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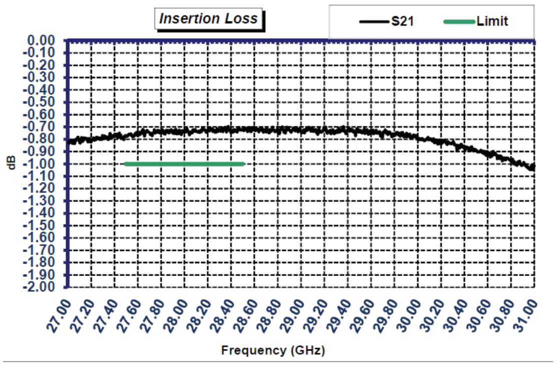

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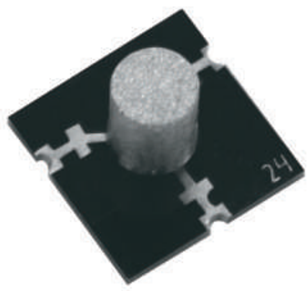

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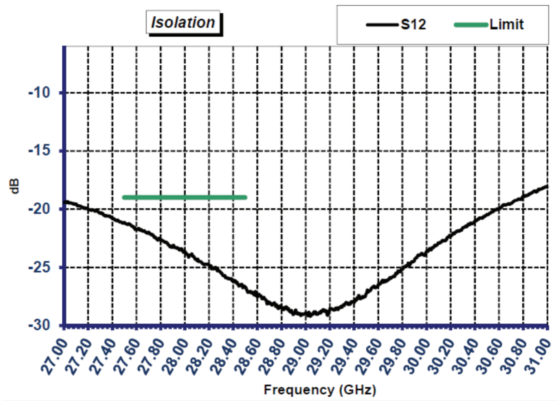

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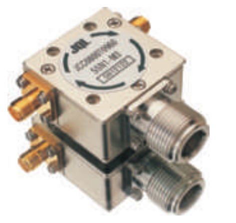

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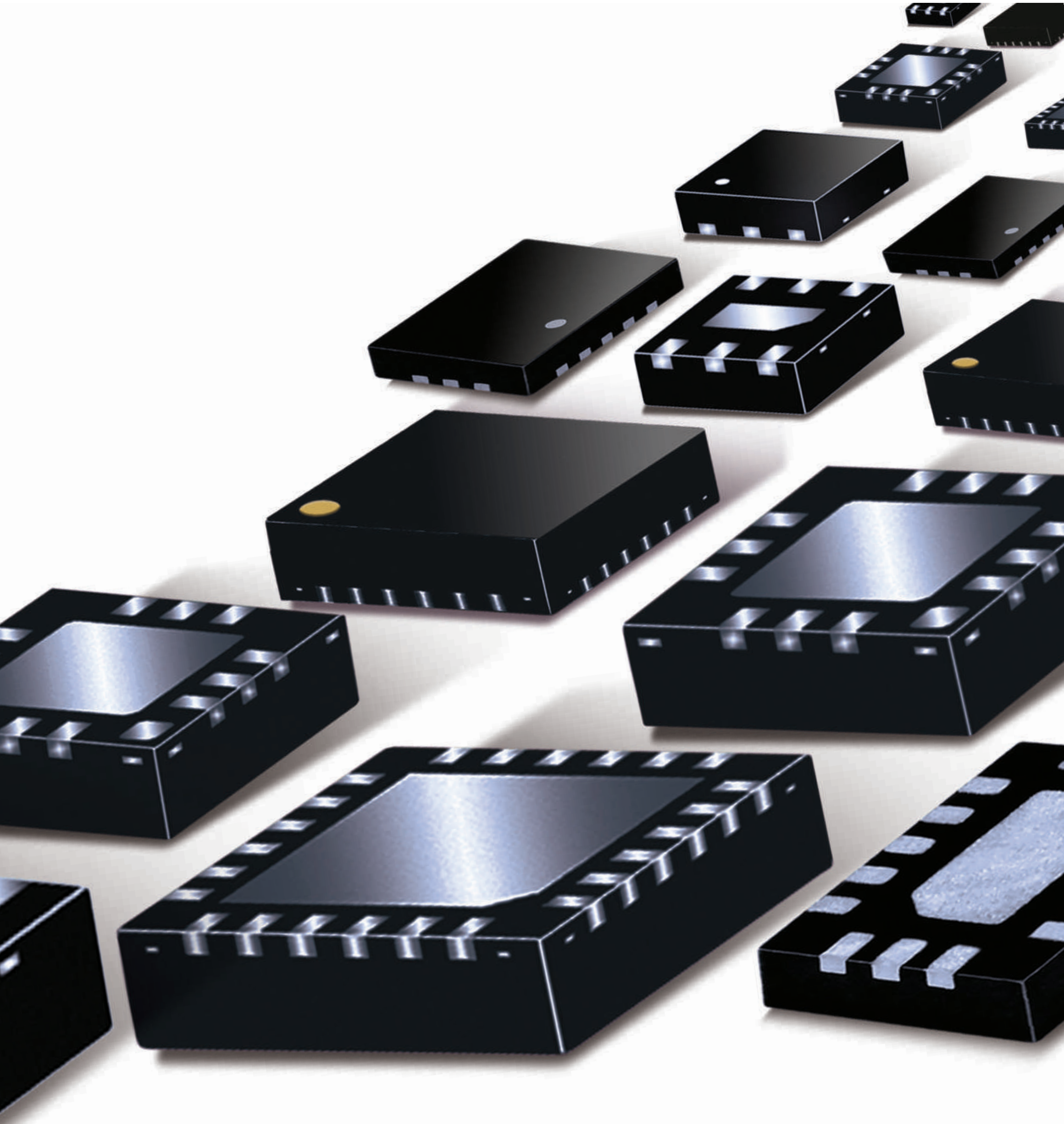

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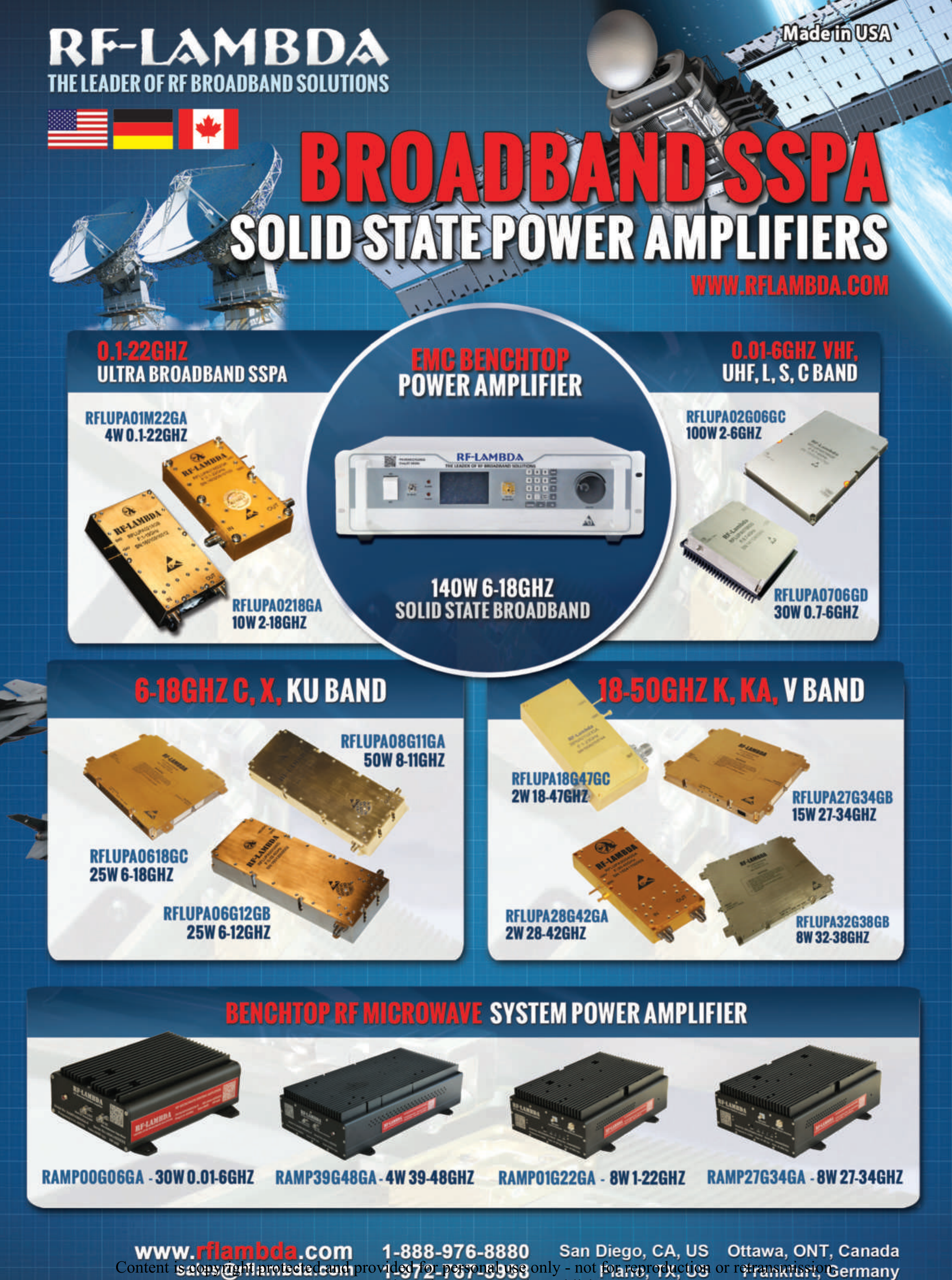
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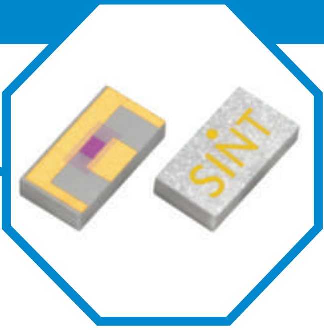

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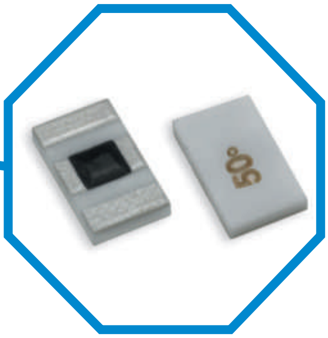

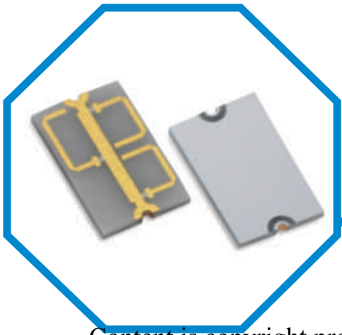

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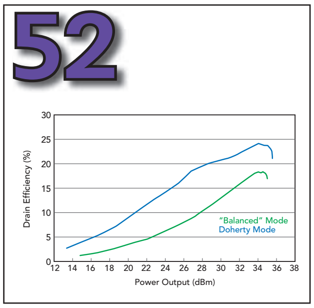

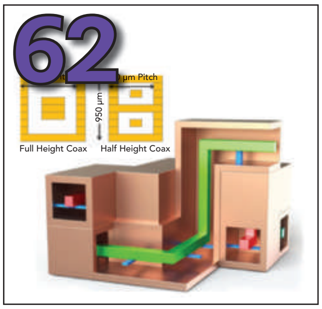

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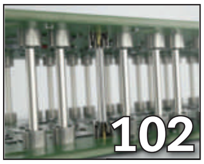

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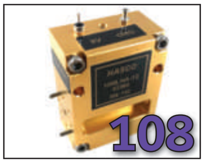

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Spectrum Above 90 GHz for Wireless Connectivity: Opportunities and Challenges for 6G

Didier Belot, José Luis González Jiménez, Eric Mercier, Jean-Baptiste Doré
CEA-Leti, Grenoble, France

The spectrum above 90 GHz is foreseen as a key enabler for the next generation of mobile networks. The large amount of spectrum paves the way for high capacity wireless links. Many challenges still need to be overcome to make this technology a success. This article describes some of the scenarios for the spectrum above 90 GHz, coveted by the cellular industry for 6G. A benchmark of semiconductor technologies is discussed to highlight promising candidates and channel-bonding architectures as a suitable option for the implementation of extremely broadband RF radios with acceptable power consumption. Opportunities, challenges and some recent experimental results of D-Band transceivers implemented in CMOS technologies are discussed.

Next generation wireless networks are imagined to be faster, more reactive, ultra-reliable and denser. Therefore, the exploitation of new and wider bandwidths at higher frequencies is a promising solution toward very high data rates (100+ Gbps) and ultra-low latency (sub-ms). The frequency from 90 to 300 GHz, and the terahertz spectrum above 300 GHz, are definitively foreseen as key enablers for 6G communication systems.[1] Several applications can already be imagined: high capacity back-haul/front-haul; short-range high data rate hot spots and device-to-device Gbps ultrashort-range communications as depicted in ***Figure 1***.

There are many challenges that need to be addressed to achieve high data rate communications for future deployments above 90 GHz. Performance and quality-of-service (QoS) are the main concerns for efficient adoption of these bands by stakeholders. Industrial concerns will be the most demanding in terms of performance and most promising in terms of market adoption. A specific aspect of very high frequency bands is that they will not provide long terrestrial-distances, as propagation losses make them impractical. Therefore, small cells

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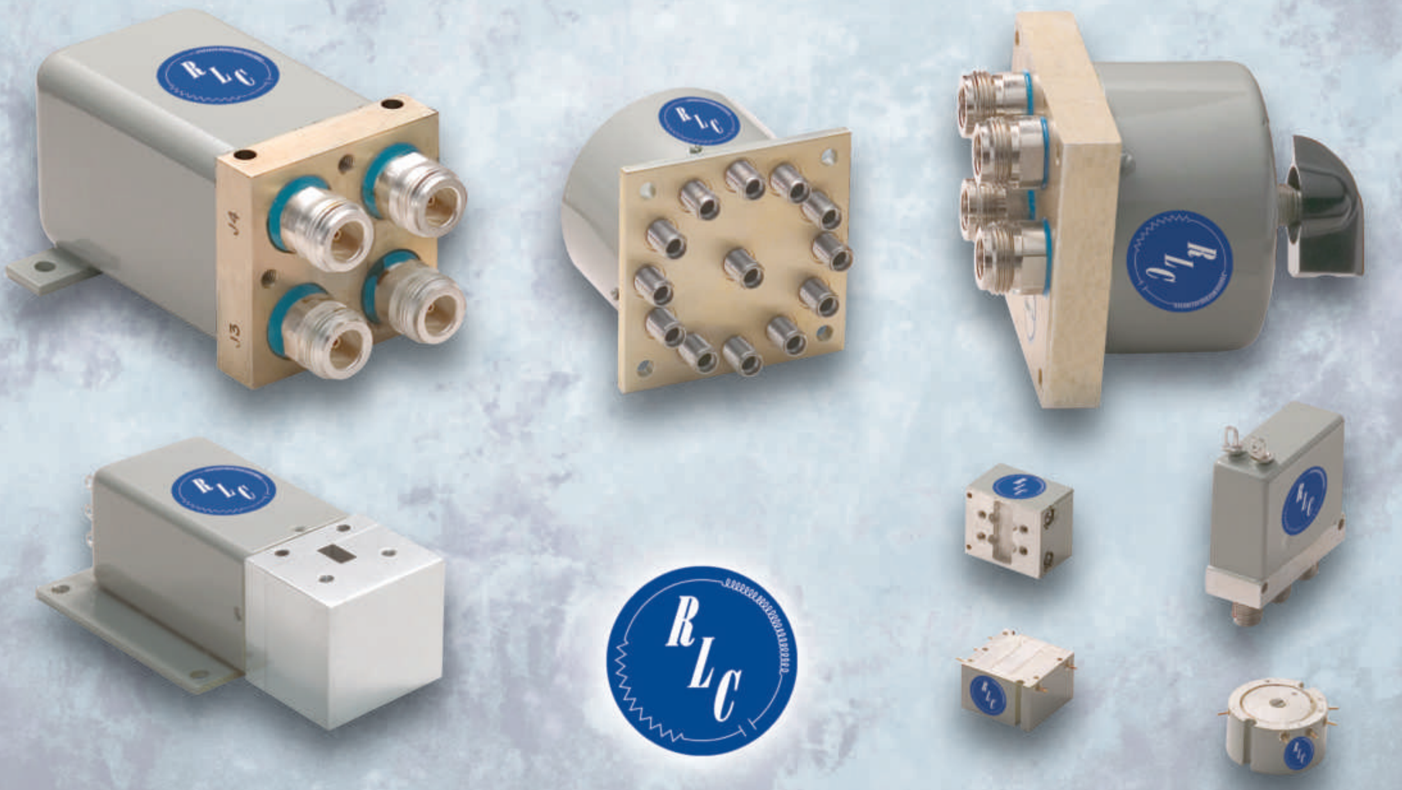

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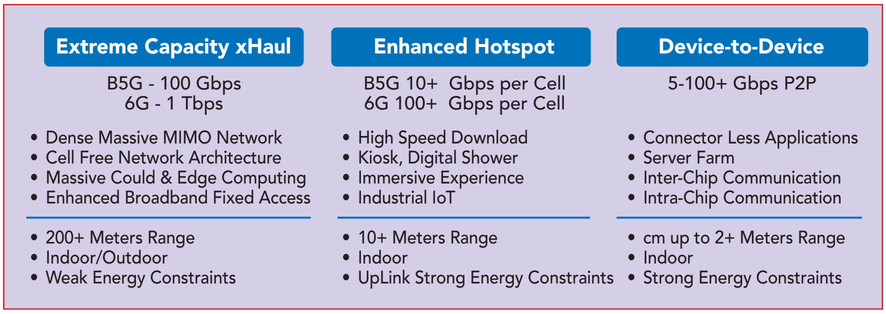

Fig. 1 Different scenarios for above-90 GHz wireless communication.

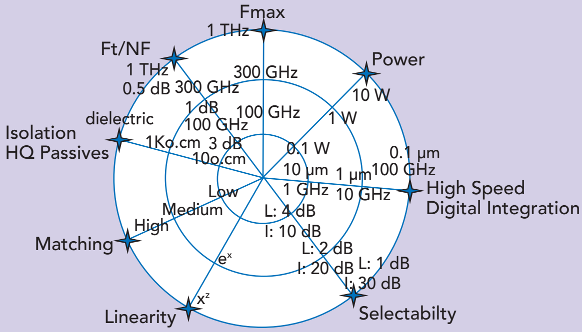

Fig. 2 Process technology target.

are expected to be a key in the network and a direct consequence of this is the higher number of required elements, implying that low-cost and high energy efficiency will be critical goals.

System developments are usually built from the best individual building blocks. However, above 90 GHz, careful attention to the overall architecture must drive the selection of individual metrics and associated performance, closely related to power consumption and cost. Size may also be regarded as a key point as actual sparsity and sustainability will support environmental considerations and social adoption. All these beginning considerations address more challenging than ever targets to address high performance, given that frequency and expected throughput are very high, and bandwidth is very wide. In addition, it must still be possible to integrate all these features into a low-cost semiconductor process.

Starting from the antenna, a key component at these frequencies, directivity becomes a major issue, as user connection relies on narrow "pencil" beam-forming MU-MIMO (multi-user MIMO) providing higher gain, enhanced selectivity and jammer blocking thanks to spatial division multiple access (SDMA). The best antenna architecture will maintain performance but not at the cost of IC count, which has to be kept low. Antenna array designs too often mean multiple front-end modules (FEM) or transceivers.

Higher bandwidth than the previous generations, spread over multiple channels, has to be addressed without multiplying transceiver building blocks, especially power hungry and IC-area-consuming frequency synthesizers. So, PHY optimization is key to be supported by frequency generation, compatible with accessible integration constraints, over which high integration on a mainstream CMOS process is to be considered.

Addressing above 90 GHz bands therefore triggers cross-domain thinking for efficient implementation including small form factors and low-cost. In this article, two topics are highlighted: the choice of semiconductor technologies to address above 90 GHz spectrum as well as some architectural clues for designing low-cost and high performance RF front ends.


Has Amplifier Performance or Delivery Stalled Your Program?
Noise Figure In Select Frequency Bands
Noise Figure (dB)
Frequency (GHz)
4.5dB
4.0dB
2.8dB
2.8dB
2.5dB
1.8dB
1.5dB
1.3dB
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Silicon-based technologies offer low-cost compromises for RF and mmWave applications. However, the comparison of technologies is always difficult as technical metrics are cross-domain and non-technical parameters are also to be taken into account. We propose a benchmark of technologies focusing on intrinsic performance. In order to compare the technologies, a target representation of what should be requested to fit with the RF and mmWave wireless transceiver challenges is proposed in ***Figure 2***.

Different criteria are depicted and will be placed in a target representation:

Power: RF output power availability from a technology depends on breakdown voltage (BV), and on the maximum current driven by the transistor (Imax) values. For a fair comparison, let's define the max power as BV multiplied by 200 mA, which is optimistic for CMOS processes, and realistic for BiCMOS.

High Speed Digital Integration: RF digital control and digital pre-processing techniques are mandatory for mass-market and cost-efficient solutions. High speed digital integration depends on inverter size and efficiency (transit time/current).

Selectability: This is the ability to switch RF and mmWave signals with high isolation.

Linearity: The relation between the output current and the input voltage-control signal of the transistor gives the first order of the linearity while gm^2 and gm^3 impact IMD2 and IMD3 of the amplifiers.

Matching: This property defines the different behavior between two minimum-size transistors close together.

Isolation and HQ Passives: These are given by substrate resistivity and the presence of thick metal levels.

Ft-NF: Ft gives the potentiality for high frequency digital-clock and RF oscillator applications, NFmin determines the sensitivity of receivers.

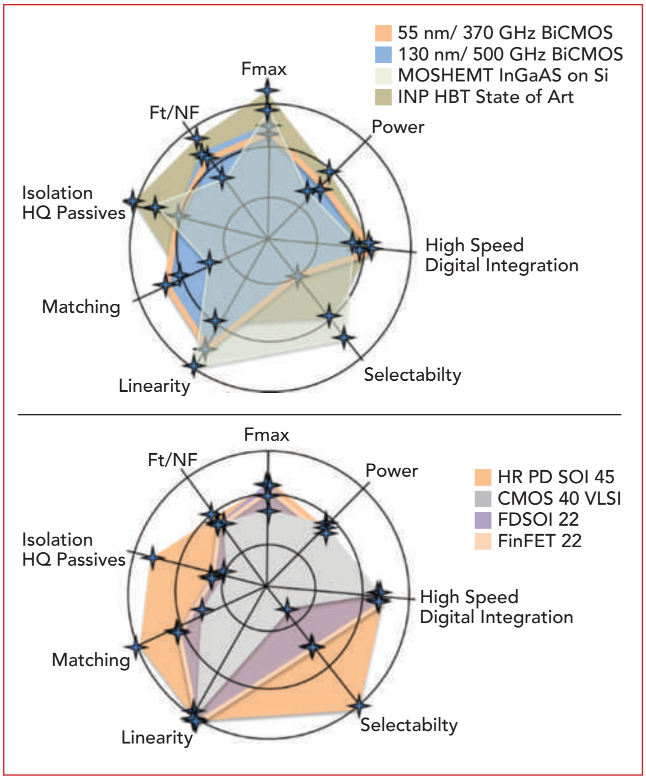


Fig. 3 **Comparison of technology over the defined key parameter indicators.**

Fmax: This the frequency of the 0 dB power gain, which impacts the gain availability of receive and transmit chains. For a linear class A amplifier, the maximum application frequency is lower than Fmax/3, (used in the comparison) for a switch-mode class-D amplifier, it is lower than Fmax/10 in an ideal case.

Advanced CMOS processes are very attractive for developing mixed RF systems-on-chip, as they offer very high integration potential and still, node after node, demonstrate better RF performance. Four differ-

ent families in the 45 to 22nm node ranges are evaluated to address above 90 GHz applications: The bulk planar family is represented by a CMOS 40nm VLSI (TSMC); the partially depleted SOI family by a RF 45nm SOI CMOS (GlobalFoundries); the fully depleted SOI family by a FDSOI 22nm CMOS (GlobalFoundries) and finally, the FinFET family by a 22nm FinFET CMOS (see ***Figure 3***). The Fmax limitation of these processes drives the only thin gate-oxide-transistor (or GO1) use, to perform RF functions, including power amplifiers targeting applications above 90 GHz.

40nm bulk CMOS, with up to 70 GHz in frequency cannot cover above the 90 GHz band. 45nm PD-SOI covers up to 120 GHz mmWave applications. FDSOI 22nm offers very nice performance with the best in class CMOS applicative frequency of 130 GHz. FinFET family provides solutions for applications up to 110 GHz. Concerning the RF output power, 28 dBm is a frontier, the 45nm SOI having the best global behavior for RF applications with the wider target filled.

Silicon-germanium HBT processes overcome the current issue of silicon N-FET transistors with emitter-collector currents in the range of 10s of mA per μm^2 emitter area. In addition, the 1/f noise-cut frequency of HBT is very low, in the 10s of Hz, which makes them very attractive candidates for oscillators and low-pass filters, functions which are critical in wireless links. The BV is proportional to the base thickness, therefore decreases with the HBT generations are targeting higher and higher Ft. We analyze and compare a 370 GHz SiGe HBT over 55nm CMOS process,[2] targeting high frequency applications with high CMOS integration, and a 500 GHz HBT over 130nm CMOS targeting very high frequency applications.[3] Both are compared to state-of-the-art III-V processes, InGaAs MOSHEMT from Fraunhofer IAF,[4] and INP HBT from Teledyne. It should be emphasized that state-of-

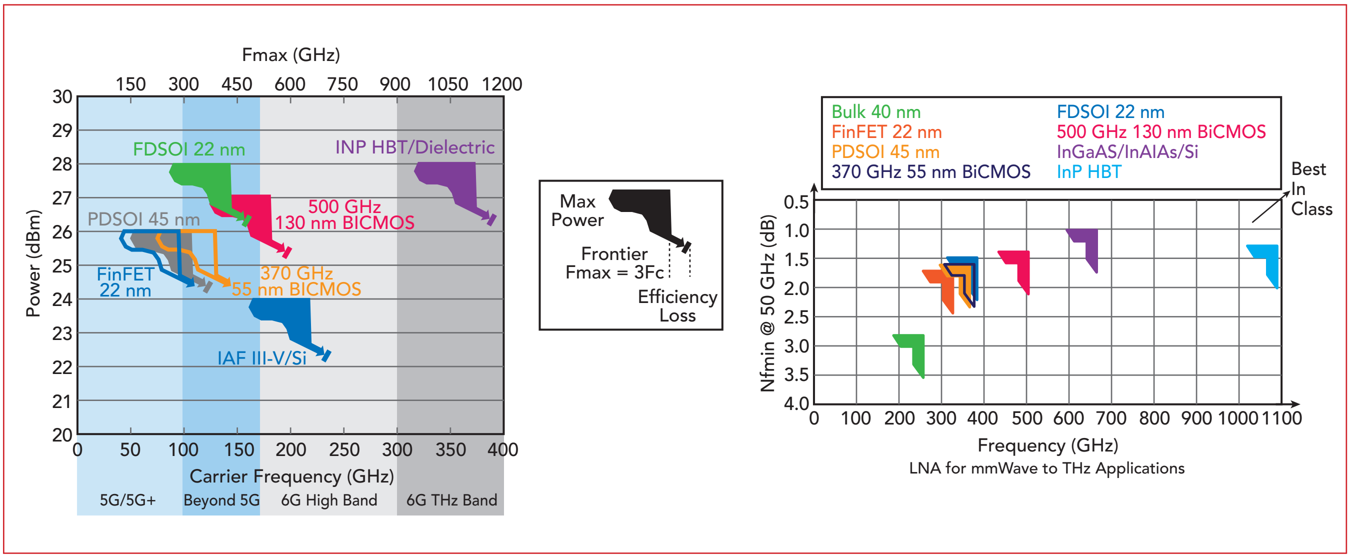


Fig. 4 PA and LNA building blocks performance frontiers.

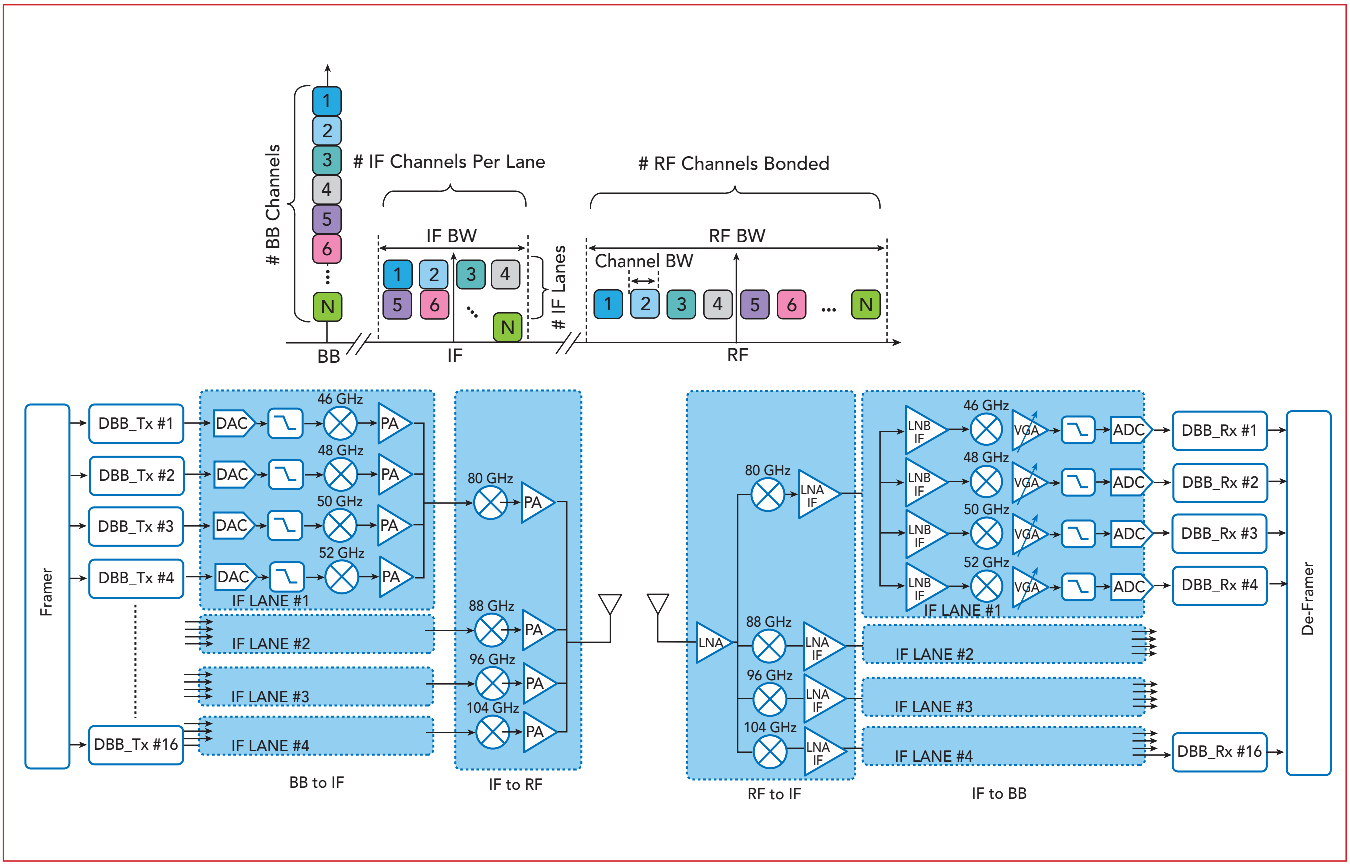
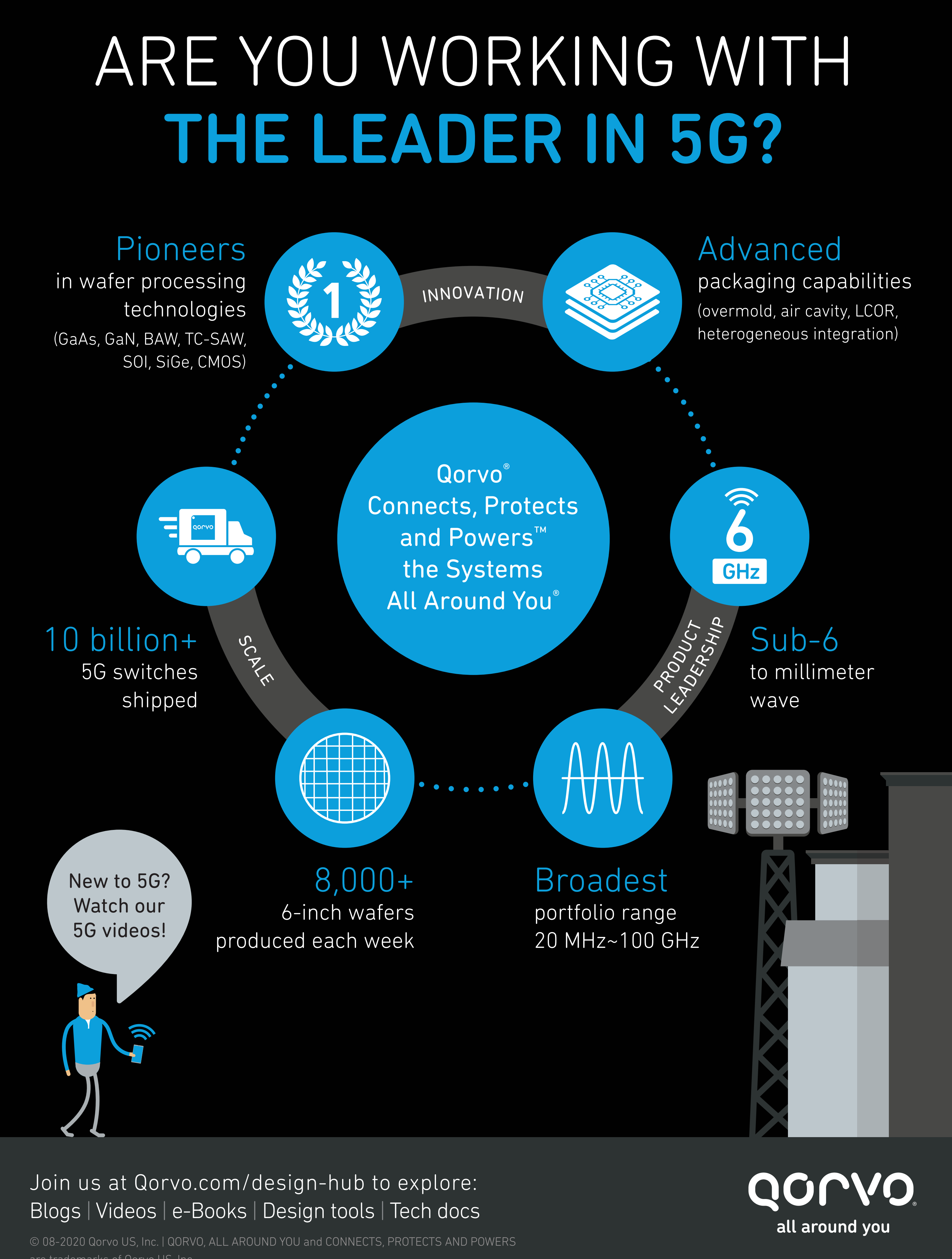


Fig. 5 Example of channel bonding transceiver architecture and frequency plan.

the-art SiGe HBT exceeds 700 GHz Fmax.

BiCMOS 370 GHz/55nm process covers applicative frequencies up to 120 GHz, while the BiCMOS 500 GHz/130nm process covers applicative frequencies up to 160 GHz, their output power remaining under 28 dBm. The 55nm process has higher capability for digital integration, while it is within the average for the other RF properties. The InGaAs MOSHEMT from Fraunhofer IAF presents a very attractive Fmax with 640 GHz, allowing it to cover up to 210 GHz applications with power output under 24 dBm. In addition, pretty good RF characteristics are demonstrated. The weakness is the integration of digital, which is not yet possible. Equivalent conclusions are for INP HBT and exceed 1 THz Fmax[5] and open all the doors for applications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up to THz frequencies.

A summary is depicted in ***Figure 4*** to answer mmWave to THz applicative requirements for PA and LNA building blocks. The main limitation, in PA design, is the Fmax. Output power can be increased by design, consideration and staking PA array. BiCMOS processes, allying high Fmax HBT with CMOS integration, are very well placed, even if III-V InGaAs and mostly INP HBT are the best in class. The LNA is limited by NFmin and Fmax at the same time, and again BiCMOS is well placed, even if III-V processes obtain very good results, but lack the integration capacity of BiCMOS.

To conclude, cost will be the main factor to earn market share. BiCMOS and RF CMOS processes have already proven to be adequate up to 40 GHz, providing better integration and overall cost than InP HBT. It is acknowledged that the beyond 5G and 6G applications will continue to benefit from CMOS improvements, but new concepts should be proposed to efficiently address the THz band.

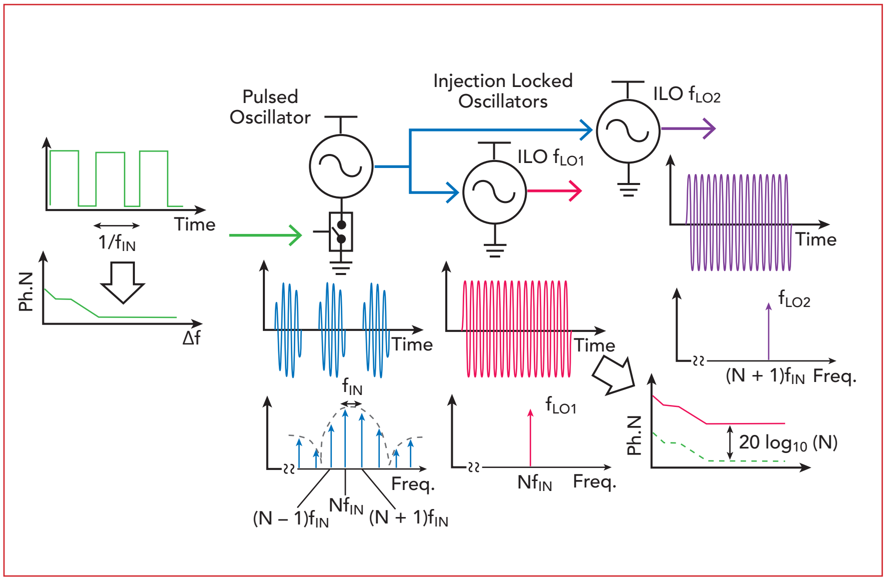


Fig. 6 Multi-LO generation technique.

CMOS FRONT-END ARCHITECTURE FOR CHANNEL AGGREGATION

The RF front-end architecture for extremely broadband applications has to be selected considering both the large amount of bandwidth that is required at the RF section and reasonable sampling frequencies in the radio-to-digital baseband (BB) interfaces. Having this trade-off in mind, channel-bonding techniques seem a natural solution. ***Figure 5*** shows an example of a Tx-and-Rx radio front-end based on such techniques. In the Tx of this example, 16 BB channels are combined and up converted in two steps up to D-Band (around 140 GHz), where each of the BB channels is found at a different RF sub-channel. The Rx realized the complementary down conversion process providing 16 parallel BB channels. Assuming reasonable D/A and A/D converters with sampling frequencies around 2.5 GS/s, this architecture is able to provide a total raw throughput of 102 Gb/s if 16-QAM modulation is used in each BB channel at a symbol rate of 1.6 Gbauds, and 156 Gb/s for 64-QAM modulation. The required bandwidth at D-Band is 32 GHz.

The main challenge for channel-bonding architectures is that they require many different local oscillator (LO) signals. The frequency plan can be optimized to minimize the number of distinct LO frequencies required as well as to relax the bandwidth requirement of the radio up-and-down conversion blocks. Figure 5 depicts a frequency plan for the above 16 channels radio

where only eight different LO frequencies are required. The signal bandwidth that has to be handled by most of the RF blocks is significantly smaller than the final 32 GHz. This approach enables the use of CMOS technologies: a large bandwidth and operation frequency are only required at the end of output of the Tx or the input of the Rx. The Tx sub-band PAs can be used to separately amplify sections of the output spectrum combined with passive power combiners to generate the full band output signal. In the Rx, a moderate gain broadband LNA can be considered with subsequent sub-band splitting of the signal, so that the LNA is the only CMOS circuit having to handle the full band signal. CMOS PAs and LNAs supporting this approach have been recently demonstrated,[6,7] as well as the multi-frequency LO generation required.[8]

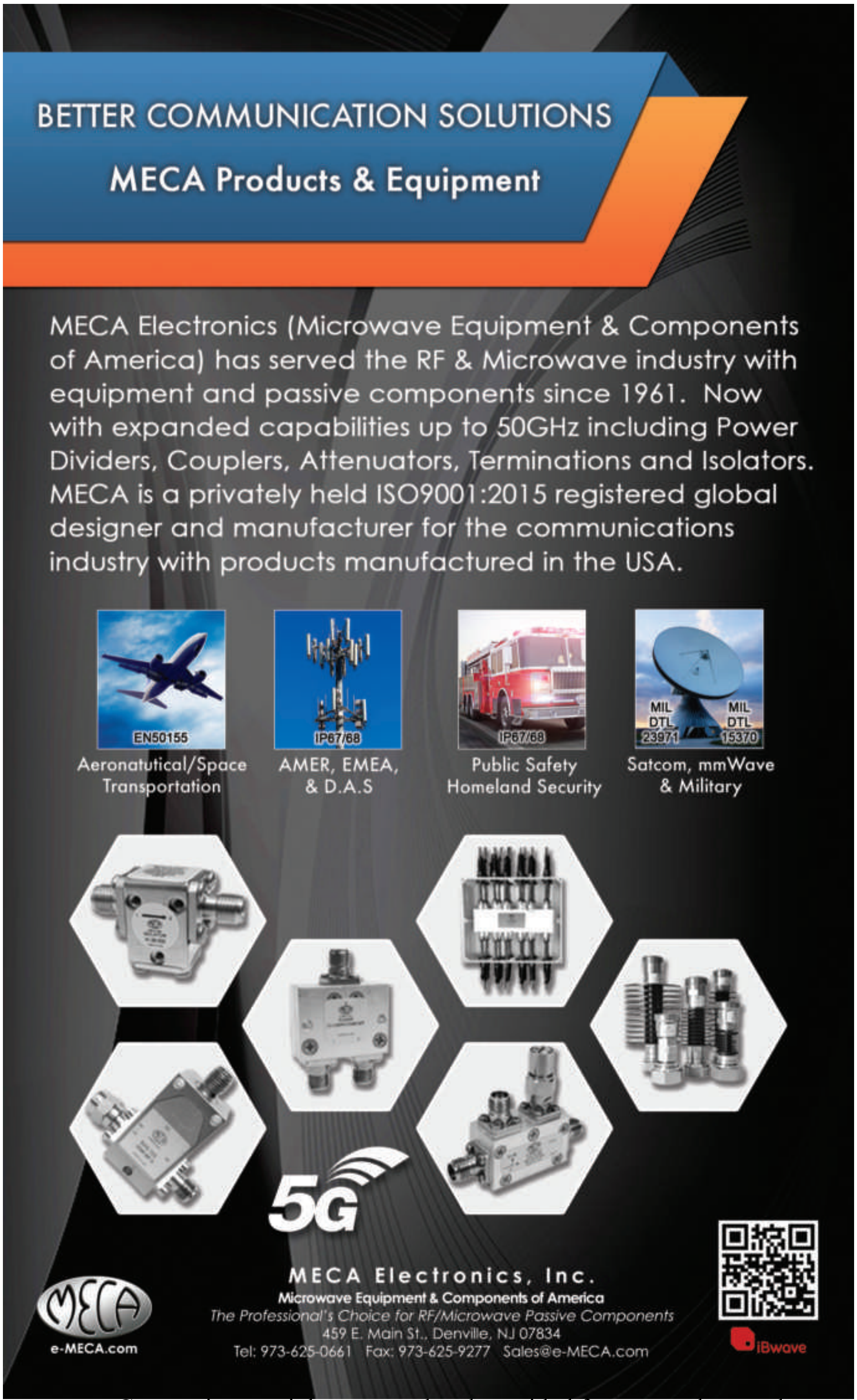
Very low phase noise LO signals are required for high-order modulation schemes such as 64 QAM and beyond. This is a hard constraint for classical mmWave LO generators based on PLLs and frequency division on top of the complexity of generating multiple LO signals of different frequencies. The technique presented in reference nine can be used as an effective way of simultaneously generating several LO frequencies, all of them integer multiples of the same input reference. It also allows achieving a low phase noise: the generation is based in frequency multiplication, which produces an output phase noise equal to the input phase noise, obtained at much lower oscillation frequency, just scaled up by the integer multiplication factor. The alternative multi-LO generation principle is depicted in ***Figure 6***.[9] A signal of a frequency much lower than the desired output LO frequencies is used to synchronously switch on and off an oscillator sized to have a free-run frequency in the LO frequency range. When operated in this way, this pulsed oscillator generates a multi-harmonic signal with terms at integer multiples of the switching input frequency (blue signal in the figure).

The spectral envelope of this signal is determined by the switching input signal duty cycle and is centered at the oscillator free-run frequency. However, note that the harmonic terms are at exact integer multiples of the input (…, N-1, N, N+1 …) and do not depend on the oscillator free-run frequency, albeit they have maximum amplitude around it. Several single-tone LO frequencies can be extracted from this signal by injection-locked oscillators that are sized to lock on one specific integer multiple of the input and to reject the adjacent terms, as shown in Figure 6. Each of the harmonic terms is synchronized in terms of phase to the input signal and therefore copies the input phase noise with an integer scaling factor (see the red signal in the figure, for example). This multi-LO generation technique has been recently experimentally

demonstrated.[8] It can be used for generating the four baseband-to-IF signals that would be required by the first channel-bonding step of the transceiver shown in Figure 5 and easily extended to generate in the same way the other four LO required for the IF to RF second conversion step.

CONCLUSION

The spectrum above 90 GHz is foreseen as a key enabler for the next generation of mobile networks for 6G. The large amount of spectrum paves the way to high capacity wireless links. Many challenges must be overcome to make this technology a success. First, where the design of CMOS RF modules is still possible for the low part of the D-Band, designing cost-efficient modules to address the THz band remains an open issue. Second, high gain antennas are required to meet the link budget. While the design of fixed-beam antenna is mastered, the holy grail remains the co-integration of RF and antenna to provide an electronically beam-steerable system. This would be significant breakthrough toward the next generation wireless system.■



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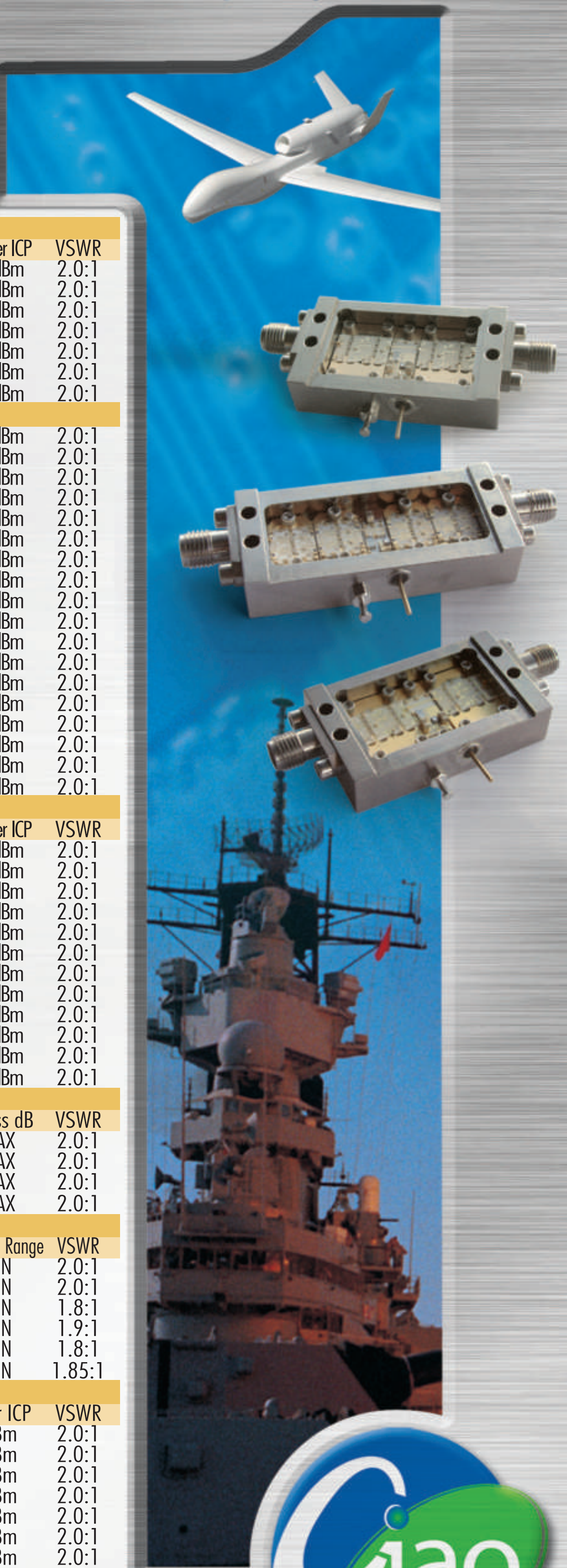

OCTAVE BAND LOW NOISE AMPLIFIERS

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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Missile Defense Becomes Part of a Great Power Competition

All aspects of the military are engaged in a great power competition, but while most analysts focus on developments in offensive missiles, Chinese and Russian defense leaders are developing even more capable missile defenses according to Defense Department officials.

"China and Russia are developing increasingly capable and numerous missile defense systems and integrating them into their defense strategies as they compete with the United States," a DoD official said.

The U.S. pioneered missile defense systems. Then—President Ronald Reagan proposed missile defense systems in the early 1980s. His "Strategic Defense Initiative" was dubbed the "Star Wars Initiative"—sometimes derisively.

The laughing stopped during Operation Desert Storm, when Patriot missile defense batteries based in Saudi Arabia and Israel stopped Iraqi Scud missile attacks.

Russia is a long-time player. The former Soviet Union created a ring of anti-ballistic missile batteries around Moscow during the Cold War. These nuclear-tipped missiles still exist as part of Russia's A-135 anti-ballistic missile system. The system consists of 68 nuclear-armed interceptors. As part of President Vladimir Putin's military buildup, the system has received new radars and updated electronics. The beauty of this system is that the Russians have only to be close to an incoming threat. The downside is radiation from an intercept would contaminate thousands of acres of countryside.

The other main threat comes from the People's Republic of China. The Chinese see missile defense as a key cog in their military ambitions. The People's Liberation Army Air Force is accelerating the transition of its tasks from territorial air defense to both offensive and defensive operations, according to a Chinese white paper on the subject. China's air force is also improving its capabilities for strategic early warning, air strikes and air and missile defense.


CHINESE AND RUSSIAN BALLISTIC MISSILE DEFENSE CAPABILITIES

	System	Capability against	MRBM	IRBM	ICBM/SLBM
DEPLOYED SYSTEMS	S-300 SAM	Russian PMU-2 and VM variants can counter MRBMs China purchased S-300 PMU-2 in 2010	✓		
	S-400 SAM	Can counter MRBMs approaching 3,500km in range China purchased S-400 in 2014	✓		
	A-135 Moscow ABM System	Initial deployment 1989 – replacement for system that began in 1960s 68 nuclear-armed interceptors Recent upgrades to fire control radar and updated electronics	✓	✓	✓
DEVELOPMENTAL SYSTEMS	HQ-19 Missile Defense System	Good capability against MRBMs at IOC, anticipated after 2021 Built-in potential for future upgrades to intercept longer-range systems	✓	✓	✓
	S-500 SAM	Good capability against MRBMs at IOC, anticipated in 2025 Built-in potential for future upgrades to intercept longer-range systems	✓	✓	✓
	Mid Course Interceptor	IOC unlikely before late-2020s, good initial capability against IRBMs Upgradeable to intercept ICBMs/SLBMs potentially	✓	✓	✓
	51T6 Follow-On Exoatmospheric Interceptor	IOC anticipated late 2020s – mid-2030s Likely to have capability against IRBMs and ICBMs/SLBMs	✓	✓	✓

PERFORMANCE

Chinese and Russian Missile Defense Capability (Source: U.S. DoD)

Right now, the Chinese are heavily dependent on Russian missile defense capabilities. The Chinese have invested in the Russian S-300 and S-400 systems missile defense capabilities. The Chinese are assiduously studying the problem and have invested in research to build their own capabilities, DoD officials said. This includes the HQ-19 missile defense system, which could be used against incoming, medium-range ballistic missiles. Initial operating capability is set for next year.

China is also developing a mid-course interceptor. The Chinese government said they tested that capability in February 2018. U.S. officials say initial operating capability is not likely until the late 2020s. They anticipate it would have good capability against intermediate-range ballistic missiles and could be adapted to target intercontinentals and submarine-launched ballistic missiles.

Raytheon Missiles & Defense, Rafael Team to Establish U.S.-Based Iron Dome Weapon System Production Facility

Raytheon Missiles & Defense and Rafael Advanced Defense Systems Ltd. have signed a joint venture to establish an Iron Dome Weapon System production facility in the U.S. The new partnership, called Raytheon Rafael Area Protection Systems, anticipates finalizing a site location before the end of the year.

"This will be the first Iron Dome all-up-round facility outside of Israel, and it will help the U.S. Department of Defense and allies across the globe obtain the system for defense of their service members and critical infrastructure," said Raytheon Missiles & Defense Systems' Sam Deneke, vice president of Land Warfare & Air Defense business execution.


Iron Dome System (Courtesy of Rafael)

The new facility will produce both the Iron Dome Weapon System, which consists of the Tamir interceptor and launcher, and the SkyHunter® missile, a U.S. derivative of Tamir. Both Tamir and SkyHunter intercept incoming cruise missiles, unmanned aerial systems and short-range targets such as rockets, artillery, mortars and other aerial threats.

Raytheon Missiles & Defense and Rafael have teamed for over a decade on Iron Dome, the world's most-used system with more than 2,500 operational intercepts and a success rate exceeding 90 percent.

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The U.S. Army has chosen Iron Dome as an interim capability to counter cruise missiles while it continues to develop a future indirect fires protection capability (IFPC) to counter those threats as well as enemy drones, rockets, artillery and mortars. Congress mandated the service buy two batteries to cover urgent cruise missile defense gaps and another set of two if the Army did not come up with a way forward for its enduring IFPC.

While the Army has said it will not buy all-up Iron Dome systems as part of the IFPC program, officials developing the capability are looking at the possibility of incorporating parts of Iron Dome in the final solution. The Army plans to field Iron Dome by the end of the year, but it will still take time to train troops on the system before deployment.

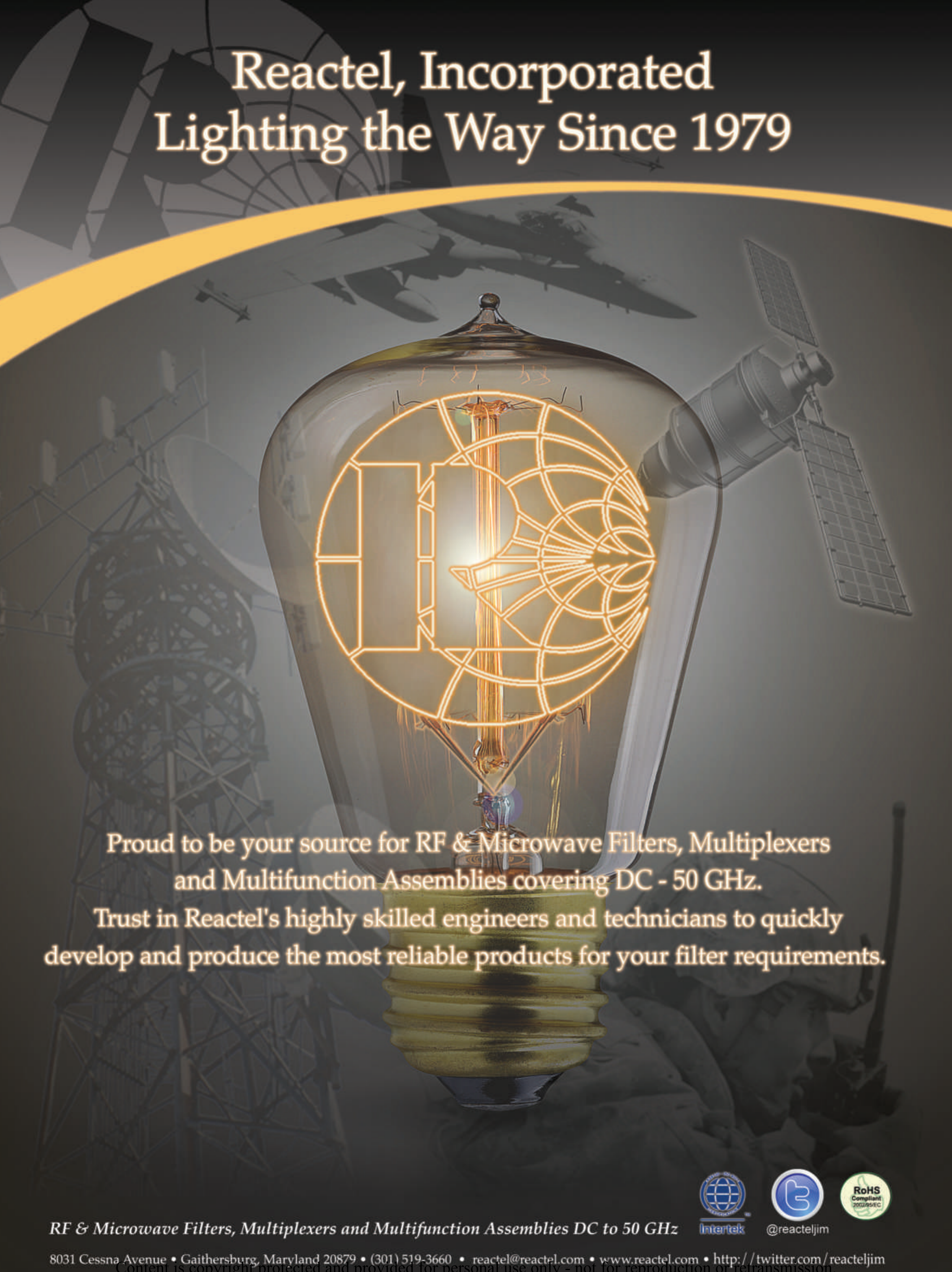
Northrop Grumman Taps Epirus for Electromagnetic Pulse C-UAS Weapon System

Northrop Grumman Corporation has formed a strategic supplier agreement with Epirus Inc. to offer the company's electromagnetic pulse (EMP) capability as a component of Northrop Grumman's counter-unmanned aerial system (C-UAS) systems-of-systems solution offering. The agreement augments Northrop Grumman's advanced end-to-end C-UAS capabilities by including Epirus' EMP systems to defeat UAS swarms and specifically supplements the company's suite of non-kinetic C-UAS effects.

"UAS threats are proliferating across the modern battlespace," said Kenn Todorov, vice president and general manager, combat systems and mission readiness, Northrop Grumman. "By integrating the Epirus EMP weapon system into our C-UAS portfolio, we continue maturing our robust, integrated, layered approach to addressing and defeating these evolving threats."

Northrop Grumman's end-to-end C-UAS solutions deliver a layered architecture with a full complement of kinetic and non-kinetic effects, aerial and ground sensors and the battle-hardened, proven and deployed Forward Area Air Defense Command and Control (C2) system, recently selected by the U.S. Army as the interim C2 system for counter-small-UAS capabilities.

Epirus' C-UAS EMP system, called Leonidas, is designed for static and mobile C-UAS defense and uses solid-state commercial semiconductor technology to deliver capability with unprecedented reduction in size and weight. This enables increased stand-off ranges and speed-of-light engagements that do not suffer from issues with magazine depth and capacity. When fired, a Leonidas creates an EMP that can be steered for precision engagements or adjusted to sanitize a volume of terrain or sky, creating a force field effect.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New Innovative Backhaul Technologies for 5G Deployments

For successful deployment of 5G, mobile network operators need transport technologies that can meet stringent throughput, latency and reliability requirements over increasingly densified networks. 5G Americas, the wireless industry trade association and voice of 5G and LTE for the Americas, recently published a white paper highlighting new innovative backhaul, midhaul and fronthaul transport technologies for 5G networks.

The fifth generation of wireless cellular ("5G") is driving increasing demands on mobile operator networks, which are faced with the need to improve operational efficiency and reduce the time required to deliver new high throughput, low latency network architectures to support emerging use cases. New wireless options like integrated access and backhaul (IAB) and significant advances in wireline like hybrid fiber coax (HFC), passive optical networks (PON), Ethernet and wave division multiplexing (WDM) can be used to efficiently and cost-effectively transport data between the 5G core network and the 5G radio access network.

Chris Pearson, president of 5G Americas said, "5G network operators are today faced with an increasing array of choices in designing, architecting and managing their networks. Operators can select from a variety of wireless and wireline transport options to address the specific topologies and use cases envisioned for their mobile wireless network."

> Americas white paper details advances in wireless and wireline transport options.

The white paper delves into these new 5G transport technologies, providing details into their advantages and disadvantages. Factors such as the specific application, deployment scenario, existing infrastructure and market situation are covered in detail.

One innovation is IAB, which was standardized in 3GPP Release 16 and will be further enhanced in Release 17. IAB repurposes some of the existing spectrum used for the 5G radio air interface for backhaul purposes as well. This technology has generated strong interest in the mobile wireless industry since it is expected to provide a cost-efficient and fast time-to-market backhaul solution.

Ranjeet Bhattacharya, principal solutions director at Ericsson and co-leader for the project, said, "Optimized backhaul is a key challenge for efficient 5G deployment, and innovative wireless solutions like IAB could be a game changer."

The paper addresses the technology aspects of IAB that are part of the standard, its use cases, deployment considerations and provides an overview of IAB-related future research and studies ongoing in the industry.

Other areas covered are key requirements of 5G transport and various technology options for alternative transport technologies with details on HFC, PON, Ethernet and WDM, including architecture, business drivers, recent advances, deployment scenarios and future trends.

RF Front End Content and Complexity in 5G Devices Has Created a 5G Conundrum for Smartphone OEMs

Using the teardown expertise of System Plus Consulting, ABI Research unpacked nine leading second-generation 5G smartphones to discover that RF Front End (RFFE) content is evidently moving to full level integrated modem-RF system designs, which will be the key to success as the market advances to wider 5G adoption.

"The 5G smartphone market is set to rapidly expand in the next 12 months, with many mobile vendors looking to quickly develop their 5G portfolios. However, a host of extremely complex challenges lie ahead for smartphone vendors, which they must overcome to fully realize the 5G demand explosion across all tiers," stated David McQueen, research director at ABI Research.

The move to 5G requires an integration of the entire 5G cellular system design into OEMs' devices, from modem-to-antenna, addressing all aspects of end-to-end performance. This complexity level includes the integration and deployment of new 5G modem and RFFE components, features and functionalities, leading to substantial changes in the design of mobile devices.

OEMs will have to rationalize the delegation of modem-RF system procurement to a handful of suppliers and, most importantly, make sure they pick the right partner. "Notably, it needs to be one with a well-proven, tested or validated rich RFFE portfolio and a comprehensive 5G roadmap. The delegation brings several advantages, many of which have become increasingly stark as the device market transitions to 5G," McQueen asserted.

The teardowns show there are already signs that several OEMs are moving away from RF component assembly and adopting 5G design from modem-to-antenna. "Such a strategic approach has been carried out by few component suppliers in the market, thus far. Qualcomm is currently the only one able to offer an end-to-end product portfolio from modem-to-antenna, supplying products with end-to-end performance in fully integrated system designs," said McQueen. How-

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ever, he added, "Third-party modem-RF system design will become a mainstream approach in support of many of the world's top smartphone OEMs to solve their 5G conundrum, also influencing decision-making across all technologies, so Qualcomm is likely to be joined by others if they can offer such turnkey solutions."

Commercial Telematics in a Post Pandemic World

COVID-19 has had a tremendous impact on businesses around the world. The transport and logistics sector, especially in the Asia-Pacific region, has been one of the hardest hit. Companies had to quickly pivot their strategies to cope with new challenges brought on by the pandemic, with initial success. ABI Research forecasts that commercial telematics system revenue in Asia-Pacific will nearly double from US$7.3 billion in 2020 to US$14.1 billion in 2025, at a CAGR of 13.9 percent.

"Throughout the supply chain, COVID-19 presented specific challenges from contactless delivery, the shutdown of truck stops and the closure of back offices, which caused disruptions between suppliers, distribution hubs, and retailers/consumers," explained Kangrui Ling, research analyst at ABI Research. "As a result, location-based solutions, including real-time traffic data, estimated time of arrival notifications and vehicle visibility, are playing an important role in tackling these challenges."

Major logistics providers are grappling with the short-term effects of country-wide lockdowns, as shuttered borders continue to restrict movement of goods and services. DHL reportedly suffered an impact of US$79 million to their February earnings. Shipments of cargo from China have seen a four-to-six-week delay; likewise, in India, over 500,000 cargo trucks were reported to have been stranded on highways. Fleet managers have a crucial need to enhance visibility and improve connections between operations, drivers and customers. Real-time location monitoring and dynamic routing have been key in allowing network operation centers to optimize routes on the fly and improve customer satisfaction by reducing late deliveries and bettering goods tracking.

Major e-commerce and delivery companies—such as Meituan Dianping, Alibaba, Grab and Gojek—have implemented distancing measures and contactless delivery to ensure the safety of their drivers and customers. Autonomous deliveries have advanced due to the pandemic. JD.com began using drones to deliver goods to remote locations in China earlier this year, making them the first e-commerce firm to do so. The Chinese giant also deployed land-based autonomous delivery robots to aid in last-mile deliveries of medical products and groceries.

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Modelithics has acquired the **ProbePoints™** substrate fixture assets formerly provided by **Jmicro Technology**. This acquisition includes test fixtures and probing accessory products for the RF/microwave and electrical test of advanced semiconductor devices and packaging products. These products include the popular ProbePoint alumina substrate fixtures that allow devices without ground-signal-ground probe pads to be tested with RF wafer probes. Modelithics will also leverage its 20 years of experience with fixturing and calibration for high accuracy measurements to offer other standard and custom microwave and mmWave test fixtures and calibration standards alongside the legacy Jmicro ProbePoint fixture products.

WESCO International Inc. announced it has completed its merger with **Anixter International Inc.**, creating a premier, industry leading global B2B distribution and supply chain solutions company. Upon completion of the merger, Anixter became a wholly owned subsidiary of WESCO International.

BAE Systems has completed its acquisition of the **Collins Aerospace Military Global Positioning System (GPS)** business from **Raytheon Technologies Corp.**, bringing decades of experience, innovative technology and an extensive installed base of products to the company. As announced in January, this asset purchase is a unique opportunity to acquire a high-quality, technology-based business that augments the existing BAE Systems Electronic Systems portfolio through the addition of world-class GPS anti-jamming and anti-spoofing technology that enables reliable navigation and guidance for a range of defense missions.

COLLABORATIONS

Anokiwave Inc. and **Ball Aerospace** are continuing their collaboration to develop and enable the next generation of SATCOM terminal solutions adding a Ku-Band option to the portfolio of flat panel phased array antennas. With the new portfolio of either Ku- or K/Ka-band antennas, customers have the flexibility to meet their broadband service needs. Ball Aerospace brings an innovative approach to the design of either a Ku- or K/Ka-Band system. Each antenna can be designed with the same footprint, allowing a consistent terminal baseplate, chasses and interfaces that can be swapped based on the user's broadband service needs.

Keysight Technologies Inc. and **Qualcomm Technologies Inc.** have enabled the Global Certification Forum (GCF) to activate certification of a cellular vehicle-to-everything communications (C-V2X) test plan. The test plan was achieved using Keysight's RF/RRM DVT & Conformance Toolset and the Qualcomm® 9150 C-V2X Platform, a standalone C-V2X modem chipset with global navigation satellite system. Test cases focused on RF and radio resource management (RRM) performance verification of devices used for vehicle-to-vehicle deployment scenarios. These test cases were validated at the GCF-hosted conformance agreement group #63 meeting in July 2020 and enabled the GCF to initiate radio certification of a C-V2X test plan based on 3GPP Release 14.

NI announced its collaboration with **Eta Wireless** to implement and demonstrate full support of ETAdvanced, the industry's first ever digital envelope tracking (ET) technology for mmWave 5G RF front-end devices. Developed by Cambridge-based Eta Wireless, the technology enables extended battery life in smartphones, wearables and IoT devices, improving both data rates and connectivity range. ETAdvanced addresses the power efficiency challenges that have historically plagued RF front-ends. Wideband power amplifiers, such as those found in 5G devices, waste a significant amount of power in the form of heat, greatly reducing battery life. ETAdvanced uses the signal's envelope information to increase the amplifier's efficiency by delivering only the power needed at that instant.

Murata Electronics and **pSemi**, a Murata company, announced they are teaming with nonprofit technology incubator, EvoNexus, to provide opportunities for a select number of growth companies to explore engagement in the areas of product development, manufacturing support, licensing, channels to market, investment or other forms of collaboration.

IMST GmbH and **AT&S** have concluded a strategic cooperation agreement focusing on the development of joint technical solutions. AT&S is the European market leader and one of the world's leading manufacturers of high-quality printed circuit boards and IC substrates. AT&S industrializes advanced technologies for its core businesses mobile devices, automotive, industrial, medical and advanced packaging. One of the first projects of the partners is a simulation for power electronics, in which a standard solution is to be compared with an embedded solution.

Analog Devices Inc. (ADI) announced its collaboration with **Intel Corp.** to create a flexible radio platform that addresses 5G network design challenges and will enable customers to scale their 5G networks more quickly and economically. The new radio platform combines the advanced technology of ADI's RF transceivers with the high performance and low power of Intel Arria 10 Field Programmable Gate Arrays giving developers a new set of design tools for more easily creating optimized 5G solutions.

NEW STARTS

From July 2020 the new name for **Plextek RFI** is **PRFI**

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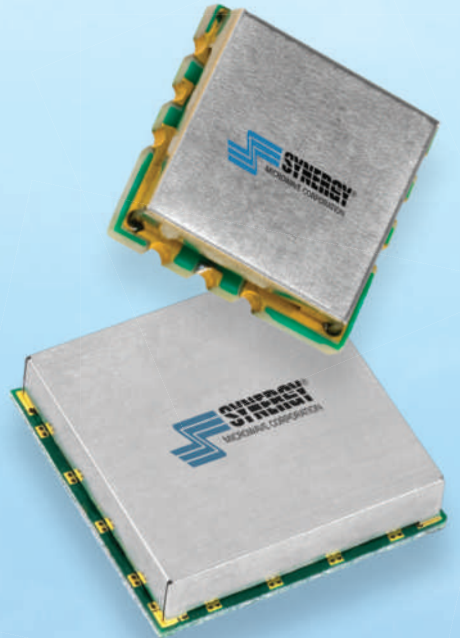
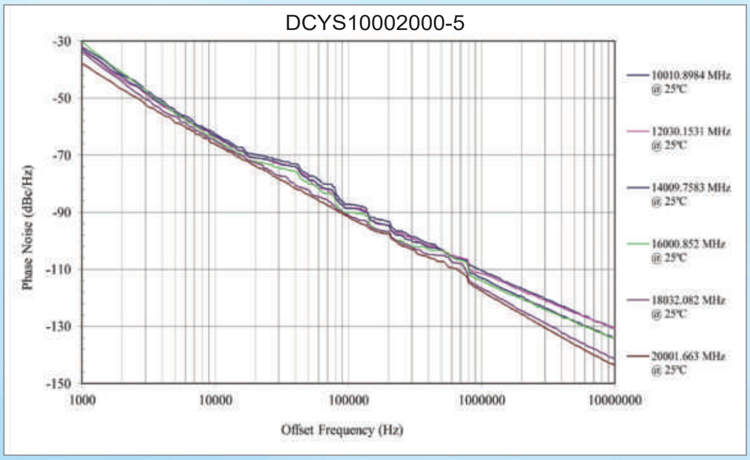
DCYS100200-12	1 - 2	-105	-125	0 - 28	+4
DCO200400-5	2 - 4	-90	-110	0 - 18	-2
DCYS200400P-5	2 - 4	-93	-115	0 - 18	0
DCO300600-5	3 - 6	-75	-104	0 - 16	-3
DCYS300600P-5	3 - 6	-78	-109	0 - 16	+2
DCO400800-5	4 - 8	-75	-98	0 - 15	-4
DCO5001000-5	5 - 10	-80	-106	0 - 18	-2
DCYS6001200-5	6 -12	-70	-94	0 - 15	> +10
DCYS8001600-5	8 - 16	-68	-93	0 - 15	> +10
DCYS10002000-5	10 - 20	-65	-91	0 - 18	> +10





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Ltd. The company has achieved recognition across the world as a leader in the design of RFICs, MMICs and microwave/mmWave modules, having originally been formed from the RF Integration Group within Plextek Ltd. Operating from offices and laboratories in the village of Great Chesterford, near Cambridge in the UK, PRFI has an impressive list of clients for its microwave and mmWave design services that includes Huawei, Inmarsat, Samsung, Analog Devices and Qorvo.

Teledyne Aerospace & Defense Electronics UK (TADE UK) announced the latest business unit addition to its brand portfolio, Teledyne Energetics UK, headquartered in Lincoln, England. The new website gives an overview of the Energetics UK systems, subsystems, and component offerings, which are ITAR-free and designed and manufactured exclusively in the UK. The website promotes the company's extensive heritage in all major deployment theatres including aerospace, land, surface maritime, subsea ASW and LEO launch. TADE UK is now comprised of eight distinct business units, including Teledyne CML Composites; Teledyne Defence & Space; Teledyne Defence Australia; Teledyne Energetics UK; Teledyne Labtech Limited; Teledyne Lincoln Microwave; Teledyne Paradise Datacom; and Teledyne Reynolds UK.

ACHIEVEMENTS

For 10 years, **Rogers Corp**.'s the ROG blog has been serving the RF/microwave community with the aid of Microwave Journal and we are happy to celebrate this milestone. We have written blogs on many different circuit-material-related topics and, admittedly, have covered the same topic a few times. This can pose a challenge to give more information on the more detailed topics, but we hope we have helped some readers through our efforts. Over the past 10 years, one factor that has changed remarkably is the number of mmWave applications. We hope to continue for the next 10 years so keep an eye out for new postings.

CONTRACTS

Science Applications International Corp. has been awarded a $950 million ceiling indefinite-delivery, indefinite-quantity contract for the maturation, demonstration and proliferation of capability across platforms and domains, leveraging open systems design, modern software, and algorithm development in order to enable Joint All Domain Command and Control (JADC2).

Comtech Telecommunications Corp. announced that during its fourth quarter of fiscal 2020, its Mission-Critical Technologies group, which is part of Comtech's Government Solutions segment, was awarded $20.0 million of additional funding on a previously announced $223.4 million contract to provide Very Small Aperture Terminals (VSATs) to support the **U.S. Army**. The contract has been funded $214.9 million to date.

Curtiss-Wright Corp. announced that it has been awarded contracts valued in excess of $220 million to provide propulsion valves, pumps and advanced instrumentation and control systems for the **U.S. Navy**'s Virginia-class nuclear powered attack submarine, Columbia-class submarine and Ford-class aircraft carrier programs. The awards were received from Bechtel Plant Machinery, Inc. (BPMI) and General Dynamics Electric Boat to support ship construction, spare parts and submarine back-fit procurements. Engineering and manufacturing has commenced and will continue through 2024.

Cubic Corp. announced its Cubic Mission Solutions (CMS) business division was awarded a contract worth $38 million to deliver a Joint Aerial Layer Network (JALN) High Capacity Backbone (HCB) prototype for the **U.S. Air Force (USAF)**. The HCB is a critical element of the JALN, designed to maintain network connectivity among joint forces across the aerial layer. Cubic's offering for USAF will consist of integrated capabilities across its Protected Communications and Command and Control, Intelligence, Surveillance and Reconnaissance (C2ISR) portfolios. Cubic will deliver a high capacity, extended range, self-organizing and self-healing JALN HCB that connects warfighters to a mission-optimized network of networks in satellite communications-challenged environments.

Collins Aerospace Systems, a unit of **Raytheon Technologies Corp.**, is developing a Software Programmable Open Mission Systems (OMS) Compliant (SPOC) radio for the **U.S. Air Force** as part of a $18.9 million competitive contract awarded in 2019. The SPOC radio program calls for an open-architecture approach to military radio development that will allow the Air Force to rapidly insert new communications waveforms, cybersecurity updates and integrate third-party software to meet the needs of the mission. The program has completed both major milestones Preliminary Design Review and Critical Design Review on time and on schedule and ready for the 1Q21 demonstration.

Comtech Telecommunications Corp. announced that during its fourth quarter of fiscal 2020, its Santa Clara, Calif.-based subsidiary, Comtech Xicom Technology Inc., which is part of Comtech's Commercial Solutions segment, was awarded contracts valued at more than $2.2 million for Ka-Band high-power traveling wave tube amplifiers ("TWTAs") for trailer-based satellite communications terminals.

PEOPLE

▲ *Richard Gibbs*

Filtronic plc announced the appointment of **Richard Gibbs** as chief executive officer (CEO). Gibbs's formal start date with the company will be September 1, 2020. Gibbs is an experienced director who has led a number of business operations supplying semiconductor, RF and electronics subsystems to the telecoms, aerospace, defense, medical, oil and gas markets. Gibbs joins Filtronic from Micross Compo-

nents Ltd., a PE owned company, where he has been managing director since 2016. Prior to his time at Micross, Gibbs spent nine years at E2V Technologies, where he was group sales and marketing director and president of the RF product and hi-reliability semiconductors divisions, and 20 years with Honeywell, of which 10 years were spent managing overseas operations.


▲ Chul Young Jin

RFMW announced the addition of a new sales manager in Korea; **Chul Young Jin** graduated from Chonnam National University with a M.S. in Computer Engineering. Experienced in both software and hardware design, his work experience includes field applications engineer and division sales manager in diverse applications such as machine control units, Zigbee, wireless charging, DC-DC conversion and fingerprint sensors. Prior to RFMW, Chul spent six years at NXP, a major RF LDMOS manufacturer.


▲ Steve Groves


▲ Craig Robinson

Intelliconnect (Europe) Ltd., a UK based specialist manufacturer of RF, waterproof and cryogenic connectors and cable harness assemblies, has increased its management team with two senior appointments. **Steve Groves** joins as global sales and marketing director to oversee sales and marketing across all of Intelliconnect's markets with their business partners around the world. Appointed as Sales Manager, **Craig Robinson** will now be heading-up management and business development of sales for the UK and Ireland with special emphasis on medical, industrial, test and measurement and cryogenic markets.

Richardson Electronics Ltd. announced the addition of two new field sales engineers in Northern Italy and Japan for the Power & Microwave Technologies group. **Stefano Modenesi** brings vast experience in RF and microwave design and sales to his new role at Richardson Electronics – Power & Microwave Technologies. He will be responsible for expanding accounts in Milan and Northern Italy, focusing on telecom, wireless, industrial and broadcast markets. **Naoki Yoshimura** brings to Richardson more than 25 years of experience in RF and microwave components and systems.

REP APPOINTMENTS

Agile Microwave Technology Inc., a product innovator in RF and microwave component and sub-system market, announced that it is expanding its presence in Europe. **The Milexia Group** has been appointed as Agile's exclusive sales representative for Italy and France. Milexia is a European leader delivering high tech components, systems, and scientific instrumentation.

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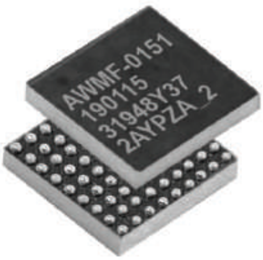
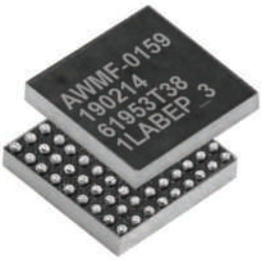


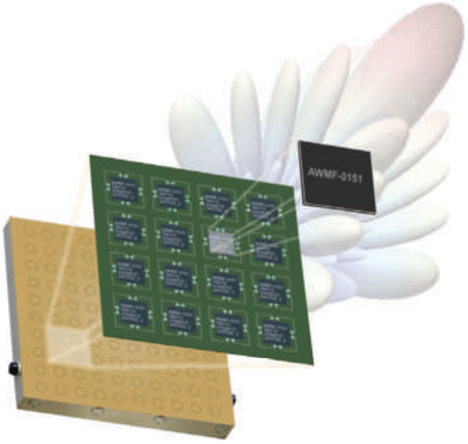
n257/261

Production Ready



n260

Production Ready



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Around the **Circuit**

AR RF/Microwave Instrumentation has named **Scientific Devices** as its distributor for Australia and New Zealand while also naming a new local representative for China, Yifeng Tech Co. AR is pleased to be represented by a company that also has a 50-year reputation for the highest quality service. Scientific Devices, founded in 1970, has expertise in a number of technologies and currently serves the following markets: telecommunications, defense and aerospace, electronic design and manufacturing, education, power and energy, research and development and automotive and industrial manufacturing.

Gowanda Electronics, a designer and manufacturer of high performance electronic components for demanding applications, announces it has signed a distribution agreement with **TTI Inc.** (Fort Worth, Texas), a leading specialty distributor of electronic components. TTI is now an authorized North American distributor of Gowanda's inductors and chokes designed for RF, microwave and power applications. Market sectors utilizing these components include: military, aerospace, avionics, communication, medical, transportation (rail safety) and industrial (harsh environments).

Mini-Circuits has announced an expansion of its distribution partnership with **Mouser Electronics Inc.**, making Mouser an authorized distributor of Mini-Circuits' product line in 206 countries. The two companies first announced their partnership in March with initial distribution in the U.S. and India. The expanded agreement will give more international customers the option to order Mini-Circuits components through Mouser or directly through Mini-Circuits. As an authorized distributor, Mouser Electronics is focused on the rapid introduction of new products and technologies, giving customers an edge and helping accelerate time to market.

PLACES

Raytheon Missiles & Defense, a Raytheon Technologies business, and **RAFAEL Advanced Defense Systems Ltd.**, an Israeli-based defense technology company, have signed a joint venture to establish an Iron Dome Weapon System production facility in the United States. The new partnership, called **Raytheon RAFAEL Area Protection Systems**, anticipates finalizing a site location before the end of the year. The new facility will produce both the Iron Dome Weapon System, which consists of the Tamir interceptor and launcher, and the SkyHunter® missile, a U.S. derivative of Tamir.

ZTE Corp. recently announced collaboration with **True Corp. Public Company Limited** to build a commercial 5G network in Thailand. True, a fully licensed operator in Thailand with a 30 percent market share in the mobile market of the country, will adopt ZTE's 5G RAN products and services to build a commercial 5G network in Thailand.


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INVITED PAPER

Doherty Power Amplifiers Move to mmWave

Robert Smith, Liam Devlin, Stuart Glynn, Tony Richards and Graham Pearson
PRFI, Great Chesterford, U.K.

Doherty power amplifiers (PA) are widely used below 6 GHz to improve power-added efficiency (PAE) for communications applications. Although the benefits of the Doherty architecture are compelling, the challenges of designing Doherty PAs increase as the frequency of operation moves toward mmWave. LDMOS, which is commonly used in discrete form below 6 GHz, has limited performance and more integrated approaches are needed to minimize parasitic inductances and capacitances. GaN technology offers significant performance advantages for realizing RF/microwave PAs. More recently, short gate length GaN on SiC MMIC processes have become commercially available, offering the possibility of designing high efficiency Doherty PAs at mmWave frequencies. This article will describe the design of a Doherty PA MMIC for the 5G frequency band at 28 GHz. First-pass design success was achieved using an asymmetric topology fabricated on the commercial 0.15 µm G28v5 GaN on SiC foundry process from Wolfspeed. The MMIC was assembled in a cost-effective, compact 4 mm × 4 mm QFN package. Details of the design, simulation, layout and packaging will be discussed.

As GaN on SiC technology advances, new possibilities for PAs emerge. GaN on SiC has been successfully used at sub-6 GHz and to Ku-Band frequencies, but the source-coupled field plates often used to enhance breakdown voltage and increase power density have limited the maximum operating frequency of GaN transistors. Competing technologies such as GaAs and SiGe achieve higher operating frequencies with similar geometries, and these have become preferred high performance semiconductor technologies at mmWave. However, GaN on SiC processes with gate lengths of 0.15 µm are now available through foundries, with attractive performance at mmWave. This means the advantages of GaN on SiC—high power density, higher output impedance and lower I^2R losses—can be realized in the 28 GHz 5G band.

PRFI has designed GaN PAs using both discrete devices and as custom MMICs, including a GaN on SiC Doherty PA for the 3.5 GHz 5G band.[1] This, combined with the company's experience with mmWave PAs and front-end modules in various GaAs technologies, has been used to extend the Doherty amplifier to mmWave.[2,3]

DOHERTY PAS

The Doherty amplifier configuration (see ***Figure 1***) comprises a main or carrier amplifier, biased in class AB, and a parallel auxiliary or peaking amplifier, biased in class C. The improvement in PA efficiency stems from the complementary operation of the main and auxiliary amplifiers: when the PA is operating at moderate power levels, only the main amplifier is active, which reduces DC power consumption. With high level input signals, the auxiliary amplifier begins to amplify, boosting the output power capability of the PA.

The output matching network of the Doherty PA consists of two impedance transformers: an impedance inverter and a common matching network. Together, they present optimal impedances to the amplifiers in both compressed and backed-off operation. The impedance inverter at the output of the main amplifier provides a 90 degree phase shift


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between the main and auxiliary amplifier paths. In large-signal operation, to ensure the outputs from the main and auxiliary PAs are combined in phase, a 90 degree phase shift is added to the input of the auxiliary amplifier.

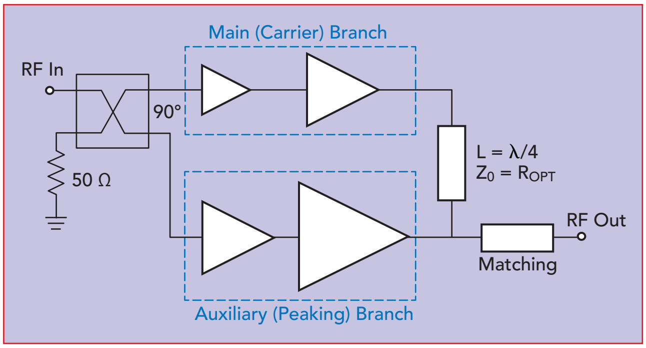

Fig. 1 Doherty amplifier architecture.

Compared to sub-6 GHz Doherty amplifiers, mmWave PAs add several design challenges. Transmission line and matching element losses are higher, and the transistors have lower transconductance, so gain is more difficult to achieve. Also, parasitic capacitances and inductances have more effect at mmWave frequencies, making it more difficult to present a real impedance (R_{OPT} in Figure 1) to the main transistor output.

GAN PROCESS

This PA design uses GaN devices fabricated on Wolfspeed's G28v5 GaN on SiC process. The transistors have 0.15 µm gate length, operate at a bias voltage of 28 V and have a breakdown voltage greater than 84 V. The devices achieve a power density of 3.75 W/mm, compared to less than 1 W/mm for a typical high power mmWave GaAs PHEMT process.[4] While most GaN on SiC processes have a substrate thickness of 100 µm (4 mils), the G28v5 substrate thickness is 75 µm (3 mils), which improves high frequency operation. A variety of transistor layouts are available in the process design kit (PDK), including intra-source and edge via layouts. The gate and drain finger spacing of the FETs can be modified to trade off the thermal resistance, high frequency operation and die area. Self-heating models in the PDK enable designers to predict the operating channel temperatures inside the transistor.

For Doherty amplifiers, GaN on SiC is preferred over GaN on Si for two reasons: the thermal conductivity of SiC is around 3x better than Si, improving the heat transfer from the die, which lowers channel temperature and improves reliability. SiC has less RF loss, so the auxiliary amplifier branch presents a high impedance when pinched off. This avoids loading the main amplifier, yielding better back-off efficiency.

PA DESIGN

An asymmetric topology was selected for the Doherty PA design to achieve better efficiency at higher back-off powers. Theoretically, a symmetric Doherty PA has a peak efficiency at 6 dB back-off, where an asymmetric Doherty with a 2:1 gate width ratio between the auxiliary and main branches achieves peak efficiency at 9.5 dB back-off. Actual device knee voltages reduce the available voltage swing, so peaks at 8 dB back-off are usual. This is compatible with modulated communications signals, which typically have peak-to-average power ratios of 8 to 10 dB. While an asymmetric configuration has performance advantages over a symmetric design, it requires considerably more design effort. Two separate PAs must be designed and then integrated into the Doherty topology. The phase and amplitude responses must be engineered to ensure the powers from the main and auxiliary branches combine in phase at the output.

The asymmetric Doherty PA is shown in ***Figure 2***. The main ampli-

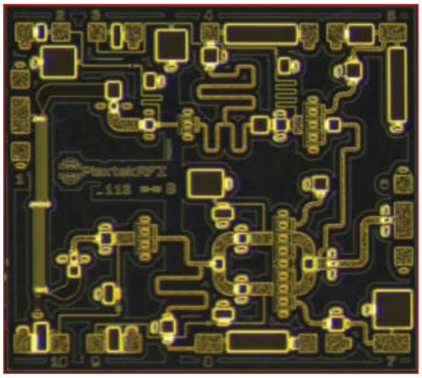

Fig. 2 28 GHz Doherty amplifier die.

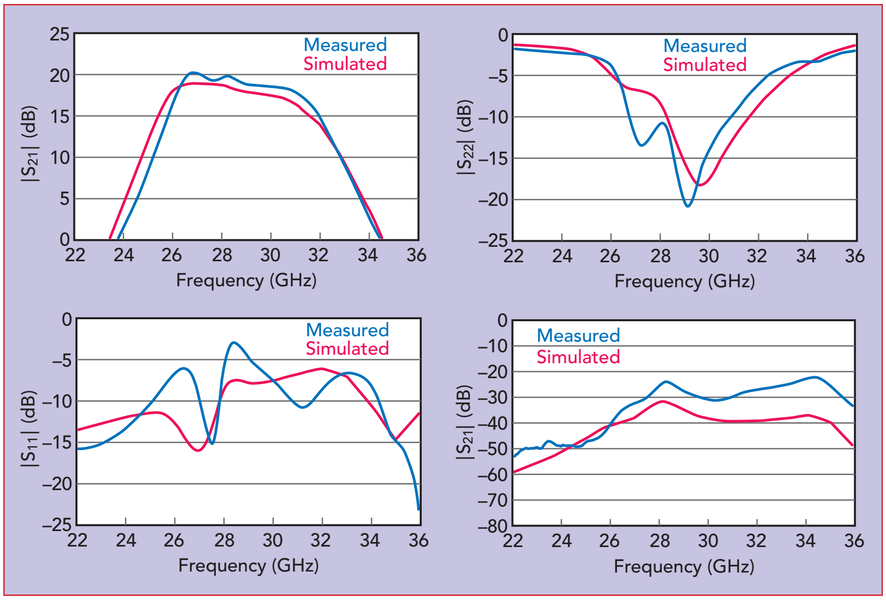

Fig. 3 Doherty PA simulated vs. on-wafer measured S-parameters.

fier is at the top and the auxiliary amplifier, with its larger gate width, is at the bottom. Designed to be compact enough to be assembled in a 4 mm × 4 mm QFN package, the die size is 2.40 mm long × 2.15 mm wide.

The input split and 90 degree phase shift use a Lange coupler, which was electromagnetic (EM) simulated for maximum accuracy. The spacing between the Lange coupler fingers determines the coupling, hence the power split between main and auxiliary branches. The 50 Ω terminating resistor on the isolated port of the Lange coupler was sized to dissipate the expected power reflecting into it.

As with all PA designs, the even-mode stability must be ensured across frequency and temperature, and the odd-mode stability of the combined auxiliary branch transistors must be considered. This is important when combining multiple transistors to increase gate width, which is the case with the auxiliary branch. Due to their class C bias, the auxiliary transistors do not provide small-signal gain, so odd-mode stability is ensured. Under large-signal operation, oscillations may occur, so stability simulations were run to determine the appropriate odd-mode stability resistors.

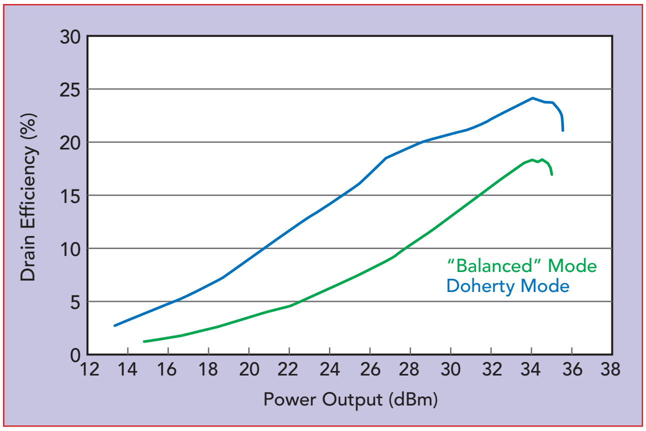

Fig. 4 Measured on-wafer drain efficiency at 29 GHz.

ON-WAFER MEASUREMENTS

The PA was measured using direct on-wafer RF probes in PRFI's cleanroom, testing both small- and large-signal performance. Because the auxiliary branch is biased to operate in class C, Doherty amplifiers often have low small-signal gain. So the measured gain of 20 dB at 27 GHz and 18.6 dB at 30 GHz is notable (see ***Figure 3***). Compared to the simulated performance, the measured small-signal gain is slightly higher, while the frequency response matches well with the simulations, reflecting the accuracy of both the Wolfspeed PDK models and the EM simulations of the on-chip matching networks.


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The maximum output power of the Doherty PA was 35 dBm (3.2 W). Because of the cable and probe losses, the driver amplifier could not fully compress the Doherty PA, so the maximum output power is expected to be higher when the packaged PA is measured. To manage the thermal dissipation of the PA, the large-signal measurements used a 100 μs pulse width, 10 percent duty cycle RF input. The efficiency of the PA at 8 dB back-off, 27 dBm (0.5 W) output, was 19 percent. This efficiency will likely be higher when the die is packaged and mounted on an evaluation board (EVB) with a better thermal environment. "Tuning" the PA bias may yield further improvement in power and efficiency.

Figure 4 shows the efficiency advantage of the Doherty configuration compared to a conventional class AB PA design. The "balanced" mode was measured by setting the same gate voltages for the auxiliary and main branch PAs. At an output power of 27 dBm (0.5 W), equivalent to 8 dB back-off, the measured Doherty efficiency is 19 percent, compared to less than 10 percent for the balanced case.

Compared to other published Doherty PAs at mmWave frequencies, this asymmetric GaN design achieved higher output power than GaAs versions and wider bandwidth than other GaN Doherty PAs, whether GaN on Si or GaN on SiC.[5,6]

PACKAGING

Packaging is a key aspect of PA design, especially at mmWave frequencies.[7] For this design, a cost-effective plastic overmolded 4 mm × 4 mm QFN package was selected to give adequate protection to the die while being compatible with volume production (see ***Figure 5***). For optimum performance and reliability, the thermal resistance between the transistor channel and the backside of the package should be minimized. While the MMIC substrate is SiC, which has excellent thermal properties, the thermal resistance between the backside of the die and the package die attach paddle (DAP) must be minimized. Typically, the die is attached to the DAP with an epoxy; using a high thermal conductivity epoxy reduces the junction-to-case thermal resistance. In addition to the bulk thermal conductivity of the epoxy, bond-line thickness, curing conditions and shear strength are also important considerations when selecting the epoxy.

The plastic overmold of the package is expected to shift the frequency response of the PA down. The die was designed for this, reflecting a higher frequency band when mea-

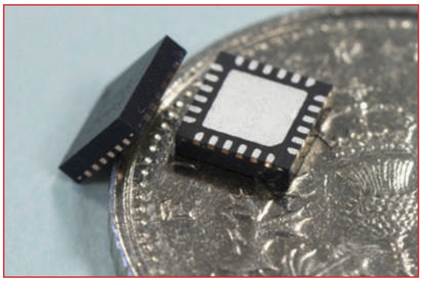
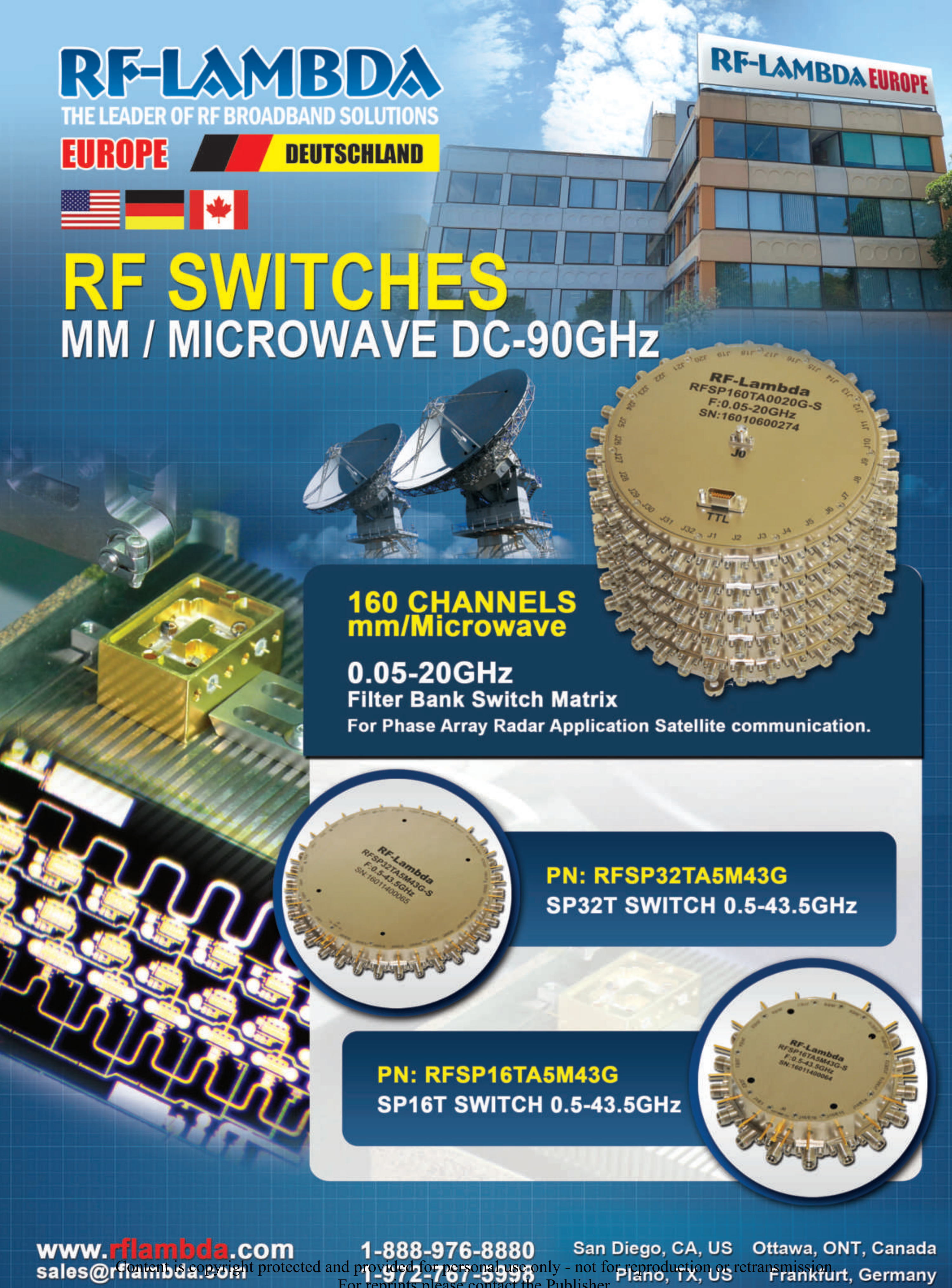


Fig. 5 Doherty PA packaged in a 4 mm x 4 mm QFN.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sured on-wafer so the packaged PA will be centered around the 26.5 to 29.5 GHz design band. The design includes guard bands above and below to accommodate MMIC and assembly process variations. The packaged PA will be extensively tested on an EVB (see ***Figure 6***) and the measured data compared with die performance. The EVB uses minimal off-chip decoupling components and requires no off-chip RF components, as all RF components are integrated on the MMIC.

CONCLUSION

Combining PRFI's experience designing mmWave MMICs and sub-6 GHz Doherty PAs with Wolfspeed's G28v5 process, PRFI designed a Doherty PA MMIC suitable for the 28 GHz 5G band. An asymmetric topology demonstrated excellent initial results on the first-pass die de-

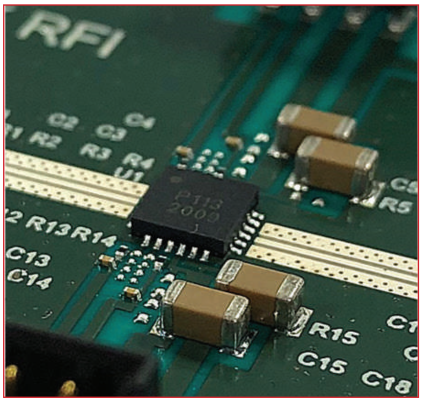

Fig. 6 Packaged Doherty PA assembled on an evaluation board.

sign, with on-wafer measurements of at least 35 dBm output power, 27 dBm at 8 dB back-off with 19 percent PAE and 20 dB small-signal gain. The packaged MMIC will next be evaluated on an EVB to compare packaged and die performance. With wide bandwidth and flat gain, the MMIC PA assembled in a low cost 4 mm × 4mm QFN package will be useful for transmitters in 5G mmWave infrastructure systems.■

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INVITED PAPER

Packaging Technology Key to Enabling mmWave Antenna Arrays

Tim Smith, Cameron Staton and Bill Rhyne
Cubic Nuvotronics, Durham, N.C.

There is growing interest and development activity for devices and systems that operate at mmWave frequencies. So much, that a billion mmWave devices are projected to be produced annually in 2023.[1] The growth is being driven by several emerging applications (see ***Figure 1***). In the U.S., fixed wireless access and 5G networks are being deployed at 28 and 39 GHz. A recent FCC auction included spectrum at 48 GHz, and 3GPP's release 17 is looking at frequencies to 71 GHz. There's also a corresponding interest in high speed wireless backhaul networks using E-Band (71 to 86 GHz), W-Band (92 to 114 GHz), even D-Band (130 to 175 GHz). Discussions about 6G propose using 95 GHz and above. Non-cellular standards such as WiGig, or IEEE 802.11ad, operate around 60 GHz and radar sensors in smartphones also operate at 60 GHz.[2] The use of automotive radar sensors, primarily at E-Band, is increasing to support autonomous driving. IMEC has demonstrated a 140 GHz radar sensor that can be used for gesture recognition or non-contact driver or patient monitoring.[3]

Whether for communications or sensors, many mmWave devices use antenna arrays, which come in many varieties depending on the requirements. They may only have a few elements or hundreds, single or dual polarization, simple patches or complex radiating elements. At mmWave frequencies, connecting the transceiver or beamformer IC to the array is important, with loss, impedance control and isolation optimized.

Despite the interest in mmWave, it is challenging to build small and cost-effective systems at these frequencies. While semiconductor design and process technologies

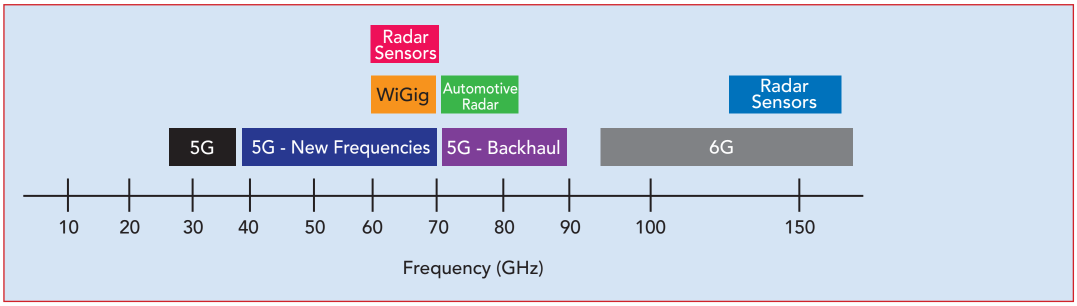

Fig. 1 **Primary mmWave applications.**

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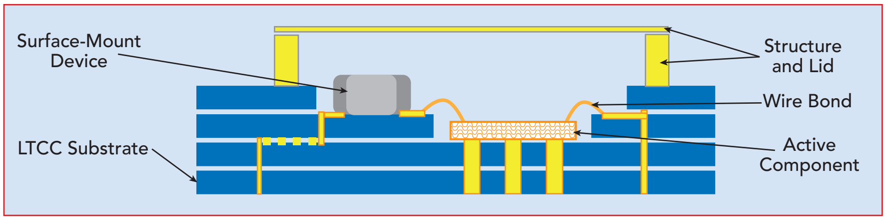

Fig. 2 LTCC package cross section.

have made considerable advances, packaging and module integration technologies can limit mmWave integration. In this article, we review the options for packaging and module integration at these high frequencies, including low temperature cofired ceramic (LTCC), antenna in package (AiP), fan-out wafer level packaging (FOWLP) and PolyStrata®. Comparing them, we discuss how each of these solutions address:

- Signal loss
- Thermal performance
- Small size and high isolation
- Support for heterogeneous integration
- Scalability

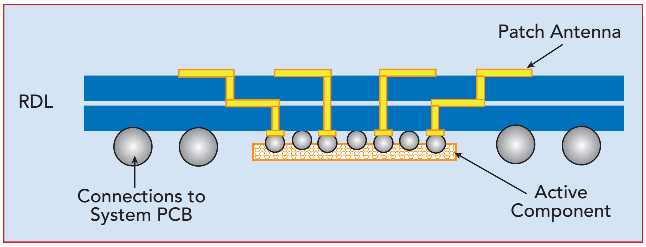

Fig. 3 AiP cross section.

APPROACHES FOR MMWAVE PACKAGING

Packaging technologies are distinguished by the process, dielectric substrates and integration of passive elements, active die and ASICs. Each technology has advantages and hurdles when used for RF system on chip packages at mmWave frequencies. The main drivers for these packaging technologies are commercial markets—5G and IoT—and ease of manufacturing. The packaging techniques discussed here are being considered by industry for commercial wireless product development and are assessed for use in mmWave systems.

LTCC

LTCC is a popular RF packaging technology, fabricated by sintering ceramic type dielectric materials below 1,000°C. The process enables embedded passive components to be connected with higher conductivity layers. Passive components such as filters, inductors and capacitors are designed into the packaging architecture, and active devices are typically integrated with standard integration processes such as wire bonding, flip chip or solder bumps (see ***Figure 2***). Like all technologies discussed in this article, the technology and materials are driven by end application, and the dielectric substrate for LTCC is often a variant of ceramic, based on the end application. For RF applications, LTCC provides moderate integration and performance at an enticing price point. Developments for mmWave applications have yielded compact RF modules with passive components embedded within the ceramic substrate.

AiP

AiP technology is a relatively new idea, rapidly gaining popularity, the interest driven by the opportunity of high volume mmWave applications such as 5G smartphones. These systems have a small number of antenna elements which can be integrated into the package with the associated active components (see ***Figure 3***). AiP is not a single package technology, rather a range of approaches, including double-sided assembly, redistribution layers (RDL), integration of passive devices and shielding.[4]

FOWLP

Similar to AiP, FOWLP is not a single technology. With many different approaches and names, the common idea is enabling a device with

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high density pads or leads to connect to a printed circuit board (PCB) when the PCB and device cannot directly interconnect. Similar to AiP, this is accomplished using a redistribution layer for routing (see ***Figure 4***).

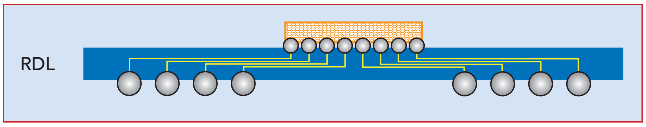

Fig. 4 **FOWLP cross section.**

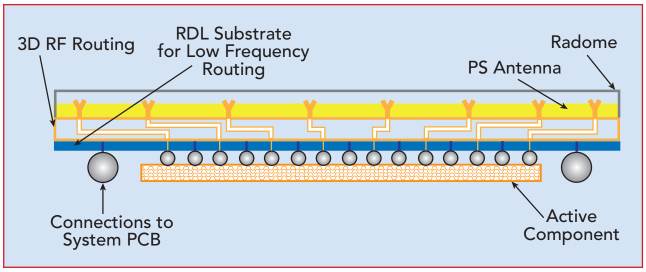

Fig. 5 **PolyStrata package cross section.**

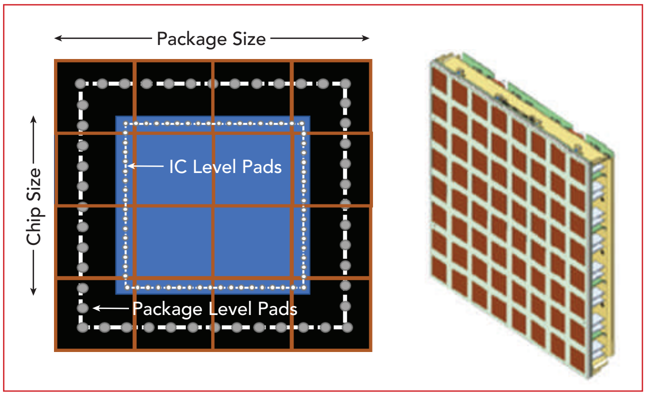

Fig. 6 **Die to array interconnect.**

PolyStrata Packaging

PolyStrata system in package technology is a commercialized technology based on DARPA's 3D Micro Electromagnetic Radio Frequency Systems program. The technology is a batch additive process that uses copper and air dielectric routing. MMICs and other surface-mount devices can be flip mounted, soldered or wire bonded onto the PolyStrata substrate (see ***Figure 5***). PolyStrata integration offers advantages for mmWave packaging: high isolation routing of the substrate can be used to integrate filters, diplexers and other high performance components, achieving isolation which is challenging at high frequencies. PolyStrata uses a copper substrate which supports microcoax signal routing from DC to >300 GHz, achieving isolation greater than 80 dB. In addition to copper and air, minimal dielectric support structures support the center conductor, and the routing maintains the performance in three dimensions, enabling the design and integration of passive components.

MMWAVE ARRAYS

While these packaging approaches are similar, they have important differences when used for mmWave arrays. First, consider loss. The importance of minimizing loss depends on the application. At lower frequencies and for smaller arrays, loss may not be a significant factor; however, it becomes very important at higher frequencies and in arrays with more elements.

To illustrate, ***Figure 6*** shows a 4 × 4 section of an array with the beamformer IC (BFIC) or MMIC driving the antenna elements. The size of the array elements will depend on frequency; at V-Band, each element is on the order of 2 mm on a side. The figure shows the size difference between the BFIC or MMIC and the antenna array. The mmWave package routes the high frequency signals from the IC to the array, which could be greater than 4 mm in this example. The packaging technology chosen must route both the mmWave, low frequency and DC signals—possibly 16 or so mmWave signals and 5× to 10× more lower frequency signals—from the IC to the antenna array or the system PCB. The packaging designs discussed here use either PCB, RDL, ceramic or PolyStrata for the mmWave routing, and their losses reflect the different transmission line structures

TABLE 1
PROPERTIES OF TYPICAL PACKAGE MATERIALS

Material	4 mm Line Loss at 60 GHz (dB)	ε_r	CTE (ppm/°C)
RDL	1.0 to 1.5	~3	
Ceramic	0.2 to 0.6		
PCB	0.15 to 0.25	~3	16 to 18
PolyStrata	0.08 to 0.1	~1	16.6
Alumina		9.8	7 to 8

used (i.e., stripline, microstrip, coax), substrate thicknesses, etc. ***Table 1*** compares the typical loss of these materials for a 4 mm long transmission line at 60 GHz.

Another important consideration is thermal performance, with two aspects to consider, the first is the thermal resistance from the heat generating component to an interface or external heat sink. For AiP, FOWLP and PolyStrata, the active devices can be coupled through a thermal interface material (TIM) to a heat sink, slug or thermal via. The TIM can be included with a ceramic package and connected to a lid or heatsink, as needed. While this aspect of thermal performance may be similar among the approaches, the second consideration, the coefficient of thermal expansion (CTE) of the package, will differ among the technologies. The CTE must be sufficiently matched between the IC, the package substrate and the PCB to which it is attached; otherwise, the reliability of the attachment will be degraded during thermal cycling. Table 1 includes CTE in the comparison of package substrate materials.

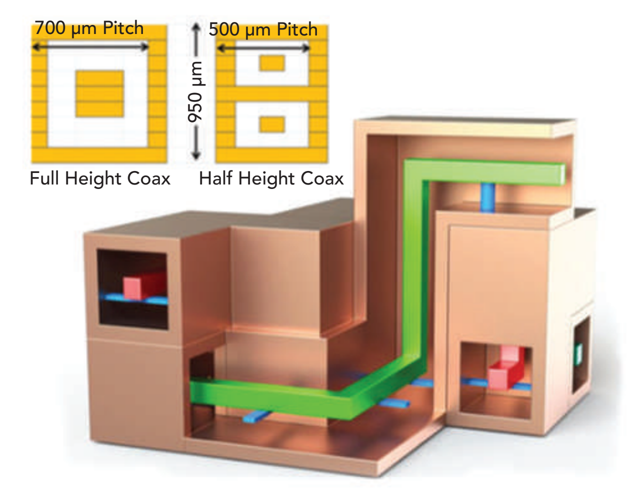

Fig. 7 Three-dimensional coaxial structures built with PolyStrata technology.

These packaging solutions are designed to route many low frequency and high frequency signals in a small space. It is important to do this while maintaining high electrical isolation among the signals, which will depend on the transmission line structures and the relative dielectric constants (ε_r) of the respective materials (also shown in Table 1). The mmWave signals are typically routed using microstrip, stripline or substrate integrated waveguide transmission lines, along with vias. An advantage of PolyStrata is the capability to build three-dimensional coaxial structures which are small yet fully shielded (see ***Figure 7***), isolation greater than 80 dB can be achieved at 70 GHz.

All the packaging technologies discussed support heterogeneous integration, i.e., the capability to solder, wire bond or flip chip devices on the substrate. An important consideration is the interconnect pitch. As frequency increases, so does the need for finer pitch interconnects. A bump pitch of 100 μm may be needed at 100 GHz, for example. Further integration is possible with the ceramic and PolyStrata technologies, which enable high performance components such as filters or couplers to be integrated into the substrate. The ability to do

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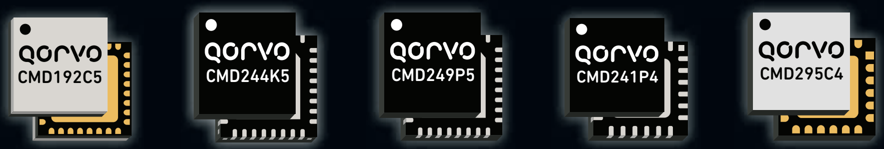

Part Number	Frequency (GHz)	Voltage (V)	Package (mm)	Description
CMD192C5	DC-20	5-8	5x5 Ceramic QFN	Distributed Amplifier MMIC
CMD244K5	DC-20	5-8	5x5 Plastic QFN	Distributed Driver Amplifier MMIC
CMD249P5	DC-20	10	5x5 Plastic QFN	Distributed Power Amplifier MMIC
CMD292	DC-30	8-10	Die	Distributed Driver Amplifier MMIC
CMD295C4	2-20	2-4	4x4 Ceramic QFN	Driver Amplifier MMIC
CMD241P4	2-22	5-8	4x4 Plastic QFN	Distributed Amplifier MMIC

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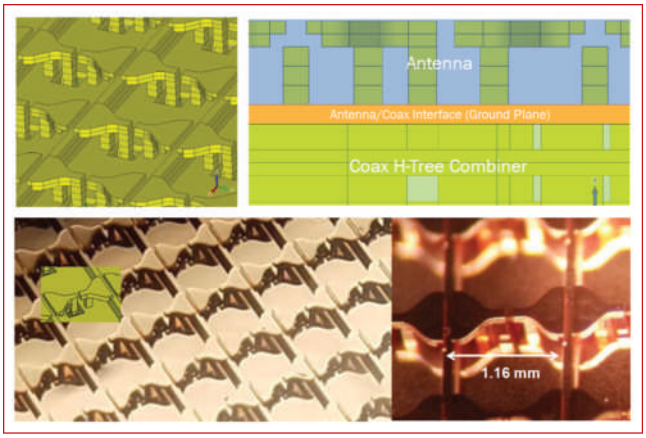

Fig. 8 PolyStrata D-Band antenna array and feed network.

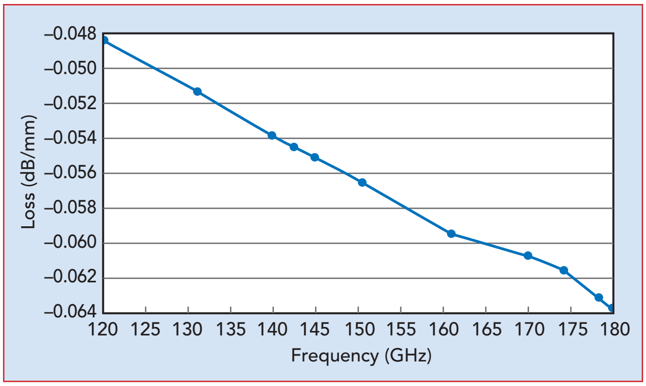

Fig. 9 PolyStrata coaxial transmission line loss vs. frequency.

this is limited with a PCB substrate.

With any packaging technology, scalability is important. This can be the capability for high volume production with repeatable performance or geometric scalability, i.e., the ability to tile packages to build a larger antenna array. As discussed, these technologies are in production for various applications. Tiling the packages into a larger array depends on the ability to route the signals in the available space while achieving the required loss and isolation. This depends on the system frequency and number of signals, so it is difficult to generalize a comparison.

Another factor for some applications is be the capability to support the antenna element design. PolyStrata has an advantage because of its three-dimensional nature and use of an air dielectric. An example of a PolyStrata antenna array is shown in ***Figure 8***. This 130 to 175 GHz array was fabricated and tested, achieving good performance across the frequency range.[5] Other technologies can support two-dimensional structures, for example, a cavity backed aperture coupled patch antenna.[6]

Finally, as applications move to higher frequencies, the same packaging technology platform chosen for lower frequency systems should remain viable to address all the applications shown in Figure 1. PolyStrata has demonstrated low loss and high isolation through D-Band (see ***Figure 9***), demonstrating better than

TABLE 2
MMWAVE PACKAGING TECHNOLOGY COMPARISON

Technology	High Frequency Loss	Isolation	Thermal Performance	Integrated Functionality	Scalability	>80 GHz
LTCC	Moderate	Moderate	Moderate	Good	Good	Limited
AiP	Low with high performance PCB	Moderate	Good	Limited	Good	Limited
FOWLP	Significant Loss in RDL	Moderate	Good	Limited	Good	Limited
PolyStrata	Low	High	Good	High	Good	Yes

0.064 dB/mm loss to 180 GHz. For comparison, a PCB-based approach demonstrated a loss of 0.19 dB/mm at 150 GHz with a microstrip transmission line and 0.18 dB/mm for a grounded coplanar waveguide transmission line.[6]

SUMMARY

Packaging technologies evolve to support market requirements. As mmWave systems and devices proliferate, the need to package and connect these devices to antennas grows, as well as the complexity of the packaging task. This article has reviewed several popular technologies, each a good solution depending on the system requirements and design approach (see the summary in ***Table 2***). When choosing a packaging platform, consider the operating frequency, number of low and high frequency signals to be routed, the components or functions to be integrated, the type of antenna element and the thermal environment.■

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A novel active filter, based on regeneration, provides tunability, variable bandwidth, stable high Q, fast frequency shifting and ease of integration. It allows any super-Nyquist image to be isolated, including frequencies far higher than the clock. A direct digital synthesizer (DDS) can directly modulate a signal with the modulation preserved in the image. The passband of the active filter can be adjusted to match the modulation, allowing dramatic simplification of radio design. These capabilities are confirmed using an Analog Devices AD9914 DDS. Both single and multi-pole filters are used to isolate multiple image tones.

Direct digital synthesis (DDS) is a long-established technique to generate RF signals. The fundamental output frequency is limited to less than half the clock frequency—the Nyquist limit. The DDS output includes image tones around the clock and its harmonic frequencies. These image tones are also usable, enabling the DDS to generate much higher frequency tones. Filtering is required to make use of these super-Nyquist frequencies by eliminating undesired tones, especially the fundamental. A fixed bandpass filter (BPF) can be used, but this limits the inherent agility of the DDS. With a fixed BPF, the DDS frequency range is limited to the non-overlapping range of single images. Further, a fixed BPF passes all spurs within its passband, typically requiring additional cleanup. Conventional tunable bandpass filters can be used to overcome this limitation, although their slow tuning speeds limit agility. They present integration challenges as well.

In RF processing there is typically a requirement to generate a signal of precise frequency and high purity. Often the application calls for an agile signal such that the generated frequency must be able to shift quickly while maintaining precision of instantaneous frequency and phase. DDS is a natural choice for generating such signals, as it has complete flexibility offered by digital processing—the waveform voltage values are stored in memory and converted to the desired signal by a digital-to-analog converter (DAC). The input clock sets the rate at which the voltage values of the DDS are output to the DAC. Frequency is determined by a stepping algorithm that determines the address increment in the DDS ROM lookup. The stepping algorithm can be complex and result in arbitrary frequency or phase modulated signals. Together with an IQ modulator, also done digitally, precise quadrature amplitude modulation and arbitrary waveform generation (ARB) signals can be produced.

The DDS digital value is output to a DAC and is converted to a quasi-analog waveform which produces a staircase-like signal

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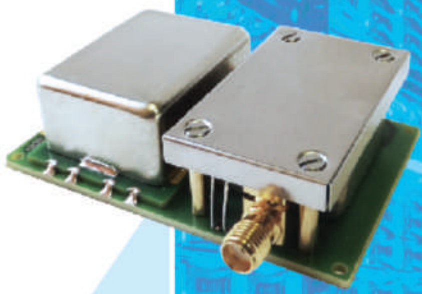

Phase noise, dBc/Hz

	for 10 MHz	100 MHz
1 Hz	<-120	<-98
10 Hz	<-145	<-125
100 Hz	<-160	<-135
1 kHz	<-165	<-160
10 kHz	<-170	<-175
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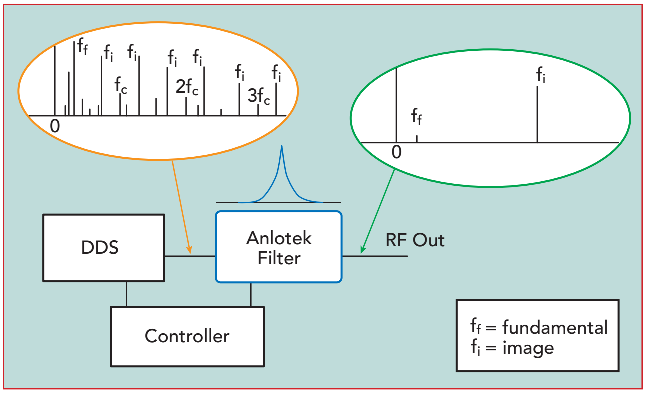

Fig. 1 **Super-Nyquist DDS block diagram.**

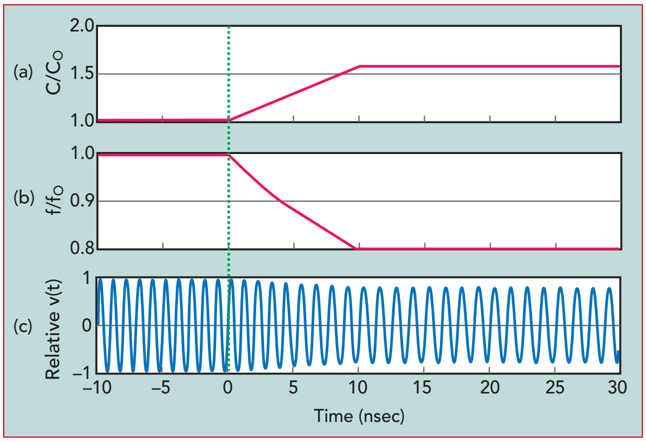

Fig. 2 **MATLAB simulation illustrating varactor capacitance (a), regenerative pole frequency (b) and DDS-filter output change (c) with the DDS and filter controlled in unison.**

with harmonic distortion. Also, the instantaneous output frequency is generally not commensurate with the input clock frequency, resulting in numerous spurious frequency components, some of which can be close in frequency to the desired frequency.

In a modern DDS implemented in non-exotic semiconductor technologies, the clock is limited to the low GHz range, meaning that the nominal output is limited to a few GHz. Typically, these signals can be upconverted, to support systems with higher frequency requirements, but with considerable added complexity and filtering.

Another alternative is possible. A DDS generates image tones around the clock and its harmonics. These tones are at lower power levels than the fundamental but are otherwise perfect copies.[1] Using these image tones, i.e. super-Nyquist tones, it is possible to generate RF signals at many multiples of the DDS clock frequency. The primary challenge is filtering. A DDS output naturally contains a myriad of spurious signals. Using a super-Nyquist tone adds further difficulty with not only more spurious tones, but with one or more at higher power levels than the desired tone.

A previously disclosed agile tunable filter technology[2] that makes use of regeneration, or positive feedback, can be used to realize a super-Nyquist DDS. Any integrated circuit technology with usable gain at the frequency of interest can be used to realize high Q tunable poles.[3] Unlike earlier regenerative circuits, this is inherently stable and does not require quenching circuits. These regenerative filters have multiple resonators, and result in a single, stable, dominant pole. Dominant poles with Qs of over 5,000 have been demonstrated. They have been used in a three-pole filter, agile both in frequency and bandwidth.[2] This enables the design of filters operating anywhere in the RF, microwave and mmWave spectrum. Filter tuning range can be arbitrarily large, depending on the implementation.

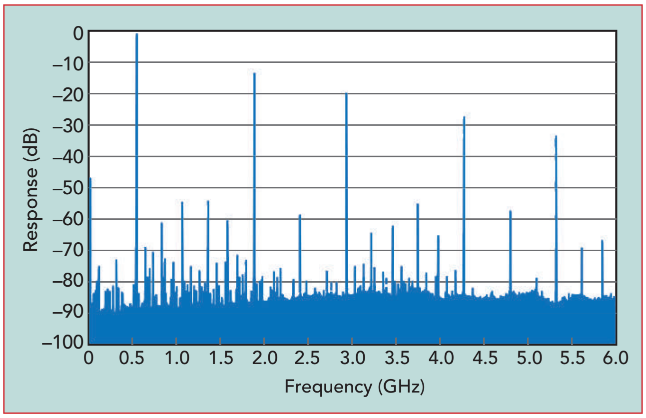

Fig. 3 **Unfiltered AD9914 DDS output spectrum with a 2400 MHz clock and a 528 MHz fundamental output.**

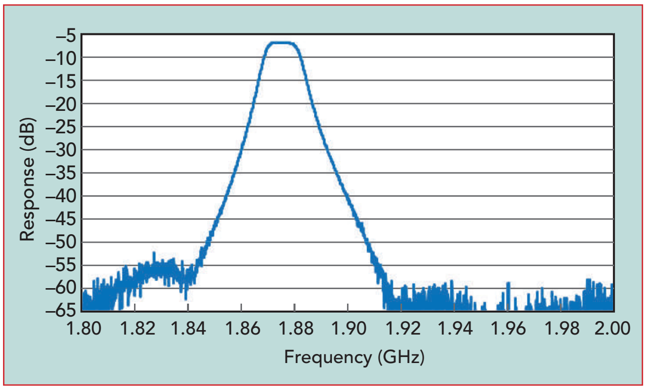

Fig. 4 **Frequency response of 3-pole filter tuned to 1875 MHz.**

SUPER-NYQUIST DDS DESIGN

A block diagram of the super-Nyquist DDS is shown in ***Figure 1***. The unfiltered DDS output spectrum has many tones. The nominal DDS output tone, f_f in the figure, is the direct fundamental output. There are various spurs, for example from the DDS clock (f_c). Of interest here are the image tones, f_i. These are exact copies of the fundamental, replicated around harmonics of the clock (xf_c). Figure 1 shows the primary DDS output (f_f) suppressed in favor of one of the higher frequency super-Nyquist images (f_i).

The key to a super-Nyquist DDS is filtering. The basic requirement is to filter out the fundamental component (f_f). A high-pass filter can be used, but then the output retains numerous spurs and all the higher frequency images. A conventional fixed-tuned bandpass filter is better, since it also eliminates other, unwanted, image tones and many other spurs. Since it is fixed-tuned, however, it has a relatively narrow super-Nyquist DDS frequency range.

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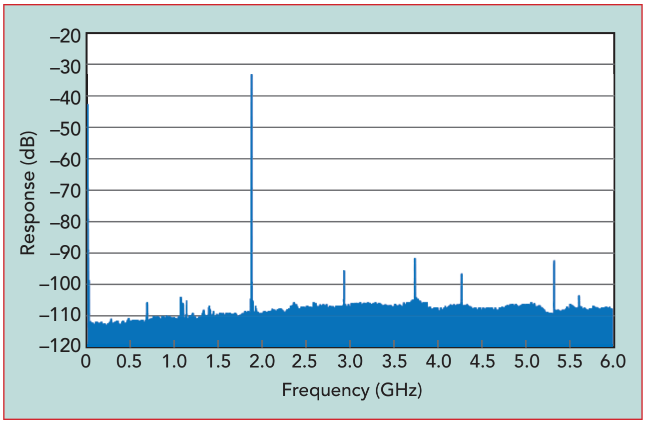

Fig. 5 Filtered DDS output.

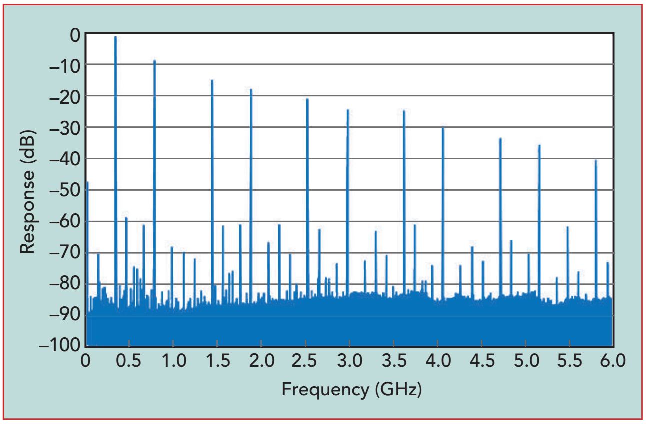

Fig. 6 Unfiltered AD9914 DDS output spectrum with a 1100 MHz clock and a 326 MHz output.

Just as the desired image moves with tuning, so do the other images, and the bandpass filter must eliminate the full range of all the other image tones and spurs.

This work takes the super-Nyquist DDS approach further. The tunable regenerative filter[2] is controlled together with the DDS and can therefore precisely track one of the image tones, eliminating the fundamental and all other spurs. To further increase the super-Nyquist DDS frequency range, the filter is not limited to tracking just one image. It can be tuned from one image to the next to provide an extremely large frequency coverage. The filter comprises multiple high Q pole circuits to ensure very high spectral purity. Not only are the fundamental and unwanted images rejected, so are the clock tones and other spurs as well.

Because the DDS and filter are controlled in unison, frequencies can be switched to a new steady state frequency and phase in as little as 10 nsec. This is illustrated in ***Figure 2***, which shows a MATLAB simulation of the DDS and filter combination. Figure 2a is the relative change in capacitance of the varactors in the filter, Figure 2b is the resulting change in the frequency of each regenerative pole and Figure 2c is the output voltage of the DDS-filter combination. The DDS output is programmed to change starting at t = 0, the same time as the varactor bias begins to change. A change in frequency initiated at t = 0 is completed within 10 nsec. Note that as the DDS and filter change, the amplitude of the output is reduced. For fast switching, it is important for the energy in the regenerative poles to remain constant; so, as capacitance is increased, amplitude must be reduced accordingly. Correcting for constant amplitude is trivial, for example with a subsequent variable gain element. This enables exceptionally agile frequency generation, far faster than is achievable with conventional phase-lock loop approaches used to generate higher frequencies and condition the fundamental DDS output.

This super-Nyquist DDS is also capable of arbitrary modulation. If the regenerative filter[2] (see Figure 1) is a single pole filter, it only supports a single unmodulated tone. When the filter comprises multiple poles, its passband can be designed to match the modulation width. In fact, the passband width is variable, so it can be tuned to match changing modulation. The combination of the DDS and filter, therefore, provides


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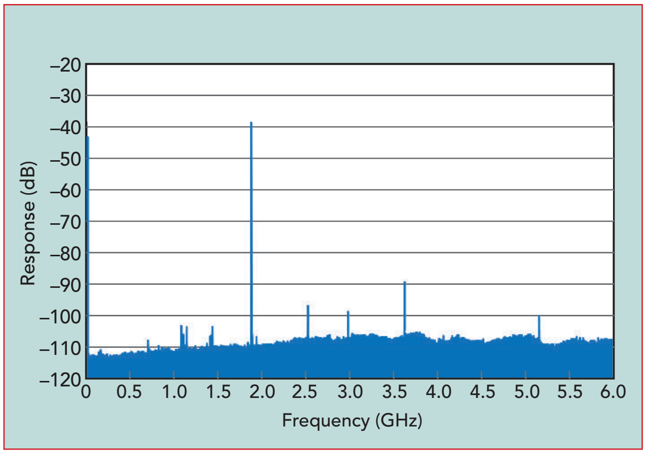
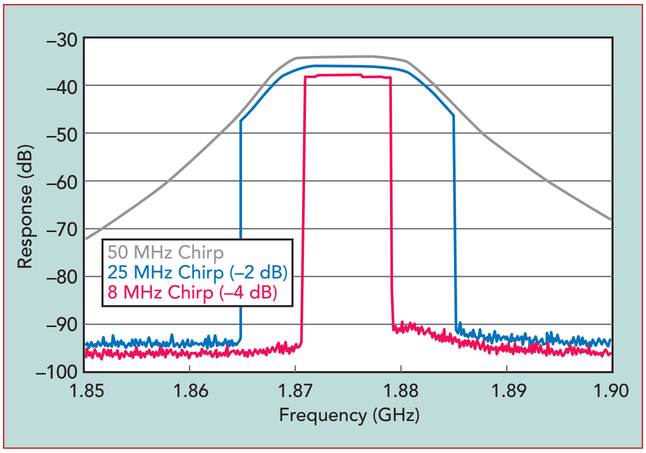


▲ Fig. 7 Filtered DDS output.



▲ Fig. 8 Filtered responses for chirp modulations of 8, 25 and 50 MHz. Amplitudes are offset to aid visualization.

excellent spectral purity along with exceptional agility.

EXPERIMENTAL RESULTS

Both a single pole and a three-pole regenerative filter[2] are paired with an Analog Devices AD9914 DDS evaluation board. The AD9914 is capable of fundamental outputs of up to 1.4 GHz. It can operate with clock frequencies of up to 3.5 GHz. A 2.4 GHz clock can be internally generated from a 100 MHz reference, or an external clock signal can be provided. The filter technology supports tunability over large frequency ranges, an octave or more. The achieved tuning range depends on the design of passive resonators and tuning circuitry. For this work, a filter with a tuning range from 1.65 to 1.95 GHz is designed using varactors to tune coupled line resonators. One to three active poles are available, each with an independent variable Q that can exceed 5,000. The poles are independently adjustable, so passband width is variable. Passband ripple is controllable and is impacted by the passband width.

For a baseline, the AD9914 is operated with its internal 2.4 GHz clock, and its output frequency set to 528 MHz. The output spectrum is shown in ***Figure 3***. The dominant output at 528 MHz is clearly seen. Its second harmonic, at 1,056 MHz is visible, but greater than 50 dB lower in power. The clock spur is visible at 2.4 GHz, as is its second harmonic at 4.8 GHz. Image tones are also present. The images of the clock fundamental are at 2,400 – 528 = 1,872 MHz and 2,400 + 528 = 2,928 MHz. They are 12 and 19 dB below the fundamental level, respectively. The images of the clock second harmonic are at 4,800 – 528 = 4,272 MHz and 4,800 + 528 = 5,328 MHz. They are 26 and 32 dB below the fundamental level, respectively. Clearly the image tones have useful power levels, while the DDS second harmonic output is significantly suppressed. Many other spurs are visible, which is typical of a conventional DDS output.

A cascade of the AD9914 and three-pole filter tuned to a 10 MHz bandwidth around 1,875 MHz is measured. The filter response is shown in ***Figure 4*** and the filtered DDS output is shown in ***Figure 5***. The spectral display contains only a handful of visible spurs. The dominant tone is now the 1,872 MHz image. The fundamental tone, at 528

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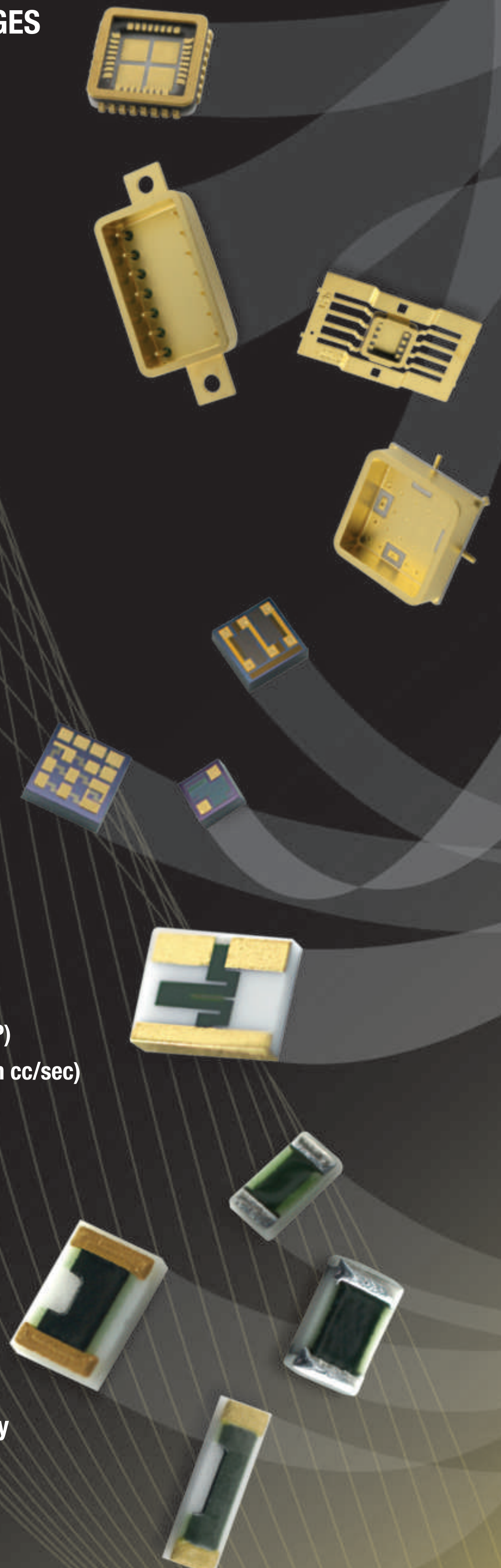

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MHz, has been suppressed and does not exceed the noise floor, greater than 90 dB below the image. There are some low-level spurs between 500 MHz and 1.2 GHz. These are ambient broadcast signals and can be ignored. The highest spur visible in the spectrum, the second harmonic of the image at 3,744 MHz, is 58 dB below the image. Other spurs are visible at 2,928, 4,272 and 5,328 MHz. These are other image tones and are at least 65 dB below the desired 1,872 MHz image.

To demonstrate the ability to select higher order images, the AD9914 is operated with an external clock at 1,100 MHz and set to a 326 MHz output frequency. The unfiltered spectrum shown in ***Figure 6*** includes a strong fundamental tone and many spurs, most notably image tones around the clock and its harmonics. The low frequency image of the second clock harmonic is at 2,200 – 326 = 1,874 MHz. The

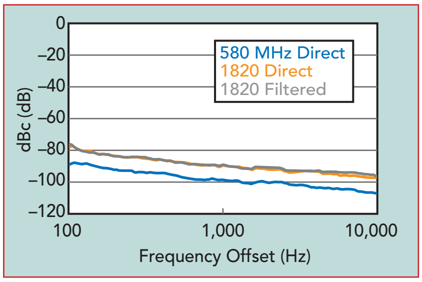

Fig. 9 Phase noise of the 1820 MHz DDS image is not degraded by the filter.

filtered output is seen in ***Figure 7***. The 326 MHz fundamental output is completely suppressed. The remaining spurs are primarily other images and are at least 50 dB below the desired 1,874 MHz image.

Modulated Signals

The AD9914 is capable of synthesizing modulated signals. The filter bandwidth can be adjusted to the bandwidth of the modulation. The effect is illustrated in ***Figure 8***. The AD9914 is set for chirp modulation of 8, 25 and 50 MHz centered at 525 MHz. The filter is set to isolate the image of the chirp with an 1,875 MHz center frequency. Note that a slow chirp is used to aid in visualization in accordance with Fourier analysis. Also note that the 25 MHz trace in Figure 8 is offset by -2 dB and the 8 MHz trace is offset by -4 dB so that the responses are better visualized. The filter's bandwidth is set to 10 MHz (0.5 percent bandwidth). The 8 MHz chirp is within the passband and has an essentially flat response over frequency. The 25 MHz chirp exceeds the filter bandwidth and the signal is attenuated by 12 dB at its frequency extremes. Similarly, the 50 MHz chirp far exceeds the filter bandwidth, and the signal is attenuated by as much at 40 dB at its limits.

Phase Noise

Phase noise, especially close to the carrier, is a key characteristic for any signal generator or transceiver. This approach, where a tunable active filter is cascaded with a DDS, does not significantly impact phase noise because the only active element of the filter is the amplifier. Amplifiers generally do not add significant phase noise.

Figure 9 shows three phase noise measurements. The blue trace is the

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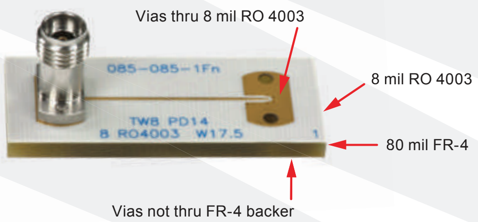

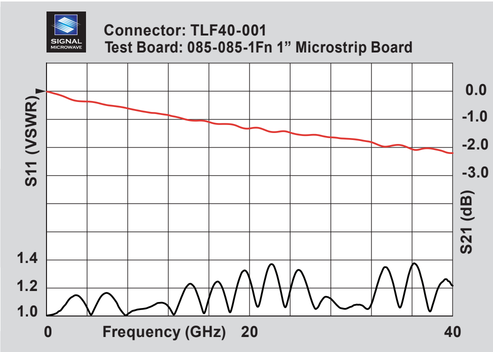

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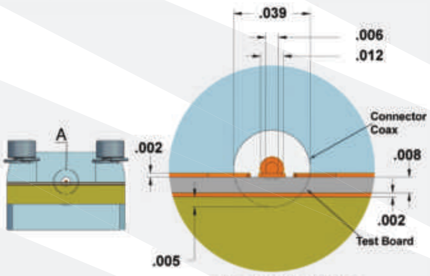

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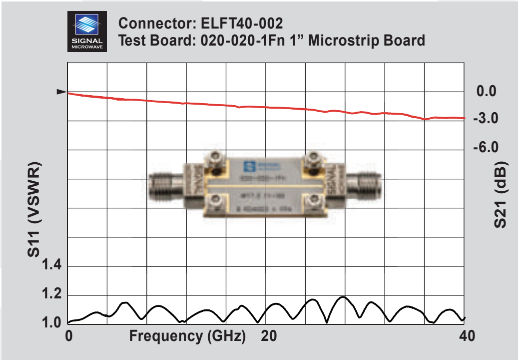

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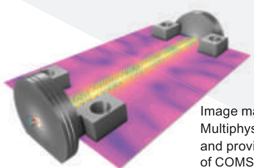

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phase noise of the direct 580 MHz output of the AD9914 DDS. The orange trace is the phase noise of the 1,820 MHz image, also directly from the AD9914 DDS. The phase noise of the 1,820 MHz signal is degraded by 12 dB. This is because the output level of the 1,820 MHz image is 12 dB lower than the reference level of the 580 MHz fundamental, as theory predicts.[1] Notably, the phase noise of the filtered signal is essentially the same as the unfiltered 1,820 MHz signal. Both the signal and the phase noise see the same level of gain as they pass through the filter. This confirms that the filter does not contribute phase noise.

CONCLUSION

The combination of a conventional DDS and an agile tunable filter can provide output frequencies much higher than half the clock to realize a super-Nyquist DDS. The tunable filter eliminates the fundamental tone and isolates the selected image, directly enabling synthesis of higher frequency signals without resorting to exotic semiconductor technologies. Further, with the use of exotic technologies, even higher frequency signals can be synthesized.

The examples discussed use a popular DDS product, the AD9914 and a regenerative tunable filter. The specific filter has a 1.65 to 1.95 GHz tuning range. Images are successfully isolated, one from the clock fundamental, and another from the second harmonic of the clock. The filter is tunable in frequency and bandwidth, ideal for supporting agile systems. This is illustrated with the chirp modulation capability of the AD9914. The filter bandwidth is adjusted to slightly greater than the chirp range to effectively isolate a chirp image. The tunable filter is based on stable regeneration, and the only active elements are in the gain stages. As such, the filter does not add phase noise.

This super-Nyquist DDS enables a new generation of agile and cognitive radios. High frequency signals can be directly synthesized, and with the inherent adjustability of the DDS and the filter, truly agile signal synthesis is possible. Modulated synthesis and selection of high frequency images, as demonstrated, allows tremendous simplification of transmit architectures. The capabilities of this DDS approach also enable simplification of receive architectures along with high levels of agility.■

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INVITED PAPER

Ceramic Waveguide Filter Design Using Computer-Aided Tuning

Diamond Liu, Yan Liang and David Shin
SynMatrix Technologies Inc., Richmond, Canada

With emerging fifth generation (5G) cellular communication systems, the demand for passive components is driving the growth of massive MIMO and carrier aggregation technologies. With this growth, microwave filters are faced with a number of technical challenges including miniature sizing with a demand for better electromagnetic performance such as lower passband loss, sharper skirts and higher isolation without increasing manufacturing costs. Ceramic waveguide filter design using different dielectric materials is well researched.[1, 2] More recently, Afridi et al.[3] studied miniaturization by using evanescent modes to provide a wide spurious-free window. Compared to a traditional metallic or dielectric resonator filter, the ceramic-filled waveguide filter offers lower loss, higher power handling capability and a wider spurious-free window while also meeting miniature size requirements. In this article, we describe a procedure to design a dielectric-filled waveguide filter using advanced computer-aided tuning techniques.

TABLE 1
DESIGN SPECIFICATIONS

Parameter	Requirement
Operating Band (MHz)	3400 to 3600
Insertion Loss (dB)	1.2
Return Loss (dB)	18
Isolation (dB)	>30, 3200 to 3360 MHz >30, 3640 to 3800 MHz
Operating Temperature (°C)	–25 to +70

DESIGN

Resonator Analysis

To meet the specifications in ***Table 1***, a ceramic material with a dielectric constant of 21.2 and loss tangent of $7.45e^{-5}$ is selected. A waveguide resonator can be treated as a

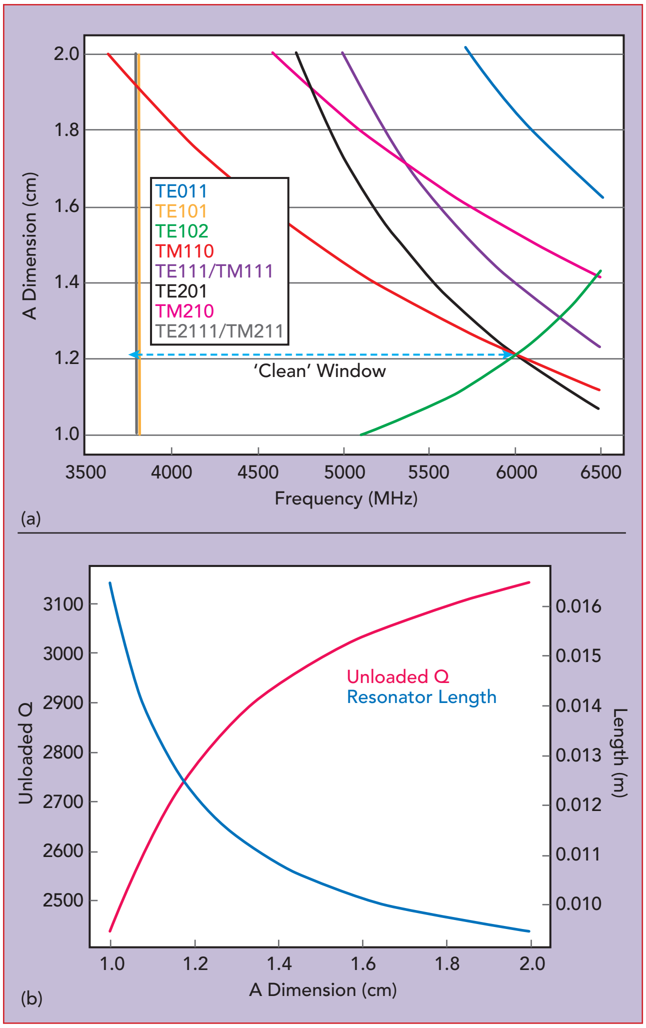


Fig. 1 **Mode (a) and corresponding unloaded Q (b).**

truncated section of rectangular waveguide with a length of half the guided wavelength with conducting boundaries on all of its walls. By filling the cavity with a material of dielectric constant ε_r, its dimensions are reduced by a factor of $\frac{1}{\sqrt{\varepsilon_r}}$.

The fundamental TE mode resonant frequency of a half wavelength ceramic waveguide resonator is determined by:[4]

$$f_0 = \left(\frac{1}{2\sqrt{\varepsilon_r \mu_r}}\right)\sqrt{\left[\left(\frac{l}{a}\right)^2 + \left(\frac{m}{b}\right)^2 + \left(\frac{n}{d}\right)^2\right]} \quad (1)$$

where l, m and n represents the half wavelength variation of electric field lines along the width (a), height (b) and length (d) of the resonator, respectively.

The resonant frequency is dependent only on the waveguide width and length while the unloaded Q and higher order spurious are bounded by the waveguide height; a shorter height provides a wider spurious-free window, while a taller height provides a higher Q. By optimizing waveguide dimensions, engineers can, therefore, trade off unloaded Q, resonant frequency and the size of the "clean" or spurious-free window of operation (see ***Figure 1***). This is illustrated by electromagnetic simulation (see ***Figure 2a***) using the ANSYS HFSS eigenmode solver.[5] It can be seen that the TE102 mode occurs at 6000 MHz and the unloaded Q value is about 2600, which is very close to the theoretical result.

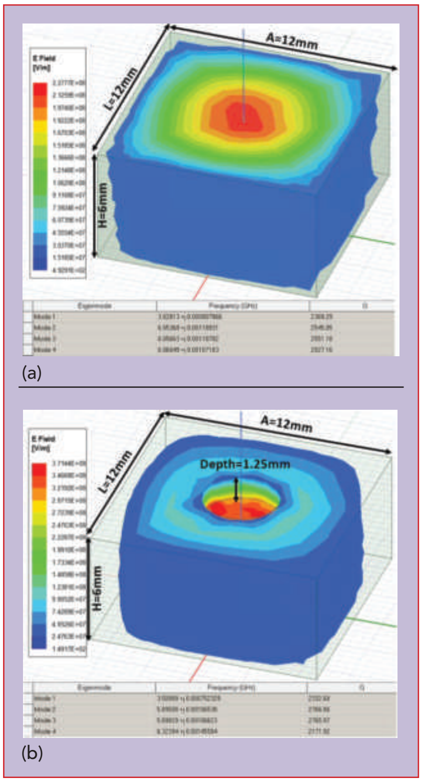


Fig. 2 **ANSYS HFSS EM simulation without (a) and with (b) tuning.**

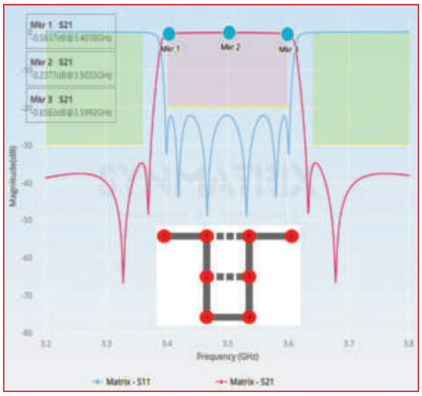


Fig. 3 **Filter topology and performance after synthesis.**

For this design, a = 12 mm, b = 6 mm and d = 12 mm. The dimensions are chosen to compensate for the electrical field variation due to the tuning mechanism on the top wall (see ***Figure 2b***). The resonator is silver plated. For design modeling, the resonator unloaded Q is assumed to be a conservative 70 percent of the simulated result, or 2000, to provide margin.

Matrix Synthesis and Coupling

The coupling matrix is generated using the SynMatrix platform which integrates coupling matrix synthesis and computer-aided tuning tools.[6] Coupling matrix synthesis is an iterative optimization process for achieving the best performance within a safe design margin; it is also a comprehensive process that considers power handling capability, tuning sensitivity, thermal shift electrical impact, physical realization and manufacturing sensitivity. For example, to improve insertion loss (IL) by flattening ripple variation, the bandwidth must be widened, which can negatively impact isolation. From a mechanical perspective, different topologies will result in different power handling capabilities. A cascade quadruplet (CQ) has a more uniform, even distribution than the cascade triplet (CT) with the same electrical performance. However, the CT structure is a more favorable engineering design because of its flexible tuning capabilities and the ease of realizing its physical structure.

Figure 3 shows the final filter performance and its

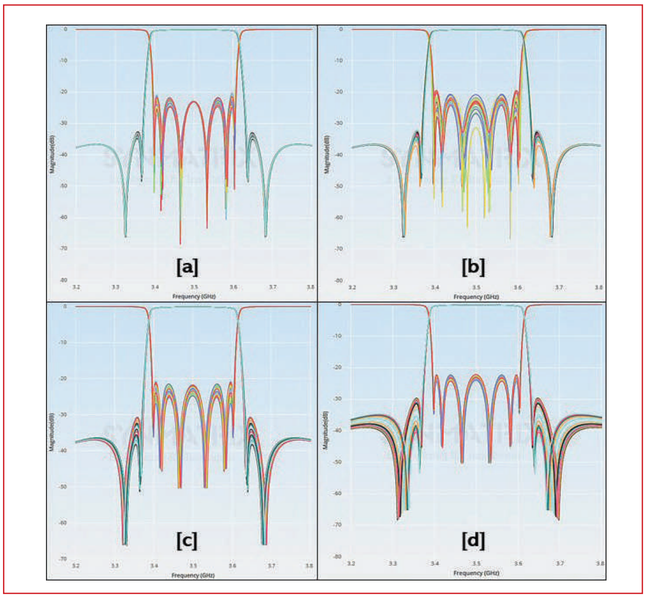


Fig. 4 Monte-Carlo analysis of the coupling matrix, showing 1 percent variation of the self-coupling (a), main coupling (b), M25 (c) and M16 (d).

corresponding topology using the SynMatrix synthesis tool. In this design, an eight pole folded CQ topology is used due to its physical compactness. One can realize the maximum transmission zeros with limited space by using this topology. The corresponding coupling matrix with a 10 MHz bandwidth extension is shown below:

$$\begin{bmatrix} 0 & 1.0751 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1.0751 & 0 & 0.9140 & 0 & 0 & 0 & 0.0822 & 0 \\ 0 & 0.9140 & 0 & 0.5683 & 0 & -0.3440 & 0 & 0 \\ 0 & 0 & 0.5683 & 0 & 0.8565 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.8565 & 0 & 0.5683 & 0 & 0 \\ 0 & 0 & -0.3440 & 0 & 0.5683 & 0 & 0.9149 & 0 \\ 0 & 0.0822 & 0 & 0 & 0 & 0.9149 & 0 & 1.0751 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.0751 & 0 \end{bmatrix}$$

Design margins must account for temperature variations to compensate for thermal drift. For a conservative design margin, a material coefficient of thermal expansion of -0.4 ppm/°C and a temperature range between -40° to +100°C is used. Note that IL performance is gained by extending the bandwidth.

To ensure stability, a Monte-Carlo method is used to analyze the coupling matrix and find the most sen-

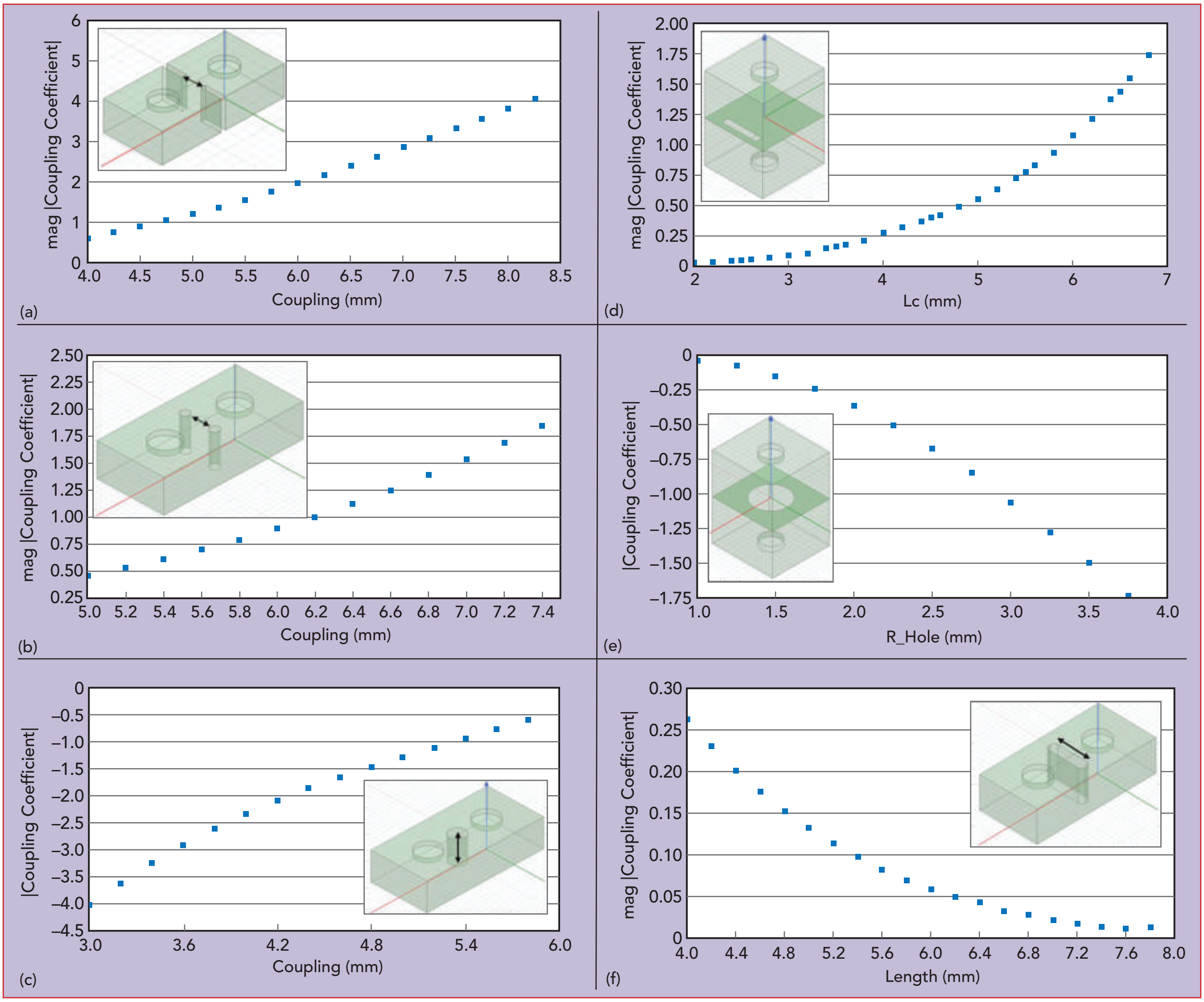
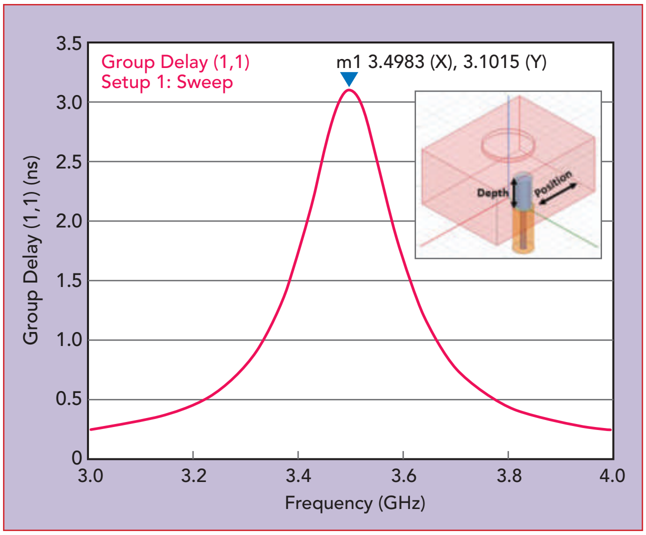


Fig. 5 Coupling coefficient magnitude contours for iris (a), through hole (b), blind hole (c), slot (d), slot (e) and iris (f) coupling.

TABLE 2

COUPLING SCHEMES

Coupling	*Property*	*Coupling Linearity*	*Manufacturing Difficulty*
Fig 5a: Iris	Capacitive	Yes	Easy
Fig 5b: Through Hole	Capacitive	Yes	Easy
Fig 5c: Blind Hole	Capacitive/ Inductive	Yes	Hard
Fig 5d: Slot	Capacitive	No	Moderate
Fig 5e: Slot	Inductive	Moderate	Moderate
Fig 5f: Iris	Capacitive	Moderate	Easy



▲ Fig. 6 Simulated group delay vs. frequency, with 3D view, of the optimized design.

sitive element. This provides useful information during the post simulation and tuning process. In this work, Monte-Carlo analysis is used to detect changes within 1 percent for self-coupling, main coupling and the transmission zeros $M_{2,5}$ and $M_{1,6}$ (see ***Figure 4***). Within 1 percent error control, the overall performance meets the specification.

Once the coupling matrix is obtained, geometric modeling starts. Two identical resonators with different coupling schemes are shown in ***Figure 5***. For this design, the iris coupling scheme with a blind hole is used to control the main coupling parameters. By adjusting the depth of the hole keeping the iris width fixed, different coupling strengths can be obtained. The blind hole coupling scheme is employed to realize the transmission zeros by means of in and out of phase variation. The coupling coefficient is calculated using Equation 2,[7] where f_1 and f_2 are the even and odd mode resonant frequencies, respectively. These values can be obtained by using the HFSS eigenmode solver.

$$\text{Coupling Coefficient} = \frac{f_0}{BW} \times \left(f_1^2 - f_2^2\right) / \left(f_1^2 + f_2^2\right) \tag{2}$$

By tuning slot length, blind hole depth or through-hole distance, a wide range of coupling coefficients can be achieved. ***Table 2*** summarizes the properties, advantages and disadvantages of each cavity coupling scheme.

The input and output structures use coaxial pins to excite the TE101 mode. By varying pin depth and its position, different input/output coupling strengths can be obtained. During the optimization process, the blind hole depth on top of each cavity, serving as the tuning screw, must be fine-tuned to compensate for frequency variation caused by the coaxial pin's loading effect. ***Figure 6*** shows the final simulated result.

3D Analysis and Simulation

To compensate for loading ef-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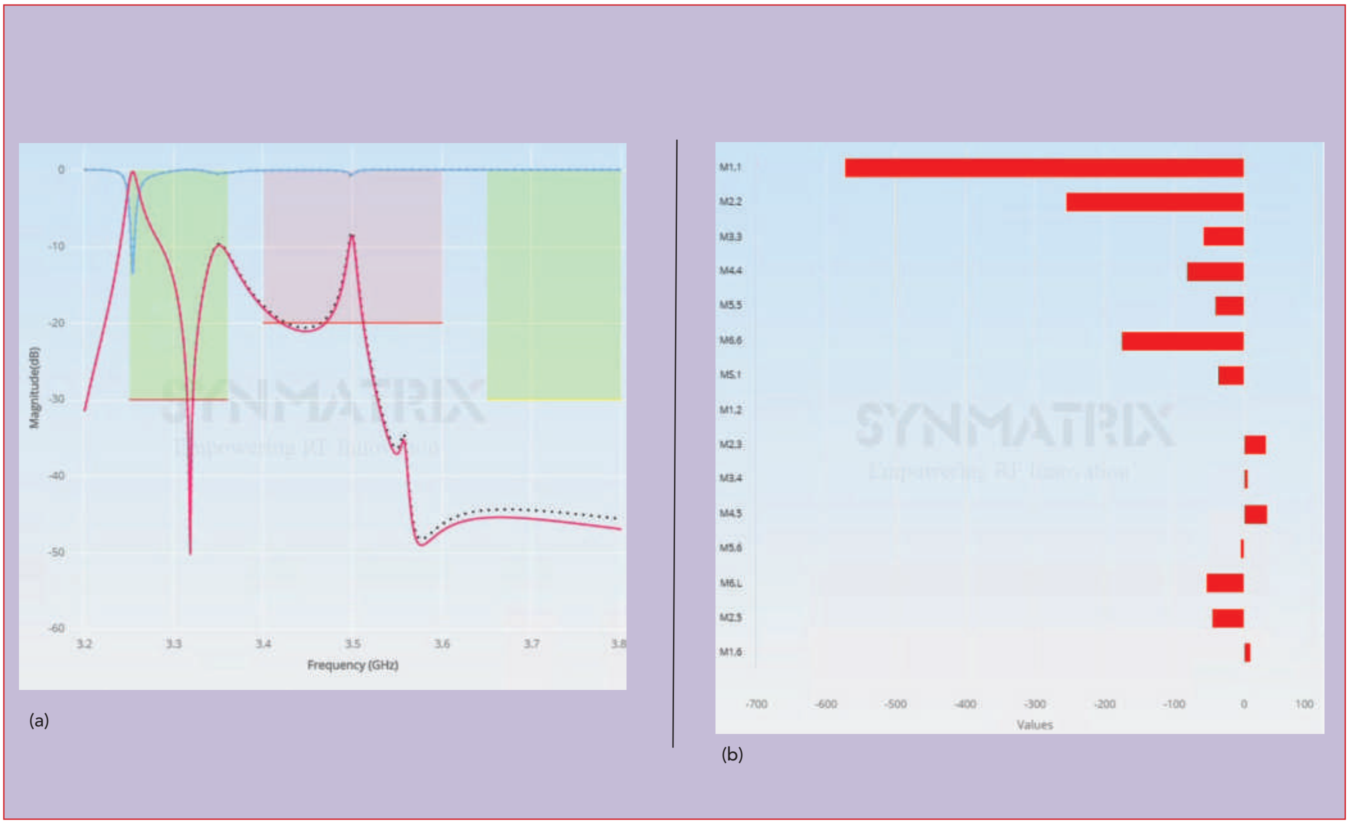
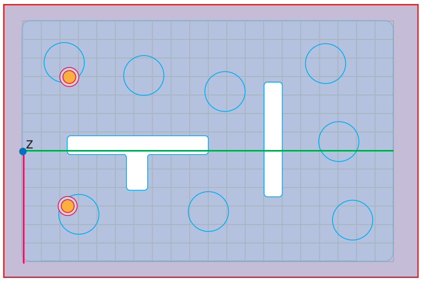


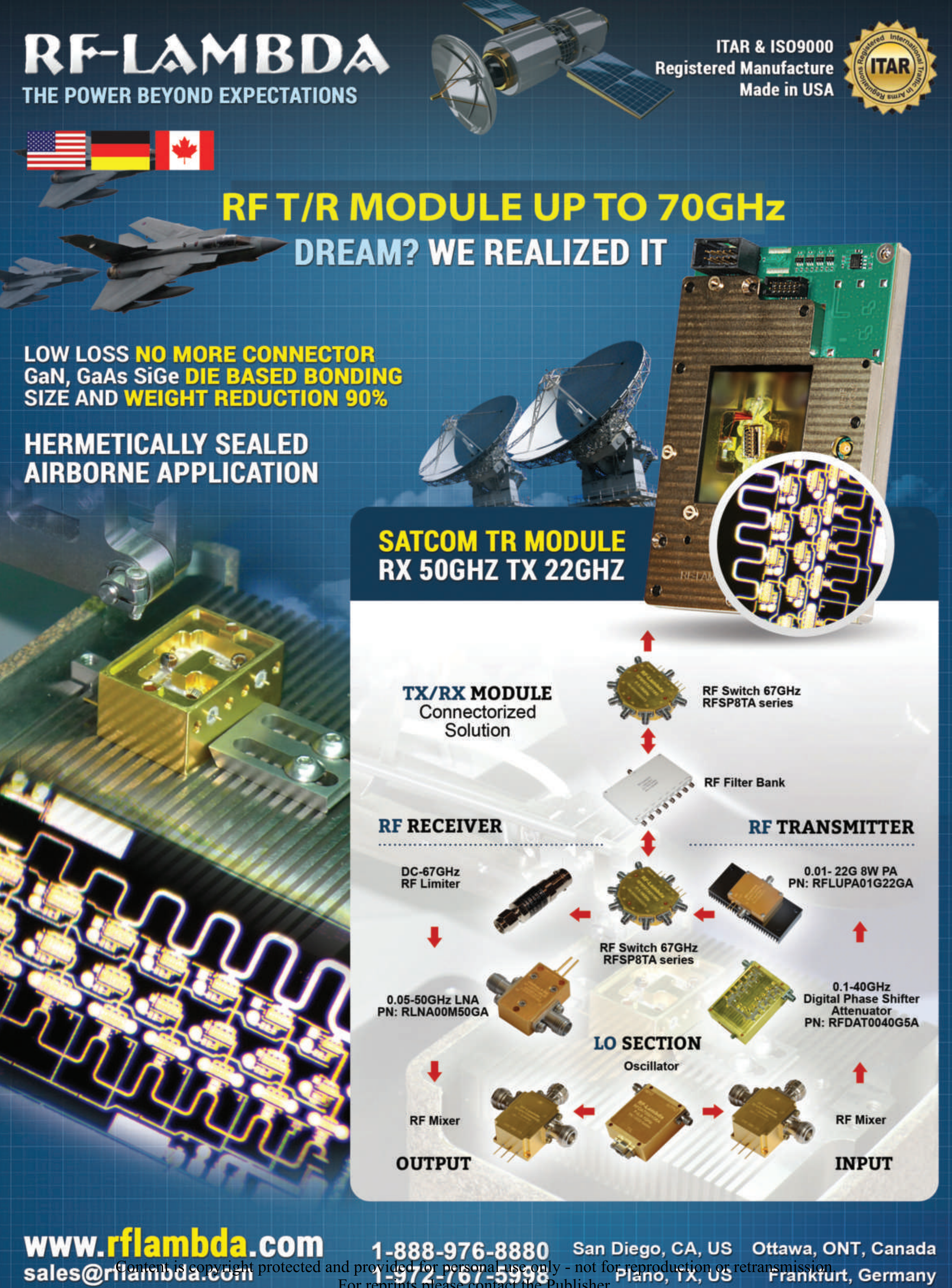
▲ Fig. 7 Initial simulated result (dotted line) vs. extracted performance (solid line) for the full 3D structure (a) and coupling bandwidth extracted error (b).



▲ Fig. 8 HFSS layout showing the open windows used to control the transmission zeros.

fects resulting from the input and output structures, the first and the last cavity lengths are shortened slightly. All critical dimensions obtained from the previous simulation are applied to the full 3D structure construction. Initial performance and corresponding error information are shown in ***Figure 7***.

To make the manufacturing process easier and avoid crack risks during mold development, the coupling coefficient signs for M_{12} and M_{34} (realized by a blind hole) are changed without any impact to performance. The transmission zeros controlled by $M_{2,5}$ and $M_{1,6}$ can be easily achieved by varying the open windows without any extra tuning mechanism as shown in ***Figure 8***.



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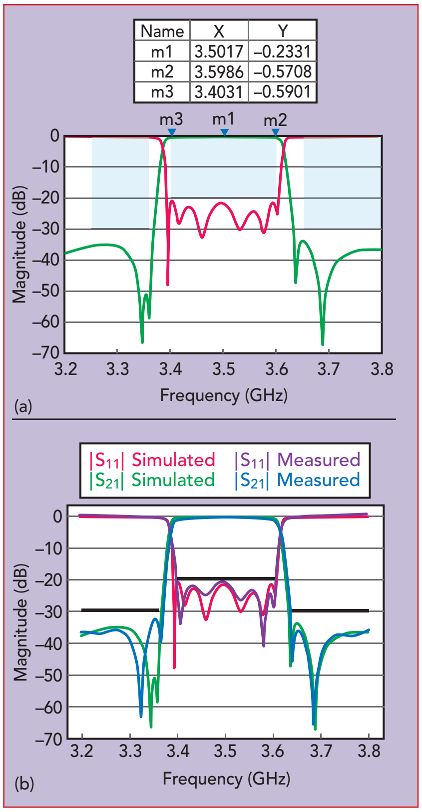
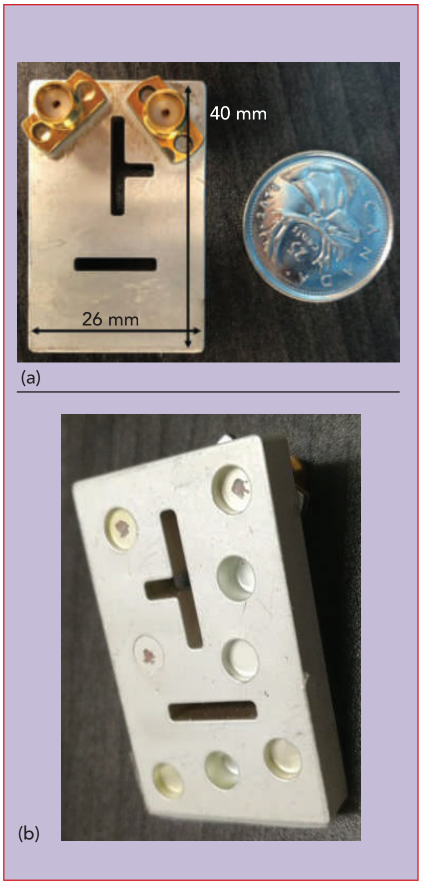
The final product benefits from a more stable manufacturing process by lowering the crack issue risk during the pressing and sintering process. The new coupling matrix is:

$$
\begin{bmatrix}
0 & 1.0751 & 0 & 0 & 0 & 0 & 0 & 0 \\
1.0751 & 0 & 0.9140 & 0 & 0 & 0 & 0.0822 & 0 \\
0 & 0.9140 & 0 & 0.5683 & 0 & 0.3440 & 0 & 0 \\
0 & 0 & 0.5683 & 0 & -0.8565 & 0 & 0 & 0 \\
0 & 0 & 0 & -0.8565 & 0 & 0.5683 & 0 & 0 \\
0 & 0 & 0.3440 & 0 & 0.5683 & 0 & -0.9149 & 0 \\
0 & 0.0822 & 0 & 0 & 0 & -0.9149 & 0 & 1.0751 \\
0 & 0 & 0 & 0 & 0 & 0 & 1.0751 & 0
\end{bmatrix}
$$

After several rounds of optimization, final performance is achieved. Dur-



▲ Fig. 9 Simulated (a) and measured vs. simulated (b) performance of the filter.



▲ Fig. 10 Top (a) and side (b) views of the ceramic waveguide filter.

ing optimization, the matrix extraction technique is used. Importing the simulated S2P file each time enables a steady and accurate optimization process.

MEASUREMENTS

Figure 9a shows the final simulation results and ***Figure 9b*** shows the correlation between simulation and measurement. All coupling errors are controlled within 1 percent. The extracted unloaded Q is about 2,020 compared to the target value of 2,000. Thermal drift value is around 0.65 MHz within the operating temperature range. Additionally, since the first and last resonator sizes are reduced due to the input and output coupling loading effect, the first spurious is pushed to 5.3 GHz. Unbalanced notch performance is caused by stray energy leakage affecting $M_{2,4}$ and $M_{1,5}$.

Figure 10 shows the fabricated filter (the surface is silver plated). The total length is 40 mm, the width is 26 mm and the height including the SMA connector is 15.5 mm. Due to material property variation, the final prototype is fine-tuned by grinding and replating the blind holes for $M_{1,1}$, $M_{2,2}$ and $M_{5,5}$ to help compensate for return loss variation.

CONCLUSION

A procedure for designing a dielectric-filled waveguide filter starts with an unloaded Q analysis followed by a specification analysis that considers material selection, temperature drift and topology (which relates to the practical mechanical design). Given the material, the coupling matrix is synthesized with margins based on design specifications. Q analysis (based on a single cavity) and a comparison of cavity coupling schemes and input/output structures are discussed. The results of 3D model simulation and optimization show excellent correlation with measurements.■

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EDI CON Online Sets Stage for Year Two

Janine Love, *Contributing Editor MWJ, Editor SIJ*

Last year, *Microwave Journal* and *Signal Integrity Journal* polled their readers. The results revealed a struggle between needing more technical training versus not being able to get out of the office (for various reasons). Based on this and other information gathered in the polling, the teams imagined and produced EDI CON Online with a vision to provide live training to practicing engineers for free. Recognizing that nothing can replace a live event, the premise of EDI CON Online was to supplement live industry events with specialized, focused training sessions at a different point in the year. The result far exceeded expectations and its timing, it turns out, was prescient.

In 2020, EDI CON Online is expanding to four days, occurring on consecutive Tuesdays in October. The event includes four tracks—Automotive/IoT/5G; PCB/Interconnect Design; Signal Integrity/Power Integrity; and Radar/Antenna—with free training for engineers and talks from some of the most well-known voices in these industries. It is sponsored by industry leading companies, including the event's platinum sponsors Samtec, Rohde & Schwarz and Keysight Technologies. Here is what attendees can expect:

October 6—Automotive/IoT/5G: This day filled with technical sessions and workshops kicks off with a keynote given by Keysight's Roger Nichols, focusing on "New Generations of Wireless and Their Impact on Measurement." Technical session speakers this day include: Chris Pearson, president of 5G Americas; Ken Wyatt, consultant; Robert Smith, consultant engineer, PRFI Ltd.; Caroline Chan, VP Data Platforms Group, Intel; and John Smee, VP of Engineering of Qualcomm. Workshops will be presented from representatives of Boonton Electronics, Sonnet Software, Anritsu, AR RF/MW Instrumentation and Mini-Circuits.

October 13—PCB/Interconnect: This day begins with a special keynote presented by the editors of *Microwave Journal* and *Signal Integrity Journal*, "Stretching the Limits of PCB Design." This is a new track for EDI CON Online and includes talks from James Drewniak, Curator's Professor Emeritus of Electrical and Computer Engineering, Missouri S&T EMC Laboratory; Lambert (Bert) Simonovich of Lamsim Enterprises; Ken Wyatt, consultant; Lee Ritchey, consultant; and Susy Webb, senior PCB designer. Workshops will be presented from representatives of Samtec, Rogers Corporation, International Manufacturing Services (IMS) and Cadence.

October 20—Signal Integrity/Power Integrity: This day starts with a video keynote from Samtec's Matthew Burns on "Real World 112 Gbps PAM4 System Architectures." It is followed by technical sessions from industry leading voices in SI/PI, including Steve Sandler, managing director, Picotest; Ransom Stephens, Signal Integrity Sage, Ransom's Notes; Benjamin Dannan, engineer and IEEE member; James Drewniak, Curator's Professor Emeritus of Electrical and Computer Engineering, Missouri S&T EMC Laboratory; and Scott McMorrow, CTO for Samtec's Signal Integrity Group. Workshops for this day will be hosted by COMSOL, Introspect Technology, Rohde & Schwarz, Cadence and Teledyne LeCroy (starring *Signal Integrity Journal* technical editor, Eric Bogatin).

October 27—Radar/Antenna: Leander Humbert, technology manager radar from Rohde & Schwarz, kicks off the keynote on this day with a video talk about "Advancements in Phase-Related Measurements for Radar Applications." This day's technical sessions include presentations from Joseph R. Guerci, president/CEO, Information Systems Laboratories, Inc.; Anil Pandey, principal R&D engineer at Keysight Technologies; Rick Sturdivant, founder and CTO at MPT, Inc.; Avik Santra, senior staff expert algorithm engineer, Infineon Technologies AG; Alkim Akyurtlu, full professor, Department of Electrical and Computer Engineering at University of Massachusetts Lowell; and Craig Armiento co-director of the Raytheon UMass Lowell Research Institute. Workshops include presentations from Boonton Electronics and Echodyne Corp.

Registration is open now, and it is free. You can select all sessions that interest you in a single sign on portal, then attend live (with a chance to ask questions) or on-demand at your convenience. Slides and resources will be available in the platform for quick download. All attendees of live technical sessions will be eligible to earn IEEE CEU credits and all attendees to any live session are entered into a drawing to win an Artech House book of their choice. All sessions are moderated by members of the editorial staff for *Microwave Journal* or *Signal Integrity Journal*. We had a fantastic time last year, and we hope you join us and bring your questions in October!


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Delivering Efficient RF Connectivity in a 5G World

Rosenberger
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The arrival of 5G is proving to be the latest disruptor in the RF/microwave industry, leading to an exciting new wave of RF connector innovation. Addressing the challenge of 5G's requirements, Rosenberger has developed the Efficient Board Connector (EBC®), a new generation board-to-board and board-to-module RF interconnection system. EBC is a low-cost, single design approach for multiple high performance applications, fully optimized and future-proofed for 5G.

BOARD-TO-BOARD CONNECTORS

The original push on, subminiature connector (SMP) comprised a blind-mate adapter, or bullet, housed between two printed circuit boards (PCB) or panel-mounted receptacles. It gave designers better electrical performance, faster installation and higher density for high frequency applications. In recent years, largely driven by the mobile telecom market's need for miniaturization, board-to-board and board-to-module connections have become increasingly popular. Able to handle higher power while saving space and weight, these lower cost board-to-board interconnects are replacing RF cable assemblies.

5G is accelerating this trend, adding design challenges for RF connectors:

Massive MIMO — For high data density locations, base stations will use massive MIMO active antennas with 32, 64 or 128 elements. Currently, the concepts integrate sandwiches of several boards with large numbers of board-to-board connections to interconnect the RF transmit and receive circuitry with the antenna array—at least one interconnect for each antenna element. With this added volume, cost will be critical.

Higher Frequency Operation — With the increasing data rates being sent and received, radio access networks (RAN) will add more and higher bands at sub-6 GHz frequencies, as well as mmWave bands extending above 40 GHz. RF connectors must maintain superior performance at frequencies increase.

Constrained Space — Increasing the data capacity of the RAN will lead to a greater density of base stations, with smaller size and weight to be deployed throughout a city. To accommodate these size constraints, the RF interconnects must have small diameter connectors capable of high mating cycles.

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VSWR and EMC — Inherently, board-to-board stacking applications have the potential for connector misalignment, which can create an inductive path degrading VSWR if the characteristic geometry of the contact surfaces is altered. The connector design includes the requirement of EMC optimization to avoid poor performance or harmful emissions.

Universal Board-to-Board Connection — In addition to providing a long-term solution to miniaturize high frequency connections, the interconnects must also address the low frequency, high density interface requirements. The interconnect must accommodate sufficient axial float without significantly affecting VSWR. A bullet interface design withstands dimensional changes or misalignment without significantly affecting the character of the transition contact surface, minimizing the effect on signals passing through the connector.

Design to Cost — All of these factors present design engineering challenges to achieve the required RF performance. At the same time, the production cost of the interconnect is under enormous pressure, as it represents a significant financial element of the system. Despite the larger number of antenna elements used in 5G, highly competitive market forces dictate that component costs need to remain the same, preferably lower. To achieve these cost targets, design to cost production methods must be implemented from the beginning of all product design and development.

FUTURE PROOF 5G CONNECTIVITY

As a leading RF connector manufacturer, Rosenberger has developed innovative RF connection solutions. Rosenberger's new low-cost, high performance EBC enables operators, network equipment manufacturers and component suppliers to meet the interconnect challenges driven by 5G, including:

- The same connector components on both sides of the PCB
- Spring-loaded parts on the PCB
- Simpler and lower cost adaptors
- High volume production
- Low-cost

EBC is a new generation universal RF board-to-board, board-to-module adaptor which provides a single design solution for many applications (see ***Figure 1***). Its one-size-fits-all design addresses the mobile industry's requirement for RF connectors to be easily and readily deployable in various con-

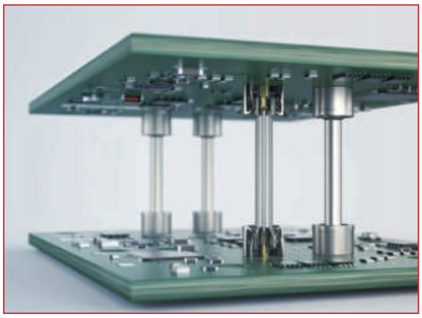


Fig. 1 EBC universal RF board-to-board, board-to-module adaptor.

figurations. The EBC integrates both limited detent and smooth bore interfaces in a single bullet, accommodating all the benefits of the most common board-to-board and board-to-module high frequency connections, including SMP, LW-SMP and P-SMP.

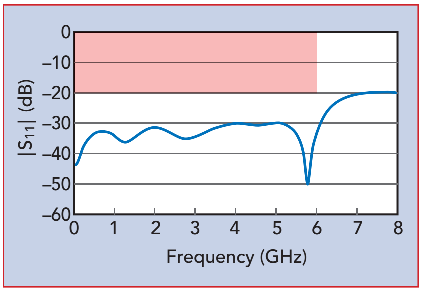


Fig. 2 Return loss specification and typical performance.

Essential characteristics include equalization of radial and axial misalignments; different holding forces; minimum PCB board spacing; and fast, cost-effective assembly. A key mechanical design feature is the locating side, which is integrated in the bullet. One side has a smooth bore, while the other has a limited detent design. The EBC supports a minimum board-to-board distance of 12 mm and a minimum on-board pitch of 6.8 mm. The axial and radial tolerances are ±0.8 mm and 4 degrees, respectively.

With a DC to 8 GHz frequency range, the EBC addresses 5G's sub-6 GHz bands, supporting both small cell and massive MIMO base stations. Return loss is specified to be 20 dB or better and is typically 30 dB to 6 GHz (see ***Figure 2***). Screening attenuation, a measure of shielding, is specified to be greater than 50 dB to

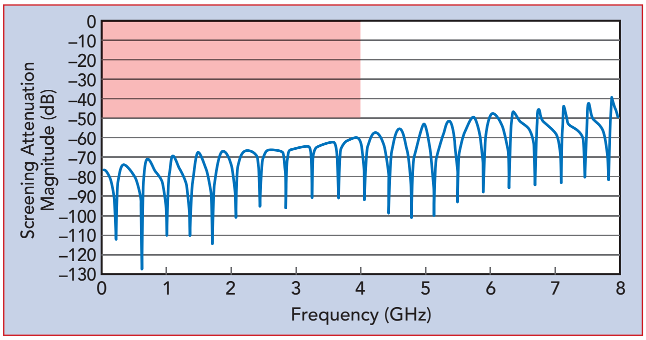


Fig. 3 Screening attenuation specification and typical performance.

4 GHz and typically measures greater than 60 dB (see ***Figure 3***). Power handling is 100 W.

RF board-to-board and board-to-module connector systems will play a key role in the 5G RAN. With the newly launched, low-cost EBC connector system, Rosenberger offers board-to-board and board-to-module RF interconnection a new level of performance for the sub-6 GHz 5G bands, with impedance control and ease of installation. It features a universal bullet design suited to multiple applications, which will simplify the design and reduce the cost of complex 5G RANs being rolled out by mobile operators.

Rosenberger
Fridolfing, Germany
www.rosenberger.com

European Microwave Week 2020

The only European event dedicated to the Microwave and RF industry

The European Microwave Week 2020 takes place in the historic city of Utrecht. Bringing industry and academia together, the European Microwave Week 2020 is a SIX day event, including THREE cutting edge conferences, THREE Forums and ONE exciting trade and technology Exhibition featuring leading players from across the globe. EuMW 2020 provides access to the very latest products, research and initiatives in the microwave sector. It also offers you the opportunity for face-to-face interaction with those driving the future of microwave technology. EuMW 2020 will see an estimated 1,500 conference delegates, over 4,000 attendees and in excess of 300 international exhibitors (inc. Asia & US).

The Exhibition

Registration to the exhibition is FREE!

- Over 300 International Companies - meet the industry's biggest names and network on a global scale
- Cutting-edge Technology - exhibitors showcase their latest product innovations, offer hands-on demonstrations and provide the opportunity to talk technical with the experts
- Industrial Workshops - get first hand technical advice and guidance from some of the industry's leading innovators
- MicroApps - attend our annual European Microwave Week Microwave Application Seminars (MicroApps)

Be There

Exhibition Dates	Opening Times
Tuesday 12th January 2021	09:30 - 18:00
Wednesday 13th January 2021	09:30 - 17:30
Thursday 14th January 2021	09:30 - 16:30

The Conferences

The EuMW 2020 consists of three conferences, three forums and associated workshops:

- European Microwave Integrated Circuits Conference (EuMIC) 11th – 12th January 2021
- European Microwave Conference (EuMC) 12th – 14th January 2021
- European Radar Conference (EuRAD) 13th – 15th January 2021
- Plus Workshops and Short Courses (From 10th January 2021)
- In addition, EuMW 2020 will include the Defence, Security and Space Forum, the Automotive Forum and the 5G Forum

The three conferences specifically target ground breaking innovation in microwave research. The presentations cover the latest trends in the field, driven by industry roadmaps. The result is three superb conferences created from the very best papers submitted. For the full and up to date conference programme including a detailed description of the conferences, workshops and short courses, please visit www.eumweek.com. There you will also find details of our partner programme and other social events during the week.

How to Register

Registering as a Conference Delegate or Exhibition Visitor couldn't be easier. Register online and print out your badge in seconds onsite at the Fast Track Check In Desk. Online registration is open now, up to and during the event until 15th January 2021.

- Register online at **www.eumweek.com**
- Receive an email receipt with barcode
- Bring your email, barcode and photo ID with you to the event
- Go to the Fast Track Check In Desk and print out your badge
- Alternatively, you can register onsite at the self service terminals during the registration.

Please note: NO badges will be mailed out prior to the event.

Registration opening times:

- Saturday 9th January 2021 (16:00 - 19:00)
- Sunday 10th – Thursday 14th January 2021 (08:00 - 17:00)
- Friday 15th January 2021 (08:00 - 10.00)

Registration Fees

Full Week ticket: Get the most out of this year's Microwave Week with a Full Week ticket. Combine all three conferences with access to the Defence, Security and Space and the 5G forum (the Automotive forum is not included), and top your week off with Workshops or Short Courses of your choosing. To keep you fueled, lunch is included everyday, as are of course the social events: the EuMIC Get-Together, the Welcome reception and the EuRAD seated lunch.

Registration at one conference does not allow access to the sessions of the other conferences.

Reduced rates are offered if you have society membership to any of the following: EuMA✪, GAAS, IET or IEEE. Reduced rates for the conferences are also offered if you are a Student/Senior (Full-time students 30 years or younger and Seniors 65 or older as of 18th September 2020). The fees shown below are invoiced in the name and on behalf of the European Microwave Association. Fees invoiced by EuMA with respect to the European Microwave Week 2020 are exempt from Dutch VAT. All payments must be in € (Euros) – cards will be debited in € (Euros).

CONFERENCES REGISTRATION	**ADVANCE DISCOUNTED RATE** (FROM 13TH SEPTEMBER UP TO & INCLUDING 6th DECEMBER 2020)				**STANDARD RATE** (FROM 7th DECEMBER 2020 & ONSITE)			
	Society Member✪		**Non-Member**		**Society Member✪**		**Non-Member**	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	€ 480,-	€ 130,-	€ 680,-	€ 190,-	€ 680,-	€ 190,-	€ 950,-	€ 260,-
EuMIC	€ 370,-	€ 120,-	€ 520,-	€ 170,-	€ 520,-	€ 170,-	€ 730,-	€ 240,-
EuRAD	€ 330,-	€ 110,-	€ 460,-	€ 160,-	€ 460,-	€ 160,-	€ 650,-	€ 220,-
2 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC	€ 680,-	€ 260,-	€ 960,-	€ 360,-	€ 960,-	€ 360,-	€ 1.340,-	€ 500,-
EuMC + EuRAD	€ 650,-	€ 250,-	€ 910,-	€ 350,-	€ 910,-	€ 350,-	€ 1.280,-	€ 480,-
EuMIC + EuRAD	€ 560,-	€ 240,-	€ 780,-	€ 330,-	€ 780,-	€ 330,-	€ 1.100,-	€ 460,-
3 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC + EuRAD	€ 830,-	€ 370,-	€ 1.160,-	€ 520,-	€ 1.160,-	€ 520,-	€ 1.630,-	€ 730,-
Full Week Ticket	€ 1.280,-	€ 750,-	€ 1.690,-	€ 970,-	€ 1.630,-	€ 920,-	€ 2.180,-	€ 1.200,-

✪ BECOME A MEMBER – **NOW!**

EuMA membership fees: Professional € 25,–/year, Student € 15,–/year.

One can apply for EuMA membership by ticking the appropriate box during registration for EuMW. Membership is valid for one year, starting when the subscription is completed. The discount for the EuMW fees applies immediately.

Members have full e-access to the International Journal of Microwave and Wireless Technologies. The printed version of the journal is no longer available.

EUMA KNOWLEDGE CENTRE
The EuMA website has its Knowledge Centre which presently contains over 20,000 papers published under the EuMA umbrella. Full texts are available to EuMA members only, who can make as many copies as they wish, at no extra-cost.

SPECIAL FORUMS AND SESSIONS REGISTRATION		**ADVANCED DISCOUNTED RATE** (UP TO & INCLUDING 6th DECEMBER 2020)		**STANDARD RATE** (FROM 7th DECEMBER 2020 & ONSITE)	
	Date	**Delegates***	**All Others****	**Delegates***	**All Others****
Automotive Forum	12th January 2021	€ 260,-	€ 360,-	€ 320,-	€ 420,-
5G Forum	15th January 2021	€ 60,-	€ 90,-	€ 80,-	€ 100,-
Defence, Security & Space Forum	13th January 2021	€ 20,-	€ 60,-	€ 20,-	€ 60,-
European Microwave Student School	12th January 2021	€ 40,-	€ 40,-	€ 40,-	€ 40,-
Tom Brazil Doctoral School of Microwaves	14th January 2021	€ 40,-	€ 40,-	€ 40,-	€ 40,-

* those registered for EuMC, EuMIC or EuRAD ** those not registered for a conference

Workshops and Short Courses

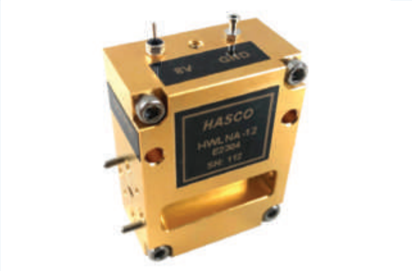
Despite the organiser's best efforts to ensure the availability of all listed workshops and short courses, the list below may be subject to change. Also workshop numbering is subject to change. Please refer to www.eumweek.com at the time of registration for final workshop availability and numbering.

NL MoD Reduced Rate

For the EuMW 2020 only, personnel of the NL MoD can register at a reduced rate. This very attractive rate includes access to EuRAD, the DSS Forum and the exhibition, lunch boxes on Wednesday and Thursday and the seated EuRAD lunch. The Advance Discounted rate for this is € 100,– (up to and including 6th December 2020), and € 140,– from 7th December 2020 onwards. No further options or combined discounts will be available.

SUNDAY 10th January 2021			
WS-01	EuMIC	Full Day	High Performance GaN MMICs
WS-02	EuMIC/EuMC	Full Day	Advanced RF Technologies for 5G
WS-04	EuMC	Full Day	Recent Advances in Additive Manufacturing of Microwave Components
WS-05	EuMIC	Full Day	Integrated Doherty PAs for Cellular and mmWave Applications
WS-07	EuMIC	Full Day	Sub-mmWave On-Wafer Measurements
WS-08	EuMIC	Half Day PM	mmWave Phased Array Front-End ICs for 5G
WS-09	EuMIC/EuMC	Half Day PM	Advanced Measurement Techniques for Next Generation Communication Systems
SS-01	EuMIC	Full Day	Fundamentals of Microwave PA Design
MONDAY 11th January 2021			
WM-01	EuMC	Full Day	Microwave Wearable Circuits and Systems for Biomedical Applications
WM-02	EuMC/EuRAD	Half Day AM	Advanced Applications of In-Band Full-Duplex Technology
WM-03	EuMC	Full Day	Antenna/Modules in Package for mmWave for 5G
WM-04	EuMC	Full Day	High-Power Microwave Industrial Applications
WM-05	EuMC	Full Day	Measurements at mmWave and Terahertz Frequencies of Three Measurement Quantities: S-Parameters, Power, and Complex Permittivity of Dielectric Materials
WM-06	EuMIC/EuMC	Half Day PM	From Enabling GaN Technology to High-Performing Space-Borne SSPAs at mmWave
SM-01	EuMIC/EuMC	Half Day AM	From Device Characterisation to Amplifier Design: Advanced Large Signal Measuring, Fast and Accurate Modelling, and Reliable Designing
SM-02	EuMC/EuRAD	Half Day PM	Multibeam Antennas and Beamforming Networks
SM-03	EuMC	Half Day PM	Intuitive Microwave Filter Design with EM Simulation
TUESDAY 12th January 2021			
WTu-01	EuMC	Full Day	Digital Predistortion for 5G MIMO Wireless Transmitters
WTu-02	EuMC/EuRAD	Half Day PM	Advanced mmWave Radar System Solutions for Industrial and Consumer Sensing Applications
WEDNESDAY 13th January 2021			
WW-02	EuMIC/EuMC	Full Day	High-Efficiency Linear Power Amplifiers for High Bandwidth, High PAR Signals
WW-03	EuRAD	Half Day PM	Automotive Radar Networks and Sensor Fusion
SW-01	EuMIC/EuMC	Half Day AM	High Power Amplification for Space Applications
SW-02	EuMIC/EuMC	Full Day	Quantum Computing for Electrical Engineers
THURSDAY 14th January 2021			
WTh-01	EuRAD	Half Day AM	High Resolution Radar for Automotive
WTh-02	EuMC	Full Day	5G and Beyond: Enabling RF Architectures and Technologies for Emerging Wireless Systems
WTh-03	EuRAD	Half Day PM	Recent Advances in Micro-Doppler Radar and its Applications
FRIDAY 15th January 2021			
WF-01	EuMC	Half Day AM	Wireless Power Transmission Recent Research Advances
WF-02	EuMC	Half Day AM	Recent Advances in Topologies, Technologies and Practical Realizations of Microwave Sensors
WF-03	EuMC	Half Day AM	Recent Advances on Microwave Filters
WF-04	EuMC	Full Day	Practical Aspects of Running a Microwave Laboratory and How to Make Good Measurements Every Time
SF-01	EuRAD	Half Day AM	Cognitive Radar Signal Processing
SF-02	EuRAD	Half Day PM	Introduction to MIMO Radar

WORKSHOPS AND SHORT COURSES	IN COMBINATION WITH CONFERENCE REGISTRATION				WITHOUT CONFERENCE REGISTRATION			
	Society Member		Non-Member		Society Member		Non-Member	
	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
Half Day	€ 100,-	€ 70,-	€ 130,-	€ 100,-	€ 130,-	€ 100,-	€ 170,-	€ 130,-
Full Day	€ 140,-	€ 100,-	€ 190,-	€ 140,-	€ 190,-	€ 140,-	€ 250,-	€ 190,-



Broadband LNAs Offer Low Full Band Noise Figure

Low noise amplifiers (LNA) are a critical component in essentially every radar receiver and satellite communications system. With systems moving to higher frequencies, designers are seeking components with lower noise figure, better over-temperature performance and lower size, weight, power and cost.

HASCO's new line of broadband E-, W- and V-Band LNAs cover the frequencies from 53 to 110 GHz and offer system designers off-the-shelf options for meeting higher frequency system requirements. The LNAs use advanced RF device technology to achieve low noise figure, gain to 23 dB, wide bandwidth and lower power consumption. The LNAs are available with various input and output coaxial connectors and waveguide ports to better match the LNA to the required frequency band. They are biased with a higher voltage, between 7.5 and 12 VDC, and have internal reverse bias protection to ensure rugged and reliable operation.

HASCO currently offers three models in the broadband line: 1) HWLNA12-E2304, covering 67 to 90 GHz, with 4 dB typical noise figure across the full band and 23 dB gain; 2) HWLNA10-W10045, covering 75 to 110 GHz, with 4.5 dB typical noise figure across the full band and 20 dB gain; and HWLNA15-V2004, covering 53 to 65 GHz, with 4 dB typical noise figure across the full band and 20 dB gain.

HASCO's broadband mmWave LNAs are designed to improve the performance of radar, communications and instrumentation systems, anywhere a low system noise figure is important. In addition to amplifiers, HASCO offers virtually all RF/microwave component functions, including connectors, adapters, cable assemblies, antennas, attenuators, circulators, crystal oscillators, detectors, directional couplers, filters, frequency multipliers, isolators, mixers, phase shifters, power dividers, oscillators, switches, terminations and waveguide.

HASCO, INC.
Moorpark, Calif.
www.hasco-inc.com/amplifiers

SMT Antennas for Cost-Sensitive 28/39/60 GHz Systems

Maja Systems has developed a series of mmWave antennas for cost-sensitive applications. The patented AirData™ family currently covers the 28, 39 and 60 GHz bands, providing 10 dBi gain with up to 10 percent operating bandwidth and with right- or left-hand circular polarization. Each antenna is available in either a surface-mount format, compatible with standard reflow attach to a PCB, or with a standard coaxial connector. The operating temperature range is from –40°C to +85°C.

For example, the 60 GHz design covers 55 to 65 GHz with 10 dBi gain, a total efficiency of 70 percent, beamwidth of 35 degrees and an axial ratio of 1.5 dB. Sidelobe levels are –10 dB relative to the main beam. The coaxial version of the 60 GHz design comes with a 1.85 mm connector.

The AirData antenna is based on a helix design, which is scalable to lower and higher frequencies, including 77 and 94 GHz. As well as offering a cost advantage, the size of the AirData antenna is smaller than a horn waveguide antenna, making it attractive for test and measurement, metrology, antenna range and 5G applications. It can also be used as an element in an active array for increasing gain and beam steering.

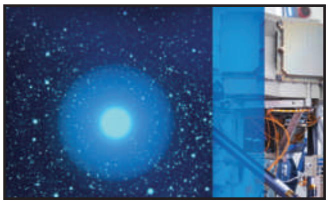
Maja Systems
Milpitas, Calif.
www.majasystems.com

AR Media-Value Added
VENDORVIEW

AR RF/Microwave Instrumentation's Conducted Immunity Test System, CI00402, makes it easy to test compliance to MIL-STD 461, automotive, commercial and DO 160 standards. This integrated solution contains all the equipment required to run tests, including a 100 W power amplifier with a frequency range of 10 kHz to 400 MHz, along with the unique ability to remove components for other test applications. Accessories and options for other power levels and frequency ranges are available.

AR RF/Microwave Instrumentation
https://www.arworld.us/html/11100_conducted_immunity_systems.asp

Growth Initiative Aerospace & Defense
VENDORVIEW



Ensuring uncompromised reliability under extreme conditions while at the same time reducing size, cost and weight calls for highly robust connectivity solutions in aerospace and defense. Watch HUBER+SUHNER AG's latest video on their growth initiative in aerospace and defense at https://www.youtube.com/watch?v=kMrjPc23AWc.

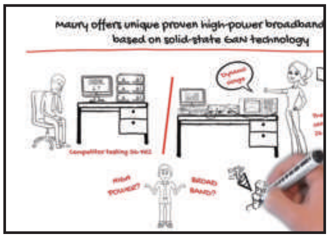
HUBER+SUHNER AG
hubersuhner.com

K&L Web Update

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

K&L Microwave
www.klmicrowave.com

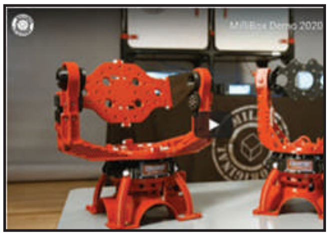
Why Maury's Instrument Amplifiers are the Right Choice for You!



Not all amplifiers are created equal, so how can you be certain that an amplifier will work for your needs? You deserve to be confident that the amplifiers used with your test and measurement lab benches will meet the requirements of your specific applications, are reliable and are equally well-supported pre- and post-sale. This video will explain the top five reasons how Maury's best-in-class instrument amplifiers will bring confidence to your measurements.

Maury Microwave
https://youtu.be/FQin7IiMdGc

MilliBox Compact and Affordable mmWave Antenna Testing System 2020 Demo



MilliBox products are cost effective test tools and accessories specially designed for mmWave over-the-air measurements. The mini-chambers fit on lab benches as a personal test setup. Construction is easily customizable and configurable with robust and lightweight material for everyday use.

MilliBox
www.millibox.org

An RF Test Bench in Your Backpack

Signal Hound RF test equipment is affordable and compact enough to fit in a backpack—perfect for portable, comprehensive RF analysis on the go. Features include: small, lightweight RF spectrum analyzers ranging from 4.4 to 20 GHz; USB-powered signal generators that can fit in your pocket; powerful, Spike™ spectrum analysis software that runs on a laptop, offers full device control and a variety of analysis mode; connects to probes, antennas and a variety of signal sources.

Signal Hound
https://signalhound.com/content/managed/bench-in-backpack/

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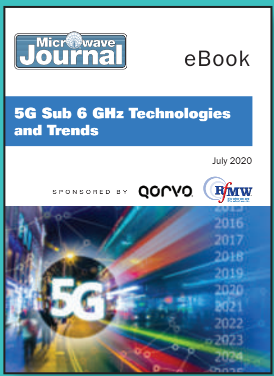

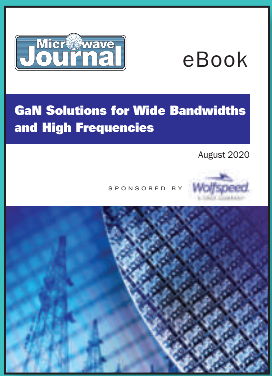

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NEW PRODUCTS

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COMPONENTS

Compact Waveguide Filters

VENDORVIEW

The WC-Series bandpass filters are compact waveguide filters designed to fit in small spaces. It is the perfect choice if your space is limited. WC-Series is small but has many advantages over standard waveguide bandpass filters. It can achieve very broad bandwidths and for certain situations it can eliminate the need for additional lowpass filters, saving even more space. WC-Series are available as filters or as diplexers.

Exceed Microwave
www.exceedmicrowave.com

Wireless M-Bus Range Extender

Following on the success of the LoRa product portfolio, IMST GmbH presents the new LoRaWAN® certified WM-bus range extender to collect wireless M-bus messages from utility meters and forward them to a LoRaWAN® network. This product allows filtering wireless M-bus messages by manufacturer ID (M-field) and sender address (A-field) to select specific groups of meters. The intelligent calendar enables a flexible configuration of events and repetition interval (minutes, hours, days, weeks…).

IMST GmbH
www.imst.com

Broadband 6 to 18 GHz Three-way Power Divider

VENDORVIEW

MECA's three-way Wilkinson power divider has been optimized for excellent performance covering 6 to 18 GHz (P3S-12.000) with specifications such as isolation of 20 dB min./25 dB typical, VSWR 1.4:1 max., 0.7 dB max. insertion loss and amplitude balance of 0.4 dB max. All in a compact package of 1"× 1.5"× 0.4". Made in the USA, 36 month warranty.

MECA Electronics Inc.
www.e-MECA.com

Directional Coupler

Model D13N010670 is a 1 to 67 GHz DC pass ultra-wideband directional coupler. Over the very wide 1 to 67 GHz frequency range, it has 13±1.8 dB max. coupling, 3.7 dB max. insertion loss, ±1.5 dB coupling flatness, 1.9:1 max. VSWR, 16 dB typ. and 7 dB min. directivity. The component can stand for 12 W CW which is limited by 1.85 mm connector, has DC pass function. The size is 88.9 × 12.7 × 17.8 mm (3.5 × 0.5 × 0.7"), working temperature range is -54°C to +85°C.

Fuzhou MIcable Electronic Technology Co. Ltd.
www.micable.cn

Lowpass Filter Rejects

VENDORVIEW

Mini-Circuits' model LFCW-103+ is a low temperature cofired ceramic lowpass filter with broad passband from DC to 10 GHz. The passband insertion loss is typically 1.5 dB while rejection of unwanted signals is typically 40 dB from 10 to 26.5 GHz. Typical passband VSWR is 1.02:1 at 100 MHz, 1.10:1 at 1 GHz and 1.45:1 at 10 GHz. The RoHS-compliant, 50 Ω lowpass filter is supplied in a compact 0603 enclosure measuring just 0.063 × 0.032 × 0.024 in. It is designed to handle input power levels of typically as high as 4 W at room temperature and features an operating temperature range of -55°C to +100°C.

Mini-Circuits
www.minicircuits.com

Hi-Q/Low ESR Capacitors

PPI is known for their outstanding customer service, high-quality product line, competitive pricing and quick delivery times. While other companies are pushing out their lead-times for product delivery, PPI is committed to delivering its quality components as quickly as possible. As PPI tries to keep a full inventory in stock, depending on the component and quantities needed, delivery times can be stock to eight weeks.

Passive Plus Inc.
www.passiveplus.com

Hybrid Couplers

VENDORVIEW

Pasternack has just expanded its line of RF hybrid couplers with new models that meet the demands for higher frequency components. Pasternack's hybrid coupler line expansion consists of 21 new models with a high frequency operating range of up to 40 GHz for wide band applications. These coaxial designs feature SMA and 2.92 mm connectors. They are ideal for RF applications that require an even split of input and output ports with 90-degree or 180-degree phase shifts while maintaining high isolation between the ports.

Pasternack
www.pasternack.com

Absorptive Pin Diode Switch

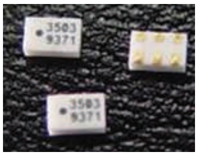
VENDORVIEW

PMI Model No. P16T-250M18G-60-T-512-SFF-DEC-1W is a single pole, sixteen throw absorptive pin diode switch (SP16T) configuration that operates from 0.25 to 18 GHz. typ insertion loss of 7 dB and 60 dB of isolation; switching speed rise/fall - 50 ns typ/10 ns typ, delay on/off - 150 ns max; power handling +30 dBm CW, 10 W Peak, 1 µs; VSWR in/out: 2.0:1 typ., 2.5:1 max; and is controlled with four-bit decoded TTL logic. Unit size is 8 × 3. × 0.65" and contains SMA (F) removable connectors.

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

Tiny 3.5 GHz Couplers

VENDORVIEW



RFMW announces design and sales support for surface mount couplers from RN2. The RN2 CMX35 series of couplers offer power handling and coupling factor options for 3.5 GHz, 5G radio systems. Offered in three different sizes, the P series is the smallest at 2 × 1.25 mm. The variety of sizes, power handling and coupling factors offer splitting and combining in standard and Doherty power amplifier designs, RSSI circuits and feedback loops for 5G NR.

RFMW Ltd.
www.rfmw.com

ATC 531Z Broadband Multilayer Capacitors

Low Insertion Loss from 16 KHz to 30 GHz

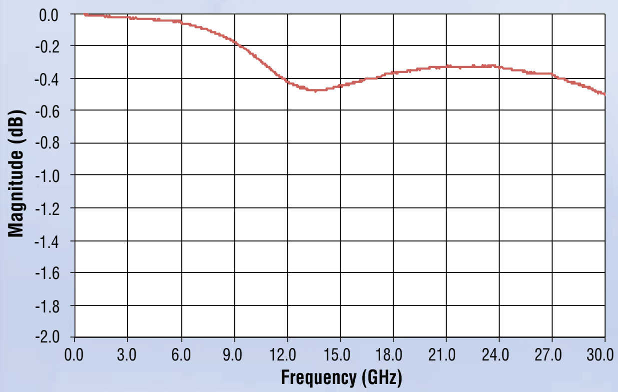
Advantages:

- Broadband Performance
- Low insertion Loss
- Flat Frequency Response
- Excellent Return Loss
- Unit-to-Unit Performance Repeatability
- Rugged Ceramic Construction

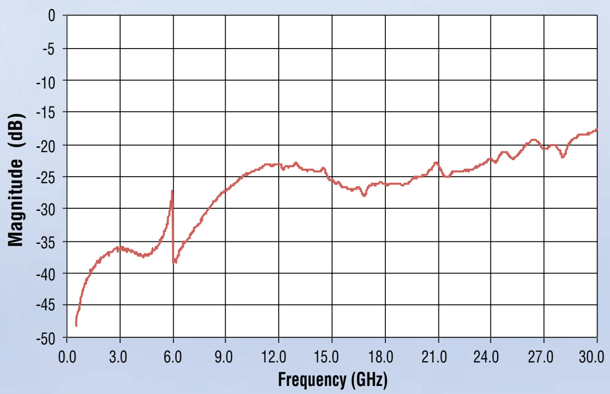
Features:

- EIA 0201Case Size
- Capacitance: 100 nF
- Operating Frequency: 16 KHz to 30 GHz
- Insertion Loss: <0.5 dB typ.
- Low Loss X5R Dielectric
- Voltage Rating: 16 WVDC
- Solderable SMT Terminations
- RoHS Compliant

531Z Insertion Loss (S21)



531Z Return Loss (S11)



RoHS Compliant

AMERICAN TECHNICAL CERAMICS
AN AVX GROUP COMPANY

THE ENGINEERS' CHOICE ISO 9001 REGISTERED COMPANY

www.atceramics.com

THE ENGINEERS' CHOICE®

NewProducts

Dual RF Transceiver

Richardson RFPD, an Arrow Electronics company, announced the availability and full design support capabilities for a new dual narrow/wideband RF transceiver from Analog Devices Inc. The ADRV9002 is a highly integrated, RF transceiver that has dual-channel transmitters, dual-channel receivers, integrated synthesizers and digital signal processing functions. The IC delivers a versatile combination of high performance and low power consumption required by battery-powered radio equipment and can operate in both FDD and TDD modes.

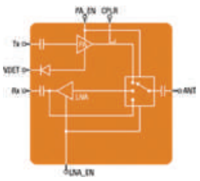
Richardson RFPD
www.richardsonrfpd.com

High Frequency Surface Mount Cavity Filter

RLC Electronics introduced a series of high frequency surface mount cavity filters for small scale, low profile system integration. Designs are created and constructed using proprietary techniques resulting in rugged, stable performance over a full range of environmental stresses. High Q cavity filter performance is available up to 30 GHz with profile height as low as 200 mm. The surface mount design is suitable for reflow attachment, providing savings on size, cost and weight.

RLC Electronics
www.rlcelectronics.com

Front-End Modules



Skyworks introduces the SKY85334-11 and SKY85750-11, 2.4 GHz and 5 GHz front-end modules (FEM) respectively, the latest additions to its portfolio of FEMs designed for growing retail, carrier and enterprise Wi-Fi 6 (802.11ax) applications. These modules offer best-in-class linearity, power dissipation and efficiency for access points, routers and gateways where regulatory, thermals or Power-over-Ethernet limitations demand low current consumption. Packaged in a compact, 16-pin 3 x 3 mm land grid array, these highly integrated FEMs incorporate switching, low noise amplifier with bypass and power amplifier.

Skyworks Solutions Inc.
www.skyworksinc.com

5G Antenna Duplexer

Tamagawa Electronics' 5G band combiner is an antenna duplexer that shares two frequency ranges, 3.5 GHz and 4.5 GHz of 5G system. This model is designed to reduce undesired noise and minimize the signal loss in 5G telecom network systems. It is equipped with two output ports and one input port, IP66 waterproof function, insertion loss -0.5 dB max, isolation 80 dB min, average maximum power 100 W, lightning protection, 4.3-10 DIN Female.

Tamagawa Electronics Vietnam Co. Ltd.
www.tmeleus.com

DLA Drawing 20001 Wet Tantalum Capacitors

Vishay Intertechnology Inc. announced that its tantalum capacitors division is now an approved source for DLA drawing 20001 wet tantalum capacitors. The new DLA drawing provides a historically approved aerospace methodology of screening MIL-PRF-39006 tantalum case capacitors with characteristic H shock and vibration. This screening on an individual manufacturing lot includes 10 cycles of thermal shock and 168-hour constant rated voltage conditioning during the 100 percent Group A Inspection.

Vishay Intertechnology Inc.
www.vishay.com

CABLES & CONNECTORS

Extreme RF Cable Assemblies

Amphenol SV Microwave offers a complete line of fixed length, high frequency cable assemblies utilizing SMA, 2.92 mm, 2.4 mm and SMPx connectors on flexible 0.047 and 0.085 cable types. With low solder wicking and high flexibility, these cable assemblies allow for tight bends behind the cable ferrule. SV's cable assemblies feature low solder wicking and the high flexibility allows for tight bends behind the cable ferrule. Amphenol SV's low loss is your gain!

Amphenol SV Microwave
www.svmicrowave.com

Precision SMPM Adapters (DC to 67 GHz)

withwave announced new precision SMPM adapter series up to 67 GHz. These SMPM Series are designed based on precision microwave interconnection technologies up to 67 GHz. These SMPM(F) to SMPM(F) with bullet type and SMPM(M) to SMPM(M) are manufactured to precise microwave specifications and constructed with female and male gender on both sides.

withwave co. ltd
www.with-wave.com

NewProducts

AMPLIFIERS

Super Low Noise PHEMT

The BeRex BCL015-70 is a GaAs super low noise enhancement mode pHEMT in an industry standard, 70 mil., ceramic, Micro-X, low parasitic, surface-mountable package. Its 0.15 µm by 150 µm recessed gate architecture provides low noise and high associated gain over a broad frequency range of 1,000 MHz to 26 GHz. Excellent for commercial, military/Hi-Rel and test and measurement applications.
BeRex
www.BeRex.com

Solid-State Power Amplifier

Model BME1829-50W is a Class A/AB CW GaN linear amplifier, which operates over the full 100 to 2,000 MHz bandwidth with a built in TTL controlled low/high band switch. In the low band mode, the SSPA supplies >2 W from 100 to 799 MHz, and in the high band mode the SSPA supplies > 50 W from 800 to 2,000 MHz, both modes provide rated power into a 3:1 load VSWR when driven with a -10 dBm RF signal. The amplifier also features a dual direction coupler on the output.
Comtech PST
www.comtechpst.com

Solid-State Broadband Amplifier
VENDORVIEW

Exodus Advanced Communications 18 to 40 GHz, 10 W+ solid-state amps are designed for general EMC testing applications as well as Mil-Std 461(RS103) standards. Exodus Model AMP4037 is a compact 5U design that provides superb RF performance with unprecedented P1dB power as compared to TWT's. It provides 40 dB min. gain, -20 dBc harmonics as well as gain control with < 10 dB noise figure. Optional waveguide output is available.
Exodus Advanced Communications
www.exoduscomm.com

SYSTEMS

Laser-based PCB Development Systems

LPKF's first ever desktop model with the compact tabletop format, the LPKF ProtoLaser ST, can be used in any laboratory for processing materials from FR4 to sensitive RF substrates. The laser system achieves exact geometries on almost any material and is ideal for creating single or double-sided circuit boards, antennas, filters and many applications where precise, steep sidewalls are required.
LPKF Laser & Electronics
www.lpkfusa.com

Single Slot Development OpenVPX Backplanes

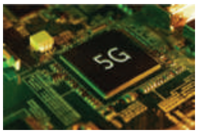
Pixus Technologies, a provider of embedded computing and enclosure solutions, now offers 3U and 6U OpenVPX power and ground backplanes in several configurations. With the SOSA/HOST efforts and move to optical and RF interfaces over OpenVPX, Pixus has developed multiple styles that allow for versatility in prototyping. The one-slot backplanes come in VITA 65 (VPX only), VITA 66.4 (optical), and VITA 67.3 (RF) formats. The optical and RF versions feature a cutout for optional insertion of the aperture housing and contacts.
Pixus Technologies
www.pixustechnologies.com

SOFTWARE

SMD Test Solution

Copper Mountain Technologies is releasing SMD Test Solution and an automatic fixture removal (AFR) software plug-in. These two component testing solutions facilitate characterization of RF devices and discrete components with metrological accuracy. The AFR plug-in and SMD test solution may be used in combination, or individually, depending on user applications. SMD Test Solution is a comprehensive product utilizing a vector network analyzer (sold separately), fixtures, software and tools—for manual, non-destructive characterization of 0402 components.
Copper Mountain Technologies
www.coppermountaintech.com

COMPLETE Library™ v20.2
VENDORVIEW



Modelithics announced the release of the newest version, version 20.2, of the COMPLETE Library for use with Cadence® AWR Design Environment® software platform. This update includes 40 new models. Included in the COMPLETE Library is a large selection of highly scalable Microwave Global Models™ for capacitor, inductor and resistor families from many popular vendors. Also included are nonlinear models for a wide range of diodes, along with nonlinear and noise models for many types of transistors from low noise to high power.
Modelithics Inc.
www.modelithics.com

New**Products**

DesignSpark Mechanical 3D CAD Modelling Software

RS Components, a trading brand of Electrocomponents plc, a global omni-channel solutions partner for industrial customers and suppliers, has unveiled the latest version of DesignSpark Mechanical, its free 3D CAD modelling software. Based on direct user feedback, DesignSpark Mechanical Version 5.0 offers new features, enhancements and customization options that have been developed following feedback from users. The new release coincides also with the 10-year anniversary of DesignSpark, RS Components' global online engineering community.

RS Components
www.americas.rsdelivers.com

TEST & MEASUREMENT

Eight-Channel Programmable RF Attenuator

The AD-US-B8AR38G95 eight-channel 50 to 8,000 MHz programmable RF attenuator is Adaura Technologies' latest design in the series of digitally programmable RF attenuators. This variable attenuator boasts eight independent RF channels in single enclosure, POE, 0 to 95 dB of attenuation range, attenuation resolution of 0.25 dB and USB control. It is ideal for cellular (3G, 4G, 5G), IoT, Wi-Fi 6E MIMO, engineering development and automated manufacturing test and U-NII-6 through U-NII-8 (5.925 to 7.125 GHz).

Adaura Technologies
www.adauratech.com

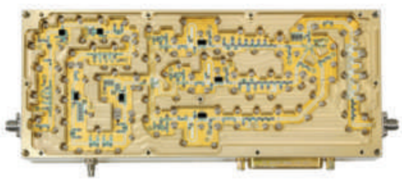
SOLT Calibration Kits

VENDORVIEW

Fairview Microwave Inc., an Infinite Electronics brand and a provider of on-demand RF, microwave and mmWave components, has unveiled a new series of short-open-load-through (SOLT) calibration kits designed for use in lab, test and measurement and RF and microwave production test applications. Fairview's expansion of its VNA calibration kit line consists of 12 models including short circuit, open circuit and load kits, as well as SOLT. Interface options include 2.4 mm, 2.92 mm, 3.5 mm, 7/16 DIN, 7 mm, N-Type and BNC.

Fairview Microwave Inc.
www.fairviewmicrowave.com

Amplitude and Control Module Series Model ACM



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

Kratos General Microwave
www.kratosmed.com

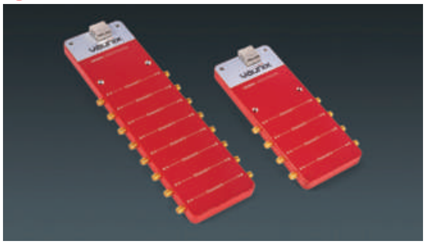
Thermal Platform System

TotalTemp's newest thermal platform system for efficient conductive thermal testing has a 15 × 6.5" active surface. It has fast cooling to -70°C using only electricity, no expendable coolants. Very fast heating to +150°C. The system is shown with under bench condensing unit saves benchtop space. Features award-winning Synergy Nano programmable temperature controller and two year warranty. Alternate sizes and many custom features are available to best meet your requirements.

TotalTemp Technologies
www.totaltemptech.com

High Resolution Multi-port Step Attenuators

VENDORVIEW



Vaunix, a provider of portable and programmable RF/microwave test devices, has recently announced the release of the first two in a series of their Lab Brick™ devices available with Ethernet control. The two new multi-port lab brick digital attenuators are the four-port LDA-802Q, and the eight-port LDA 802-8, each operating from 200 MHz to 8 GHz for a variety of L-, S- and C-Band applications that require the need for single shot or repeating attenuation ramps.

Vaunix
www.vaunix.com

Medical Device Cybersecurity for Engineers and Manufacturers

Axel Wirth, Christopher Gates, Jason Smith

Cybersecurity is no longer optional. We must not allow sensationalism or headlines to drive the discussion… Nevertheless, we must proceed with urgency. In the end, this is about preventing patient harm and preserving patient trust.

A comprehensive guide to medical device secure lifecycle management, this is a book for engineers, managers and regulatory specialists. Readers gain insight into the security aspects of every phase of the product lifecycle, including concept, design, implementation, supply chain, manufacturing, postmarket surveillance, maintenance, updates and end of life.

Learn how to mitigate or completely avoid common cybersecurity vulnerabilities introduced during development and production. Grow your awareness of cybersecurity development topics ranging from high-level concepts to practical solutions and tools. Get insight into emerging regulatory and customer expectations. Uncover how to minimize schedule impacts and accelerate time-to-market while still accomplishing the main goal: reducing patient and business exposure to cybersecurity risks.

Medical Device Cybersecurity for Engineers and Manufacturers is designed to help all stakeholders lead the charge to a better medical device security posture and improve the resilience of our medical device ecosystem.

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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
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Japan
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Tel: +81 3 5691 3335
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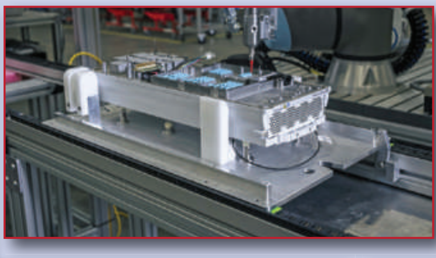
Ed Kiessling • Traffic Manager • 685 Canton Street, Norwood, MA 02062 • Tel: (781) 619-1963 FAX: (781) 769-6178 • ekiessling@mwjournal.com

FABS and LABS

Ericsson's US 5G Smart Factory — Automating mmWave Base Station Production





To supply the rollout of 5G throughout North America, Ericsson has built an automated factory in Lewisville, Texas, shipping the first base station product less than a year after announcing its plans. Ericsson will invest some $ 100 million in the 300,000 square foot factory, which will be fully automated by the end of the year.

Initially, the smart factory will build the 28 GHz Street Macro advanced antenna system, which is being deployed by Verizon in its 5G radio access network. The Street Macro base station comprises an active antenna and baseband processing in a compact housing, designed for mounting every few blocks in an urban or suburban environment where installation on rooftops or large towers is not practical.

The manufacturing flow begins with acceptance of the RF, digital and passive components used in the design, followed by surface-mount assembly, board-level test, assembly into the housing and final test of the complete base station. The surface-mount assembly and testing operations are currently automated, and the final assembly and packing the Street Macro for shipment will be automated by the end of the year. Autonomous mobile robots (AMR) shuttle the work-in-process (WIP) throughout the factory, and the staff — around 100 initially — will supervise the automation and manage the production flow to meet the demand from mobile operators.

As well as building base stations, Ericsson's 5G Smart Factory serves as a case study for how a 5G network can be used in an industrial application to provide flexibility in manufacturing and low latency connections for critical process steps. The internal 5G network uses Ericsson's own 5G equipment to provide a wireless IT backbone for the manufacturing workflow, connecting the AMRs to the assembly and test operations and transporting the WIP data.

Ericsson is committed to sustainability, so the facility was designed to receive a Leadership in Energy and Environmental Design (LEED) zero carbon certification — the first in the U.S. to be certified. The building diverts rainwater from the roof into 26,000 gallon storage tanks, and the collected water is used inside the building and to irrigate the landscape. Magnetic levitation chillers will reduce the energy used for heating and cooling, and solar panels are expected to generate 17 percent of the facility's electrical demand. Overall, the factory should be 24 percent more efficient than a comparable building.

To keep close to its markets and customers, Ericsson has built smart factories in Tallinn, Estonia; Nanjing, China; and Sao Jose dos Campos, Brazil. The Lewisville site establishes Ericsson's 5G manufacturing presence in North America. The U.S. facility came online so quickly because it was built using Ericsson's smart factory template. Erik Simonsson, who leads the Lewisville factory, came from Tallinn, and the U.S. team was trained by the Tallinn staff. Using virtual reality running on Ericsson's internal 5G network, the Lewisville team was "transported" to walk through the Tallinn factory and train on its capabilities and operations. The relationships established during these virtual exchanges have facilitated ongoing collaboration and knowledge sharing among the two sites.

Ericsson's decision to establish a 5G factory in the U.S. is a good move for the company, North American operators and mobile customers. FCC chair Ajit Pai commended Ericsson's commitment, saying "Building 5G equipment in the United States is good for our economy, good for the supply chain and good for the rapid rollout of the next generation of wireless connectivity in the United States."

www.ericsson.com/en/cases/2017/smartfactory

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At European Microwave Week

EuMA — Microwave Journal

Wednesday 13 January – Jaarbeurs Utrecht, The Netherlands – 08:30 to 18:30

A one-day focused Forum addressing Space Situational Awareness

Programme:

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

10:10 – 10:50 **Coffee Break**

10:50 – 12:30 **Space Situational Awareness**

12:40 – 13:40 **Strategy Analytics Lunch & Learn Session**
Space Situational Awareness in the New Space Era
Eric Higham, Strategy Analytics

13:50 – 15:30 ***Microwave Journal* Industry Session**
The Microwave Journal Industry Session will be made up of several company presentations that illustrate the technological innovation that industry is developing for Space Situational Awareness related topics.

15:30 – 16:10 **Coffee Break**

16:10 – 17:50 **Executive Round Table Forum: Space Situational Awareness**

17:50 – 18:30 **Cocktail Reception**

The opportunity to network and discuss informally the issues raised throughout the Forum.

Registration and Programme Updates

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

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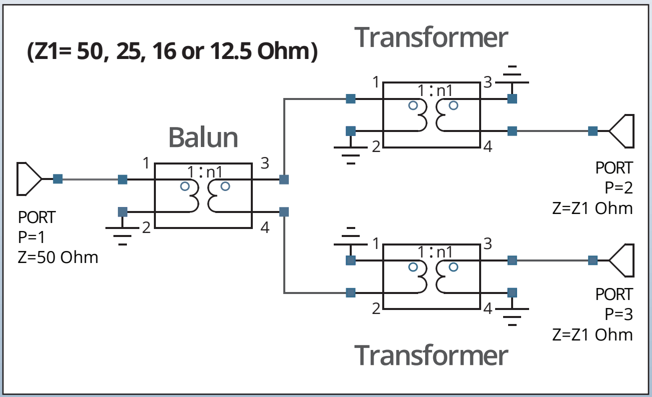
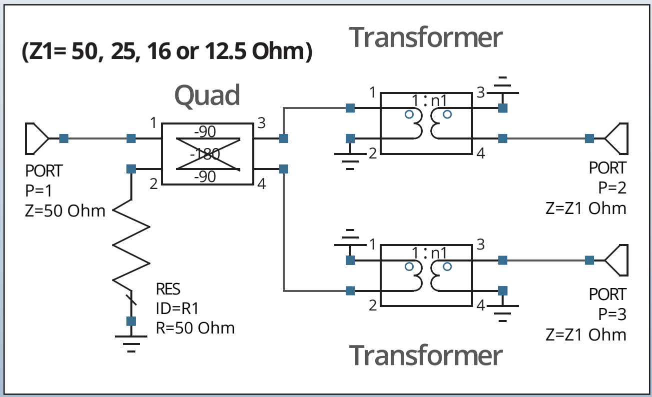
Balun - Transformer Assembly



Quad - Transformer Assembly



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Understanding Quantum Computing

Mark Elo
Tabor Electronics, Nesher, Israel

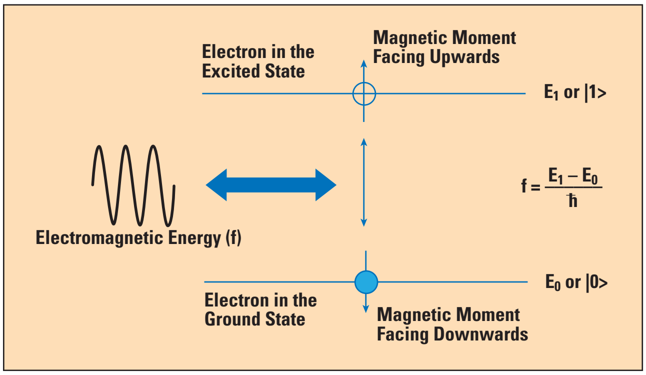
"I think I can safely say that NOBODY understands quantum mechanics."
— Physicist Richard Feynman, winner of the 1965 Nobel Prize for his groundbreaking theory of quantum electrodynamics.

Research into quantum physics applications such as computing, communications, simulation and sensing is moving at a frantic pace. Its promise for orders of magnitude advances in cryptanalysis, secure communications, prediction of materials properties and spectroscopy has caught the attention of many national governments and private investors eager to fund further research.

So, what is the big deal?

A regular digital computer performs data processing tasks by manipulating bits; each bit can have a value of one or zero. A quantum physicist would say this is a "classical" implementation of computing. A "quantum" implementation of a computer manipulates quantum bits (qubits). Qubits can have a value of one, zero or both simultaneously. When the bit is simultaneously a one and a zero, the bit is said to be in a state of superposition. Moreover, the state of one qubit can influence another qubit, even if they are separated by great distance, in this case, the states are said to be entangled. Superposition and entanglement are at the heart of quantum computing and provide capabilities that can speed the types of calculation required for cryptanalysis from years to minutes.

To understand how a quantum computer works, we need to understand the properties of an electron, how electrons behave in the presence of electromagnetic (EM) fields and how this is used within a qubit. We can then understand the implementation of the qubit and how to control and measure its state. Finally, we will address how qubits interact with each other and how, when put all together, they can perform computing. Putting Richard Feynman's comments regarding quantum physics to one side, we can more easily understand how to control and manipulate data and perform computations with a fairly basic understanding of RF/microwave signal behavior, especially transmission lines and the inductor/capacitor (LC) tuned circuit.



▲ **Fig. 1 The frequency of applied EM energy causes electrons to move from one energy state to another.**

HOW ATOMS AND ELECTRONS WORK

Quantum computing is built on the work of the great physicists: Planck for saying energy is not contiguous but quantized, Einstein for discovering the photoelectric effect, Bohr and Rutherford for applying Planck's quantized energy rules to electron orbits, Louis de Broglie for proposing that electron particles also have wave properties and Schrödinger for introducing probabilities into the energy states of an electron.

Each atomic orbital is represented by an energy level measured in electron volts (eV), with the lowest orbit called the ground state. As a particle can also be a wave, its energy level has a frequency equal to the energy level in eV divided by Planck's constant (the quantization constant). Consider ***Figure 1***. If we want the electron to move to a higher energy state, we apply EM energy at a frequency equal to the desired energy level minus the current energy level, divided by Planck's constant. The electron will absorb the energy and jump to the next quantum energy level. Once the energy is removed, it will fall back to its original level, emitting the energy at the frequency previously absorbed. The frequency of the stimulus—not the amplitude—is key. Increasing the amplitude will not cause the electron to move to a higher

energy level, increasing the frequency will. With this understanding, if we can constrain the energy levels to two, we have the fundamental building blocks for manipulating ones and zeros with a single electron.

Electrons also possess a type of angular momentum called spin. As the electron moves from one energy level to another, the spin momentum changes. At the lower energy level, the momentum is pointing down, called the "spin-down." When EM energy is applied, the spin changes until the momentum is pointing upwards as the electron achieves the next energy level. This is the "spin-up" state. When the electron state can be defined like this, it is said to possess an eigenstate, as both the position and momentum are known and can be quantified through measurement.

Schrödinger postulated the probability that an electron can be in neither a spin-up or spin-down state, rather between. As the electron is not at one energy state or the other and not oscillating between the two, it is in both states at the same time or a superposition of the two states. Another way to say this is: when two disturbances occupy the same space at the same time, the resulting disturbance is the sum of two disturbances, like standing waves in a transmission line. We know that each energy level is proportional to frequency, and since a particle is a wave, the state of superposition is simply the vector addition of the upper and lower states.

While superposition is fundamental to the operation of a quantum computer, we have what is referred to as the "measurement problem." A state of superposition only can exist if you don't "observe" it—the idea behind the popularized Schrödinger's cat example. In a quantum system, observation is synonymous with measurement. By applying a measurement frequency pulse to a qubit in superposition, the state of that qubit collapses or snaps back to one of the two quantized energy levels. As a physicist would say, the measurement causes the particle to be projected to one of its eigenstates.

WHAT IS A QUBIT AND HOW DO I MAKE ONE?

A qubit is an artificial implementation of an atom. As described, two energy states are associated with the electron orbits of an atom, and applying the appropriate frequency can affect the energy level and spin of the electron to create a logical one state, a logical zero state or something in between, i.e., superposition.

There are many implementations of quantum bits, ranging from solid-state superconducting qubits to photon-based systems using lasers and modified crystals. To illustrate quantum computing, we'll look at the transmon solid-state implementation. A transmon, which is short for transmission line shunted plasma oscillation qubit, is a type of solid-state qubit. Fundamentally, a transmon is a tuned LC circuit connected to a transmission line, which resonates when an appropriate frequency is applied. In many cases, the frequency is sub-10 GHz, although some systems use higher resonant frequencies. This type of resonant circuit and transmission line is ideal, as the resonant frequency equates to the equivalent of an electron energy state.

Figure 2 represents an actual qubit circuit. As the spin and energy level change with the application of certain frequencies, a qubit is fundamentally based on several tuned circuits connected via transmission lines, for both qubit control and measurement. Note the inductive component in the qubit has been replaced with a Josephson junction. While still fundamentally an LC structure, this modifies the inductive properties of the circuit so only two resonant or energy states can occur, since the system must be constrained to two levels. The circuit is cooled to about -450°F to obtain superconducting properties and exhibit the behavior of an electron, following the rules of quantum physics. To control the qubit,

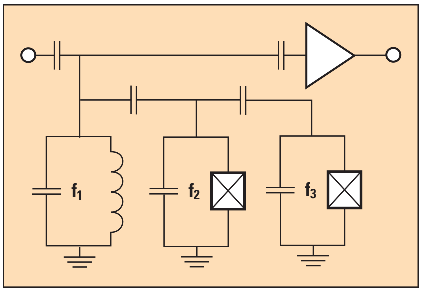
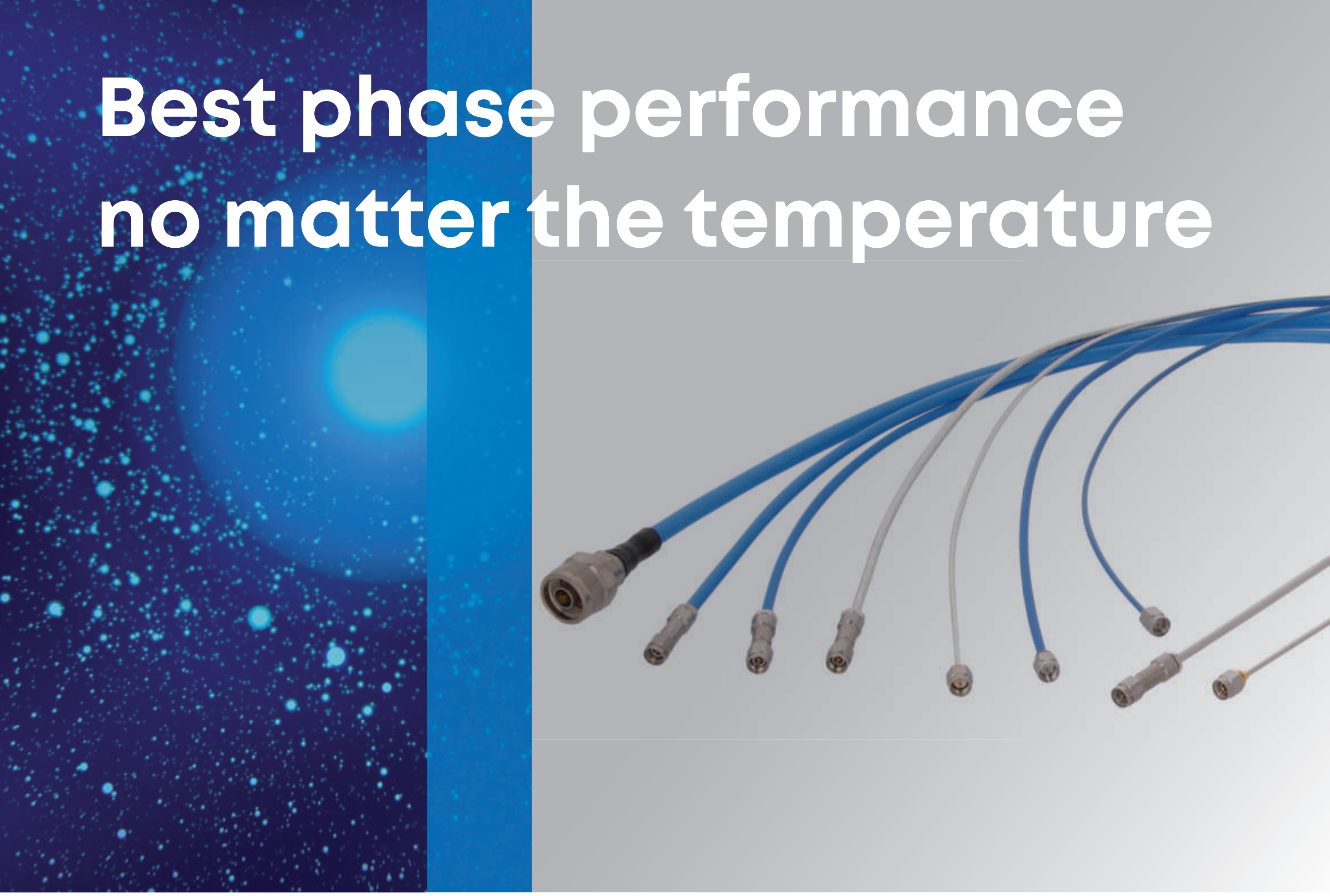


Fig. 2 Schematic representation of a qubit.


Best phase performance
no matter the temperature

we apply the appropriate frequency for a certain duration to set the qubit to a one, zero or state of superposition. This pulse of RF energy can have different durations and different time domain shapes, depending on the control required.

Quantum states or spins are sometimes visualized by physicists on a unitary circle diagram. Spin-up and spin-down are opposites. If a base state is defined on a unit circle as the horizontal vector (1, 0), after applying energy the orthogonal spin-up state would be at the vector (0, 1) or $\pi/2$ on the unitary circle. This is a simplification, as these are complex numbers, i.e., a spin-down is represented by the vector (1 + j0, 0 + j0) and spin-up as (0 + j0, 1 + j0). Adding the two vectors give the superposition vectors $(\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}})$. Another method of visualizing the quantum spin state is the three-dimensional model called the Bloch sphere. The unitary circle and Bloch sphere are mathematically related; however, instead of using cartesian coordinates, the Bloch sphere uses polar coordinates and defines spin as the difference in angle between the horizontal and vertical base states. A spin-up is represented by a vertical arrow pointing upwards within the sphere, i.e., to the north pole; with the downward spin, the arrow points to the south pole. Positions along the equator represent the spin in superposition. Both visualization methods are shown in ***Figure 3***.

HELLO QUANTUM WORLD

With a qubit supercooled, its states can be controlled and measured by applying specific pulses of RF energy. Another fundamental: a quantum computer is not an independent computer with an operating system and programming language. It has no operating system or programming language, it is a set of bits manipulated from a classical computer (see ***Figure 4***), with a classical computing bit or register usually mapped to a quantum bit. When the classical register is set high, a value of one, an appropriate RF frequency pulse is applied to the qubit circuit, which causes the electron to move to the next energy state, orthogonally changing the magnetic spin on the unitary circle or rotating the vector by 180 degrees on the Bloch sphere, setting the quantum bit to a value of one. This can be verified by reading the classical register, which means another RF pulse is applied and a measurement made to determine the state of the bit. The value of the measured phase or frequency defines whether the system has snapped to a logical one or a logical zero. In most cases, multiple measurements are required to ensure the answer is correct. Making 100 measurements, the probability that a value of one will be read back will be very high; however, the answer can never be 100 percent, as there will always be some level of interference affecting the measurement. We can do the same with zero, again, with the probability of the qubit returning a zero after several measurements will be very high.

QUANTUM LOGIC GATES

We can use gates with the qubit and cover three types of circuits: the NOT, Hadamard and controlled NOT (C-NOT). Each gate is implemented by applying an appropriate RF pulse to the qubit cir-

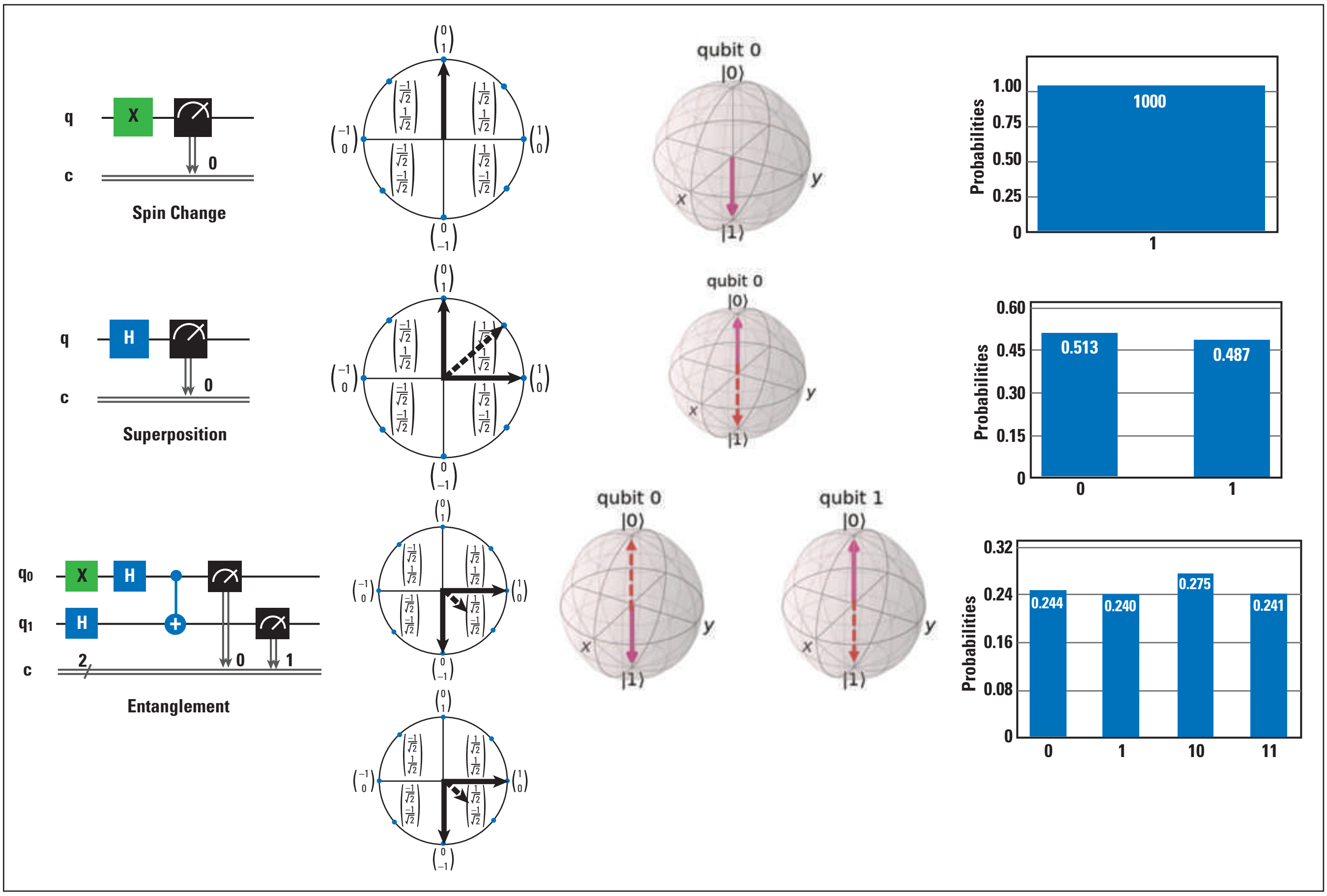
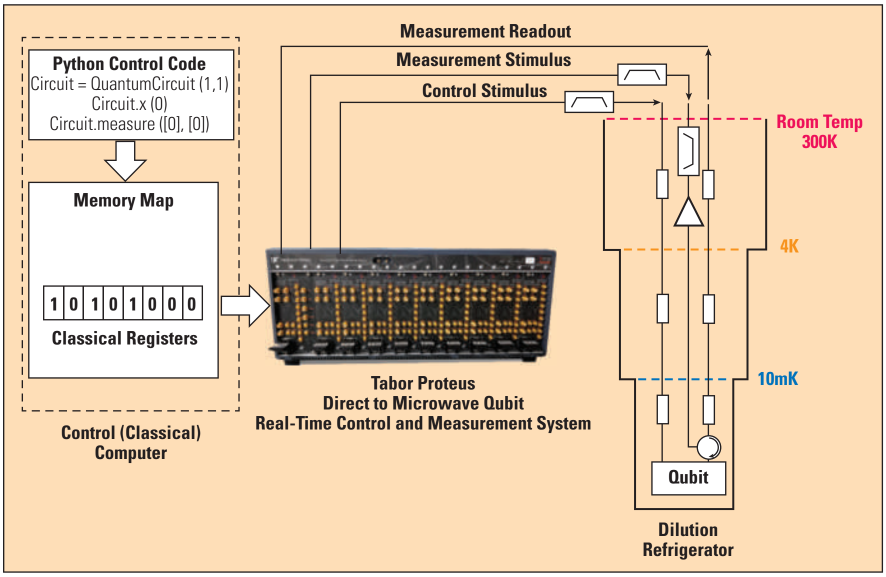


Fig. 3 Quantum gate programming and visualization methods.

cuit. All the gates are shown in Figure 3.

A NOT gate means changing the energy state of the electron and changing the spin. Starting with a bit in a zero or ground electron energy state, application of the appropriate frequency will cause the electron to move to the next quantized energy state, visualized with a unitary circle or Bloch sphere diagram. Applying a Hadamard gate puts the qubit into a state of superposition—two energy levels at the same time—until it is observed. When we make a measurement, the quantum state will collapse and the qubit will return to a classical quantized energy state representing a one or zero. Making 100 measurements, the chance of returning a logical one 50 percent of the time and a logical zero the other 50 percent are very high. Two perfect qubits and Hadamard gates on each bit would create a 2-bit random number generator that generates the values zero, one, two and three, each 25 percent of the measurements. With interference present, the probabilities will be less even. Outside or unintended RF interference can seriously affect the probability of a correct answer, so designers of quantum systems need to ensure noise and interference are minimized. However, one form of interference can be used to the computer's advantage. We call this entanglement.



▲ Fig. 4 Quantum computing system hardware.

WHAT IS ENTANGLEMENT?

When two electrons become entangled they will no longer exhibit independent behaviors. If one electron is measured and has a clockwise spin, the second will have an anti-clockwise spin. So why is this useful?

Electrically, the superconducting, very cold qubits are part of a cavity oscillator. As such, they are close enough to share EM fields and resonate, enabling the phenomena of quantum entanglement. A practical example of a type of entanglement is the C-NOT gate. The C-NOT connects two bits together, i.e., "entangles" them. Logically, the C-NOT gate works as follows: if the control port is set to a one, the output is the inversion of the input; if the control port is set to zero, the output of the gate equals the input.

The power of the Hadamard and C-NOT gates can be understood when guessing the value of an unknown number. Not knowing the value of a bit and wanting to guess with high probability that it is a logical one, we would use two bits to perform this operation. Both bits would be set into superposition, except one of the Hadamard gates would have its basis state out of phase by placing a NOT gate before it. If we collapse the quantum state and measure the output, one would be a one, and the other a zero. Entangling the qubits by connecting a C-NOT between the bits means the probability of the output being a one with a single guess is high.

While this seems fairly benign when guessing whether a single bit is set to a one or a zero—after all, you can guess a single bit number with a maximum of two (2^1) attempts: it is either a one

or a zero. A 2-bit number would require 2^2 guesses and an 8-bit number would require 2^8 or 256 guesses. The number of guesses increases exponentially as the power of two increases. Guessing a number with 72-bits would require up to 4,722,366,482,869,645,213,696 guesses—which would potentially take a supercomputer hundreds of years to crack.

A good 8-bit analogy: eight coins spinning together hold 256 possible states in limbo. We know one of these states represents the right answer. But which one? The problem is the act of measuring the qubits will cause the superposition to collapse, like banging a fist on the table will cause the coins to fall to either heads or tails. We can increase the probability that each coin will fall heads or tails to give the correct answer with a collection of gates, or quantum algorithms, which loads the probability of the qubits to make each more likely to fall on the correct side and give the right answer. The quantum algorithm effectively weighs the superposition on the unitary circle, increasing the probability that it will snap to a one, rather than a 50/50 chance of snapping to a one or a zero.

CONCLUSION

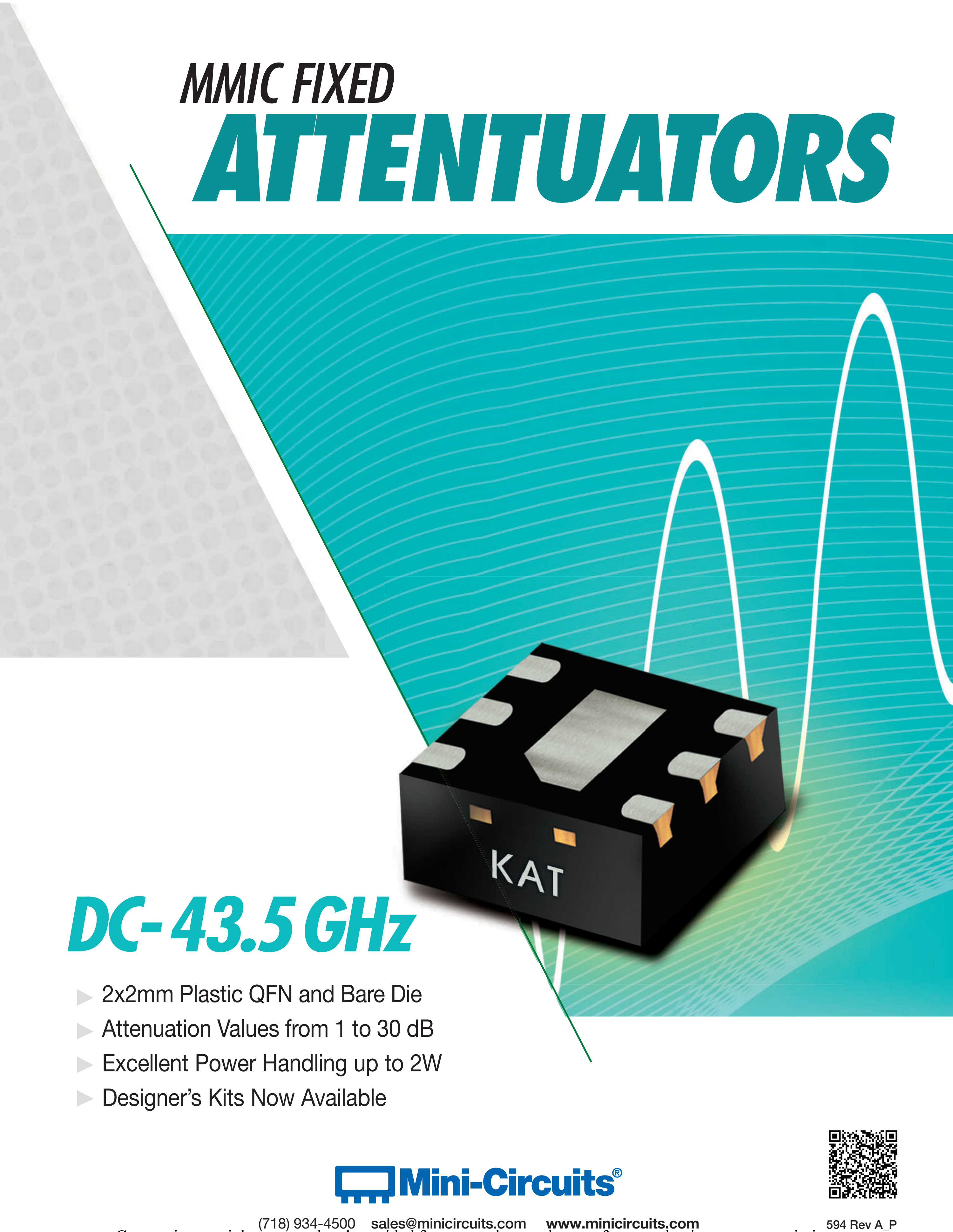
A classical computer uses groups of transistors to form NAND gates that perform the logical functions which enable data processing. A quantum computer uses groups of RF/microwave pulses with different shapes and durations, acting on supercooled semiconducting resonators to create different logical operations, such as NOT, Hadamard and C-NOT. Putting these together, we have demonstrated some simple quantum circuits and shown how superposition and entanglement can be used to guess numbers.

Wave-particle duality, the photoelectric effect, magnetic resonance and probability are key elements. The manipulation of these phenomena to create various electron or photon spins can ultimately help crack codes and facilitate secure communications, although there is still a long way to go. Most quantum computing machines reside in research labs, with scientists trying to solve problems such as how long a state of superposition can last and reducing interference so more qubits can work together.

The industry has two benchmarks: 1) quantum advantage, the demonstration that a quantum device can solve a problem faster than classical computers; and 2) quantum supremacy, the ability that a programmable quantum device can solve a problem that classical computers practically cannot. Skeptics say that a large scale quantum device may never be realized, however, the research continues to move forward, achieving new breakthroughs every year. In October 2019, Google published an article in *Nature* stating they achieved quantum supremacy with their benchmarking, claiming the equivalent task for a state-of-the-art classical supercomputer would take approximately 10,000 years.[1]

Reference

1. Frank Arute, Kunal Arya, et al., Quantum Supremacy Using a Programmable Superconducting Processor, Nature, October 23, 2019, www.nature.com/articles/s41586-019-1666-5.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Instrument Applications in Quantum for the Aerospace and Defense Industry

Suren Singh
Keysight Technologies, Santa Rosa, Calif.

This article focuses on a couple of key application areas for quantum technology in the aerospace and defense industry. In addition, it covers some of the measurement tools that are used in the development and analysis of performance for quantum-based systems. This article does not cover the physics of the quantum systems but refers to some of the key characteristics of quantum bits (qubits) as they are manipulated and measured (read the previous article in this supplement for the basics on quantum computing).

In general, the application of quantum technology in the aerospace and defense arena aligns well with the current adoption of quantum technologies in computing, sensing and communications. From an aerospace and defense perspective, one of the key application areas for quantum computing includes quantum key distribution (QKD) for encryption of sensitive data and prevention of cyberattacks. The extremely fast speeds of quantum computers for optimization of exponentially challenging algorithms enables them to also be used in the management of military missions and in deep space exploration.

The aerospace industry has for a long time taken advantage of the quantum effects for timing; an example is in the adoption of the cesium atom for precision timing. However, with the advent of the latest advances in the application of quantum mechanical behavior with newer atomic species, these structures offer more secure systems for positioning, navigation and timing.

Overall, quantum technologies are expected to provide several advantages that will include resilient and integrated communication systems and, in addition, open opportunities for precision navigation and timing. Also, providing the aerospace industry with the capability of having advance persistence, long range sensing systems.

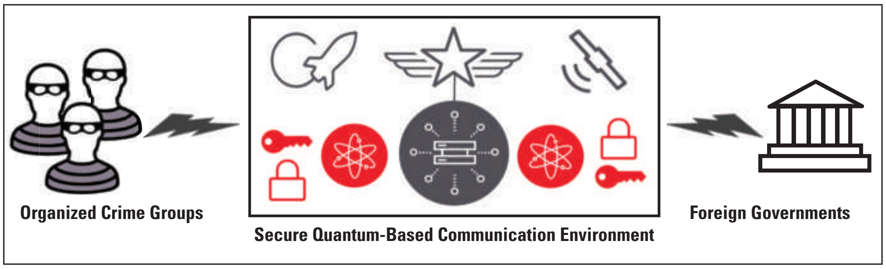

Fig. 1 Quantum key distribution enables encryption and security.

CYBERSECURITY AND OPTIMIZED COMPUTATION

Today, cyberattacks can come from a variety of places and in a variety of forms. In ***Figure 1***, two of the typical attackers and sources of cybersecurity threats are shown that include organized crime groups and foreign governments. Due to the potential processing power and sensitivity of quantum technologies, as well as the concept of quantum entanglement, it is expected that quantum computers will allow for the rapid development of highly encrypted communication systems using quantum cryptography. The currently safe and secure classical encryption has the potential of being broken using quantum computing technologies so governments are aggressively pursuing these new solutions.

Quantum cryptography is the science of exploiting quantum properties to perform cryptographic tasks. The advantage of quantum cryptography lies in the fact that it allows the completion of various cryptographic tasks that are proven to be impossible using only classical communication. The other area is the application of quantum optimization algorithms that could be used to speed up modeling of aircraft design for the ultimate performance.

Since the development of quantum computing technologies forms the ba-

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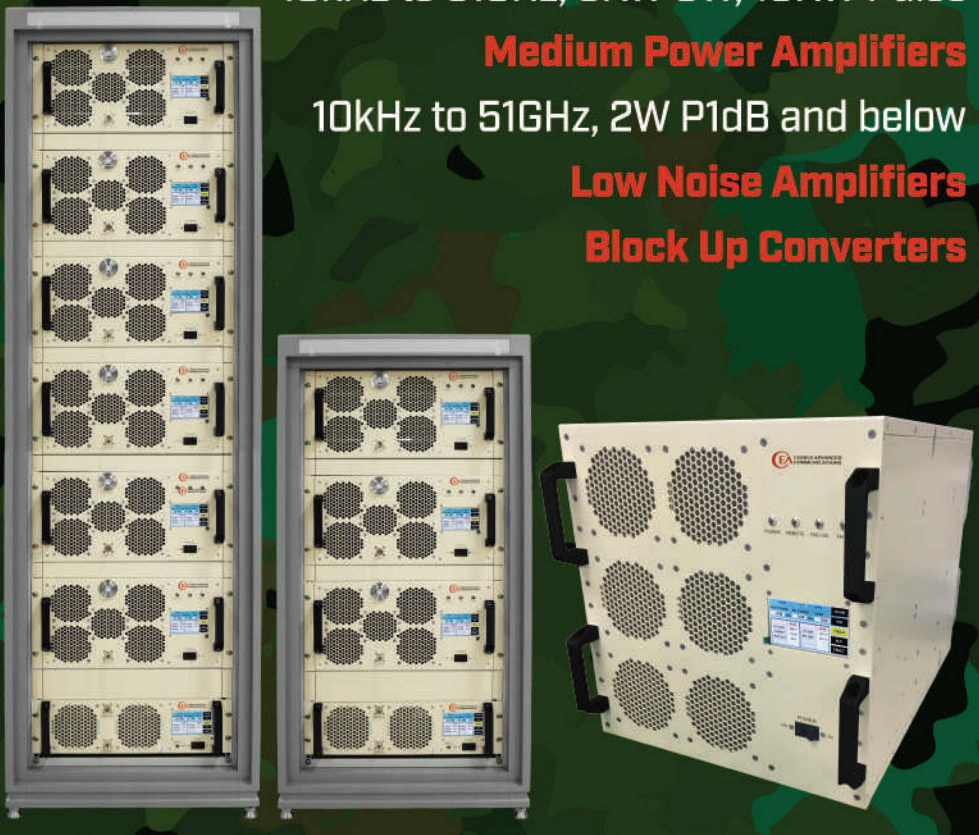

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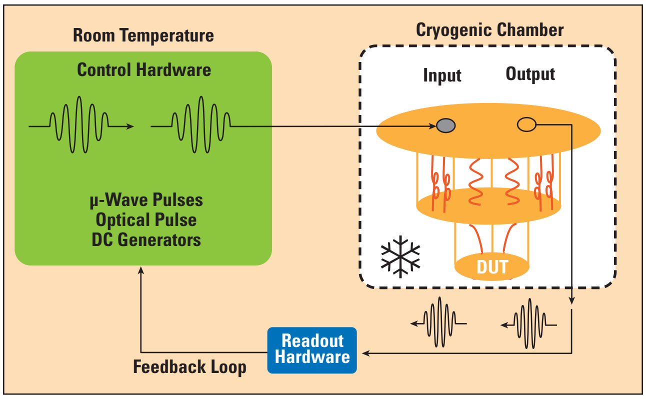

Fig. 2 Simplified block diagram of a quantum computer.

sis for enabling the development of algorithms that offer robust methods of encryption and decryption in the aerospace industry, let's start with a discussion on these solutions and how they may be applied, as well as how we may provide testing for these platforms. From a quantum mechanics perspective, the properties of "superposition state" and "quantum entanglement" form the basis for enabling the development of encryption and optimized computation algorithms. This implies that the quantum computers that are developed to address these needs would have to ensure that the quality of the qubits are based on providing high fidelity gates with low crosstalk.

Fig. 3 Qubit control and readout hardware.

In the physical realization of quantum computers, several technologies are used, including superconducting systems, trapped ion systems, spin qubits and neutral atoms. The cryogenic-based systems that operate in the millikelvin temperatures are typically superconducting and spin qubit systems. In some of the aerospace industry applications, trapped ion, superconducting qubits and neutral atom systems are more commonly adopted.

Superconducting qubits can consist of transmon qubits that require complex connection and cryogenic systems to perform operations on the qubit. Ion traps are slightly different and use atomic particles that are confined and suspended in free space using electromagnetic fields and are controlled using complex laser systems.

In order to understand the performance and measurement of these platforms, let's look at the architecture of a typical quantum computer. From ***Figure 2***, we see the key elements that make up the system include the control hardware for

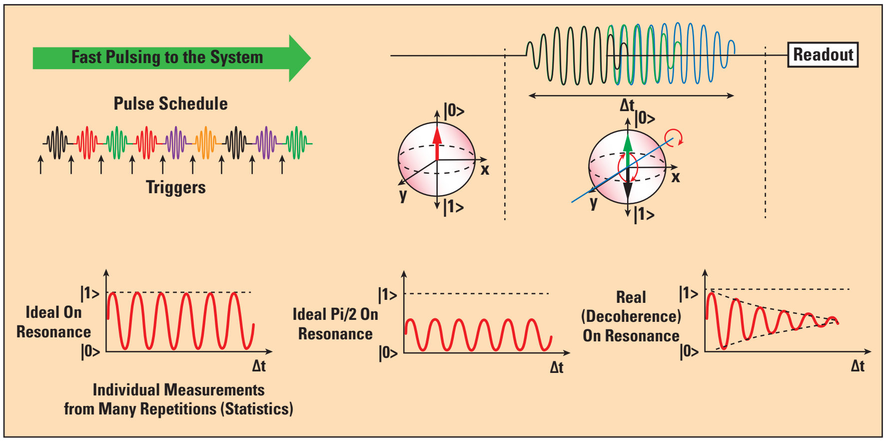

Fig. 4 Qubit resonance and decoherence.

the qubits, the cryogenic chamber that includes the inputs and outputs, and the superconducting quantum computer chip itself. In general, the quantum computer is operated at cryogenic temperatures of ten millikelvin. The quantum computer control and readout are done using microwave pulses provided by control hardware.

The control hardware supplies signals to the system by means of microwave pulses, optical pulses and DC generators usually in the form of unique waveforms. Next, the quantum system requires a readout system that consists of making an excitation coupled with the quantum system. In many quantum error correction experiments, a feedback loop can be created between the control and readout hardware so that adjustments can be made to the control hardware.

Imperfections in the control hardware can affect qubit coherence times: jitter, phase noise, amplitude and temperature stability, noise and frequency accuracy. These problems are compounded as the number of qubits increases and the control system must deal with tens or hundreds of simultaneous control signals applied to these qubits.

To support these requirements, the control hardware that is typically used includes arbitrary waveform generators (AWG) and digitizers. For a quantum computing application, the AWG and digitizers must ensure high gate efficiencies, low latency, phase coherent time-dependent and sequential control pulses. In addition, the measurement and control hardware need to be extensible to allow for the control of several qubits as required in the computation as well as the seamless integration into the QKD distribution code and the cybersecurity algorithms.

This demands that the hardware is modular, allows for the lowest latency, provides excellent phase coherency and customizable software for the control of the quantum computer. In ***Figure 3***, we see an example of the current PXI based AWG and digitizer solutions that has these capabilities.


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The PXI AWG and digitizer platform shown in Figure 3 can be programmed at the hardware level using a hardware virtual interface and provides access to the FPGA's used in the generation of the required waveforms. This addresses the need for low latency from control to readout and ensure ease of synchronization of the waveforms generated.

When utilizing quantum computers for any type of computation, it is important to know the resonance frequencies for each of the qubits that form part of the computer and how long your qubit will remain in a certain state. To characterize the qubit lifetime, Rabi oscillation experiments that help in the tuning of single qubit gates are used.

In ***Figure 4***, we see a measurement of a qubit on an ideal resonance that was measured using a fast-triggered pulse sequence. The experiment involves driving the qubit between two energy states |0> to |1> and |1> to |0> repeatably. The Rabi experiment is such that a series of pulses of different amplitudes are applied to the qubit that is fixed on the resonance frequency.

Figure 4 also illustrates the on-resonance pi/2 condition that is determined by selecting an amplitude sweep that is half of what is used for the ideal on-resonance. As an example, the pi/2 pulse resembles the ideal qubit being manipulated from a |0> state into a superposition state |0> + |1>, which is in both the ground and excited state.

Another phenomenon that qubits exhibit is that of decoherence which essentially is the loss of information and can be due to the quantum system environment. One can think of it as the loss of information from the quantum system into the environment and cannot be avoided. However, by understanding the decoherence time, like shown in Figure 4, one can calibrate the qubit to maintain its state while it is being used for the execution of algorithms.

TIMING NAVIGATION AND SENSING

When it comes to the navigation and sensing applications, the aerospace industry is turning to the application of quantum physics to provide a more resilient set of solutions that are not easily compromised. There are several quantum-based sensing technologies that are under investigation, and these cover motion, such as acceleration, rotation and gravity, along with electric and magnetic fields and imaging.

A commonly used structure is based on the quantum effect of a magnetic field on a diamond-based nitrogen vacancy structure as shown in ***Figure 5***. It is a highly sensitive structure that

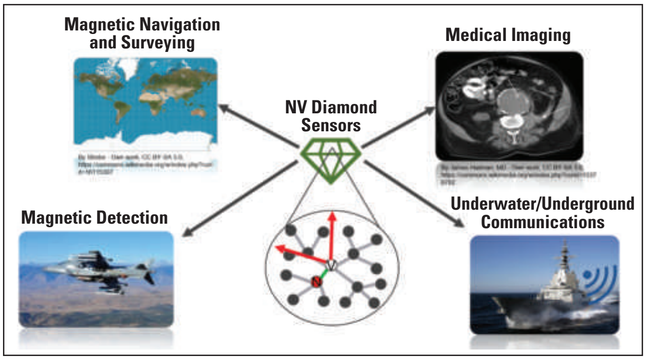
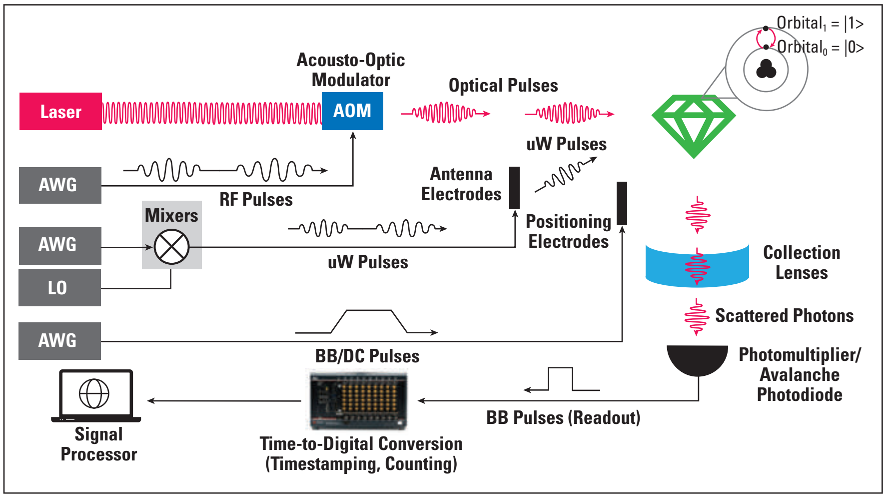


Fig. 5 Quantum-based sensing and navigation applications.



▲ Fig. 6 Nitrogen vacancy control and readout.

enables fast accurate sensing of aircraft, underwater communications and positioning using a gyroscope that senses the Earth's magnetic field for navigation. It is important to note while navigation and surveying are feasible and being deployed, the magnetic detection of fast-moving objects is not something that has yet to be realized with this technology.

Intercepting communications is still a long way away but presents a real opportunity for the aerospace and defense industry. The fundamental nature of this technology does not allow external interferences and making it a much more secure approach for positioning and navigation.

Another area of adoption for quantum phenomena is the application of the Rydberg atomic effect for sensing electromagnetic energy. This works on the principle of excitation of atoms in a vapor cell to a Rydberg state and can then be used to detect signals that cover anything from 0 to 100 GHz. This concept can be extremely useful in the aerospace and defense industry since it can be used by military personnel to detect any radio communications over this wide frequency range limiting the need to carry additional hardware. One of the challenges facing the full adoption is implementation of compact lasers that are required to excite the atoms into a Rydberg state.

The example in ***Figure 6*** shows a typical application of a diamond-based nitrogen vacancy (NV) structure. That is acousto-optically modulated which excites NV centers sensitive to magnetic fields for spin initialization and readout. A microwave source such as an AWG, is mixed and sends microwave pulses to the diamond providing coherent spin manipulation. Next, the collection lens receives the emitted light pulses which are sent to a photodetector to be converted into an electric signal. The electrical signals are returned to the digitizer and sent to a computer for data interpretation.

RADAR AND SATELLITE COMMUNICATION

The application of quantum technologies in the satellite communication space is in its early stages of research. The concepts of quantum entanglement and QKD are proving to be very attractive advantages for quantum-based communication systems. These two concepts can provide highly encrypted communication channel between ground stations and satellites in space.

Another path for quantum communications is quantum illumination that is the archetype for quantum communication as we know it today and works in line with quantum networks. A free space quantum network would enable the ability to communicate with satellites over very long distances.

In the case of radar applications as shown in ***Figure 7***, quantum illumination may be used and is subject to similar aspects of transmission as with classical radar. The path to detect unknown objects through air requires a method known as two-mode squeezing. A high frequency pump emits a photon that is split through spontaneous parametric down-conversion to two lower frequency beams called

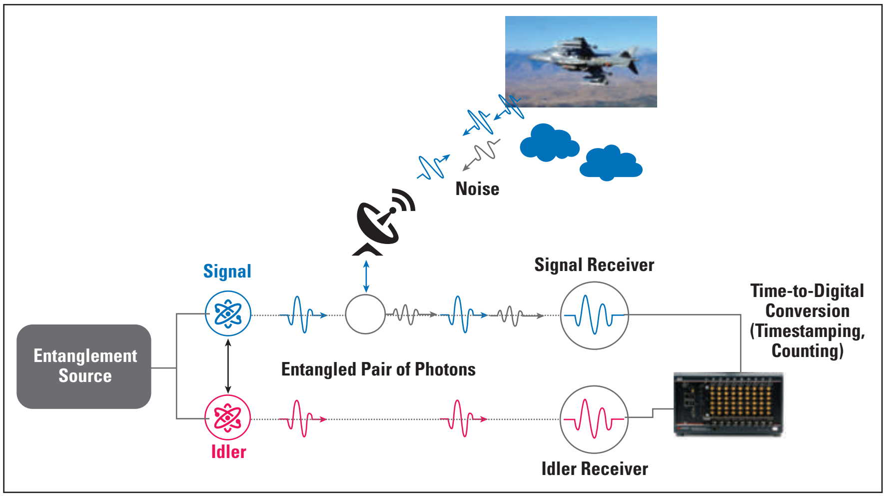


Fig. 7 Aircraft detection using quantum illumination.

Fig. 8 Real-time scope with display of Rabi oscillation waveforms.

the signal and the idler. Entanglement of two photon pairs dramatically increases sensitivity. The idler is immediately measured and kept at a base station, while the signal is sent as a probe toward the unknown object. The signals both pass through a receiver and an entanglement detector, which are measured by a digitizer.

ADDITIONAL DEVELOPMENT TOOLS

In the discussion thus far, the focus has been on a couple key areas for adoption of quantum technology in the aerospace and defense industries. Next, some of the complimentary hardware that enables the development of quantum-based solutions is covered. In the development of the quantum computer for instance, it was noted that AWGs and digitizers play a key role in control of the qubit states.

A real-time oscilloscope is key in establishing the waveforms for the Rabi oscillation experiments for example. In ***Figure 8***, the application of a real-time oscilloscope that shows the different pulses to help establish the qubit resonance is shown. The result is a consistent Rabi measurement as the schedule of pi pulses increases. This marks a consistency in the resonance frequency that is tuned to the qubit that can now oscillate around the Bloch sphere proportional to the amplitude of the pulse.

Resonator measurements are key to ensuring the highest quality materials designs for the Josephson junctions used in the deployment of quantum systems. Therefore, vector network analyzers (VNA) play a key role since these measurements do not require time-domain operation. One of the challenges that is under research is the ability to make a calibrated measurement at the very low cryogenic temperature.

Figure 9 shows the application of the VNA in the development of superconductor microwave resonators. These resonators form the core for understanding the material loss properties when developing qubits and are also used for qubit readout. Finally, in ***Figure 10*** other complimentary hardware is used to ensure we have the highest quality materials and models as well as the appropriate noise levels are shown. Several instruments may be used, these include semiconductor analyzer, DC power analyzers and bit error rate testers.

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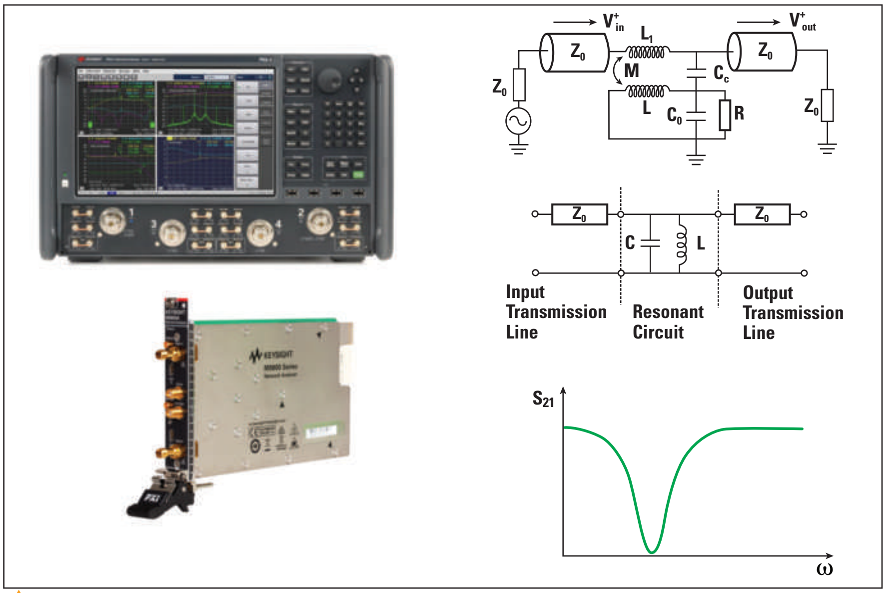
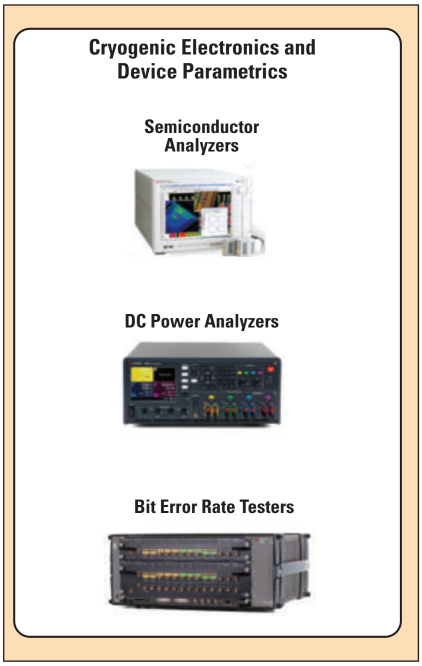


▲ Fig. 9 Benchtop and modular VNA used for quantum resonator measurements.



▲ Fig. 10 Equipment used to qualify quantum system designs.

SUMMARY

For the aerospace and defense industry, the adoption of quantum computers for development of safe and secure communication will be a fertile area of research, while the fast speeds offered by quantum computers for optimization of exponentially challenging algorithms is leading the way. In the area of sensing navigation and positioning, there are clear opportunities and materials that allow for the development of newer, less vulnerable positioning and navigations solution.

In the satellite and radar space, this is clearly in the early stages of adoption for some of the quantum technologies, although there are single photon systems that are more evolved in this space. Finally, in the development of quantum solutions, there is a growing need for more software tools, like Labber, that allow for the ease of control of hardware, while providing a suitable platform for the development of the different quantum control experiments. ■

Suren Singh received his BSEE from University of Durban-Westville, Durban South Africa in 1985. He completed a Graduate Diploma at the University of Witwatersrand, Johannesburg South Africa in December 1992. He then went on to complete his MSEE at the University of Witwatersrand, Johannesburg in 1995. Suren has been with the Hewlett-Packard Company, Agilent Technologies and now Keysight Technologies since 1986. His experience includes application engineering, product design, manufacturing and test process development for microwave hybrid microcircuits. He also held the position of an application specialist and system architect, focused on the terahertz measurement solutions for Keysight. In addition, he is responsible for the metrology products for performance network analyzers, including both calibration and verification and both ambient and cryogenic temperatures. More recently, Suren has been appointed as the business and application development lead for the Keysight quantum initiative focused on the aerospace industry. He has been working closely with the Quantum Engineering Solutions team within Keysight to bring solutions to the quantum research and development that is part of the aerospace industry.

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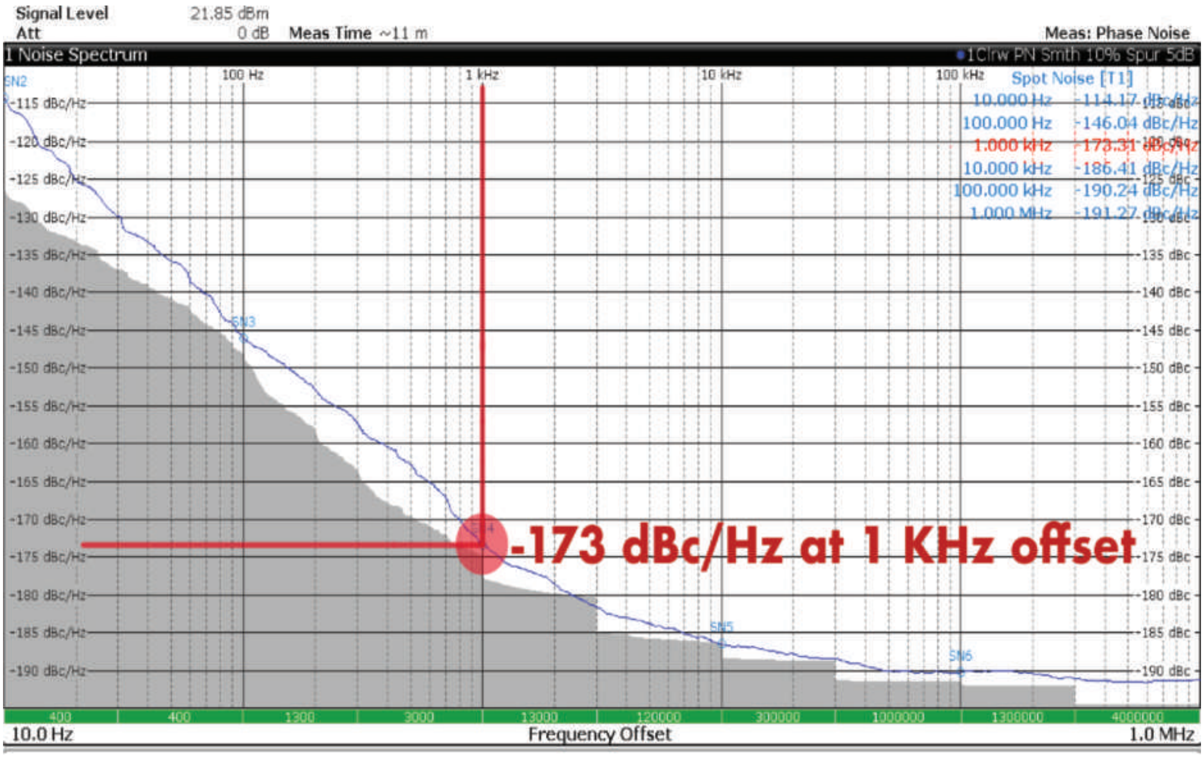

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A New Approach for an Old Problem: Testing Secondary Surveillance Radar

Walt Strickler
Boonton Electronics, Parsippany, N.J.

Secondary surveillance radar (SSR) has been around since World War II, based on the military's "identification friend or foe" radar system. While the radar systems have evolved, many of the test challenges have remained constant. Whether designing, characterizing, installing, maintaining or troubleshooting an SSR, one may have different requirements for testing the RF transmission. As a result, different instrumentation is often used, based on the task, or the same equipment is used throughout, requiring users to accept compromises. The former leads to higher equipment cost, the latter inefficiency and lower productivity. This article describes a new approach to these test challenges, where the same test equipment can be used without the compromises.

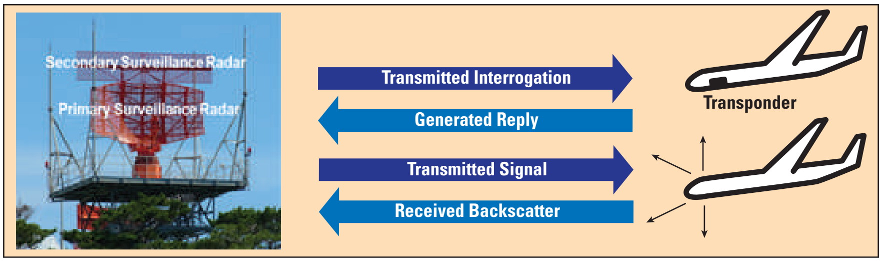
SSR is used in air traffic control to complement the primary radar system (see ***Figure 1***). The primary radar measures the bearing and distance of aircraft or other targets using the reflections of transmitted radar signals. The SSR provides additional information, such as an aircraft's identification code or its altitude. Unlike primary radar, which only depends on signal reflection, SSR systems require the aircraft to have transponders—a transmitter responder, which receives a signal, then transmits a response. An SSR sends an interrogation signal to the aircraft requesting specific information. The interrogation signal is received by the aircraft's transponder, which responds with an encoded signal containing the requested information. Correspondingly, an SSR system has two transmitters to test: the interrogator and the transponder.

The interrogation signals are categorized by modes, primarily A, C and S. The interrogation signal parameters depend on the mode (see ***Figure 2***), where mode A requests identity, mode C requests altitude in 100 foot increments and mode S is multi-purpose. The time between P1 and P3 of the mode A/C and S interrogation signals are 8 and 21 µs, respectively. Mode S comprises P1 and P2 in a preamble followed by a data block of 56 or 112 bits modulated with differential phase-shift keying. Mode A and C transponders respond with 12 and 11 pulse replies, respectively, and the mode S reply includes a four pulse preamble followed by a data block of 56 or 112 bits (see ***Figure 3***). Mode C does not use the D1 pulse.

A simplified block diagram of an SSR is shown in ***Figure 4***. Proper design and operation of SSR systems is critical to the safety and security of aviation, with testing essential both at the time of installation and on an ongoing basis. To reduce the possibility of a catastrophic event, federal aviation safety standards, such as defined by the U.S. Federal Aviation Administration, require periodic maintenance and calibration of the transponders. If any issues are found, they must be resolved expeditiously to get the system back online.

POWER MEASUREMENT CHALLENGES

RF power measurement is a cornerstone of the testing process to ensure proper power levels at various points in



▲ **Fig. 1 Primary and secondary surveillance radar systems.**

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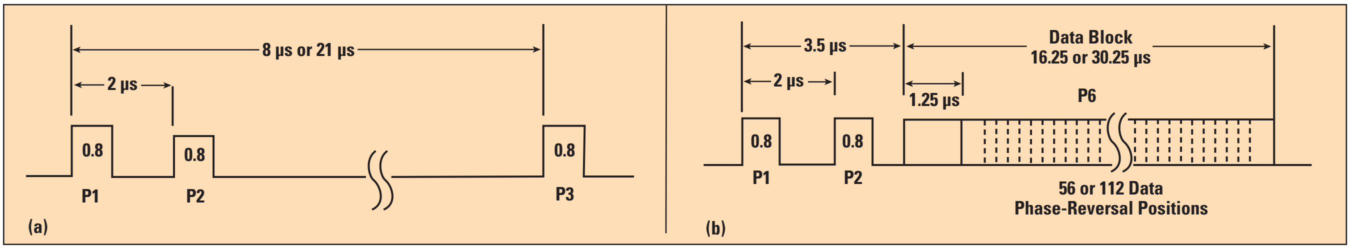


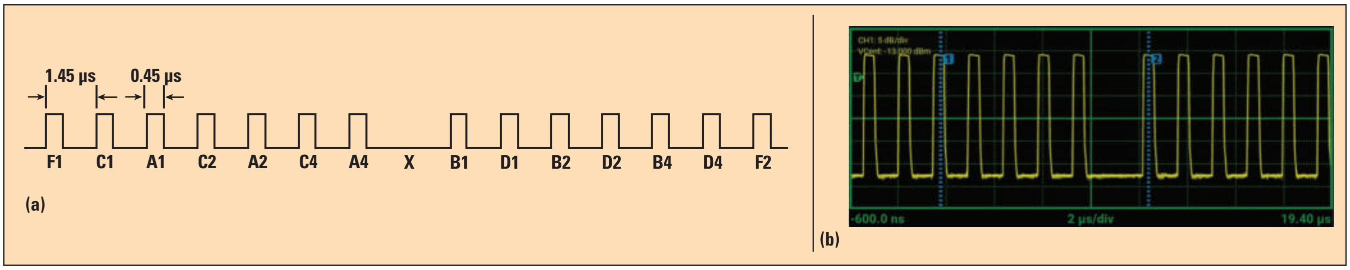
Fig. 2 Modes A and C (a) and S (b) interrogation waveforms.

the system, verify the pulse shape and the timing between pulses, monitor the reflected power from the antenna and watch for anomalies in transmission, such as signal glitches or dropouts. One example of an anomaly is a VSWR spike caused by a faulty connection as an SSR antenna rotates.

The equipment used to make the RF power measurements will depend on the parameters to be measured. For example, while an average power meter may make the nominal power level and VSWR measurements, the SSR would likely need to generate a CW test signal—a special test mode that would take the system offline for maintenance. Otherwise, the pulse waveform may be too complex to accurately measure the average power without advanced triggering and time gating. However, a peak power meter can make pulse measurements, including the pulse shape and timing between pulses, and monitor for waveform glitches or dropouts (see ***Figure 5***).

RF power measuring equipment has traditionally been available in two configurations. The first is the benchtop power meter, which uses a complementary power sensor or sensors connected with an analog cable. The second is the USB power meter, typically a USB power sensor, which integrates most of the functionality of the benchtop power meter in the sensor and eliminates the display and traditional physical buttons and knobs interface. A USB RF power sensor has the advantages of being a smaller and more economical solution with simplified operation and lower measurement uncertainty. However, it also has tradeoffs: a USB sensor requires a computer to perform measurements, either with user-developed software or a graphical user interface.

The SSR measurement scenarios—installation, maintenance and troubleshooting—determine the features and performance priorities for the RF power measurement equipment. For example, portable equipment may be more important during installation, making the USB RF power sensor a good choice. They are small, lightweight and pow-



▲ Fig. 3 Mode A and C reply sequence (a) and waveform (b).

ered through the USB port of a laptop. A maintenance team may want an instrument that can be rack mounted and remotely accessed. Here, benchtop RF power meters may be the best choice, as they are easy to install in equipment racks and often have remote interface options. Troubleshooters may want better performance for diagnostics, such as wide video bandwidth, fast rise time and fine time resolution, as well as a fast trace update rate for the pulse waveform's power versus time, to aid finding anomalies in real-time. Test equipment with leading performance, fast measurement speed and computer processing would meet these requirements.

As noted, the differing test requirements and priorities will determine the instrumentation best suited for the task. This may lead to higher equipment costs to address all the scenarios or using the same equipment for all scenarios and accepting compromises, which may be inefficient and lower productivity. Because of the criticality of SSR for aviation safety, equipment compromises may not be possible, requiring the purchase of test equipment for each scenario. Unfortunately, this has several disadvantages. In an ideal scenario, the installation, maintenance and troubleshooting teams would share the equipment to maximize equipment utilization and return on investment. Purchasing separate equipment for the different teams reduces utilization and obviously adds cost. Different equipment requires multiple procedures for making the same measurements, which can double or triple the documentation and training. Also, an aberrant measurement will lead to uncertainty. Is there an actual issue with the SSR or is it simply a discrepancy between the measured values, caused by the different measurement techniques and equipment?

INTEGRATED MEASUREMENT SYSTEM

For these reasons, the test challenges posed by SSR systems would

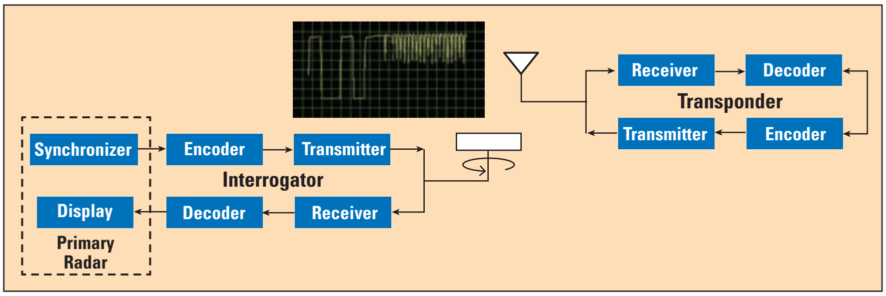


Fig. 4 SSR simplified block diagram.

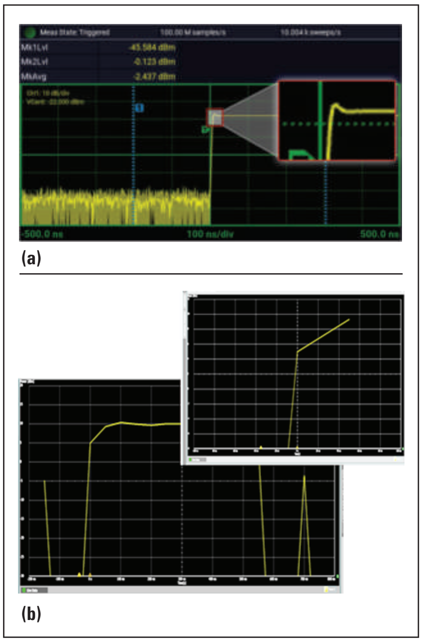


Fig. 5 For accurate measurements, the power meter must have sufficient rise time and resolution (a). Traditional power meters may not (b).

Fig. 6 Pulse train measured on the Boonton PMX40 RF power meter.

benefit from a new approach: using an instrument built with leading measurement technology that combines the utility of the traditional benchtop instrument, the flexibility and performance of USB RF power sensors and the simplicity of a multi-touch display. Used as a benchtop meter with an intuitive touchscreen display, it would provide a standalone solution for capturing, displaying and analyzing peak and average RF power in both the time and statistical domains. The instrument would have the capacity for at least four USB RF power sensors and the capability for independent or synchronized multi-channel measurements of CW, modulated and pulsed signals. The sensors should use standard USB cables, avoiding adapters to convert from specialized connectors to standard USB cables. Each sensor could be used as an independent standalone instrument when disconnected from the benchtop instrument.

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TABLE 1

IDEAL POWER METER VS. TRADITIONAL INSTRUMENTS

Ideal Power Meter	*Traditional Benchtop Power Meters*
Large, intuitive, multi-touch touchscreen display.	Smaller, non-touchscreen display.
Up to four USB RF power sensors.	Up to two traditional analog sensors.
No analog cables between meter and sensor; no calibration.	Measurements must be stopped to perform calibration.
	Traditional USB Power Sensors
Large, intuitive, multi-touch touchscreen display.	Laptop or workstation required for software or manual control.
Internal RF source for verifying sensor operation.	User-provided RF source to verify sensor operation.
Synchronized multichannel measurements with a common time reference.	Common time reference measurements may require external hardware.
Standard LAN interface with optional internal GPIB interface for remote control and use with legacy ATE systems.	Different models for USB, LAN. GPIB interface requires external USB-to-GPIB converter.
Standalone, speeds time to measurement.	Requires installation of drivers, software and applications.

TABLE 2

PERFORMANCE CAPABILITIES

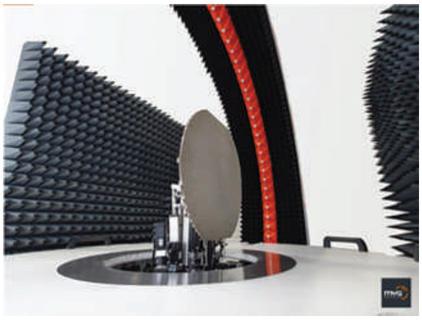
Parameter	*Desired Performance*
Rise Time	3 ns
Minimum Pulse Width	10 ns
Time Resolution	100 ps
Measurement Processing	Real Time
Measurement Speed	100,000/s

The sensors would cover the 1,030 and 1,090 MHz SSR bands with the capability to capture and analyze peak and average power and measure the parameters for evaluating SSR performance. With broad frequency coverage, the sensors would enable testing other radar systems operating at X-, K- and Ka-Band. Using USB RF power sensors makes the instrument essentially futureproof. New sensors can be added to address new requirements, which is not always possible with traditional power meters, as benchtop instruments can limit the performance of the sensors. ***Table 1*** summarizes the desired capabilities of this ideal test system compared with traditional benchtop and USB power measurement options, and ***Table 2*** shows the desired performance of the primary measurement parameters.

An example of an instrument which provides this flexible, high performance power measurement capability for SSR testing is the new Boonton PMX40 RF Power Meter (see ***Figure 6***). It works with Boonton's real-time peak power sensors (RTP5000), real-time true average USB power sensors (RTP4000) and true average connected USB power sensors (CPS2008).

SUMMARY

The installation, maintenance and troubleshooting of SSR systems is challenging. Each test scenario has its own priorities for RF power measurement defining the features and capabilities of the equipment making it. Historically, either different instruments were used, tailored to each measurement task, or the same equipment was used for all, requiring users to compromise test setup and performance. A better approach to solve the challenge uses a single, integrated test system combining the utility of a traditional benchtop instrument, the simplicity of a multi-touch display and the flexibility and performance of USB power sensors.■



Fast, Accurate Aircraft Nose Radome Testing

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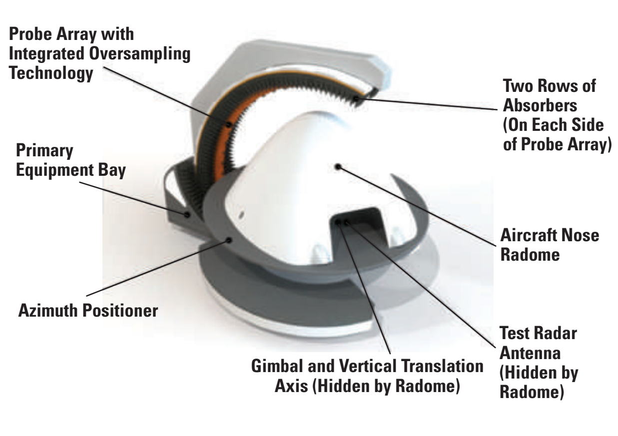

▲ Fig. 1 AeroLab near-field, multi-probe measurement system for testing nose-mounted aircraft radomes.

Evolution within the commercial aircraft market and changes to the most recent RTCA quality standards have led to a new set of challenges for testing nose-mounted radomes after they are repaired. To meet the changing needs of the sector, RTCA-DO-213A now requires testing with higher accuracy, within a shorter time and in less space.

Among the requirements for greater accuracy: assessment of transmission efficiency, beam width and secondary lobe levels through measurements in the Fraunhofer zone, i.e., $r = 2D^2/\lambda$, where r is the measurement distance, D the diameter of the minimum sphere encompassing the antenna under test (AUT) and λ the wavelength. In previous versions of the standard, results were accepted with measurements at shorter distance. However, growing concern that radomes were not accurately assessed and inadequately transparent for the precision radar antennas below their surface drove the need for a compact, accurate and fast measurement solution.

Responding to this, MVG developed the AeroLab to supersede single-probe radome test systems with a faster, more flexible, compact system. The AeroLab is a near-field, multi-probe measurement system designed specifically to test nose-mounted aircraft radomes from 9.3 to 9.5 GHz and within an anechoic chamber no bigger than 4 m × 4 m × 5 m (see ***Figure 1***).

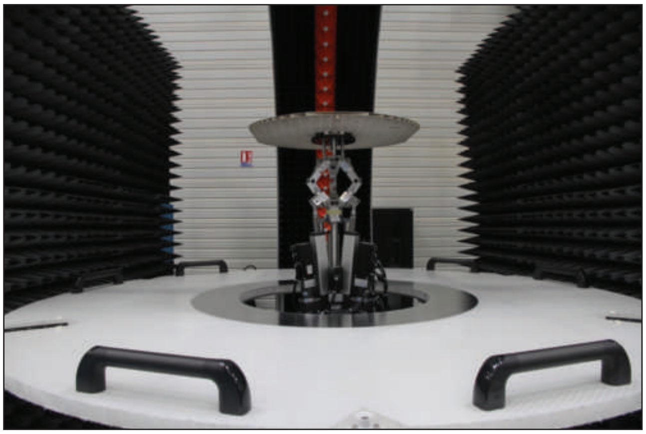

Fig. 2 AeroLab positioners, gimbal and probe array.

Composed of a quarter arch supporting an array of 31 precision, dual-polarized measurement probes, the system uses oversampling to recreate an infinite number of additional virtual probes. The positioning subsystem includes an azimuth positioner for the radome with a vertical translation axis positioner and unique multi-axis gimbal for the AUT. The AeroLab's rapid characterization accurately assesses the radome's transmission efficiency, beam width and sidelobe levels and presents the radiation patterns in 3D.

REDUCING MEASUREMENT TIME

Using multi-probe technology reduces measurement time by more than 50 percent. Near-field measurements must respect the Nyquist criteria, meaning a minimum number of measurement points are required to have sufficient data for comprehensive, accurate characterization. The larger the radome, the more measurement points are necessary. AeroLab has been designed to accommodate various radome sizes and, with its integrated oversampling capabilities, can measure the required number of points on the largest radomes much faster.

As an example, the Airbus A400M radome is one of the largest in use, with a radius of 1.312 m. Applying the Nyquist criteria, at 9.4 GHz, 258 measurement points on just one circle are required, which would take more than four hours for a complete near-field measurement using a single-probe measurement system. The AeroLab can complete the full measurement in 2.3 hours using an array of 16 probes scanning an angle of 95 degrees, with nine oversampling positions. This meets the RTCA-DO-213A accuracy requirements.

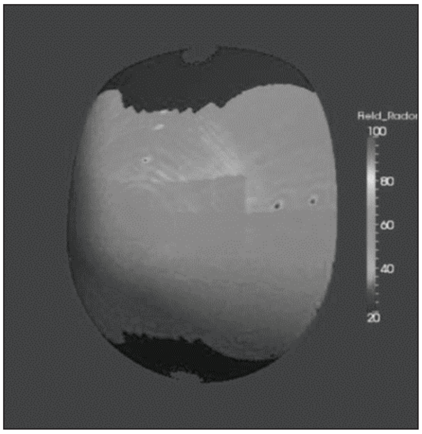

Fig. 3 Cartography reconstruction of the radome surface.

TEST FLEXIBILITY

A multi-axis gimbal adds test setup flexibility. According to the new DO-213A standards, the radar antenna must be positioned on a typical gimbal below a radome under test, replicating the usual antenna and gimbal installed on the aircraft. It is important to know the stacking order of the aircraft gimbal to emulate its typical scanning movements in opposite coordination with the radome positioner.

The AeroLab has a multi-axis gimbal: a vertical translation axis (elevation) positioner for the radar antenna and an azimuth positioner to rotate the radome (see ***Figure 2***). The vertical translation positioner sets the required height of the radar antenna and gimbal below the radome. The asynchronous multi-axis gimbal enables accurate antenna positioning to the specified spherical coordinates at any angle and supporting any stacking order. This testing flexibility accommodates many radome and antenna system combinations.

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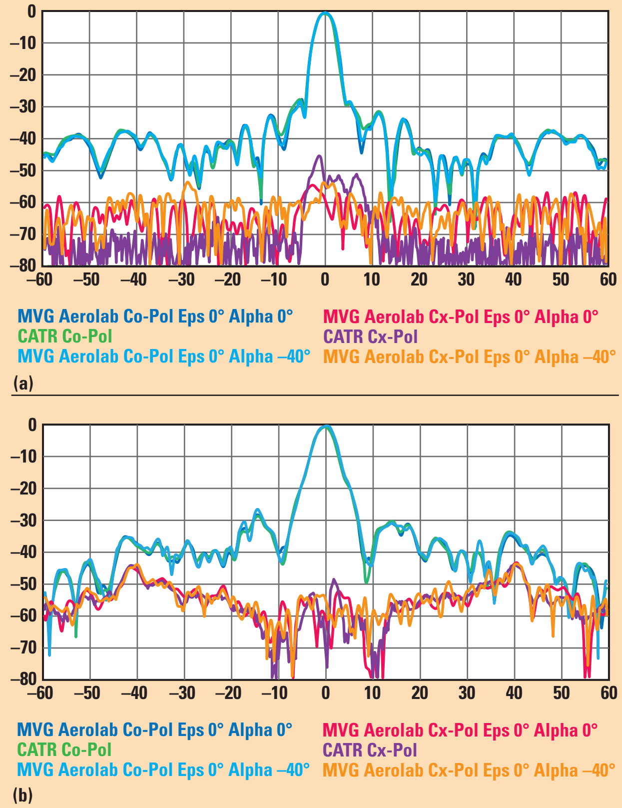

Fig. 4 Comparing AeroLab and CATR co- and cross-polarization pattern measurements at Θ = 0 and –40 degrees with ϕ = 0 degrees (a) and Θ = 0 and –40 degrees with ϕ = 90 degrees (b).

3D MAPPING

The AeroLab enables repair facilities to compute the fields on the radome surface using 3D holographic reconstruction from the near-field measurements, to detect the presence of dielectric patches as small as $\lambda \times \lambda \times 0.1\lambda$ (see ***Figure 3***). The AeroLab acts as a non-destructive control system to diagnose radomes, making repair and test more efficient. In addition to faster test results, 3D holographic diagnostics provide in-depth visualization of any anomalies, yielding more precise repair as well as accelerating the repair and test process.

VALIDATION

The AeroLab has been validated by comparing its results with measurements using a compact antenna test range. ***Figure 4*** shows excellent agreement between the two sets of measurements on a weather radar's antenna patterns at 9.375 GHz. Figure 4a compares the co- and cross-polarization measurements with θ = 0 and -40 degrees and ϕ = 0 degrees. Figure 4b repeats the same measurements with ϕ = 90 degrees.

The AeroLab introduces an innovative, multi-probe, near-field measurement technique for testing aircraft nose-mounted radomes. It provides high accuracy for testing radomes after repair and meets the RTCA-DO-213A standard requirements, enabling repair facilities to decrease the time for repairing and testing commercial aircraft nose-mounted radomes. The AeroLab provides measurement flexibility while keeping the testing footprint to a minimum, and its 3D visualization and diagnostics tool offers the repair process new insight.

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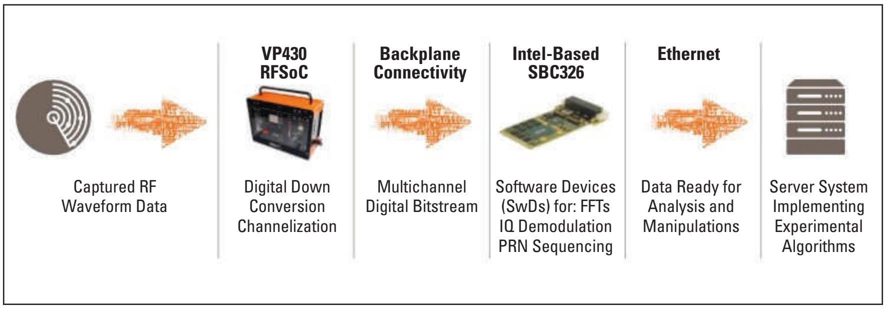
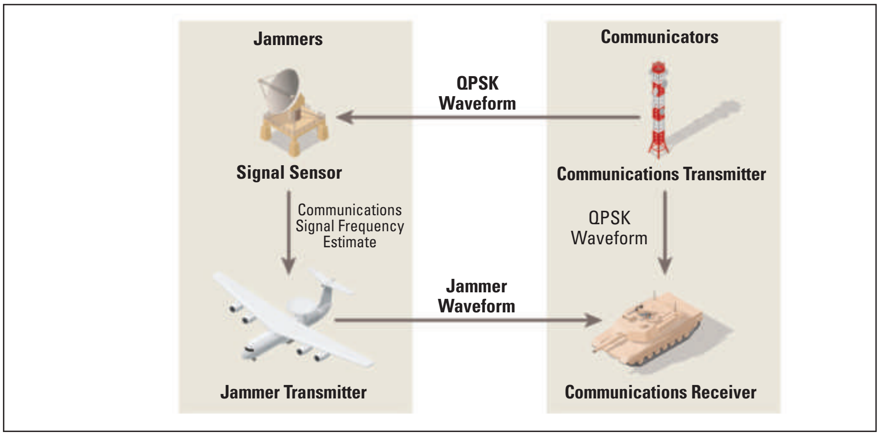


▲ Fig. 1 The combined AMERGINT-Abaco system enables rapid prototyping.



▲ Fig. 2 The modular architecture eases configuring EW and communication systems.

In the dynamic field of electronic warfare (EW) and communication applications, the only constant is change—because governments and militaries face EW threats constantly growing in number and complexity. EW uses the electromagnetic (EM) spectrum to control the spectrum, attack an enemy or block enemy onslaughts. Originating from all directions—air, land, sea or space—the threats target people, radar, communication and more. EW solutions must be ever vigilant, nimble and agile to keep up with the threats or, ideally, stay one step ahead. The way to do so is with technology that:

- Achieves rapid time to market and time to deployment
- Reduces latency
- Cuts cost and program risk

Major disadvantages of the traditional hardware and firmware approach to EW systems are the time it takes to develop a capability and, when it is developed, the long time it must remain operational. You can hope the EW environment will not change during this time—but, of course, it always does.

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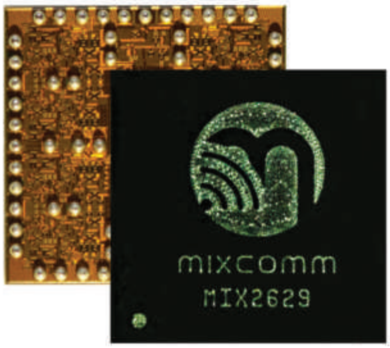

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To meet these challenges, AMERGINT Technologies has integrated its SOFTLINK architecture with Abaco Systems' VP430 RFSoC platform. The result: companies can rapidly build software applications from prototype through full operational capability, applying a mature software implementation ecosystem with agile development methodologies (see ***Figure 1***). The inherent agility of this combined approach means no longer being inhibited by the design and development lifecycle of traditional hardware and firmware-based products.

MODULARITY IS KEY

How did the two companies achieve this capability? Modularity is key. The joint AMERGINT-Abaco solution uses proven, modular software devices. With this approach, nearly any signal, data processing or network transport capability can be designed, configured and deployed, because one large, monolithic application can be broken into small, self-functioning parts, then put together so they function like a monolithic application. Development of a much smaller subset is easier and faster to complete and test.

This is like building things with Legos. Just as your son or daughter can build nearly any airplane, racecar or spaceship out of a tub of modular Lego bricks, the AMERGINT-Abaco technology can build nearly any communication system, data processing or network transport capability using the libraries of modular software devices (SwD) developed over the past 10 years. A key feature of SOFTLINK is the use of code generation technologies that ensure SwDs are interoperable. Much like Lego bricks use a common hole-and-plug pattern, SOFTLINK uses tightly controlled interfaces for data transfer between SwDs to ensure modularity and compatibility.

To meet the needs of EW signal monitoring, companies can change modulation or anything else with the agility of AMERGINT software and the modular hardware from Abaco (see ***Figure 2***). The two companies are bridging all the way to the network and end-user, which is how this modular approach speeds time to market and time to deployment.

REDUCING LATENCY

Lowering latency, the response time of software, is critical in a networked application to achieving optimal performance battling EW threats. Latency is always a big concern companies have with software-based processing, especially signal processing. AMERGINT's latency is in milliseconds—sub-milliseconds in some cases—depending on how the latency is measured. Even with the same hardware, low latency applications can always improve the software. Again, modularity plays an important role. In a monolithic application, any small change may have latency ramifications for the system,

requiring the entire system be tested to assess the impact. With a modular system, only the module is tested.

AMERGINT is providing real-time voice processing for the International Space Station and real-time monitor control of the rockets on the launch pad, proving its ability to meet extremely strict and tight latency requirements. Those same latency and performance metrics are applied to the Abaco platform.

COST AND RISK

A modular software approach also reduces cost and security risk. Compared to a module, an entire system is more costly to analyze, design and test every time there is an issue. It is that simple. The joint AMERGINT-Abaco technology mitigates the risk because no single person is developing the security of the system. With this technology, companies can rapidly validate and deploy new capabilities without enduring complex software development cycles.

By implementing a modular approach combining the AMERGINT SOFTLINK architecture with Abaco's VP430 RFSoC platform, companies developing EW applications can realize the benefits of faster time to market and time to deployment, lower latency and reduced cost and risk—all critical to battling the increasingly complex and multiplying threats.

AMERGINT Technologies is a trusted partner in the space and defense industries, focusing on mission-critical communication and data paths through the capture, processing, transport and exploitation of vital mission data. Abaco Systems is a leader in modular, high performance, open architecture, standards-based rugged embedded computing for demanding applications in defense and industry, offering a broad range of commercial off-the-shelf rugged embedded computing and networking products.

AMERGINT Technologies
Colorado Springs, Colo.
www.amergint.com

Abaco Systems
Huntsville, Ala.
www.abaco.com

From the Department of Defense Electromagnetic Spectrum Strategy, 2013

"DoD must act now to ensure access to the congested and contested electromagnetic environment of the future. Specifically, the Department must adapt how it acquires and uses spectrum resources. Our approach must include acquiring more efficient, flexible, and adaptable systems while developing more agile and opportunistic spectrum operations to ensure that our forces can complete their missions." — Ashton B. Carter, Deputy Secretary of Defense


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Temperature-Conditioned, High-Reliability RF Cables

Fairview Microwave has a new line of low loss, temperature-conditioned, high-reliability RF cable assemblies for avionics, IFF, satellite communications, electronic countermeasures and other high-reliability applications. They operate to 18 GHz with VSWR as low as 1.35:1. Fairview's new series comprises 128 basic configurations from three cable types, providing more than 1,100 part numbers—all commercial off-the-shelf with same-day shipping.

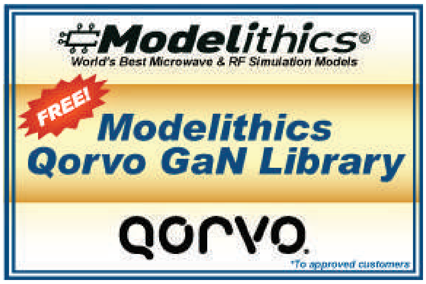
These cable assemblies are constructed with a thermally preconditioned, triple-shielded coaxial cable using an expanded PTFE low loss dielectric. They use captivated stainless steel connectors ¾ TNC, type N and SMA ¾ and are assembled to WHMA-A-620 workmanship criteria and use J-STD soldering processes. The cable assemblies have material lot traceability, are 100 percent tested and ship with a test report. The test flow includes connector gaging, insertion loss, VSWR, dielectric withstand voltage (DWV), workmanship, configuration and marking, with sampled AQL inspections for length and mass.

Together, the combination of stable materials, processing and acceptance testing creates a dependable cable assembly for applications where performance over time is important or the cost of failure is high.

This new line is the second release in Fairview Microwave's series of high-reliability cables designed to address critical applications requiring the highest quality components and workmanship. Like Fairview Microwave's MIL-DTL-17 Hi-Rel cables, this new family is in stock, able to ship the same day.

VENDOR**VIEW**

Fairview Microwave
Lewisville, Texas
www.fairviewmicrowave.com



GaN Library Speeds PA Design

The Modelithics® Qorvo GaN Library is a collection of accurate nonlinear simulation models for Qorvo die and packaged GaN transistors, developed to support power amplifier (PA) designers using a simulation-based design workflow. The library is available for Keysight Technologies' PathWave Advanced Design System and Cadence AWR Design Environment.

While PA designers can use load-pull data to design PAs, load-pull measurements may not be available at the required frequencies. Also, load-pull data may not support optimization and analysis of the PA's linear and nonlinear performance over frequency and output power. Fortunately, when designers don't have load-pull, the models in the Modelithics Qorvo GaN Library enable quick PA design.

Each model in the library is developed through multiple precision measurements at test conditions tailored to the device. The models have features such as variable bias, temperature scaling, self-heating effects and intrinsic current-voltage (IV) sensing. For the die models, bond wire effects can be included or removed. Each model has a datasheet containing the measurement and test-fixture details and measurement validation, with comparisons between modeled and measured data.

Because of the intrinsic IV access in the models, designers can perform waveform and dynamic load-line simulations; waveform engineering enables PAs operating in advanced modes to be designed. The models help determine the optimal load and source impedance targets to achieve the linear and nonlinear performance goals for the design, which can quickly be performed at any frequency within the model's validated frequency range. Designers can also simulate the maximum operating limits.

The Modelithics Qorvo GaN Library is available free for qualified customers.

VENDOR**VIEW**

Modelithics Inc.
Tampa, Fla.
www.modelithics.com
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609 Rev A_P

Wideband HPAs With Flat Output Power

ERZIA Technologies recently announced what it describes as a breakthrough design approach for wideband high power amplifiers (HPA), one achieving both broad frequency coverage and consistent output power across the band. With designs as high as E-Band, these wideband HPAs are among the first to maintain output power in the harshest environments. ERZIA developed these solutions responding to electronic warfare designers expressing frustration with the power variation in wideband systems. Other designers asked for a single HPA capable of serving multi-band applications.

The current lineup of ERZIA wideband HPAs includes models with the following output power-bandwidth combinations: 27 dBm from 1 to 23 GHz, 30 dBm across 2 to 18 GHz, 29 dBm from 15 to 27 GHz, 22 dBm across 17 to 43 GHz, 22 dBm from 24 to 40 GHz, 33 dBm across 26 to 40 GHz, 29 dBm from 33 to 47 GHz and 27 dBm across 75 to 83 GHz.

To illustrate the performance, the Q-Band ERZ-HPA-3300-4700-29 provides 29 dBm saturated output power from 33 to 47 GHz and has 30 dB small-signal gain with ±5 dB gain flatness. Typical VSWR is 1.8:1 and 1.5:1 at the input and output, respectively. The HPA is biased with +12 V and consumes 11 W. It's packaged in a gold plated aluminum housing with 2.4 mm female connectors. The operating temperature range is -45°C to +85°C.

ERZIA offers two locations for customer orders: Santander, Spain, and Arlington, Va. Many ERZIA amplifier products are available from stock at Richardson RFPD. Founded in 2002, ERZIA specializes in the design and production of RF/microwave low noise amplifiers, high power amplifiers and integrated multi-function assemblies.

VENDORVIEW

ERZIA Technologies
Santander, Spain
www.erzia.com

IMS2021 ATLANTA, GA | 6-11 JUNE 2021

International Microwave Symposium

CALL FOR PAPERS

IEEE

MTT-S IEEE MICROWAVE THEORY & TECHNIQUES SOCIETY

IMS

The IEEE Microwave Theory and Techniques Society's 2021 International Microwave Symposium (IMS2021) will be held June 6–11, 2021 at the Georgia World Congress Center in Atlanta, Georgia. You are cordially invited to join us in Atlanta at the intersection of communications, aerospace, automotive, IoT and other emerging technologies to learn the latest developments in MHz-to-THz theories, techniques, devices, systems and applications. IMS2021 is the centerpiece of Microwave Week 2021 which is comprised of three conferences including the RFIC Symposium (www.rfic-ieee.org) and the ARFTG Conference (www.arftg.org)

New this year: IMS will be a hybrid conference – both face-to-face and virtual. More details will be reported soon.

Microwave Week, with more than 8000 participants and 600 industrial exhibits of state-of-the-art microwave products, is the world's largest gathering of radio-frequency (RF) and microwave professionals encompassing MHz to THz ranges and is the most important forum for the latest research advances and practices in the field. IMS2021 offers something for everyone, including the following:

- Technical Program – Oral/Poster Sessions, Workshops, Technical Lectures, and Panel/Rump Sessions
- Connected Future Summit (formerly 5G Summit) showcasing the next-generation wireless technologies for mobility, V2X and IoT
- RF Bootcamp intended for students, engineers, and managers from non-microwave engineering disciplines
- Job Fair for students offering employment opportunities within our exhibitor community
- Exhibitor workshops and application seminars featuring presentations by the preeminent technologists from our exhibitors, explaining the technology behind their products
- Special small business/entrepreneurs' area on the exhibitor floor
- Discounted pricing for students with a SUPERPASS offering access to all conference events
- Competitions for Best Industry Paper, Advanced Practices Paper, Student Paper Award, Three-Minute Thesis (3MT), Student Design Competitions and Student Demonstrations; a Student Demonstration event to showcase the prototypes developed by students and presented in the technical papers
- Project Connect for underrepresented minority engineering students, and the Ph.D. Student Initiative for new students
- Networking events for Amateur Radio (HAM) enthusiasts, Women in Engineering (WIE)/Women in Microwaves (WIM), and Young Professionals (YP)
- STEM Program featuring hands-on activities and exhibitions designed to help students in middle and high school expand their understanding of what it is to be an engineer
- Guest hospitality suite and tour programs for attendees and their guests
- New technical areas on RF to mm-wave physical layer security, quantum electronics and AI/ML for RF and microwave

Paper Submission: Authors are invited to submit technical papers describing original work on RF, millimeter-wave, and terahertz theory and techniques.The deadline for submission is 16 December 2020. A blind review process will be used to ensure anonymity for both authors and reviewers. Detailed instructions on submitting a blind-review compliant paper can be found at www.ims-ieee.org. Papers will be evaluated on the basis of originality, content, clarity, and relevance to IMS.

PAPER SUBMISSION INSTRUCTIONS:

1. All submissions must be in English.
2. Authors must adhere to the format provided in the template, which can be downloaded from www.ims-ieee.org.
3. For regular submissions, authors must submit their paper at www.ims-ieee.org by 11:59 PM Hawaii Standard Time on 9 December 2020. Late submissions will not be considered. The initial submission should be between three and four pages, must be in PDF format, must be double-blind compliant, and cannot exceed 2MB in size. Hardcopy and email submissions are not accepted.

Page Limit: For the initial submission deadline, the paper length should be three pages. Papers longer than three pages will not be considered. The final page length for the papers accepted for publication in the proceeding is three pages.

Paper Selection Criteria: Papers are reviewed by IMS2021 Technical Program subcommittees. The selection criteria will be:

- **Originality:** Is the contribution unique and significant? Does it advance the state of the art of the technology and/or practices? Are proper references to previous work by the authors and others provided?
- **Quantitative content:** Does the paper give a comprehensive description of the work with adequate supporting data?
- **Clarity:** Is the paper contribution and technical content presented with clarity? Are the writing and accompanying figures clear and understandable?
- **Interest to MTT-S membership:** Why should this work be reported at this conference?

Technical Areas: During the paper submission process, authors will choose a primary and two alternative technical areas (see the Technical Areas). The paper abstract should contain information that clearly reflects the choice of the area(s). Author-selected technical areas will be used to determine an appropriate committee for reviewing the paper. The technical areas are divided into five different categories that are used to organize the paper presentation schedule. It is permissible to choose primary and alternative technical areas that are in different categories.

Presentation Format: IMS offers three types of presentation formats. The authors' preference will be honored where possible, but the IMS2021 Technical Program Committee (TPC) reserves the right to place papers in the most appropriate technical area and presentation format.

1. Full-length (20-minute) papers report significant contributions, advancements, or applications in a formal presentation format with questions and answers (Q&A) at the end.
2. Short (10-minute) papers typically report specific refinements or improvements in the state of the art in a formal presentation format with Q&A at the end.
3. Interactive forum papers provide an opportunity for authors to present their theoretical and/or experimental developments and results in greater detail and in a more informal and conversational setting. Papers will be presented in a standard poster format. An IMS2021 poster template will be provided. In addition, authors have the opportunity to display hardware, perform demonstrations, and conduct discussions with interested IMS attendees.
4. Authors of accepted IMS2021 papers must submit a pre-recorded video of their paper presentation. Details of the video presentation will be communicated with the first author of the selected papers.

Notification: Authors will be notified of the decision by 10 February 2021 via the email address(es) provided with the initial paper submission. For accepted papers, an electronic version of the final manuscript (three to four pages, to be published in the Symposium proceedings) along with a copyright assignment to the IEEE must be submitted by 4 March 2021. Authors will be required to submit their presentation slides using the approved template by 20 May 2021, and these will be made available to all attendees at the conference. The submission instructions will also be provided through emails and can be accessed through the Symposium website. The Symposium proceedings will be recorded on electronic media and archived in IEEE Xplore.

Clearances: It is the authors' responsibility to obtain all required company and government clearances prior to submitting a paper. Authors are strongly urged not to wait until the last day to start the paper submission process. Those unfamiliar with the process may encounter paper formatting or clearance issues that may take time to resolve. A statement certified by the submitting author that such clearances have been obtained and a completed IEEE copyright form must accompany the manuscript of each accepted paper. Details regarding clearances will be available during the paper submission process.

Student Superpass: IMS2021 enthusiastically invites participation from students at all levels to attend IMS2021. All students will be offered the opportunity to purchase a SUPERPASS allowing access to the IMS, RFIC, and ARFTG conferences, all workshops, short courses and panel sessions, Connected Future Summit (formerly 5G Summit), and most other events over the course of the week. Student SUPERPASS prices are significantly discounted to encourage student participation.

Student Paper Competition: Eligible students are encouraged to submit papers for the Student Paper Competition. These papers will be reviewed in the same manner as all other contributed papers. First, second, and third prizes will be awarded based on content and presentation. To be considered for an award, the student must be a full-time student during the time the work was performed, be the lead author, and personally present the paper at IMS. During the submission process, the student is required to provide the email address of the faculty advisor, who will be asked upon the selection of the paper to certify that the work is primarily that of the student. Please refer to www.ims-ieee.org for full eligibility details.

Industry and Advanced Practice Paper Competitions: Eligible authors from industry are encouraged to submit papers for the Industry Paper Competition. Additionally, any author who submits a paper on advanced practices may be entered into the Advanced Practice Paper Competition. A paper on advanced practices describes an innovative RF/microwave design integration technique, process enhancement, and/or combination thereof that results in significant improvements in performance and/or in time to production for RF/microwave components, subsystems, or systems. The papers will be evaluated using the same standards as all contributed papers. Please refer to www.ims-ieee.org for details.

Workshops, Technical Lectures, Focus and Special Sessions, Panel and Rump Sessions: Topics being considered for these areas include, but are not limited to, next-generation wireless systems (5G and beyond), emerging RF/microwave applications, latest technologies for RF/microwave measurements, and advances in RFIC technology. Please consult www.ims-ieee.org for a more detailed list of desired topics and instructions on how to prepare a proposal. Proposals must be received by 23 September 2020.

MicroApps and Exhibitor Workshops: Microwave Application Seminars (MicroApps) continue as a forum on the exhibition floor for IMS exhibitors to present the technology and special capabilities behind their commercial products. In addition, the Exhibitor workshops provide IMS exhibitors a unique opportunity to provide more in-depth presentations of technical topics to the attendees. Both events are open to all conference and exhibit attendees. Exhibitor workshops require a nominal fee while MicroApps are free of charge.

Student Design Competition: All eligible students or student teams are invited to consider taking part in the Student Design Competitions (SDCs) during the IMS2021. Please refer to www.ims-ieee.org for full eligibility details, a list of IMS2021 SDCs, and the rules for each SDC.

Student Demonstrations: All students who have submitted papers for oral or interactive forum are invited to participate in the Student Demonstrations during the IMS2021. This will be a unique opportunity for students to showcase prototype hardware that was presented during technical sessions. Please refer to www.ims-ieee.org for full eligibility details.

Three-Minute Thesis (3MT®) Workshop: For eligible students and young professionals, participants with accepted papers are invited to attend a full-day workshop on Sunday on presenting technical work for broader audiences. Following the workshop, students will be invited to enter the 3MT® competition. The 3MT® contestants will make a presentation of three minutes or less, supported only by one static slide, in a language appropriate to a non-specialist audience.

IEEE T-MTT Special Issue: Authors of all papers presented at IMS2021 can submit an expanded version of their IMS papers to the Special Issue of the IEEE Transactions on Microwave Theory and Techniques (IEEE T-MTT) devoted to the IMS2021. Please refer to www.ims-ieee.org for details.

TECHNICAL AREAS:

Electromagnetic Field, Device and Circuit Techniques

1. **Field analysis and guided waves** – Novel guiding and radiating structures, new physical phenomena in transmission lines and waveguides, and new analytical methods for solving guided-wave and radiation problems.
2. **Numerical techniques & CAD algorithms** – Finite-difference, finite-element, integral equation, and hybrid methods for RF, microwave, and THz applications. Simulation, modeling, uncertainty quantification, and design optimization; circuit-, EM-, multi-physics-, and statistics-based, including surrogate modeling, space mapping, and model order reduction techniques.
3. **Instrumentation and measurement techniques** – Theoretically supported and experimentally demonstrated linear and nonlinear measurement techniques for devices and materials, error correction, de-embedding, calibration, and novel instrumentation.
4. **MHz-to-THz device modeling** – Active and passive, linear and nonlinear device and structure modeling (physical, empirical, and behavioral) including characterization, parameter extraction, and validation.
5. **Nonlinear circuit and system analysis, simulation, and design** – Distortion, stability and qualitative dynamics analysis; circuits and systems (C&S) simulation techniques and applications; behavioral modeling of nonlinear C&S (excluding PAs); and nonlinear C&S design and implementations.

Passive Components and Packaging

6 **Transmission-line structures** – Novel transmission-line structures and devices, transmission-line equivalent circuits, artificial transmission lines and metamaterial structures, transmission-line applications for devices and systems.

7 **Passive circuit elements** – Couplers, dividers/combiners, hybrids, resonators, and lumped-element approaches.

8 **Planar passive filters and multiplexers** – Planar passive filters and multiplexers including lumped elements, theoretical filter and multiplexer synthesis methods.

9 **Non-planar passive filters and multiplexers** – Resonators, filters and multiplexers based on dielectric, waveguide, coaxial, or other non-planar structures.

10 **Active, tunable, and integrated filters** – Integrated (on Si, LTCC, LCP, MCM-D, GaAs, etc.), active, and tunable filters.

11 **Microwave acoustic, ferrite, ferroelectric, phase-change, and MEMS components** – Surface and bulk acoustic wave devices including FBAR devices, bulk and thin-film ferrite components, ferroelectric-based devices, and phase-change devices and components. RF microelectromechanical and micromachined components and subsystems.

12 **Packaging, MCMs, and 3D manufacturing techniques** – Component and subsystem packaging, assembly methods, inkjet printing, multi-chip modules, wafer stacking, 3D interconnect, and integrated cooling. Novel processes related to 3D printing or additive manufacturing techniques.

Active Devices

13 **Semiconductor devices and process characterization** – RF, microwave, mm-wave, and THz devices on III-V, silicon and other emerging technologies. MMIC and Si RFIC manufacturing, reliability, failure analysis, yield, and cost.

14 **Low-noise amplifiers, variable-gain amplifiers and receivers** – LNAs, VGAs, detectors, receivers, integrated radiometers, cryogenic amplifiers and models, and characterization methods for low-noise integrated circuits and components.

15 **Signal generation, modulators, frequency conversion, and signal shaping ICs** – CW and pulsed oscillators in silicon and III-V processes including VCOs, DROs, YTOs, PLOs, and frequency synthesizers, signal modulators, and frequency conversion ICs in silicon and III-V processes, such as IQ modulators, mixers, frequency multipliers/dividers, switches, and phase shifters.

16 **Mixed-signal and wireline ICs** – High-speed mixed-signal components and subsystems for transmission; equalization and clock-data recovery techniques for electrical backplanes and electro-optical interfaces. High-speed mixed-signal components and subsystems, including ADC, DAC and DDS technologies.

17 **High-power MHz, RF and microwave amplifiers** – Advances in discrete and IC power amplifier devices and design techniques based on III-V and LD-MOS devices, demonstrating improved power, efficiency, and linearity for HF, UHF, VHF, RF and microwave bands (< 26 GHz). Power-combining techniques for SSPA and vacuum electronics.

18 **Compound semiconductor power amplifiers** – Advances in IC power amplifier devices, design techniques and power combining based on III-V and other compound semiconductor devices demonstrating improved power, efficiency, and linearity for millimeter-wave bands; vacuum electronics for millimeter-wave.

19 **Silicon power amplifiers** – Advances in RFIC and digital power amplifier design and power combining techniques based on silicon CMOS and SiGe processes, demonstrating improved power, efficiency, and linearity for RF, millimeter-wave, and sub-THz bands.

20 **Linearization and transmitter techniques for power amplifiers** – Power amplifier design, characterization, and behavioral modeling; linearization and pre-distortion techniques; envelope-tracking, outphasing and Doherty transmitters for III-V and silicon technologies

21 **Integrated transceivers, beamformers, imaging and phased-array chips and modules** – Design and characterization of complex III-V ICs, silicon ICs, heterogenous systems, and related packaging in the RF to mm-wave including narrowband and wideband designs. Innovative circuits and sub-systems for communications, radar, imaging, and sensing applications. Integrated on-chip antennas and on-package antennas.

22 **Millimeter-wave and terahertz integrated circuits and systems** – Design and characterization of active components including LNAs, PAs, and frequency conversion ICs in silicon and III-V processes and/or packaging in the upper mm-wave and THz regimes; innovative THz circuits systems for communications, radar, imaging, and sensing applications. Demonstrations of on-chip antennas. Novel multi-feed antennas and antenna-electronics co-designs and co-integrations.

23 **Microwave photonics and nanotechnology** – Integrated devices and 1D-2D material-based technology. Multidisciplinary field studying the interaction between microwaves, THz waves, and optical waves for the generation, processing, control, and distribution of microwave, mm-wave, and THz signals. Emerging RF applications of nanophotonics, nanoplasmonics, and nano-optomechanics; nanoscale metrology and imaging.

Systems and Applications

24 **Phased Arrays, MIMO and Beamformers** – Technology advances combining theory and hardware implementation in the areas of phased-array antennas, integrated beamformers, spatial power combining, retro-directive systems, built-in self-test techniques, broadband arrays, digital beamforming, and multi-beam systems. New beamforming, beam-tracking, and spatial notching algorithms, signal processing, and demonstrations.

25 **Radar and Imaging Systems** – RF, millimeter-wave, and sub-THz radar and imaging systems, automotive radars, sensors for intelligent vehicular highway systems, UWB and broadband radar, remote sensing, radiometers, passive and active imaging systems, radar detection techniques, and related signal processing.

26 **Wireless, 5G & Beyond, and New Satellite Communication Systems** – RF, millimeter-wave, and sub-THz communication systems with hardware implementation for terrestrial, vehicular, satellite, and indoor applications, point-to-point links, backhaul and fronthaul applications, radio-over-fiber links, cognitive and software-defined radios, MIMO and full-duplex technologies, and simultaneous transmit and receive (STAR) systems.

27 **Wireless System Characterization and Architectures** – Wireless and 5G & Beyond enabling technologies including but not limited to beamforming techniques, MIMO, massive MIMO, multiple radio access technologies, centralized radio access networks, shared and novel spectrum use, waveform design, modulation schemes, and channel modeling.

28 **Sensing and RFID Systems** – Short range wireless and RFID sensors, gas and fluidic sensors, passive and active tags from HF to millimeter-wave frequency, RFID systems including wearables and ultra-low-power.

29 **Wireless Power Transmission** – Energy harvesting systems and applications, rectifiers, circuits, self-biased systems, combined data and power transfer systems

30 **MHz-to-THz instrumentation for biological measurements and healthcare applications** – Devices, components, circuits and systems for biological measurements and characterizations; biomedical therapeutic and diagnostic applications; systems and instrumentation for biomedical applications; wireless sensors and systems, and implantable and wearable devices for health monitoring and telemedicine.

31 **MHz-To-THz interaction of materials and tissues** – Electromagnetic field interaction at molecular, cellular, and tissue levels; electromagnetic characterization of biological materials and living systems; MRI and microwave imaging. Industrial and scientific, medical applications utilizing microwave power technology; microwave-enhanced chemistry; non-destructive evaluation /testing and material property measurements at nanometer to millimeter. Multi-modal and multi-physical imaging techniques, such as microwave-induced acoustic imaging.

Emerging Technologies

32 **Innovative systems and applications** – Emerging technologies and novel system concepts for RF/microwave applications such as 6G, Internet of Things (IoT), Internet of Space (IoS), wearable computing/communication systems, machine-to-machine (M2M) communication, intelligent transportation, smart cities, smart environment, heterogeneous integration and 3D ICs, silicon photonics and plasmonics.

33 **MHz-to-THz physical layer security** – Devices, circuits, and systems for secured communication and sensing from MHz to THz, addressing general security vulnerability due to electromagnetic emissions, hardware and software co-design for physical layer security, advanced devices and materials to enhance RF, mm-Wave, and THz physical layer security, trusted design, fabrication, packaging, and validation for RF, mm-Wave, and THz electronics;

34 **AI/ML for RF and Mm-Wave** – AI/ML algorithms, implementations, and demonstrations for spectrum sensing, mobile edge networking, and MIMO and array beam operations and management; AL/ML algorithms for design and optimization of RF/mm-Wave components, circuits, and systems; AL/ML algorithms for in-situ sensing, diagnostics, control, reconfiguration, and optimization of MHz to THz communication and sensing circuits and systems.

35 **Quantum devices, systems, and applications** – Cryogenic RF devices, circuits, and systems for general quantum device interfacing and quantum computing applications.

Important Dates

16 September 2020
(Wednesday)
PROPOSAL SUBMISSION DEADLINE
For workshops, short courses, focus and special sessions, panel and rump sessions

9 December 2020
(Wednesday)
PAPER SUBMISSION DEADLINE
All submissions must be made electronically.

3 February 2021
(Wednesday)
PAPER DISSEMINATION
Authors will be notified by email.

3 March 2021
(Wednesday)
FINAL MANUSCRIPT SUBMISSION DEADLINE
Manuscript and copyright of accepted papers

5 May 2021 (Wednesday)
WORKSHOP NOTES SUBMISSION DEADLINE
Electronic upload of workshop notes to the Workshop Organizers.

5 May 2021 (Wednesday)
VIRTUAL PRESENTATIONS SUBMISSION DEADLINE

19 May 2021
(Wednesday)
FINAL PRESENTATIONS SUBMISSION DEADLINE
Electronic upload of presentations in both PDF and PPT format

6–11 June 2021
MICROWAVE WEEK
IMS2021, RFIC 2021, ARFTG, and Exhibition

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Ultra-agile Vector Signal Generator

The APVSG is an ultra-fast-switching vector-modulated signal source, covering a continuous frequency range from 0.01 to 40 GHz. The standard APVSG enables outstanding ultra-fast CW frequency sweeping, chirping, intra-pulse modulation, pulse shaping, all with very low phase noise. A high performance internal I/Q modulator enables customized modulation waveforms and supports dedicated modulation schemes, including avionics modulation. Now also available as multi-channel version APVSG-X with 1, 2, 3 or 4 channels.

AnaPico Ltd.
www.anapico.com

New Integrated RF Transceiver

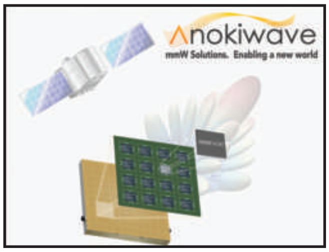
VENDORVIEW

ADRV9002, first in a new family of integrated RF transceivers with two independent transmit paths, receiver paths and RF synthesizers. Operates from 30 MHz to 6 GHz, provides high dynamic range (150 dB/Hz) and best-in-class blocker tolerance for narrow and wideband signals from 12 KHz to 40 MHz. The ADRV9002 is a highly versatile transceiver that enables the user to adjust performance Vs power consumption, incorporates error correction algorithms and advance system features. Ideally suited for challenging portable and networking applications.

Analog Devices
www.analog.com/en/index.html

Silicon ICs for Aerospace and Defense Electronically Steered Antennas

VENDORVIEW



Anokiwave has been providing mmWave technology for A&D applications for over 21 years and is now enabling new capabilities in SATCOM, radar, EW, COMMs and space by leveraging the advances in mmWave Silicon commercial technologies. Its solutions offer small SWaP-C, flexibility to customize for specific needs and a phased IC development approach to meet budgetary constraints. Contact Anokiwave now to discuss your specific A&D needs.

Anokiwave
www.anokiwave.com/a_d/index.html?utm_source=mwj&utm_medium=adsupp&utm_campaign=202009

Shockingly Powerful—Anritsu's New ShockLine™ ME7868A Family of Modular 2-port VNAs

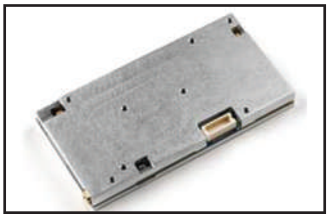
VENDORVIEW

Powered by PhaseLync™ synchronization, the ShockLine ME7868A system enables engineers to conduct full vector S-parameter measurements over wide distances of 100+ meters. By synchronizing two portable ShockLine MS46131As, engineers can connect directly to a DUT to conduct vector transmission measurements, which eliminates the need for long cable runs while improving dynamic range and measurement stability of S-parameter measurements—all at a lower cost. Be a leader—discover how you can get better measurement confidence over distance with Anritsu.

Anritsu
www.anritsu.com

AM9017 18 GHz, 500 MHz Bandwidth Miniature Tuner Module

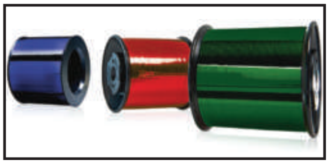
VENDORVIEW



AM9017 is a fully integrated 0.1 to 18 GHz miniature tuner module with 500 MHz instantaneous bandwidth and analog IF output centered at 1 GHz. The superheterodyne tuner provides high performance, low SWaP, includes integrated LO synthesizers and supports multi-channel coherent receiver applications. The module easily mounts to a host circuit board through miniature blind-mate connectors. (1.38" x 2.69" x 0.26" (35.1 x 68.2 x 6.7 mm).

Atlanta Microwave
www.atlantamicro.com/tuners

Flat Enameled Micro Wires



Bruker-Spaleck recently launched the product group "Flat Enameled Micro Wires," which combines weight savings of up to 10 percent, installation space savings in the range of approximately 8 percent, increase the copper filling factor by 8 percent and the possibility to implement additional heat conduction properties. Dimensions in the range for thickness (0.03 to 0.7 mm) and width (0.5 to 2 mm) are possible to miniaturize your products. Several customers are already using the company's flat enameled micro wires in their products/projects.

Bruker-Spaleck
www.bruker-spaleck.com

Comtech PST High Power SSPAs and Control Components

Comtech PST designs and manufactures solid state high power amplifiers, high power control components and receiver protection products. Amplifier products operate to 18 GHz with output power levels to multi-kilowatts. Control components and receiver products operate to 40 GHz and multi-kilowatts power. Comtech's products are utilized in various military and commercial applications and are designed to operate in airborne, ground, mobile and severe military environments. Products include amplifier modules and rack-mounted amplifier systems, high power (T/R and multi-throw) switches, limiters and multifunction assemblies designed to meet specific requirements.

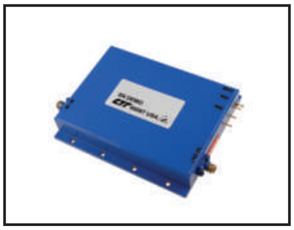
Comtech PST
www.comtechpst.com

CPI Microwave Products

VENDORVIEW

CPI is the world's largest manufacturer of receiver protectors. CPI designs and manufactures a broad range of RF and microwave products for radar, communications, electronic warfare, medical and scientific applications. They also manufacture a broad range of pressure windows and pressure bypass windows. Their products are found in numerous radar systems operated by the U.S. military and militaries around the world. Contact CPI at www.CPII.com or ElectronDevices@CPII.com for high power microwave components.

Communications & Power Industries
www.CPII.com



2 to 18 GHz, 8 W GaN Power Amplifier

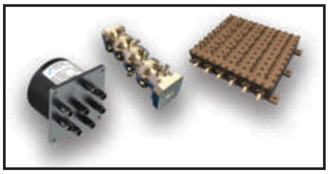
SWaP solutions for many applications including EW, radar, missile guidance and SATCOM. CTT's new solid state GaN-based power amplifier, Model NGX/0218-3946, covers 2 to 18 GHz with 8 W (+39 dBm) of CW power output. The compact size of 4.25 (L) x 3.25 (W) x 0.88 in. (H) offers RF/microwave designers an excellent choice for SWaP solutions in many S through Ku-Band applications, including EW, radar and SATCOM.

CTT Inc.
www.cttinc.com

RF Receivers and Sources for Radar Simulation

dB Control introduced a line of radar simulation systems to test the field-worthiness of EW systems. This new line of RF sources and receivers includes frequency locked oscillators, instantaneous frequency measurement units, digital control units, antenna control units and integrated digital control units. These products can be customized even for the most rigid SWaP requirements and can remain effective across a range of temperature extremes.

dB Control
www.dBControl.com



High Performance Passive Components

VENDORVIEW

Exceed Microwave provides custom high performance passive microwave component designs up to 67 GHz for defense, space and commercial applications. Exceed Microwave is AS9100 certified and ITAR registered, providing high-quality, high performance passive components. The company provides various types of designs, each with its own unique values and are designed and made in U.S. Many of its designs offer extremely high-q factor, allowing very low insertion loss and high power handling.

Exceed Microwave
www.exceedmicrowave.com

18 to 40 GHz, 10 W Solid State Broadband Amplifier

VENDORVIEW

Exodus Advanced Communications 18 to 40 GHz, 10 W+ solid state amplifiers are designed for general EMC testing applications as well as Mil-Std 461(RS103) standards. Exodus Model AMP4037 is a compact 5U design that provides superb RF performance with unprecedented P1dB power as compared to TWT's. It provides 40 dB min-gain, -20 dBc harmonics as well as gain control with < 10 dB noise figure. Optional waveguide output is available.

Exodus Advanced Communications
www.exoduscomm.com

The Right RF Parts, Right Away

VENDORVIEW

Fairview Microwave brings customers a wide selection of off-the-shelf, high-reliability RF components and cable assemblies, available for same day shipment. Its components meet the immediate requirements of engineers around the world for prototype development of military systems and technologies. From hi-rel cable assemblies to power amplifiers, and everything in between, Fairview has you covered. Order online and have your parts shipped today!

Fairview Microwave
www.fairviewmicrowave.com

Stable Reference Sources for Aerospace & Defense

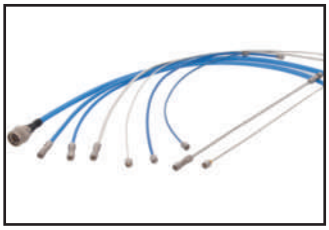
Serving the military and aerospace industries since 1961, Greenray Industries provides high performance oscillators that offer low phase noise, tight stability and low g-sensitivity and function as high precision reference sources for communications, missile guidance, mobile receivers, radar systems, SATCOM and much more. Greenray products include TCXOs, OCXOs, VCXOs and clock oscillators. For more information, visit Greenray online or call (717) 766-0223 and talk to a frequency control expert today.

Greenray Industries Inc.
www.greenrayindustries.com

Holzworth is now ISO Certified

As part of the 2020 Wireless Telecom Group acquisition, Holzworth Instrumentation has been on the fast track for completing its ISO9001 and ISO17025 certifications, which were completed in August 2020. Holzworth has strictly followed ISO standards for the past decade without formal certifications, but it is now official. The ISO9001 and ISO17025 certificates can be downloaded at the new Holzworth website along with datasheets, application notes, white papers and more.

Holzworth Instrumentation
www.HOLZWORTH.com

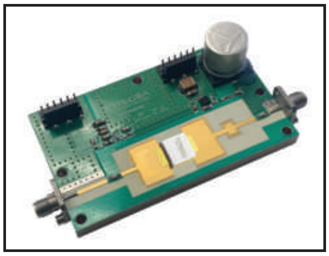


Declare Independence from Thermal Management

VENDORVIEW

The phase-invariant 'CT' line of high performance microwave assemblies from HUBER+SUHNER enables worry-free system performance in phase-critical applications where thermal fluctuations are inevitable. Cable options include low loss, SWaP-C optimized flexible, hand-formable and semi-rigid designs supporting frequencies up to 67 GHz. The CT portfolio from HUBER+SUHNER is available as COTS product pre-terminated with a wide array of MIL-qualified connector configurations with quick-turn customization to suit every application. Join the rest of its customers in declaring your signal's independence from thermal management.

HUBER+SUHNER AG
hubersuhner.com



Pallet Solutions

Integra Technologies Inc., a provider of RF and microwave power semiconductor and pallet solutions for state-of-the-art radar, EW and advanced communications systems, announced a new family of S-Band pallet and transistor products based on Integra's patented Thermally Enhanced GaN/SiC for high performance radar applications. Integra's IGN2729M400R2 pallet solution provides best-in-class gain and efficiency performance delivering 400 W. Integra offers a full selection of RF power solutions ranging from UHF through X-Band.

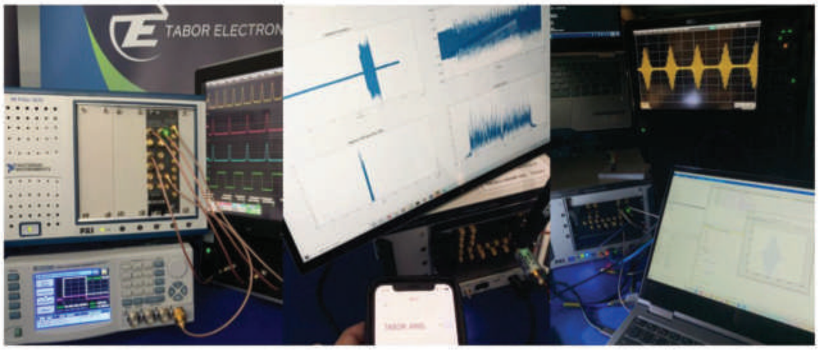
Integra Technologies Inc.
www.integratech.com

Advertorial:

Arbitrary Waveform Transceivers - A Case Study from Tabor Electronics

Real Time Wideband Microwave Measurement Feedback and Control

Solving signal generation challenges in Physics, Communications, Radar/Electronic Warfare and Automotive Sensors.



Automotive Sensing — Wideband Communications — Quantum Physics

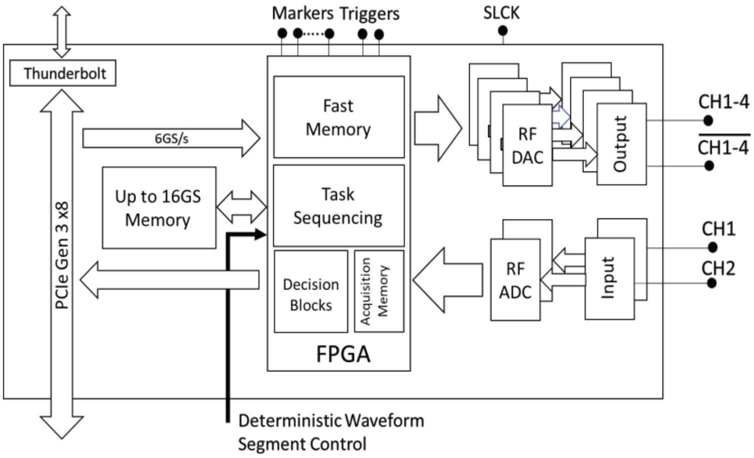
Physics – As you scale your quantum experiment and need to quickly optimize the control waveform, an Arbitrary Waveform Transceiver (AWT) provides the ability to measure process and redefine the control waveform when dealing with very short time intervals.

Communications – If you are designing amplifiers for next-generation wireless communications, such as WiFi-6, 5G, and UWB (Ultrawide Bandwidth) the ability to stimulate, measure, process, and re-stimulate in real time means you can achieve faster and more cost-effective characterization of devices.

Automotive Sensors – With 9GHz of bandwidth, the Proteus AWT allows creation of Linear Frequency Modulated Chirps in excess of 4GHz for mmWave RADAR. For LIDAR, high-resolution target emulation is possible with the industry's lowest trigger jitter performance.

Electronic Warfare – The high-fidelity signal creation ability of the Proteus Arbitrary Waveform Generator (AWG) means you can recreate the finest details of a threat signal. With the added AWT, the ability to receive, process, and adapt the signal based on the environment or countermeasure enhances Test and Evaluation with more realistic scenarios.

What makes an Arbitrary Waveform Generator (AWG) an Arbitrary Waveform Transceiver (AWT)? Fundamentally the Tabor Proteus AWG is a state-of-the-art, complex signal generator enabled by the latest generation of RF DAC technology. When you add a direct RF Analog-to-Digital Converter to the system with a user-programmable FPGA, multiple Nyquist Zone operation, and 9GHz of analog bandwidth, you turn a performance AWG into the new standard of measurement instrumentation.



Block Diagram Overview

At the heart of the AWT is a performance FPGA. This facilitates all the operational modes of the instrument:

- Sequencing waveforms stored in its memory.
- Controlling the powerful RF Digital to Analog Converters (DAC's) with built in IQ modulators.
- Acquiring wideband signals with RF Analog to Digital (ADC) converters.
- Performing high speed measurement processing using a decision block system.
- High speed waveform streaming from an external computer or disk system.

Learn more about the Proteus Family of AWG's and AWT's:
https://proteus.taborelec.com/
Info@taborelec.com
Tabor Electronics' US Solutions Provider:
www.astronicstestsystems.com

Benchtop — PXIe — Desktop

TABOR ELECTRONICS ASTRONICS TEST SYSTEMS

High Power Products

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

Insulated Wire Inc.
www.iw-microwave.com

10 to 50 GHz Dual-Directional Coupler for Military and Commercial Applications

VENDORVIEW

KRYTAR's Model 510050010 dual-directional coupler lends itself to design and test and measurement applications in mmWave and 5G markets. Within a broadband frequency range of 10 to 50 GHz performance ratings include nominal coupling of 10 dB, ±1.8 dB, frequency sensitivity is ±1 dB, insertion loss is less than 3 dB, directivity is greater than 10 dB and maximum VSWR is 1.8. The coupler comes with 2.4 mm female connectors and measures just 2.24 (L) x 0.40 (W) x 0.62 in.(H).

KRYTAR
https://krytar.com/products/couplers/dual-directional-couplers/dual-directional-coupler-510050010/

Data Secure Power Meter

VENDORVIEW

LadyBug Technologies' new LB5944A, self-contained, 1 MHz to 44 GHz True-RMS power sensor features two security options to protect user information. Option MIL disallows user data storage. Each time the sensor is powered it starts at the factory default settings. Option secure erase allows users to take advantage of the sensor's storage features such as offsets, cal tables and unattended operation. Secure erase can be utilized to securely erase all user information prior to removing the sensor from a secure environment.

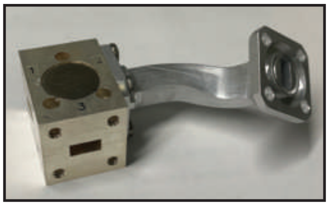
LadyBug Technologies
www.LadyBug-Tech.com

Pushing the Technological Barrier Since 1961

Are you in need of RF switches with high-rel military and airborne requirements? Logus Microwave is comprised of UAV Switch specialists who engineer the world's top cutting-edge designs. Logus features proven reliability custom coaxial switches (SPDT, DPDT, SPMT), waveguide switches (WR10 through WR975) and much more. Trust in a family-owned company that has been pushing the technological barrier since 1961. Please contact Logus Microwave below for more information.

Logus Microwave
www.logus.com

High Performance Components Since 1988



M Wave Design Corporation has been supplying low loss, high performance Ferrite and Waveguide components since 1988. The company specializes in high-mix, low volume microwave components. The unit illustrated above was a system design "afterthought" by a customer who ran out of space. It solid modeled and built the WR28 full-band circulator and waveguide run into their package constraints and "on time and in budget." M Wave Design Corp. designs and manufactures a broad range of custom passive microwave hardware from 100 MHz to 50 GHz.

M Wave Design Corp.
https://mwavedesign.com

MCV Microwave High Performance Exact Shape Ceramic Filters

VENDORVIEW

MCV Microwave, a leader in high-q dielectric resonator, substrate and filter is offering high performance exact shape ceramic filters to space, aerospace defense and military industries. These bandpass filters exhibit low passband insertion loss, sharp roll off, maintain ultimate rejection, exact shape with matched delay. For example, a 2,300 MHz filter has ~0.5 dB insertion loss over 25 percent bandwidth and 40 dB near band rejection up to 5 to 6 GHz Wi-Fi band in 2" x 0.6" x 0.4" package, as shown.

MCV Microwave
www.mcv-microwave.com

Newly Designed MUOS/UHF Products

For 50 years, Metropole Products has consistently introduced new solutions to markets that enable military, government and commercial clients to achieve success. Metropole expert engineers offer decades of proven experience in design, development, manufacturing and testing of microwave and RF components. Its state-of-the-art technologies are critical components to the satellite, radar, communications and electronic warfare systems of the military. Contact Metropole Products today to discuss their newly designed MUOS/UHF products.

Metropole Products
https://metropoleproducts.com

MIcable Releases New User-Friendly Passive Component Catalog

MIcable is excited to start with the release of a new web and new passive component catalog loaded with features for improved user experience and look-up accuracy. The new passive component catalog introduces power divider/combiner, coupler, hybrid and adaptor with the frequency range of 0.3 to 67 GHz. With its new responsive design, you can find the parts you need from a desktop, laptop or mobile device easily. The web catalog can be accessed directly at: http://en.micable.cn/uploadfile/file/wyqjsc.pdf

Fuzhou MIcable Electronic Technology Co. Ltd.
www.micable.cn

Mini-Circuits Updates Calculator App

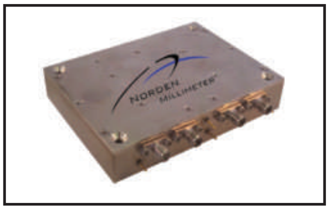
VENDORVIEW

The latest version of Mini-Circuits' Microwave Calculator app now includes 31 RF/microwave calculations commonly used by engineers in the lab and in the field. New functions include frequency to wavelength conversion, voltage divider circuit analysis, Ohm's Law circuit analysis and more. The app also features a fully redesigned user interface for improved navigability and user experience. Mini-Circuits offers the Microwave Calculator app for free.

Mini-Circuits
www.minicircuits.com

Norden Millimeter's 18 to 40 GHz Down-Converter

VENDORVIEW



The NDC1840I0217N14 is an 18 to 40 GHz down-converter, part of Norden Millimeter's expanding line of catalog and custom frequency converters. This product is available with a 0.5 to 18 GHz bypass channel and hermetic case. Custom designs incorporate temperature compensation, variable gain and meet military environmental requirements. Norden can also provide RF and microwave assemblies which include frequency conversion, switch matrices, amplifiers, LNAs and filters.

Norden Millimeter
www.NordenGroup.com

MILITARY & AEROSPACE
COMPANY SHOWCASE

Pasternack: The Engineer's Immediate RF Source

PASTERNACK an INFINITE brand

VENDORVIEW

Pasternack, an Infinite Electronics brand, is a leading global supplier of in-stock, ready-to-ship RF, microwave and mmWave components, assemblies and devices. Pasternack offers over 40,000 popular and hard-to-find items across 107 categories of interconnect, passives, actives and antennas. Pasternack's 99.4 percent in-stock availability allows them to ship your products the same day they are ordered, with no minimum order size required. Visit them online, where you will find detailed datasheets, CAD drawings and a host of additional resources.

Pasternack
pasternack.com

A Different Type of Electronic Packaging

Pixus Technologies offers embedded computing chassis platforms and electronics enclosures with superior quality and competitive prices. Pixus specializes in rugged and commercial OpenVPX/SOSA backplane-based systems including versions for RF via VITA 67. The company also offers ruggedized versions of the Ettus Research (a NI brand) X310 family of SDRs. Pixus also provides unsurpassed thermal management solutions, creative design innovations, backplane design and subsystem integration expertise. This powerful combination results in the premier value in the industry for electronics packaging.

Pixus Technologies
https://pixustechnologies.com/

P16T-100M52G-100-T-DEC

VENDORVIEW

PMI Model P16T-100M52G-100-T-DEC is a SP16T absorptive switch that operates from 0.1 to 52 GHz. This model offers a typical insertion loss of 16 dB while maintaining a typical isolation of 70 dB. It operates at 20 dBm CW, 100 ns switching speed and is controlled with TTL logic. Power requirements are +12 VDC at 800 mA max, -12 VDC at 720 mA max. Other features include 2.4 mm connectors, nickel plated finish and 12.00" x 5.50" x 0.65" package size.

Planar Monolithics Industries
www.pmi-rf.com/product-details/p16t-100m52g-100-t-dec

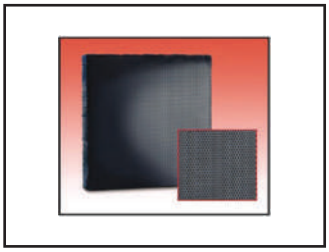
RF POWER DEVICES

We understand what's at stake at the end of a radar signal

At Integra, we've spent decades building a vast RF power library with breakthrough products for radar delivering up to 85% efficiency with best in class power and efficiency. We know the challenges you are facing and we're here to help. Integra can rapidly optimize a cost-effective semicustom or custom RF pallet solution for your exact system needs.

Learn more @ Integratech.com

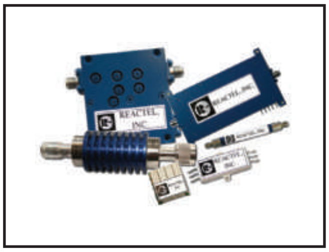
INTEGRA



C-RAM HC Series

C-RAM HC is a series of radar absorbing products made from Nomex/phenolic or honeycomb with a proprietary lossy coating. The hexagonal open cell structure provides a high strength-to-weight ratio, making C-RAM HC an ideal material for aircraft parts, such as fairings, covers and leading edges, which must combine strength, lightweight and low radar reflections. Honeycomb is also ideal for cavity backed spiral antenna applications. The open cells permit forced air cooling, allowing high power applications. Custom composite shapes are also available per customer drawing.

PPG Cuming Microwave
www.cumingmicrowave.com



Filters, Multiplexers and Multifunction Assemblies

VENDORVIEW

Reactel manufactures a line of filters, multiplexers and multifunction assemblies covering up to 50 GHz. From small, lightweight units suitable for flight or portable systems to high power units capable of handling up to 25 kW, connectorized or surface mount—Reactel's talented engineers can design a unit specifically for your application.

Reactel
www.reactel.com

Brochure for Aerospace, Security & Defence

Rosenberger provides a comprehensive product portfolio of highly-reliable interconnect components and devices which is in accordance with the stringent requirements of MIL-PRF 39012, DIN EN 9100 or ESCC Certification of the European Space Agency. A new brochure showcases Rosenberger's wide product range qualified for aerospace, security and defense applications including RF coaxial components, microwave components and cable assemblies, RF test and measurement products or fiber optic connectivity components. PDF version is available for download from the Rosenberger website, print copies can be ordered at marketing@rosenberger.com.

Rosenberger
www.rosenberger.com/en/products/aerospace_defence

SemiDice
Wafer & Die Products

Aerospace & Defense Bare Die Users!

SemiDice is the preferred global wafer and bare die component supplier to the A&D industry. SemiDice is the only global wafer processor with a High Reliability Division dedicated to providing bare die for high reliability, military, aerospace and robust industrial applications. Its internal capabilities include, but are not limited to, dicing, upscreening, testing, visual inspection and long-term storage. Visit www.semidice.com for more information.

SemiDice
www.semidice.com

An RF Test Bench in Your Backpack

Signal Hound RF test equipment is affordable and compact enough to fit in a backpack—perfect for portable, comprehensive RF analysis on the go. Features include: small, lightweight RF spectrum analyzers ranging from 4.4 to 20 GHz; USB-powered signal generators that can fit in your pocket; Powerful, Spike™ spectrum analysis software that runs on a laptop, offers full device control and a variety of analysis mode; connects to probes, antennas and a variety of signal sources.

Signal Hound
https://signalhound.com/content/managed/bench-in-backpack/

SPINNER Rotary Joints for ATC Radar Systems

VENDORVIEW

To dependably track aircraft movements and ensure smooth, orderly traffic while minimizing accidents, it is essential to deploy state-of-the-art technology with components that leverage the power of digitization. SPINNER has launched a new generation of future-proof RF rotary joints that deliver a number of major benefits. They work contactlessly, which eliminates friction and makes them virtually maintenance-free. Made from high quality, precision-made mechanical components, the new joints feature real-time gigabit-volume Ethernet with high-quality signal transmission.

SPINNER
www.spinner-group.com/atc

Planar Monolithics Industries, Inc.

Integrated RF/Microwave Assemblies & Modules

PMI offers the highest quality multi-function modules and integrated microwave assemblies for industrial and military applications in frequency ranges up to 50 GHz. Built to your specifications with functions that include amplification, attenuation, filtering, switching, phase shifting, power detection, modulation, coupling, limiting and digital/analog control. PMI offers many other standard models with various options that are available at: https://www.pmi-rf.com/categories/integrated-mic-mmic-assemblies

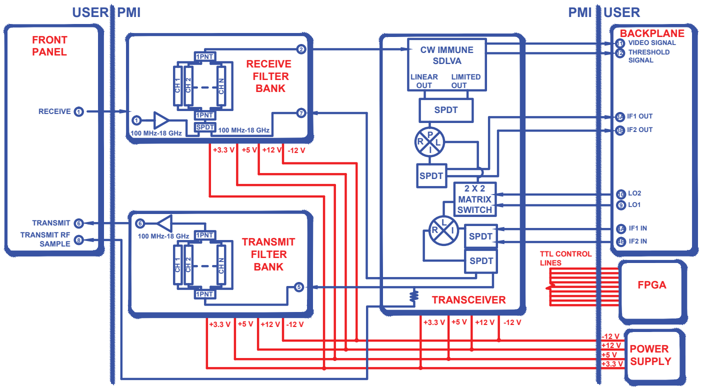
- Amplifiers - Solid State
- Attenuators - Variable/ Programmable
- Bi-Phase Modulators
- Couplers (Quadrature, 180, Directional)
- Detectors - RF / Microwave
- DLVAs, ERDLVAs & SDLVAs
- Filters & Switched Filter Banks
- Form, Fit, Functional Products & Services
- Frequency Converters
- Frequency Sources
- Frequency Discriminators & IFM
- Frequency Synthesizers
- Gain & Loss Equalizers
- Integrated MIC/MMIC Assemblies (IMAs)
- IQ Vector Modulators
- Limiters - RF / Microwave
- Log Amps
- Miscellaneous Products
- Monopulse Comparators
- Multifunction Integrated Assemblies (IMAs)
- Phase Shifters & Bi-Phase Modulators
- Power Dividers/Combiners (Passive & Active)
- Pulse Modulators - SP1T
- Rack & Chassis Mount Products
- Receiver Front Ends & Transceivers
- Single Side Band Modulators
- SMT & QFN Products
- Switch Matrices
- Switch Filter Banks
- Switches - Solid-State
- Systems - Radar Sense & Avoid
- Systems - Fly Eye Radar
- Threshold Detectors
- USB Products

PTRAN-100M18G-SDLVA-SFB-3UVPX-10HP-MAH-MX

https://www.pmi-rf.com/product-details/ptran-100m18g-sdlva-sfb-3uvpx-10hp-mah-mx

PMI Model No. PTRAN-100M18G-SDLVA-SFB-3UVPX-10HP-MAH-MX is a transceiver that covers the frequency range of 100 MHz to 18.0 GHz and fits into a 3U open VPX form factor utilizing the high speed VITA 67 RF connector. This unit up-converts a 100 MHz to 4.0 GHz transmit signal to the 2.0 to 18.0 GHz range and down-converts a 100 MHz to 18.0 GHz received signal to the 100 MHz to 4.0 GHz intermediate frequency range for analog to digital conversion. A receive filter bank incorporates a 2-way absorptive switch to select an input, along with two 6-way switches allowing one of six filter paths to be chosen. A filter bank is used also on the transmit path, with two 6-way switches allowing one of six filter paths to be chosen. The unit is designed to attach to an FPGA controller card allowing for a total solution in a 10 HP (2”) form factor.

- 100 MHz to 18.0 GHz Transceiver
- Integrated Up and Down Converters
- IF up to 4 GHz
- Time Gated SDLVA for Pulse Blanking
- -80 to -10 dBm Input Dynamic Range
- Customizable Switched Filter Banks
- 0 to +10 dBm Transmit Power
- 100 ns Switching Speed
- Less than 30W Power Consumption
- Over 100 dB of Isolation between Tx and Rx
- 300% smaller than individual single function components
- Fits into a 3U open VPX form factor utilizing the high speed VITA 67 RF connector.
- CW Immunity
- Unit Size: 6.299” x 3.937” x 1.915”

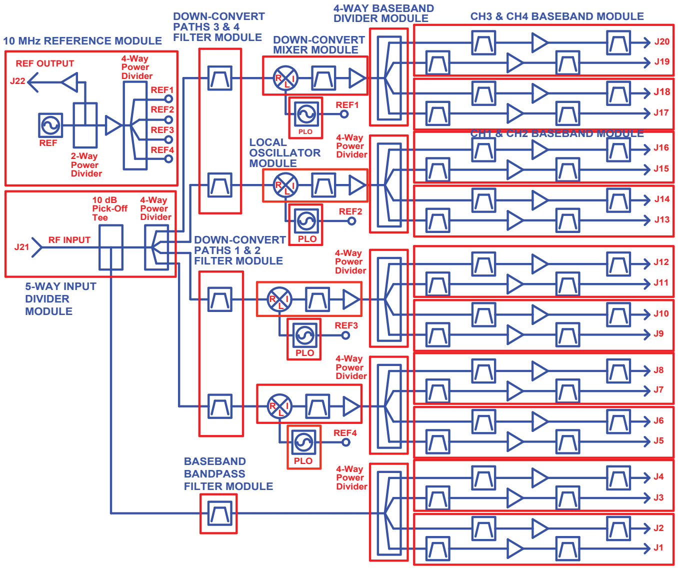


PRX-20-1G18G-850M-SFF

https://www.pmi-rf.com/product-details/prx-20-1g18g-850m-sff

PMI has developed a channelized receiver covering 1 to 18 GHz instantaneously in 20 channels. IF frequencies between 1 and 4.4 GHz are output and ready to be digitized. The receiver is designed to cover a 60 dB dynamic range using a built-in internal 10 MHz reference to lock the internal LO’s used in down-converting the signal into the necessary frequency bands. The reference is also output at a +20 dBm level to be used for synchronization.

- 1.0 to 18.0 GHz Channelized Receiver
- -58 to +2 dBm Input Dynamic Range
- 60 dB Output Spurious Free Dynamic Range
- 20 Output Channels, IF Frequencies of 850 MHz BW from 1 to 4.4 GHz (4 Filtered Thru Path and 16 Down-Converted Paths)
- Overall Gain of 0 dB +/-3 dB
- 10 MHz Output Reference with output stability of +/-1 PPM
- Input and Output SMA RF Connectors and 9 Pin D-Sub male for Power
- Less than 50 W Power Consumption
- Unit size : 10.0” x 8.0” x 3.0”



West Coast Operation:
4921 Robert J. Mathews Pkwy, Suite 1
El Dorado Hills, CA 95762 USA
Tel: 916-542-1401, Fax: 916-265-2597

East Coast Operation:
7311-F Grove Road
Frederick, MD 21704 USA
Tel: 301-662-5019, Fax: 301-662-1731

sales@pmi-rf.com • www.pmi-rf.com

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Proteus—the First Arbitrary Waveform Transceiver

Proteus combines a high speed arbitrary waveform generator, a high speed digitizer and a user programmable FPGA, in a single instrument. Based on a PXIe platform, the modular, compact and cost-effective system offers various configuration options and an innovative task oriented programming for application specific solutions. Including technologically advanced options such as real-time data streaming and fast feedback loop, Proteus enables you to understand and emulate every threat, enhancing your test and evaluation strategy.

Tabor Electronics
https://proteus.taborelec.com

SALES REPRESENTATIVES

Eastern and Central Time Zones
Carl Sheffres
Publisher
(New England, New York, Eastern Canada)
Tel: (781) 619-1949
csheffres@mwjournal.com

Michael Hallman
Associate Publisher
(NJ, Mid-Atlantic, Southeast, Midwest, TX)
Tel: (301) 371-8830
mhallman@mwjournal.com

Pacific and Mountain Time Zones
Brian Landy
Western Reg. Sales Mgr.
(CA, AZ, OR, WA, ID, NV, UT, NM, CO, WY, MT, ND, SD, NE & Western Canada)
Tel: (831) 426-4143
blandy@mwjournal.com

International Sales
Richard Vaughan
International Sales Manager
Tel: +44 207 596 8742
rvaughan@horizonhouse.co.uk

Germany, Austria, and Switzerland (German-speaking)
WMS.Werbe- und Media Service
Brigitte Beranek
Tel: +49 7125 407 31 18
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 International
Tel: +82 2 481-3411
yschinn@horizonhouse.com

China
Shenzhen
Michael Tsui
ACT International
Tel: 86-755-25988571
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.
Nishiiko, Adachi-Ku
Tokyo 121-0824, Japan
Tel: +81 3 5691 3335
amskatsu@dream.com

Ed Kiessling • Traffic Manager • Tel: (781) 619-1963 • ekiessling@mwjournal.com

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At European Microwave Week

EuMA | Microwave Journal

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A one-day focused Forum addressing Space Situational Awareness

Programme:

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

10:10 – 10:50 **Coffee Break**

10:50 – 12:30 **Space Situational Awareness**

12:40 – 13:40 **Strategy Analytics Lunch & Learn Session**
Space Situational Awareness in the New Space Era
Eric Higham, Strategy Analytics

13:50 – 15:30 ***Microwave Journal* Industry Session**
The Microwave Journal Industry Session will be made up of several company presentations that illustrate the technological innovation that industry is developing for Space Situational Awareness related topics.

15:30 – 16:10 **Coffee Break**

16:10 – 17:50 **Executive Round Table Forum: Space Situational Awareness**

17:50 – 18:30 **Cocktail Reception**

The opportunity to network and discuss informally the issues raised throughout the Forum.

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