, such as high-resolution Doppler processing. Note, for example, the processing load of a fast Fourier transform, which is commonly used in radar signal processors, has an order greater than one

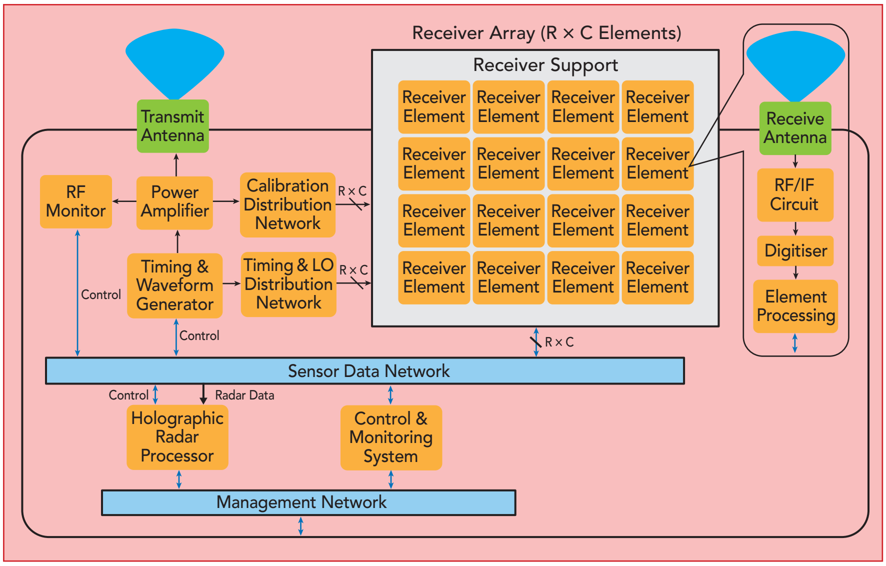


Fig. 2 Holographic radar system architecture.

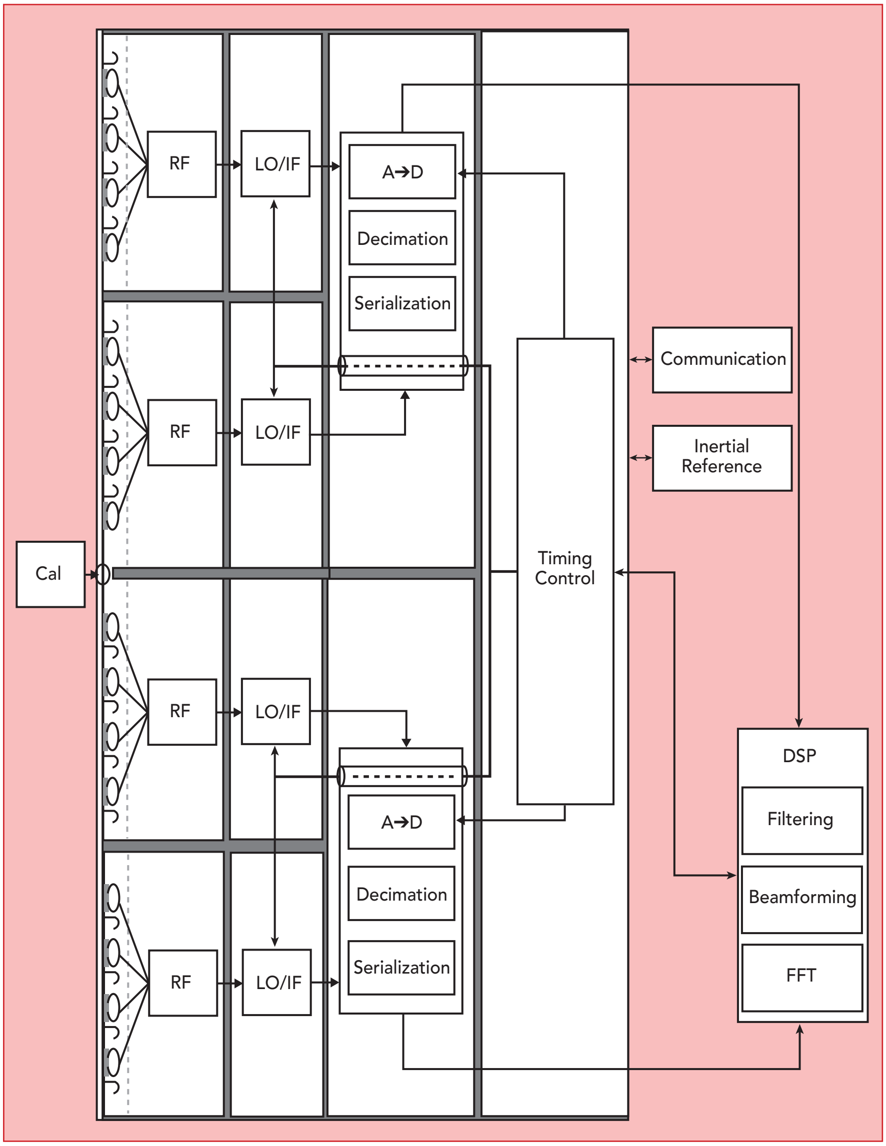
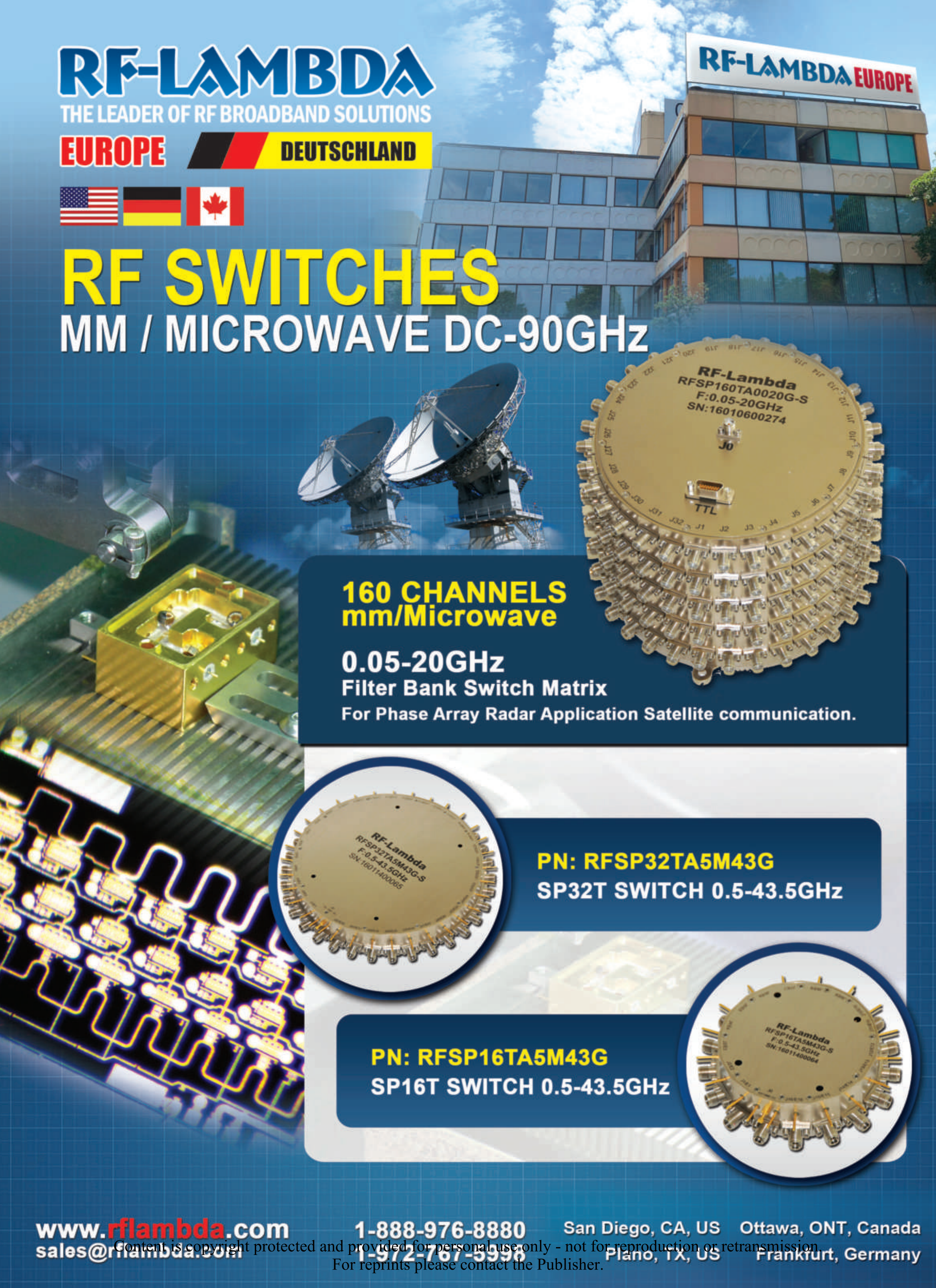


Fig. 3 Hardware design approach enables multiple applications.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with increasing length.

Staring radars tend to be smart, adaptable and defined by software. Furthermore, due to sensor persistence, staring radars are ideally suited to operate with multiple coincident modes in multiple, software-defined processing chains and/or cognitive processes.

MODULAR ETHOS

The radar hardware is designed to be re-used for multiple applications and units that can be reconfigured (see ***Figure 3***). This design ethos results in numerous atypical radar design features, including:

- Antenna elements spaced at $\lambda/2$, allowing scanning and adaptive processing over up to ±90 degrees from boresight.
- Independently digitized receiver elements to maximize flexibility, allowing the creation of small to large arrays.
- Signals digitized at IF to minimize calibration problems, with digital down-conversion local to the element, in addition to other rudimentary pulse-level, raw data radar-processing functions.
- Use of a single low phase noise oscillator reference distributed to all transmit and receive modules, each deriving its own RF frequencies and clocks. Each receiver module comprises just 2 × 2 elements, for high flexibility.
- Use of distributed simple timing signals, processed locally within each transmit and receive module for detailed timing.
- Transmit power generated in a single or small number of solid-state power amplifiers and distributed to a small number of transmitter elements, appropriate to broad-beam transmission.
- Near linear mode transmit power amplifier operation, with digitally controlled pulse-shaping technology to manage spectral masks and sidelobes.
- A calibration network for monitoring the transmitted waveform, so the smallest variations in performance can be tracked and accounted for.
- A flexible and expandable processing architecture comprising GPUs and general purpose server-class processors.

HOLOGRAPHIC RADAR DEVELOPMENTS

The original concept for holographic radar was as a C-Band demonstrator for a defense application. Successful proof of that concept led to the development of a long-range holographic radar for the civilian market, to address windfarm mitigation in air traffic management systems. Given existing air traffic control radar standards and long-range requirements for this application, L-Band was selected for its frequency of operation. From this early work, the Theia radar family[1] was developed to address a range of applications, from land-based windfarm mitigation to longer range systems covering off-shore windfarms. With operational systems in continuous use for over five years, Theia is a good example of the expandable modular architecture in practice.

This modular architecture formed

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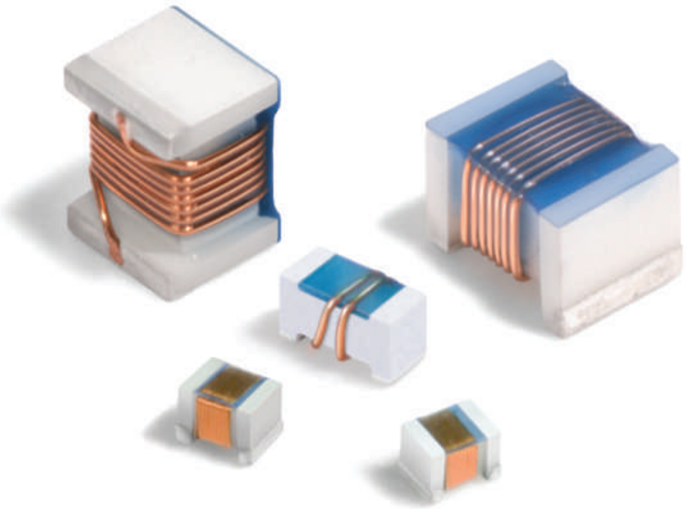

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Fig. 4 Radar developed for long-range detection, tracking and recognition of drones.

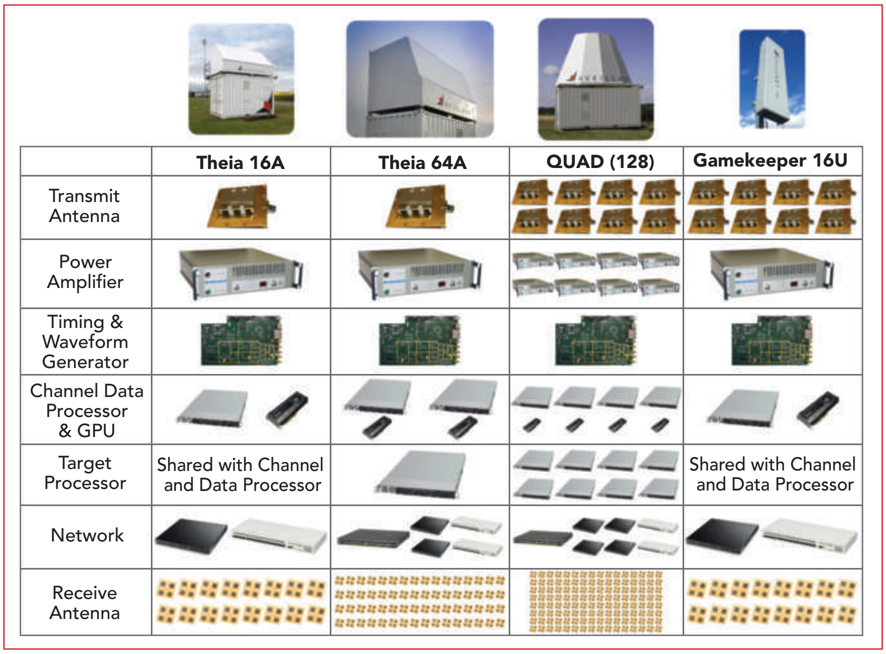

Fig. 5 Radar family based on the reconfigurable design approach.

the foundation for developing a new concept radar with a conformal antenna, to investigate the efficient implementation of a staring array comprising 12 interdependent planar arrays for 360-degree azimuthal coverage. A demonstrator radar system, developed to explore this concept, contained four planar arrays, each with 128 receiver elements and sufficient transmit power to achieve 54 nautical mile detection of passenger aircraft. This four array demonstrator, nicknamed the Quad, was the basis for developing further ubiquitous radar sensing concepts and applications, including detecting drones. The initial investigations indicated the technology can support flight safety requirements: long-range detection, tracking and recognition of drones. A new product, named Gamekeeper, was rapidly developed to meet the needs of this emerging market, marking the coming of age of holographic radar (see ***Figure 4***).

COUNTER DRONE RADAR

Radar is the only sensor capable of providing the essential sensing requirements for a drone surveillance and counter-UAV system: long-range, all weather performance; non-cooperative/autonomous drone detection and recognition; and consistent accuracy, coverage and performance. Market requirements for such a system are very demanding. They include: a high power-aperture product capable of detecting very low radar cross section (RCS) objects up to 7.5 km range; high dynamic range for detecting very low RCS objects in the presence of high clutter; high elevation accuracy for effectively discriminating air targets from ground objects; and high confidence tracking and recognition, to reduce the burden on operators given "con-

fuser" targets in environments of interest. Normally, these requirements can only be met by large, high cost military radar systems, such as weapons locating radars.

Aveillant has addressed these market needs with a system more compatible with the civilian market. An initial operational capability for early adopters was developed for operational deployments in 100 days, by reconfiguring standard transmit and receive modules and commercial off-the-shelf (COTS) components used across Aveillant's product line (see ***Figure 5***). Gamekeeper radar's capability has continuously evolved since its first operational deployment, with performance, stability and operational improvements released regularly, often multiple times per year, predominantly through software upgrades. These upgrades use a combination of adaptive agile development methodologies and the design features of holographic radar that make it a software-defined radar. This enables rapid technology insertion; in some cases, low technology readiness level techniques and technologies have been matured and implemented in the Gamekeeper radar to provide both step changes and continual improvements in capabilities.

TECHNOLOGY ENABLERS

Key enablers for this adaptivity include advanced pulsed waveform control and state-of-the-art processors. Advanced pulsed waveform control is essential, given that the electromagnetic spectrum is congested, particularly in areas around airports and urban areas. Thus, radar transmissions, particularly those providing new capabilities, are highly controlled. This objective is more easily achieved using a staring radar architecture, versus other array antenna architectures, as the staring radar contains just one independent, easily accessible transmit channel. Transmitter and waveform control properties include:

- Linear, solid-state power amplifiers. At L-Band, COTS units using LDMOS transistors are readily available. They provide several kilowatts output power and greater than 50 dB gain with gain flatness less than 1 dB, which simplifies interfacing.
- Programmable and adaptable, high dynamic range pulse-shaping circuits. Implementations include circuits based on calibrated vector modulators or combinations of controllable phase shifters and attenuators. Using FPGAs, these circuits adjust transmitted RF amplitudes to accuracies less than 1 dB and phase to within 2 degrees approximately every 10 ns.
- Calibration networks, with all receivers continuously evaluating transmitted waveforms. These passive networks split a coupled version of the transmitted waveform and route it to the input of each receiver element during designated calibrated periods. The signal is analyzed real-time to ensure consistent performance. Passive splitter networks and cable distribution networks have high

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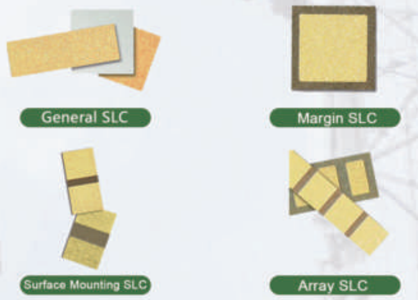

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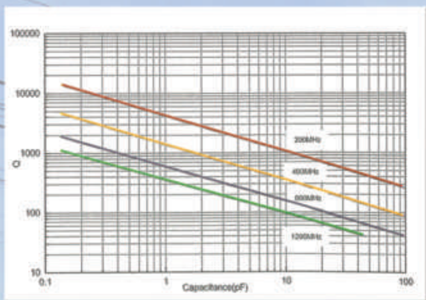
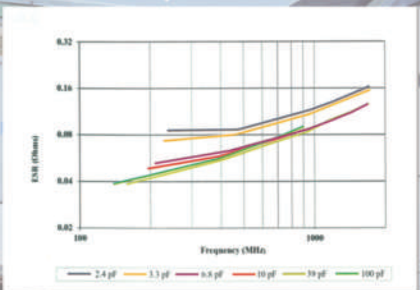


DLC70A(0505) Q Value and Capacitance Curve



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- Full synchronization and adaptive control of transmitted waveforms and receiver modes. Programmable waveform generators and processing in each receiver element module (using FPGA and Zynq SoCs) enable rapid adaptivity. All processors are synchronized to an accurate timing datum generated at a single source. Adaptivity includes changing the transmitted waveforms and associated matched filters and can include receiver processing modes to adapt to changing requirements or environments.
- High-order filtering of transmitted and received signals, ensuring low interference and susceptibility to adjacent spectrum users. While accurately controlling the transmitted waveforms ensures transmissions are accurately constrained in frequency, to ensure no unintentional transmission, the transmitted RF signals and all local oscillator frequencies require high-order filtering, typically using surface acoustic wave filters. Also, due to high use of the electromagnetic spectrum, particularly at L-Band, to operate in the presence of other users of adjacent frequencies, multiple stages of filtering are necessary to remove interference. High-order receiver filtering is required before the low noise amplifier, to prevent saturation, and at multiple stages within the receiver, to minimize the likelihood of interference affecting performance. Using this design methodology, signals at just 40 MHz separation from the holographic radar's center frequency are attenuated by 120 dB.
- Low gain receiver antennas and IF digitization, enabling adaptive interference monitoring and cancellation. A low gain receiver antenna reduces the risk that in-band and adjacent frequency systems will saturate the front-end of the receiver. Antenna gain is provided by digital beamformers which can be configured to place deep nulls in the directions of interference sources. If moving, this is performed adaptively. If digitization is performed using digitizers operating at sample rates many times the radar's bandwidth, which enables perfect quadrature down-conversion (i.e., no image frequencies) and the ability to sense returns over much greater bandwidths. Digital decimating filters are typically employed in digital down-conversion; adaptive digital filters can be used to minimize sources of interference at any adjacent frequencies within the digitized bandwidth.

The use of state-of-the-art processors has enabled significant developments unbounded by the limitations of processing performance. Key aspects of the processing architecture include:

- Processors with supported, clear development roadmaps, enabling future upgradability. Typically, these are supplied by the market leaders, such as Intel for general purpose processing,

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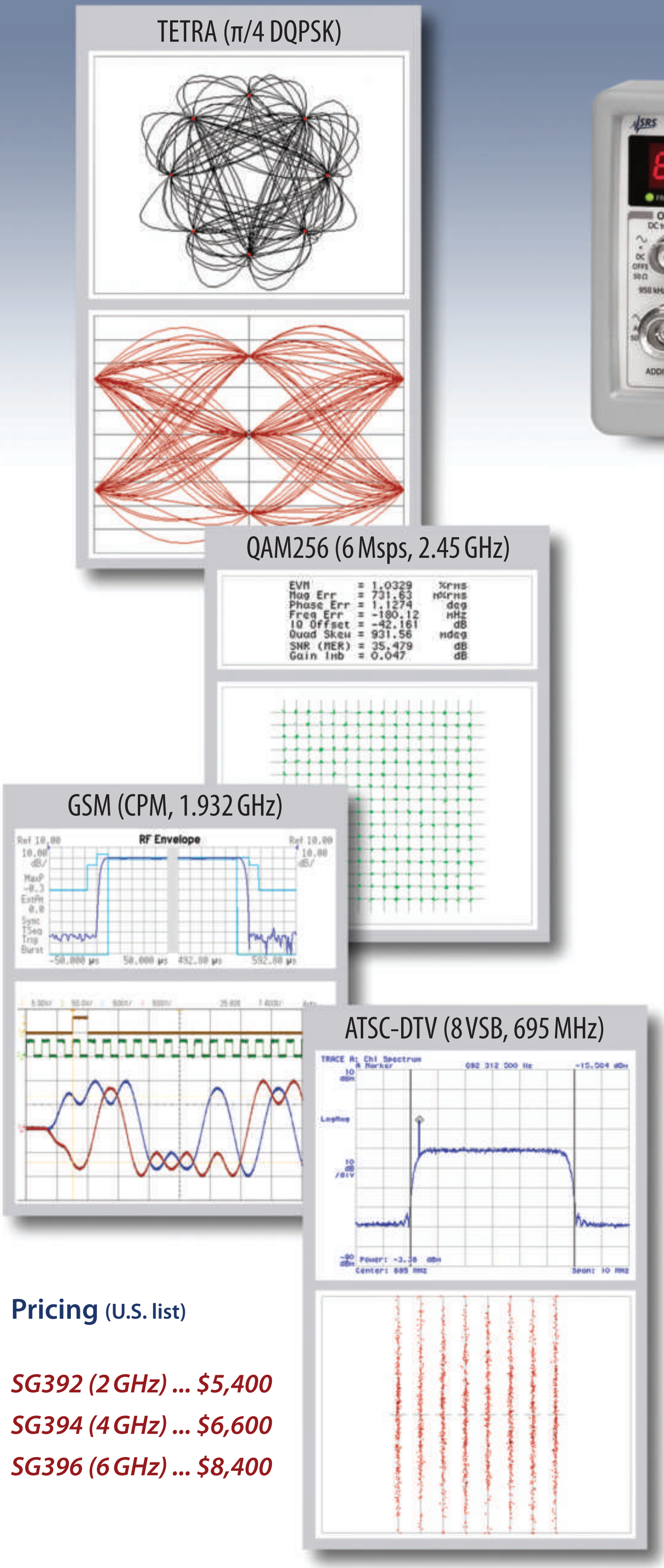

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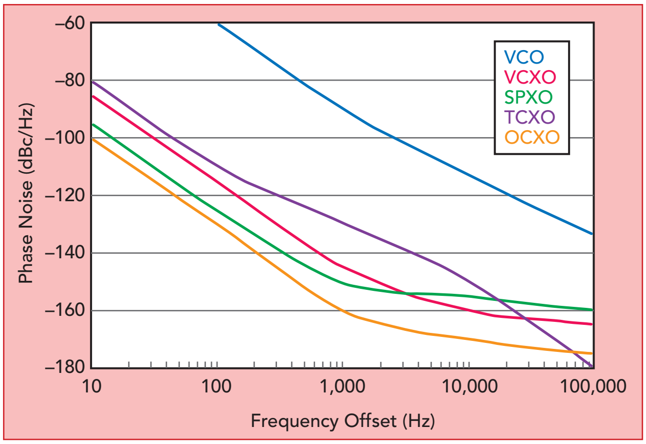
- Expandable processing architectures compatible across the product line. Initially, range processing is performed at the element level, which is then followed by beamforming processing. Algorithms are configured so that different bands of ranges or angles can be processed in isolation by different processors, enabling division of both processing resources and data. This capability is facilitated using a combination of high bandwidth network switches and lossless data compression at key data communication interfaces.
- Use of FPGAs and Xilinx Zynq SoCs to provide critical timing functionality and high rate element level processing. For example, these devices perform down-conversion of signals in approximately 100 MHz sample rate data streams with sub-ns timing; they also provide flexibility to meet the needs of multiple applications.
- Use of GPUs for element, antenna array and raw array signal processing. GPUs are ideal for common signal processing tasks at high processing rates, so they are effective performing the high data rate radar signal processing for beamforming, Fourier transforms and detection.
- Server-class processors for conditional processing, general purpose processing and interfacing to other systems. These processors are used for operations such as tracking and recognition.

Examples of further development include:

- Innovations to reduce the radar's overall phase noise, to enable detection of smaller targets in the presence of high clutter. Ovenized crystal oscillators (OCXO) provide cost-effective, low phase noise: the latest devices have provided a 100 MHz reference frequency to the radar with -160 dBc/Hz phase noise at 1 kHz offset (see ***Figure 6***). Further improvement is achieved by developing filters in frequency multiplication circuits to improve the phase noise at higher frequency offsets.
- Numerous improvements in tracking and target recognition, to use the benefits of operating in a staring radar configuration. As an example, machine learning



▲ **Fig. 6** An OCXO enables low phase noise and improves detection of small targets in high clutter.

is used to determine the difference between a bird and a drone, judging their respective track kinematics and the properties of their micro-Doppler signatures.

- Adaptive beamforming, to improve the sensitivity in the presence of high static and dynamic clutter. Holographic radars are used in high clutter environments, such as airports and urban areas. Given the natural sidelobes of planar antenna arrays are high compared to a parabolic antenna, static and dynamic clutter (e.g., road vehicles) can obfuscate targets across a radar's entire field of view. Adaptive techniques have been developed to identify regions of high clutter and generate beam patterns with nulls in these regions, to reduce the impact of clutter across the entire field of view, significantly improving detection sensitivity in affected environments.
- Techniques to enable multiple radars to coexist using the same frequency channel without interference. This development uses waveform and processing schemes and implements synchronization and frequency locking circuitry between radars to provide a common pulse timing reference and identical frequency reference.

THE FUTURE

Like the challenges offered by the proliferation of windfarms and drones in the medium- to long-term future, concepts of modular staring radar architectures will be adaptable to emerging sensor needs. In the shorter term, the development of variants with extended coverage, higher power and higher sensitivity against drones are planned. System developments will improve discrimination and overall installed performance, which are essential to reducing the operator burden of security systems. Development plans include implementing concepts such as deep learning, adaptive cognitive techniques and frequency and polarization diversity.

Holographic radar is integral to the development of non-cooperative sensing concepts for unmanned traffic management systems, which will enable drones to operate safely in the lower airspace environment, unlocking their potential. Initial concept development and experimentation has begun as part of the National Beyond visual line of sight Experimentation Corridor initiative. This will grow to meet future needs for ubiquitous sensing, broad area and localized generic sensing for applications ranging from security to environmental monitoring. This need to improve coverage while maintaining accuracy is unlikely to be met by increased radar power and sensitivity, rather by sensor proliferation. In the near future, multi-site and multi-static holographic radar (polygraphic) operation is inevitable.■

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2. "GAMEKEEPER 16U Counter-UAS Radar," *AVEILLANT Ltd.*, Web: www.aveillant.com/products/gamekeeper/.

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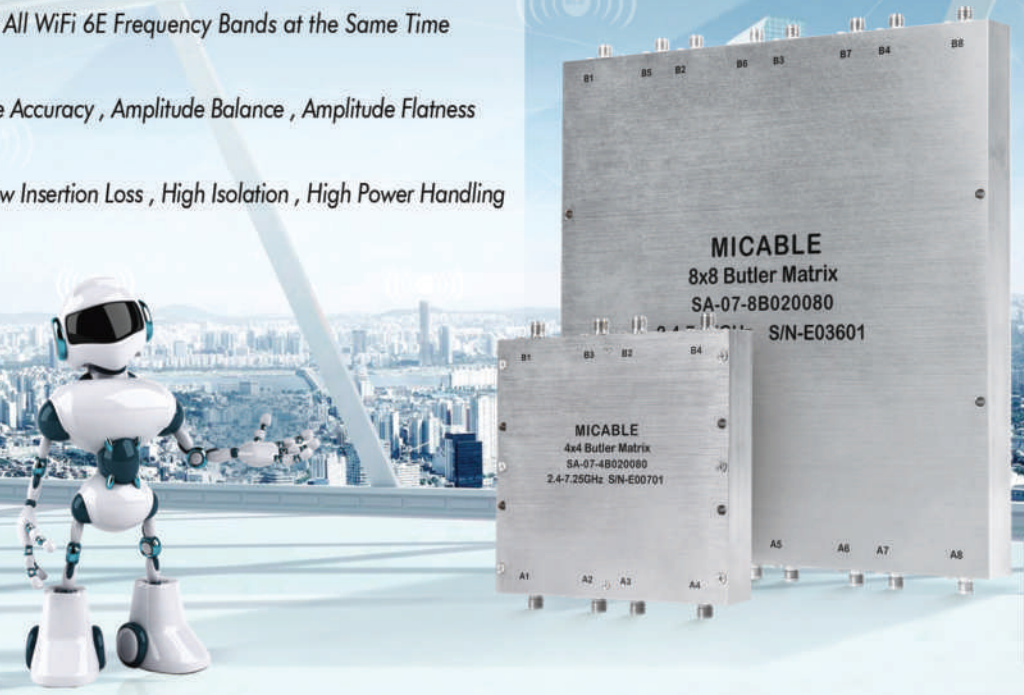

DATASHEET

	Model	Frequency Range (GHz)	VSWR Max.(:1)	Insertion Loss* Max.(dB)	Amplitude Bal. Max.(dB)	Amplitude Flatness Max.(dB)	Phase Accuracy Max.(Deg)	Isolation Min.(dB)
4x4	SA-07-4B020080	2.4~2.5	1.4	7.3	±0.5	±0.3	±4	14
		5.18~5.83	1.5	7.7	±0.6	±0.4	±5	13
		5.9~7.25	1.5	7.8	±0.7	±0.5	±6	13
8x8	SA-07-8B020080	2.4~2.5	1.5	11.2	±0.6	±0.4	±8	13
		5.18~5.83	1.5	11.6	±0.8	±0.5	±10	12
		5.9~7.25	1.55	11.8	±0.9	±0.7	±12	12

* Theoretical IL. Included

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Gamma Irradiation-Induced Degradation of the Collector-Emitter Saturation Voltage in InGaP/GaAs Single Heterojunction Bipolar Transistors

Jincan Zhang, Ligong Sun, Min Liu, Liwen Zhang and Bo Liu
Henan University of Science and Technology, Luoyang, China

We report the investigation of gamma irradiation effects on the collector-emitter saturation voltage of InGaP/GaAs heterojunction bipolar transistors (HBTs). It is found that the saturation voltage increases by more than 0.1 V after exposure to gamma irradiation with a total dose of 10 Mrad(Si) and subsequent annealing at room temperature. Analysis shows the increase of saturation voltage is mainly caused by irradiation-induced defects in the base-collector space charge region, including its bulk and periphery.

The GaAs HBT is widely used in the design of high speed integrated circuits because of its superior performance.[1-5] The recent growth of wireless and other high-end communication applications continues to draw attention to the long-term reliability of its performance under irradiation. An important and undesirable problem is degradation of the collector-emitter saturation voltage, $V_{CE(sat)}$, after irradiation because it affects the operation of analog and digital circuits.[6] In analog circuits, an increase in $V_{CE(sat)}$ can affect the gain of an amplifier, depending on its quiescent point, and can cause output distortion. In logic applications, the increase can decrease noise margin significantly due to an increase in the on-state voltage drop of the output.[7]

This article reports experimental data showing the $V_{CE(sat)}$ of InGaP/GaAs single heterojunction bipolar transistors (SHBTs) increases significantly after exposure to gamma irradiation and subsequent annealing. The increase in $V_{CE(sat)}$ is related to gamma irradiation-induced defects in the base-collector space charge region (SCR).

TEST SEQUENCE AND RESULTS

The InGaP/GaAs SHBTs used in this study are commercial products from WIN Semiconductors (see ***Figure 1***). The base-emitter is an InGaP/GaAs heterojunction and the emitter area of the transistor is 1.0 × 20 μm^2, IC is 8 mA maximum.

The SHBTs were irradiated without bias in a gamma cell using a Co^{60} source, with a dose rate of about 50 rad(Si)/sec and irradia-

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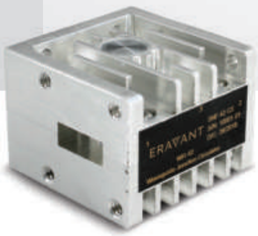

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The DC common-emitter ICVCE characteristics at 10 µA base current for gamma total doses of 7 and 10 Mrad(Si) are shown in ***Figure 2***. Figure 2(a) compares the pre-irradiation and post-irradiation results, showing little variation of the collector current. Figure 2(b) compares the pre-irradiation, post-irradiation and post-annealing characteristics, showing notable changes in the col-

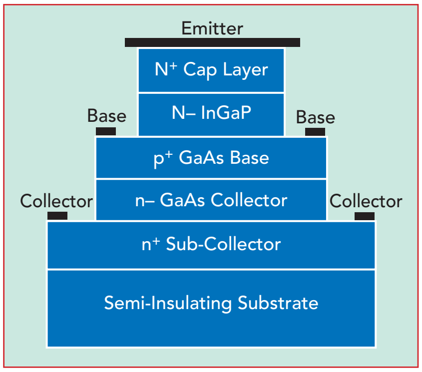


Fig. 1 GaAs HBT cross-section.

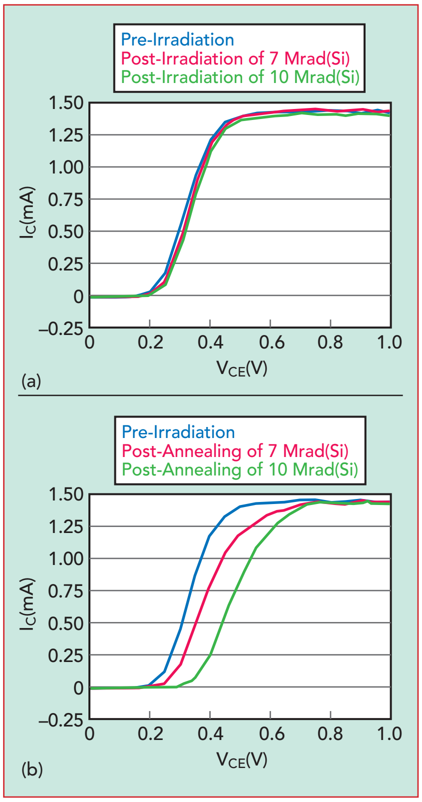


Fig. 2 CE I_CV_{CE} characteristics pre-irradiation and post-irradiation (a) compared to pre-irradiation and post-annealing (b).

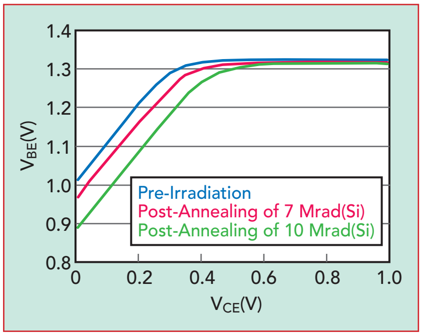
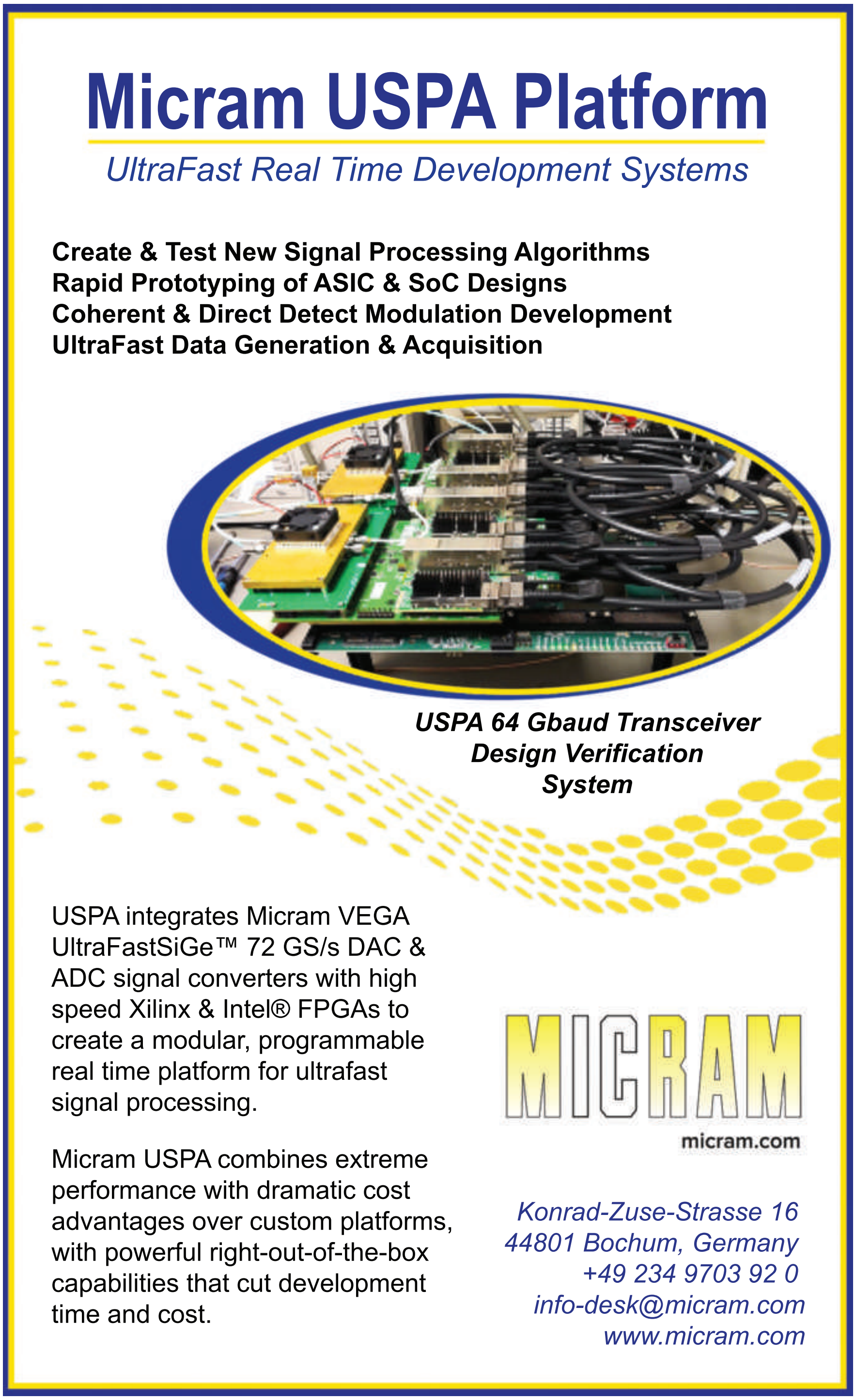


Fig. 3 V_{BE} vs. V_{CE} for pre-irradiation and post-annealing.

lector current. One major effect of post-annealing is evident from Figure 2(b): $V_{CE(sat)}$ increases with increasing gamma total dose. V_{BE} versus V_{CE} at a fixed base current of 10 µA was measured before irradiation, post-irradiation and post-annealing (see ***Figure 3***).

ANALYSIS

Why does $V_{CE(sat)}$ increase after annealing but not post-irradiation? Gamma irradiation possibly induces slow interface states at the interface between the air and insulating passivation layer that exchange charges with the semiconductor over a long time, which causes $V_{CE(sat)}$ to degrade as annealing time increases. The increase in $V_{CE(sat)}$ post-annealing may be understood by considering a modified Ebers–Moll model of the transistor (see ***Figure 4***). I_{BE} and I_{CC} are the base and collector currents, respectively, caused by the forward injection across the base-emitter junction. These two components can be measured independently using forward Gummel measurements with $V_{BC} = 0$. Similarly, I_{BC} and I_{EC} are the base and emitter currents, respectively, that are reverse injected by the base-collector junction. These can also be measured using inverse Gummel measurements with $V_{BE} = 0$.



In the saturation region, where both the base-emitter and the base-collector are forward biased, the total collector current is given by

$$I_C = I_{CC} - I_{EC} - I_{BC} \quad (1)$$

The inverse Gummel measurements show that $I_{EC} \ll I_{BC}$, so I_C is approximately

$$I_C \approx I_{CC} - I_{BC} = I_{CCS}\left(e^{qV_{BEi}/\eta_{BE}kT} - 1\right) - I_{BCS}\left(e^{qV_{BCi}/\eta_{BC}kT} - 1\right) \quad (2)$$

where V_{BEi} and V_{BCi} are the base-emitter and base-collector junction voltages, respectively, I_{CCS} and η_{BE} are the saturation current and ideality factor of the collector current from the forward Gummel measurements. Similarly, I_{BCS} and η_{BC} are the saturation current and ideality factor of the base current from the reverse Gummel measurements. The junction voltages may be different than the terminal voltages because of the voltage drops across the parasitic series resistances R_E, R_B and R_C of the emitter, base and collector, respectively.

$$V_{BEi} = V_{BE} - I_B R_B - I_E R_E \quad (3)$$

and

$$V_{BCi} = V_{BC} - I_B R_B + I_C R_C \quad (4)$$

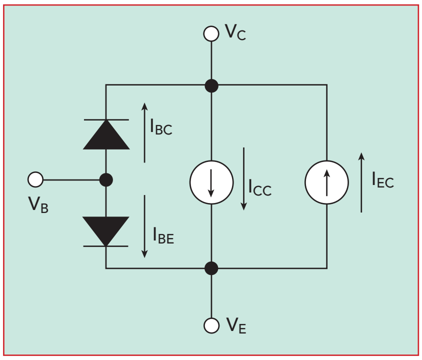


Fig. 4 Modified Ebers–Moll model of a bipolar transistor.

The collector-emitter saturation voltage, $V_{CE(sat)}$, is given by

$$V_{CE(sat)} = V_{BE} - V_{BC} \quad (5)$$

where V_{BE} and V_{BC} are obtained by solving Equations 3 and 4, respectively. This gives

$$V_{CE(sat)} = I_E R_E + I_C R_C + V_{BEi} - V_{BCi} \quad (6)$$

These equations provide physical insight for understanding the gamma irradiation-induced increase of $V_{CE(sat)}$. The measured values of I_{CC} versus V_{BE} and I_{BC} versus V_{BC} are plotted in ***Figure 5***. Two horizontal lines, A and B, are drawn at the values of V_{BE} and V_{BC} determined, respectively, from Figures 2(b) and 3 and Equation 5 at $I_C = 0.5$ mA. In this case, the HBT operates in the saturation region, so $V_{CE(sat)}$ is simply the horizontal voltage separation between V_{BE} and V_{BC}.

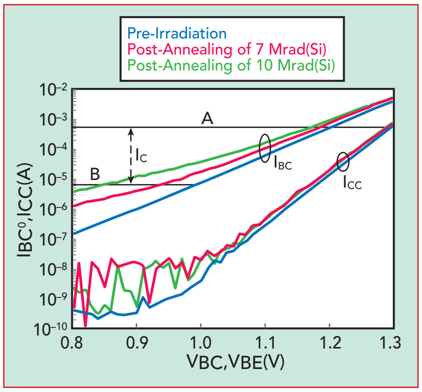


Fig. 5 Inverse Gummel I_{BC} and forward Gummel I_{CC} characteristics pre-irradiation and post-annealing.

Figure 5 shows that I_{CC} increases slightly after annealing, the increase with gamma dose due to the increased saturation current of the base-emitter junction. This is caused by the large number of radiation-induced defects, causing amphoteric interface states to serve as efficient generation/recombination centers. On the other hand, the base current, I_{BC}, in the inverse Gummel plots increases significantly after annealing, the increase in gamma dose is due to additional recombination in the SCR and quasi-neutral region. The increase of $V_{CE(sat)}$ is caused by the increase in current injected by the base-collector junction; the physical mechanism is discussed by Shatalov et al.[8]

The physical mechanism responsible for the increase of base-collector junction saturation current can be further understood by analyzing the base current, I_{BC}, in the inverse Gummel measurements. For SHBTs, I_{BC} has two main components: 1) recombination of electron-hole pairs in the bulk of the SCR and along its periphery and 2) recombination of injected holes in the bulk of the neutral collector region and at the surface. In the Vertical Bipolar Inter-Company (VBIC) model, I_{BC} is given by

$$I_{BC} = I_{BCi} + I_{BCn} = I_{BCI}\left(\exp\left(\frac{V_{BC} - I_B R_B + I_C R_C}{N_{CI} V_{tv}}\right) - 1\right) + I_{BCN}\left(\exp\left(\frac{V_{BC} - I_B R_B + I_C R_C}{N_{CN} V_{tv}}\right) - 1\right) \quad (7)$$

I_{BC} is the sum of two components: I_{BCi}, modeled with a satura-

tion current, I_{BCI}, and ideality factor $N_{CI} \approx 1$ that comprises the neutral collector region recombination; and a non-ideal component for the SCR, modeled with saturation current I_{BCN} and ideality factor $N_{CN} \approx 2$ for InGaP/GaAs SHBTs.

Using the data from the gamma total dose of 10 Mrad(Si) and the VBIC model in Advanced Design System, the non-ideal base-collector saturation current, I_{BCN}, increases significantly from 5.06×10^{-14} A to 6.04×10^{-11} A, and the ideal base-collector saturation current, I_{BCI}, increases relatively slightly from 1.49×10^{-20} A to 2.24×10^{-19} A. The observed increase in the saturation current of the base-collector junction appears to be mainly due to an increase of recombination current in the SCR.

Considering the effects of R_C and R_E in Equation 6 on the collector current after annealing, the first term, $I_E R_E$, is proportional to R_E, assuming I_E is a fixed constant in this analysis. The total emitter series resistance is measured with the fly-back technique, where the emitter is grounded, current is forced into the base and the open circuit collector voltage is measured. The emitter resistance is the slope of the linear segment of the curve. ***Figure 6*** compares R_E from fly-back measurements for the GaAs HBTs before irradiation and after annealing. The figure shows almost no change in slope after annealing with 10 Mrad(Si) gamma irradiation, which means R_E has not contributed to an increase in $V_{CE(sat)}$. The second term of Equation 6 represents the contribution from R_C, the total collector series resistance, which includes the extrinsic collector resistance, R_{CX}, and the intrinsic collector resistance, R_{CI}, in the VBIC model. ***Figure 7*** shows the R_{CX} obtained from fly-back measurements, similar to the R_E measurements shown in Figure 6. The value of R_{CX} equals the slope of the linear segment of the curve, which changes slightly after annealing. R_{CI} can be determined by optimizing the fit to the data from the common-emitter $I_C V_{CE}$ characteristics of the quasi-saturation region.

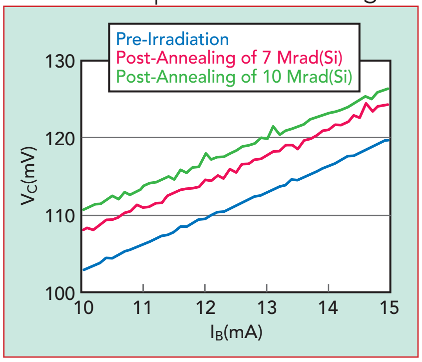


Fig. 6 Fly-back measurement of V_C vs. I_B, showing emitter resistance, R_E.

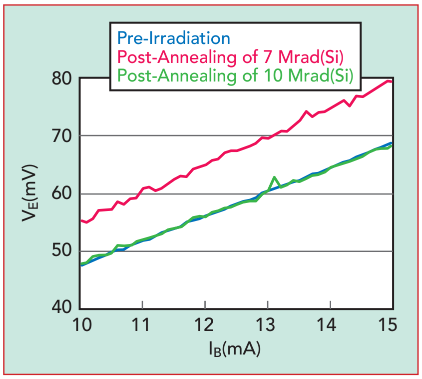


Fig. 7 Fly-back measurement of V_E vs. I_B, showing extrinsic collector resistance, R_{CX}.

R_C increases from 3.94 to 4.94 Ω with the irradiation dose of 10 Mrad(Si) due to an irradiation-induced carrier decrease in the neutral collector region. In the post-annealing following 10 Mrad(Si) gamma irradiation, the second term increases by only 8 mV, even with I_C = 8 mA, which is the maximum I_C of the test samples. Thus, the contribution of the parasitic series resistances to the increase of $V_{CE(sat)}$ is negligible, even at the maximum I_C.

CONCLUSION

The collector-emitter voltage drop, $V_{CE(sat)}$, across the InGaP/GaAs SHBTs at saturation increases by more than 0.1 V after annealing gamma irradiation with a total dose of 10 Mrad(Si). From the analysis, the $V_{CE(sat)}$ increase is caused by irradiation-induced defects in the SCR and the neutral collector region. Experiments and analysis show that the defects in the SCR play a more important role increasing $V_{CE(sat)}$ than defects in the neutral collector region. With an increase in maximum I_C, however, defects in the neutral collector region restrain the increase in $V_{CE(sat)}$ in gamma radiation environments.■

ACKNOWLEDGMENTS

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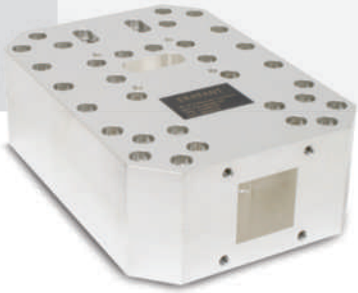

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INVITED PAPER

On-Wafer, Large-Signal Transistor Characterization from 70–110 GHz Using an Optimized Load-Pull Technique

Jason Zhang, Jonas Urbonas and Giampiero Esposito
Maury Microwave, Ontario, Calif.

Andrea Arias-Purdue and Petra Rowell
Teledyne Technologies, Thousand Oaks, Calif.

The ability to benchmark the performance of semiconductor technologies using small periphery devices, quickly and accurately, can reduce development cost and expedite time to market. This can now be achieved using hybrid-active vector receiver load-pull measurements that enable E- and W-Band device characterization up to gamma magnitudes of 1 at the device-under-test (DUT) reference plane.

Much of the next generation of wireless technologies for mobile, satellite, automotive and radiolocation are being designed to operate in the upper mmWave bands of 70 to 110 GHz. For mobile and satellite, this means 10× to 100× more available unlicensed spectrum compared to the sub-10 GHz bands, leading to increased data bandwidth, transmission rate and data throughput. For automotive applications and radiolocation, mmWave frequencies provide higher imaging resolution and improved intra- and inter-vehicle communications. This enables applications such as automotive radar, collision avoidance and traffic information exchange between vehicles.

TABLE 1
TRANSISTOR TECHNOLOGY MMWAVE PERFORMANCE

Technology	fmax (GHz)	Frequency (GHz)	Power-Added Efficiency (%)	Power (dBm)	Reference
InP HBT	580	76	26.9	26.4	1
SiGe HBT	360	76	12.4	27.3	2
CMOS SOI	410	77	18	19.6	3
GaN HEMT	400	76	10	32.4	4

Designing solutions to work effectively and efficiently in these frequency bands is not a simple task. It is especially challenging to design mmWave circuitry, such as transmitters and receivers, which include amplifiers to boost signal power levels. Active components are critical to achieving the required performance. Some of the biggest challenges to overcome are the low gain, output power and efficiency of transistors at these frequencies. To address these limitations, multiple technologies have been developed (see ***Table 1***). While these semiconductor technologies offer good performance for applications in the 20 to 40 GHz range,[5] i.e., the 5G FR2 range, transistor performance

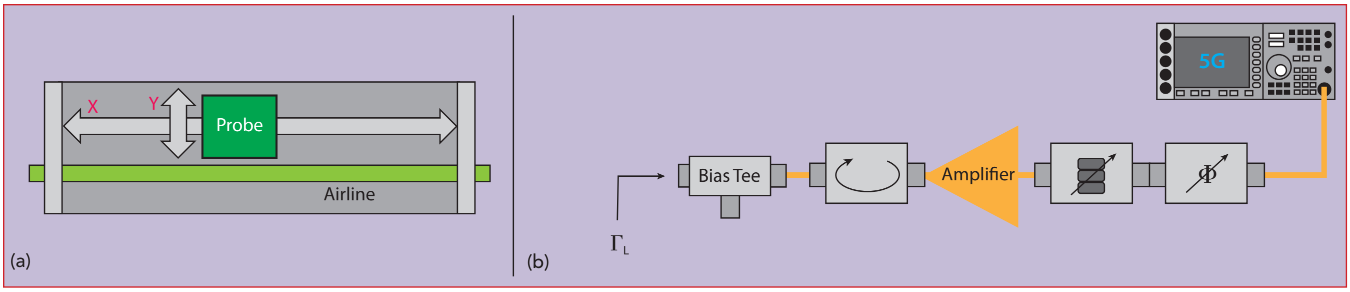

Fig. 1 Mechanical tuner (a) and active loop (b) load-pull measurement.

drops as frequency increases, limiting their use for applications over 70 GHz. This is due to the device parasitics becoming significant at E- and W-Bands. The cutoff frequency (f_t) of a device should ideally be about 10× the target operating frequency for the device not to become one of the major limiting factors in a high efficiency power amplifier design. So it is critical to optimize the circuit design to squeeze out every last tenth of a dB of gain, dBm of output power and percent of efficiency.

Optimal circuit design can only be realized with accurate device models or fully characterized transistors. While a robust mmWave device model is often available for a mature device technology, newer modeling approaches can use accurate device reference plane measurements to develop device models for less mature technologies.[6] mmWave device models based on neural networks, for example, may offer an advantage compared to the current modeling paradigm.

Load-pull, the technique of systematically varying the reflection coefficient (Γ_L) at the output of a DUT and measuring changes in its performance, is a practical method for extracting and validating models and for performing small- and large-signal device characterization.

A common consideration when performing load-pull at E- and W-Band is choosing the size of device to characterize. Performing load-pull on devices with small peripheries—less than four fingers—results in lower fabrication costs and time and contributes to faster time to market and higher profitability.[7] The small periphery, however, usually has high device S_{11} and S_{22}. This makes characterization challenging because $\Gamma_L > 0.9$ at the DUT reference plane is required to fully characterize the device. Conventional tuner-based load-pull setups struggle to achieve $\Gamma_L = 0.7$ at the DUT reference plane, limited by high insertion loss of the RF probes connecting the test system to the DUT. As such, designers tend to fabricate larger devices with more than four fingers[8] or include pre-matching circuitry[9] to lower the Γ_L required to characterize DUTs. This, however, increases fabrication cost and time, which can delay technology development and time to market.

Recent advances in measurement technology and instrumentation have enabled hybrid-active vector receiver load-pull for high-power, mmWave device characterization, including the 70 to 110 GHz bands discussed here.

HYBRID-ACTIVE LOAD-PULL

Consider a two-port network where the waves incident to and reflected by the network are denoted as a_x and b_x, respectively, where x denotes the network port. This network has an input reflection coefficient $\Gamma_{in} = b_1/a_1$ and a load reflection coefficient defined as $\Gamma_L = a_2/b_2$. Load-pull characterization enables the user to systematically vary Γ_L presented to the DUT while measuring a multitude of device parameters versus drive power at each

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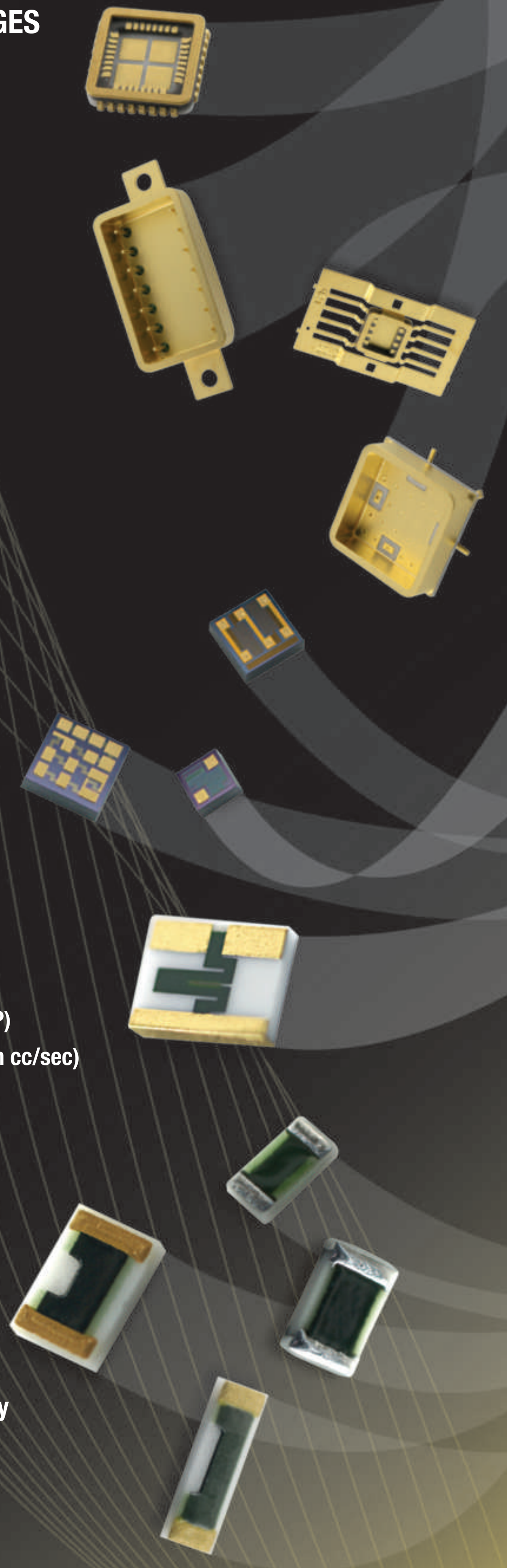

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impedance state. Passive load-pull[10] uses mechanical impedance tuners to change the magnitude and phase of the reflected signal a_2 and vary the Γ_L presented to the DUT. This is accomplished by moving a probe up, down, left and right along a 50 Ω airline (see ***Figure 1a***). $|\Gamma_L|$ will always be < 1, since a_2 will always be smaller due to losses between the output of the DUT and the tuner. Open-loop active load-pull systems[10] do not rely on a mechanical tuner to reflect part of b_2 back as a_2. Instead, they use active signal injection with magnitude and phase control to create a new signal a_2 (see ***Figure 1b***). When amplified by an external amplifier, any a_2 and any Γ_L can be achieved.

Active tuning has several advantages over passive tuning, including faster speed and increased coverage of the Smith chart. This is because there are no mechanical moving parts, and the actively generated a_2 wave can be used to set $|\Gamma_L| > 1$. The challenge with active tuning is the availability of driver amplifiers

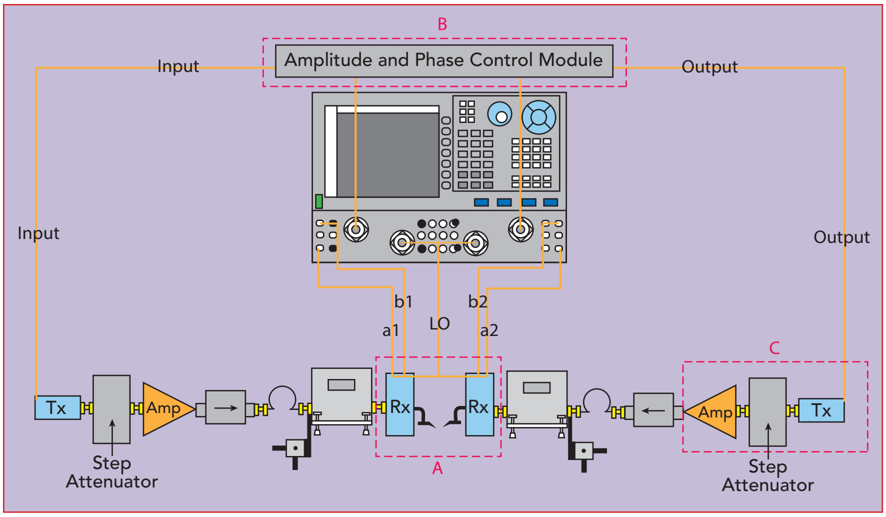

Fig. 2 **W-Band hybrid-active load-pull measurement system.**

to boost the a_2 signal. Typically, they are required to have 5× to 10× higher output power than the DUT due to the mismatch between the DUT output impedance and the nominal 50 Ω impedance of the driver amplifier. A modified approach, hybrid-active load-pull, overcomes this challenge by pre-matching the DUT impedance with a passive impedance tuner, which lowers the driver amplifier output power required to deliver the same signal a_2 to the output of the DUT (see ***Figure 2***).

To date, active and hybrid-active load-pull have been limited to coaxial measurements in commercially available systems because of the impracticality of measuring and controlling the magnitudes and phases of the a and b waves using waveguide frequency extenders. To overcome this limitation, Maury Microwave has introduced custom low-loss couplers with integrated down-conversion (see block A in Figure 2), which extend VNA-based load-pull measurements to 110 GHz, and a source control unit (see block B in Figure 2) enables accurate amplitude and phase control to 110 GHz. The custom couplers enable direct a and b wave measurements at the vector calibrated DUT reference plane, increasing system measurement accuracy and providing critical device performance—output power, power gain, input Γ and power-added efficiency (PAE)—for each input power level and load impedance state. The amplitude and phase controller with the frequency multiplier and step attenuator on the load loop (see block C in Figure 2) enable 0.01 dB magnitude and 0.1 degree phase control of the a_2 wave.

This hybrid-active load-pull solution enables W-Band VNA-based load-pull measurements, reaching $|\Gamma_L| = 1$ at the probe tip reference plane for DUTs with output power on the order of 1 to 2 W. These

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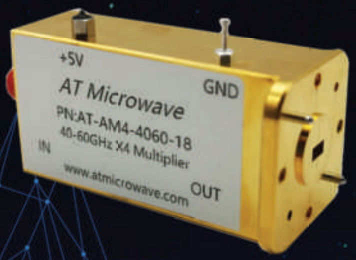

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- ✓ F Band 90-140GHz, X8, Pout=0dBm

High Power Active Multiplier:

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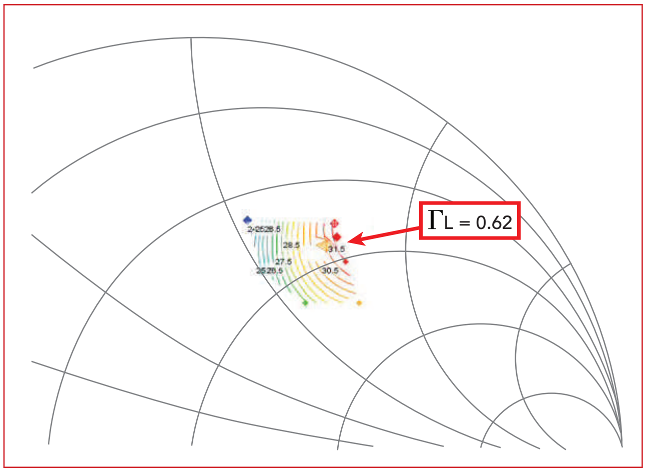
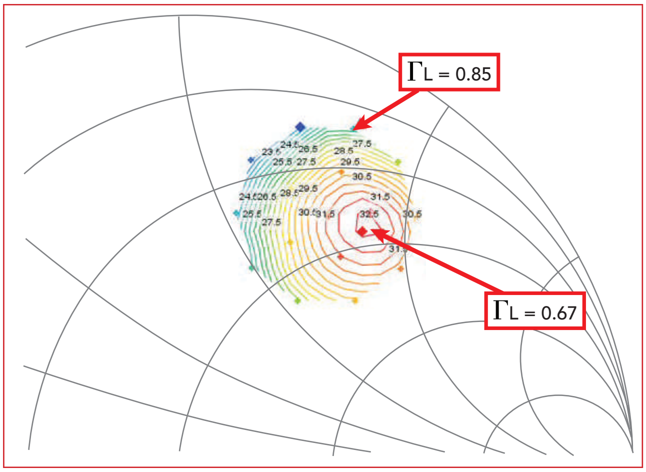


▲ Fig. 3 **Device drain efficiency measured using a traditional load-pull setup, showing a maximum drain efficiency of 31.5 percent at 75 GHz. The traditional setup can't obtain closed contours.**



▲ Fig. 4 **Device drain efficiency measured using a hybrid-active load-pull setup, which provides closed contours. At 2 dB compression, the maximum drain efficiency is 32.5 percent at 75 GHz.**

capabilities enable measurements of highly mismatched devices previously impossible to characterize due to system limitations. The implementation of active load-pull using waveguide frequency extenders is possible up to 1.1 THz, frequencies where commercial automated impedance tuners are unavailable or impractical.[11]

DEVICE MEASUREMENTS

To demonstrate this solution, a small periphery, two finger, GaN HEMT was characterized at 75 GHz using passive and hybrid-active load-pull systems. A traditional waveguide passive load-pull system could only achieve a maximum $|\Gamma_L|<$ 0.62. Without closed contours (see ***Figure 3***), the best device performance may be missed, leading to incorrect conclusions about the optimum DUT impedances. As noted, this is problematic when characterizing small periphery active devices, where the output impedance is typically close to the edge of the Smith chart. The same device PAE characterization using a hybrid-active load-pull system is shown in ***Figure 4***. Much higher magnitude Γ_L is achieved at the DUT reference plane, enabling closed contours and providing confidence the correct load impedances are identified to maximize DUT performance.

Other benefits of hybrid-active vector receiver load-pull include real-time measurements of the a and b waves at the input and output of the DUT, which enable characterizing power gain variation and input reflection coefficient versus available input power and load impedance. ***Figure 5*** shows the measured gain variation with load impedance of the GaN HEMT. The characterization of input impedance variation is important when optimizing the power gain at a particular DUT input power level, to optimize the design of the input and output matching networks. Due to the low device gain at these frequencies, designers must consider the tradeoffs among power gain, drain efficiency, PAE and output power.

CONCLUSION

During the initial stages of device technology development, timely feedback to device develop-

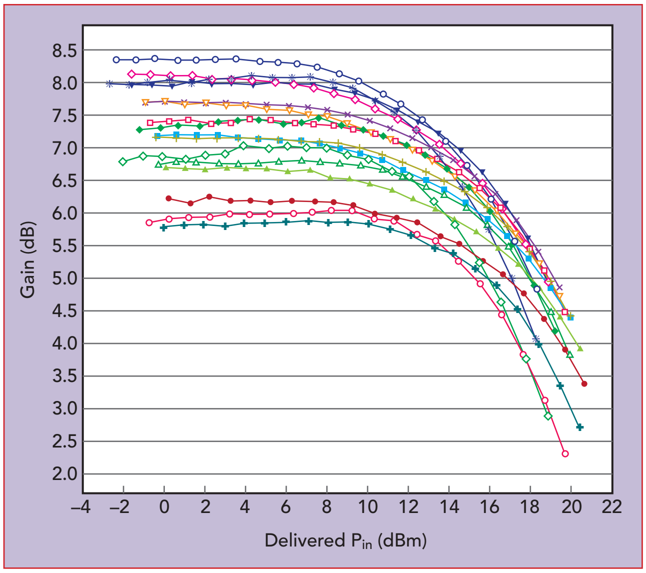


Fig. 5 **GaN HEMT power gain vs. load impedance measured with the hybrid-active vector-receiver load-pull system.**

ment engineers is important to accelerate the development process. Quickly and accurately benchmarking the performance of various semiconductor technologies using small periphery devices contributes to reducing development costs and expediting time to market. This can be achieved using hybrid-active vector receiver load-pull systems providing $|\Gamma_L|$ = 1 at the DUT reference plane at E- and W-Band frequencies. The measured vector a and b waves enable the characterization of various DUT parameters, such as delivered input power, output power, power gain and PAE that are not normally available from scalar measurements. This enables higher device characterization accuracy, facilitating more accurate device parameter extraction for better model fidelity.■

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Regarded as a leading instrument for ultra-wideband signal analysis, the R&S FSW signal and spectrum analyzer offers an input frequency range to 90 GHz and a recently introduced option extending the analysis bandwidth to 8.3 GHz.

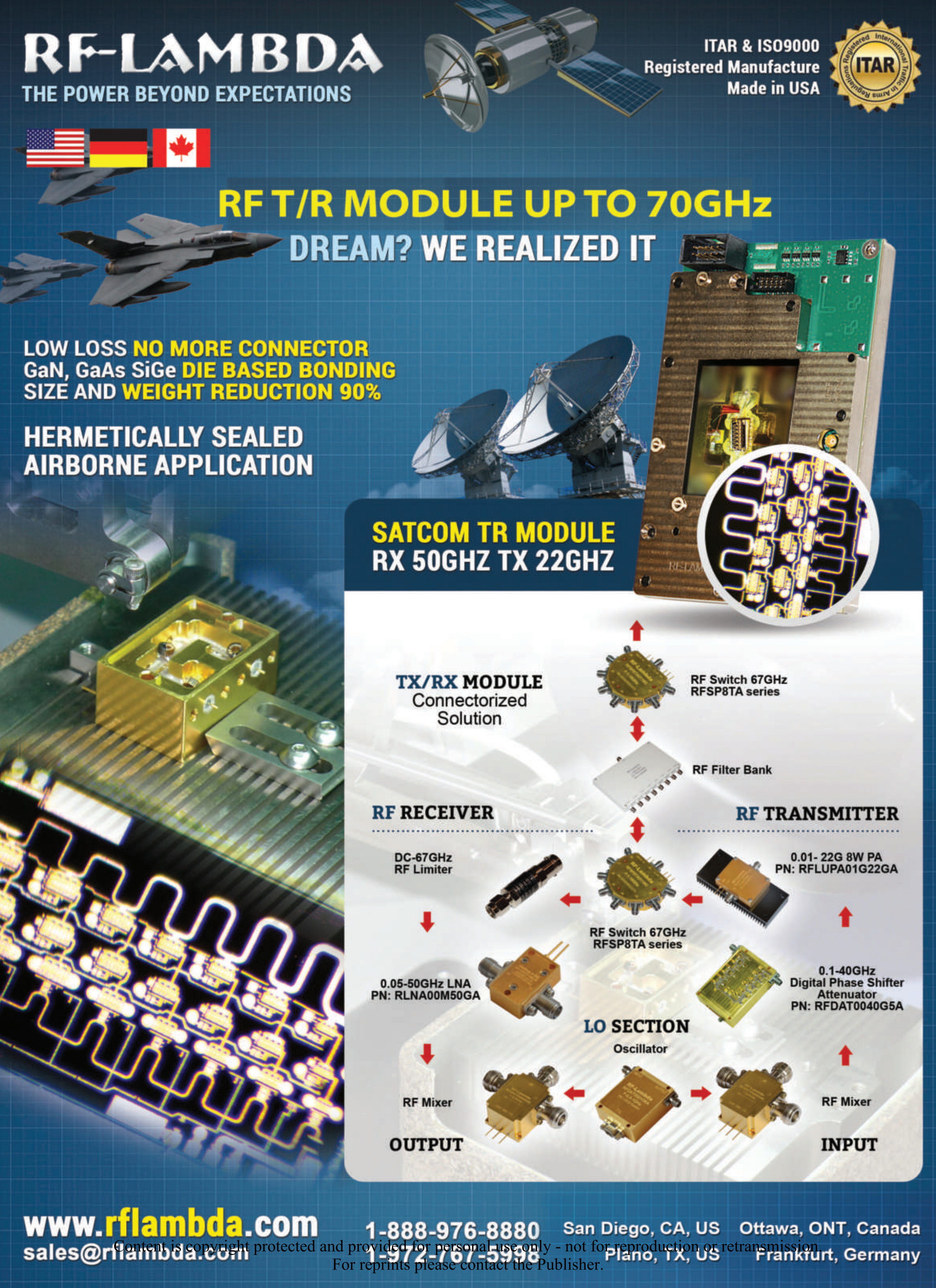
While already standard in radar and communications, bandwidths of 4 GHz or more are becoming common in multiple industries with the trend to higher frequency applications. Traditionally, the approach for signal analysis in these wideband systems has resorted to workaround practices, since a user-friendly, single box solution was not available. Since the high speed analog-to-digital converters needed to sample the modulated signal were only available in oscilloscopes, workaround solutions used a signal and spectrum analyzer as a wideband down-converter feeding the signals to an oscilloscope.

While this approach produces good results, Rohde & Schwarz offers a more convenient alternative: a single box solution offering ease of automation and full datasheet capabilities for both signal and spectrum analysis. The R&S FSW signal and spectrum analyzer now includes options to extend the internal signal analysis bandwidth to 4.4, 6.4 and 8.3 GHz. The R&S FSW enables users to take advantage of the analyzer's wide dynamic range and high sensitivity in a single instrument. With its precision measurement and low error vector magnitude performance supporting large modulation bandwidth, the R&S FSW provides a future-proof solution for the measurement challenges of many applications.

SAFETY ON THE ROAD

In radar systems, wider bandwidth improves range resolution. Applied to automotive radar, frequency modulated continuous wave radars are considered the state-of-the-art architecture, as they provide extremely good resolution at short range. Current automotive radar systems operate in E-Band (76 to 77 or 77 to 81 GHz) with bandwidth as high as 4 GHz (see ***Figure 1***). This performance imposes stringent requirements on the signal processing chain, particularly the analog components, which must have better signal-to-noise ratio and frequency stability. The R&S FSW signal and spectrum analyzer offers the frequency coverage and bandwidth to assess the performance of these high performance systems.

With higher signal bandwidth and the growing number of radar sensors on vehicles, the risk of interference among sensors is increasing. Signals from neighboring vehicles can limit radar sensor functionality and, worst case, cause driver assistance sys-



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ITAR
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RF T/R MODULE UP TO 70GHz
DREAM? WE REALIZED IT
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SATCOM TR MODULE
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Solution
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RF TRANSMITTER
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RF Limiter
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Ottawa, ONT, Canada
Frankfurt, Germany

Fig. 1 Analysis of automotive radar FMCW signal at 77 GHz.

Fig. 2 IEEE 802.11ay channel bonded signal spanning 8 GHz.

tems to make incorrect decisions. To avoid this, precision measurements are necessary to identify potential faults. Validating compliance with ETSI and FCC standards requires both signal and spectrum analysis to measure the occupied bandwidth and detect spurious emissions. The R&S FSW signal and spectrum analyzer offers both signal and spectrum analysis.

COMMUNICATIONS

In communications, increasing frequency and modulation bandwidth has a long history, as each new generation of technology provides higher content. 5G introduced the use of wideband channels at mmWave frequencies in handsets. Digital predistortion (DPD) is widely used to correct the nonlinearities of power amplifiers. To analyze the performance of DPD systems, both the user channel and adjacent channels must be measured. For an 800 MHz multicarrier 5G NR signal, this requires up to 4 GHz analysis bandwidth. The 802.11ay standard for Wi-Fi supports channel bonding, which leads to signals with bandwidths greater than 8 GHz at 60 GHz (see ***Figure 2***). To support the data rates enabled by 5G, Gbps point-to-point radio links are used at E- and D-Band, and R&D is beginning on communications links in the sub-THz bands.

Future high throughput satellites, being designed to support Tbps capacity, will also move to higher frequencies and wider bandwidths, with bandwidths expected to reach 6 to 8 GHz at frequencies to 90 GHz.

DEFENSE

A radar system designed for military applications will typically change its modulation and frequency with each pulse and hop across a wide frequency range. These pulse-to-pulse changes reduce the probability of intercept by enemy reconnaissance and subsequent jamming. Jammers attempt to reduce the sensitivity of the radar or render it completely blind by using wideband noise or frequency agile signals. The R&S FSW's wideband acquisition capability can analyze wideband frequency hops, for testing both radar and jamming systems.

With the expanded analysis bandwidth options and dedicated measurement applications tailored to meet industry needs, the R&S FSW is ready for whatever direction technology takes. As a testament to the instrument, Rohde & Schwarz is relying on the wide analysis bandwidth capabilities of the R&S FSW for its own R&D on new wireless systems.

VENDORVIEW

Rohde & Schwarz
Munich, Germany
www.rohde-schwarz.com

Managing Many Devices and Multiple Standards in the Connected Home

Qorvo, Inc.
Greensboro, N.C.

The number of connected devices in our homes and cars continues to rise, and we increasingly rely on them for convenience, comfort, health and safety (see ***Figure 1***). Although connected, these devices communicate using different standards depending on the application. In addition to Wi-Fi, several IoT standards have been developed: Bluetooth® Low Energy (LE), Zigbee® and Thread®. More technologies are coming, such as the Connected Home Over IP initiative, which combines several technologies—802.15.4 and Bluetooth LE—into a single standard.

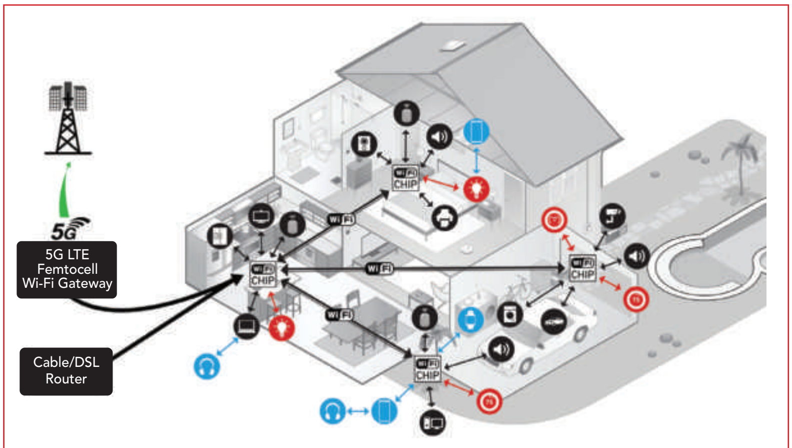
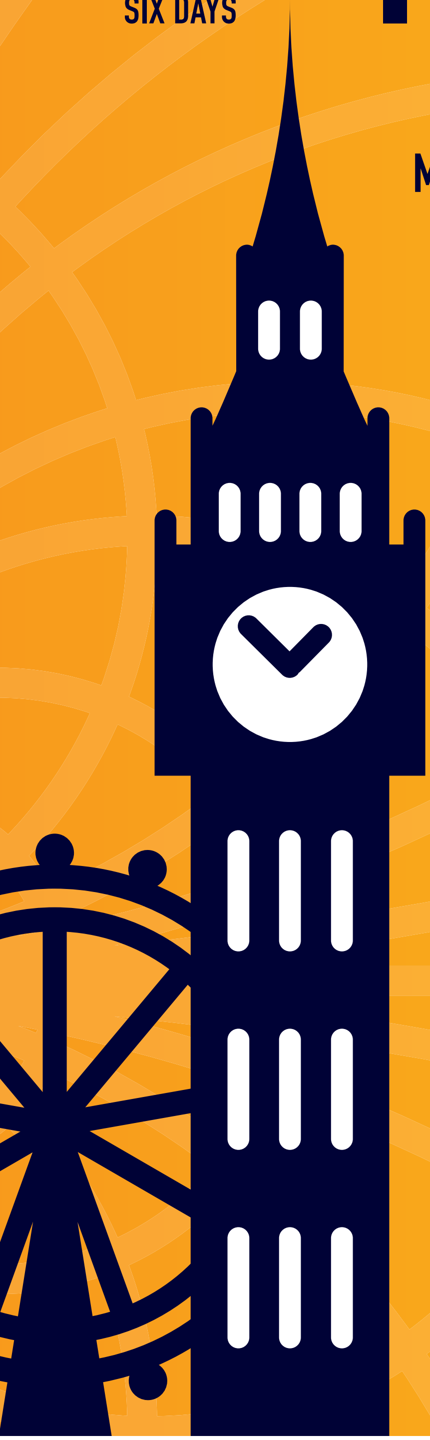


Fig. 1 **The "smart" home has an array of devices connected using various wireless standards.**

These low-power, low data rate wireless standards are commonly used in products from door locks to LED lights to appliances. The multiple wireless technologies force product designers to decide, in advance, which technology to use and that choice affects the product's design. The increasing options make choosing among them and future-proofing products more challenging. While communications devices do have some form of dynamic multi-protocol (DMP) support, it requires tradeoffs; DMP is not sufficient to realize the full benefits of the connected home. Truly seamless connectivity can only be achieved with the capability to simultaneously listen and hear all the devices on the network, not just a few.

To address this challenge, Qorvo has developed ConcurrentConnect™ technology, the next step in managing the multiple wireless standards in the home. ConcurrentConnect technology supports multiple networks on different protocols, such as Zigbee + CHIP or Zigbee + Bluetooth LE to a smartphone or CHIP + Bluetooth LE Mesh. With ConcurrentConnect technology, the consumer experiences seamless operation of their devices without loss of performance, regardless of the wireless protocol.



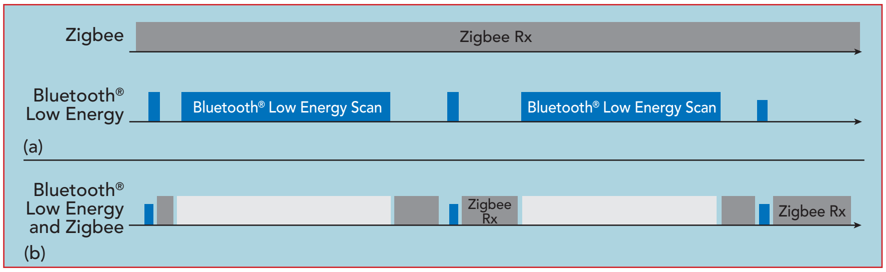


Fig. 2 Separate Zigbee and Bluetooth LE nodes operating independently (a). ConcurrentConnect support enables concurrent listening and faster switching between standards (b).

Consider a network combining ZigBee or Thread with Bluetooth LE devices and without ConcurrentConnect support. The wireless node must switch back and forth between standards, communicating with one at a time, the other blocked until the medium becomes free (see ***Figure 2a***). In addition to inefficiency, switching between the standards can drop the link and increase latency, limiting the data exchanged through both networks. With ConcurrentConnect technology, the node has concurrent listening capability and near-instantaneous switching from Bluetooth LE to Zigbee or Thread, with little dropped communication, if any (see ***Figure 2b***). Communication between devices is faster, more efficient and scalable, yielding more data packets exchanged. ConcurrentConnect support improves the exchanges among devices using different protocols to levels not achievable using separate nodes, providing designers the ability to support multiple standards more easily.

Qorvo has integrated ConcurrentConnect technology into a single IC, single radio solution and software development kit (SDK). In addition to managing data traffic from multiple standards at the same time, with no detectable latency, ConcurrentConnect technology reduces the part content for a product design, which enables smaller, sleeker form factors and lower product cost.

Developing a single radio to support multiple protocols simultaneously posed major hardware and software challenges. Each protocol has unique specifications governing how and when devices listen to incoming packets and transmit outgoing packets. Some protocols define fixed time intervals during which the radio predicts when it should switch to the appropriate frequency. Most of the time—especially while listening, before the connection phase, while detecting candidates for connection—the radio must constantly detect incoming packets asynchronously, without prior knowledge of when it should open its receive window for incoming packets. Additionally, Qorvo's solution required a simple interface, so developers could be agnostic to the various protocols.

WHY IT WORKS BETTER

Qorvo's concurrent listening technology shifts the paradigm. It enables asynchronous interleaving of packets from different protocols on the hardware, the device virtually listening to multiple protocols at the same time, with no blind spots while listening. This maximizes use of the medium, as ConcurrentConnect technology maintains a synchronized connection, at the same time listening to asynchronous events from multiple protocols. It is abstracted with a SDK, which provides straightforward APIs so the application developer can easily integrate the capability into new products.

The key differentiator of ConcurrentConnect technology compared to DMP is predictability versus unpredictability. DMP is based on the predictability of the packets received and sent. It requires knowing the times to switch to Bluetooth LE, then back to Zigbee or Thread, for example. ConcurrentConnect supports unpredictability: simultaneous synchronous and asynchronous operation. It uses the unique hardware features in Qorvo's platform to detect and identify packets efficiently. Once

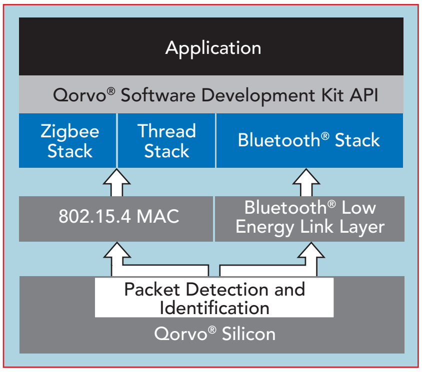


Fig. 3 **ConcurrentConnect technology architecture with Zigbee and Bluetooth LE.**

detected, each packet is identified, real-time, by the hardware, which sends the packet to the appropriate protocol stack, eliminating the need for additional, routing logic at the higher software layers (see ***Figure 3***). The SDK enables combinations of the preferred protocols for the application, so the application "thinks" it has its own radio. This simplifies application development and enables developers to focus on the differentiators of their products.

BENEFITS

Supporting high frequency data transfers among multiple devices, ConcurrentConnect technology enables new use cases across the home network—gateways, hubs and end devices. A gateway can seamlessly switch among the standards and protocols on the home network, enabling more devices using different standards to be connected and controlled. Device owners are no longer locked into a prior wireless technology when expanding their home applications. With gateways able to understand multiple protocols at the same time, enabling a mix of connected devices, new IoT use cases enabled by the end devices themselves become possible. For example, devices can be connected to Bluetooth LE Mesh and Zigbee or Thread networks at the same time, or a Bluetooth LE-based smartphone can be connected in a Zigbee or Thread network.

The ability to listen concurrently also enables new uses by combining protocols. For example, a device connected with Zigbee or Thread can be aware of its location by scanning for beacons from Bluetooth LE trackers. Connected lighting will benefit,

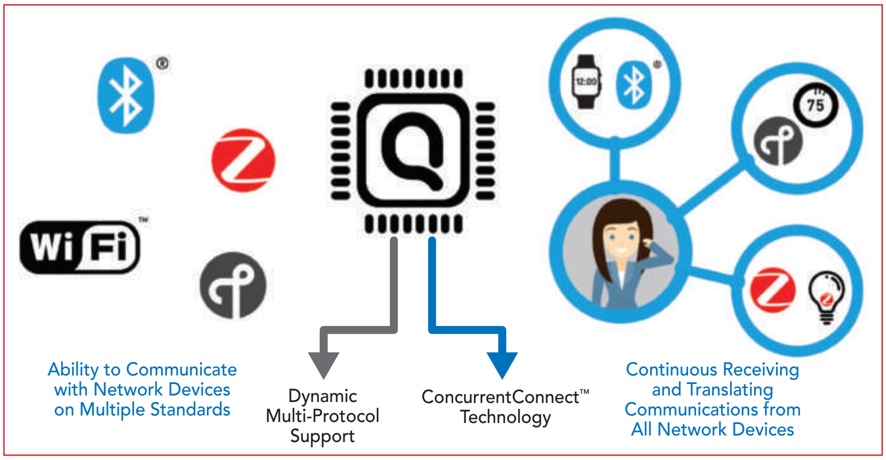


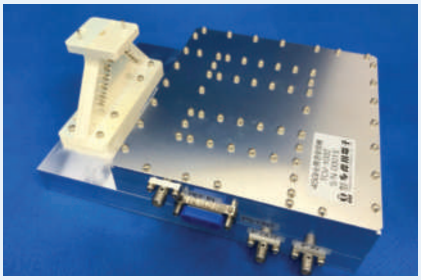
Fig. 4 **Benefits of ConcurrentConnect technology.**

as ConcurrentConnect technology enables a light to be controlled by Zigbee, Thread and Bluetooth LE switches simultaneously. Motion sensors, thermostats and other sensors and control devices have similar capabilities.

With multiple standards and new devices developing quickly, Qorvo's patented ConcurrentConnect technology provides the next step beyond DMP (see ***Figure 4***). For IoT applications, it offers efficiency and flexibility for greater concurrence and interoperability among multiple wireless protocols and standards. It is no longer necessary for consumers to be locked to one standard and compromise future connection options. Almost any use case becomes possible.

VENDORVIEW

Qorvo, Inc.
Greensboro, N.C.
www.qorvo.com



45 GHz Transceiver Platform Supports Custom Design Spins

Tamagawa Electronics' (TME) 45 GHz frequency division duplexing transceiver was developed as a mmWave radio communications system and a platform for design spins to meet custom applications.

The transceiver is a single conversion design for both transmit and receive. A 2 GHz input signal drives a harmonic mixer, where it is up-converted to 45 GHz. The signal is then filtered and amplified before feeding an isolator and duplexer. The receive signal passes through the duplexer and separate isolator before being amplified and down-converted to 2 GHz with an image rejection mixer. The transceiver includes a 10 GHz phase-locked oscillator which provides the local oscillator (LO) for the up- and down-conversion mixers. The 10 GHz LO directly drives the harmonic mixer in the transmit path and a x4 multiplier feeding the image rejection mixer in the receive path. An external 10 MHz reference is required for the phase-locked oscillator.

The transceiver's output power is typically 27.5 dBm at 1 dB compression and is guaranteed to be at least 23 dBm. Typical gain is 47 dB, and spurs below −65 dBc. The receiver has 25 dB typical gain with 12 dB noise figure and spurs below −60 dBc. The 2 GHz ports use SMA connectors, and the 45 GHz port connects to the antenna with WR19 waveguide. The transceiver is compact, with all circuitry on a single printed circuit board, which makes the unit half the size of a radio built with discrete coaxial modules.

For more than 50 years, TME has been providing high-quality, high performance, cost effective components and subsystems for wireless communications and broadcasting. TME's products comprise attenuators, terminators, filters, switches, power divider/combiners, directional/hybrid couplers, amplifiers, oscillators and frequency synthesizers.

Tamagawa Electronics
Kanagawa, Japan
www.tmeleus.com

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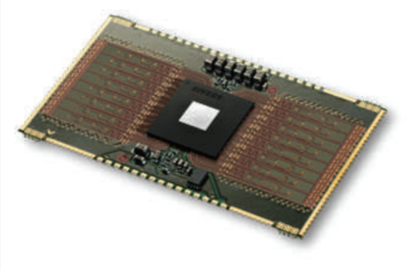


2D Beam Steering Module Covers Full 57–71 GHz Unlicensed Band

Sivers Semiconductors has released a 2D beam steering module, comprising the antenna and analog radio, covering the full 57 to 71 GHz unlicensed band. The BFM06009 was developed for fixed wireless access (FWA) applications and supports the 802.11ad and 5G NR-U, TDD standards and data rates to 10 Gbps.

The BFM06009 combines the performance of the TRX BF/01 RFIC with an innovative antenna design in a single module, which provides 2D beam steering and transmit power of approximately +40 dBm. Integrating the antenna and RFIC simplifies radio design, reduces the total cost of ownership and supports FWA systems for many applications.

The unique antenna design provides consistently flat performance over the full 14 GHz frequency band from 57 to 71 GHz. Antenna gain is within 1.5 dB, with transmit power between 39 and 40 dBm on boresight. The antenna beam can be steered to cover >100 degrees in azimuth and >50 degrees in elevation, enabling a wide range of placement options.

The RFIC module has a zero IF baseband interface, integrated analog baseband and autonomous calibration. It is compatible with any baseband solution that supports zero IF and has been demonstrated to work seamlessly with Renesas' RWM6050/6051 modems.

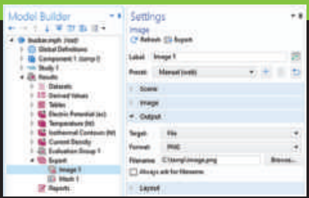
To support volume manufacturing, castellated vias provide the physical and electrical interface between the beam steering module and the printed circuit board of the next higher assembly. For customers using earlier Sivers Semiconductors modules, an adapter board is available to ensure backward compatibility.

Sivers Semiconductors AB
Kista, Sweden
www.sivers-semiconductors.com/sivers-wireless

How to Run COMSOL Multiphysics® from the Command Line

Walter Frei discusses work within the user interface of the COMSOL Multiphysics® software, where you can augment your model file with a method that can automate quite a bit of model setup and evaluation from the command line.

COMSOL
http://bit.ly/3pSCZiS



Simulate Early for Better EW Results

Learn about the available technological approaches for EW signal and environment simulation, and the latest progress in flexible, high-fidelity solutions. Get the application note today.

Keysight Technologies, Inc.
https://bit.ly/38hxsMU

You Have a Filtering Job to Do—We Have the Right Candidate for You

When designing an RF or microwave application, you will always need some level of filtering to attenuate or remove unwanted signals.

Knowles Precision Devices
knowlescapacitors.com

Selecting a USB Power Sensor

This short video is designed to guide customers to the best RF power sensors for their application, covers True-RMS, peak and pulse sensors.

LadyBug Technologies, LLC
youtu.be/JKC5a-DSPuM

Using the Dam & Fill Method to Protect Electronic Components

One of the ways to protect components on a circuit board is by utilizing the dam-and-fill process. Watch it in action in this video.

Masterbond
youtube.com/watch?v=teuuVN0yv_s

New App by MIcable

MIcable Microwave Cable & Cable Assembly Solution Tools is an easy app for engineers to find the appropriate cable assembly for their different applications!

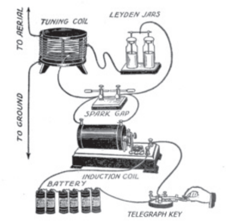
MIcable
micable.cn

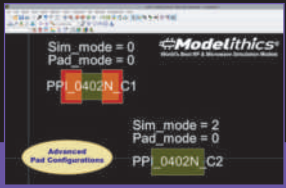
Titanic's Wireless Officer and the Spark Gap Telegraph

Jacqueline Hochheiser, Corporate Communications, Mini-Circuits, shares the telegraph's contribution to maritime communication and how Titanic's telegraphist contributed to the ship's untimely demise in a new blog post.

Mini-Circuits

blog.minicircuits.com





Modelithics 5-Minute Feature Video: Advanced Pad Configurations

The Modelithics' video, Advanced Pad Configurations, explains how to manage component solder pads for models within the Modelithics COMPLETE Library, enabling designers to perform effective EM/circuit co-simulations.

Modelithics

modelithics.com/Literature/Videos

PPI Announces C.A.P. Online Engineer Tool

Passive Plus, Inc.'s (PPI) brand new online Capacitor Application Program (C.A.P.) helps engineers and designers select capacitors according to parameters such as cap value and frequency.

Passive Plus, Inc.

passiveplus.com

Turnkey Microwave Switch Subsystems Service

Pickering Test engineers can turn your high level requirements for a microwave switching subsystem into a fully integrated solution. Provide them with your unique configuration and they will deliver a well-defined supportable end product that satisfies your microwave testing needs.

Pickering Interfaces Inc.

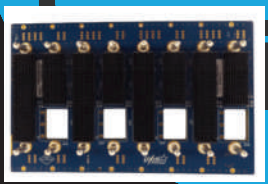
pickeringtest.com/turnkey

Web Update for RF Products

New website sections for OpenVPX chassis managers and VITA 67 products for RF interfaces across the COTS backplanes/chassis are now available. Versions are designed with SOSA implementation in mind.

Pixus Technologies

pixustechnologies.com/products



SSBB Connectors Demo

Southwest Microwave SuperMini Board-to-Board (SSBB) solutions optimize interconnect performance for board-to-board stacking applications. See a demonstration of how these SSBB connectors can accommodate high misalignment of +/-10 mils axial with no resonance.

Southwest Microwave

mpd.southwestmicrowave.com

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COMPONENTS

Solid-State Switch

VENDORVIEW

SK4-7531148030-1010-R1-M is a MMIC based, solid-state single pole, four throw (SP4T), reflective type switch with a TTL driver that operates between 75 and 110 GHz. This model offers a small form factor by integrating the switch and driver into a common housing and achieves a low insertion loss by minimizing circuit loss transmission losses. The SP4T switch offers 30 dB port-to-port isolation with a switching speed of up to 100 nanoseconds. The input and output connectors of the switch are WR-10 waveguides with standard UG-387/U-M anti-cocking flanges.

Eravant
www.eravant.com

RF Circulators/Isolators

VENDORVIEW

Fairview Microwave Inc. has extended its selection of high performance circulators/isolators that are ideal for 5G telecommunication, satellite communication, automotive radars, aerospace applications and point-to-point radios. Fairview Microwave's expanded line of RF circulators/isolators includes 75 models that cover operating frequency ranges up to 42.5 GHz. They provide excellent isolation and low insertion loss and are available with same-day shipping and no minimum order quantity. These circulators/isolators boast a maximum power rating of up to 100 W and are offered in SMA, N-type, 2.4 mm and 2.92 mm connectorized designs.

Fairview Microwave Inc.
www.fairviewmicrowave.com

6 to 18 GHz Bi-Directional Detector

Model SA-06-06 is a 37 dB bi-directional detector. It has 1.2 ± 0.2 V (100 W CW) forward detection voltage, 15 percent maximum detection voltage flatness, ± 2.5 percent maximum (-50 ~ +55°C) temperature change rate, 1.4: 1 maximum main line VSWR, 0.5 dB maximum insertion loss, 37 ± 1 dB Max. coupling, 10 dB minimum directivity. The CW power is 200 W average. The size is 50 × 40 × 20 mm.

Fujian MIcable Electronic Technology Group Co. Ltd.
www.micable.cn

30 W Loads

VENDORVIEW

MECA's low PIM (-161 dBc typical) 30 W loads feature industry leading PIM verified at 1,900 MHz at -155 dBc minimum and are thermally compensated to handle full rated power to 85°C, covering 0.380 to 2.700 GHz.

MECA Electronics Inc.
www.e-meca.com

Limiter Passive

VENDORVIEW

PMI model: LM-10M62G-20DBM-1W-24FF is a limiter passive that has been designed for minimal insertion loss that operates over the 10 MHz to 62 GHz frequency range. This model can handle an input power of 1 W CW and 4 W pulse peak with 1 µs PW, 1 percent duty cycle, this limiter uses 2.4 mm female connectors.

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

Pickoff Tee

RLC Electronics has recently launched a DC to 26.5 GHz pickoff tee with 15 dB of pickoff loss. The units provide extremely broadband signal monitoring in a very small package (0.54" × 0.39" × 0.32"). Other/custom pickoff losses are available if desired. Units are offered in standard

New**Products**

frequency ranges from DC to 18 GHz, DC to 26 GHz and DC to 40 GHz. RLC offers both catalog options and customized options and can provide form factor drop-in replacement/obsolescence assistance as needed.
RLC Electronics Inc.
www.rlcelectronics.com

CABLES & CONNECTORS

Flexible Coaxial Cable

VENDOR**VIEW**

Mini-Circuits' model FL47-6VM+ flexible coaxial cable assemblies are available in a variety of lengths for low loss interconnections in commercial, industrial and military systems. The RoHS-compliant cables can form tight bends, with minimum static bend radius of 5 mm and minimum dynamic bend radius of 10 mm. The durable 50 Ω cables are constructed with PTFE dielectric, silver-plated copper-clad steel center conductor and tin-soaked copper braid outer shield. They are supplied with 2.4 mm male coaxial connectors for sure, broadband low loss connections.
Mini-Circuits
www.minicircuits.com

Waveguide-to-Coax Adapters

VENDOR**VIEW**

Pasternack has expanded its line of euro-style flange, waveguide-to-coax adapters that are ideal for satellite communications, radar, wireless communications and test instrumentation applications. These new waveguide-to-coax adapters feature waveguide sizes that range from WR-22 to WR-430, European IEC standard flanges (including UBR square cover, UDR and PDR types), right-angle and end-launch coaxial connector options and N-type, SMA, 2.92 mm and 2.4 mm connector choices. These new waveguide-to-coax adapters transform waveguide transmission lines into 50 ohm coaxial lines.
Pasternack
www.pasternack.com

AMPLIFIERS

Low Noise MMIC Amplifier

VENDOR**VIEW**

The HMC8412 is a self-biased low noise MMIC amplifier that operates from 0.4 GHz to 10 GHz. The amplifier provides 15 dB gain, 1.2 dB noise figure and a typical output third-order intercept of 32 dBm. The RF input and output are internally matched to 50 Ω. RF blocking caps and bias choke are integrated on chip saving significant board space. The HMC8412 is housed in a 2 × 2 mm surface-mount package and is also available as die.
Analog Devices
www.analog.com

Solid-State Amplifier

VENDOR**VIEW**

Model 6000W1000 is a self-contained, air-cooled, broadband, completely solid-state amplifier designed for applications where instantaneous bandwidth and high gain are required. Push-pull circuitry is utilized in all high-power stages in the interest of lowering distortion and improving stability. Model 6000W1000, when used with an RF sweep generator, nominally provides over 6,000 W of RF power. Model 6000W1000 is equipped with a digital control panel which provides both local and remote control of the amplifier.
AR RF/Microwave Instrumentation
www.arworld.us

Solid-State PA System

VENDOR**VIEW**

Exodus AM-P2107ADB-2 is a superb 1 to 18 GHz, 50 W power amplifier (PA) system. This dual-band amplifier features 47 dB minimum gain, Type N female RF input, sample and RF output ports. Built-in VVA circuits for gain control local and remote functionality, designed for high-reliability and ruggedness in a compact 4U chassis. This system is suitable for all industry testing standards requiring high power such as EMI/RFI General and specialized test equipment requirements.
Exodus Advanced Communications
www.exoduscomm.com

GaN-on-SiC Transistor

Richardson RFPD Inc. announced the availability and full design support capabilities for a new RF power GaN transistor from NXP Semiconductors. The MRF24G300HS is a 300 W CW GaN transistor designed for industrial, scientific and medical applications at 2,450 MHz. It offers 73 percent drain efficiency at 2,450 MHz, and the high-power density of GaN enables the device to reach high output power in a small footprint.
Richardson RFPD Inc.
www.richardsonrfpd.com

High Efficiency PA Family

The SKY66317-11 is a highly efficient, wide instantaneous bandwidth, fully input/output matched PA with high gain and linearity. The compact 5 × 5 mm PA is designed for FDD and TDD 4G LTE and 5G

systems operating from 2,496 to 2,690 MHz. The active biasing circuitry is integrated to compensate PA performance over temperature, voltage and process variation. The SKY66317-11 is part of high efficiency, pin-to-pin compatible PA family supporting major 3GPP bands.
Skyworks
www.skyworksinc.com

SYSTEMS

OpenVPX Chassis Platform

Pixus Technologies has provided the fastest known customized OpenVPX backplane/chassis design in the market. The system was utilized in a military data center installation. The 9U RiCool chassis platform for 6U OpenVPX boards features dual hot-swappable 191 CFM fans for cooling up to 2,500 W. The design allows the use of rear transition modules in all slots. Rear-pluggable PSU's provide power for the VPX and custom rails, available in various wattage and output options.
Pixus Technologies
www.pixustechnologies.com

SOURCES

Ultra-Low Phase Noise Signal Generator

The APLCXX is an agile ultra-low phase noise signal generator from 100 kHz to 12.75 (APLC12), 20 (APLC20) or 40 GHz (APLC40) with excellent harmonic and spurious performance. The signal source is available as mountable module or in a compact enclosure with display and front panel control. Using the FCP—fast control port, frequency and amplitude, the unit can be switched within less than 10 µs.

AnaPico
www.anapico.com

Low Cost CRO VCO

VENDORVIEW

The new CRO6550X2-LF utilizes a doubled CRO oscillator design to cover 6550 MHz within a tuning window of 0.3 to 4.7 VDC. This ceramic resonator VCO features exceptionally low phase noise of -102 dBc/Hz at 10 kHz and better than -125 dBc/Hz at 100 kHz offset. Besides the spectral purity, making the CRO6550X2-LF even more remarkable is that it is available in Z-COMM's standard MINI-16-SM package measuring 0.5 x 0.5 × 0.22 in. The CRO6550X2-LF is well suited for satellite communication systems requiring unmatched performance levels.
Z-Communications Inc.
www.zcomm.com

SOFTWARE

Microwave Global Models™

VENDORVIEW

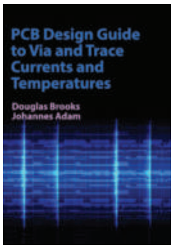
Modelithics Inc. announced the availability of new broadband Microwave Global Models™ for Vishay Intertechnology's CH02016, CH0402 and CH0603 surface-mount chip resistor families. The new models are available within the Modelithics COMPLETE Library™ as well as the Modelithics mmWave & 5G Library. For Vishay's CH02016, CH0402 and CH0603 surface-mount chip resistor families, each model offers part value-, substrate- and solder-pad-scalability and is validated to 67 GHz, making them well suited for mmWave applications such as next-generation 5G networks.

Modelithics Inc.
www.modelithics.com

Trace Width Calculator

Sierra Circuits Inc., a premier manufacturer of prototype PCBs, has launched the Trace Width Calculator. This tool incorporates a unique three-in-one feature to calculate the trace width, maximum current capacity and temperature rise above the ambient for both internal and external layers. This calculator abides by the latest IPC-2152 standard.
Sierra Circuits Inc.
www.protoexpress.com

MICRO-ADS



PCB Design Guide to Via and Trace Currents and Temperatures

Douglas Brooks
Johannes Adam

"This book provides a good introduction to the complex field of reliability engineering as well as a useful reference for more experienced professionals. I found the examples given throughout the text to be practical and relevant to real-world problems that are often encountered in the field. The examples also provide support to understanding the material and applying the various analytical methods."

—Francesco Palmeri,
Reliability Engineering and Asset Management Professional

A very important part of printed circuit board (PCB) design involves sizing traces and vias to carry the required current. This exciting new book explores how hot traces and vias will be and what board, circuit, design and environmental parameters are the most important. PCB materials (copper and dielectrics) and the role they play in the heating and cooling of traces are covered. The IPC curves found in IPC 2152, the equations that fit those curves and computer simulations that fit those curves and equations are detailed.

Sensitivity analyses that show what happens when environments are varied, including adjacent traces and planes, changing trace lengths and thermal gradients are presented. Voltage drops across traces and vias, the thermal effects going around right-angle corners and frequency effects are covered. Readers learn how to measure the thermal conductivity of dielectrics and how to measure the resistivity of copper traces and why many prior attempts to do so have been doomed to failure. Industrial CT scanning, and whether they might replace microsections for measuring trace parameters, are also considered.

To order this book, contact:

Artech House
www.artechhouse.com
Email: artech@artechhouse.com
US 800-225-9977
UK +44 (0)20 70596 8750

ISBN: 978-1-63081-860-9
246 pages
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https://us.artechhouse.com/PCB-Design-Guide-to-Via-and-Trace-Currents-and-Temperatures-P2191.aspx

Use code PCB25 to receive 25% discount on this title! (expires 02/28/2021)

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FAX: (301) 371-8832
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Northeastern Reg. Sales Mgr.
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685 Canton Street
Norwood, MA 02062
Tel: (781) 619-1942
FAX: (781) 769-5037
salomendosa@horizonhouse.com

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144 Segre Place
Santa Cruz, CA 95060
Tel: (831) 426-4143
FAX: (831) 515-5444
blandy@mwjournal.com

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

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

France
Gaston Traboulsi
Tel: 44 207 596 8742
gtraboulsi@horizonhouse.com

Israel
Dan Aronovic
Tel: 972 50 799 1121
aronovic@actcom.co.il

Korea
Young-Seoh Chinn
JES MEDIA, INC.
F801, MisahausD EL Tower
35 Jojeongdae-Ro
Hanam City, Gyeonggi-Do
12918 Korea
Tel: +82 2 481-3411
FAX: +82 2 481-3414
yschinn@horizonhouse.com

China
Shenzhen
Michael Tsui
ACT International
Tel: 86-755-25988571
FAX: 86-755-25988567
michaelt@actintl.com.hk

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

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

Hong Kong, Taiwan, Singapore
Mark Mak
ACT International
Tel: 852-28386298
markm@actintl.com.hk

Japan
Katsuhiro Ishii
Ace Media Service Inc.
12-6, 4-Chome,
Nishiiko, Adachi-Ku
Tokyo 121-0824, Japan
Tel: +81 3 5691 3335
FAX: +81 3 5691 3336
amskatsu@dream.com

Ed Kiessling • Traffic Manager • 685 Canton Street, Norwood, MA 02062 • Tel: (781) 619-1963 FAX: (781) 769-6178 • ekiessling@mwjournal.com

FABS and LABS

Akoustis Technologies XBAW® Wafer Fab

Akoustis Technologies is building a new generation of RF filter technology, adding a phase to the history of upstate New York's original technology companies: Corning, Xerox and Kodak. In 2017, Akoustis acquired a MEMS manufacturing facility in Canandaigua, not far from Rochester, to manufacture its XBAW® filters for the Wi-Fi and mobile wireless markets. Xerox had developed the site in the late 1980s as a center for microtechnology. In 2003, after Xerox departed, the Research Foundation for the State of New York made the site a center of excellence to support economic development in the region.

XBAW—Akoustis' patented, high purity piezoelectric bulk acoustic wave (BAW) filter technology—is actually a MEMS device, which made the fab perfect for Akoustis' production manufacturing. Formed in 2014, Akoustis' first years were spent developing the piezoelectric technology underlying the XBAW process. By 2017, company executives were assessing strategic alternatives for volume manufacturing and learned of the Canandaigua operation. Acquiring an existing capability was far faster and less expensive than building a green field operation: Akoustis paid less than $3 million for the building, equipment and 57 acres of land—capitalizing on an investment of $88 million by the previous owners. The fab was already staffed with an experienced technical and operations team, who joined Akoustis and began transferring and optimizing the XBAW process for production, which was qualified in July 2018.

Akoustis uses high purity piezoelectric material for its XBAW filters, which improves performance compared to BAW filters fabricated with poly-crystalline material. XBAW filters offer lower insertion loss, higher power handling and tighter k_t^2 coupling, which extends bandwidth and upper frequency coverage and increases the steepness of the skirts. The higher power handling of XBAW meets the requirements of Wi-Fi access points, small cells and 5G mMIMO base stations, and the XBAW filters are significantly smaller than dielectric resonator filters, which have historically been used.

The number of mask levels for the MEMS-based process is comparable to other BAW processes, so there's no added complexity. Akoustis uses in-process RF testing and high accuracy trimming to tune filter performance and increase yields. The process is compatible with SMT packaging and wafer-level packaging, and wafer-level packaging for mobile applications is currently being qualified.

To support an ambitious production ramp from multiple design wins, the fab is running two shifts while in the middle of a 500 percent equipment capacity expansion, scheduled to be completed by mid-year. With three clean rooms in the 120,000 square foot building, capacity is not constrained by space: the 150 mm fab's capacity is ultimately scalable to 150,000 wafer starts per year, which will support up to 5 billion XBAW filters per year.

Upstate New York's technology base includes well-known semiconductor companies—IBM, GlobalFoundries, ON Semiconductor, Cree—ensuring a pool of experienced technical talent to support Akoustis' growth, and nearby community colleges and universities—Rochester Institute of Technology and Cornell—are sources for recruiting new graduates.

The Akoustis team in Canandaigua is diverse and driven by an innovative, tight-knit culture. They see the impact of their work, the opportunity to make a difference in a small cap company aiming to penetrate a multi-billion dollar market at the center of society's desire to be connected at all times, anywhere on the globe.

www.akoustis.com