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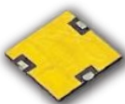
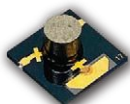
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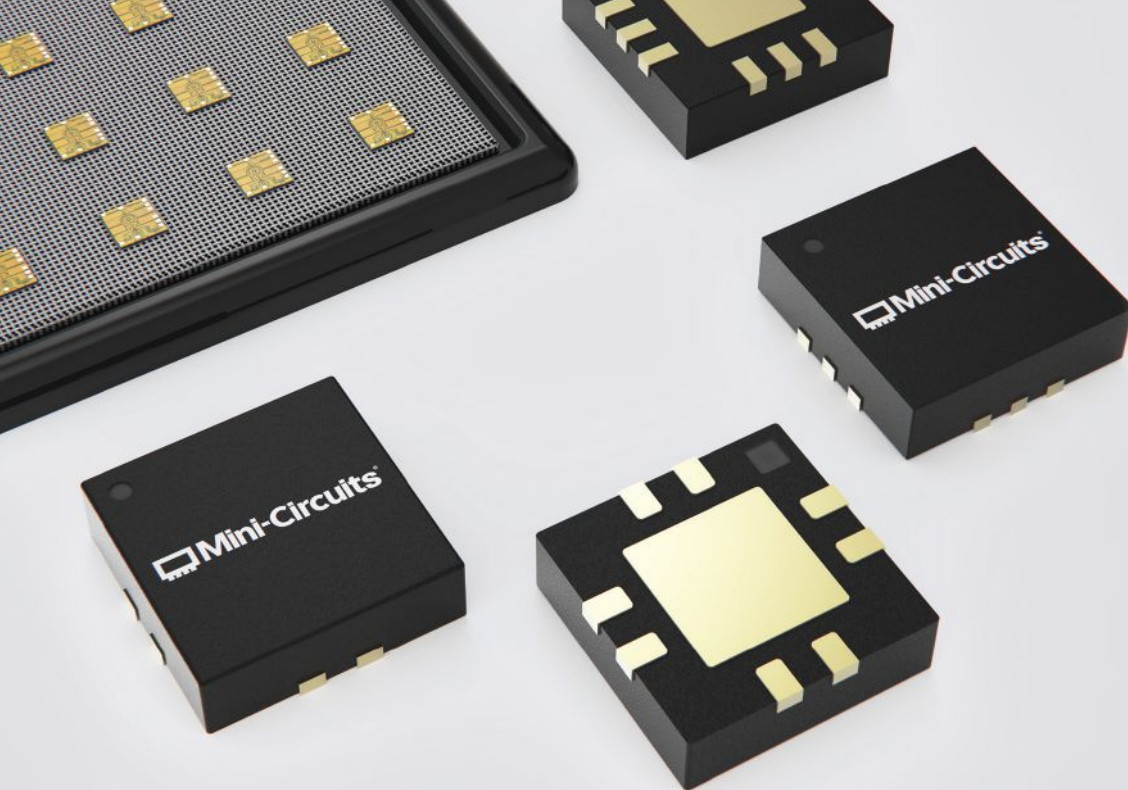
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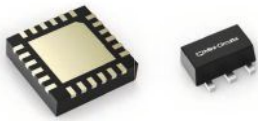


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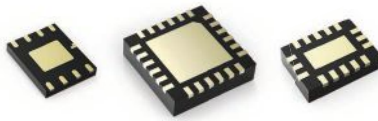
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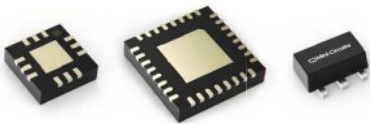
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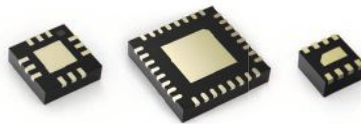
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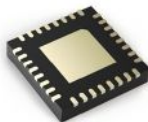
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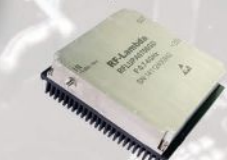
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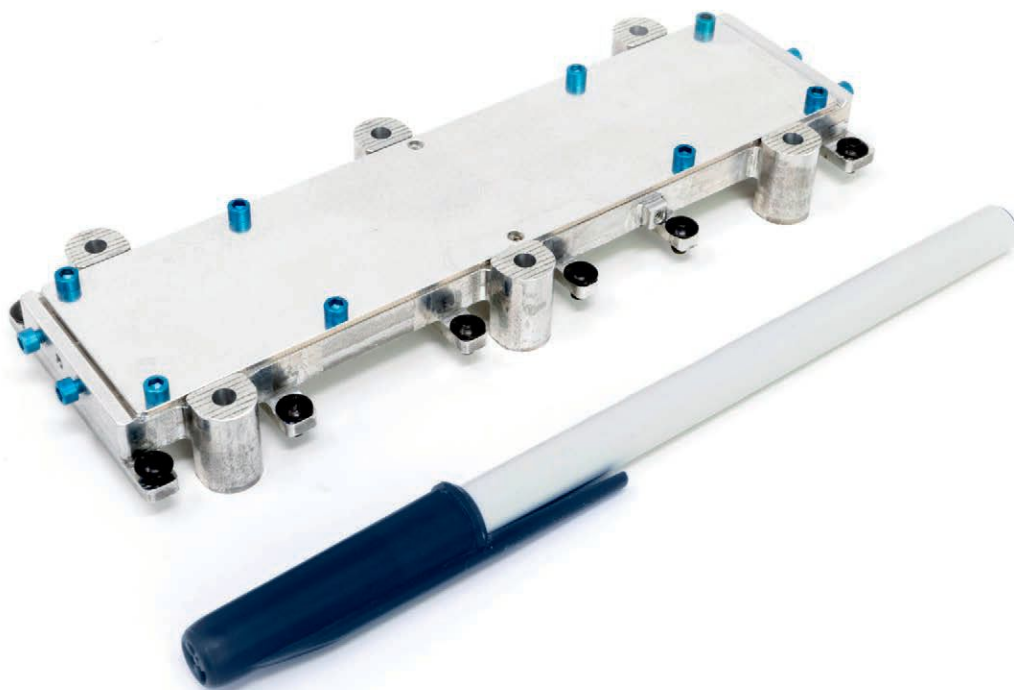
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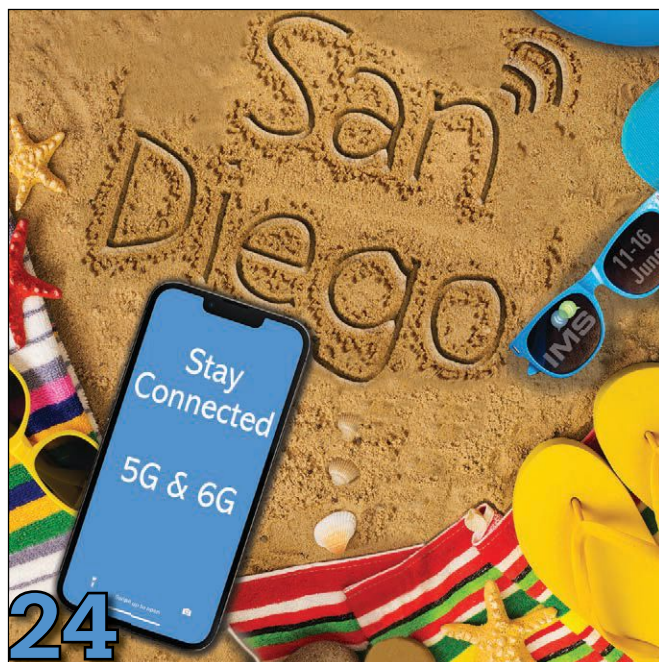


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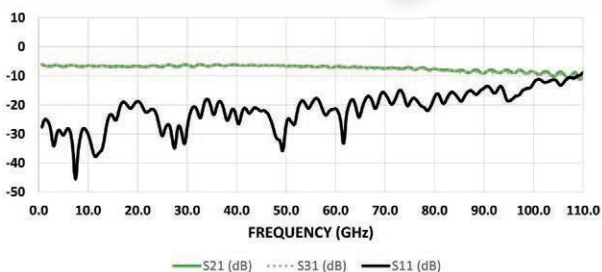
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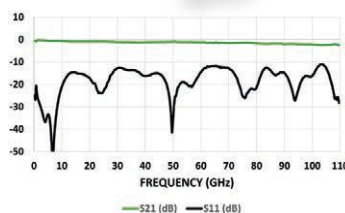
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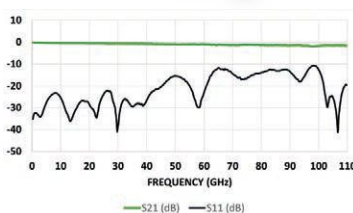
HL9449 Bias Tee

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HL9439 DC Block

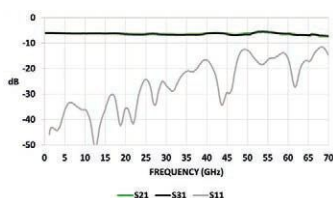
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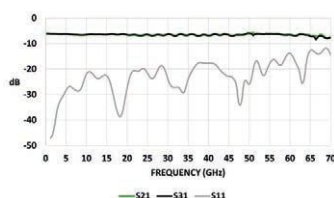
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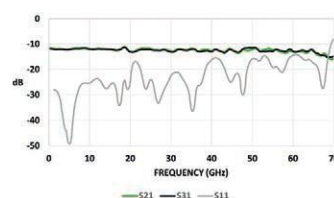
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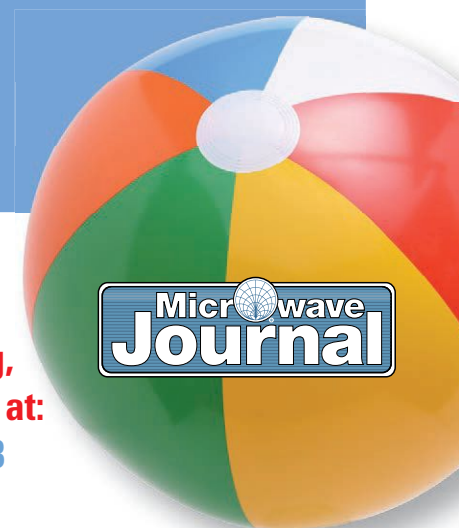
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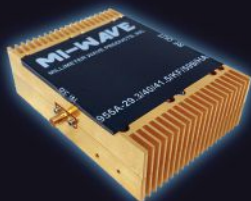
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970980A-35.61 /KF	Up-Down	35.61 GHz	Ka-Band	1,2,3,4
970B-38.25/387S	Down	38.0-38.5 GHz	Q-Band	1,2,3,4
970A-39.65/599	Down	39.4-39.9 GHz	Ka-Band	1,2,3,4
980B-43.25/387S	Up	42.0-43.5 GHz	Q-Band	1,2,3,4
970U-47.2/51 .4/1.85MMF	Down	42.2-51.4 GHz	U-Band	1,2,3,4
970980U B-47.2/51 .4/1.85MMF	Up-Down	47.2-51.4 GHz	U-Band	1,2,3,4
970E-70.4/86.4/387	Down	70.4-86.4 GHz	E-Band	1,2,3,4
970V-62.5/385	Down	65-75 GHz	E-Band	1,2,3,4
970980W-20/387S	Up-Down	95-100 GHz	V-Band	1,2,3,4

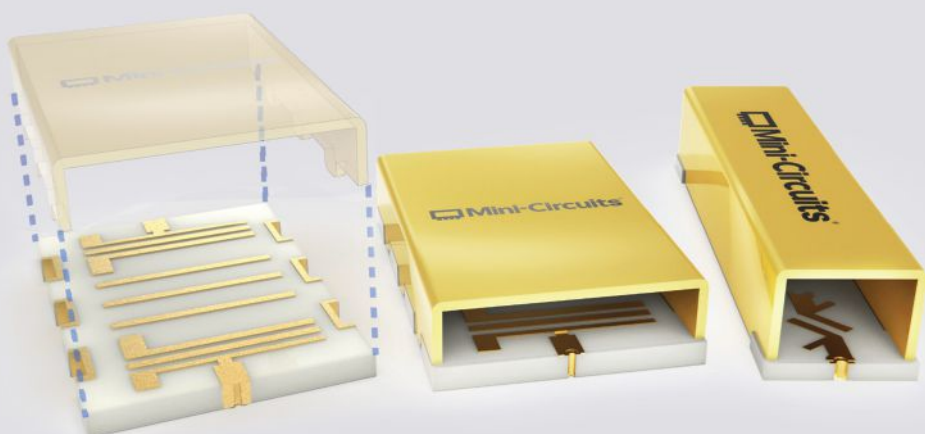


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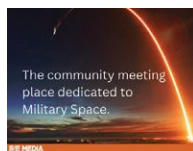
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Eric Higham, Microwave Journal Technical Editor



Laying the Foundation for Quantum Applications: Max Planck

Quantum technology is an emerging field of physics and engineering that promises to fundamentally change the way we do things. As we prepare for IMS2023 and the latest developments in quantum, photonic and wireless applications, it seems appropriate to commemorate the life of the man credited with what the Nobel Prize Organization claimed is a turning point in the history of physics.¹ Max Planck is widely recognized as the originator of quantum theory and for introducing Planck's Constant.

Planck was reportedly a gifted musician but chose to pursue physics and focus on thermodynamics despite an early professor at the University of Munich telling him "In this field, almost everything is already discovered and all that remains is to fill a few holes."²

In 1889, Planck succeeded Gustav Kirchhoff, creator of the famous Kirchhoff's Voltage and Current Law. Planck remained in that position until his retirement in 1926, where he began investigating the problem of

black body radiation, identified by Kirchhoff 35 years previously.

Kirchhoff had defined a black body as a perfect emitter and absorber of radiation, where all the energy incident on an object is re-radiated. He questioned how the intensity of the electromagnetic (EM) radiation emitted by a black body depends on the frequency of the radiation and the temperature of the body. For the next three decades, physicists couldn't develop a theory that predicted experimental results across all frequencies. Planck set out to answer this question, and he presented a theory known as the Planck postulate. Planck's paper theorized that EM energy could not be emitted continuously, but only as quantized or discrete values. This theory ran counter to the principles of classical physics and it was not widely acknowledged until it began accounting for discrepancies between observed results and classical theory in many areas. The



Photo from the Nobel Foundation archive.

relationship is summarized as:

$$E = h\nu$$

Where: **E** = Energy of a photon or one quantum of energy

h = Planck's Constant ($6.62607015 \times 10^{-34}$ joule-second)

ν = Oscillator frequency

Planck's work was rewarded with the Nobel Prize for Physics in 1918 and is also credited as the origin of quantum physics, with this theory serving as the basis for all the quantum work that has followed.

References

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2. A. P. Lightman, "The discoveries: great breakthroughs in twentieth-century science, including the original papers," 2005, p. 8.



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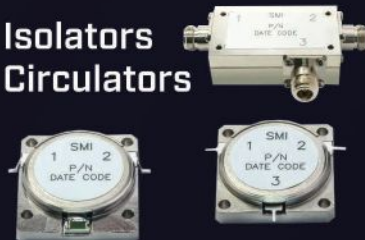
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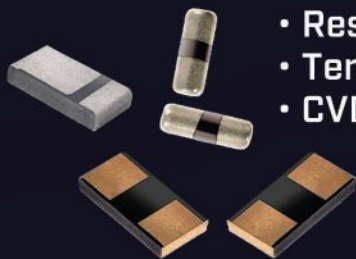
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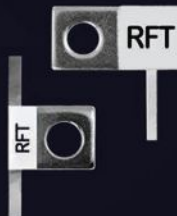


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THz Generation and Analysis with Electronic and Photonic Technologies

Dr. Taro Eichler
Rohde & Schwarz, Munich, Germany

With commercial 6G networks on target to launch in 2030, the race is on to harness radio technologies that can deliver lower latency, higher capacity and enhanced spectrum sharing. Specifications for 6G and most crucially, the optimal adoption of distributed radio access networks, push beyond 5G's gigahertz (GHz) technologies. One possibility to enable this leap in performance is stepping up to terahertz (THz) frequencies. THz science occupies the frequency range between microwave electronics and photonics. This area has attracted increasing interest during the past two decades and now targets the exciting opportunities that exist in sensing, imaging and data communications. Since the pioneering work to create a link between the electrical and optical/infrared regions nearly 100 years ago, the development of efficient, stable and compact THz sources and receivers is making THz science a practical reality.

6G mobile communications success will depend fundamentally on improved latency, higher data rates, better quality of service and expanded system capacity with THz waves central to realizing this ambition. With frequencies extending from 0.1 to 10 THz or wavelengths between 3 mm and 30 μm , THz occupies the spectral region between microwaves and optical waves. The prospect of large contiguous frequency bands providing extremely high data transfer rates in the Tbps range is making this a key research area for next-generation 6G wireless communications. Efforts to explore and unlock this frequency region require an interdisciplinary approach demanding close interaction between high frequency semiconductor technology for RF electronics and alternative approaches using photonic technologies. The THz region shows great promise for many application areas ranging from imaging to spectroscopy and sensing.¹

There are multiple options for generating THz radiation. MMICs are an obvious candidate, but methods based on photonic technologies will also play a key role. The prospect of miniaturizing today's lab setups into photonic ICs means these approaches could become mainstream. In communications, the frequency range of 100 to 500 GHz remains an untapped region, but research in this area is attracting increasing interest because these high carrier frequencies are associated with the promise of unprecedented channel capacities. The challenges and opportunities are making THz the final frontier in the electromagnetic spectrum.

CLOSING THE "THZ GAP"

Figure 1 shows the so-called "THz gap" in the frequency spectrum of 0.1 to 10 THz. This chart shows conventional THz sources with solid lines and recently developed THz sources with ovals. The chart shows a visible power drop in this region.

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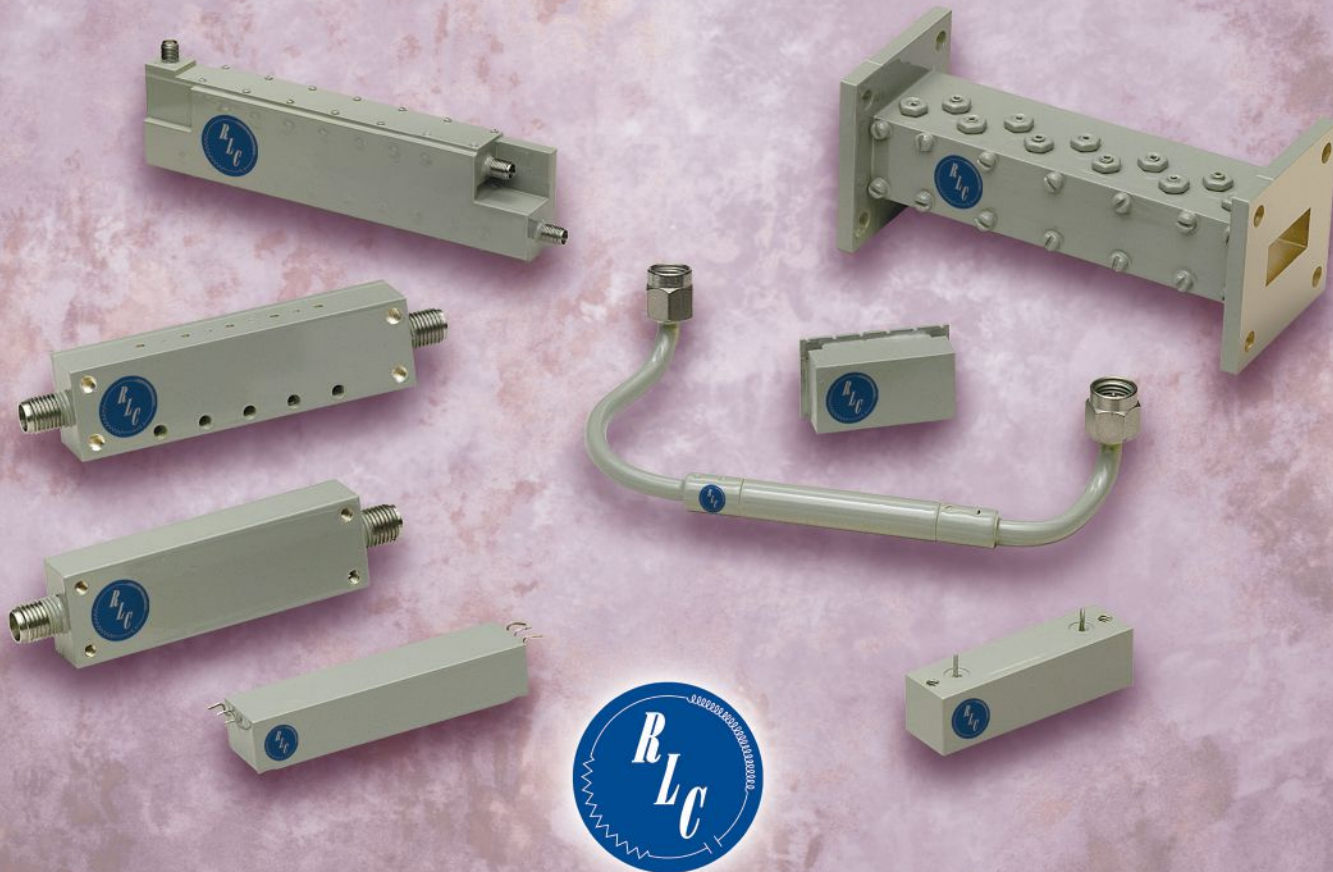
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LL00110-1	0.01-1.0	-10	-	-11
LL00110-2		-5	-	-6
LL00110-3		0	-	-1
LL00110-4		+5	-	+4
LL0120-1	0.1-2.0	-10	-	-11
LL0120-2		-5	-	-6
LL0120-3		0	-	-1
LL0120-4		+5	-	+4
LL2018-1	2-18	-	-10 TO -5	-10
LL2018-2		-	-5 TO 0	-5
LL2018-3		-	0 TO +5	0

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3. Threshold level is the input power level when output power is 1dB compressed.

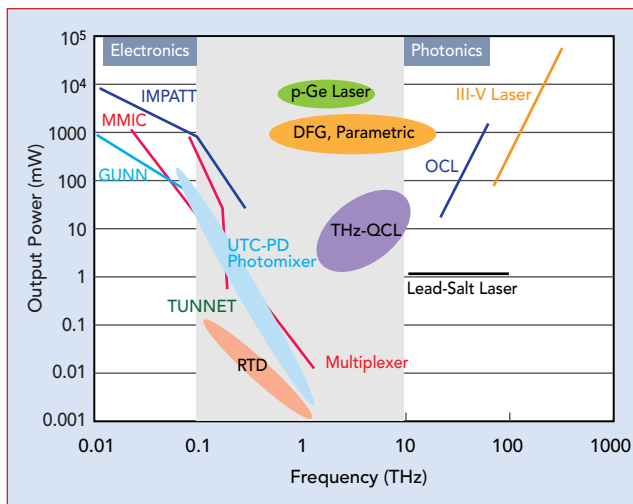
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▲ Fig. 1 THz emission power as a function of frequency.²

THz frequencies are too high for electronic devices because of excessive loss and limited carrier velocity. They are too low for photonic devices because of a lack of materials delivering a sufficiently small band-gap. Available power around the THz region is still much lower than in other spectral regions. A similar trend also occurs in signal detection where such a gap keeps this two-decade spectrum under-utilized in our spectrum-congested world.

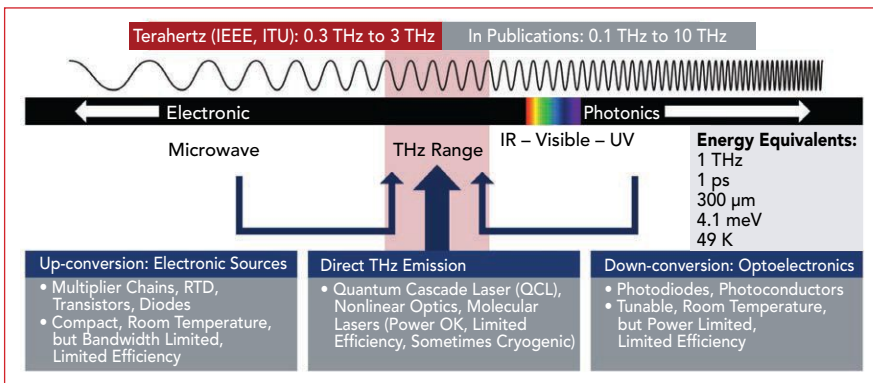
There are three major approaches for generating THz radiation: classical electronics, direct THz generation with quantum cascade lasers and indirect generation optoelectronics. **Figure 2** shows sources for THz radiation on the borderline between electronics and photonics.

UP-CONVERSION: ELECTRONIC THZ GENERATION AND ANALYSIS

The "classic" approach has evolved tremendously. These components are very compact and can be

operated at room temperature. The downside is that classical electronics cannot resolve bandwidth and efficiency limitations. Worse, electronic sources become inefficient at THz frequencies and provide only limited frequency tuning.

Fortunately, RF test and measurement equipment is available from vendors like Rohde & Schwarz to support 6G semiconductor, device and circuit characterization research in the mmWave and THz region. D-Band, with frequencies from 110 to 170 GHz, with frequencies from 110 to 170 GHz, is seeing a strong research focus. Solutions supporting sub-THz and THz research include vector network analyzers (VNAs) for device characterization with frequency converters to 1.1 THz. External harmonic mixers extend frequency range support for signal and spectrum analyzers to D-Band and other frequency bands up to 500 GHz. Frequency multipliers extend signal generator frequency ranges to 170 GHz and beyond. Signal generation and analysis for the D-Band spectrum is possible with transmit (Tx) and receive (Rx) converters and antenna radiation performance measurements can be made using anechoic chambers. What follows investigates these test solutions in detail, outlining ways to generate and analyze THz waves for 6G research. We also describe the challenges presented by these bands.



▲ Fig. 2 The three major approaches for THz radiation generation.



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VNA THZ MEASUREMENTS WITH METROLOGY-LEVEL ACCURACY

Measurements at frequencies up to 67 GHz are part of the standard repertoire of network analyzers. However, tests in the mmWave and THz ranges are significantly more demanding as they require external frequency converters. These frequency extenders up-convert stimulus signals and down-convert response signals to characterize devices operating at THz frequencies.

Characterizing active components in linear and nonlinear ranges requires a defined input power at the probe tip. Since on-wafer power calibration is not possible, the power at the waveguide output is calibrated by accounting for losses in additional waveguides, 1 mm cables and the probe tip. For power sweeps and compression point measurements, an integrated calibration routine in the R&S ZNA

compensates for mmWave converter nonlinearities, providing maximum measurement dynamic range and reproducibility. The R&S ZNA uses system-integrated mmWave converters with metrology-level precision.³ This allows active component measurements to be as convenient at high frequencies as they are at lower frequencies. **Figure 3a** shows a representative test setup with the R&S ZNA. **Figure 3b** shows that test setup modified for 330 GHz wafer-level measurements.

WIDEBAND SIGNAL GENERATION AND ANALYSIS IN D-BAND

D-Band, with the prospect of several GHz of bandwidth, has become one of the focus frequency bands for 6G research. **Figure 4** shows a typical signal generation and analysis setup supporting component and transceiver research in D-Band. The R&S FE170ST transmitter front-end up-converts the modulated signals from the R&S SMW200A vector signal generator to the 110 to 170 GHz frequency range. The R&S FE170SR receiver front-end down-converts the signals and transmits the intermediate frequency (IF) to the R&S FSW signal and spectrum analyzer.

ANTENNA RADIATION PERFORMANCE MEASUREMENTS IN D-BAND

5G pioneered the use of over-the-air (OTA) testing concepts for wireless communications in mmWave frequency bands. This was because large-scale and highly miniaturized antenna arrays are not easily accessible for conducted testing.⁴ OTA antenna test concepts can be extended into D-Band and beyond for exploring THz communications and sensing. Future devices will incorporate even more highly integrated active antenna systems for ultra-massive MIMO and sens-



(a)



(b)

▲ **Fig. 3** R&S ZNA vector network analyzer (a). R&S ZNA with MPI TS150-THz integrated probe system for 330 GHz measurements (b).



▲ **Fig. 4** FE170ST and FE170SR D-Band signal generation and analysis test setup.

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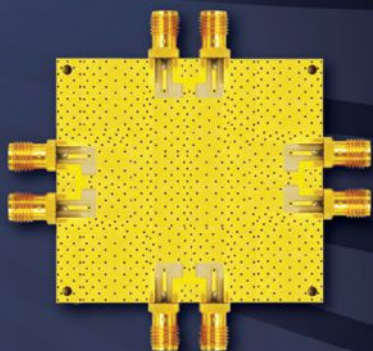


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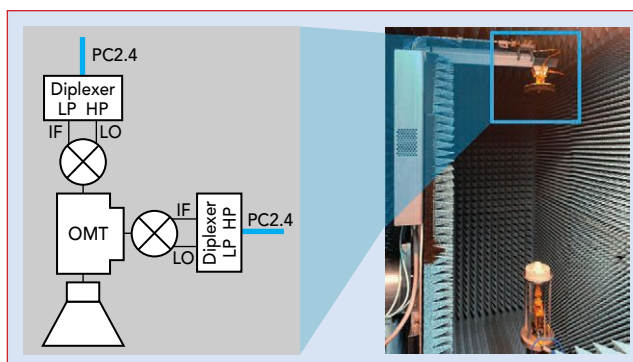
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▲ Fig. 5 Block diagram and measurement setup of the spherical scanning system.

ing applications. With 6G research focusing on frequencies above 100 GHz, advances in new wideband high gain antenna concepts and applied antenna measurement procedures are needed.

Moving from legacy sub-6 GHz cellular services to 5G NR frequency range 2 (FR2) required a major technological leap. Since path loss increases with the square of frequency, higher gain antennas with electronic beam steering capabilities were introduced into user equipment and network infrastructure to ensure radio link performance. With the dramatic increase in IC complexity as a function of frequency, a majority of developments are now targeting a new incremental step at waveguide D-Band and G-Band (140 to 220 GHz). Rohde & Schwarz have developed a spherical scanning solution for measuring radiation performance in D-Band. The solution uses a new probe design with direct down-conversion that provides more than 50 dB dynamic range at 170 GHz. The R&S ATS1000 anechoic mobile spherical scanning range simplifies the test requirements because no mechanical modification or additional RF cabling is needed to measure the amplitude and phase-coherent response of a device under test (DUT) from 110 to 170 GHz.

EXAMPLE: OTA TESTING OF A D-BAND ANTENNA

Figure 5 shows a newly designed IMST D-Band lens-based leaky-wave-fed antenna evaluated in a system using spherical near-field scanning. The radiation pattern measurements were carried out in

the R&S ATS1000, which includes a distributed axis positioner. The DUT could be used in 6G fronthaul point-to-multipoint scenarios. The simplified feed structure consists of an elliptical lens made of low permittivity ($\epsilon_r = 2.34$), low loss, high density polyethylene (HPDE)

with 35 mm diameter (20λ at 170 GHz). The feed consists of a $\lambda/2$ leaky wave air cavity, excited by a WR6 waveguide. The radiation pattern can be steered by displacing the feeder along the lens focal plane.

A DUT feeding assembly, shown below the lens antenna in Figure 5, is used to perform phase-coherent and time-stable measurements. This chain consists of a D-Band subharmonic mixer identical to the one used at the probe and a D-Band isolator that is attached to the WR6 split block of the DUT. Measurements are performed with the R&S ZNA43 four-port VNA where one port at the front feeds the IF signal to the DUT.

The block diagram in Figure 5 shows the measurement probe concept. An orthomode transducer is connected to a 20 dBi squared horn antenna with a 3 dB beamwidth of 16 degrees and a cross-polarization isolation of 25 dB over the complete D-Band frequency range. The assembly works reciprocally, transmitting or receiving two orthogonally-polarized fields when the DUT is set to Rx or Tx. Down-conversion or up-conversion occurs directly at the probe, removing RF cable loss. Both polarizations can be measured simultaneously.

The results in Figure 6 reveal excellent agreement between the DUT full-wave simulations and the measurements. This confirms the accuracy of the measurement system and technique involving the new probe design. Phase-coherent data acquisition such as near-field-to-far-field (NF2FF) transformation can be successfully realized for pas-



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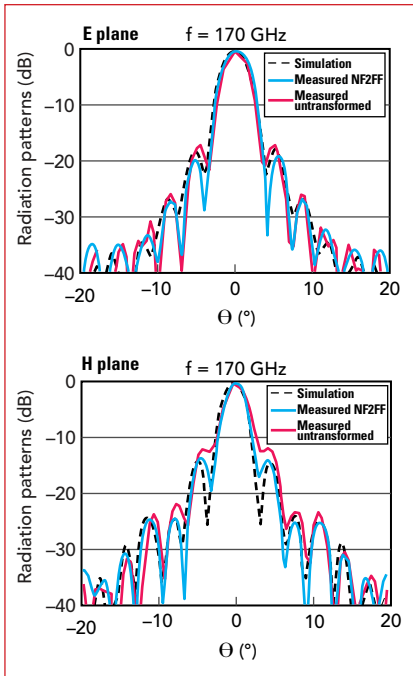
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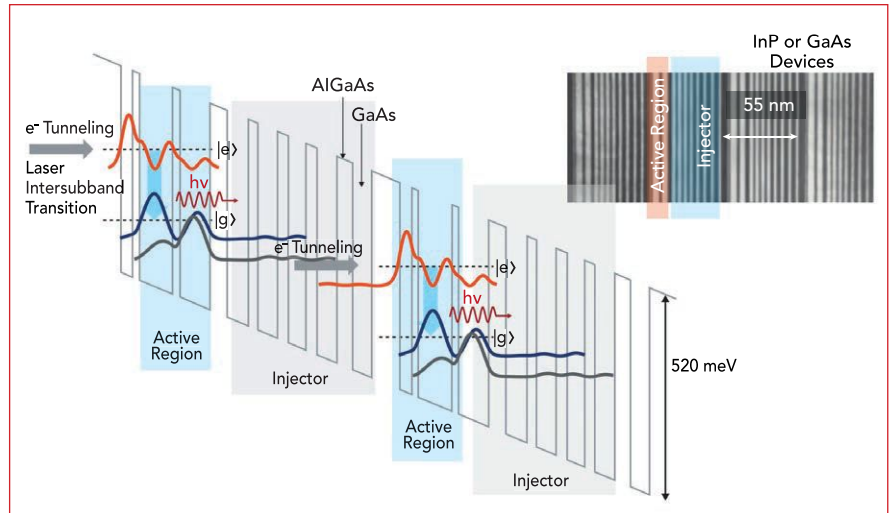
▲ **Fig. 6** E-plane and H-plane directivity patterns.

sive antenna measurements. The untransformed measurement results in red show that the main beam of the radiation pattern is already close to far-field asymptotic behavior.

The high efficiency D-Band lens antenna design realized gain greater than 30 dB over 42 percent bandwidth. Accurate characterization of this antenna was performed with a spherical scanning test system, capable of stable phase-coherent measurements, with direct frequency conversion at the DUT input and the test probe outputs. Phase coherence is a must to support the precise application of the near-field to far-field transformation algorithms that are essential for the accurate determination of radiation pattern nulls and sidelobe levels.

DIRECT THZ GENERATION WITH A QUANTUM CASCADE LASER

An alternative to electronic up-conversion is direct THz generation. This approach uses a quantum cascade laser (QCL) and nonlinear optics (parametric optical processes). Reasonable power levels can already be reached with a QCL, but efficiency remains limited and often they must operate at cryogenic temperatures.



▲ **Fig. 7** Lasing transition between inter-subbands engineered by semiconductor heterostructures in a QCL.

To meet these challenges, down-conversion from the optical frequency regime using ultrafast photodiodes and photoconductors is another approach gaining interest. Down-conversion promises tunability over a broad range, operation at room temperature and the potential to reuse mature technologies developed for fiber-optic communications. The power envelope is being pushed, albeit with limitations in efficiency.

The generation of phase-coherent radiation in a laser is well-established and has led to applications combining optical communications with optical fiber technology. Central to success is allowing direct conversion of electrical current into coherent light. For optoelectronics, the direct bandgap III-V semiconductor materials GaAs and GaN are the most important.

Interband diode lasers are an inexpensive and efficient method for generating photons across the ultraviolet, visible light and IR frequency regions. However, THz photons have energies 100x to 1000x lower than visible photons and there are no materials with such a small bandgap and population inversion. To overcome these issues, laser emission is achieved in a QCL using inter-subband transitions in a periodic stack of semiconductor multiple-quantum-well heterostructures as depicted in **Figure 7**.

Well depths can be engineered by controlling the layer depths dur-

ing the fabrication process. The wavelength of the lasing transition is dependent on the physical structure of the device. So-called “electron wavefunction engineering” allows the generation of low energy THz photons not accessible with inter-band diode lasers. Multiple photons can be generated by a single electron, making the process extremely efficient. Tunneling from one well to the next is where the term “quantum cascade” originates. Light is emitted as electrons that “cascade” through multiple quantum wells forming a superlattice.

Successful operation of a QCL at THz frequencies was first demonstrated in 2002.⁵ QCLs have quickly progressed in terms of frequency coverage, power output and operating temperature. By carefully designing the quantum wells, lasing has been achieved at wavelengths as short as 2.75 μm (109 THz) and as long as 161 μm (1.9 THz). Longer wavelength devices still require cryogenic cooling, but room temperature operation has been observed to at least 16 μm .

An approach using long wavelength THz QCL sources with intracavity nonlinear frequency mixing has made frequencies below 1 THz accessible. The journey towards a THz QCL that operates at room temperature has taken a step forward with the recent publication of a device that operates at -23°C. This temperature is within the reach of Peltier coolers.



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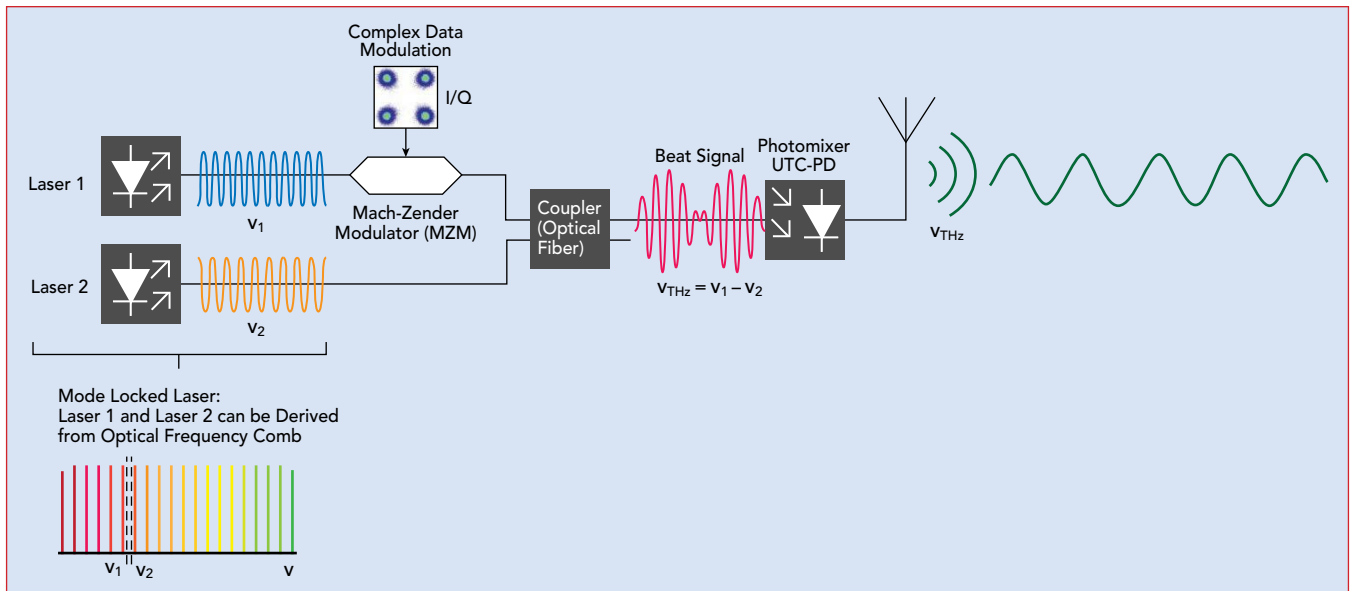
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▲ Fig. 8 Photomixing process to generate THz radiation.

DOWN-CONVERSION PHOTONIC APPROACH: FROM OPTICAL TO THz VIA PHOTOMIXING

The third approach is optoelectronic frequency domain THz generation, which uses a uni-traveling

carrier photodiode or PIN photodiode as a photomixer. This indirect approach for continuous-wave THz generation has attracted strong interest. A photodiode can efficiently convert an optical signal into an electrical signal via a process where

optical/infrared laser light generates free charge carriers in a semiconductor or organic crystal. The antenna structure surrounding the photomixer translates oscillating photocurrent into a THz wave, as depicted in the photomixing process in **Figure 8**.

The photomixing process generates THz radiation at the beat frequency ($\nu_{THz} = \nu_1 - \nu_2$) of two slightly detuned single-mode lasers. One way to attain extreme frequency and phase stability is to derive both frequencies from an optical frequency comb. For data transmission, one of the lasers is modulated by a Mach-Zehnder modulator that consists of an interferometer that splits the beam into two arms. In one of the interferometer arms, the phase of the laser light is shifted relative to the other path by an electro-optic modulator resulting in a constructively or destructively modulated laser beam after the recombination of both beams. The beat signal impinges the photomixer uni-traveling carrier photodiode and the integrated antenna emits THz radiation.

State-of-the-art photomixers are based on either GaAs or InGaAs/InP and require laser wavelengths below the semiconductor bandgap (around 0.8 or 1.5 μm , respectively). By tuning the lasers, the beat note frequency can be varied over a broad spectral range, which translates directly into widely tunable THz radiation. This allows for use of

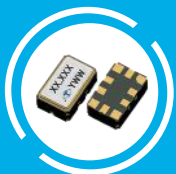


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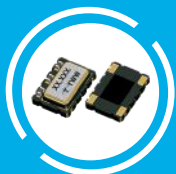
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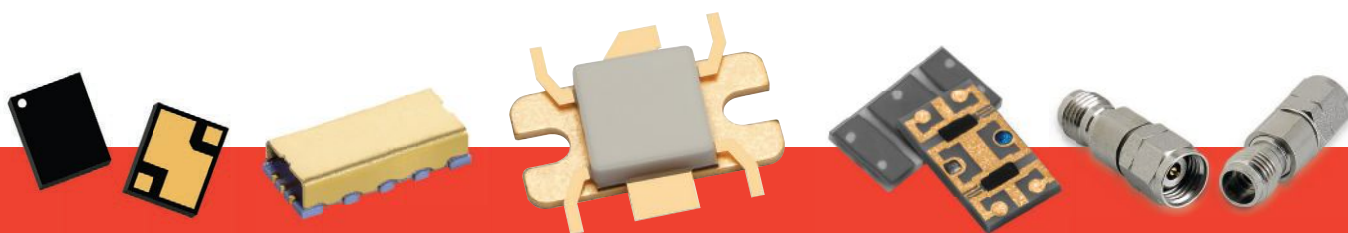
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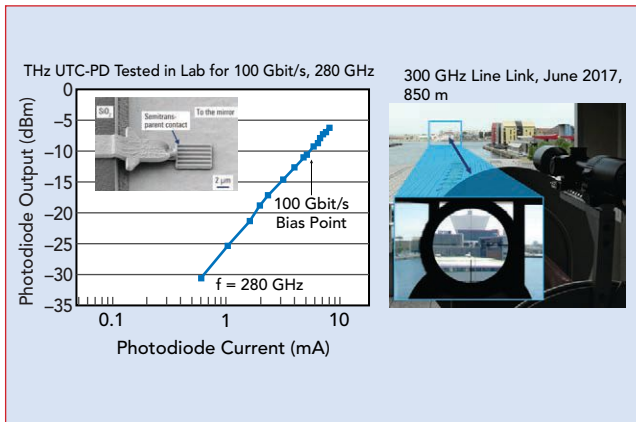


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▲ Fig. 9 300 GHz data transmission in the lab (left) and an outdoor trial (right) (courtesy of Prof. G. Ducournau, IEMN, CNRS-Université de Lille).

the techniques developed to generate optical vector fields in optical communications, pushing these frequencies into the THz range. When adding frequencies, these techniques make it easier to implement multi-frequency communications. The combination also allows easy integration of these wireless links into fiber-optic infrastructure.

and frequency stability of optical combs in a broadband and tunable manner into the THz range. The receiver could be a Schottky diode or a setup symmetrical to the transmitter. This also holds promise for test and measurement instrumentation, since it can be scaled up to extend into the THz region range.

On-chip communications and future high speed inter-device communications will also require THz waveguides. These can be accomplished with topological valley photonic crystals exhibiting near-zero bending loss and zero back-scattering. Referencing both frequencies to the same frequency comb generator allows the transfer of the unique phase

THz WAVES FOR COMMUNICATIONS: 300 GHZ POINT-TO-POINT TRANSMISSION

THz data transmission trials with one Tx antenna and one Rx antenna have been performed in the lab and outdoors. Between 200 and 300 GHz, there is a transmission window with low atmospheric losses. In contrast to free-space optical links, mmWave or THz transmission is much less affected by adverse weather conditions such as rain and fog.

Figure 9 shows the successful trial results from the harbor of Dunkerque. This trial involved a 300 GHz, 850 m transmission link with an extremely focused beam. The responsivity of the device can be increased further with a metallic mirror below the diode mesa through wafer bonding. Further tests of 100 Gbps transmission in the terahertz window between 200 and 300 GHz have been demonstrated successfully.⁶

CONCLUSION

Continuous innovation in the field of test and measurement is a key enabler for making future 6G a reality. It will require intensive research in academia as well as innovative development in the industry. This research will continue to assist in the design of THz test and measurement products to provide solutions and expertise to pave the way for 6G, the next wireless communications standard. ■

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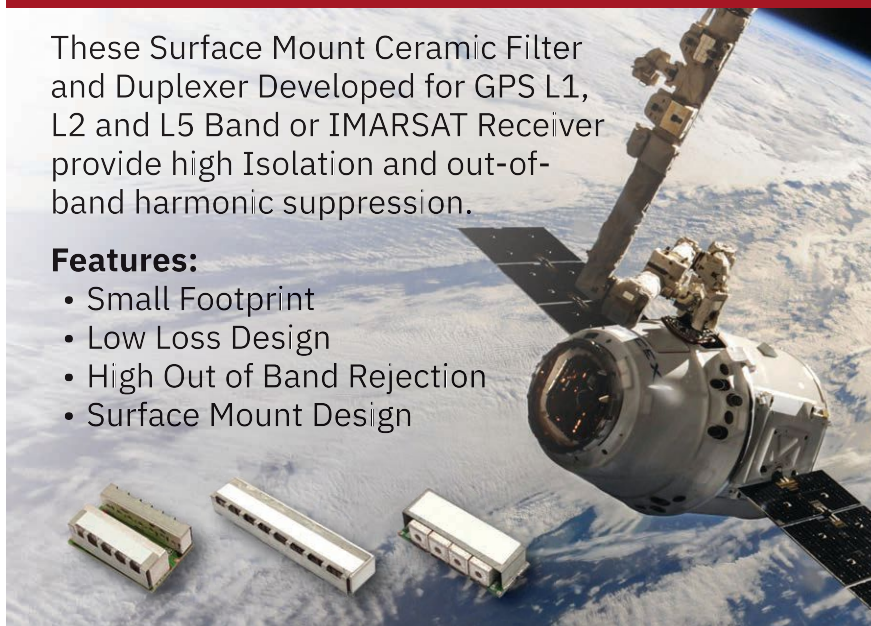


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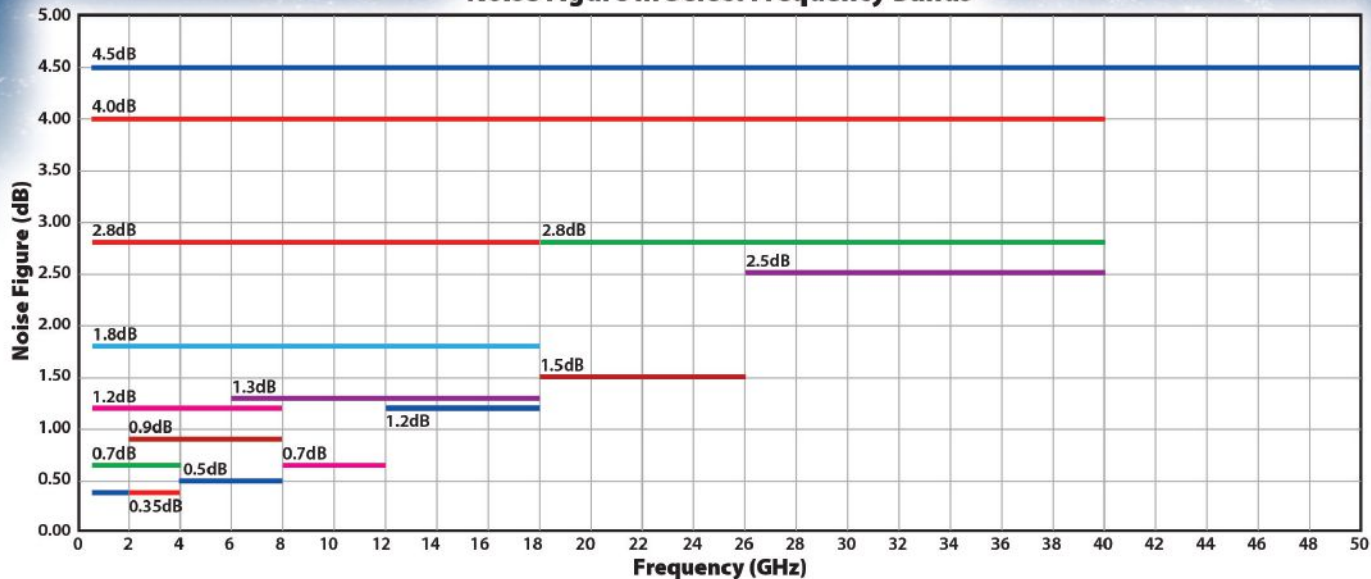
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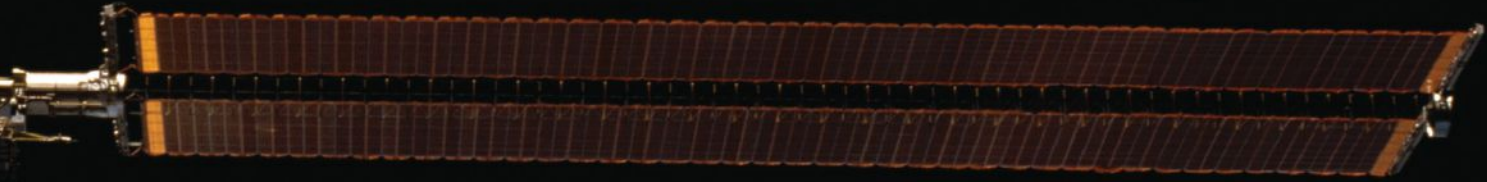
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Looking to the Future Convergence and Coexistence of Terrestrial and Non-Terrestrial Networks

Ke Lu
Anokiwave

THE NEED FOR UBIQUITOUS CONNECTIVITY

As terrestrial networks evolve to 5G to meet the ever-increasing need for ubiquitous connectivity, many operators are realizing that mobile networks cannot by themselves achieve global coverage without assistance from satellite constellations. This is especially true at the network edge, over the oceans and in remote land areas. Such ubiquity is becoming essential in how industries compete and generate value, how people communicate and interact and how militaries pursue security for their citizens. As the number of subscribers, uses and requirements of connectivity continue to grow exponentially, so does the importance of extending terrestrial 5G networks beyond the urban and densely networked communities. We believe the result will be a unified network infrastructure that incorporates terrestrial 5G networks and large multi-orbit constellations to increase the scale and scope of access to communications networks.

In a 5G terrestrial network, satellites serve as an ideal means of providing additional backhaul, incorporating redundancy to critical segments

and delivering greater connectivity to remote and rural areas. The 3GPP standards body considers non-terrestrial networks (NTNs), including high-altitude platform systems, drones and non-geostation-

ary and geostationary equatorial orbit (GEO) satellites as an area of expansion for 5G. They feel this is important enough to include support for NTNs in Release 17.





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Dynamic Range (BW=10Hz, dB, typ) (BW=10Hz, dB, min)	120 110	120 105	120 110	120 110	120 110	120 110	120 110	120 110	115 110	115 105	100 80	110 100	100 80	95 75
Magnitude Stability (±dB)	0.15	0.15	0.10	0.10	0.10	0.15	0.25	0.25	0.3	0.3	0.5	0.5	0.4	0.5
Phase Stability (±deg)	2	2	1.5	1.5	1.5	2	4	4	4	6	6	6	4	6
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THE CHALLENGE OF MERGING TECTONIC FORCES

In recent years, NTN have matured rapidly with help from the advances of multiple industries including cost reduction of satellite launches, new and disruptive business models in low earth orbit (LEO) and GEO constellations, cost reductions of ground terminals and the global initiative to break down the “digital division” of connected and non-connected areas. Meanwhile, terrestrial networks across the globe are migrating from 4G to 5G. With the inclusion of NTN in 3GPP Release 17, the grand vision of merging terrestrial telecom networks and NTN is starting.

For this grand vision of convergence to become a reality, the industry needs to address the following:

- Satellites will need to play a far more central role within telecommunications networks going forward with both terrestrial and space-based components working in tandem for a wider diversity of functions at price points that are acceptable for mass

market adoption

- Coordinating and selecting NTN spectrum managed and owned by different entities and managed by different countries
- Adding technology to today's smartphones to communicate with LEO satellites located 500 km above the earth without increasing the cost of the handset.
- A new 3GPP standard revision is needed to tolerate various unique attributes of NTN networks including long signal delays to and from the satellite, the doppler shift due to the satellite's speed and the large cell size (~30 km² per cell area for LEO)
- Solving the NTN and terrestrial networks spectrum puzzle to effectively re-use spectrum already assigned to each segment to avoid interference between the space and the terrestrial segments
- A holistic network architecture to accommodate and connect different terrestrial service providers in different countries.

One common intersection of terrestrial networks and NTNs is

that both require advanced phased array active antennas to drastically increase antenna gain in the gNB, handset, LEO satellite and satellite ground terminal radios. Low-cost, high performance active electronically scanned antennas (AESAs) will be the key enabler to the merging of terrestrial and NTNs.

SOLVING THE PRICE QUESTION FOR MASS MARKET ADOPTION

To reach attractive consumer price points, the industry must leverage the cost reductions learned from Wi-Fi technology introduced in the early 2000s and apply them to 5G and satcom networks. Silicon for mmWave ICs is the technology that achieves the delicate balance of cost and performance for commercial deployment of phased array antennas in 5G and satcom systems. Active antennas follow a typical volume curve of cost decreasing with increased volume, very similar to other consumer electronics, where the best value comes from a flexible solution that can meet the needs across all market segments.

Silicon ICs built on a commercial Silicon process designed for volume RF device production is a key enabling technology. This technology helps to make electronic beam steering in flat panel active antennas commercially viable at both volume and cost points. Planar phased arrays utilizing a multi-layer commercial printed circuit board (PCB) construction with standard surface-mount assembly is the finishing technology needed to build commercially viable antennas in volumes that meet consumer price goals.

SOLVING THE TECHNICAL QUESTIONS

To create the phased array of the future that is cost-effective and enables convergence and coexistence, one must consider several factors:

Scalability

The many satcom and 5G use cases lead to differing power, noise and cost requirements for the antenna. Active antennas are naturally a good technical solution as they are inherently scalable in size with the right design implementa-

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tion. Anokiwave's mmWave Silicon IC portfolio offers a complete RF signal chain solution for 5G mmWave arrays with system-level performance optimized for each 5G use case. This enables OEMs to rapidly design arrays to meet any given use case within a scalable platform. This platform offers proven capabilities in handling use cases with different EIRP requirements, from low to the maximum allowed under the FCC. **Figure 1** demonstrates how an array based on the quad-channel beamforming architecture scales in EIRP and frequency to address multiple use cases in multi-region markets. For very large satcom terminals, scaling is achieved through scalable sub-array building blocks. This is based on the same concept as 5G arrays and it allows systems to be designed and easily sized based on the application requirements.

Performance

Silicon ICs used in phased array antenna designs offer high performance, application flexibility and ease of integration, high energy efficiency and compelling economics. For the highest performance in any radio system, the power amplifier and low noise amplifier need to be placed as close to the antenna as possible to minimize front-end feed loss. In phased array antennas this means that the Tx/Rx and beam steering functions need to be placed right at the radiating element. Since the distance between radiating elements in the array (the lattice) is typically one-half wavelength, this means the real estate available for the phased array antenna

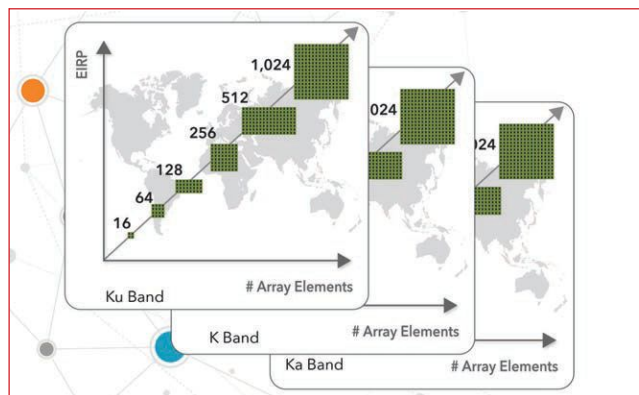


Fig. 1 Anokiwave's IC platform enables arrays that scale in EIRP, G/T and frequency.

electronics is quite limited, especially at higher frequencies where the wavelengths are very short. Silicon beamformer ICs (BFICs) provide the optimum balance of integration of the RF, analog and digital functions all within a single IC. This results in an active antenna with significant cost savings and simpler planar construction. The underlying architecture for the BFICs in both 5G and satcom systems is the same, ensuring maximum economies of scale from each market.

Thermal

Active antennas for both 5G and satcom must be designed to support a wide range of temperature environments, with satcom terminals having the most

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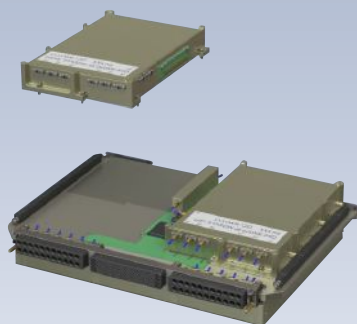
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stringent requirements. Satcom airborne user terminals are a good example of the temperature extremes experienced by all terminal types in all markets. They must operate on the tarmac where temperatures can reach well over 120°C with solar loading and at -46°C to -62°C when the altitude of the aircraft is over 40,000 ft.

This temperature range requires good thermal designs with stable performance of the electronics over temperature. BFIC architectures can be a significant driver depending on the implementation. Phase shifter circuits implemented with vector modulators will require significant amplitude and phase calibration across temperature as their performance varies with temperature. Anokiwave avoids this challenge by using propriety structures that have stable amplitude and phase performance over temperature.

Beamforming Implementations

A misconception in the industry is that satcom terminal receive ICs require dual-beam implementations to support a make-before-break connection. Currently, none of the LEO providers support multi-beam hand-offs. The make-before-break connections are managed in the network, enabled by the inherently fast beam steering capabilities of the active antenna.

For future satcom terminals to benefit from the volumes of the 5G market and for the convergence of the two networks to be commercially viable, the underlying architecture needs to remain constant. This is true,

not only for the devices but also for the PCB design. Single-beam architectures come with significant savings that result from removing the requirement to integrate a second analog beamforming network or include more complicated and costly digital beamforming to achieve the dual-beam architecture. The result is savings in complexity, power and cost.

THE FUTURE OF CONNECTIVITY AND CONVERGENCE IS NOW

Market trends predict market convergence in the very near future. These are the trends that we are seeing:

Megatrend 1: Connecting the unconnected with the most economical solution that makes the business case for operators and consumers commercially viable.

Megatrend 2: Ubiquitous connectivity requires satellite systems to meet the full spectrum of demands placed on 5G networks. These include increasing the traffic and the number of connections outside city centers, providing coverage for devices on the move and seamlessly connecting the asset at the edge of the network as it moves away from an area of dense connectivity.

Megatrend 3: Increasing energy efficiency in future networks as operators look to reduce their carbon footprint while increasing the capacity of their networks. By using satellites to connect low density areas, operators can eliminate large numbers of tower-mounted base stations that consume power and only serve a few subscribers.

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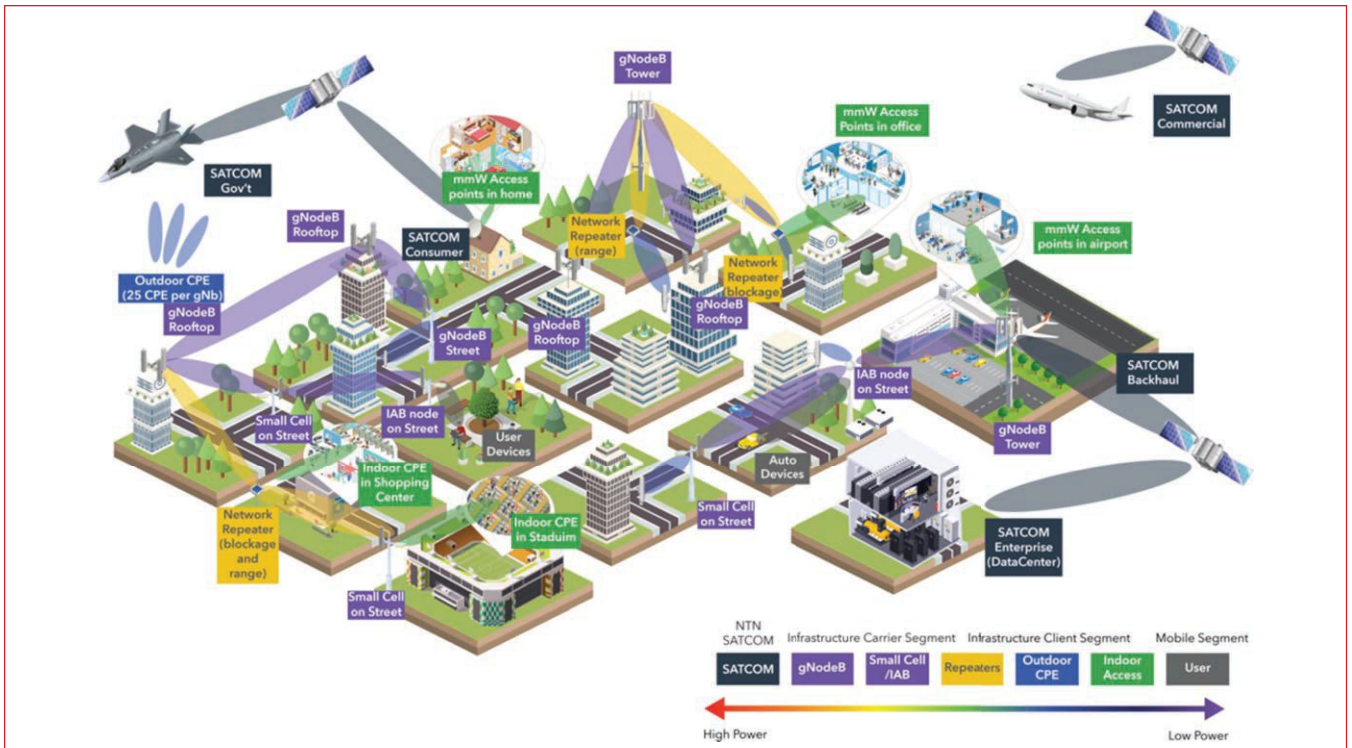


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▲ Fig. 2 Non-terrestrial satellite networks coexisting with terrestrial 5G networks move us closer to the goal of ubiquitous connectivity.

Megatrend 4: NTN systems offer benefits to public safety by providing overlay networks that

duplicate critical segments of terrestrial networks. In the event of a catastrophe, an NTN can provide

additional resiliency through redundancy.

Figure 2 shows a graphic of the future of connectivity and convergence. To realize these mega market trends, we believe that commercial, high volume terminals communicating with multi-orbit satcom and 5G systems require low-cost antennas with extremely fast steerable beams. We believe these systems must be designed with IC architectures that enable stable temperature performance and a flexible polarization scheme. The Anokiwave Silicon-based mmWave BF-ICs improve performance, reduce cost, simplify thermal management and provide a host of unique digital functionality to simplify overall system design and enable the optimal AESA solution for the future of convergence and coexistence.

Anokiwave has been in these markets for over 20 years. The company has developed multiple generations of both satcom and 5G products shipping in volume production and offer OEMs unparalleled application expertise. This allows customers to develop better arrays with faster time to market as well as, most importantly, the experience to support customers who are expanding their networks beyond traditional 5G or satcom use cases. ■

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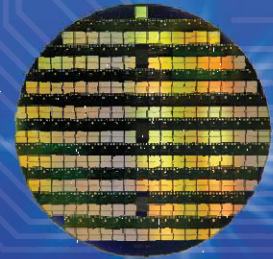
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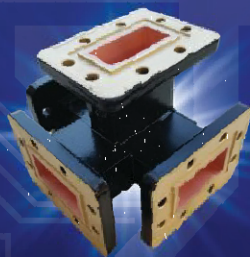
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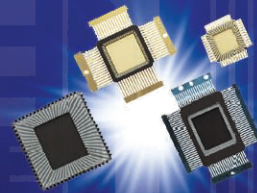
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CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	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

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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

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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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Northrop Grumman to Produce MESA for The U.S. Air Force E-7

Northrop Grumman will begin production of the multi-role electronically scanned array (MESA) sensor for the U.S. Air Force E-7 aircraft.

As part of the E-7 weapons system, the combat proven MESA sensor will provide critical long-range sensing, detection and identification in challenging environments equipping the U.S. Air Force with simultaneous air and maritime sensing capabilities, critical early warning and air battle management capabilities.

This modern airborne active electronically scanned array sensor is already in production and deployed for customers worldwide, providing 360-degree situational awareness and flexibility to adapt to missions and environments in all weather conditions. MESA allows operators to simultaneously focus on priority missions, rapidly revisit targets with increased accuracy and pass relevant information to enable timely battle management command and control decisions.

MESA is on an active production line to address global threats in the modern-day battlespace and evolve to meet future mission requirements. Australia, Turkey and South Korea have fielded the E-7 system, with production underway on the U.K. E-7 AEW&C fleet.



MESA (Source: Boeing)

Airbus Achieves Drone In-flight Autonomous Guidance and Control from Tanker Aircraft

Airbus Defence and Space and the company's wholly-owned subsidiary, Airbus UpNext, have achieved in-flight autonomous guidance and control of a drone using an A310 multi-role tanker transport (MRTT).

In a first step toward autonomous formation flight and autonomous air-to-air refueling, the technologies demonstrate a significant breakthrough for future aerial operations involving manned and unmanned assets.

These 'made in Europe' solutions could reduce crew fatigue and the potential for human error, as well as minimizing crew-training costs and providing more effective operations.

Known as Auto'Mate, the technologies were inte-

grated on an A310 MRTT flying testbed, which took off from Getafe, Spain, in March and on several DT-25 target drones, acting as receiver aircraft and flying from Arenosillo Test Centre at Huelva, Spain.

Over the waters of the Gulf of Cadiz, the control of the drone transitioned from a ground station to the A310 MRTT, autonomously guiding the DT-25 to the in-flight refueling position.

During almost six hours of flight testing, the four successively launched receivers were sequentially controlled and commanded thanks to artificial intelligence and co-



A310 (Source: Airbus Defense and Space)

operative control algorithms, without human interaction. The different receivers were controlled and guided until a minimum distance of 150 ft. (around 45 m) from the A310 MRTT.

Navy Moves Forward with Hypersonic Carrier-Based Weapon

The U.S. Navy recently awarded two contracts to Raytheon Missiles and Defense and Lockheed Martin for the initial development for a carrier suitable long-range, high speed missile designated hypersonic air launched offensive anti-surface (HALO).

The contracts, valued at a total of \$116 million, is the first step to fielding a critical capability over the next decade that will address advanced threats and enable the Navy to operate in and control contested battle space in littoral waters and anti-access/area denial environments.

The initial contracts to Raytheon and Lockheed Martin will provide technical maturation and development through preliminary design review of the propulsion system required for a carrier suitable hypersonic weapon system. The contract period of performance for each award will end in December 2024 with each company's preliminary design review working toward a prototype flight test.

HALO will be a carrier-based, high speed, long-range air launched weapon that will provide greater anti-surface warfare capability than what is available today.

These contracts are the first of potentially additional development and production contracts based on initial designs and supplier performance that will inform Navy leadership on future program decisions.

HALO's predecessor, the Long-Range Anti-Ship Missile (LRASM), is currently fielded on the Navy's F/A-18 and Air Force B-1B. To bridge the gap until HALO is operational, the Navy recently funded an upgrade to the exist-

ing weapon, which will incorporate missile hardware and software improvements to enhance targeting capabilities.

The Navy plans to pursue a competitive acquisition strategy leveraging LRASM requirements and concept of operations to meet future maritime threats beyond mid-2020s. Initial operational capability for HALO is planned to field late this decade.

Raytheon Technologies Awarded U.S. Navy Contract for SPY-6 Family of Radars

Raytheon Technologies was awarded a \$619 million contract to continue to produce AN/SPY-6(V) radars for the U.S. Navy. This is the second option exercised from the March 2022 hardware, production and sustainment contract that is valued up to \$3 billion over five years.

"SPY-6 is the most advanced naval radar in the world providing unprecedented integrated air and missile defense capabilities," said Kim Erzen, president of naval power at Raytheon Missiles & Defense. "Integration into the U.S. fleet is well underway with SPY-6 operating on the Navy's first, new Arleigh Burke class (DDG 51)



SPY-6 (Source: Raytheon Missiles & Defense)

Flight III destroyer. This contract enables the radar to be added to more ships including the first of existing Flight IIA destroyers that will be modernized."

The SPY-6 family of radars can defend against ballistic missiles, cruise missiles, hostile aircraft and surface ships simultaneously. They provide several advantages over legacy radars, including significantly greater detection range, increased sensitivity and more accurate discrimination. Their scalable and modular radar arrays reduce cost and sustainment needs, while meeting the mission requirements of seven classes of ships.



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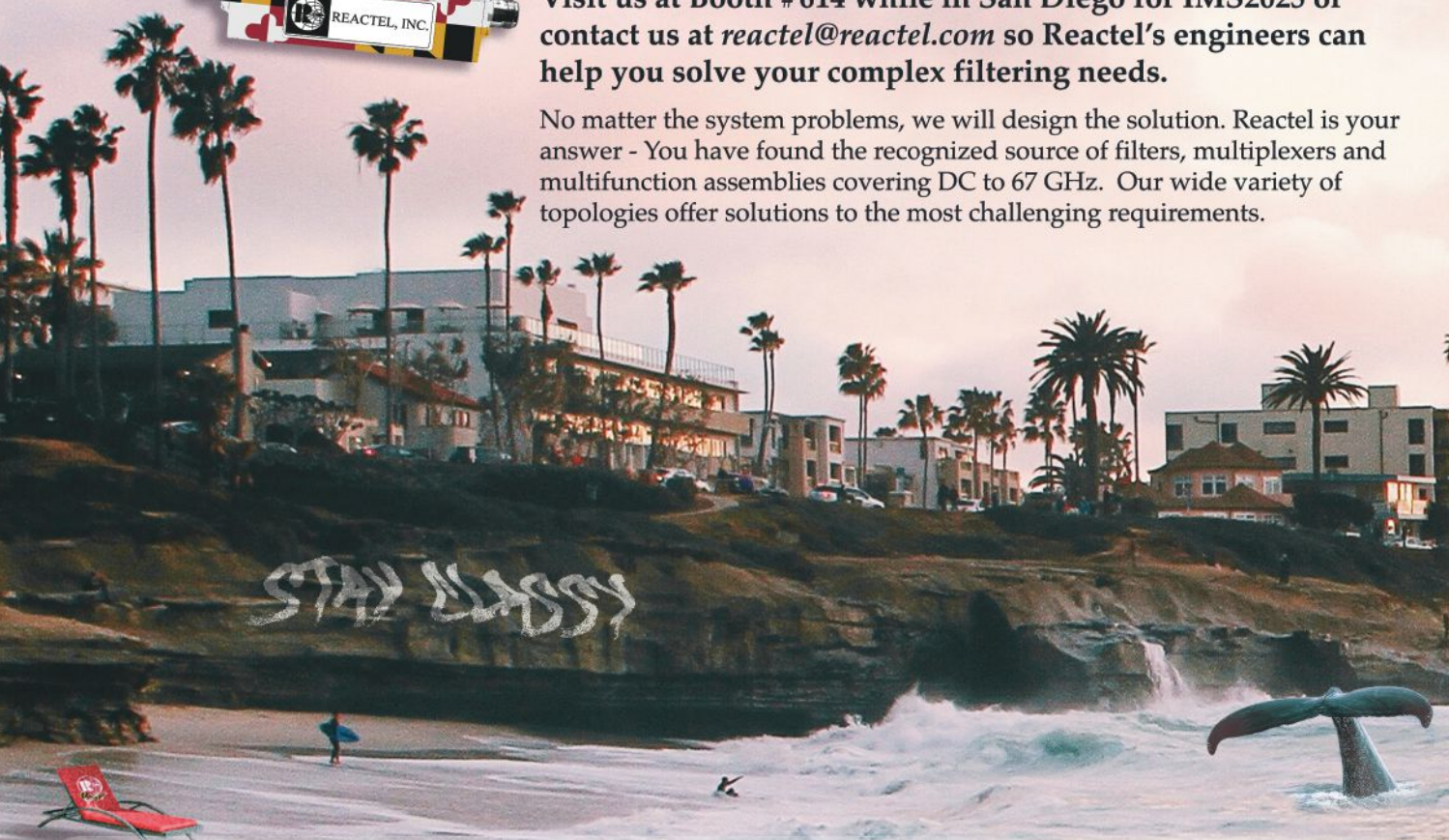
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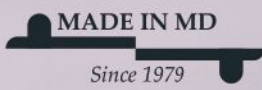
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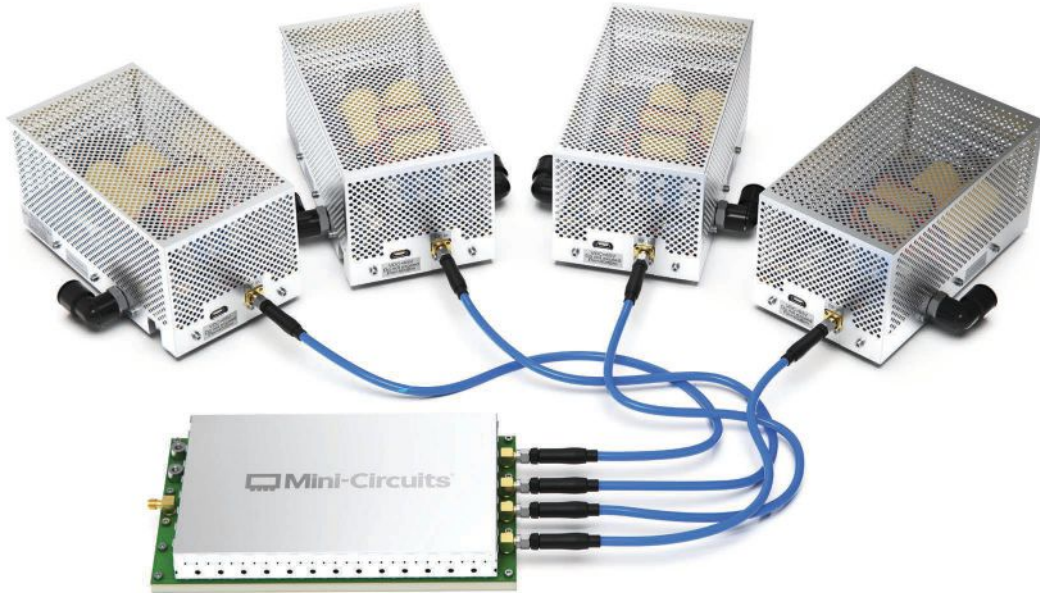


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- Integrated harmonic suppression
- Built-in temperature & current monitoring
- Built-in emergency switch off



Thales Alenia Space Wins Contracts for IRIDE Radar and Optical Satellites

Thales Alenia Space, the joint venture between Thales (67 percent) and Leonardo (33 percent), has won contracts from the European Space Agency (ESA) to supply a first batch of six small satellites with synthetic aperture radars (SARs) and one satellite based on optical technology for the Italian Earth observation constellation, IRIDE. This new constellation, based on several different sensing instruments and technologies, will range from microwave radar imaging to optical sensors at various spatial resolutions and in different frequency ranges.

The contract for the six SAR satellites is worth €112 million and includes an option on a second group of four satellites, worth €75 million. The optical satellite contract is worth €30 million, and includes an option on an additional satellite for €19 million.

The satellites will be built in Italy under the responsibility of Thales Alenia Space and thanks to the contribution of the supply chain of small and medium-sized enterprises (SMEs) in the space sector. It will provide valuable data to researchers studying the evolution of the environmental conditions of Italy and to the civil protection and public administrations to counter hydrogeological instability and fires, protect coasts, monitor critical infrastructures, air quality and weather conditions. Finally, IRIDE will provide analytical data for the development of commercial applications by start-ups, SMEs and industries in the geospatial sector.



IRIDE (Source: Thales Alenia Space)

tions by start-ups, SMEs and industries in the geospatial sector.

Both the radar and optical satellites are built on the modular New Italian Micro Bus (NIMBUS) platform, weighing about 170 kg. Built by Thales Alenia Space, the high performance NIMBUS can be produced rapidly and is designed for high revisit and high capacity constellations. The optical payload is being developed by Italian companies Media Lario and TSD-space.

IRIDE is a government project funded by Italy's National Recovery and Resilience Plan, managed by ESA in conjunction with the Italian Space Agency. Scheduled for completion by 2026, IRIDE features a hybrid constellation of different satellites with dedicated earth observation sensors. This end-to-end system comprises a series of low earth orbit satellite sub-constellations,

ground infrastructures (downstream) and services dedicated to Italian public administration.

These innovative satellites also feature sophisticated operating modes to support high revisit rates, providing data that can be integrated with that from other existing or future programs and infrastructures, including COSMO-SkyMed Second Generation and Prisma, as well as Europe's vast Copernicus earth observation program.

Smart Poles and Smart Corridors to Redefine Smart Urban Infrastructure

According to ABI Research, worldwide investments in smart pole and smart corridor technologies will grow from US\$10.8 billion in 2022 to more than US\$132 billion in 2030. More than 10.8 million smart poles will have been installed by 2030.

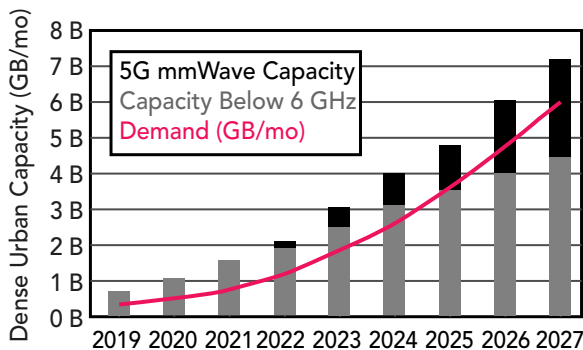
"The aging concept of smart cities has largely failed to deliver its promises. New approaches are required in the form of more scalable, holistic and effective solutions to transform smart urban infrastructure and accelerate its deployment," said Dominique Bonte, vice president of verticals and end markets at ABI Research. "Smart corridors and smart poles are expected to redefine the Intelligent Transportation Systems and the wider smart cities markets."

Smart poles are multi-functional aggregation points for smart urban infrastructure, built on top of smart streetlights and connected utility poles. They represent a cost-efficient, scalable and modular framework for deploying the whole spectrum of smart urban infrastructure, ranging from 5G small cells (in the form of cellular network densification) and Wi-Fi hotspots to surveillance and traffic cameras, signage and information displays, air quality and flood monitoring solutions and charging points for two- and four-wheel vehicles and drones, including renewable energy generation. Key smart pole technology vendors include Ubicquia, Verizon, Huawei, Signify, Nokia/LuxTurrin5G and Ekin Smart City Solutions.

The new concept of smart corridors refers to technologies such as cooperative adaptive traffic lights and roadside infrastructure enabling autonomous driving on 5G-enabled cross-border highways and optimizing traffic flow, road safety and sustainable transportation across longer distances. Premium signal priority for freight and delivery vehicle preemption will offer new monetization opportunities for governments and road operators, ultimately leading to dedicated freight corridors. Key smart corridor government initiatives include the E.U.'s Connecting Europe Facility digital program for funding and deploying 5G corridors and the U.S. Bipartisan Infrastructure Law.

The 5G mmWave Market Finally Becomes Clear

Mobile Experts Inc. released technical analysis and market forecasts recently, outlining the future for 5G mmWave networks, smartphones and Fixed Wireless Access. After the high expectations of the Verizon network resulted in disappointing smartphone data impact, new architectures and use cases are coming into the market. The new report outlines the architectural changes, the cost impact and the likely future growth of mmWave in Fixed Wireless and in data offloading applications.



(Source: Mobile Experts)

Mobile Experts has been tracking the mmWave market for more than eight years, and their original investment thesis remains: 5G mmWave will support high capacity fixed wireless links and will supplement mobile networks in hotspots with high density of traffic. The market has been delayed by other deployments in C-Band and other low bands, but future spectrum availability will be tight, resulting in stronger mmWave demand.

This new report covers networks, smartphones, CPEs, repeaters and Reconfigurable Intelligent Surface (RIS) products, with global forecasts through 2028.

"mmWave performance has increased dramatically with improved transmitters for the uplink," commented Dan McNamara, principal analyst at Mobile Experts. "We have detailed analysis of this change and its impact on networks and all kinds of client devices. In the end, we expect this market to be driven by the relentless push for more capacity in FWA, plus dense areas such as stadiums, airports and some hybrid private/public networks."

Subscribers to Mobile Experts research will receive:

- Full access to the 100-page 5G mmWave 2023 report
- Eight comprehensive charts and figures
- Deep technical analysis related to radio infrastructure and client RF front-ends
- Cost analysis for networks, UEs and CPEs
- Access to the analysts behind the reports.



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Delivering operational frequencies of up to 40 GHz, these RF test cables are available with various connector types including high performance SMA, Right Angle SMA, and 2.92mm connectors. The FastEdge™ RF product line eliminates the need for RF adapters, which would otherwise introduce additional and unnecessary signal loss. The FastEdge™ RF product line is designed to be used in a variety of test environments, and suitable for a broad range of uses including:

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Around the Circuit

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Wireless Logic, a leading IoT connectivity platform provider, has acquired Singapore-headquartered **Blue Wireless**, a global service provider for managed wireless solutions. This agreement follows the company's 2022 acquisitions of **loThink Solutions**, **Mobius Networks** and **Jola**, continuing Wireless Logic's strategy of strengthening its global footprint, service offering and routes to market. Blue Wireless was founded in 2015 in Singapore with the single focus of delivering Wireless WAN Solutions to the enterprise. Since then, it has rapidly expanded in coverage and capabilities, becoming the first provider of fixed wireless access services on a global scale.

COLLABORATIONS

Rohde & Schwarz announced that its tried-and-tested R&S CMW100 communications manufacturing test set for non-signaling wireless device testing has been validated by **Qualcomm Technologies** for QDART to verify **Iridium Communications** waveforms used for the new Snapdragon® Satellite solution. Rohde & Schwarz is the first to supply test and measurement equipment to support non-signaling research and development and production testing of this new feature. This will help enable the Android ecosystem to reliably offer the satellite-based global emergency and two-way messaging provided by Iridium on next-generation smartphones.

Keysight Technologies Inc. has signed a three-party agreement with **NTT DOCOMO Inc.**, and **NTT** to advance the development of key technologies expected to drive the innovation necessary for 6G. With 5G deployment under way, research on enabling technologies for 6G – the next generation of wireless communications – is gaining momentum. These technologies involve new spectrum, artificial intelligence, digital twins and new network architectures including non-terrestrial networks. Organizations developing semiconductors, next-generation device technology, new network capabilities and 6G applications are working with academia, government and each other to meet the challenges and demands of bringing these future communications technologies to market.

MaxLinear Inc announced it has partnered with **EdgeQ** on an all-in-one small cell reference design, converging 4G, 5G and compute onto a single software-defined platform. Combining EdgeQ's 5G "Base Station-on-a-Chip" with MaxLinear's MXL1600 RF transceiver and MaxLIN™ wideband digital predistortion solution creates a new software-programmable paradigm that allows developers to scale rapidly and dynamically across the wide range of small cell applications and use cases with a high level of system integration, performance and flexibility.

Infineon Technologies AG and **Delta Electronics, Inc.** are expanding their long-term cooperation from industrial to automotive applications. Both companies signed a Memorandum of Understanding that will deepen their joint innovation activities to provide more efficient and higher density solutions for the fast-growing market of electric vehicles (EV). The agreement covers a wide range of components such as high voltage and low voltage discretes and modules as well as microcontrollers to be used in EV drivetrain applications such as traction inverters, DC-DC converters and on-board chargers.

ACHIEVEMENTS

Mini-Circuits' facility in Hialeah, Fla., was visited by DEKRA's long-standing auditor for Mini-Circuits, Mr. Bill Brown. The facility was scheduled for a three-day audit event that took place from February 21 to 23. The main scope of the three-day audit event was the recertification to the ISO 9001:2015 standard, and for the first AS9100 certification for this facility. The audit was a success due to the team's dedication to quality and safety. The audit was a significant milestone for the Mini-Circuits Florida (MCFL) team, and a testament to the hard work of the MCFL members who led the audit.

Eravant announced it has been certified to the AS9100 Rev D quality management standard for both engineering and manufacturing operations. As a U.S. designer and manufacturer of custom and commercial off-the-shelf (COTS) components, sub-systems and test equipment for mmWave and sub-THz applications (18 to 330 GHz), becoming certified for all business operations signals commitment and readiness to serve the aerospace and defense community along with Eravant's heritage customers in commercial and scientific markets. Becoming AS9100D certified strengthens Eravant's competitive position through systematic continuous improvement and business monitoring processes.

ERZIA Technologies, a full-service RF/microwave amplifier and integrated assembly designer and manufacturer of high-reliability COTS devices, celebrated its 20th anniversary this year. To mark the occasion, the company is launching several new products, expanding its facilities and exhibiting at all the industry's main events in 2023. In addition, there will be multiple celebrations with its customers and employees throughout the year, which started at SATELLITE 2023. Over the past two decades, ERZIA has experienced tremendous growth and innovative success, expanding its reach into electronic warfare, aeronautics, satcom, radar and space industries across the globe. ERZIA's commitment to engineering excellence and product reliability has earned it an enviable reputation of success.

Junkosha launched their second Technology Innovator of the Year Awards. The Awards program has been designed to recognize the innovative work of an individual or team working in the delivery of products used within interventional medical procedures or microwave/

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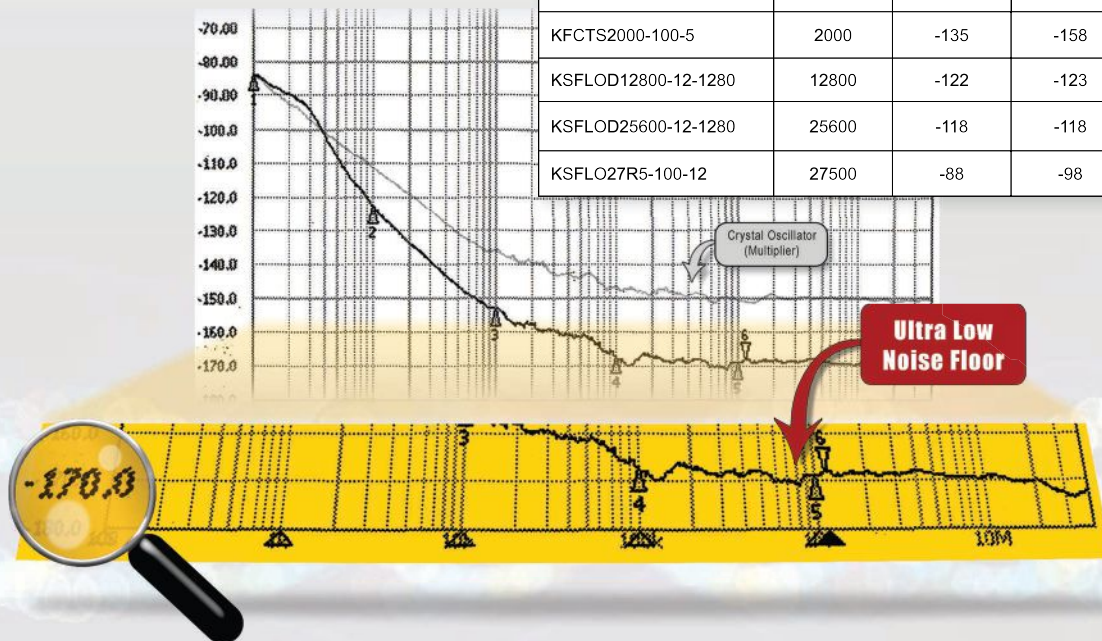
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VFCTS105-10	105	-156	-165	
VFCTS120-10	120	-156	-165	
VFCTS125-10	125	-156	-165	
VFCTS128-10	128	-155	-160	
FCTS800-10-5	800	-144	-158	
FCTS1000-10-5	1000	-141	-158	
FCTS1000-100-5	1000	-141	-158	
FSA1000-100	1000	-145	-160	
FXLNS-1000	1000	-149	-154	
KFCTS1000-10-5	1000	-141	-158	
KFCTS1000-100-5	1000	-141	-158	
KFSA1000-100	1000	-145	-160	
KFXLNS-1000	1000	-149	-154	
FCTS2000-10-5	2000	-135	-158	
FCTS2000-100-5	2000	-135	-158	
KFCTS2000-100-5	2000	-135	-158	
KSFL0D12800-12-1280	12800	-122	-123	
KSFL0D25600-12-1280	25600	-118	-118	
KSFL027R5-100-12	27500	-88	-98	



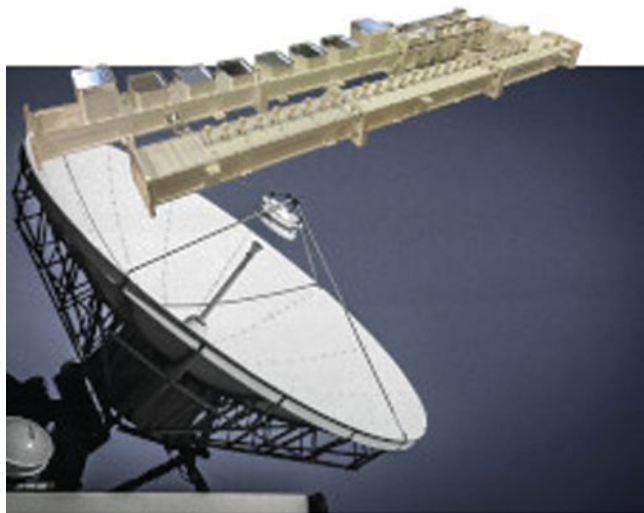
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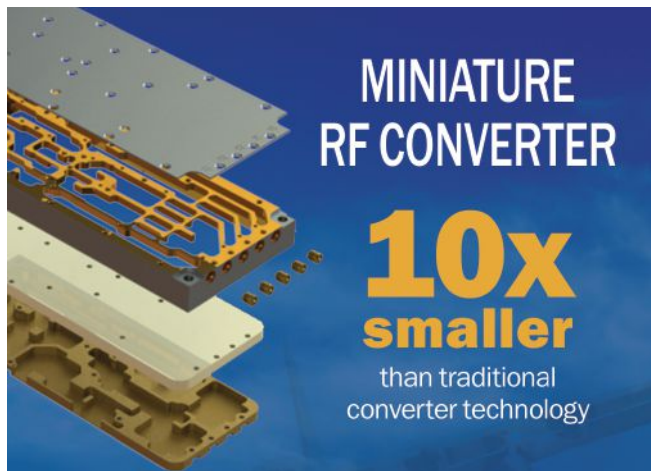
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Around the Circuit

mmWave technologies. A year-long scheme, the winning entrant will receive a sum of \$25,000 to invest in their worthwhile project. The award aims to continue the legacy of the first year by providing a platform for microwave technologies and medical device sectors to showcase the achievements of pioneers in advanced technology together with their contributions to society.

PEOPLE



▲ Dan White

Stellant Systems Inc. announced that **Dan White** has been hired as the new vice president/general manager of the Torrance, Calif., facility. In this role, White will be responsible for driving operational performance across the 460,000 square-foot manufacturing facility, and for executing the company's strategic operating objectives.

White has over 30 years in engineering, program management, strategy and executive leadership within the aerospace and defense industry. Prior to joining Stellant, White was president of the Swedish Space Corporation where he led the Americas Business Area, including North and South America. He was also president of COM DEV USA, a subsidiary of COM DEV International.



▲ Mary-Beth DePaolo

CAES, a leading provider of mission-critical advanced RF technology, announced that one of its human resources leaders has been presented the Patriotic Employer Award from the Employer Support of the Guard and Reserve (ESGR), a DOD office that develops and promotes supportive work environments for service

members in the National Guard and Reserve. Senior Manager of Human Resources **Mary-Beth DePaolo** received the honor in a ceremony at the CAES Lansdale, Pa., site on March 16. Major General Wesley E. Craig Jr. traveled to Lansdale to present the award.

REP APPOINTMENTS

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Compact Antenna Systems for Future Smartphone Multi-Frequency Wireless Standards

Shiban K. Koul, *Indian Institute of Technology, Delhi, India*

G. S. Karthikeya, *BMS College of Engineering, Bangalore, India*

Ajay K. Poddar, *Synergy Microwave, Paterson, N.J.*

Ulrich L. Rohde, *University of the Armed Forces Federal University, Munich, Germany*

Future smartphones will contain a mix of wireless technologies. Hardware operating in different wireless spectra will co-exist. To realize these multiple hardware transceivers, compact antenna systems must be designed without significant compromise in individual antenna electrical performance and be compliant with respective standards. They must be operational in both the sub-6 GHz and mmWave bands. These systems must also be physically compact with minimal form factors constrained by the height of commercial smartphones. Several design approaches are described.

Most of the smartphones available in the market today have numerous sub-6 GHz antennas integrated within them. These radiators are electrically small with poor radiation efficiency. Antenna gain is not a critical parameter to be considered during design; thus, they radiate omnidirectionally with low gain.

Antennas operating in the mmWave band, however, must deliver high gain without compromise in their form factors. Furthermore, mmWave antennas must be impedance matched for wide bandwidth to cover existing 5G bands in their respective geographical locations.

While antennas with multi-frequency functionalities are integrated together, the performance integrity of the sub-6 GHz and mmWave antennas must be maintained. The challenge, with reference to both bands, is to accomplish this in an electrically small form fac-

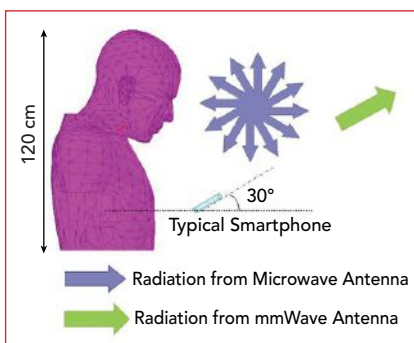
tor, with reference to both the bands. Mutual coupling between the sub-6 GHz and the mmWave antennas must be minimal. The forward gain of the mmWave 5G antenna must be high to support the radio link.

In this article, several design strategies to achieve the aforementioned requirements are illustrated with experimental results.

DESIGN CONSTRAINTS

The reason for multi-octave carrier systems is to enhance the bandwidth allotted per user. Sub-6 GHz antenna systems must be co-designed with the mmWave antenna systems for optimal functionality of smartphone transceivers.¹ Typically, the microwave antennas operate at sub-6 GHz frequencies while mmWave antennas function in the 28 GHz bands; specific frequencies depend on the geography and the licensing authorities. The carrier frequency of the mmWave band (28 GHz) is the eighth harmonic of the sub-6 GHz band (3.5 GHz). Hence, co-design of antennas operating in these bands is challenging.²⁻⁴

Figure 1 shows the typical use case for microwave and mmWave antennas integrat-



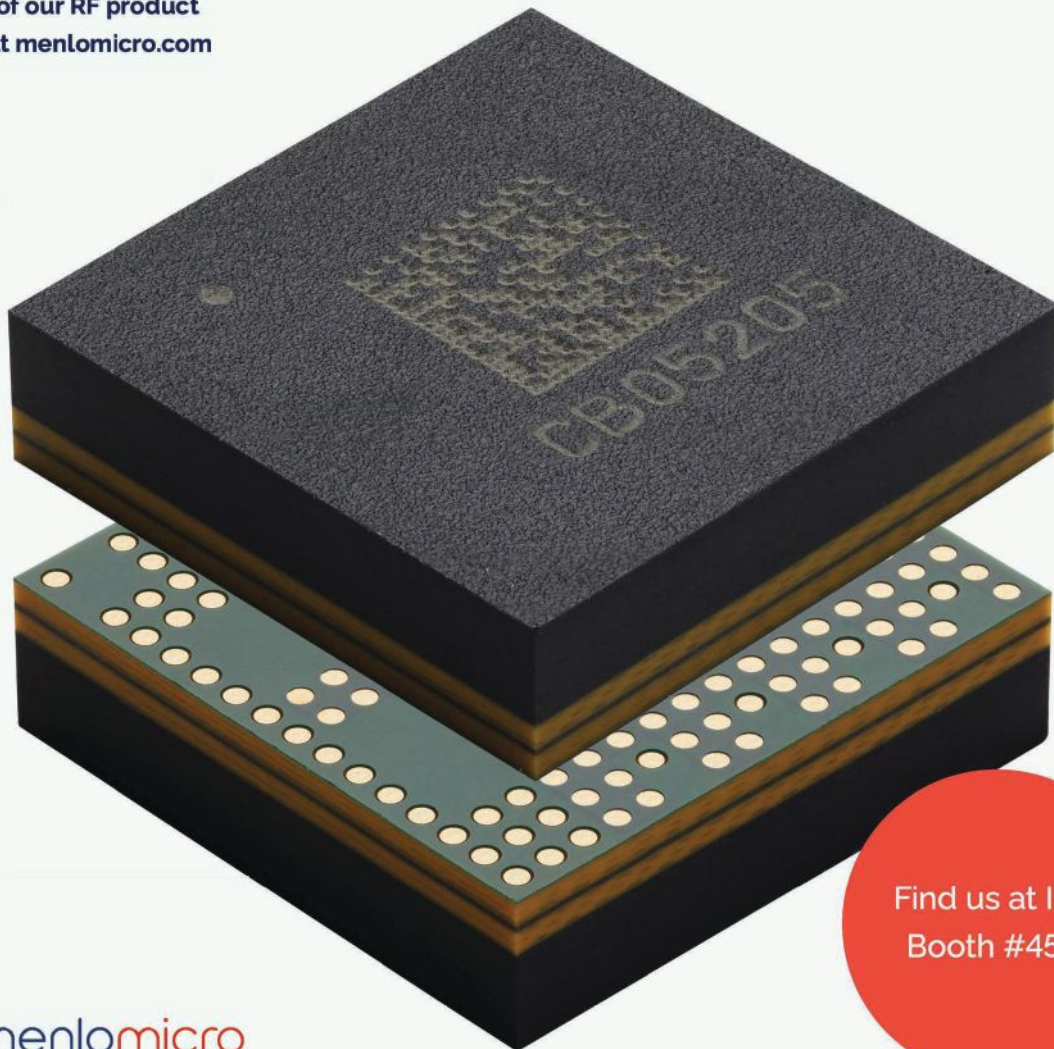
▲ Fig. 1 Typical radiation characteristics of mmWave and microwave antennas in a smartphone.



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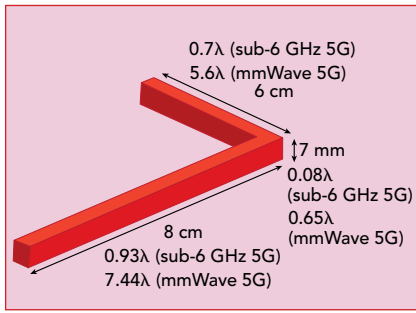
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▲ **Fig. 2** Electrical real estate available within a typical smartphone.

ed within the panel of a commercial smartphone. The sub-6 GHz antenna radiates omnidirectionally, in contrast to the unidirectional beam of the mmWave antenna. The beam radiated by the mmWave antenna must be pointed away from the user to facilitate a reliable high data rate link with the nearest base station.

The available real estate on a commercial smartphone is shown in **Figure 2**. The physical form factor of

a sleek smartphone is approximately $8 \times 6 \times 0.7$ cm, which translates to $0.93 \times 0.7 \times 0.08 \lambda$ for the sub-6 GHz band at 3.5 GHz. The same physical form factor translates to $7.44 \times 5.6 \times 0.65 \lambda$ for the mmWave band at 28 GHz.⁵ The co-designed, or integrated, antenna system must fit within the dimensional constraints of the mobile device without performance deterioration in either band.

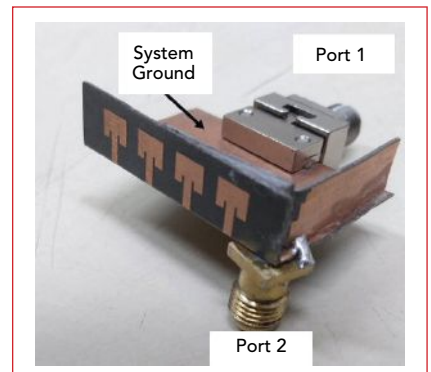
The simplest solution for this design problem is a single antenna tuned to both carrier frequencies. The problem is that the antenna will operate quite well in the sub-6 GHz band but its gain and pattern integrity in the mmWave band will be significantly deteriorated. Hence, various multi-port antenna systems are explored in this article.

MULTI-PORT ANTENNA SYSTEM DESIGN EXAMPLES

Example 1

The first antenna system is shown in **Figure 3**. Port 1 is connected to the mmWave antenna, and Port 2 is connected to the microwave antenna. The same nomenclature is followed for all the designs presented in this article. The mmWave antenna is fabricated on a 20-mil thick Rogers 5880 substrate. It is a corporate inset-fed patch antenna array with a standard half-wavelength separation between elements.⁶ The radiators are in line with the panel of the smartphone, while the feed network is in the orthogonal plane. This corner-bent antenna exhibits a 10 dB impedance bandwidth of 10 percent (see **Figure 4**).

The electrically close placement of the sub-6 GHz antenna does not detune the mmWave antenna.



▲ **Fig. 3** Fabricated prototype of co-design Example 1.

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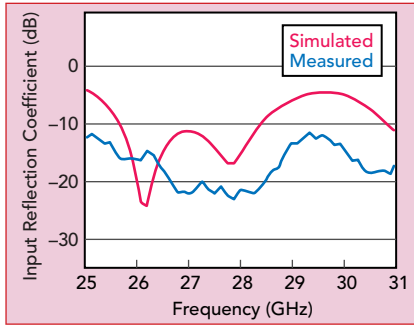
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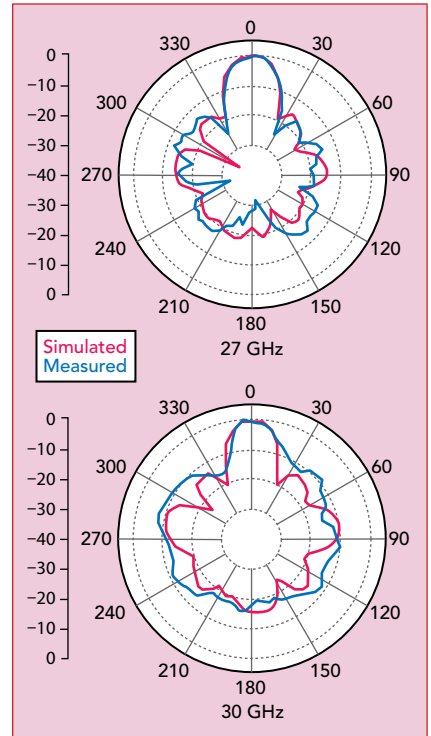
▲ Fig. 4 Input reflection coefficient of Port 1 for Example 1.

Unidirectional radiation patterns of the mmWave antenna are shown in **Figure 5**. The antenna system offers high gain of close to 8 dBi at 28 GHz with minimal back radiation toward the user. The narrow beamwidth is due to the corporate-fed array action of the inset-fed patch antennas.

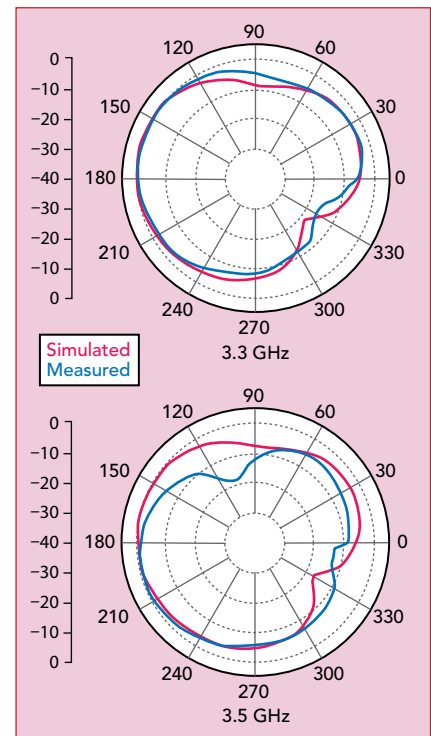
Radiation patterns of the microwave antenna within the co-designed ecosystem are shown in **Figure 6**. These patterns offer omnidirectionality. The slight tilt in the

patterns is due to the presence of the system ground of the mmWave antenna. The printed dipole antenna operating at 3.5 GHz detunes slightly due to the electrical proximity of the ground plane.

The microwave antenna was re-



▲ Fig. 5 Radiation patterns of Port 1 for Example 1.



▲ Fig. 6 Radiation patterns of Port 2 for Example 1.

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ID41411DR	3700 ~ 4100	410	47.5
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	3300 ~ 3700		
	3400 ~ 3800		
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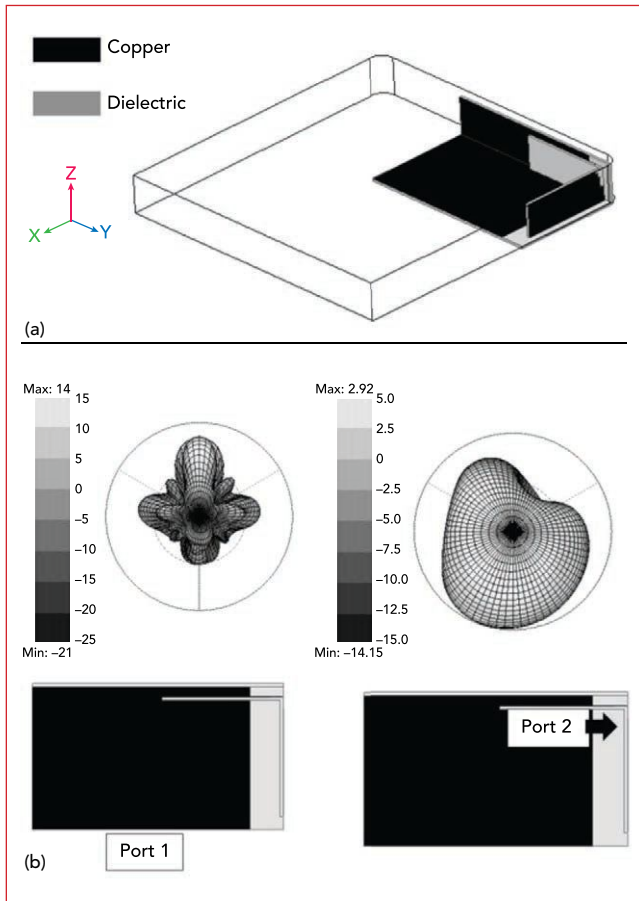
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designed for this topology to preserve its input impedance characteristics. The actual placement is shown in **Figure 7a**. It occupies minimal space in the smartphone. The mmWave antenna radiates away from the user in contrast to the microwave antenna, which is connected to Port 2 (see **Figure 7b**).



▲ **Fig. 7** Antenna placement within a smartphone for Example 1: orientation (a) and radiation patterns (b).

Example 2

The second design approach mounts the mmWave and microwave antennas orthogonally for enhanced isolation between the ports. The fabricated antenna assembly is shown in **Figure 8**. The corner-bent mmWave antenna array is truncated at the non-radiating edge without hampering its radiating characteristics. The microwave antenna is a simple electrically small, printed monopole resonating at 3.5 GHz. This concept could be generalized with any mmWave antenna with a unidirectional beam and a printed monopole operating in the sub-6 GHz bands.

Example 3

The third design approach employs a shared overlapped ground for both antennas (see **Figure 9**). A high gain broadside radiator operating in the 28 GHz band is placed on top of its microwave counterpart. The ground plane of the mmWave antenna is common with the printed microwave monopole. The entire ground plane for Port 1 ensures a unidirectional beam. On the other hand, the partial ground plane associated with Port 2 delivers an omnidirectional beam throughout the operating band. Isolation between the ports is greater than 20 dB in both the microwave and mmWave frequency bands. Mutual coupling and the input reflection coefficient for the mmWave band are shown in **Figure 10**.

Panel mounting is shown in **Figure 11**. Only one smartphone panel is needed, saving integration space. The 3D-printed smartphone mockup matches the dimensions of a commercial smartphone with a panel height of 7 mm.

Example 4

Another uniplanar design technique is to integrate both antennas on a single substrate (see **Figure 12**). The broadside high gain mmWave antenna is microstrip-fed at one of the substrate edges. The microwave monopole is fed with a microstrip as well, on another edge of the substrate. A small gap of 0.1 mm is introduced in the

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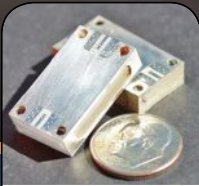


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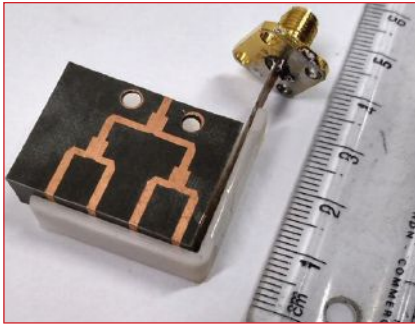


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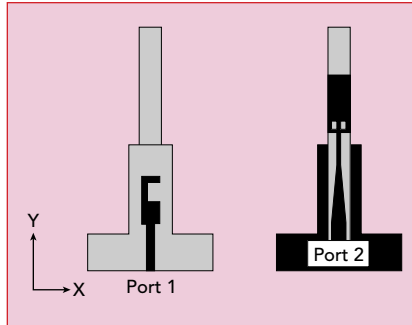
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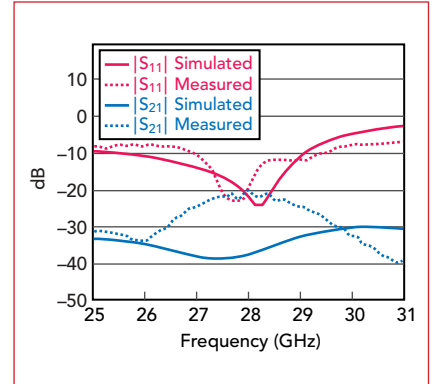
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▲ Fig. 8 Fabricated prototype of co-design Example 2.



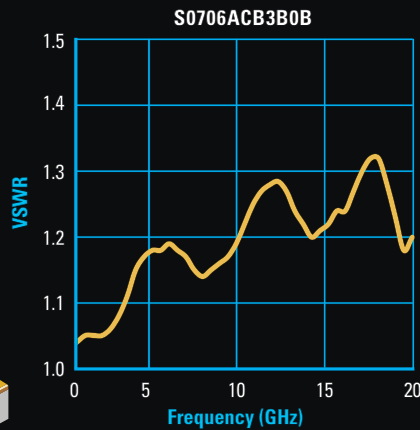
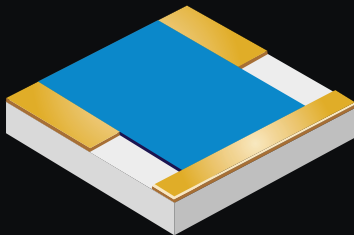
▲ Fig. 9 Schematic of co-design Example 3.



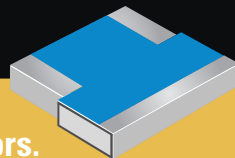
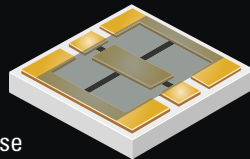
▲ Fig. 10 Mutual coupling and input reflection coefficient of co-design Example 3.

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ground plane to enhance isolation to 25 dB in both frequency bands. The input reflection coefficient and mutual coupling in the mmWave band is shown in **Figure 13**.

Neither the impedance nor the radiation characteristics of the constituent antennas change when co-designed with this technique. The panel mockup and its corresponding 3D-radiation patterns are shown in **Figure 14**. The design meets the radiation specifications for both the microwave and mmWave frequency bands.

Example 5

The last approach is to integrate a high gain end-fire mmWave antenna with a microwave-printed monopole (see **Figure 15**). Here, the high gain compact printed Yagi-Uda antenna delivers a unidirectional beam in the mmWave frequency band. The printed monopole with a truncated ground is tuned along with the presence of the printed Yagi antenna. The panel mount configuration for commercial phones and corresponding 3D radiation patterns are shown in **Figure 16**.

CONCLUSION

Multi-frequency antenna systems are essential for compatibility with hardware transceivers in upcoming smartphones. In addition, the impedance and radiation integrity of the individual antennas operating in the mmWave and microwave bands must be preserved. Several design approaches to realize these requirements are demonstrated in this article as potential candidates for future smartphones.



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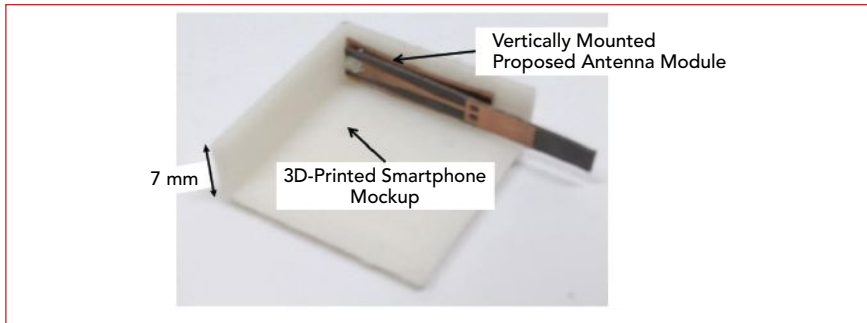
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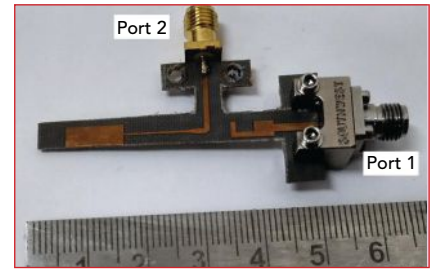


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▲ Fig. 11 Panel mounting of co-design Example 3.



▲ Fig. 12 Fabricated prototype of co-design Example 4.



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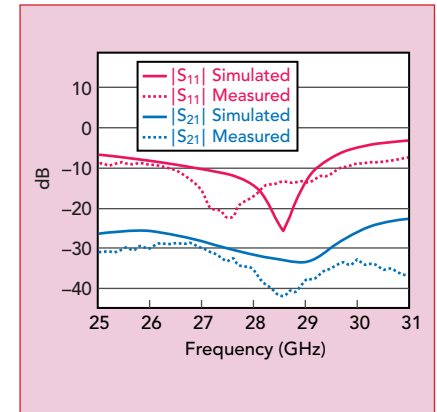
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▲ Fig. 13 Mutual coupling and input reflection coefficient of co-design Example 4.

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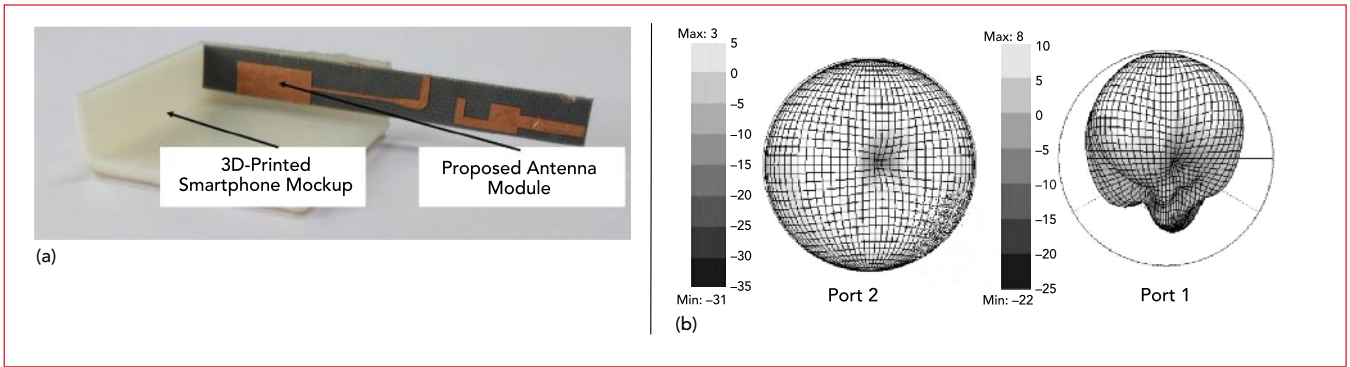
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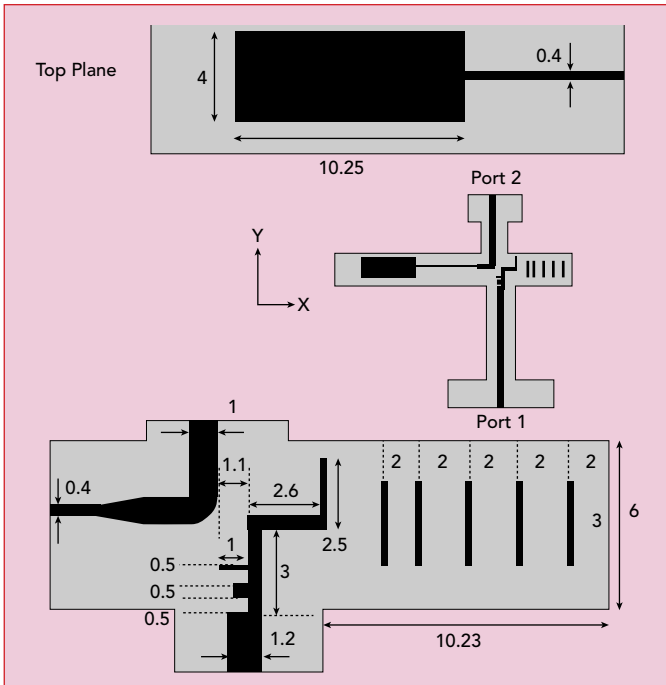


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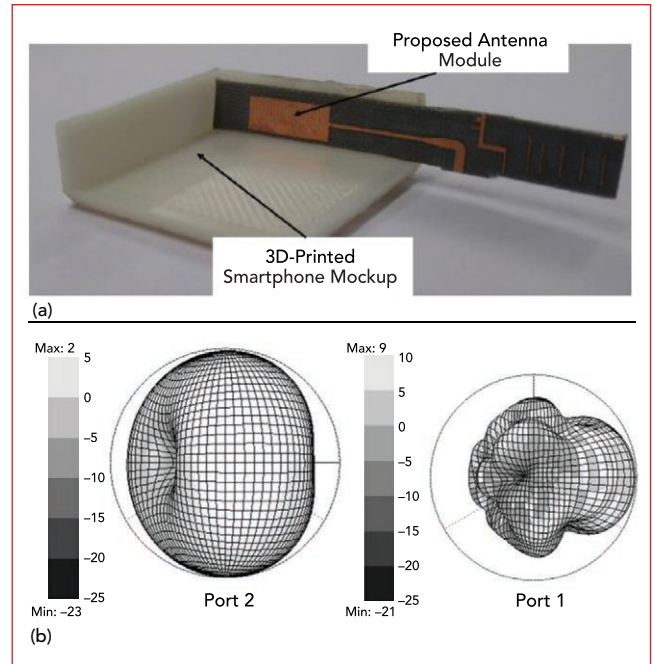
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▲ Fig. 14 Antenna placement within a smartphone for Example 4: orientation (a) and radiation patterns (b).

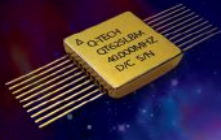


▲ Fig. 15 Schematic of co-design Example 5.

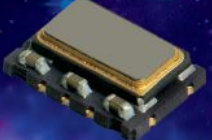


▲ Fig. 16 Antenna placement within a smartphone for Example 5: orientation (a) and radiation patterns (b).

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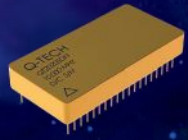
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mmWaves are defined as electromagnetic waves with wavelengths from 1 to 10 mm. They belong to the extremely high frequency band of the radio spectrum with a frequency range from 30 to 300 GHz.¹ Research and industry are finding the larger bandwidth of mmWave bands attractive, which is increasing the use of these bands in current and emerging RF applications. These bands offer higher data rates and lower latency, which makes them useful for data communication applications like 5G. In addition to communications applications, automotive radars use the 77 GHz band to achieve a better resolution.

5G frequency spectrum is divided into two ranges; frequency range 1 (FR1) consists of the sub-6 GHz bands and frequency range 2 (FR2) covers frequencies above 24 GHz.² Thanks to its larger available bandwidth, 5G FR2 frequencies allow for higher capacity and faster connectivity in comparison to the FR1 frequencies that older generations of networks use. Densely populated

areas like stadiums and factories, along with video streaming services are some of the many application areas where 5G mmWave technology can be especially useful.

Automotive mmWave radars operating in the 76 to 81 GHz band, are widely used in advanced driver assistance systems such as adaptive cruise control, cross-traffic alert and blind spot detection.³ These systems increase the safety and comfort of the drivers, and they are commonly utilized in the automotive industry. Radars are used to measure the range, velocity and angular position of the surrounding cars and obstacles. These radars can be integrated invisibly into the car bodies since the mmWave signals will easily radiate through the body material. This allows for stable target detection even under harsh weather conditions.⁴

The antennas that radiate or receive electromagnetic energy are one of the key components of communication and radar systems. The performance and size of these radar systems are greatly affected by the design and performance of the anten-

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▲ Fig. 1 Printed circuit board traces.

nas. Planar antenna arrays manufactured with printed circuit board (PCB) technology are commonly used in both applications because of their low cost and profile. However, the performance of the antennas can be affected significantly by high dielectric losses. If this occurs, the antennas will provide only moderate gain and efficiency at the mmWave bands. A solution to reduce dielectric loss involves introducing air cavities by removing part of the dielectric material. Typically, these air cavities are formed in the PCB stack-up by laser cutting or by controlled depth milling.

MATERIAL IMPACT ON TRANSMISSION LINE PERFORMANCE

Planar transmission lines are traditionally utilized in PCBs as traces to transmit electrical signals between different components such as resistors, capacitors and ICs, as shown in **Figure 1**. They are also used to transmit high frequency signals between the IC and RF front-end, where controlling the line impedance is required to minimize signal propagation distortion. The high volume requirements of wireless applications increase the interest in PCB technologies for mmWave applications. Unfortunately, the high loss of the traces at mmWave frequencies reduces the power efficiency and signal integrity significantly. The impedance of the line is

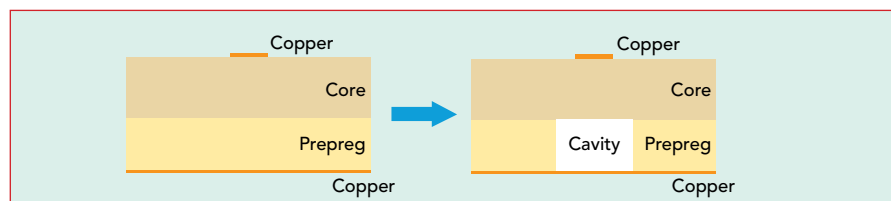
TABLE 1

DIELECTRIC MATERIAL PROPERTIES

Material	Dielectric Constant	Dissipation Factor
FR4	4.3 (at 10 GHz)	0.025 (at 10 GHz)
RO3003	3 (at 10 GHz)	0.001 (at 10 GHz)
MEGTRON6	3.34 (at 13 GHz)	0.0037 (at 13 GHz)
MEGTRON7	3.31 (at 14 GHz)	0.0023 (at 14 GHz)

determined mainly by the dielectric constant of the material, while the dielectric loss is related to the material's dissipation factor. As a result, the selection of proper dielectric material is important for PCB and HF designers.

FR4 is one of the most popular materials used in PCB construction. It consists of glass fiber and epoxy resin. Due to its low cost and known electrical and mechanical properties, it is preferred in a wide range of applications where the highest performance is not required. However, it becomes inefficient at mmWave bands because of its high dissipation factor. Furthermore, the dielectric constant can vary considerably across the length and width of the PCB depending on the glass fiber and resin content. This variation causes a degradation in circuit performance. Low loss PTFE materials or materials that contain special resin and glass cloths are used in high frequency applications. In addition to their low dissipation factors, these materials provide a more stable dielectric constant. RO3003 and MEGTRON7 are examples of common high frequency laminates. The dielectric constant and dissipation factor of some representative dielectric materials are given in **Table 1**.



▲ Fig. 2 Cross-section of the stack-ups without and with an air cavity.

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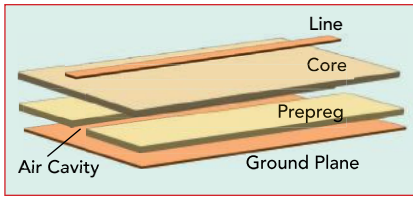


Fig. 3 Exploded view of the microstrip line with an air cavity.

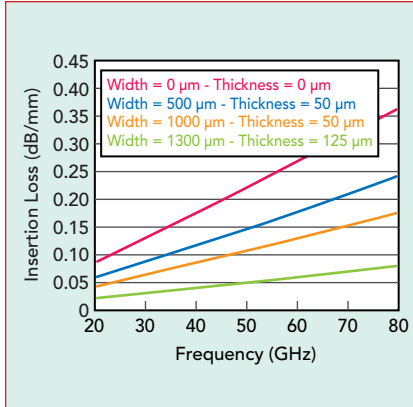


Fig. 4 FR4 insertion loss comparison.

Microstrip Line Insertion Loss Comparison

A microstrip line consists of a conducting strip, which is printed on a grounded dielectric substrate. Electromagnetic fields occur between the conducting strip and the ground plane. Most of the fields are concentrated inside the dielectric material underneath the line, which causes the atoms to polarize, creating dipole moments.⁵ Vibration of these dipole moments will create heat and that energy dissipation manifests as dielectric loss. Together with the conductor and radiation loss, dielectric loss contributes to the insertion loss of the line. Dielectric loss is quantified by the dissipation factor or loss tangent of the material. Since air has a dissipation factor ideally of 0, replacing the dielectric material with air reduces the dielectric loss, along with the total insertion loss of the line. **Figure 2** illustrates the cross-section of the proposed stack-up that contains an air cavity in the prepreg layer, while **Figure 3** shows an exploded view of the material stack.

Figure 4 compares insertion loss for different air cavity dimensions when the dielectric material is FR4. The total stack-up thickness is kept constant at 200 μm for all cases and the traces are simulated at 50 GHz.

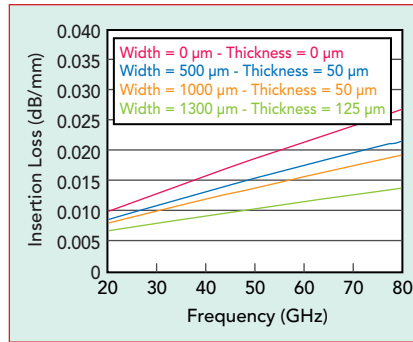


Fig. 5 RO3003 insertion loss comparison.

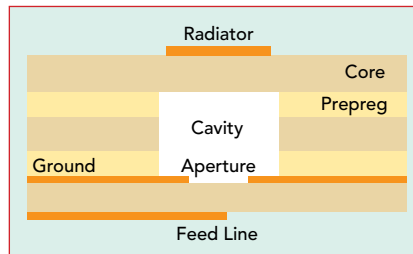


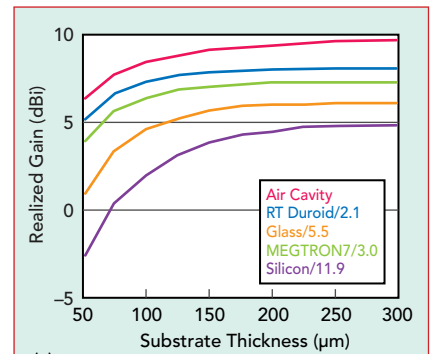
Fig. 6 Cross-section of an air cavity-backed aperture-coupled patch antenna.

The red curve at the top corresponds to the conventional microstrip line, without an air cavity. Creating an air cavity in the stack-up with a width of 500 μm and a thickness of 50 μm decreases the insertion loss by 33 percent compared to the basic microstrip line. By increasing the air cavity dimensions further and setting the width to 1300 μm and the thickness to 125 μm , the insertion loss can be reduced by 77 percent. As shown in **Figure 5**, there is also a considerable reduction in the loss by using RO3003 dielectric material. For the smaller air cavity with a width of 500 μm and a thickness of 50 μm , the insertion loss decreases by 17 percent, while loss decreases by 44 percent for the air cavity with a width of 1300 μm and a thickness of 125 μm . RO3003 is a low loss material with a low dissipation factor, so the reduction of insertion loss created by introducing air cavities should be larger for FR4.

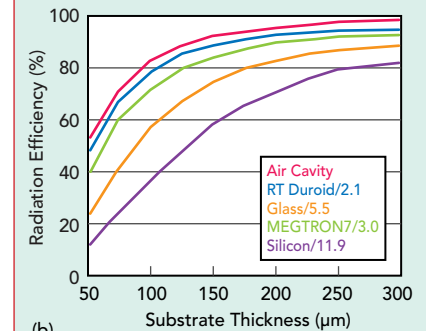
AIR CAVITY-BACKED ANTENNAS

28 GHz Air Cavity-Backed Aperture-Coupled Patch Antennas

An aperture-coupled rectangular patch antenna (ACPA) is a common antenna design for 5G mmWave modules. This type of antenna is



(a)



(b)

Fig. 7 Single patch ACPA performance.

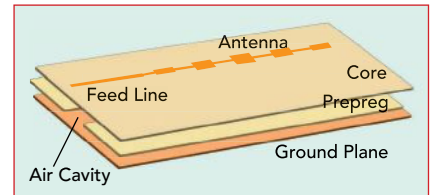


Fig. 8 Exploded view of the air cavity-backed series-fed patch antenna array.

typically fabricated using multilayer PCB technology. It includes a patch radiator on the top layer, a feed network on the bottom layer and a ground plane on the middle layer. In the ground, there is an aperture, which acts as a coupler between the feed line and the radiator. In this work, an air cavity is created in the stack-up to improve the antenna performance, as illustrated in **Figure 6**. The thickness of the air-filled layer in the MEGTRON7 material is two-thirds of the entire antenna substrate. The antenna substrate needs to have a certain thickness of low dielectric constant to obtain good radiation performance. As shown in the performance curves of **Figure 7**, the stack-up with the air cavity outperforms the other dielectric materials in terms of gain and radiation efficiency.



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TABLE 2

ANTENNA PERFORMANCE COMPARISON AT 76.5 GHZ

Model	Max. Dimension (Length-Width)	Realized Gain	Radiation Efficiency	Impedance Bandwidth (-10 dB)	Beamwidth (El.-Az.)	Side Lobe Level
FR4 without air cavity	8.71 mm - 1.1 mm	5.96 dBi	18%	6%	22.8° - 80°	-17.8 dB
FR4 with air cavity	12.1 mm - 1.5 mm	12 dBi	51%	2.57%	16.4° - 74.3°	-18.9 dB
MEGTRON6 without air cavity	9.86 mm - 1.22 mm	11.9 dBi	65%	1.73%	19.4° - 76.7°	-18.2 dB
MEGTRON6 with air cavity	12.61 mm - 1.58 mm	14.3 dBi	80%	1.77%	15.5° - 73.1°	-18.5 dB
MEGTRON7 without air cavity	9.9 mm - 1.23 mm	12.3 dBi	70%	1.6%	19.3° - 76.7°	-18.3 dB
MEGTRON7 with air cavity	12.66 mm - 1.59 mm	14.3 dBi	83%	1.7%	15.7° - 72.9°	-19.1 dB

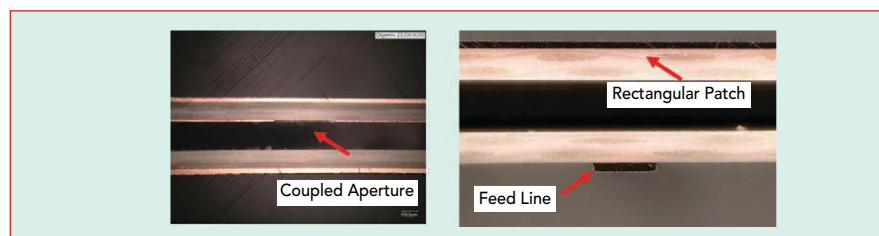


Fig. 9 Cross-section of the fabricated air cavity-backed ACPA.

77 GHz Air Cavity-Backed Series-Fed Patch Antennas

A series-fed patch array is one of the most common types of antennas used in 77 GHz automotive radars. These antennas provide a wide beamwidth in the azimuth plane to enlarge the field of view and a narrow beamwidth in the elevation plane to suppress the ground clutter. Typically, the antenna array is fed by a microstrip line on the top layer with the ground plane located on the bottom layer. In this work, an air cavity is created in the prepreg layer between the top and bottom layers as shown in **Figure 8**. Antennas are designed using different materials and with/without air cavities to make the comparison. For the stack-ups without an air cavity, the dielectric thickness is chosen as 127 μm . In the stack-ups that contain an air cavity, a total thickness of 133 μm is used. The air cavity width is set to 2000 μm , while the cavity thickness is 58 μm . As seen in **Table 2**, the air cavities increase antenna performance at the expense of larger size. The larger dimensions result from the reduction in the effective dielectric constant.

With no air cavity, the antenna on the FR4 has very poor gain and efficiency. The conclusion is that even though it has a large impedance bandwidth, FR4 alone is not suitable for this application. Forming an air cavity in the FR4 stack-up provides more than 6 dB higher gain and 33 percent better radiation efficiency. The antenna performances on the MEGTRON6 and MEGTRON7 are similar. In both cases, air cavities increase the antenna gain by roughly 2 dB and efficiency by 15 percent, while increasing the antenna dimensions by 28 percent.

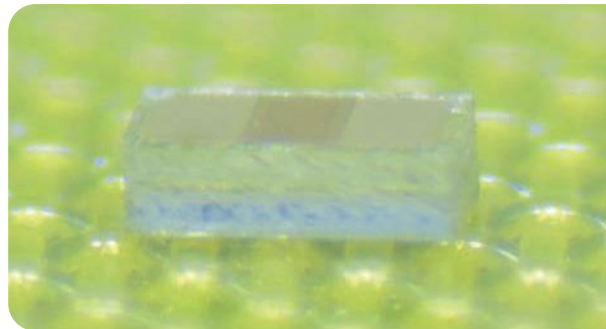
5G mmWave Air Cavity-Backed Antenna Demonstrator

This example describes a 28 GHz aperture-coupled patch antenna array with an air-filled cavity in the substrate.⁶ The stack-up consists of a core and a prepreg material using MEGTRON7 ($D_k=3.34$, $D_f=0.0037$) with a thickness of 127 μm and Doosan ($D_k=4.5$, $D_f=0.016$) with a thickness of 80 μm . The three cores are stacked with the two prepreps in a high temperature lamination process. The air cavity is produced

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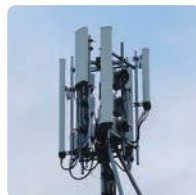


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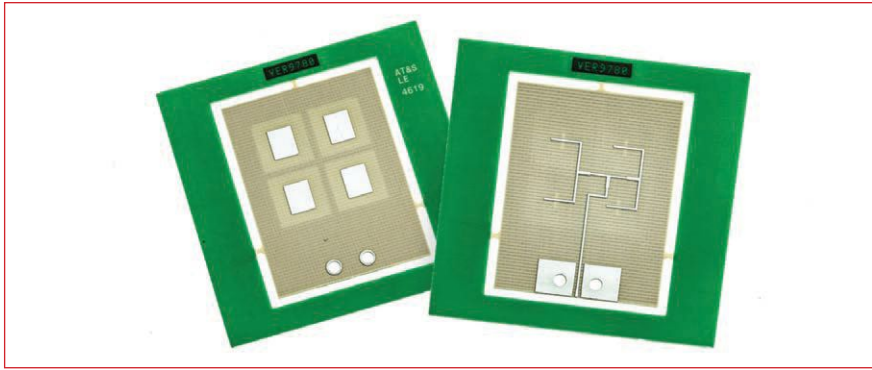
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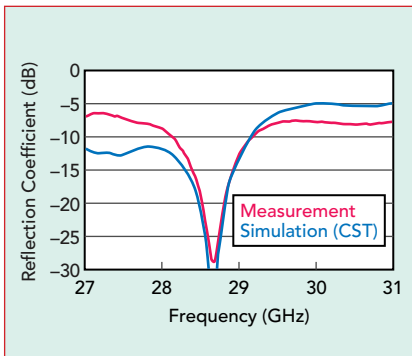
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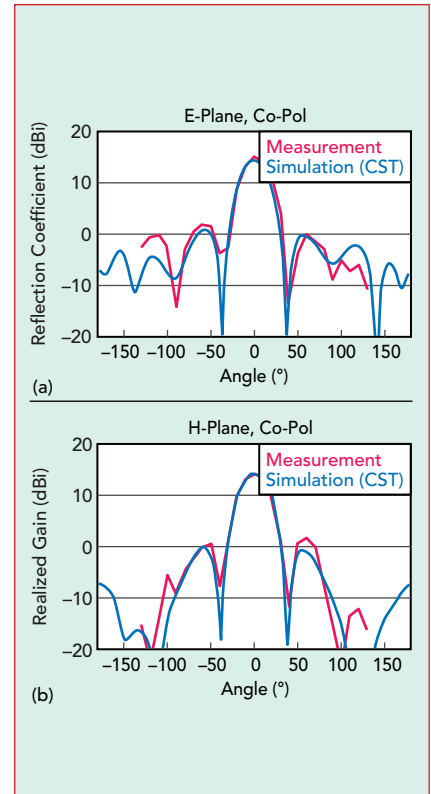


▲ Fig. 10 28 GHz air cavity-backed aperture-coupled patch antenna array.



▲ Fig. 11 Measured and simulated return loss of the air cavity-backed ACPA.

in advance of the pressing cycle by laser cutting. The dimension of the air cavity is chosen to be sufficiently larger than the patch so that the impact from fringing fields becomes negligible. It is worth noting that the Doosan prepreg material has a no-flow property. This is because the prepreg material can flow into the air cavity region and has been left as residuals that may cause significant degradation of the radiation performance. The patch dimension is 4.5 mm in width and 3.6 mm in length. The length of the open stub in the



▲ Fig. 12 Radiation patterns of the air cavity-backed ACPA at 28 GHz.



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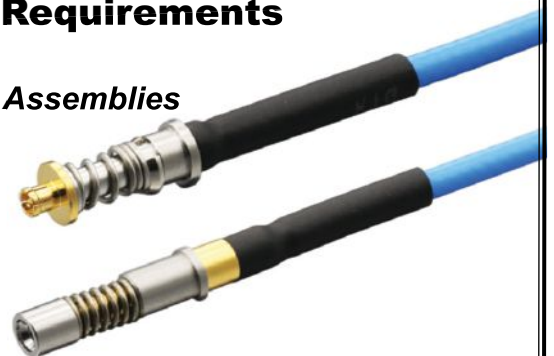
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microstrip feed line and the aperture on the ground are adjusted so that the antenna resonates at 28.5 GHz. With these patch dimensions and this configuration of the antenna substrate, a single patch antenna achieves a realized gain of 9.3 dBi.

As a demonstrator, we fabricated an ACPA array with four radiators. The cross-section of the stack-up and a picture of the fabricated array are shown in **Figure 9** and **Figure 10**, respectively. The S-parameters of the demonstrator were measured using a Rohde & Schwarz vector network analyzer and the far-field radiation pattern was measured in an anechoic chamber. **Figure 11** and **Figure 12** show the measured return loss and the radiation patterns at 28 GHz, which are compared to numerical simulation results. The antenna had a realized gain of 14.8 dBi with a 10 dB impedance bandwidth of 3.8 percent with a substrate thickness of $0.035 \lambda_0$.

CONCLUSION

Creating an air cavity in the PCB stack-up decreases the insertion losses of the traces and increases the antenna performance in the mmWave bands. The effectiveness of the air cavity depends on the cavity dimensions and dielectric material type. To realize these benefits, the air cavity dimension needs to be sufficiently larger than the traces or radiators so that the impact from fringing fields becomes negligible.

5G mmWave modules and 77 GHz automotive radars are some of the applications that can benefit from the improved performance of antenna substrates that use air cavities. To demonstrate the implementation of this concept, we fabricated and measured a 28 GHz aperture-coupled patch antenna. This antenna achieved a realized gain of 14.8 dBi and 10 dB bandwidth of 3.8 percent. ■

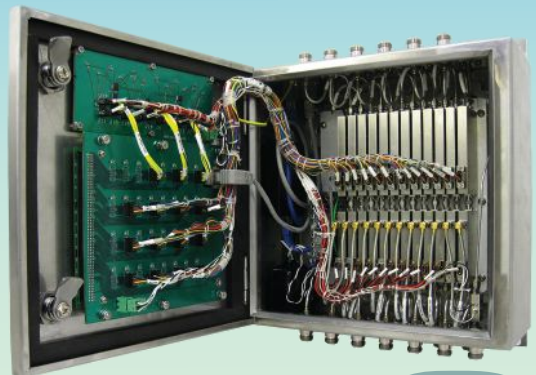
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When a signal with power P_{in} is delivered to Port 1 of a circulator with characteristic impedance Z_0 and Port 2 of the circulator is terminated in an impedance Z_L , the output power P_{out} at Port 3 is equal to $P_{in} |\rho|^2$, where ρ , the reflection coefficient, is given by Equation 1.

$$|\rho|^2 = |(Z_0 - Z_L) / (Z_0 + Z_L)|^2 \quad (1)$$

Figure 1 shows a three-port circulator terminated in Z_L . If Z_L is a resistance of Z_0 , ρ is equal to zero and P_{out} is equal to zero. If Z_L is a reactance, $|\rho|^2$ is equal to 1.0 and P_{out} is equal to P_{in} . If Z_L is a negative resistance, then $|\rho|^2$ given by Equation 2 is greater than 1.0 and the input power P_{in} is amplified. If, for example, $R = -44.68$ and Z_0 equals 50 Ω , then $|\rho|^2 = 316.7$ and $P_{out}/P_{in} = 25$ dB.

$$|\rho|^2 = |(Z_0 + R) / (Z_0 - R)|^2 \quad (2)$$

Figure 2 shows a lossless two-port network characterized by jX_{11} , jX_{12} , jX_{21} and jX_{22} defined by Equations 3a and 3b.

$$V_1 = I_1(jX_{11}) + I_2(jX_{12}) \quad (3a)$$

$$V_2 = I_1(jX_{21}) + I_2(jX_{22}) \quad (3b)$$

For a reciprocal network $X_{21} = X_{12}$. If the network of Figure 2 is terminated in a positive resistance R_{out} , then $V_2 = - (I_2) R_{out}$. By solving Equations 3a and 3b one finds that the input impedance Z_{in+} is given by Equation 4.

$$Z_{in+} = jX_{11} + \frac{(R_{out}(X_{12})^2 - j(X_{12})^2(X_{22}))}{(R_{out}^2 + X_{22}^2)} = R_2 + jX_2 \quad (4)$$

where, R_2 and X_2 are the real and imaginary parts of the input impedance Z_{in+} . If the network of Figure 2 is terminated in $-R_{out}$, then the input impedance Z_{in-} is given by Equation 5.

$$Z_{in-} = jX_{11} + \frac{(-R_{out}(X_{12})^2 - jX_{12}^2(X_{22}))}{(R_{out}^2 + X_{22}^2)} \quad (5)$$

It can be seen from Equations 4 and 5 that $Z_{in-} = -R_2 + jX_2$.

By substituting Equation 4 into Equation 2, the reflection coefficient ρ_+ , when the network of Figure 2 is terminated in R_{out} , is given by Equation 6.

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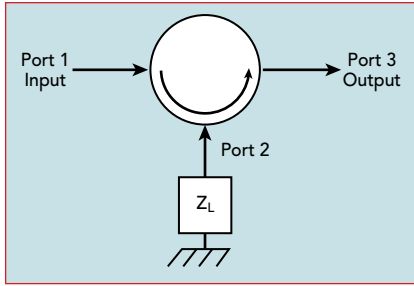
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▲ Fig. 1 Three-port circulator with Port 2 terminated in Z_L .

$$\rho^+ = \frac{((Z_0 - R_2) - jX_2)}{((Z_0 + R_2) + jX_2)} \quad (6)$$

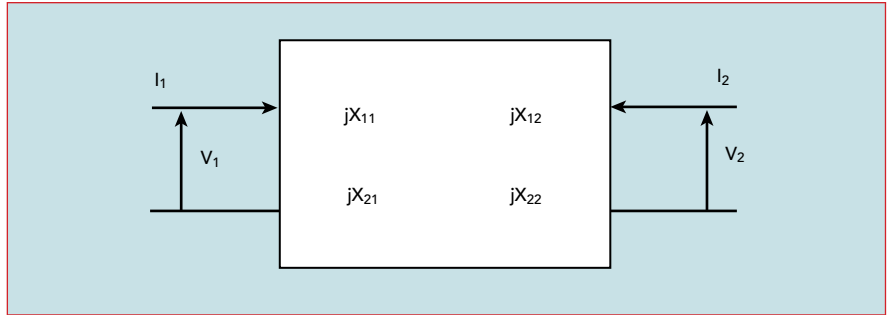
By substituting Equation 5 into Equation 2, the reflection coefficient ρ^- , when the network of Figure 2 is terminated in $-R_{out}$, is given in Equation 7. Then $(\rho^-)^*$ is given by Equation 8, where $(\rho^-)^*$ is the complex conjugate of ρ^- , and $|\rho^-|^2$ is given in Equation 9.

$$\rho^- = \frac{((Z_0 + R_2) - jX_2)}{((Z_0 - R_2) + jX_2)} \quad (7)$$

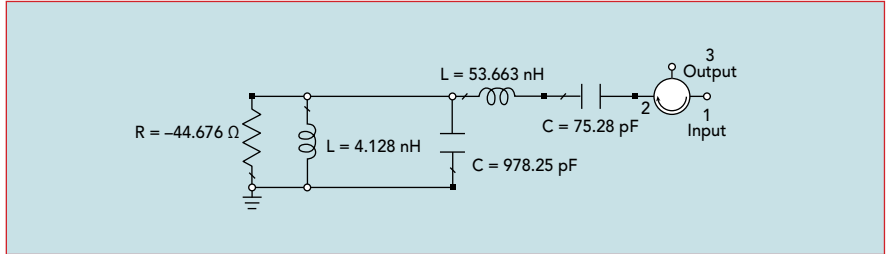
$$(\rho^-)^* = 1/\rho^+ \quad (8)$$

$$|\rho^-|^2 = 1/|\rho^+|^2 \quad (9)$$

Figure 3 shows a GNRA containing a two-section filter resonant at 79.2 MHz with a bandwidth of 6.7 MHz when terminated in 50 Ω . When the filter is terminated in a negative



▲ Fig. 2 Lossless two-port network characterized by its impedance matrix.



▲ Fig. 3 GNRA with a two-section filter resonant at 79.2 MHz.

resistance of 44.68 Ω , Equation 1 yields $|\rho^-|^2$ equal to 316.7 (25 dB) at frequency f_0 .

If the filter has an attenuation of 3 dB at f_1 and f_2 when terminated in a positive resistance, then when terminated in a negative resistance of 44.68 Ω , $|\rho^-|^2$ equals 3 dB at f_1 and f_2 and the gain of the amplifier is then 3 dB at these frequencies. The gain of the GNRA at f_1 and f_2 is therefore 22 dB below the gain at 79.2 MHz.

If, for example, the two-section filter shown in Figure 3 had a 10 percent bandwidth, then the gain of

the amplifier would be 22 dB below the gain at f_0 at frequencies $0.95f_0$ and $1.05f_0$ where f_0 equals 79.2 MHz. This result is independent of the number of filter sections; one or two sections will suffice.

COMPUTER ANALYSIS

Results of a computer analysis of the GNRA in Figure 3 are shown in **Figure 4**. The gain of the amplifier at 79.2 MHz is 25 dB and the bandwidth at a gain of 22 dB is 0.4 MHz (0.5 percent). The gain is 3 dB at 75.9 and 82.7 MHz, 22 dB below the gain at 79.2 MHz.

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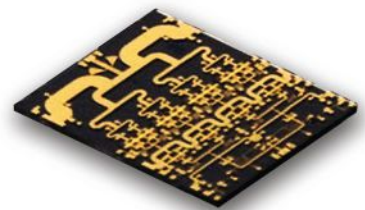
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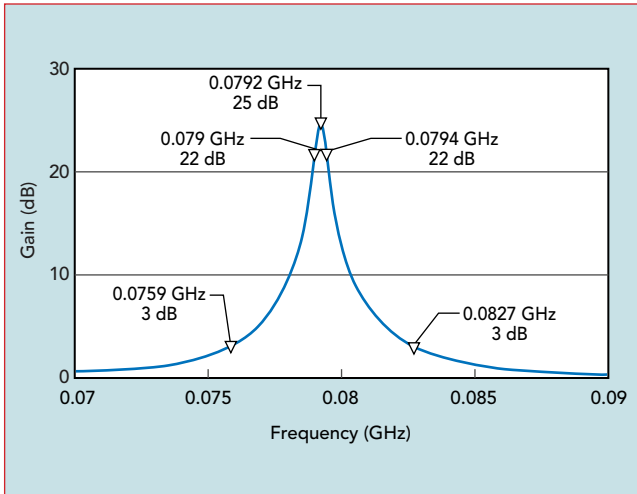
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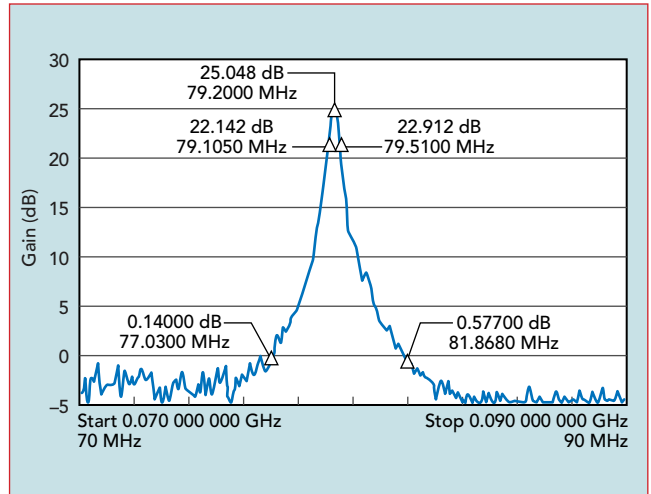
▲ Fig. 4 Results of an analysis of the GNRA in Figure 3.

EXPERIMENTAL RESULTS

The GNRA in Figure 3 exhibits a negative resistance using an operational amplifier with appropriate feedback. The measured results in **Figure 5** show a 3 dB bandwidth of approximately 400 KHz (0.5 percent). Gain is approximately zero at 77.0 and 81.9 MHz.

SUMMARY

Analysis of a lossless two-port terminated in a negative resistance has been presented which shows that the reflection coefficient of the two-port when terminated in a negative resistance is the reciprocal of the complex conjugate of the reflection coefficient when terminated in a positive resistance. The GNRA uses this property to realize very narrow bandwidth amplifiers. A bandwidth of 0.5 percent is experimentally achieved. ■



▲ Fig. 5 GNRA measured results.

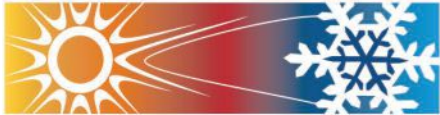
ACKNOWLEDGMENT

The author wishes to acknowledge the support provided by Dr. Ashok Gorwara and the staff of Gorwara & Associates International, Inc., 2200 South Ocean Lane, Suite 2002, Fort Lauderdale, Fla.

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Editor's Note: Although this work was accomplished at VHF frequencies, the method should apply generally to higher frequencies as well.



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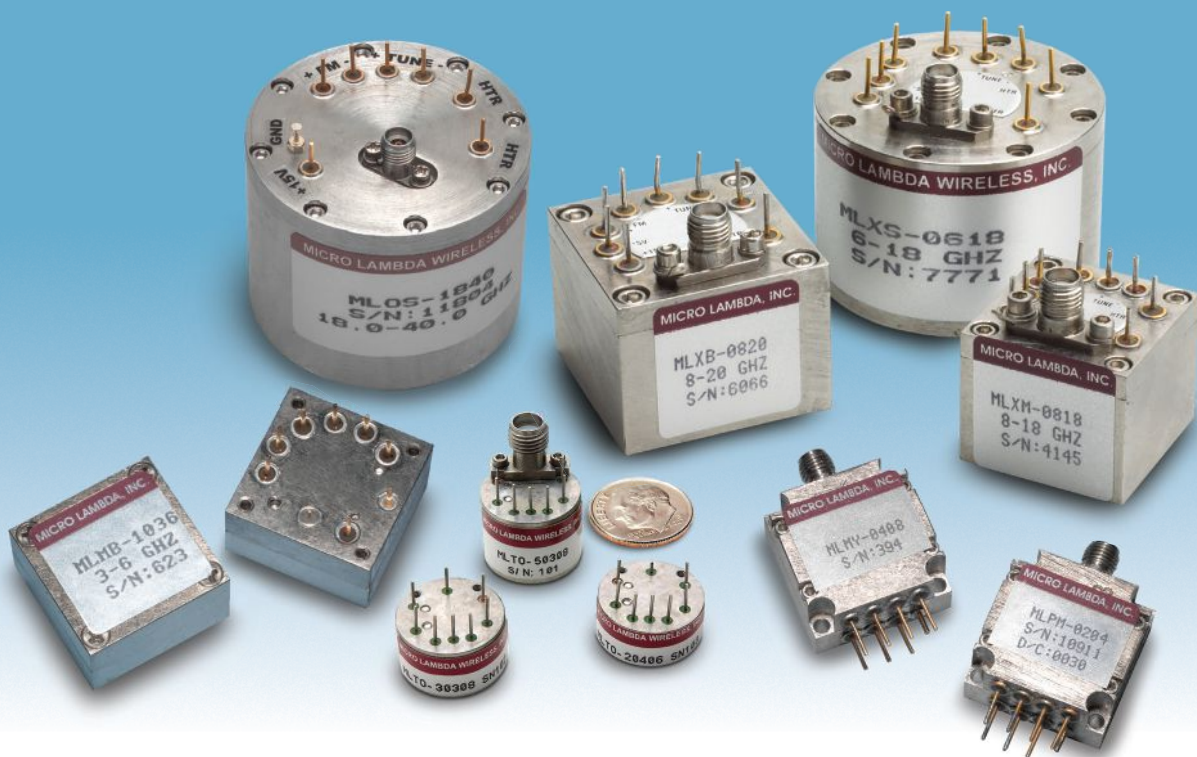



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Design of a Tri-Band Microstrip Bandpass Filter with High Performance for 5G Applications

Qingqing Ye and Lijun Zhang

Institute of Microelectronics of Chinese Academy of Science, Beijing, China

A tri-band microstrip bandpass filter is designed for 5G applications. It uses multi-mode stepped-impedance resonators (MSIRs) and open loop ring resonators (OLRRs). By controlling the impedance ratio and electric length of the MSIRs, higher resonant modes are suppressed out of band. The meander OLRRs produce two extra transmission zeros in the upper and lower sides of the second passband that provide good isolation between passbands. A high performance passband response is demonstrated with a small shape factor and low insertion loss. Measured results show good agreement with simulation.

With the rapid development of modern wireless communication systems, the multi-band filter has become a critical circuit component for versatile 5G applications. Much work has been done on the design of multi-band filters with low loss and high selectivity.¹⁻³

There are several approaches. In the work of Tsai and Hsue,⁴ a bandpass filter (BPF) and a bandstop filter were cascaded to realize a dual-band BPF. It results in a large circuit size, however, and requires addi-

tional external matching networks as well. The use of OLRRs and stub-loaded OLRRs^{5,6} is a simple and effective method for multi-band filter design. Unfortunately, higher-order modes are easily excited. Stepped-impedance resonators (SIRs), characterized by controlling higher-order modes conveniently, are also typically used;⁷⁻⁹ however, poor isolation between passbands and complexity are major disadvantages.

In this work, a novel tri-band microstrip BPF is designed based on a simple and effective method. The filter comprises two open-end microstrip lines,

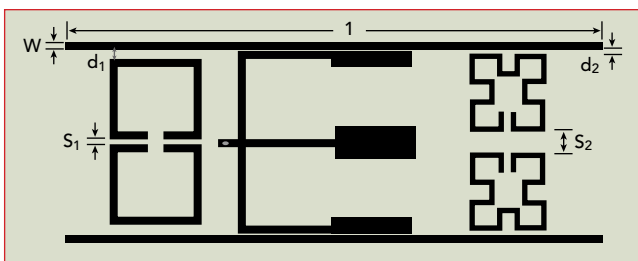
greater skirt selectivity with two extra transmission zeros.

RESONATOR ANALYSIS

The OLRRs and meander OLRRs have been analyzed by Hong,¹⁰ therefore, only the MSIRs will be reviewed theoretically here. **Figure 2a** shows the MSIR structure. Even-odd mode analysis can be used due to its symmetry. **Figure 2b** is the even mode equivalent circuit and **Figure 2c** is the odd mode equivalent circuit.

The input admittances for even and odd modes can be expressed by Equations (1) and (5).

Here, l_1 , l_2 , l_3 , l_4 and l_5 are the lengths of each stub with impedances z_1 , z_2 , z_3 , z_4 and z_5 . The corresponding electrical lengths of the stubs are $\theta_1 = \beta_1 l_1$, $\theta_2 = \beta_2 l_2$, $\theta_3 = \beta_3 l_3$, $\theta_4 = \beta_4 l_4$ and $\theta_5 = \beta_5 l_5$. The impedance ratio $k_1 = z_2/z_1$ and $k_2 = z_3/z_1$. The resonant condition of the MSIRs is when the input admittance



▲ Fig. 1 Tri-band filter schematic layout.

The filter comprises two open-end microstrip lines, a pair of MSIRs and two pairs of OLRRs (see **Figure 1**). The MSIRs tune the higher-order modes and higher-order upper stopband. The meander OLRRs, provide

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equals zero, namely, $Y^e = Y^o = 0$. Then:

$$Y_{in}^e = (jY_2 k_1 C + \tan \Theta_2) / (D - k_1 \tan \Theta_2 C) \quad (1)$$

$$C = 2 \tan \Theta_1 + B - \cot \Theta_5 \quad (2)$$

$$D = \tan \Theta_1 \cot \Theta_5 - B \tan \Theta_1 + 2 \quad (3)$$

$$B = (\tan \Theta_3 + k_2 \tan \Theta_4) / (k_2 - \tan \Theta_3 \tan \Theta_4) \quad (4)$$

$$Y_{in}^o = jY_2 (\tan \Theta_2 \tan \Theta_1 - k_1) / (\tan \Theta_1 + k_1 \tan \Theta_2) \quad (5)$$

As shown in **Figure 3**, the first even mode (f_{even}^1) and the first odd mode (f_{odd}^1) resonant frequencies can be tuned by changing the impedance ratio k_1 . The impedance ratio k_2 mainly influences the second even mode (f_{even}^2). **Figure 4** shows that f_{even}^1 and f_{even}^2 also depend on the lengths of l_3 and l_5 ,

respectively. The resonator can then be determined by properly choosing these parameters.

TRI-BAND BPF DESIGN

Based on the theory of MSIRs, the tri-band BPF centered at 2.4, 4 and 5.6 GHz is designed (see Figure

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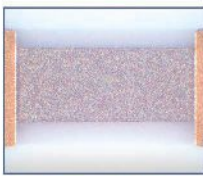
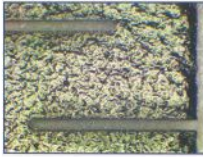
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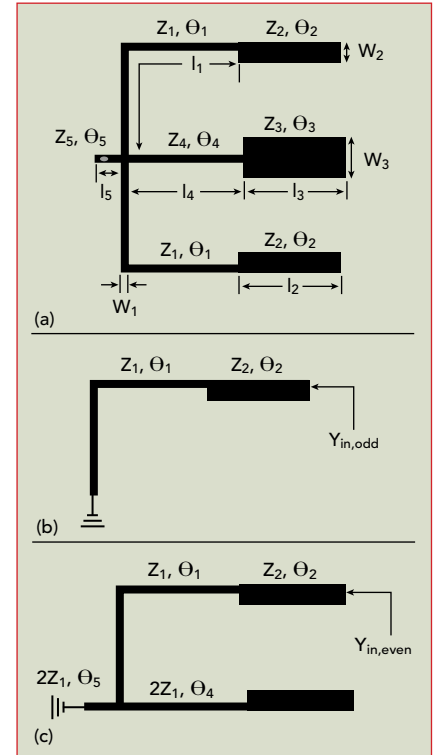




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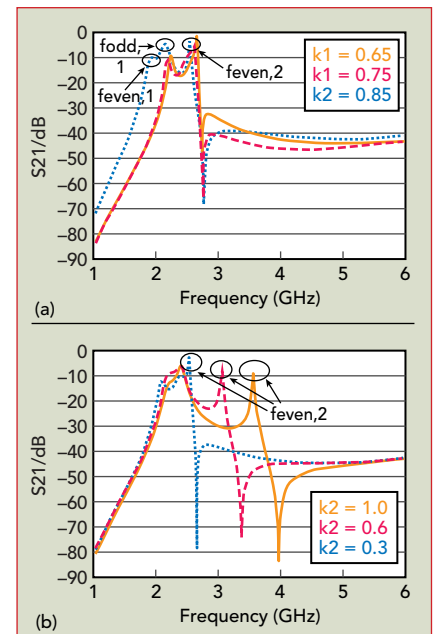
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▲ **Fig. 2** MSIR structure (a), even-mode equivalent circuit (b) and odd-mode equivalent circuit (c).



▲ **Fig. 3** Operating frequencies as a function of impedance ratios k_1 (a) and k_2 (b).

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1). It comprises two open-end feed lines, a pair of MSIRs and two pairs of OLRRs. The MSIRs determine the first passband center frequency, fractional bandwidth and selectivity. The chosen parameters are: $k_1 = 0.75$, $k_2 = 0.3$, $l_1 = 7.6$ mm, $l_2 = 3.93$ mm, $l_3 = 3.6$ mm, $l_4 = 3.24$ mm, $l_5 = 0.1$ mm, $w_1 = 0.195$ mm, $w_2 = 0.4$ mm and $w_3 = 1.8$ mm.

The OLRRs are traditional half wavelength resonators determining the second and third passband responses. The difference is that the OLRRs used in the second passband are meandered. Two extra transmission zeros are produced between the first and second and the second and third passbands. This improves passband isolation and selectivity.

The bandwidths depend on the coupling coefficients and external quality factors. That is, s_1 , s_2 , d_1 and d_2 affect the bandwidths; $s_1 = 0.4$, $s_2 = 0.6$, $d_1 = 0.1$ and $d_2 = 0.2$ mm. The length L of the open-end feed line is about a half wavelength at the first operating frequency of 2.4 GHz and

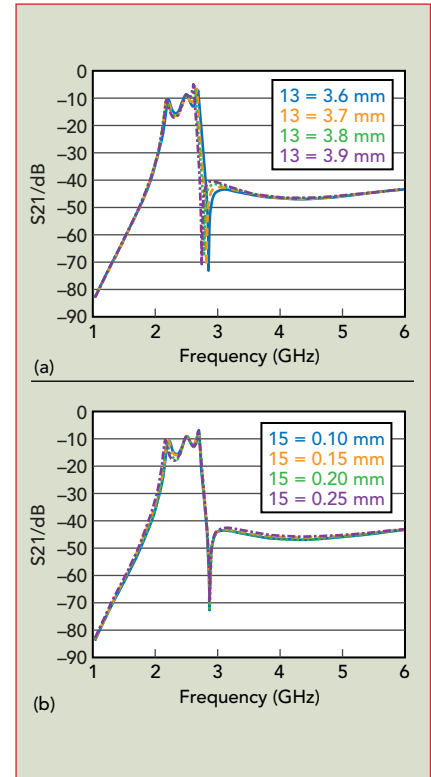
the impedance is 50 Ω . Here $L = 30$ and $w = 0.5$ mm.

Figure 5 shows the current distribution of the feed line at 2.4, 4 and 5.6 GHz. The resonators are placed at positions of maximal current distribution for strong magnetic coupling.

The filter is fabricated on a substrate with a relative permittivity of 9.6 with a dielectric height of 0.5 mm. The overall size of the filter is 30 $\times$ 9 mm.

RESULTS AND DISCUSSION

The tri-band BPF (see **Figure 6**) is simulated using ADS Momentum and measured using a Keysight 8719ES network analyzer (see **Figure 7**). Measured results show good agreement with the simulation. The passbands are centered at 2.4, 4 and 5.6 GHz with 3 dB bandwidths of 5.9, 44 and 22.4 percent, respectively, with insertion loss less than 1.1, 0.8 and 0.1 dB. The locations of transmission zeros are at 2.72, 3.2, 3.68, 4.35, 4.8 and 6.6 GHz, providing rejection greater than 35 dB.



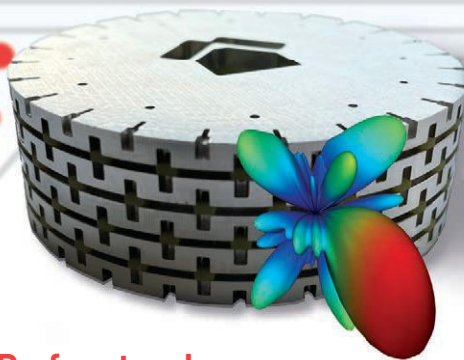
▲ Fig. 4 Operating frequencies as a function of lengths l_3 (a) and l_5 (b).



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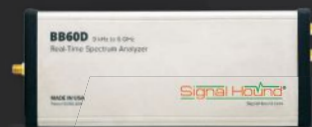
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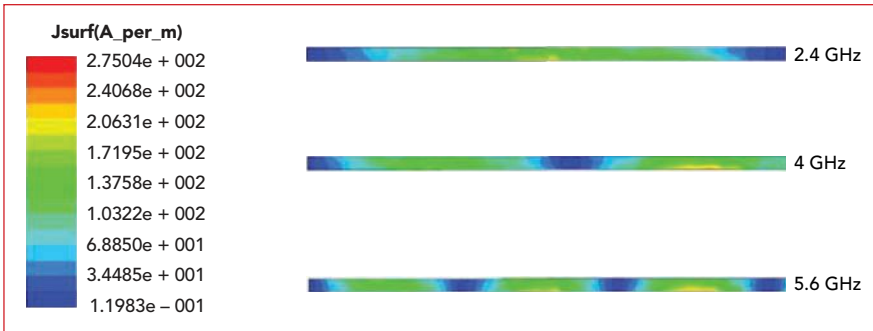


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▲ Fig. 5 Current distribution of open-ended feed line.



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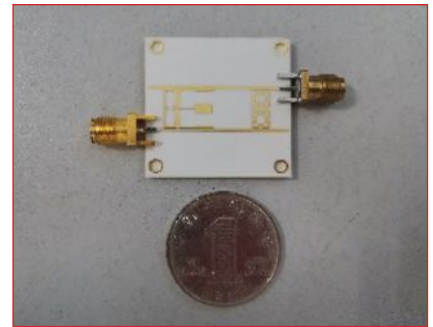
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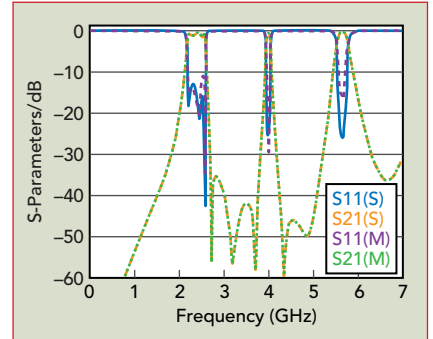
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▲ Fig. 6 Tri-band BPF photograph.



▲ Fig. 7 Tri-band BPF simulation and measurements.

Table 1 compares this performance with other work, showing that this filter contains the most transmission zeros and the best isolation between passbands.

CONCLUSION

A novel tri-band BPF combines MSIRs and OLRRs. The proper impedance ratios and electrical lengths of the MSIRs realize a wide upper stopband. The meander OLRRs produce two extra transmission zeros at the upper and lower sides of the second passband, which improves band-to-band rejection. Consequently, the low-cost tri-band BPF is only $30 \times 9 \text{ mm}^2$ with operating frequencies at 2.4, 4 and 5.6 GHz. The insertion loss of each band is less than 1.1 dB and band-to-band rejection is better than 35 dB. High selectivity, compact size and low insertion loss makes it attractive for use in 5G applications. ■

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TABLE 1

COMPARISON WITH OTHER WORK

Reference	Frequency (GHz)	Zeros at 2nd Passband	3 dB Bandwidth (percent)	IL (dB)	Shape Factor
6	2, 3.2, 4.3	2	10.7, 9.8, 5.8	1.5, 1.8, 2.2	6, 3.53, 3.67
11	0.93, 2.19, 3.61	4	49.5, 43.1, 14.09	0.28, 0.42, 0.82	2.9, 2.8, 4.5
12	1.37, 2.43, 3.53	3	4.4, 5.9, 2.7	1.7, 1.8, 2.5	5.0, 4.1, 7
This Work	2.4, 4, 5.6	5	5.9, 44, 22.4	1.1, 0.8, 0.1	2, 1.27, 4



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Next-Generation DAS Technology Emerges to Serve 5G Needs

Kevin Hietpas
Pasternack, Irvine, Calif.

Previous generations of cellular networks have relied on distributed antenna systems (DAS) to provide in-building coverage and to fill coverage gaps in complex structures. Though the same is true for emerging 5G systems and rollouts, there is a twist. Where previous generations of DAS antenna usually meant just covering new bands, 5G DAS also needs to support multi-antenna operation for advanced/active antenna system (AAS) beamforming and MIMO techniques that enable 5G. To support 5G speeds and coverage goals, new 5G DAS must also offer superior electrical performance. This is a challenge for network and antenna solutions.

5G REQUIREMENTS & CHALLENGES FOR NEXT-GENERATION DAS SOLUTIONS

Much of the cellular deployment and application discussion focuses on outdoor usage. We are familiar with mobile handset and automotive outdoor usage, but recent studies¹ show that over 80 percent of voice and data usage for handsets occurs indoors. This means that much of the demand for 5G services is likely to come from users located in buildings. While cellular network deployments will be able to provide outdoor coverage to users, it is unlikely that these networks will provide adequate coverage in mass transit systems, large venues, office spaces, warehouses and other indoor spaces. 5G will rely heavily on high frequency

spectrum and the propagation characteristics of these signals mean they do not effectively penetrate buildings with concrete and low emissivity glass.

Traditional DAS Challenges

These new challenges are similar to traditional DAS challenges: how do we get cellular coverage into large, complex structures that are made up of a diverse mix of reflective and absorptive materials, along with odd geometries and layouts? With traditional cellular deployments, the link to the cellular services is often through an external antenna that connects to an existing cellular base station and tower. Alternatively, if the venue is large enough, it may have its own base station or use a nearby base station to route signals into the DAS.

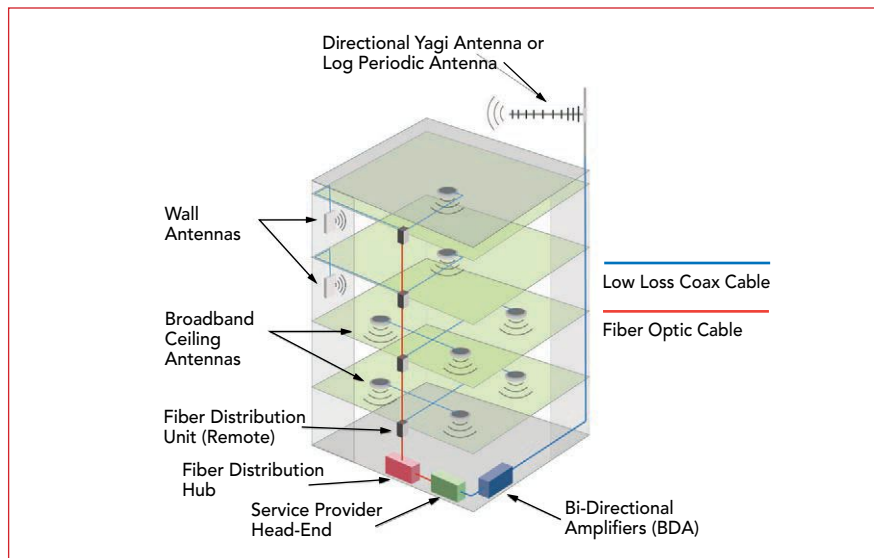
Much of the design challenge is determining an appropriate layout for the DAS antenna, remote radio heads or nodes depending on the DAS architecture. Network designers must consider the use of RF cable runs, repeater antennas, fiber optic and Ethernet interconnections between the cellular network and the DAS. The DAS architecture must ensure adequate coverage with the desired frequency bands. As Wi-Fi has grown in popularity, DAS designers are facing the new challenge of offering multi-operator cellular services along with Wi-Fi services. The solution to these challenges typically involved upgrading the DAS hubs, antennas and interconnects to accommo-



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▲ Fig. 1 Indoor DAS network architecture.

date these new frequency bands while ensuring that DAS placement met customer expectations for service coverage. A typical indoor DAS network is shown in **Figure 1**.

Emerging 5G DAS Challenges

5G currently uses three frequency ranges, with a variety of frequency bands within those ranges. GSMA defines these three 5G frequency ranges as low-band, with frequencies below 1 GHz, mid-band with frequencies from 1 to less than 7 GHz and high-band as frequencies above 7 GHz, but generally mmWave frequencies. The low-band frequencies generally exhibit the greatest range and coverage capability, but at limited data rates and capacity. Low-band networks are being deployed mostly in rural areas lacking good 4G coverage. These areas likely will not be significant for new DAS deployments. The mid-band range covers the frequency capability of most cellular handsets and this band is seeing the majority of current 5G activity. The mid-band frequency range is adjacent to other common wireless services, such as the 2.4 and 5 GHz ISM bands with services like Wi-Fi, Bluetooth, Zigbee and Matter. The high-band frequency ranges are in the mmWave spectrum where there is currently less activity and deployment effort. However, high-band services are likely to continue to be developed and deployed for

the next several decades and future DAS deployments will increasingly need to account for services in these frequency ranges.

Beyond extending the frequency range to 7 GHz, or 7.125 GHz to accommodate Wi-Fi 6e, other capabilities differentiate 5G mid-band systems from legacy cellular technologies. Though 4G/LTE standards did introduce multi-antenna MIMO technologies, these are relatively simple arrangements of a handful of antennas, at most. In these cases, MIMO is generally used to achieve peak data rates for a single-user device. 5G standards introduced multi-antenna technologies to enhance coverage for several users in a given area, as well as beamforming technologies to enhance the gain of a given 5G antenna toward target user devices. For DAS to provide the same capabilities as 5G network antennas, they must become more complex and capable with multi-antenna technology.

New 5G AAS technology enables much higher data rates and coverage in complex deployment scenarios, but this capability must be supported by the DAS distribution system and infrastructure. To do this, DAS interconnects must be able to support higher capacities, regardless of the 5G signal source. In addition, 5G DAS must support the legacy 4G/LTE cellular systems along with new 5G frequency bands and technologies.

Fundamentally, DAS is entering a new era with 5G. Legacy 4G/LTE networks and services have evolved with mobile handsets as the focal point. The 5G vision addresses ultra-reliable low latency communications (URLLC), massive machine-type communications (mMTC) and enhanced mobile broadband (eMBB). These additional use cases and implicit capabilities broaden the focus to IoT devices and critical systems requiring reliability and low latency services. This repositioning envisions applications from real-time monitoring systems to autonomous mobile robots operating alongside human workers, customers and/or pedestrians.

Aside from massive MIMO (mMIMO) and beamforming, additional 5G technologies will impact how DAS are designed and deployed. While things like network slicing and network function virtualization are more of a consideration for 5G network operators, these features will influence the DAS requirements. New and emerging business cases will also influence DAS requirements as many large enterprises, government organizations and large campuses are considering 5G private networks alongside public 5G networks.

DAS EVOLVES TO ADDRESS 5G COVERAGE CHALLENGES

To address these challenges, the underlying infrastructure, interconnects and DAS antennas must evolve. Despite a large diversity of DAS solutions, more product solutions and availability are needed to maintain, upgrade and deploy new DAS installations.

Signal Source

The cellular network is an extension of the internet backbone. A mobile core in the cellular access network is the bridge between the radio access network (RAN) and the internet infrastructure. In 5G networks, that mobile core may be deployed at the edge and the mobile core and RAN may be co-located. A backhaul network connects the RAN to the base stations and then a remote radio unit (RRU) distributes wireless service from the base sta-

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tion to the user equipment. In these systems, the DAS may connect to the cellular network through an antenna, a base station or a small cell.

Using small cells to drive DAS is becoming a more common solution to support the throughput and capacity expected from 5G services. This solution requires multiplexing small cells from each service provider to the backhaul internet connection. Aggregating rapidly

growing 5G traffic may strain transport capabilities and this may necessitate the installation of higher capacity transport networks. Worst case, this increases the DAS costs and complexity, but much of this 5G traffic may be replacing already existing traffic, resulting in little to no need for increased capacity. Small cell connections are likely to be the biggest growth sector as DAS seeks to enable 5G performance expecta-

tions and features. In response to a perceived need for in-building 5G services, small cell manufacturers are enhancing their DAS-like distribution systems. The result appears to be a convergence of small cell and DAS technology for in-building applications.

Signal Distribution

There are three main strategies for DAS signal distribution: passive, active and hybrid. Passive DAS uses a DAS head end connected to a signal source, which feeds a passive DAS network of antennas and other passive components. Common passive components in this arrangement include splitters, coaxial cable, coaxial adapters, tappers, combiners, dividers and couplers. Passive DAS systems rely on RF signal generation, so they are only as capable as the signal source. These systems have limitations in 5G installations and may be useful only for applications like the last stage of distribution in a hybrid DAS system. An active DAS system uses digital data transmitted over a fiber or Ethernet network to a master unit. The master unit converts the source data to digital signals for distribution to the active DAS antenna. Electronics in these units convert the data stream to RF or digital as needed. A hybrid DAS is similar to an active DAS, but the RF/digital conversion takes place in a separate unit that feeds several RRUs.

It is difficult to determine the mix of signal distribution techniques for 5G services. All methods will likely be necessary to accommodate various installation dynamics and cost considerations. To integrate DAS with 5G services, the antenna units or RRUs must support 5G multi-antenna or AAS technology. DAS antenna units must evolve from omnidirectional and directional antennas to arrays supporting MIMO and beamforming technologies. These technologies require much higher interconnect densities and signal distribution complexity than previous cellular technologies. To reduce costs and maintain small footprints, DAS systems will become more integrated and incorporate denser board-level technologies.

DAS antennas and distribu-



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KBM9010180	1.0 – 18.0	1.7	12.0	±18	±1.0	14
KBM9014265	1.4 – 26.5	2.0	13.5	±17	±1.6	10
KBM9020060	2.0 – 6.0	1.4	7.5	±8	±1.0	15
KBM9020070	2.0 – 7.0	1.5	8.0	±10	±0.8	14
KBM9020080	2.0 – 8.0	1.5	8.5	±10	±0.8	14
KBM9060265	6.0 – 26.5	2.0	13.5	±16	±1.6	10
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KBM9180400	18.0 – 40.0	2.0	12.0	±15	±1.3	12
KBM9240300	24.0 – 30.0	1.9	11.0	±15	±1.3	12
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tion systems must support higher throughput and higher frequency signals and provide better performance than prior generations of cellular networks. Higher frequency 5G signals will experience higher transmission and RF component losses. Offsetting these losses may require higher transmit power, but this will create concerns about passive intermodulation distortion and other nonlinear characteristics. Degrading

performance in these areas could reduce the signal-to-noise ratio, bit-error rates or packet-error rates. The active components in a DAS will need higher levels of linearity over a much wider bandwidth than with previous cellular generations. The RF-to-digital and digital-to-RF conversion electronics will require much higher conversion rates in response to the new 5G frequency bands. Conversion electronics in these bands are

expensive and this may drastically increase the cost of active and hybrid DAS compared to passive DAS.

Future mmWave DAS

The previous discussion focuses primarily on sub-6 GHz 5G implementations. Incorporating mmWave 5G technologies into DAS systems presents a different set of challenges. mmWave 5G enables high throughput and much more targeted signal distribution. mmWave 5G is seeing some success in the fixed wireless broadband market where 5G wireless services are used to deliver home internet and other media services. Enterprise and in-building applications have been slow to emerge at these frequencies and it seems unlikely that millimeter DAS will be deployed in the short term. Enabling faster millimeter DAS adoption will require an ongoing evolution of RF and digital technologies, along with new building construction material and layout considerations.

CONCLUSION

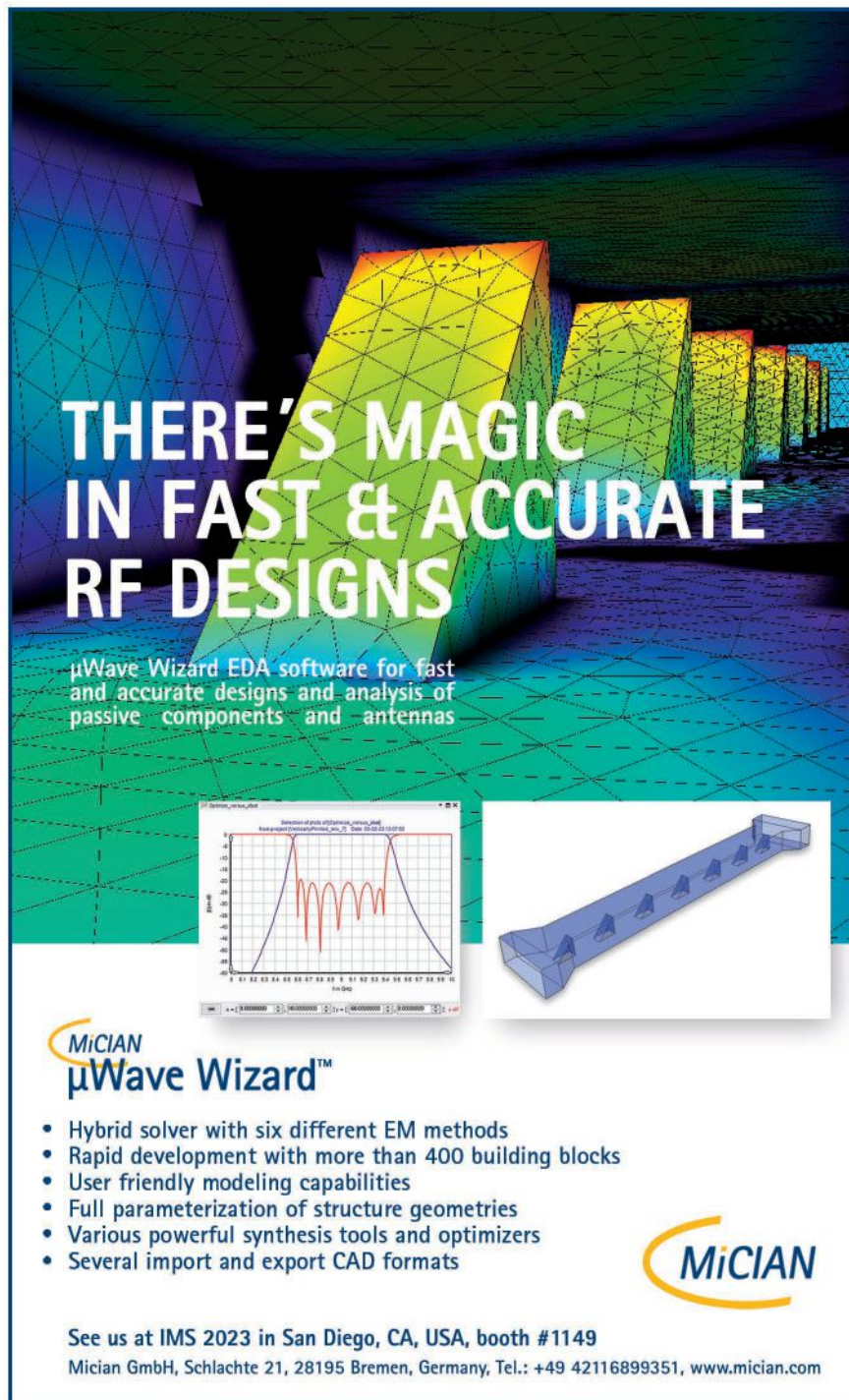
The outcomes and exact steps along the way are never clear with any emerging technology. This is the same with DAS evolving to include 5G technologies. What is clear is that there is currently competition from small cell manufacturers, service providers and DAS installers. The lines are blurring between DAS and small cells when it comes to providing 5G services in venues, stadiums, arenas, mass transit systems, campuses and enterprise locations. Much more flexibility will be needed for DAS installers and service providers to develop methods of delivering 5G services in buildings, where most 5G services will be used. ■

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1. <https://blog.pasternack.com/antennas/distributed-antenna-system-das-basics>.
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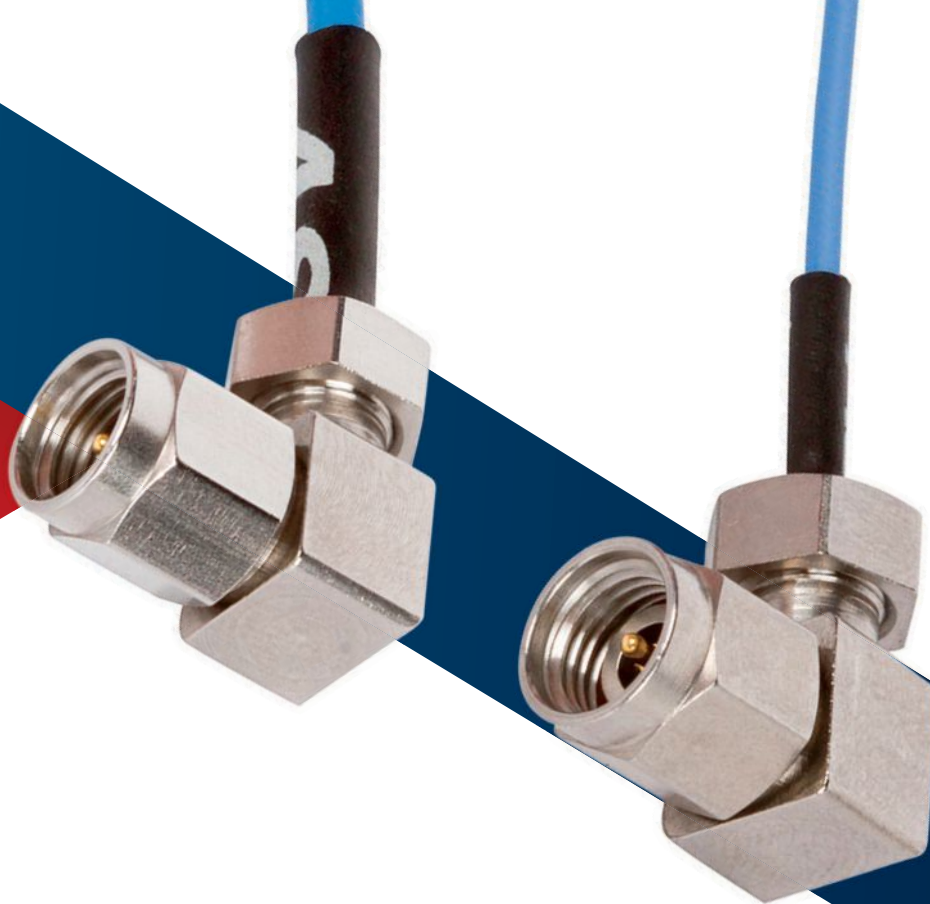
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Editor's Note: This application note describes signaling and timing methods, along with power management architectures used in planar phased arrays. In a companion article entitled "Overcoming Planar Phased Array Circuit Design Challenges," published in the March 2023 issue of Microwave Journal, the authors discuss the PCB and thermal design and layout challenges associated with the digital and RF circuitry used in planar phased arrays.

Signaling and Timing Methods for Planar Phased Arrays

Joel Dobler and Sam Ringwood
Analog Devices, Wilmington, Mass.

Two-dimensional planar phased array systems, where the RF circuitry and the antenna elements are on the opposite sides of the same PCB as shown in **Figure 1**, offer a significant size advantage over 3-D blade-style structures. But that size advantage brings layout, power management and thermal challenges in addition to the traditional timing design challenges associ-

ated with radar systems. This application note discusses the signaling and timing methods to control power amplifier (PA) and low noise amplifier (LNA) biasing, transmit (Tx) and receive (Rx) switching, memory loading and beam advance in planar phased arrays. The power management design for the RF front-end is explained, including the power tree and the specific bias sequencing required to avoid PA damage.

RADAR SYSTEM DESIGN AND TIMING

In modern phased array radars, the variable phase and amplitude blocks are consolidated into a beamformer integrated circuit (BFIC), with each BFIC containing several variable amplitude and phase blocks. Also, the PA, LNA and Tx/Rx switch can be integrated into a single Tx/Rx module and be optimally designed to work directly with the BFIC.

A monostatic pulse radar has two critical timing characteristics: the transmit pulse duration (τ) and the pulse repetition time (PRT), which is the time between transmit pulses. Modern radars have transmit

pulse durations that range between 10 and 100 μ s. However, some applications feature pulse durations as short as 500 ns. Typical rise and fall times are between 500 ns and 1 μ s and transmit duty cycles are between 1 and 20 percent. Typical pulsed radar timing is illustrated in **Figure 2**.

Radar metrics such as the minimum measurement range (R_{MIN}) or blind range, range resolution and hits-per-scan are directly proportional to τ and PRT. The minimum measurement range is also directly proportional to Tx-to-Rx switching time:

$$R_{MIN} = \frac{c \times (\tau + t_{TR_Switching})}{2} \quad (1)$$

Minimizing Tx-to-Rx switching time is critical in search radar where targets can be relatively close to the transmitter. Monostatic phased array radar oftentimes is a half-duplex system. Tx-to-Rx switching is accomplished with several control signals that must be sequenced together. These control signals perform the following functions:

- Toggle the Tx/Rx switch
- Enable and disable the PA
- Enable and disable the LNA
- Enable and disable the BFIC's Tx and Rx paths.

When the beam direction changes, new beam weights must be loaded into the variable amplitude and phase blocks. If local on-chip



Fig. 1 A planar phased array front-end prototyping board (component side).

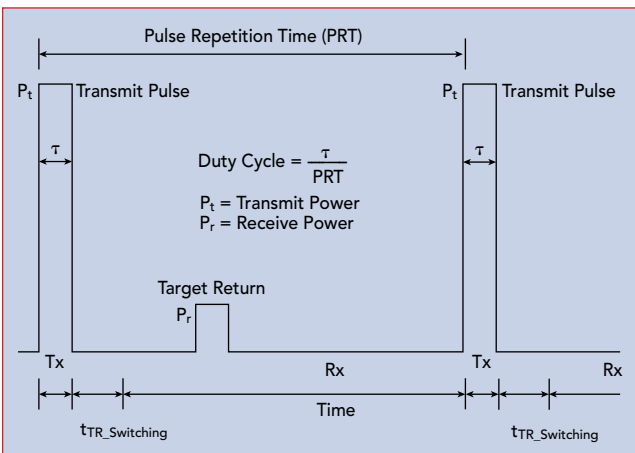
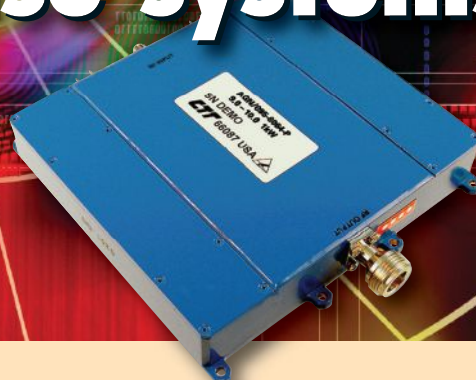


Fig. 2 Simplified radar timing.



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ApplicationNote

memory is available to store multiple sets of beam weights, the beam advance can be initiated with a single pulse of a control pin and with no SPI writes. An example of the sequencing and voltage levels of these controls is shown in **Figure 3**.

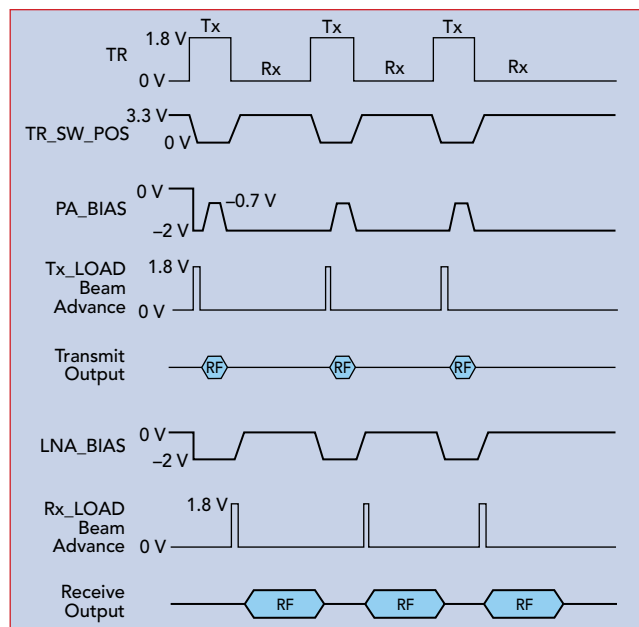
An example of real-world control signaling and interfacing is shown in **Figure 4**. A single channel of the ADAR1000 BFIC is shown connected to a single ADTR1107 Tx/Rx module. The two chips feature a single Tx/Rx control signal going to the ADAR1000 via the Tx/Rx pin. This pin, in turn, controls the PA bias, LNA bias and the Tx/Rx switch on the ADTR1107 Tx/Rx module. It also controls the enabling/disabling of the ADAR1000 internal Tx and Rx beamforming paths. Integrating the Tx/Rx control not only reduces the board layout complexity by eliminating numerous control lines but also enables fast Tx-to-Rx switching times so that metrics like the minimum measurement range are as short as possible.

BEAM MEMORY

A discrete beamforming solution must apply beam weights from a memory chip to the various variable amplitude and phase shifter blocks. The increased routing complexity and time required to do a beam advance are two major drawbacks of discrete system design. Modern phased array radars using integrated BFICs like the ADAR1000 have on-chip memory requiring a single load pulse and a few additional clock cycles to advance to a new beam. Newer BFICs like the ADAR3000 and

ADAR3001 have simplified this to a single pulse with no clock cycles.

In the example shown in Figure 4, the ADAR1000 BFIC features two on-chip locations that can store beam data: registers and random-access memory (RAM). There are advantages and disadvantages to using ei-



▲ **Fig. 3** Transmit and receive timing with RF signaling, switch control and amplifier bias.

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ther type of memory for the storage of beam data. Both types are limited by the maximum SPI clock rate of 25 MHz when writing and reading beam data.

Sourcing beam data from the registers has the advantage of having only enough data for one beam position. That data is directly stored in the registers, meaning there is no need to operate the sequencer or perform any memory fetching. This mode of operation can be im-

portant in applications where users do not know what their next beam steering angle is a priori and thus an on-the-fly scheme of writing new beam data needs to be implemented for each new beam steering angle. The downside of using the registers is the time it takes to clock in each new beam position, which is limited by the 25 MHz maximum clock rate. At this clock rate, it takes 4.16 μ s to load either a Rx or Tx beam position. Additionally,

a quick load command is required to instruct the chip to use the new beam position data in the registers, since the ADAR1000 uses dual-rank registers.

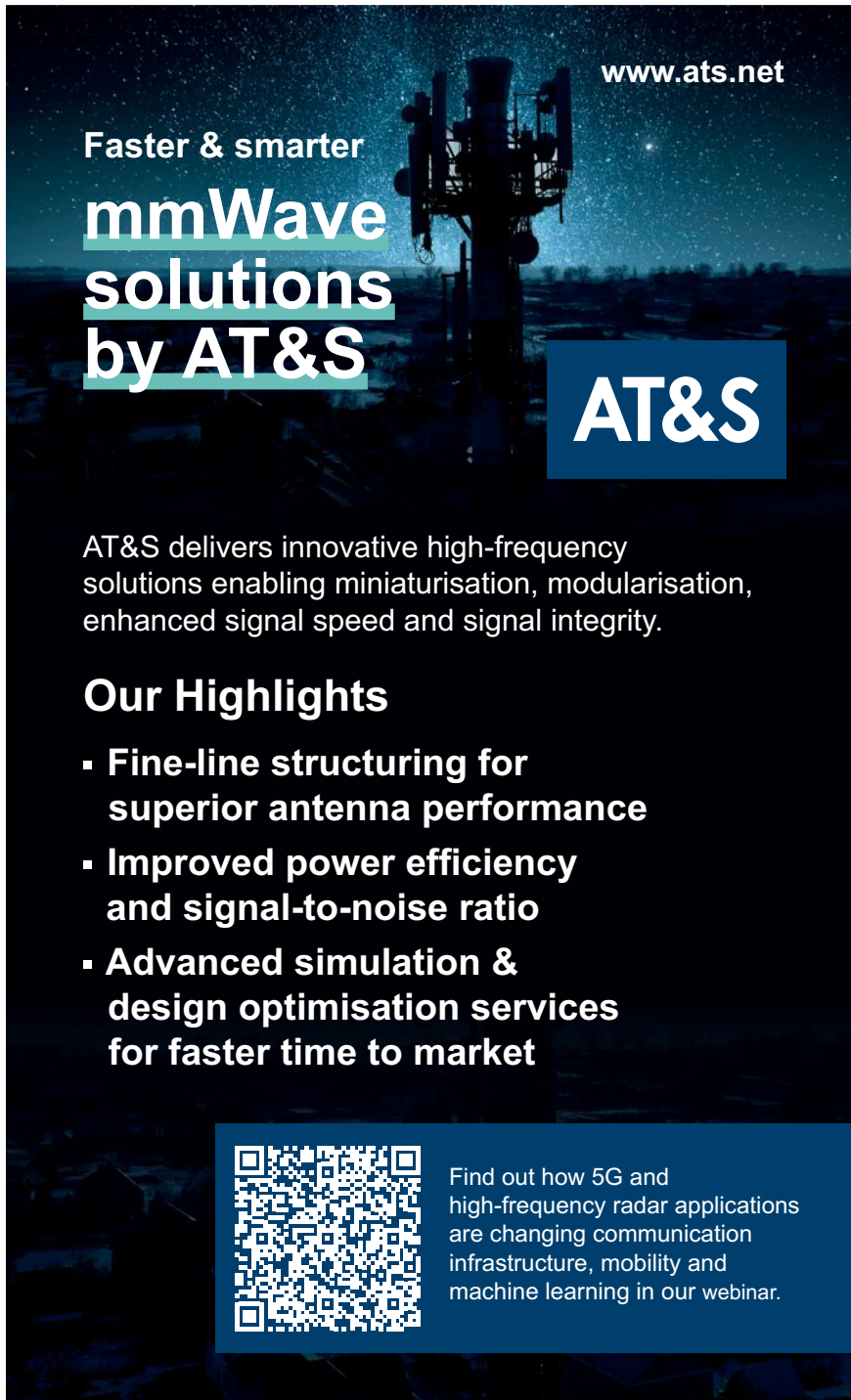
Sourcing data from the RAM is advantageous if the system knows the needed beam steering angles a priori and thus can clock in all the needed beam position data before the active operation of the system. Applications that employ a raster scan like weather and search radars can take advantage of storing beam positions in RAM. The time it takes to clock each beam position into RAM is the same as the registers, but since this is normally done before active operation, the ADAR1000 needs only six clock cycles plus a load command to select a new beam position. This operation takes as little as 320 ns.

RAM Partitioning

If RAM is used to source the beam position data, RAM partitioning can be used to update one section of the RAM while the other section is accessed by the radar controller. Only one section is actively used to source beam position data, while new beam position data is written into the other section(s). This is possible due to the ADAR1000's use of start and stop RAM pointers, which enable the sequencer to start and stop at any arbitrary beam position in RAM.

Dividing the RAM into two sections provides a simple example. Section 1 contains beam positions 0 to 60 and Section 2 contains beam positions 61 to 120. Initially, start and stop pointer values are set to 0 and 60, respectively. Beam data is also clocked into beam positions 0 to 60 and beam position 0 is loaded. The beam is advanced from positions 0 to 60 several times (the sequencer wraps around and loads the start beam position after the stop beam position). In between beam advances of Section 1, Section 2 beam data is loaded.

When ready to switch from Section 1 data to Section 2 data, a new stop pointer value must be set. To ensure a smooth transition between beam positions 60 and 61, the new stop pointer must be written when the sequencer is at beam position 58 or before. On the first sequence



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through beam positions 61 to 120, a new start pointer value must be written. The new start pointer value must be set when the sequencer is at beam position 118 or before, or a smooth

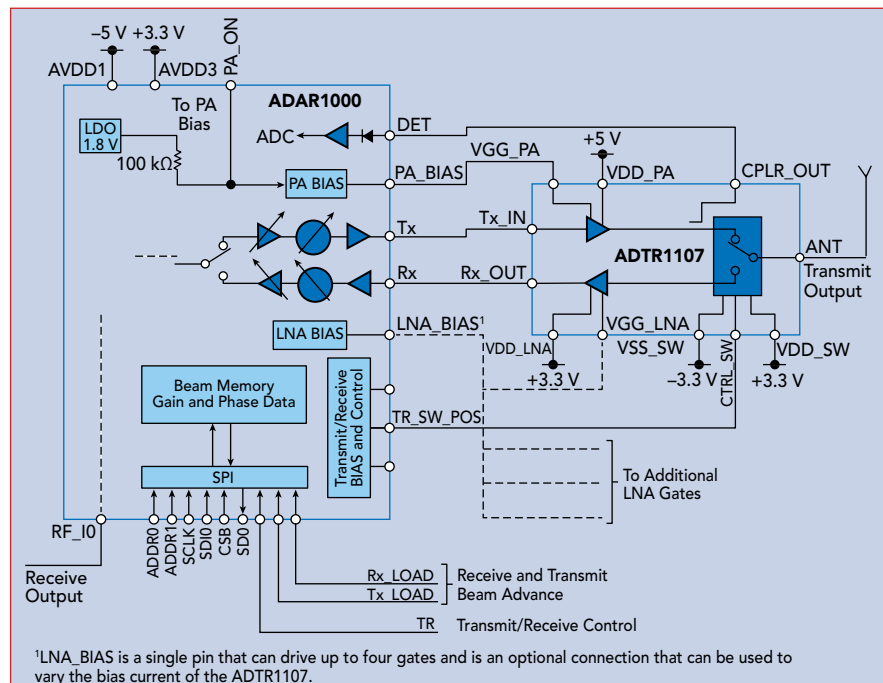
transition to beam position 61 will not occur. In general, any new beam data or new pointer values should be clocked in two beam positions ahead of the active beam position. Writing

new data and then switching back to Section 1 memory can be achieved using the same technique as outlined.

POWER MANAGEMENT

Planar phased arrays that feature BFICs and Tx/Rx modules usually require several different supply voltage domains. Additional supply domains may be required for support circuitry for the BFIC and Tx/Rx modules. These may include a low voltage digital supply and/or an intermediate step-down voltage to feed required supply domains.

For the power tree design, a common voltage such as 12 V is usually chosen to feed all the power management blocks. Common voltage rails of +5 and +3.3 V can be generated easily and efficiently, as well as the common negative counterpart voltage rails of -5 and -3.3 V. PAs and LNAs that use depletion mode field-effect transistor devices often require their gates to be biased to a negative voltage before bringing up the drain voltage to prevent damage to the device. Proper sequencing of the drain and gate voltages



▲ **Fig. 4** The ADAR1000 and ADTR1107.



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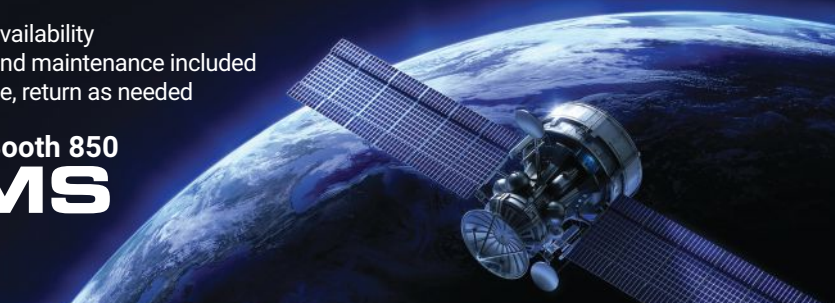
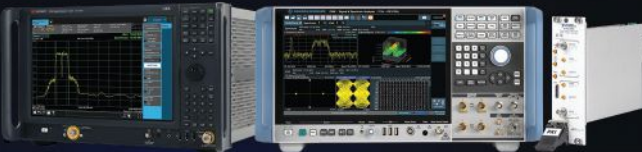
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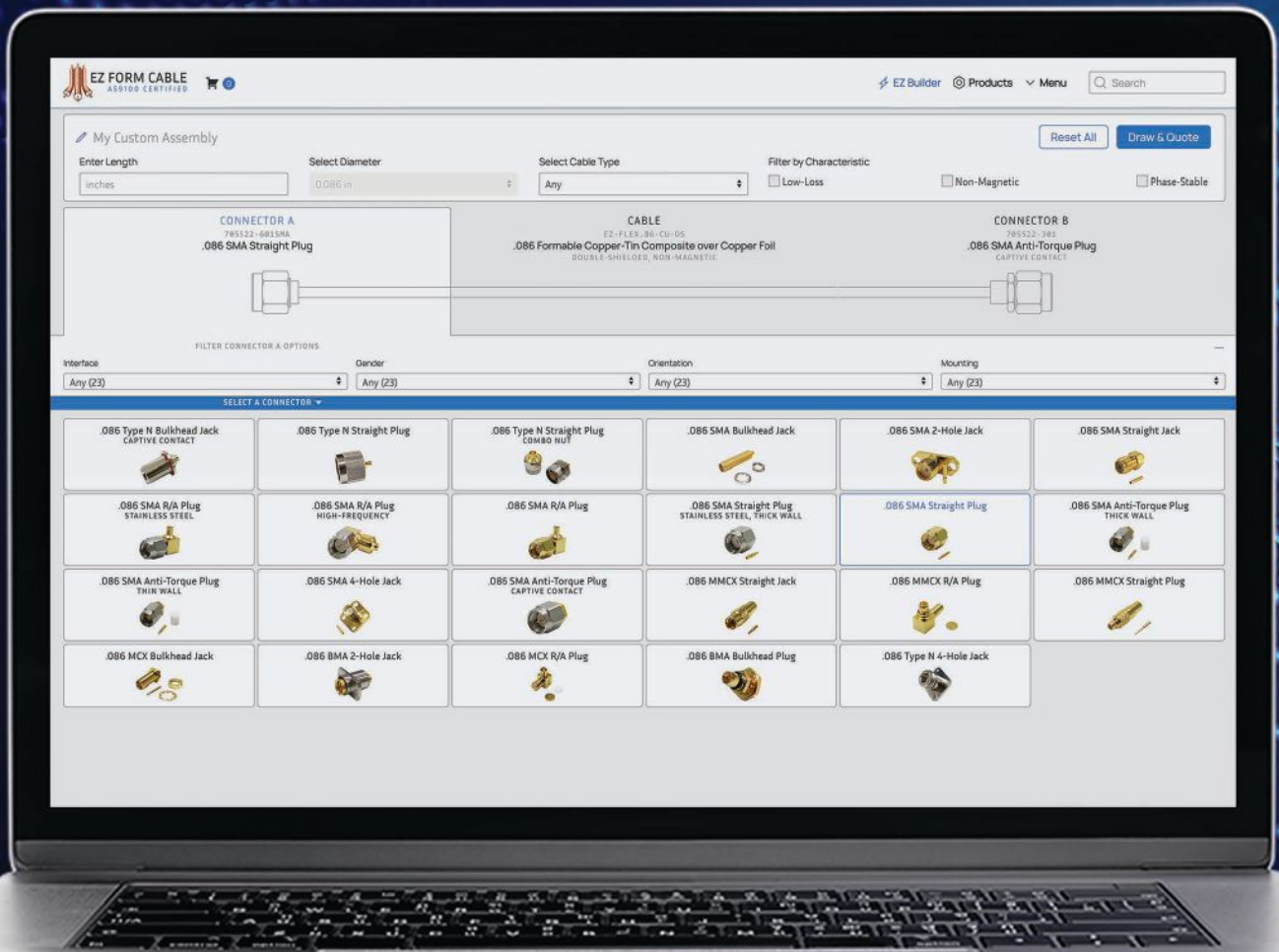
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is crucial and must be considered when designing the power management circuitry.

Design of Power Management Tree

Figure 5 shows the power tree that was used to provide supply voltages for BFICs and Tx/Rx modules that are on the planar phased array board shown in Figure 1. The 12 V input drives a hot-swap circuit featuring the ADM1172 hot-swap controller. This controller provides a protected 12 V with an 8.33 mA current limit to the branch of the power tree that powers the ADAR1000 and ADTR1107 ICs.

From the protected 12 V, the 3.3 and 5 V supplies powering the ADAR1000 and ADTR1107 are generated by the LT8642 and the LT8652, a pair of synchronous step-down Silent Switcher® regulators. These regulators ensure low noise and low spurious tones on critical RF supplies. The LT8642 provides 3.3 V for the ADAR1000's main supply and the VDD for the switch and LNA of the ADTR1107, while the LT8652 provides the 5 V VDD for the ADTR1107 PA.

To generate the negative supply voltages needed by the ADAR1000 and ADTR1107, an intermediate -6 V negative supply is generated from the protected 12 V rail, using the ADP5074 DC-to-DC inverting regulator. The ADP5074 drives the LT3093 and LT3094 negative linear regulators in parallel. This generates the -3.3 V for the ADTR1107 switch VSS and the -5 V for the ADAR1000.

A secondary branch off the 12 V input powers the LT8606 step-down switching regulator and the ADP150

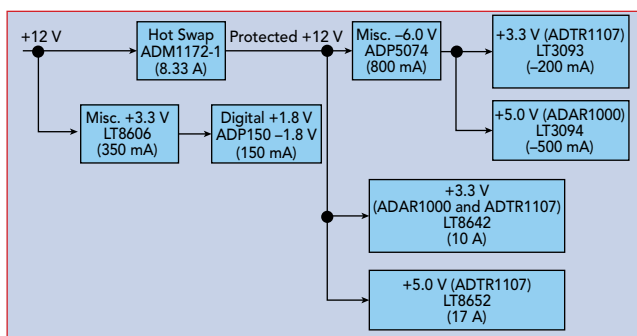
linear regulator that provides a separate miscellaneous 3.3 V supply and a 1.8 V digital supply, respectively.

Power-Up Supply Sequencing

Powering up the tree shown in Figure 5 is complex. It requires the user to input specific control signals at specific times during the overall power-up sequence. The critical control signal sequencing is described in **Figure 6**.

To start the power-up sequence, first, apply the 12 V power to the board and then the following are powered up:

- The 3.3 V miscellaneous and 1.8 V digital supplies from LT8606 and ADP150 turn on immediately
- Once the ADM1172 hot-swap gives its power good signal (HOT_SWAP_PG, Control Signal 1 in Figure 6), the ADP5074 turns on and provides its -6 V negative rail. Powering up the LT8606, ADP150 and ADP5074 is



▲ **Fig. 5** Power tree for a planar phased array system with BFICs and TR modules.

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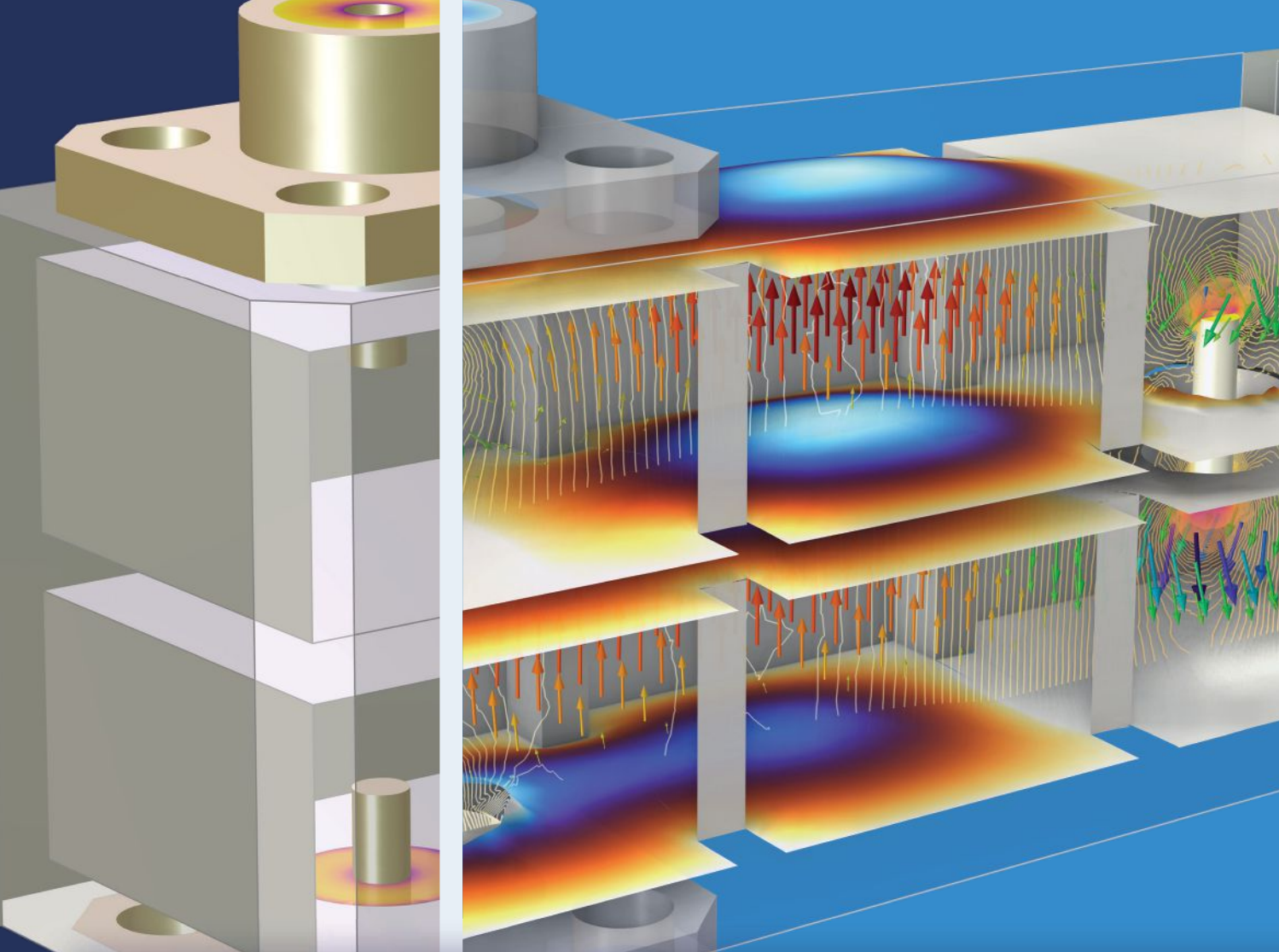
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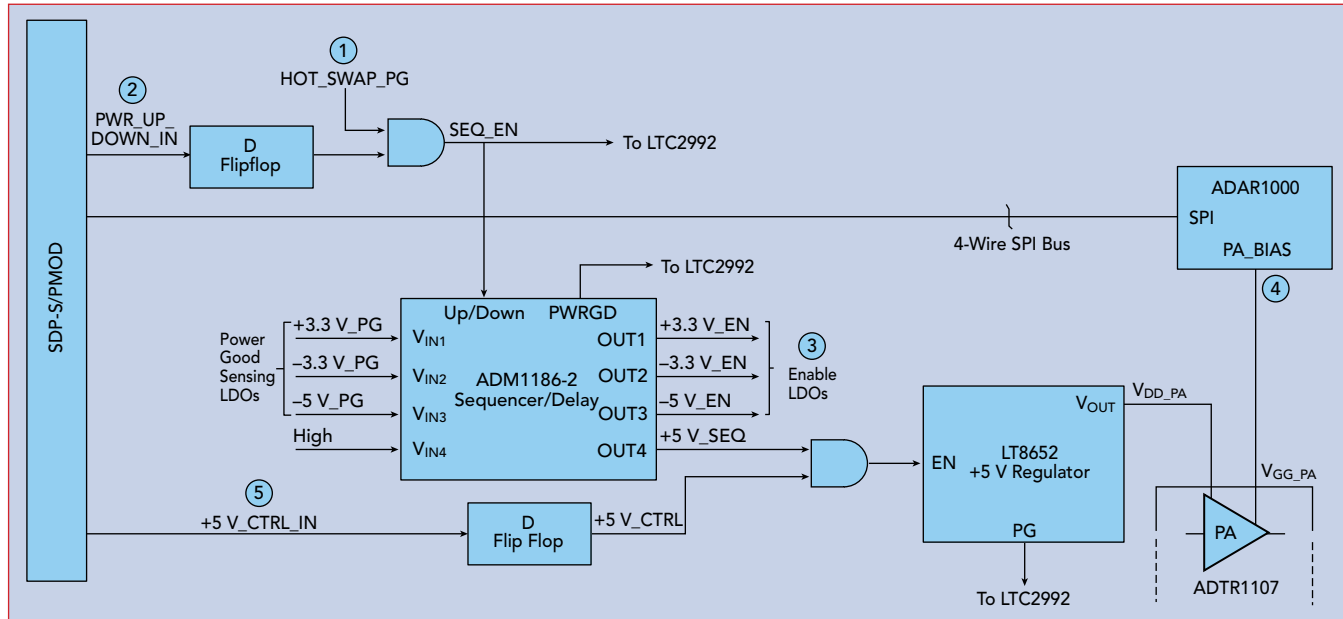
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ApplicationNote

done automatically and requires no input from the user.

Second, the remaining regulators power up in a specific sequence so that the ADTR1107 PA is not damaged. The sequence is initiated by providing a rising-edge power-up signal (POWER_UP_DOWN_IN, Control Signal 2 in Figure 6) to a D-flip-flop, which holds a high state at its output. The D-flip-flop output is AND'd

with the hot-swap power good signal. If both signals are high, then the sequencer-enable (SEQ_EN) signal is asserted high on the ADM1186-2. The ADM1186-2 allows each linear and low-dropout (LDO) regulator 47 ms for power-up (otherwise a fault condition is raised). An additional 2.2 ms of delay is inserted between each LDO regulator power-up. The exact LDO regulator en-



▲ Fig. 6 Power-up sequencing for ADTR1107 PA protection.



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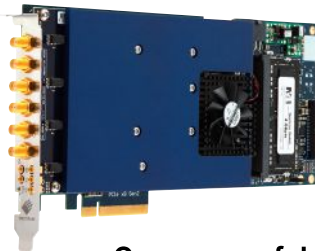
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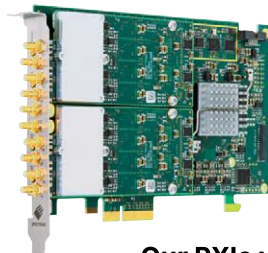
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able sequence is:

- The ADM1186-2's OUT1 pin (Control Signal 3 in Figure 13) asserts high and drives the LT8642 3.3 V LDO regulator-enable pin. The LT8642 has 47 ms to assert its power good signal to the ADM1186-2's VIN1 pin, after which a delay of 2.2 ms occurs.
- The ADM1186-2's OUT2 pin asserts high and drives the LT3093 -3.3 V LDO regulator-enable pin. The LT3093 has 47 ms to assert its power good signal to the ADM1186-2's VIN2 pin, after which a delay of 2.2 ms occurs.
- The ADM1186-2's OUT3 pin asserts high and drives the LT3094 -5 V LDO regulator-enable pin. The LT3094 has 47 ms to assert its power good signal to the ADM1186-2's VIN3 pin, after which a delay of 2.2 ms occurs.
- The ADM1186-2's OUT4 pin asserts high and drives an AND gate whose other input is a 5 V control signal. The ADM8611-2's PWDGD pin will then assert high. The ADAR1000 is now completely powered up along with the ADTR1107 switch and LNA.

Third, the ADAR1000 is programmed for -2 V PA bias outputs (Control Signal 4 in Figure 6), which is a safe value for the ADTR1107 PA during its +5 V power-up. Once all the PA bias outputs are programmed, a rising-edge 5 V control signal (5 V_CTRL_IN, Control Signal 5 in Figure 6) drives a D-flip-flop, which holds a high state at its output. The flip-flop drives an AND gate whose other input is the ADM1186-2's OUT4 pin. The AND gate drives the LT8652 5 V regulator-enable pin high and starts up the last supply rail. The overall power-up

sequencing solution is shown in Figure 6.

Power Monitoring

The LTC2992 monitors the DC power delivered by the LT8642 and LT8652 regulators. The power is monitored by measuring the voltage across a sense resistor on each regulator output. The voltage is sampled with an on-chip analog to digital converter and can be read-back via the I²C port.

The LTC2992 also has four GPIO pins, which can be used to sense the state of digital signals. The four digital signals sensed are:

- Power good signal from the LT8652
- The sequencer-enable signal that drives the ADM1186-2 UP/DOWN pin
- The sequencer power good signal from the ADM1186-2
- The 5 V control signal (5 V_CTRL) that enables the LT8652 regulator. The state of the GPIO pins can also be readback over the I²C port. The power monitoring solution can be seen in **Figure 7**.

The power monitoring and digital signal sensing that the LTC2992 provides help to ensure that the main supplies to the ADAR1000 and ADTR1107 are functioning properly. The power monitoring can also serve as a debug tool and built-in test for the ADAR1000 and ADTR1107 chips themselves. Individual chips in the array can be isolated and powered up to make sure that they are consuming the correct amount of power.

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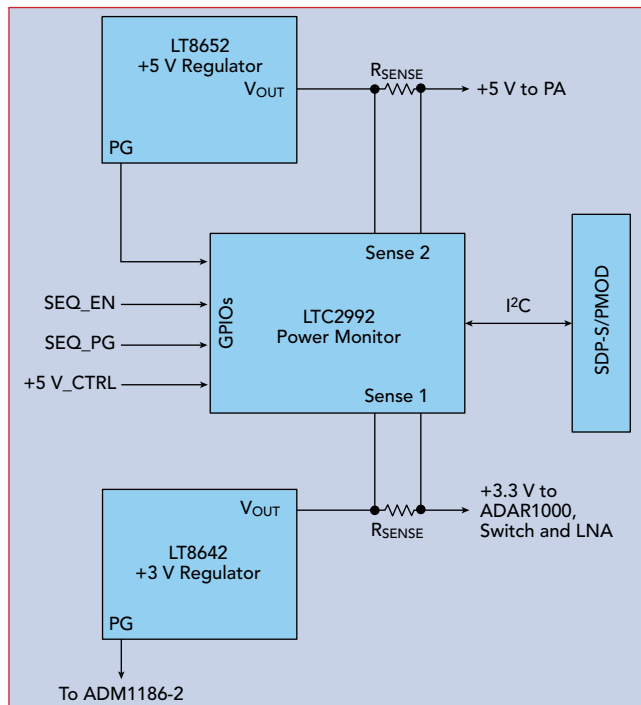
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The GPIO sensing of the LTC2992 informs the user if the LT8652 has powered up properly by sensing its power good signal. With this, users can ensure that the 5 V



▲ Fig. 7 Power monitoring of 5 V and 3.3 V regulators and digital signal sensing.

control signal is low until they are ready for 5 V power-up on the ADTR1107 PAs. The GPIO sensing also gives the sequencing state of the ADM1186-2 by sensing whether the LDO regulators are powering up or powering down and if the power-up/down sequence is complete.

CONCLUSION

This application note has discussed some of the challenges associated with designing the RF front-end of a planar phased array system. The size restrictions that stem from the required lattice spacing at high frequencies demand novel approaches to circuit and heat sink design and these challenges have been discussed in a companion article appearing in the March *Microwave Journal* (J. Dobler and S. Ringwood, "Overcoming Planar Phased Array Circuit Design Challenges," *Microwave Journal*, Vol. 66, No. 3, pp. 48-56.). To address all these challenges, most phased array radar systems use BFICs and Tx/Rx modules that interface easily and while this architecture enables shorter RF traces and fewer control lines, it creates timing, control and power management challenges. This application note has described these challenges, along with a power management tree and sequencing scheme resulting in systems with fast responses that are easier to calibrate. Simple single-pin controls and on-chip memory of the BFIC enable quick Tx/Rx transitions and beam advance. This RF front-end power management solution minimizes noise and spurs and avoids amplifier damage. ■

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For decades, direct-reading waveguide attenuators have provided users with the ability to easily adjust microwave signal levels over wide ranges with accuracy as good as 0.1 dB. Based on rotary vane designs that were first developed in the 1950s, direct-reading waveguide attenuators have endured as standard microwave lab equipment due to their accuracy, durability and flat frequency responses. More recently, direct-reading attenuator designs have advanced to sub-terahertz frequencies. Many now include stepper motors and internal electronics that enable remote control in automated test systems. Eravant's newly upgraded family of direct-reading and programmable attenuators provide the accuracy and "ease of use" expected in traditional attenuator designs, in addition to the remote control capability needed for automated test and measurement applications. An example of this family is shown in **Figure**



▲ **Fig. 1** Direct-reading and programmable attenuators.

1. The attenuators cover full waveguide bands ranging from 18 to 330 GHz as seen in **Table 1**.

A rotary vane attenuator has a circular waveguide section containing a thin, lossy

TABLE 1 ERAVANT DIRECT-READING AND PROGRAMMABLE ATTENUATOR FAMILY			
Model	Waveguide Size	Frequency (GHz)	Attenuation Range (dB)
STA-40-03-S1	WR-03	220 to 330	40
STA-40-05-S1	WR-05	140 to 220	40
STA-60-06-S1	WR-06	110 to 170	60
STA-60-08-S1	WR-08	90 to 140	60
STA-60-10-S1	WR-10	75 to 110	60
STA-60-12-S1	WR-12	60 to 90	60
STA-60-15-S1	WR-15	50 to 75	60
STA-60-19-S1	WR-19	40 to 60	60
STA-60-22-S1	WR-22	33 to 50	60
STA-60-28-S1	WR-28	26.5 to 40	60
STA-60-34-S1	WR-34	22 to 33	60
STA-60-42-S1	WR-42	18 to 26.5	60

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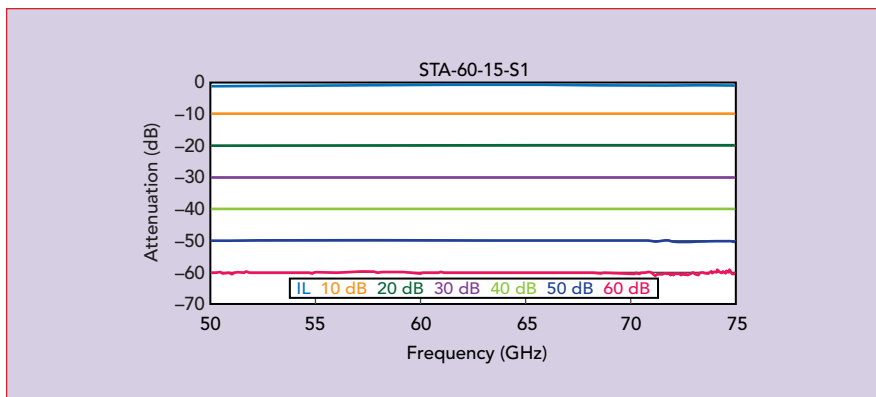


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▲ Fig. 2 Frequency response of STA-60-15-S1.

plate that functions as an attenuating vane. The vane absorbs a portion of the incident waveform with the amount of absorption depending on the orientation of the vane. The electric field component parallel to the vane is highly attenuated while the perpendicular field component is unaffected. Total attenuation follows a precise trigonometric function of the vane's angular position relative to the polarization of the incident waveform.

Manually operated rotary vane attenuators traditionally included a numerical scale and a mechanical indicator that provided a direct-reading of attenuation. The scale indicator and the circular waveguide containing the absorbing vane were mechanically linked to a rotary dial. A variety of motor-driven rotary vane attenuators were developed for automated test and measurement systems and other applications, but most could not be operated without a computer interface.

Eravant's direct-reading and programmable attenuators are hybrid instruments, capable of either manual or programmed operation. During manual operation, the user adjusts the attenuation by rotating a large dial. The attenuation value appears on an LCD screen powered by an internal rechargeable battery. With the attenuators in programmed mode, control is fully automated via a USB connection to a host computer. The USB connection emulates a serial port providing a reliable interface to automated test and measurement programs such as LabVIEW or VEE. The attenuator's command set allows setting the attenuation to a specified

level, resetting the attenuation to the maximum level, or reading the current attenuation level. Setting up the controlling software entails selecting and configuring the communication port connected to the attenuator.

Attenuation flatness and accuracy have always been hallmarks of rotary vane attenuators. Eravant's direct-reading and programmable attenuators are no exception. Model STA-60-15-S1 operates from 50 to 75 GHz, providing accuracy of ± 0.1 dB or 3 percent of the reading, whichever is larger, up to 40 dB, as seen in **Figure 2**. Resolution is 0.1 dB for attenuation up to 10 dB, 0.2 dB for attenuation between 10 and 30 dB and 0.5 dB for attenuation between 30 and 40 dB. The typical return loss is 20 dB.

Automated measurement of amplifier responses using different levels of input power is a common application for programmable attenuators. A representative test set-up to measure 1 dB compression is shown in **Figure 3**. When such measurements are performed in a coaxial test environment using a typical network analyzer, the source power can be adjusted over a wide range using a variable attenuator internal to the instrument. When waveguide frequency extenders are involved, however, the test signal power cannot be controlled accurately by the network analyzer. By adding a waveguide attenuator to the test signal path, the signal power applied to the amplifier input can be controlled accurately.

A common amplifier test is to measure gain (S_{21}) at various input power levels to determine

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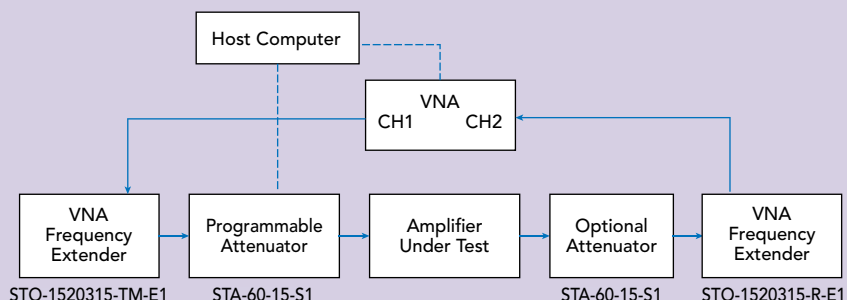


Fig. 3 Measuring amplifier 1 dB gain-compression point with a 50 to 75 GHz test system.

the 1 dB gain-compression point. In a coaxial test environment, this test is easily performed manually using an automatic network analyzer that allows the operator to vary the test signal amplitude. The measured amplifier response for a small input signal is saved and subsequently compared to new gain measurements taken at increasing power levels. When the gain trace decreases by 1 dB, the desired 1 dB compression point is reached and the test is concluded.

When using an external attenuator in the signal path between a pair of waveguide frequency extenders, the combined response of the attenuator and the DUT is measured for different levels of attenuation. As a result, manually finding the 1 dB compression point is more tedious. If only one variable attenuator is used, the test system operator must repeatedly vary the attenuation between a fixed high level and a variable low level, each time comparing the change in S21 to the change in the attenuator setting. If two variable attenuators are used at the input and output ports of the amplifier, both attenuators can be adjusted by equal amounts in opposite directions between

gain measurements, thus simplifying the measurement task somewhat. With either approach the procedure is time-consuming and prone to operator errors, making it an excellent candidate for automated testing.

A wide range of other components can be measured or calibrated automatically using a programmable attenuator, including signal detectors, mixers, modulators and receivers. By allowing manual operation as well as automatic control, Eravant's direct-reading and programmable attenuators support the manual adjustments that are often required during calibration or verification procedures. Switching between manual and automated modes of operation is a fast and fail-safe task, providing maximum flexibility for various test system needs. In many new or upgraded test facilities, dual-use attenuators are economical and practical alternatives to separate sets of direct-reading attenuators and programmable attenuators.

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The BMZ 6 is capable of bending small parts from tubes or wires up to an outer diameter of 6 mm. The modular design enables the production of highly complex component geometries by combining different bending processes such as coiling and free-forming. For example, closed bends of 360 degrees can be wound around a mandrel or large radii can be produced by free-form bending. In addition, the BMZ 6 is designed in such a way that further machining steps, such as end forming, can be easily integrated.

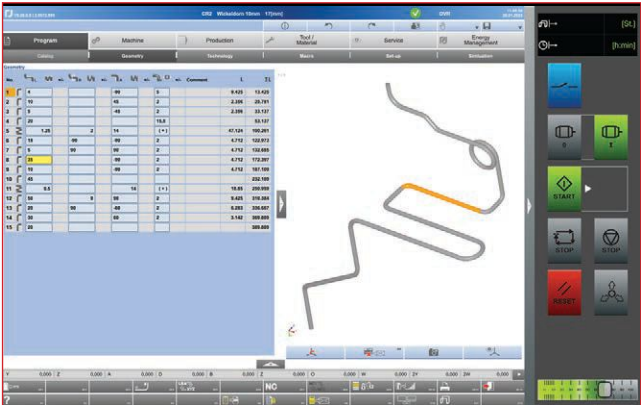


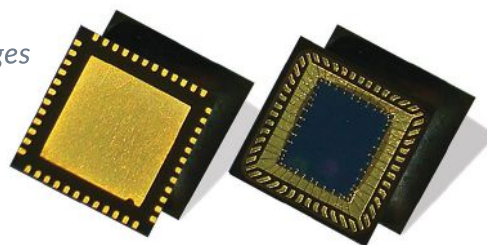
Fig. 1 An example of geometric programming of complex parts.



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ProductFeature

The bending machine offers some exclusive capabilities. Coaxial cables can be processed in the BMZ 6 with pre-assembled attachments, such as connectors. The unique WAFIOS bending technology is characterized by very short straight lines between the add-on part and the first bend. This bending approach offers clear advantages, especially in cramped installation situations. For fine wire and tube components like coaxial cables, it is possible to use a handling robot with an integrated palletizing function. The EasyRobot from WAFIOS is fully integrated into the programming system of the machine, making it easy to operate.

Thanks to the intuitive operating concept, the BMZ 6 can be used universally and new parts can be set up quickly. A high level of operating convenience is ensured by the use of 3D simulation for feasibility analysis and cycle time determination. In addition to direct programming at the machine, new components can also be set up at an external workstation and centrally checked for manufacturability. As part of a desire to increase manufacturability, the BMZ 6 can be equipped with WAFIOS's proven iQinspect software option. With this option, external measuring devices can be connected directly to the machine. The automatic correction of the bending program based on the measurement results supports the operator in quickly setting up even complex geometries. An example of the complex geometries that the BMZ 6 can address is shown in **Figure 1**.

The new BMZ 6 CNC tube bending machine concept sets new standards in tube processing of small dimensions. It does this with its compact design and different bending technologies, combined with state-of-the-art software solutions. This machine will open up new fields of application for 3D bending technology in medical and high frequency market applications.

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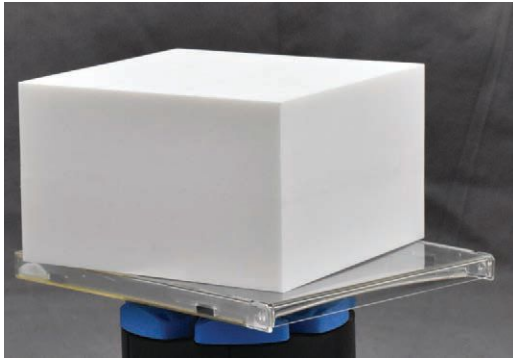
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Garlock released WavePro® 150 (WP150), a ceramic-filled polytetrafluoroethylene (PTFE) dielectric material with a dielectric constant (relative permittivity) of 15.0 and a loss tangent of 0.003 at 6 GHz. PTFE is a versatile and durable dielectric that is used in antennas, cables, radomes, RF circuit boards and many other microwave and mmWave applications due to its low loss and high performance. WP150 extends the range of PTFE dielectrics to higher Dk values that were previously unavailable, unlocking applications where stability and higher dielectric constants are advantageous. It is available in standard flat panels up to 10 mm thick, as well as made-to-order 3D shapes and conformal surfaces.

For unclad WavePro dielectrics, a variety of methods for metallization are available. These methods include metallic ink printing/writing, plating, vapor deposition and fusion

bonding. Proper surface preparation or the use of additives ensures proper adhesion of the metal to PTFE. An example of a device that was silver printed on a WavePro substrate is shown in **Figure 1**.

PTFE

PTFE is a thermoplastic polymer with many dielectric and mechanical properties that make it attractive for RF applications:

- Low loss tangent (Df)
- Dielectric constant (Dk) and other material properties can be engineered with the addition of ceramic and other fillers
- Low moisture absorption (hydrophobic)
- Chemically stable and inert
- High operating temperature.

Pure ceramics tend to be brittle, which can be challenging when fabricating small, complex shapes. Weight may also be a concern, especially at lower frequencies where the wavelength is longer. At these longer wavelengths, the shapes are larger and that requires more material.

As a ceramic-filled PTFE composite material, WavePro combines attributes of PTFE and ceramics. Pure PTFE acts as the host

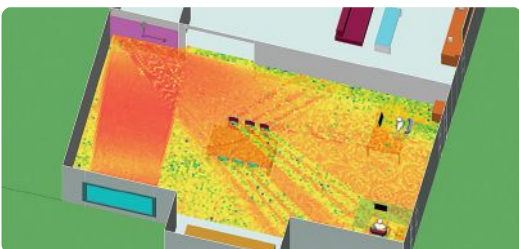
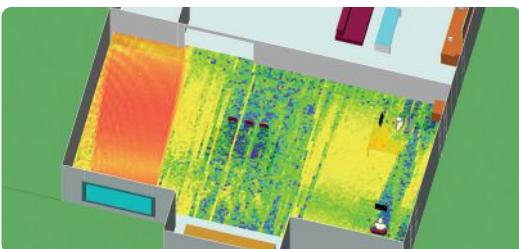


Fig. 1 Log periodic dipole array antenna on a WavePro substrate.



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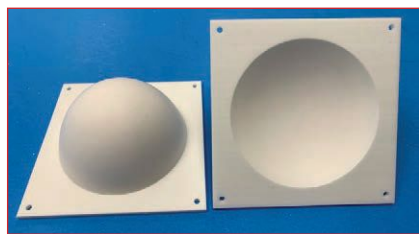


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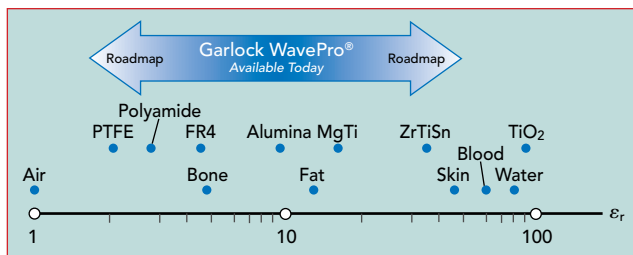
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▲ **Fig. 2** mmWave lens fabricated with WavePro. substrate, to which micro-particles of ceramic are added. Depending on the ceramic(s) used, the dielectric constant, loss tangent, thermal coefficient of expansion and other properties can be substantially altered and engineered for a desired outcome. Achieving a target value for a specific property requires both the correct recipe of filler materials, as well as precise processing and manufacturing steps. **Figure 2** shows examples of mmWave components fabricated from WavePro WP150 substrates.

EXTENDING THE DIELECTRIC CONSTANT RANGE OF PTFE

As material science and polymer experts, Garlock's vision for Wave-



▲ **Fig. 3** Comparison of dielectric constants of WavePro and different materials.



▲ **Fig. 4** Realizing complex 3D geometries and small feature sizes.

Pro dielectrics is to push the limits of what can be achieved with PTFE and expand the range of RF designs and applications for which PTFE is well suited. While several material properties can be engineered for specific requirements, we are focusing on the dielectric constant as the key determinant for suitability in a range of applications.

Garlock's WP150, the highest

permittivity commercially available PTFE-based dielectric on the market with a Dk of 15, is the first step in extending the upper limit. Higher Dk are on the product roadmap for 2023, with a Dk of 28 already achieved in prototypes. On the low end, research and development efforts targeting Dk in the range of 1.6 to 2.0 are also in progress. The

WavePro Dk roadmap, compared to other materials is shown in **Figure 3**.

SIZE AND WEIGHT REDUCTION

Materials with high dielectric constants and low loss tangents are interesting to RF designers because of their potential to reduce size and weight. The wavelength of a 10 GHz signal is 30 mm in air, compared to 7.75 mm in WP150 (Dk = 15). Microstrip transmission lines become narrower and the size of resonators is greatly reduced. For example, a simple geometry dielectric resonator antenna (DRA) fabricated with Dk = 15 instead of Dk = 10.2 will have each axial dimension reduced by the square root of 10 divided by 15, or the overall DRA volume reduced by 44 percent. From loaded cavity filters to patch antennas to beam steering elements, the use of high Dk dielectrics can play a vital role in many size reduction strategies. Examples of the size and weight reduction possibilities with WavePro's WP150 are shown in **Figure 4**.

Garlock has more than 50 years of experience developing, manufacturing and forming filled PTFE for different applications in multiple industries. Our techniques and know-how result in highly consistent and uniform isotropic materials with superior quality and performance.

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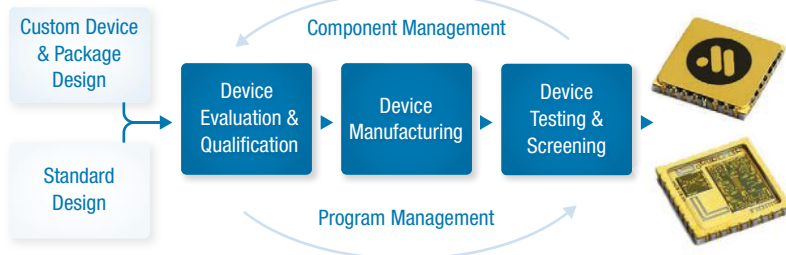
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Cable Assemblies Ensure Accurate and Repeatable On-Wafer Probing

and filters may be needed depending on the application.

While often underappreciated, the cable assembly can be as important as the RF probe and must have appropriate electrical and mechanical characteristics to ensure accurate and repeatable on-wafer RF measurements. StabilityWafer™ microwave/RF cable assemblies have been designed specifically to achieve highly accurate and repeatable on-wafer small-signal S-parameters and large-signal measurements. These assemblies are optimized for size and weight and to fit on any probe station, with or without shielding enclosures. They are also highly flexible to minimize the pressure applied on the RF probes.

StabilityWafer cable assemblies have industry-leading phase and amplitude stability to ensure that the signal passing through the cables has minimal change as the RF probes move across a wafer. These assemblies are offered with standard male and female connectors, as well as with 90° right angle and extended ferules and 83° extended ferules. StabilityWafer assemblies are available up to 67 GHz (70 GHz extended performance) with 1.85 mm, 2.4 mm, 2.92 mm and 3.5 mm connectors. They are in stock in standard configurations and available for custom configurations.

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8- and 12-Port Triple-Band Antennas

Cellmax introduced the 1209xx, 8-port and 1207xx, 12-port triple-band antenna platforms. The first release of these products operates from 698 to 2690 MHz, with more than 18 dBi gain at low-band frequencies and up to 21.6 dBi gain at mid-band frequencies. Later releases will support both L-Band and 600 MHz.

The antenna gain and frequency coverage of these antenna platforms allow operators to realize CAPEX and OPEX savings, along with increasing customer satisfaction.

Today, operators lose the equivalent of millions of kWh of energy dissipated as heat in traditional base station antennas, yearly. The gain

of the CellMax antennas enables an operator to decrease output power at a site while maintaining equivalent coverage during non-peak hours or enhance throughput during busy hours. This provides OPEX savings. Alternatively, the gain of the antennas allows for a broader coverage area at maximum output power, reducing the number of sites and CAPEX.

The broad frequency coverage and three bands allow for more frequency aggregation. Improved traffic distribution between low-band and mid-band frequencies means more connections, fewer dropped calls and higher throughput on the low-band frequency, while the high-band performance leads to better coverage, indoor penetration and

data throughput. This increases subscriber satisfaction, which reduces churn and leads to higher revenue. The platforms support 4X4 MIMO for both mid-band and low-band frequency ranges.

The antennas have the following characteristics:

- 4 x 698 to 960 MHz ports (both types of antennas)
- 4 x 1695 to 2690 MHz ports (8-port antennas)
- 8 x 1695 to 2690 MHz (12-port antennas)
- Low-band gain: 18.2 dBi
- High-band gain: 21.6 dBi
- PIM: -160 dBc.

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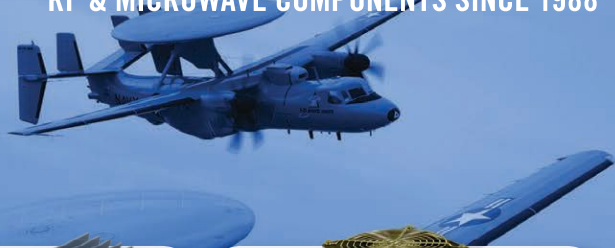
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Signal Generator Options Improve Input Power and Harmonic Performance

The AnaPico APSINxx-series signal generators with 12 or 20 GHz upper frequency range are now available with FILT and PE2 options. The FILT option provides a harmonic level of -60 dBm in the X- and Ku-Band frequency ranges while keeping the maximum power level at +25 dBm. The PE2 option includes a mechanical step attenuator that allows the signal generator to operate down to an input power of -120 dBm.

The phase noise of the generator at 1 GHz and 20 kHz offset has a maximum value of -130 dBc/Hz. The signal generator has a maximum frequency tuning speed of 30 μ s and it accommodates all stan-

dard analog and pulse modulation schemes. The instrument weighs 3 kg and it can operate from an external DC battery without being connected to line power. The AnaPico APSINxx-series signal generators also have an available option that modifies the form factor to a 19-in. rack-mountable 1HU enclosure.

A combination of characteristics such as high signal purity, low phase noise and fast switching speed, along with compact size, low weight and low power consumption makes the APSINXXG RF and microwave signal generators suitable for a variety of lab, production and outdoor applications. These include general-purpose portable

RF and microwave signal sources to test electronic, wireless and satellite modules and systems such as:

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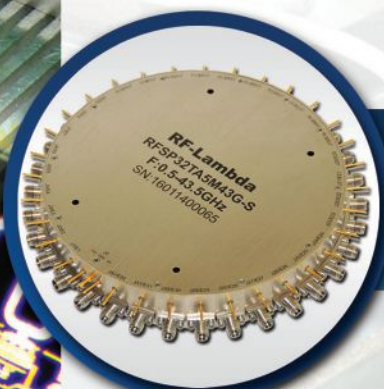


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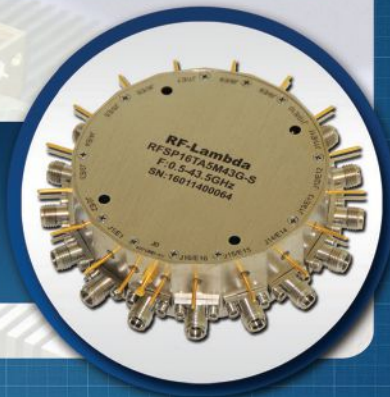


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HYPERLABS has developed a thermally compensated, ultra-linear 40 GHz amplifier/data driver targeted for use in high speed digital networks and telecom systems. The model HL5887 is a single-stage GaAs MMIC traveling wave amplifier (TWA) delivering 15 dB of gain over a bandwidth of 40 kHz to 40 GHz. The HL5887 data driver is specifically designed with a focus on 64 Gbps PAM4 data signaling applications. The HL5887 can also be used as a general-purpose gain stage in a variety of other applications where maintaining high pulse fidelity is important.

The HL5887 design leverages HYPERLABS' broadband and time domain experience to provide a flat step response that translates to an

Thermally Compensated 40 kHz to 40 GHz Linear Amplifier

accurate representation of the input signal. A flat pulse response is crucial for maintaining optimized eye diagrams while keeping the added jitter to a minimum. HYPERLABS has designed a proprietary thermal compensation algorithm into the amplifier that automatically adjusts the bias points of the amplifier to keep the amplitude and crossing point constant over a temperature range of 0°C to 60°C while maintaining a power dissipation of 1.6 W (typical).

Utilizing proprietary techniques developed for HYPERLABS broadband bias tees and DC blocks, the TWA is internally biased, while the RF ports are AC-coupled to the user. Specific measures have been taken to incorporate power sequencing circuits that protect the TWA so that

the external +6 and -8 V power supplies can be applied in any order. The HL5887 data driver housing measures 1.45 x 1.10 x 0.40 in. (36.8 x 27.9 x 10.2 mm).

Founded in 1992, HYPERLABS develops an array of ultra-broadband components that include baluns, bias tees, DC blocks, power dividers, pick-off tees, samplers and more with several products operating up to 110 GHz. The growing instrumentation line of HYPERLABS includes pulse/impulse generators, TDRs/TDTs, impedance analyzers, cable skew testers and more.

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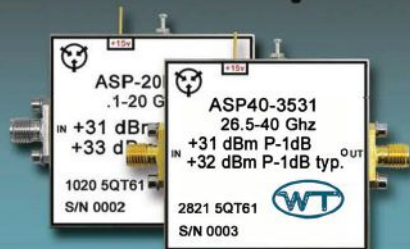
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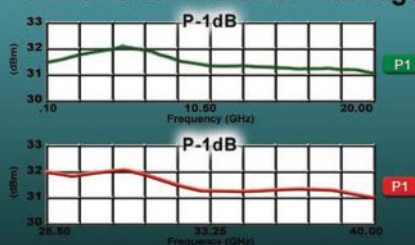
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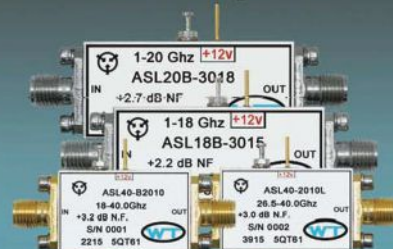
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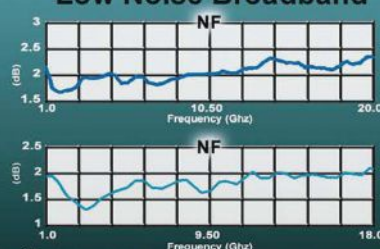


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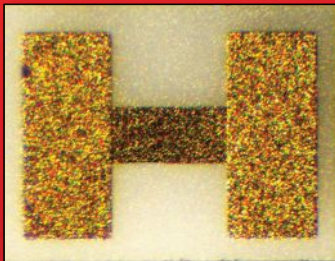
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Welcome to IMS2023 in Sunny San Diego!

John Wood and Gayle Collins
IMS2023 General Chairs



It is our pleasure to invite you to the 2023 IEEE MTT-S International Microwave Symposium (IMS2023), the centerpiece of a microwave week that is bookended by the Radio Frequency Integrated Circuits (RFIC) Symposium and the Automatic RF Techniques Group (ARFTG) Microwave Measurements Conference. The IMS week is the world's largest technical conference and industry exhibition for RF, microwave, mmWave and THz researchers and practicing engineers from academia, industry and government.

IMS2023 will be a live, in-person event with an exciting technical program of some 360 technical papers, presenting "the Coolest Ideas under the Sun" in the RF and microwave field, in addition to the industry exhibition with over 500 vendors demonstrating their latest products. We will also have multiple

great networking events and plenty of opportunities for attendees and exhibitors to re-establish old connections and make new ones.

This year's event takes place from Sunday 11 June through Friday 16 June, and will be held in the San Diego Convention Center, which is on the bayfront in San Diego.

While several aspects of the microwave week will be comfortably familiar, at IMS2023 we will introduce several innovations. We have focus themes to highlight a number of areas of RF and microwave engineering that are of topical interest, with a continued emphasis on RF and microwave systems and applications. These themes include:

- Wireless Communications, including 6G developments, Wi-Fi, RF and microwave system-on-chip integration, massive MIMO systems and subsystems and more

- Artificial Intelligence and Machine Learning (AI/ML) Technologies for Microwaves
- Model-Based Systems Engineering, including Digital Twins
- Space and Aerospace
- Wireless Power Transfer
- RF and Microwave Technology in Biomedical Applications.

Each theme will have focused technical sessions, workshops, a keynote speaker, a panel session and a technical lecture. Additionally, we will have a "Systems Pavilion" in the industry exhibition, showcasing wireless, with demos by the finalists in the 'MTT-Sat Challenge.' Since San Diego is a stone's throw from Latin America, one of our IMS2023 focus themes is to highlight advances in RF and microwave research in Latin America.

IMS2023 also features the "Connected Futures Summit" on Tuesday. This is a conference-within-a-

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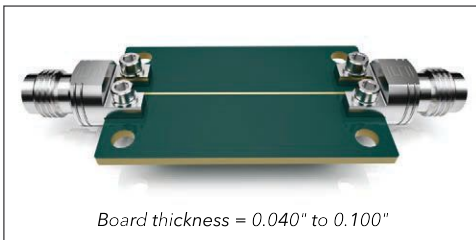
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conference, co-sponsored by the IEEE Communications Society. The focus is on strategic and tactical developments in 5G/6G technologies for future wireless communication systems, with several invited speakers. The theme for 2023 is "Connected Transportation."

At IMS2023, we are encouraging greater participation by industry.

We will host the Industry Showcase, where authors of the best technical papers from industry will present their work in a poster and demo session, giving attendees the opportunity to see the latest results and projects in industry, and to meet the authors and discuss their work.

New for 2023 will be Industrial Keynote Speakers, who will provide

the featured presentations on the major technical tracks of IMS. The speakers are invited technical leaders from industry, and they will be providing an overview of the latest developments in their topics. Also new in IMS2023 is the "Early Career" Best Paper award, encouraging younger engineers in industry to publish their work.

In post-conference surveys, the most frequently-cited reason for attending IMS is networking. IMS2023 will be an in-person conference, and we are looking forward to the return of face-to-face networking at IMS2023. There will be several networking receptions held on the Tuesday evening, including the Women in Microwaves reception, the Young Professionals mixer, the Ham Radio Social and the MTT Society Reviewers' Reception. Top marks if you make it to all of them. All of these events will be held in the Hilton Bayfront Conference Hotel, which has some great open spaces and bay-view terraces for hosting, so you can easily move from one event to another to meet old friends and make new ones. The Convention Center is adjacent to the famous Gaslamp Quarter, which is the lively social center of San Diego, with plenty of restaurants and bars for all tastes. Many of the industry-sponsored social and networking events will be held in the Gaslamp Quarter.

And finally, a brief comment on diversity and inclusion: the IMS2023 Steering Committee, which organizes the technical program and our social and networking events, is probably the most diverse ever. The committee comprises about 25 percent women participants, with women co-chairs of all the subcommittees, and, of course, Gayle is the General Co-Chair. We definitely have the "international" in IMS, with about 25 percent of our Steering Committee being located outside the U.S., including Australia, Austria, Belgium, Canada, China, Germany, India, Ireland, Italy, Mexico, the Netherlands, Portugal, Spain and U.K.

We look forward to meeting you in San Diego, 11-16 June 2023! ■



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coupling factors for
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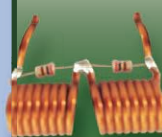
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ratios of 1:1, 1:2,
1:4, 1:8, 1:16.

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MICROWAVE POWER SOLUTIONS: TWO TECHNOLOGIES ONE MISSION



In recent years of continuous development and improvement of Microwave Power Solutions a clear direction has been observed and followed: to increase the operating frequency and/or power output parameters Systems.

Leonardo, with his centre of excellence based in Palermo (Italy) since 1956, was not long in coming and thanks to appropriate strategic investments it continues to be in line with market trends as world player in the supply of both technologies solutions (Vacuum High Power and Microelectronic Solid State Power Amplifiers) with the mission to be able to respond the present and future challenges of this specific area. As leader in the design and manufacturing, Leonardo Microwave Power Solutions (MPS)

offers a complete set of High Power Microwave products developed to achieve complex solutions, based on emerging technologies.

Building upon a 70-year heritage in this area, with more than 4000 TWT/30,000 Microelectronics Hybrid/300 SSPA delivered for airborne platforms, 3000 TWT/200 SSPA for naval and 3,000 TWT/300 SSPA for seeker, today Leonardo MPS has an extensive expertise in the development and production of state-of-the-art of TWT-A/HPA (TWT-Amplifiers/High Power Amplifier), TWTs, mini TWTs, Microwave Power Modules (MPM), Transmitter/Receiver (Tx/Rx), Solid State Power Amplifiers (SSPA), Microelectronic Hybrids (HLLNA, SYNTH, UP/DOWN CONVERTER, WBFEE).

All Leonardo's products and solutions can be customized in accordance with specific needs to be able to

deliver a worldwide Microwave Power Solutions for all platforms (airborne, land & naval, missile and space) and different applications (Electronics Warfare, Fire Control and Surveillance Radar, Meteo, Air Traffic Management, Communications, Seeker, SAR).

Leonardo MPS portfolio includes a wide range of solutions, in terms of operating frequency, power output and duty cycle key parameters and boasts of an important "two technologies best in class" product list (for Microelectronic Power Solutions: SSPA X-Band 1kW Pulsed, SSPA Ku-Band 400W Pulsed, SSPA Ka-Band 100W Pulsed and for Vacuum Power Solutions: HPA Ka-Band up to 800W Pulsed, MPM 6-18 GHz 120W up to CW, TWT 4.5-18 GHz 150W up to CW, mini-TWT Ka-Band 150W up to CW and CC TWT X-Band 12kW Pulsed).



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RFIC'23 Overview

Donald Y.C. Lie, RFIC 2023 General Chair
Texas Tech University, Lubbock, Texas



On behalf of the Executive and Steering Committees, I would like to cordially invite you all to the 2023 IEEE Radio Frequency Integrated Circuits (RFIC'23) Symposium. The IEEE RFIC Symposium (RFIC) is the premier annual forum focused on presenting the latest breakthroughs and research results in all areas related to RF, mmWave and wireless ICs. The RFIC Symposium, combined with the International Microwave Symposium (IMS), ARFTG and the Industry Exhibition, form "IMS Week," the world's largest RF and microwave technical meeting of the year. RFIC'23 will be held at the beautiful San Diego Convention Center, in the heart of "America's Finest City," San Diego, Calif., from Sunday morning, 11 June, through Tuesday night, 13 June. The RFIC'23 Plenary Session will be on Sunday night, followed by a welcome reception and the Symposium Showcase. The RFIC technical sessions will be held on Monday and Tuesday in parallel tracks. Our sessions will include topics spanning from highly integrated wireless systems-on-chip and low-power radios to new power amplifiers, voltage-controlled oscillators and front-end circuitry designs. As mmWave 5G/6G research is getting considerable attention lately, increasingly more mmWave

and terahertz (THz) IC content is being published at RFIC. RFIC'23 also continues to include sessions on RF systems and applications, and on the emerging RFIC technologies.

RFIC'23 will feature a rich educational program on Sunday, 11 June 2023, with 11 RFIC focused workshops and one technical lecture. The workshops cover a wide range of advanced topics in RFIC technology. The excellent 80-minute technical lecture will be delivered by Prof. Behzad Razavi of University of California, Los Angeles (UCLA) on "Modern Radio Architectures – From WiFi to 5G and Beyond." This lecture covers both RFIC and radio system design aspects, and would be instructive and beneficial for students, newcomers and for senior practicing designers. Following the full day of Sunday workshops, the RFIC Plenary Session will be held in the evening beginning with conference highlights, the presentation of the Student Paper Awards and the Industry Best Paper Awards. The RFIC'23 Plenary Session will conclude with two visionary plenary talks: "The Roaring 20s: A Renaissance for the Semiconductor Industry?" by Dr. Todd Younkin, president and CEO of the Semiconductor Research Corporation; and "Future System-on-Chip for Full Spectrum Utilization from RF to Optics" by Prof. Mau-Chung Frank Chang, the

Wintek chair in electrical engineering and distinguished professor of UCLA. Immediately after the plenary session, the RFIC Reception and Symposium Showcase will follow, with highlights from our industry showcase and student paper finalists in an engaging social and technical event supported by RFIC'23 corporate sponsors. The showcase will provide authors the opportunity to demonstrate their work in a lab-like environment for close-up discussions.

On Monday and Tuesday, RFIC will offer panel sessions during the lunch breaks. Monday's panel will debate "How Soon Will We Become Cyborgs?" and Tuesday's RFIC/IMS joint panel will discuss "AI/ML Based Wireless System Design and Operation – Hope or Hype?" RFIC'23 will feature a new, dedicated Student Session, where students can meet, interact and learn about exciting technology trends and their potential future careers from industry experts. This new Student Session includes an industry chip chatting and reception on Tuesday afternoon, where prominent industry leaders will discuss "3 Things to Know to Start Your RFIC Design Career with a Bang." All parties are welcomed to stay chip chatting at the RFIC nacho station with free food and drinks. Please visit RFIC'23 website (<http://rfic-ieee.org/>) for more details and updates. ■

GOLD STANDARD

8 to 15 GHz DRO / SDRO series

FEATURES:

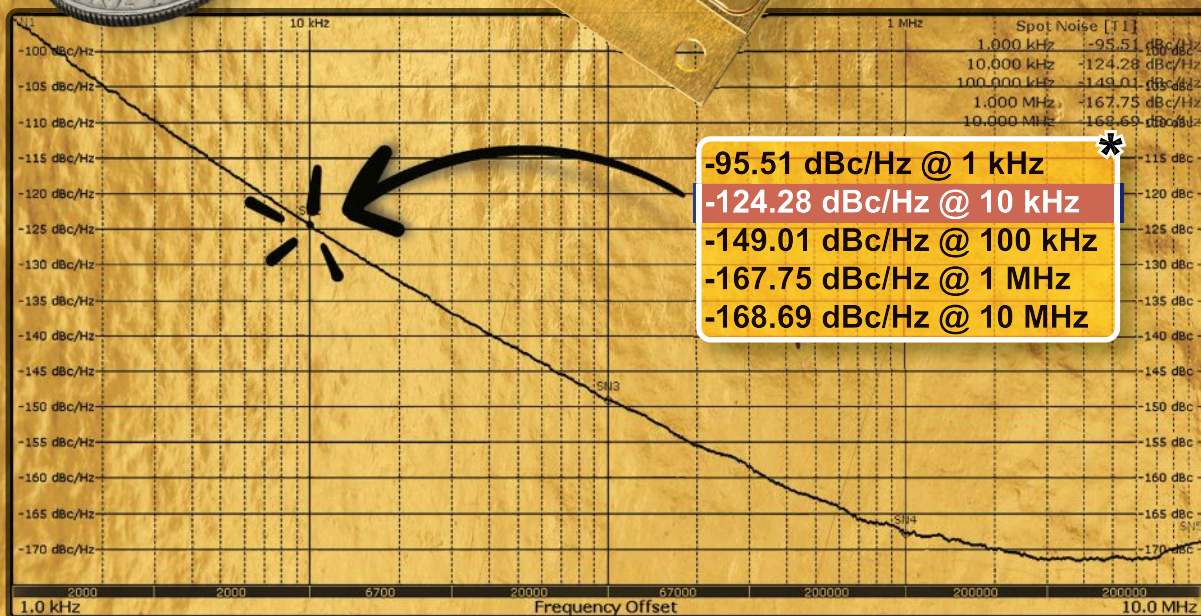
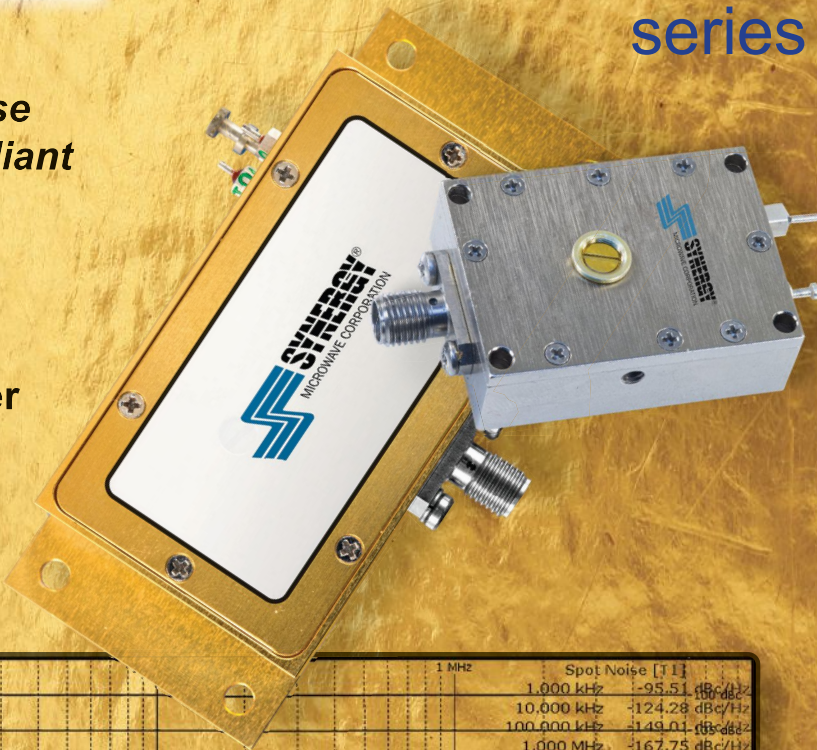
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101st ARFTG Microwave Measurement Conference

Marco Spirito, Jeffrey Jargon
ARFTG 2023 Chairs

Jon Martens and Dennis Lewis
Tech Program Chairs



Welcome to the 101st ARFTG Microwave Measurement Conference! The Automatic RF Techniques Group (ARFTG) is a technical organization interested in all aspects of RF and microwave test and measurement. Originally created as a users' forum focused on the calibration and automation of early vector network analyzers, ARFTG has grown to encompass all aspects of microwave measurements from RF to THz.

ARFTG's core mission is education. ARFTG achieves this by hosting conferences, workshops and short courses covering a wide range of measurement topics, as well as awarding fellowships and sponsorships to students. Additionally, ARFTG's close association with the top vendors of measurement instrumentation ensures high-quality exhibits at its conferences. The extended breaks from conference technical sessions enable meaningful interactions to take place among colleagues, students, experts and vendors.

ARFTG sponsors two conferences each year. The fall/winter conference has recently been co-located with Radio & Wireless Week (RWW), while the spring/summer conference

is co-located with the International Microwave Symposium (IMS). The 2023 Spring/Summer Conference will be a single-day event on Friday, 16 June. The theme of this 101st ARFTG Microwave Measurement Conference is "Challenges in Complex Measurement Environments." Conference topics will cover on-wafer, over-the-air (OTA) or hybrid measurements: methodologies, calibration approaches and related topics; calibration and uncertainty considerations in moving OTA measurements (robotics, stages, UAVs, etc.); nonlinear characterizations, including linearization, of devices, circuits and systems; de-embedding and calibration approaches for complex media; uncertainty topics in integrated system testing; THz/mmWave measurements, including modulated signals; and other developments in measurements and metrology.

Oral technical sessions are presented in a single-track format. Extended breaks combine an exhibition and interactive forum, which provides networking opportunities with vendors and colleagues, whether researcher or practitioner.

Our Keynote speaker will be Stuart Gregson of Next Phase Measurements. The topic of his presentation will be "Measurement Chal-

lenges and Novel Approaches to Modern Antenna Measurements in Complex Environments Using UAVs and Multi-Axis Robots."

The Nonlinear Network Vector Analyzer Users' Forum and the On-Wafer Users' Forum preceded the conference, both held on Thursday, 15 June.

Additionally, ARFTG is co-sponsoring two full-day workshops – WSM: "Advances in Microwave and Millimeter-Wave Wideband Measurements for Radar and Communications Applications" and WMD: "Device Thermal Noise Metrology: Needs, Challenges and Opportunities."

ARFTG also offers student sponsorship and fellowship programs. The sponsorship program gives financial aid to students presenting at an ARFTG conference, and the fellowship program provides financial assistance in support of research.

If you have an interest in measurements from 1 kHz to 1 THz and beyond, be sure to add the 101st ARFTG Conference to your plans in San Diego this June. You will find our atmosphere to be informal and friendly. For further details regarding the conference as well as the student sponsorship and fellowship programs, visit www.arftg.org. ■

Unleash mmWave Performance With Peraso

Unique Advantages of Peraso mmWave Modules

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The IMS2023 Exhibition

Carl Sheffres
Horizon House Publications, Inc.

The IEEE MTT-S International Microwave Symposium (IMS) features the largest exhibition in our industry, showcasing the world's leading suppliers of products and services. When you visit the exhibition, you will have the opportunity to see and experience the latest technologies and innovations available for all your design requirements. There will be live demonstrations, new product launches, a new Executive Forum and plenty of networking.

IMS2022 in Denver, Colo., was a great success, with 450 exhibiting companies in 726 booth spaces. IMS2023 features more than 520 exhibiting companies in over 850 booth spaces, so we expect an even more robust and active exhibit floor in San Diego, Calif. California is home to hundreds of RF/microwave companies and San Diego is a perfect venue to host our annual event.

The exhibition will take place in halls D through H on the ground floor of the San Diego Convention Center. Exhibition hours are Tuesday, 13 June from 09:30 to 17:00, Wednesday, 14 June from 09:30 to 18:00 and Thursday, 15 June from 09:30 to 15:00. Registration will be held in the lobby area of hall D, next to the entrance to the exhibition. A Starbucks is conveniently located near the entrance to boost your mornings and coffee breaks will be provided on the exhibit floor each morning and Tuesday and Wednesday afternoons. "Sweet Treat Tuesday" has be-

come a welcome staple of the exhibition on Tuesday afternoons, providing all attendees with an afternoon indulgence.

The traditional "Industry Reception" will take place on Wednesday from 17:00 to 18:00 with a themed "beach party" vibe to help get you in to the California groove. Food, beer and wine will be served in the aisles and from participating sponsors booths. Attendees can also visit the "game zone" to compete with colleagues in an assortment of fun activities.

The MicroApps Theater is located on the exhibition floor and features more than 60 presentations from exhibiting industry experts. These sessions are 15 minutes each and take place the entire duration of the exhibition. They are grouped by topic to make it convenient for attendees to work into their schedules. The Executive Forum will make its debut this year in the MicroApps Theater on Tuesday from 15:30 to 16:30, featuring a panel of technologists discussing their strategies for addressing emerging markets.

There is no other international marketplace where you can meet face-to-face with thousands of RF and microwave decision makers. Nearly 90 percent of all IMS2022 attendees surveyed report that the IMS Exhibition is THE #1 reason for attending. This is the place to connect with the industry's movers and shakers. Join us in San Diego for the Coolest Ideas Under the Sun. ■



SIGNAL MICROWAVE

Leading in Innovation

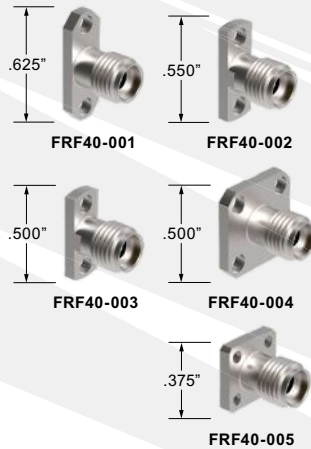
FRF40 2.92 mm (40 GHz)

Field Replaceable Connectors

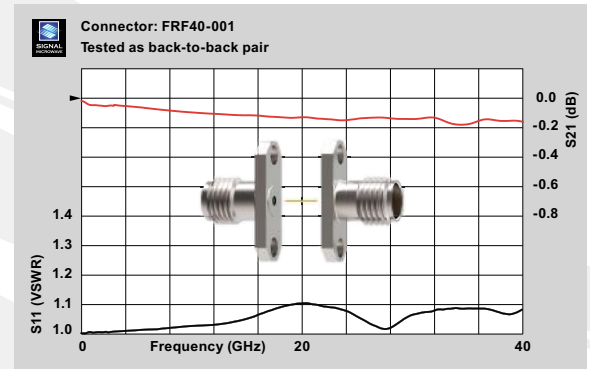
- 2.92 mm Interface
- Rear Socket for 12 mil pins
- **NEW** Rear Socket for 9 mil pins available now
- Standard 2 & 4 Hole Flanges
- 40 GHz Bandwidth



FRF40-001



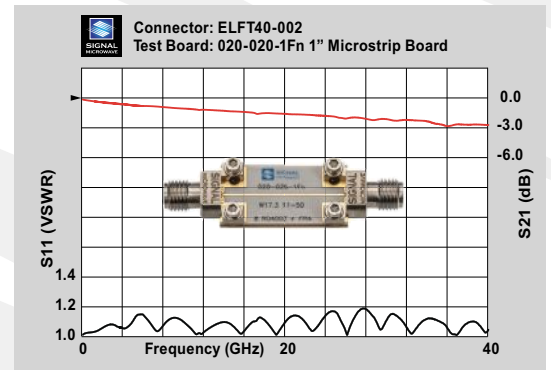
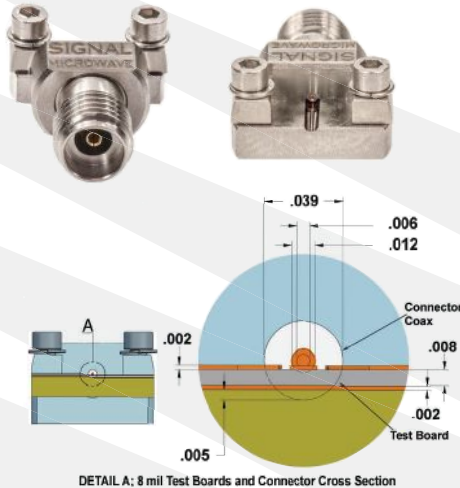
- Low VSWR: DC–27.0 GHz...1.10:1
27.0–40.0 GHz...1.15:1
- Temp Range -55°C to +105°C



ELFT40 2.92 mm (40 GHz)

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- 2.92 mm Interface
- 1.15:1 VSWR Max
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- Board Design Support Available
- Test Boards Available
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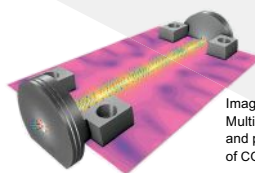


Image made using COMSOL Multiphysics® software and provided courtesy of COMSOL.



Drop-ins, Modules & IMAs to 100 GHz

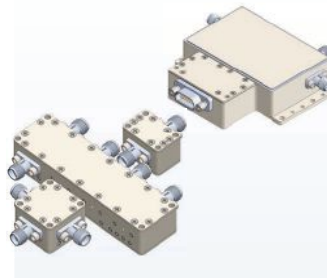
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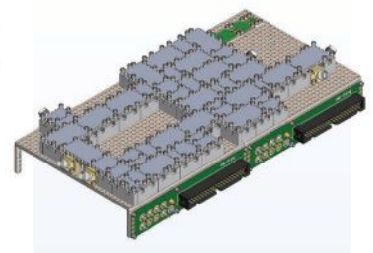
Drop-In Everything

- Over 5000 X-MWblocks
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- Solderless Interconnect



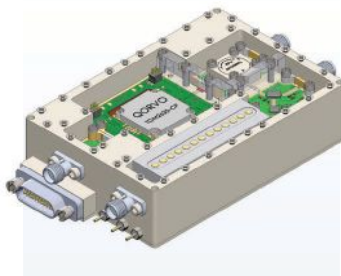
Connectorized & Hermetic Modules

- RF/Bias X-MWblocks
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- Field Replaceable Connectors



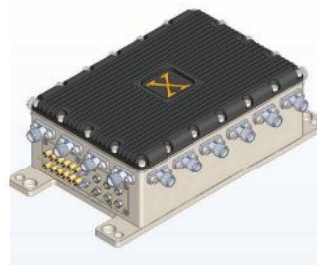
Quick-Turn Prototypes

- Complete Signal Chains
- Modular Walls & Lids
- RasPi Control



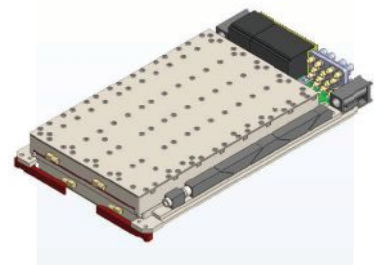
Integrated Microwave Assemblies

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- TxRx Modules
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- Quick-Turn Enclosed IMAs
- Versatile input/output options
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- 3U & 6U Card Assemblies
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IMS Booth 1947

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San Diego, June 11-16

Have You Seen Who's Exhibiting at IMS2023?



Join Us at the World's Largest Exhibition for RF and Microwave Professionals, 13-15 June 2023:

- **520+ Companies**
- **65+ MicroApps Sessions**
- **IMS Plenary Session, Welcome Reception, and Closing Session**
- **Systems Pavilion Featuring IEEE MTT-SAT Challenge**
- **Build a "Foxhole" Radio Receiver presented by Dr. David S. Ricketts, North Carolina State University**
- **IMS Game Zone**
- **Free Professional Headshots**
- **Executive Forum on Emerging Markets, Tuesday, 13 June 2023, 15:30-16:30**
- **Industry Hosted Reception, Wednesday, 14 June 2023, 17:00-18:00**
- **Unlimited Networking**

PROGRAM PREVIEW



IMS



Register Now!

IEEE MTT-S International
Microwave Symposium
11-16 June 2023
San Diego 🌻 California



Week At-A-Glance/IMS & RFIC Plenary Speakers

	Sunday 11-Jun-23	Monday 12-Jun-23	Tuesday 13-Jun-23	Wednesday 14-Jun-23	Thursday 15-Jun-23	Friday 16-Jun-23
Workshops						
Technical Lectures						
RFIC Plenary Session, Reception, Industry Showcase						
Quantum Bootcamp						
AI/ML Bootcamp						
RF Bootcamp						
RFIC Technical Sessions and Interactive Forum						
Three Minute Thesis						
IMS Industry Showcase, Plenary and Welcome Reception						
IMS Technical Sessions and Interactive Forum						
Panel Sessions						
Connected Future Summit						
Exhibition						
MicroApps and Industry Workshops						
Amateur Radio Reception						
Young Professionals Reception						
Industry Hosted Reception						
Women In Microwaves Reception						
IMS Closing Ceremony						
101st ARFTG						

Workshops Technical Lectures RFIC Bootcamp Three Minute Thesis IMS Panel Sessions
Connected Future Summit Exhibitor Activities Focus Groups ARFTG

IMS and RFIC Plenary Speakers



RFIC SPEAKER

Prof. Mau-Chung Frank Chang
Wintek Chair in Electrical Engineering and
Distinguished Professor, University of California, Los Angeles (UCLA)



RFIC SPEAKER

Dr. Todd Younkin
President & CEO,
Semiconductor Research Corporation (SRC)



IMS SPEAKER

Ed Godshalk, PhD
Consultant and Engineer in Residence, George Fox University

Panel Sessions, Technical Lectures & Workshops

PANEL/RUMP SESSIONS

- Meet the MTT-S Editors and Publication Enthusiasts
- How Soon Will We Become Cyborgs?
- RF-Microwave Packaging and Interconnect Technologies for Global Integration – Are We on the Right Track?
- Industrial Future of Wireless Power Transfer as Game Changing Technology
- AI-ML Based Wireless System Design and Operation – Hope or Hype?
- Model Based System Engineering in Electronics Design: Building Bridges from Micro to Macro
- 5G FR1-FR2 Convergence: Challenges and Outlook for Remote Healthcare and Time-Critical Communications

TECHNICAL LECTURES

- Modern Radio Receivers – From WiFi to 5G and Beyond
- Integrated Digital Twins for Design and Test of 5G Networks
- Smart Radar Circuits and Systems for Healthcare and IoT Applications
- The Insight of Spaceborne Solid-State Power Amplifiers: From Semiconductor Technologies to Flight Model Equipment

WORKSHOPS

- Human Body Communications
- Advances in SATCOM Phased-Arrays and Constellations for LEO, MEO and GEO Systems
- Hands On Phased Array Beamforming using Open Source Hardware and Software
- Quantum RF Receivers: Using Rydberg Atoms for Highly Sensitive and Ultra Wideband Electric Field Sensing
- SWIPT – Simultaneous Wireless Information and Power Transmission for Future IoT Solutions
- mm-Wave and Terahertz Systems for Near-Field Imaging, Spectroscopy and Radar Sensing Applications
- Emerging MIT/PCM Based Reconfigurable Microwave Devices
- Toward Tbps Optical and Wireline Transceivers: A Tutorial for RFIC Designers
- GaN/GaAs Technology Development and Heterogeneous Integration for Emerging mmWave Applications
- System Design Considerations for Advanced Radios
- On-wafer mm-wave Measurements
- Health Aspects of Millimeter-Wave Radiations in 5G and Beyond
- Measurement and Modeling of Trapping, Thermal Effects and Reliability of GaN HEMT Microwave PA Technology
- Wideband and High Efficiency mm-Wave CMOS PA Design for 5G and Beyond
- Supply Modulation Techniques: From Device to System
- Front-End Module Integration and Packaging for 6G and Beyond 100 GHz Communication and Radar Systems
- Wireless Proximity Communication
- Advanced Interference Mitigation in Integrated Wireless Transceivers
- In-Band Full-Duplex Integrated Devices and Systems
- Advanced Manufacturing and Design Techniques for Emerging 3D Microwave and Millimeterwave RF Filters
- AI/ML-Based Signal Processing for Wireless Channels
- Large-Scale Antenna Arrays: Circuits, Architectures, and Algorithms
- Superposition and Entanglement: When Microwaves Meet Quantum
- mmWave Design Challenges and Solutions for 6G Wireless Communications
- RF Large-Signal Transistor Performance Limits Related to Reliability and Ruggedness in Mobile Circuit Applications
- Microwave Techniques for Coexistence Between 5G and Passive Scientific Systems
- Commercial Applications of Medical RF, Microwave and Millimeter-wave Technology
- Emerging Low-Temperature/Cryogenic Microwave Techniques and Technologies for Quantum Information Processing
- Digitally Intensive PAs and Transmitters for RF Communication
- Recent Developments in Sub-6 GHz PAs and Front-End Modules
- Micro and Nano Technologies Challenges to Address 6G Key Performance Indicators

For the latest on IMS and Microwave Week visit ims-ieee.org

IMS Technical Sessions

Tuesday, 13 June

Tu1A	AI-Machine Learning Technologies for Microwaves
Tu1B	Recent Advancements in HBTs and HEMTs for RF Applications
Tu1C	Advanced Techniques in Multichannel and MIMO Systems
Tu1D	Millimeterwave CMOS LNAs and Receivers
Tu1E	Advanced Techniques for mm-Wave Signal Generation
Tu2A	Machine Learning for RF to mm-wave Systems
Tu2B	Emerging mm-Wave GaN Technologies for DoD and 5G-6G Applications
Tu2C	Advances in RF and mm-Wave Phased Array Antennas and Modules
Tu2D	Microwave and Millimeterwave LNAs
Tu2E	Advanced Frequency Conversion and Signal Generation
Tu3A	Artificial Intelligence and Machine Learning Techniques for Signal and Power Integrity
Tu3B	Integrated Passive Devices
Tu3C	Emerging mm-Wave Integrated Transceivers and Beamformers
Tu3D	Power Amplifier Design Solutions for Sub 6-GHz Applications
Tu3E	Advanced High-Frequency Mixed-Signal Circuits and Systems
Tu4A	Advances in Computer-Aided Analysis and Design
Tu4B	Integrated Filters
Tu4D	Advanced Linearization Techniques for Power Amplifiers and MIMO Transmitters

Wednesday, 14 June

We1A	Space Systems and Technologies
We1B	Enabling Technologies for Sub-THz and THz Systems
We1C	Broadband and High Frequency GaN Power Amplifiers
We1D	Advanced Additively Manufactured RF Systems and Heterogeneous Solutions
We1E	Theory and Inverse Design for Novel Applications
We1F	Emerging Technologies for Transmission Lines and Planar Components
We1G	Automotive and MIMO Radar
We1H	Innovative Non-planar Filter Topologies and Synthesis
We2A	Model Based Systems Engineering for RF, Microwave, and Millimeter-Wave Applications
We2B	Thz and Sub-Thz System Demonstrations
We2C	High-Power (>10W) Load Modulated GaN Power Amplifiers
We2D	Advanced Packaging and Interconnects

We2E	Sensors and Models for Microwave and mm-Wave Propagation
We2F	Substrate Integration Technology for GHz and THz Applications
We2G	Advanced MMW Radar Systems
We2H	Advanced Waveguide Filters
We3A	Quantum Computing-Sensing Components and Techniques
We3B	THz Imagers and Detectors and Microwave Photonics
We3C	Novel Power Amplifier Architectures for High Power Applications
We3E	Advances in Computational Techniques for Microwave and Millimeter Wave Applications
We3F	Emerging Planar Filters: From L-band to mm-Waves
We3G	RF-Microwave Research in Latin America
We3H	Non-Planar Passive Components and Technologies
We4A	Advances in Quantum Devices, Circuits and Systems
We4B	THz Communications Components
We4C	HF Through UHF, Watts to Kilowatts Power Amplifiers and Applications

Thursday, 15 June

Th1A	Reconfigurable Planar Filters and Diplexers
Th1B	Advances in Biomedical Sensing and Wave Interaction
Th1C	Recent Advancement in Injection Locked Radar Sensing
Th1D	Advanced Near Field Wireless Power Transfer
Th1E	Recent Advances on Microwave Acoustics
Th1F	Advances in Over-the-Air and Millimeter Wave Measurements
Th1G	High Linearity Millimeter-Wave Power Amplifiers
Th2A	Advanced Reconfigurable Filters
Th2D	Advanced Far Field Wireless Power Transfer
Th2E	Application of Integrated Magnetic Materials and Control Circuits
Th2F	Conducted and Over-the-Air Nonlinear Characterization Techniques
Th2G	Broadband Millimeter-Wave MMIC Power Amplifiers
Th2H	Microwave-mm-Wave Sensing Techniques and Applications
Th3A	Tunable Devices
Th3B	Integrated RFID Systems and Applications
Th3C	High Accuracy Physiological Sensing and Positioning
Th3G	MTT-S Sat Challenge
Th3I	Recent Advances in Microwave and mmWave Biomedical Radar Sensing Techniques

Technical Track Key:

Field, Device and Circuit Tech.	Passive Components & Packaging	Active Devices
Emerging Technologies	Focus or Special Sessions	RFIC Sessions
	Systems & Applications	

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Boot Camps and IMS2023 Technical Themes

AI/ML BOOT CAMP



This course on **Sunday, 11 June** will present the basics of Artificial Intelligence (AI)/machine learning (ML) for microwaves. The course is targeted to general audiences in the microwave community who are not necessarily experts in AI/ML and want to learn the basics of AI/ML. This includes engineers that are interested in using AI/ML for microwave applications, marketing and sales professionals who are interested in understanding the basics and relevance of AI/ML for microwaves, and university students who like to acquire the basic knowledge of AI/ML. The course will provide ample opportunities for audience interaction and Q&A. The fee includes a lunch, and an afternoon refreshment break.

QUANTUM BOOT CAMP



This course on **Sunday, 11 June** will provide an introduction to the basics of Quantum engineering, targeting microwave engineers who want to understand how they can make an impact in this emerging field. The intended audience includes new engineers, engineers who may be changing their career path, marketing and sales professionals seeking a better understanding of Quantum technology, as well as current university students looking to learn more about the practical aspects of Quantum technology. The format of the Quantum Boot Camp is like that of a short course, with speakers covering quantum engineering basics with a focus on the control and measurement of Quantum systems and will conclude with a hands-on introduction to the design of superconducting qubits using modern microwave CAD tools. The bootcamp is geared towards making the remainder of Quantum-week more accessible to attendees. The fee includes a morning refreshment break and a lunch.

RF BOOT CAMP



This course on **Monday, 12 June** will cover real-world, practical, modern design and engineering fundamentals needed by technicians, new engineers, engineers wanting a refresh, college students, as well as marketing and sales professionals. Experts within industry and academia will share their knowledge of RF/Microwave systems basics, simulation and network design, network and spectrum analysis, and microwave antenna and radar basics. Attendees completing the course will earn two IEEE CEUs. The fee includes a morning refreshment break, lunch, and an afternoon refreshment break.

IMS2023 TECHNICAL THEMES

Tuesday:

Wireless Communications
Future Directions: Artificial
Intelligence (AI)/Machine Learning (ML)
Connected Future Summit

Wednesday:

Model Based Systems Engineering
(MBSE)
Space

Thursday:

Wireless Power Transfer
Biomedical

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Deadline: 18 May 2023

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Exhibition, MicroApps, Industry Workshops and Mobile App



EXHIBITION OVERVIEW

The IMS2023 Exhibition includes 480+ exhibitors from around the world, showcasing their products and services. All conference pass holders gain free access to the exhibition, from 13-15 June. You can also register for a FREE EXPO-only pass for the Wednesday exhibition or attend all three days of the exhibition including presentations in the MicroApps Theater for only \$30 if you register by the Early Bird Deadline of 12 May 2023.

SHOW HOURS

Tuesday, 13 June 2023	09:30-17:00
Wednesday, 14 June 2023	09:30-18:00
Thursday, 15 June 2023	09:30-15:00

SHOW FLOOR NETWORKING HIGHLIGHTS

- IMS Game Zone
- Sweet Treat Tuesday
- IEEE Societies Pavilion
- Three Networking Lounges with Charging Stations
- Build a "Foxhole" Radio Receiver
- Coffee Breaks
- Industry Hosted Reception
- Systems Pavilion
- Professional Headshots
- MicroApps

MICROAPPS

The Microwave Application seminars (MicroApps) offered Tuesday, 13 June through Thursday, 15 June 2023, provide a unique forum for the exchange of ideas and practical knowledge related to the design, development, production, and test of products and services. MicroApps seminars are presented by technical experts from IMS2023 exhibitors with a focus on providing practical information, design, and test techniques that practicing engineers and technicians can apply to solve the current issues in their projects and products. View the complete MicroApps schedule at <https://ims-ieee.org/exhibition/microapps/microapps-seminars>

IMS MICROWAVE WEEK MOBILE APP

The IMS Microwave Week app is now available in the Apple App store and Google Play store. Install the app on your Android or iOS device to view the full schedule of Workshops, Technical Lectures, IMS and RFIC Technical Sessions, ARFTG, Panel Sessions, Social Events and Exhibition information. On-site during Microwave Week you will be able to download IMS and RFIC papers and presentations, access Workshop materials, locate exhibitors and explore all that San Diego, CA, has to offer! Download today!



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INDUSTRY WORKSHOPS

The Industry Workshops are 2-hour industry-led presentations featuring hands-on, practical solutions often including live demonstrations and attendee participation. These Workshops are open to all registered Microwave Week attendees for \$25 per Workshop. View the complete Industry Workshop schedule at

<https://ims-ieee.org/exhibition/microapps/industry-workshops>

Title	Affiliation
.01-20 GHz Small Form Factor Multiport Network Analyzer Design Accelerators	Richardson RFPD
5G Front End Modules Principles	Skyworks Solutions
6G: Enabling the Path Towards THz Frequencies	Rohde & Schwarz GmbH & Co KG
Advances In Multi-Technology Design Flow to Sign-Off	Cadence Design Systems, Inc.
Balancing Tradeoffs: Taming Signal Integrity Challenges in mmWave Antenna-to-Bits Implementations	Samtec, Inc.
Building a Hybrid Beamforming Digital Twin of Commercial Off the Shelf (COTS) Hardware using Commercially Available EDA Software	Keysight Technologies
Co-design Techniques for Wideband mmWave and SatCom Phased Array Systems	MathWorks, Inc.
DC-44 GHz Wireless Test System Design Accelerator Blocks for Wireless Test Systems	Richardson RFPD
Design Technology Co-Optimization (DTCO) of RF Power Amplifier Designs with GaN Device Technology	Synopsys, Inc.
Efficient Simulation of (Semi)Periodic Microwave Devices using ANSYS HFSS	ANSYS, Inc.
GaN-on-SiC: From Technology to System Design through Systematic and Accurate Modeling of Device Building Blocks	Wolfspeed, A Cree Company
Improved DUT Characterization by Virtue of Accurate Vector Signal Generation at a Remote (DUT) Plane	National Instruments
Linearization of Upcoming High-Efficient RF Power Amplifiers using Simulation and Hardware Measurements	MathWorks, Inc.
Low-Loss 3D-Printed Flat Cylindrical GRIN Lens for 5 dB Gain Enhancement of a 20 dBi Horn Antenna	Fortify
Maximizing Return on Investment for On-Wafer Over-Temperature Millimeter-Wave Characterization	FormFactor Inc.
MBSE Introduction: Systems to Silicon and Back	INCOSE
mmWave Permittivity Standard Reference Material Development	QWED Sp. z o.o
Optimizing High Performance Wireless RF Front End Products Time-to-Market; From Engineered Substrates to Systems	SOITEC
Phased Array System Modeling and Design using MATLAB and Analog Devices Hardware	MathWorks, Inc.
Production OTA and ORAN Testing for 5G mMIMO Radio	Keysight Technologies
Silicon to Phased Array Design, Analysis and AiP Implementation	Cadence Design Systems, Inc.
Validating a CATR Benchtop OTA Test System for 5G FR2 Phased Array Antenna R&D Testing	Rohde & Schwarz GmbH & Co KG

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Exhibitor List

2pi-Labs GmbH	Dongwoo Fine-Chem Co. Ltd.	JFW Industries Inc.	Orolia USA	Stellant Systems
3D Glass Solutions Inc.	Doosan Electro Materials	Jiangsu Caign Technology Co. Ltd.	Palomar Technologies	Stellar Industries Corp.
3G Shielding Specialties	Ducommun Inc.	Jiangsu Trijiant Technology Co. Ltd.	Pasquali Microwave Systems	StratEdge Corp.
3H Communications Systems	ECHO Microwave	Johanson Technology	Passive Plus	Sumitomo Electric Device Innovations
3Rwave	Eclipse MDI	JOL Technologies Corp.	PCB Power Inc.	Summit Interconnect
A-Alpha Waveguide Inc.	Egide USA	Junkosha Inc.	PCB Technologies USA	Sunfire Technologies
Accu-Tech Laser Processing Inc.	Electro Ceramic Industries	Keysight	Phase Sensitive Innovations	Sung Won Forming
ACE-Accurate Circuit Engineering	Electro Rent	Knowles Precision Devices	Photonics Systems USA Inc.	SuperApex Corporation
ACEWAVE/ETECH	Element Six	KOESTOSYS Co. Ltd.	Pickering Interfaces	Susumu International (USA) Inc.
Admotech Co. Ltd.	Elite RF	Kratos Microwave Electronics Division	Pico Technology	SV Microwave
Advanced Circuitry International	EM Labs Inc.	KRYTAR	Piconics Inc.	Switzer
Advanced Test Equipment Corp.	EMARGES	KVG Quartz Crystal Technology GmbH	PM Industries Inc.	Sylatech Limited
Aerospace & Defense Technology	Empower RF Systems Inc.	Kyocera AVX	Polarity Inc.	Symphony Microwave Technologies
Aethertek Technology	EMWorks	Kyocera International Inc.	Polyfet RF Devices	SynMatrix Technologies Inc.
AFT Microwave Inc.	ENGIN-IC Inc.	LadyBug Technologies LLC	PPG Cuming Microwave	Synopsys Inc.
AGC Multi Material America Inc.	EPIO Solutions	Lake Shore Cryotronics Inc.	PPI Systems Inc.	Syscom Advanced Materials
Agile Microwave	Eravant	Lanjan Electronics	Presidio Components	Tabor Electronics
AI Technology Inc.	Erzia Technologies	Laser Processing Technology Inc.	PRFI Ltd.	Tactron Elektronik GmbH
A-INFO Inc.	ETL Systems Ltd.	Leader Tech Inc.	pSemi Corporation	Tagore Technology Inc.
AJ Tuck Co.	ETS-Lindgren Inc.	Liberty Test Equipment Inc.	Q Microwave Inc.	Tai-Saw Technology Co. Ltd.
Akoustis Inc.	European Microwave Association	Linearizer Communications Group	Qorvo US Inc.	Taitien Electronics
Alifecom Technology Corp.	European Microwave Week	Linwave Technology	QP Technologies	Talent Microwave Inc.
ALMT/Sumitomo Electric USA	everything RF	LISAT	Q-PAR Antennas/STEATITE	TDK Corporation
Altum RF	evissaP Inc.	Logus Microwave	QRT Inc.	TDK-Lambda Americas
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Ampleon Netherlands BV	Farran Technology Ltd.	MACOM	Quantic Evans	Teledyne
AmpliTech Inc.	FILPAL (M) SDN BHD	Malico Inc.	Quantic MWD (Microwave Dynamics)	Telepartner Inc.
Analog Devices Inc.	Filtronics Inc.	Marki Microwave Inc.	Quantic Ohmega Ticer	Telonic Berkeley Inc.
AnaPico Inc.	Filtronic	Marvin Test Solutions	Quantic PMI (Planar Monolithics)	TEVET
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Anokiwave Inc.	Finwave Semiconductor Inc.	Maury Microwave	Quantic Wenzel	The Boeing Company
Anritsu	Flann Microwave Ltd.	MaXentric Technologies	Quantic X-Microwave	The EMC Shop
Ansys	Flexco Microwave Inc.	MCV Microwave East Inc.	QuinStar Technology Inc.	The Goodsystem Corp.
Antennex BV	Focus Microwaves Inc.	MECA Electronics Inc.	QWED Sp. z o.o.	TICRA
AR RF/Microwave Instrumentation	FormFactor Inc.	Mega Circuit Inc.	R&K Company Limited	Times Microwave Systems
AR Modular RF	Fortify	MegaPhase	Rapidtek Technologies Inc.	TMV Technology Inc.
Arion EMD	Fraunhofer IIS	Menlo Microsystems Inc.	Reactel Inc.	Tower Semiconductor
Artech House	Frontynk Technologies Inc.	Mercury Systems	RelComm Technologies Inc.	TPT Wire Bonder
ASB Inc.	Fujian Micable Electronic Technology Group Co. Ltd	Metallix Refining	Reldan	Transcom Inc.
ASI CoaxDepot	Gallium Semiconductor	Metamagnetics Inc.	Remcom Inc.	Transline Technology Inc.
Association of Old Crows	Gel-Pak	Mician GmbH	Remtec Inc.	Trexon / EZ Form Cable
Astronics Test Systems	General Atomics	Micro Harmonics Corp.	Renaissance Electronics	Tronser Inc.
Auden Techno	General Microwave Corporation	Micro Lambda Wireless Inc.	Res-Net Microwave Inc.	TRS-RenTelco
Avalon Test Equipment	GGB Industries Inc.	Microchip Technology Inc.	Response Microwave Inc.	TTM Technologies
Axiom Test Equipment	Gigalane Co. Ltd.	Micro-Mode Products	RF Globalnet	Ulbrich Specialty Wire Products
B&Z Technologies LLC	Gigatronix Ltd.	Microsanj LLC	RF Materials Co. Ltd.	Ultra Electronics Defense
Benchmark Electronics	Glenair Inc.	Microcross Components	RF Morecom Korea	United Monolithic Semiconductors
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Celanese Micromax	Harbour Industries	Microwave Factory Co. Ltd.	Richardson Electronics Ltd.	Valence Surface Technologies
Centerline Technologies	HASCO	Microwave Journal	Richardson RFPD	Vanteon Corporation
Cernex / Cernexwave	Hermetic Solutions (Qnnect)	Microwave Product Digest	RJR Technologies Inc.	Varioprint AG
ChongQing Ceratronics Technology Ltd.	Herotek Inc.	Microwave Products Group	RLC Electronics	Vauxnix Technology Corp.
Ciao Wireless Inc.	Hesse Mechatronics Inc.	Microwave Techniques LLC	Rogers Corp.	Ventec International Group
Cicor Group	High Frequency Electronics	Microwave Town Company LLC	Rohde & Schwarz USA Inc.	VIAS3D
Cinch Connectivity Solutions	Hirose Electric USA	Microwavefilters & TVC S.r.l.	Rosenberger North America	Viking Tech America
CML Microcircuits UK Ltd.	HJ Technologies	Microwaves & RF	SAF North America	Virginia Diodes Inc.
Coilcraft	HRL Laboratories LLC	Microwaves 101	Sales & Service Inc.	Virtual Industries
Colorado Microcircuits Inc.	Hughes Circuits Inc.	MilliBox	Samtec	Vishay Intertechnology Inc.
Communications & Power Industries	Hybrid Sources Inc.	Millimeter Wave Products	San Diego State University	WAFIOS Machinery Corp.
Comotech Corporation	Hyperlabs Inc.	Mini-Circuits	San-tron Inc.	Waka Manufacturing Co. Ltd.
Component Distributors Inc.	iCanal Ltd.	Mini-Systems Inc.	Sawnics Inc.	Wakefield Thermal
COMSOL Inc.	IEEE Future Directions: LEO Sats Project	MISOTECH	Schmid & Partner Engineering AG	Wave Mechanics Pvt. Ltd.
Conduant Corporation	IHP GmbH	Mitsubishi Electric US Inc.	Scientific Microwave Corp.	Wavepia Co. Ltd.
Connectronics Inc.	Impulse Technologies Inc.	MJS Designs Inc.	Seikoh Giken USA Inc.	WavePro
Continental Resources	IMS Connector Systems GmbH	mmTron Inc.	Sensorview Co. Ltd.	Wavice Inc.
Copper Mountain Technologies	IMST GmbH	Mnemonics Inc.	SGMC Microwave	WayGear
Corning Inc.	InCize	Modelithics Inc.	Shanghai Hexu Microwave	Weaslic Microelectronics S.A.
Cosmic Microwave Technology Inc.	InCompliance Magazine	Modular Components National	Shanghai XinXun Microwave Technology Co. Ltd.	Weinschel Associates
CPS Technologies Corp.	Indium Corp.	Molex	Shenzhen Superlink Technology Co. Ltd.	Werlatone Inc.
Crane Aerospace & Electronics	INGUN USA Inc.	Morion US LLC	Siglent Technologies NA	West Bond Inc.
Crystek Crystals Corp.	Innertron Inc.	Mouser Electronics	Signal Hound	Weyercomm Co. Ltd.
CTT Inc.	Innovative Power Products	MPI Corp.	Signal Integrity Journal	Wilkes University
Cubic NuvoTronics	In-Phase Technologies Inc.	MRSI Systems, Mycronic Group	Signal Microwave	WIN Semiconductors Corp.
Custom Cable Assemblies Inc.	INRCORE LLC	MtronPTI	SignalCore Inc.	Winchester Interconnect
Custom Microwave Components Inc.	Inspower Co. Ltd.	Naprotek/SemiGen	Signal Solutions USA LLC	WIPL-D
CW Swift & Associates Inc.	Insulated Wire Inc.	Narda-MITEQ	Signatone	Wireless Telecom Group
CX Thin Films	Insulectro	Network International Corp.	Skyworks Solutions	Withwave Co. Ltd.
Daico Industries Inc.	Integra Technologies Inc.	NI	Smiths Interconnect	WL Gore & Associates Inc.
Dalian Dalicap Tech Corporation	Intelliconnect LLC	Noble Metal Services	Soitec	Wolfspeed Inc.
Danyang Teruillai Electronics Co. Ltd.	International Manufacturing Services Inc.	Norden Millimeter Inc.	SOMACIS	Wupatec
Dassault Systemes SIMULIA Corp.	inTEST Thermal Solutions	Northrop Grumman Systems	Somefly Technologies Co. Ltd.	XMA Corporation
dB Control	IRON Tech	NTK Technologies Inc.	Sonnet Software Inc.	Xpedit Technology Inc.
DB Design Communication Technology	Ironwave Technologies	NuIspace Inc.	Southwest Microwave Inc.	XYZTEC Inc.
Delta Circuits	Ironwood Electronics	Nxbeam Inc.	Space Machine & Engineering	Y.TECH
Delta Electronics Mfg. Corp.	Isola	Oak-Mitsui Technologies LLC	Spectrum Control	YITEK Technology Corp.
Denka Corporation	iTest	Okmetic	Spinner GmbH	Z-Communications Inc.
DeWeyl Tool Company	ITF Co. Ltd.	Onano Industrial Corp.	SRTTechnology Corp.	
Diamond Antenna & Microwave	IWorks Co. Ltd.	Ophir RF Inc.	SSI Cable Corporation	
Dino-Lite Scopes		Optenni Ltd.	State of the Art Inc.	
Diramics		Optomec	Statek Corp.	
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First time exhibitors are noted in purple

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3H Communication Systems product offering includes filter products from DC to 50 GHz. 3H's filters offer custom designed, high performance filters in the smallest packages on the market today. 3H filter products support military, space and commercial applications. 3H's NEW VHF/UHF, eight-channel multiplexer with bidirectional coupler ports offers a frequency range from 5 MHz to 2 GHz with low pass-band insertion loss and sharp co-channel isolation and is available in leadless surface-mount application as well as other mounting options and meets MIL-STD-202 conditions. www.3hcommunicationsystems.com

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Achieve 200 V/m for MIL-STD-461 RS103 testing with the AA-618G-300. A rugged and reliable solid-state RF amplifier designed for high-power applications in the 6 to 18 GHz frequency range. With a minimum output power of 300 W and a gain of 55 dB, this amplifier provides exceptional performance in demanding environments. The AA-618G-300 incorporates the latest technology in RF amplifiers, including Class A/AB design and VSWR protection. Rent and save from Advanced Test Equipment Corporation today. www.atecorp.com

Agile Microwave Power Amplifier



Agile Microwave's new power amplifier AMT-A0560 specs include: 27 to 31 GHz, 10 W, 40 dB gain, +48 V single supply, lin-

ear and saturated output power, compact size with 2.92 mm connectors. They are ideal for 5G and satellite communications. Check out our full collection of power amplifiers. www.agilemwt.com

Altum RF Power Amplifier



Altum RF's ARF1014 is a monolithic 27 to 31.5 GHz power amplifier die fabricated in a GaN on SiC process technology. With 12 W saturated output power and 22% PAE, it is well suited for satcom terminals and other Ka-Band applications. Linear operation at 37.5 dBm output power achieves -25 dBc IMD3 with 18 dB power gain. Input and output ports are internally matched to 50 Ω . The ARF1014 is in production and 100% RF tested, including phase measurements to support power-combining applications. www.altumrf.com

Analog Devices Inc. Highly Integrated Satcom Beamformer

VENDORVIEW



Analog Devices continues to expand its low-power, highly integrated satcom beamformer portfolio with the addition of its Ka-Band terminal beamformers. The ADAR3002 is a dual-beam, four-element dual polarization receive beamforming IC operating from 17.7 to 21.2 GHz. The ADAR3003 is a single beam, four-element dual polarization transmit beamforming IC operating from 27.7 to 31.5 GHz. Their low power and high level of digital integration make them ideal for applications such as airborne terminals, man-pack radios and satcom-on-the-move. www.analog.com

AmpliTech Inc. Low Noise Amplifier



AmpliTech is known for offering the finest cryogenic low noise amplifiers (LNAs) in the world. These amplifiers operate in near absolute zero cryogenic environments and are utilized in pioneering scientific endeavors where optimal sensitivity is crucial. These include quantum computing, space exploration and radio astronomy. The heightened precision and sensitivity of measurements of the qubit state that AmpliTech's cryogenic LNAs provide, are essential to the function of quantum computers for executing quantum computations.

MMIC Amplifiers, Components and Custom Designs



Empower your communication systems with AmpliTech's innovative LNA MMIC amplifiers designed to meet the demands of today's fast-paced, connected world. These highlighted MMIC designs for 2 to 4 GHz and 4 to 8 GHz frequency ranges serve as pivotal components enhancing 5G connectivity for both S- and C-Band applications. Enable better performance and efficiency in your wireless communication systems, radar and satellite networks with AGMDC's unparalleled low noise performance utilizing state-of-the-art technologies. AmpliTech also offers custom design solutions tailored to your exact specifications. www.amplitechinc.com



AnaPico AG

Wideband Low Noise Frequency Synthesizers

VENDORVIEW



AnaPico recently started to deliver the new wideband low noise frequency synthesizers covering 10 MHz to 40 GHz. The phase noise at 20 kHz from 10 GHz is -125 dBc/Hz. The output power range is -30 to +25 dBm. It features fast switching of 50 us, absolute phase adjustment, pulse modulation, fast sweeping and triggering functions. The compact-size module works with both 100 MHz and 1 GHz references. Multiple units can be synchronized by the common 1 GHz reference from the master unit to provide multi-channel phase-coherent signals.

www.anapico.com

Anoison Electronics

VITA 67 and D38999 Coax Assemblies

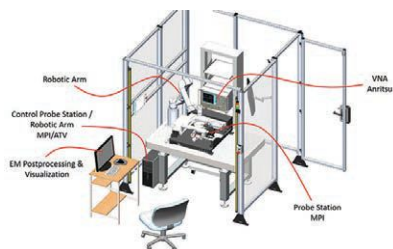


Anoison Electronics has the professional staff and engineers to create custom cable assemblies to meet our customers' needs. That is especially true when it comes to VITA67 and D38999 multi-coax connection systems. Anoison experts can create VITA67 and D38999 coaxial assemblies using either of two major cable diameters, 0.086 and 0.047, with working frequencies up to 65 GHz. Custom a cable to fit your RF, microwave or mmWave requirements.

www.anoison.com

Anritsu

VectorStar ME7838 System



Anritsu, in collaboration with MPI, are showcasing their single-sweep

70 kHz to 220 GHz VectorStar ME7838 system at IMS2023. A live demonstration of accurate antenna gain and radiation pattern measurements of an AiP antenna in the D-Band using a robotic arm will be presented. Since Anritsu's mmWave modules are small and lightweight, they can be mounted on a robotic arm, allowing precise measurements. Single-sweep broadband VNA measurements form the fundamentals of device modeling and characterization of transistors, amplifiers and filters.

www.anritsu.com

AR RF/Microwave Instrumentation

TWTA Replacement

VENDORVIEW



AR's 250S6G18C model with 250 W from 6 to 12 GHz and 200 W from 12 to 18 GHz is the company's newest

250 W Class A, solid-state, 6 to 18 GHz TWTA replacement. Designed for EMC RI, CI testing (MIL-STD-461, RTCA/DO-160), antenna testing and microwave component testing, this model has full VSWR mismatch tolerance with protection circuits. The second and third harmonics are < -20 dBc at rated power without external filtering, and its high linearity supports all wireless modulation standards. Manufactured in U.S.

www.arworld.us

AT & S Austria Technologie & Systemtechnik Aktiengesellschaft

GaN Doherty Power Amplifier for 5G Radios



AT&S embedded technology delivers the superior GaN Doherty power amplifier

solution for mmWave radios, mMIMO modules, indoor or outdoor FWA, surpassing the capabilities standard non-embedded technolo-

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www.ats.net

B&Z Technologies

State-of-Art Microwave and mmWave Amplifiers



Over the years, B&Z Technologies has earned a reputation for delivering the lowest noise figure broadband and narrowband high dynamic range amplifiers to the microwave industry. B&Z proprietary design techniques allow us to design most of our standard and customized amplifiers with various power, gain and noise figure combinations, anywhere in the 5 kHz to 50 GHz range in a single very compact standard housing with standardized parts required in extremely high-reliability applications.

www.bnzttech.com

Boonton



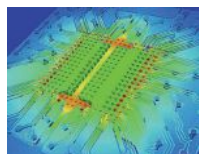
Real-Time Peak USB Power Sensors providing the highest video bandwidth and fastest rise times,

RTP5000 peak USB power sensors with Boonton's Real-Time Power Processing™ deliver 100,000 measurements per second, no gaps in signal acquisition and zero measurement latency. Combining this performance with automatic pulse measurements, CCDF and crest factor statistical analysis, multi-channel capabilities and documentation tools RTP5000 peak power sensors are the ideal instrument for fast, accurate and reliable RF power measurements.

www.boonton.com



Cadence RF to mmWave Product Solutions



Cadence enables engineers developing RF to mmWave products for 5G/6G, radar and other wireless applications to drastically reduce turnaround times with AWR® Microwave Office® circuit simulation and in-design 3D EM and thermal analyses using Clarity™, EMX® and Celsius™ solvers. These solutions are fully integrated with Cadence® MMIC/RFIC, module, package and PCB implementation software via the AWR Design Environment®, Virtuoso® and Allegro® PCB platforms to speed design throughput and greatly improve the simulation accuracy of highly integrated large system designs.

www.cadence.com

Cernexwave High-Power Waveguide Circulators



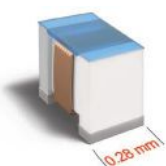
Cernexwave's CWC series high-power waveguide circulators are great solutions for directing signals



of any strength. They are made to fit your project requirements with small to very large frequency bands and power levels into the kilowatts. The precision internals provide low insertion loss and high isolation while the robust aluminum construction keeps temperature levels manageable.

www.cernexwave.com

Coilcraft Inc. Chip Inductors



Measuring just $0.47 \times 0.28 \times 0.35$ mm, the Coilcraft 016008C Series chip inductors are the smallest wire-wound chip inductors in the world. They are offered in 36 inductance values from 0.45 to 24 nH and feature up to 40% higher Q-factors than the best thin film counterparts. High Q is required to minimize insertion loss in RF antenna impedance matching circuits, making the 016008C Series ideal for high frequency applications such as cell phones, wearable devices and LTE or 5G IoT networks.

www.coilcraft.com

Communications and Power Industries X-Band Solid-State Power Amplifier



CPI's VSX3717 is an air or liquid cooled 4.0 kW X-Band solid-state power amplifier optimized for pulse radars. X-

Band solid-state power transmitters are efficient, high-power and compact with proven GaN transistor technology. CPI's VSX3717 solid-state power amplifier is rugged, reliable and easy to maintain. The VSX3617 solid-state transmitter is designed for use in radar applications and covers the 9 to 10 GHz frequency band.

www.cpii.com

COMSOL COMSOL Multiphysics® Version 6.1



Version 6.1 of COMSOL Multiphysics® is now available. Major upgrades to platform features (the Model Build-

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DC~110GHz

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- VSWR <1.45:1@110GHz
- Shielding Effectiveness <-90dB
- Amplitude Stability vs. Flex. <±0.1dB@110GHz
- Phase Stability vs. Flex. <±8°@110GHz
- Phase Stability vs.Temp. 400ppm@-40°C~+70°C
- Wire Diameter 3.0mm w/ armor

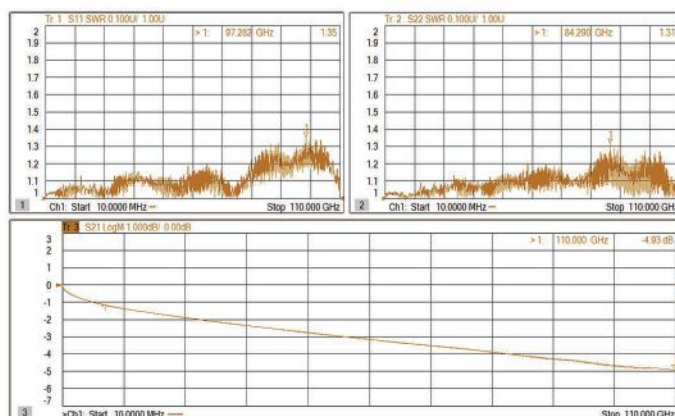


Model	Connector Configure	Length (inches)	Unit Price (1-9pcs)
T110-1Y-1Y-6	1mm male to 1mm male	6	\$1,094
T110-1Y-1Y-12	1mm male to 1mm male	12	\$1,116
T110-1Y-1Y-24	1mm male to 1mm male	24	\$1,161

Applications

- Connections of module to module or rack to rack
- Various test systems
- Temperature cycle test in chamber
- Military & commercial millimeter wave equipment

VSWR





er, Application Builder and Model Manager) as well as to many add-on products, bring additional physics interfaces, new simulation tools and enhanced workflows. There are new modeling capabilities for application areas such as turbulent and multi-phase flow, thermal management of battery packs, acoustic simulation of micro speakers, electric motor design, mechanical contact, optimization and more. Check out the release highlights to see what's new.

www.comsol.com

Connectronics Non-magnetic RF Connectors



Connectronics can modify its extensive product line of 6,000 RF connectors to feature non-magnetic and cryogenic qualities critical to quantum computing applications. These high frequency, coaxial RF connectors are U.S. manufactured with base material and plating finish combinations that minimize magnetic signature. Connectronics delivers connectivity solutions, ensuring no interference with quantum computing's applied magnetic fields. The company produces a complete range of RF connectors in large and small quantities, including

unique and hard-to-find connectors. Visit Connectronics at IMS booth 515.

www.customrfconnectors.com

Copper Mountain Technologies Frequency Extender Modules



Copper Mountain Technologies and Eravant have partnered to deliver co-branded frequency extender modules. Anchored by CMT's 9 GHz CobaltFx compatible VNAs, CMT offers a cost-effective frequency extension system with options for adjustable and high output power. Complete the system with a calibration kit and accessories, like the Wave Glide™ rail system for an easy-to-use setup, Waveguide Quick Connect™ for streamlined calibration and Proxi-Flanges™ to facilitate a more accurate test setup.

www.coppermountaintech.com

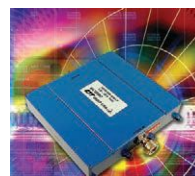
Crane Aerospace & Electronics RF Converter Miniaturization Using Multi-Mix®

Our multilayer Multi-Mix technolo-

gy provides a miniature footprint with maximum flexibility and performance. Key benefits include a 5x to 10x reduction over traditional converters with packages less than $5 \times 2 \times 0.5$ in., multi-layer Multi-Mix motherboard with double-sided SMT populated in a lightweight housing frame that provides excellent RF channelization and isolation, four integrated coherent wideband synthesizers, embedded pre-select frequency filters and fast tuning and settling times. Let us meet your most complex RF converter needs.

www.craneae.com

CTT Inc. Multi-Mode Radar Solutions



CTT's GaN-based solid-state power amplifier (SSPA) Model AGN/095-6064 can operate from 9 to 10 GHz, in 500 MHz band segments, with 1 kW pulse power output at 5% duty cycle (100 μ Sec pulse width). The compact SSPA, measuring $6.17 \times 4.36 \times 0.82$ in., is an excellent solution for your multi-

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mode radar applications. Type "N" or waveguide output options. Export license may be required.
www.cttinc.com

Custom Microwave Components Inc. 40 GHz 8×8 Switch Matrix

CMCI1150 is a 20 to 40 GHz non-blocking 8×8 solid-state switch matrix system controlled through an embedded browser-based patented intuitive GUI with near zero learning curve and start-up time promised. Bench-top (12 x 12 x 6 in.) model shown. Rack-mount and wall-mount configurations are



available.
www.customwave.com

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www.electrorent.com

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IMS in the MWJ Booth 424

Electro-Photonics LLC High-Power Resistors, Attenuators and Terminations



Electro-Photonics LLC, a leading provider of RF, microwave and mmWave products, has released a new product line of high-power resistors, attenuators and terminations. These products offer power ratings up to 1650 W and frequency ranges from DC to 40 GHz in a chip, flange, flangeless and coaxial configurations.
www.electro-photonics.com

Empower RF High-Power GaN SSPA Products VENDORVIEW



Another notable addition to Empower RF's high performance, high power GaN SSPA product portfolio is delivering now for replacement of aging 2 to 4 GHz traveling wave tubes (TWTs). The 2245 provides a minimum of 4100 W CW from 2 to 4 GHz with 5 kW mid-band performance. Its lower total cost of ownership over TWT amplifiers and 15-minute MTTR make it the smart choice for those seeking to modernize their waveform handling capabilities with a more efficient, reliable and cost-effective solution.

www.empowerrf.com

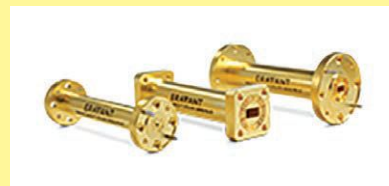


Eravant VNA Frequency Extenders VENDORVIEW



Providing dynamic range up to 120 dB, the STO series of VNA frequency extenders from Eravant occupy dimensions of 1.9 x 3.0 x 11.5 in. They enable VNA measurements at frequencies up to 330 GHz. Their reach extends beyond the commonly recognized frequency limits of standard waveguide sizes to fully cover many of the bands allocated for radar and communication systems. One-port, two-port/one-path and full two-port VNA configurations are supported. The extenders are compatible with select VNA models from all major OEMs.

Contactless Waveguide Adapters



One of the challenges of operating any VNA is to properly connect calibration standards and tested devices to the VNA test ports. When the test ports are waveguides, the challenges are compounded by the need to carefully engage and tighten waveguide screws. Proxi-Flange™ contactless waveguide flange adapters from Eravant can eliminate the need for waveguide screws, greatly lowering the hurdles encountered when working with VNAs at waveguide frequencies. The adapters are available in sizes ranging from WR-42 to WR-03.

www.eravant.com



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Exodus Advanced Communications Exodus AMP2065E-LC

VENDORVIEW

Exodus AMP2065E-LC is designed to replace aging TWT technology. A broadband rugged EMC Class A/AB linear solid-state design for all modulations and industry standards. Covers 6 to 18 GHz, produces > 500 W minimum, 600 W typical with > 57 dB gain. Excellent flatness, optional monitoring parameters for forward/reflected power in both dBm and watts, VSWR, voltage, current and temperature indication for superb-reliability. Gain control is standard as well as power-indication accurate to within ± 0.2 dB in a 12U package with incorporated quiet-cool technology.

www.exoduscomm.com



EZ Form Cable .086 in. Phase Stable Semi-Rigid Cable



EZ Form Cable has developed the next advancement in semi-rigid cable technology with the introduction of our EZ-PT86 phase stable semi-rigid cable. This high performance cable was developed for applications where minimal phase change over temperature is required and critical to the overall performance of RF systems. EZ Form Cable can now offer this cable with both build-to-print cable assemblies as well as bulk cable shipments.

www.ezform.com

Fujian Micable Electronic Technology Group Co. Ltd. High Linearity High Power Amplifier

VENDORVIEW



Micable introduces the new 100 W solid-state, high gain, wideband power amplifier MPAR-010060S50 with the latest high-power RF GaN transistors, built-in control, monitoring and protection functions. It is designed for applications, such as 5G/LTE, Wi-Fi and other related system and EMC tests. Custom designs are available.

High Accuracy Butler Matrices



Micable 24.2 to 27.5/26.5 to 29.5/37 to 40 GHz 4x4 high accuracy butler matrices can

transfer the signal reciprocally from any of four ports to any other four ports. They cover 5G n257/258/260 frequency bands and have high versatility for 5G test applications. Because the high performance passive components and cables are used inside, the systems have super phase accuracy, amplitude balance, stability and repeatability.

www.micable.cn

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VENDORVIEW



A global distributor of 'just-in-time' RF and microwave components, HASCO is expanding their line of ultra-flexible cables to include the HLB055 Littlebend 110 GHz flexible cable series. These super flexible cables are terminated with high performance 1.0 mm straight connectors and are available in multiple lengths and configurations, including SMA, 1.85 mm, 2.4 mm, 2.92 mm, SMP and SMPM connectors, with additional configurations available upon request. To learn more or place an order, visit HASCO's website.

www.hasco-inc.com

Herotek Limiter



Herotek offers a wide range of high power limiters. Model LS-00105P200A is a 200 W CW limiter operating from 10 to 500 MHz with 1 kW peak, 1 μ s pulse width limiting protection. It has a low insertion loss of 0.8 dB and 2.2:1 VSWR with typical leakage of +20 dBm at 200 W CW input. This limiter has built-in input and output DC blocks. It comes in a hermetically sealed package with removable connectors for drop-in assembly and designed for both military and commercial applications.

www.herotek.com

HYPERLABS

Broadband Amplifier Products

VENDORVIEW

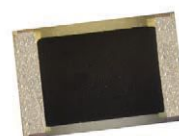


HYPERLABS is a leading provider of high performance, broadband amplifier products including linear amplifiers that cover to 65+ GHz in support of PAM4 data driver requirements with a focus on maintaining optimized eye patterns. For higher power requirements, HYPERLABS offers a new 10 Vp-p high power amplifier (to 20 GHz). Since 1992, HYPERLABS has built a reputation as an industry leader in broadband component designs including: baluns, bias tees, DC blocks, power dividers and more. Visit HYPERLABS at IMS booth 2440.

www.HYPERLABS.com

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The IMS N-Series thick film high-power chip resistors and chip terminations on aluminum nitride (AlN) are ideal for most applications requiring high thermal conductivity in a small size package. AlN is an ideal replacement for BeO with its high-power dissipation and no environmental or health hazards. Thick film technology provides a stable resistive element at a very affordable price.

www.ims-resistors.com

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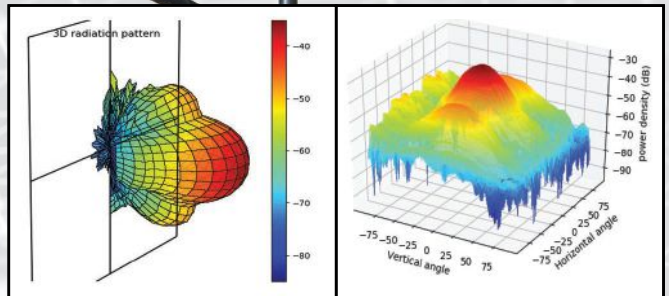
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or any combination
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Filters, Switches

Parameter	Unit	Value
Uplink Frequency Band	GHz	26 to 32
Dowlink Frequency Band	GHz	18 to 24
Max Insertion Loss	dB	4 Downlink 5 Uplink
I/P & O/P VSWR		1.6:1
Gain Flatness	dB	1.0
Port to Port Variation	dB	1.0
Port to Port Isolation	dB	25



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PRODUCT SHOWCASE

sive filter products include band-pass, notch, highpass, lowpass, high power lowpass and cavity designs covering the RF and microwave frequency spectrum, with diplexer and multiplexer designs available. TTE's products are custom-made and built-to-order with most of our products being delivered within two weeks.

www.tte.com

Insulated Wire Inc. Re-Flex™ Starter Kits

To simplify RF system development, IW is pleased to introduce our range of Re-Flex Starter Kits. Three kits are currently available: CT-1879 (SPSD-TPRF085-XXX-SPSD) direct solder



SMA male/male, TPRF085 (RG405 line size), CT-1880 (SPSD-TPRF141-XXX-SPSD) direct solder SMA male/male, TPRF141 (RG402 line size) and CT-1881 (SPSH-TPRF141-XXX-SPSH) shell style SMA male/male, TPRF141 (RG402 line size). Each kit comprises seven different assembly lengths: 3, 4, 5, 6, 8, 9 and 12 in., 5 pieces of each.

www.iw-microwave.com

JFW Industries Inc. Attenuator Assemblies



Four new attenuator assemblies from JFW operate at 200 to 7125 MHz with attenuation ranges of 0 to 95 dB by 1 dB steps. All of the models feature Ethernet remote control that can be used with scripts for automated testing. One and two attenuator versions are available in benchtop chassis. And rack-mounted assemblies allow for anywhere three to 16 attenuators in a system. Support for Python scripting is available from JFW Engineering.

www.jfwindustries.com

JQL Technologies Corp. SMT & Microstrip Isolators and Circulators



JQL Technologies Corporation has launched space qualified surface-mount and microstrip isolators and circulators.

These devices have gone through Group B qualification testing and screening per MIL-STD. Surface-mount isolators are available from L-Band to Ku-Band and microstrip isolators are available from C-Band to Ka-Band. JQL has built hundreds of these devices for LEO programs.

www.jqltechnologies.com

Kratos General Microwave mmWave Control Components and Integrated Assemblies



General Microwave Corporation is a key partner with major OEM's and primes, having been chosen for our broad and

comprehensive understanding of mmWave technologies. The company offers catalog mmWave phase and amplitude control modules, which includes IQ modulators, phase shifters, switches, attenuators, as well as custom integrated assemblies operating in the 18 to 50 GHz frequency range. If it is a catalog unit or a highly customized mmWave assembly designed specifically for your high performance system needs, contact General Microwave.

www.kratosmed.com

Krytar Butler Matrices

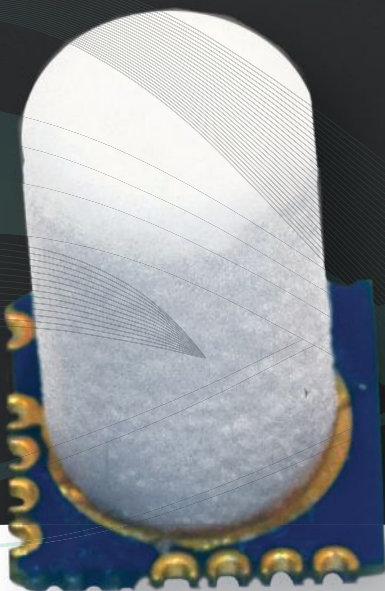


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perior phase accuracy, amplitude imbalance, stability, high isolation, low insertion loss, low VSWR and repeatability. Offering coverage of multiple microwave bands, from 0.5 to 40 GHz, a Krytar butler matrix is the ideal choice for antenna array beamforming, 5G New Radio testing, mmWave testing, MIMO testing, multipath simulation and performance evaluation and many other applications.

www.krytar.com

LadyBug Technologies New RF Power Sensors

VENDORVIEW



LadyBug Technologies' LBSF09 USB power sensor offer several features specifically designed to enable ease of use and ease of system integration. The NIST traceable calibration and patented NoZero NoCal feature enables the sensor to make temperature stabilized measurements with industry leading accuracy. Similarly, thermal stabilization is an active process, so offsets from thermal drift associated with accurate, low-power measurements are eliminated. Lastly, the PC interface, I2C, SPI and triggering are all supported through a single secure connecting USB-C connection, enabling rapid system integration.

www.LadyBug-Tech.com

LPKF ProtoLaser H4



Sometimes the laser is the tool of choice, sometimes a drill, sometimes a milling cutter. If you use the LPKF ProtoLaser H4 for circuit board prototypes, you don't have to worry too much about it. The latest device in the ProtoLaser series decides independently and is therefore even more flexible than its predecessors.

www.lpkf.com/en

Marki Microwave Miniature Bias Tee



The BTM-0026PSM is a packaged miniature bias tee featuring excellent insertion loss and superior isolations over a broad 10 MHz to 26 GHz bandwidth. Unlike in-house designs that take up internal resources and use non-optimized components, the BTM-0026PSM design and layout is optimized for smooth, resonance-free response with high DC isolation and low loss. Performance of each unit is well characterized on the datasheet and in the de-embedded S-parameters and verified with production RF testing. Available as a 2.25 x 3.7 mm SMT or connectorized evaluation board.

www.markimicrowave.com

Massachusetts Bay Technologies Silicon RF/Microwave Semiconductor Devices



Massachusetts Bay Technologies (MBT) designs and manufactures silicon (Si) RF/microwave semiconductor devices. Our quality devices are used in various industry applications such as consumer products, telecommunications, medical, aerospace and military. MBT's product line includes but is not limited to point contact diodes, Si and ceramic capacitors, Si resistors, attenuator pads, abrupt tuning varactors, step recovery, PIN, limiter diodes, Schottky and obsolete discontinued devices. Headquartered in Stoughton, Mass., MBT is certified to the ISO9001:2015 standard. Si foundry and fabrication service is available for the discerning electronic component requirement.

www.massbaytech.com

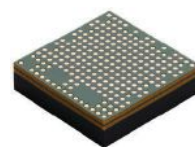
MCV Microwave Ceramic Patch Antennas



MCV Microwave introduces a series of ceramic patch antennas utilizing various dielectric constant materials in custom shape for GPS L1/L2, GLONASS, OmniStar, Imsat, Iridium and medical applications. These patch antennas exhibit tight electrical and mechanical tolerance and consistency in large volume. High performance antenna/LNA modules are designed and manufactured to have low latency in satellite tracking with LTE signal resistance. Please contact MCV Engineering for consultation.

www.mcv-microwave.com

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The Menlo Micro differential dual DP3T relay supports the high speed differential signal switching required in PCIe Gen 6, SerDes and other applications. The MM5620 is based on Menlo's Ideal Switch® technology and can operate up to 64 GT/s or 20 GHz for high performance applications. The MM5620 has low insertion loss, fast switching speed and can operate with greater than 3 billion switching cycles. The MM5620's integrated charge pump and driver can be controlled through SPI or GPIO interfaces by a host processor.

www.menlomicro.com

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By standardizing processes and technologies across multiple sites, an integrated manufacturing approach can bring trust and agility to mission-critical programs. From chip-scale microelectronics to system-scale RF integration, Mercury invests

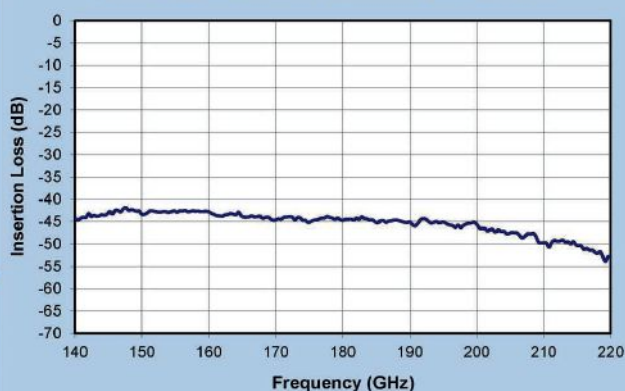
New 1" Compact Fixed Attenuator

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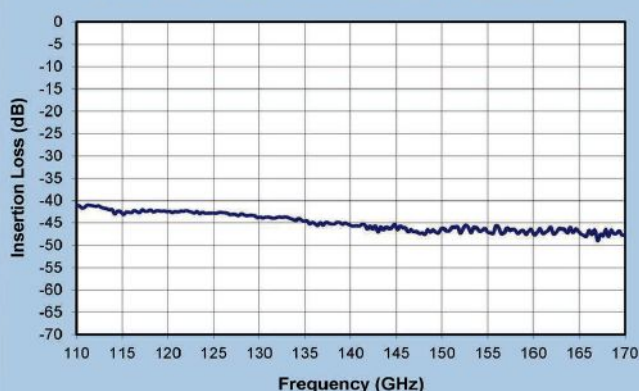
Standard attenuation values and custom attenuation available



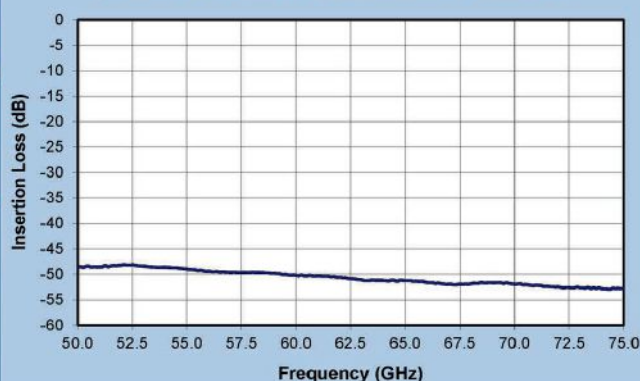
Typical 05F45 45 dB Fixed Attenuator Performance



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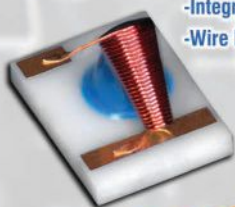
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Mician GmbH μWave Wizard



μWave Wizard software products are geared towards rapid development of passive RF components in aerospace and telecommunications. The software combines the flexibility of fast and powerful numerical methods with an appealing and ergonomic GUI that enables flexibility and openness. Typical applications include waveguide and comb line filters, feed clusters, OMTs, polarizers, circulators, multiplexers, couplers, horn and reflector antennas and more. At IMS2023, Mician will preview the latest version of μWave Wizard which will be available later in 2023.

www.mician.com

Micro Lambda Wireless Notch Filters



Micro Lambda's breakthrough product line of notch filters cover mmWave frequencies. This family of new Yttrium Iron Garnet based filters provide superior notch depths over the 20 to 40 GHz frequency range. Two models provide tunable notches of 15 MHz minimum at 40 dB down across the 20 to 36 GHz (MLFR-2036) and 28 to 40 GHz (MLFR-2840) bands. The 3 dB bandwidth is 100 MHz maximum for both models. Typical passband insertion loss is 3 dB and the pass-band range is 20 to 42 GHz.

www.microlambdawireless.com

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Micro-Mode Products offers the industry's first calibration kits developed exclusively for SMPM and



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www.micromode.com

Micross Hi-Rel RF Solutions



KCB Solutions, a best-in-class supplier of highly-engineered, leaded and leadless, GaN/GaAs RF and microwave switches, attenuators, amplifiers, multi-chip and functional modules in both standard and custom form, is now Micross Hi-Rel RF Solutions. Micross is the most complete provider of advanced microelectronic services and component, die and wafer solutions. With the broadest authorized access to die and wafer suppliers, and the most comprehensive advanced packaging, assembly, modification and test capabilities, Micross is uniquely positioned to provide unparalleled high-reliability solutions.

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MilliBox

Benchtop mmWave Radar Testing Setup

MilliBox has a range of over-the-air test setups specifically designed for mmWave radar measurements. They feature MBX3x large cavity benchtop anechoic chamber,



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from 0.1 to 3 Hz with course from 1 to 30 mm. These affordable mmWave test setups are ideal for developers testing and tuning their radar performance at any incident angle for a wide range of use cases. www.millibox.org

Millimeter Wave Products Inc.

High Power Amplifier



Mi-Wave's 955A-29.3/40/41.5/KF/599HAC 14 W high power amplifier comes in a 29.3 GHz frequency with a typical small signal gain of 40 dB and PSAT of 41.5 dBm. This unit is 5G ready. In addition, Mi-Wave's 955 Series microwave and mmWave 5G power amplifiers offer a wide variety of frequency ranges, bandwidths, gain and power outputs. All manufactured in-house in America and fully customizable to meet your 5G and mmWave needs. Consult with us for your specific needs. www.miww.com

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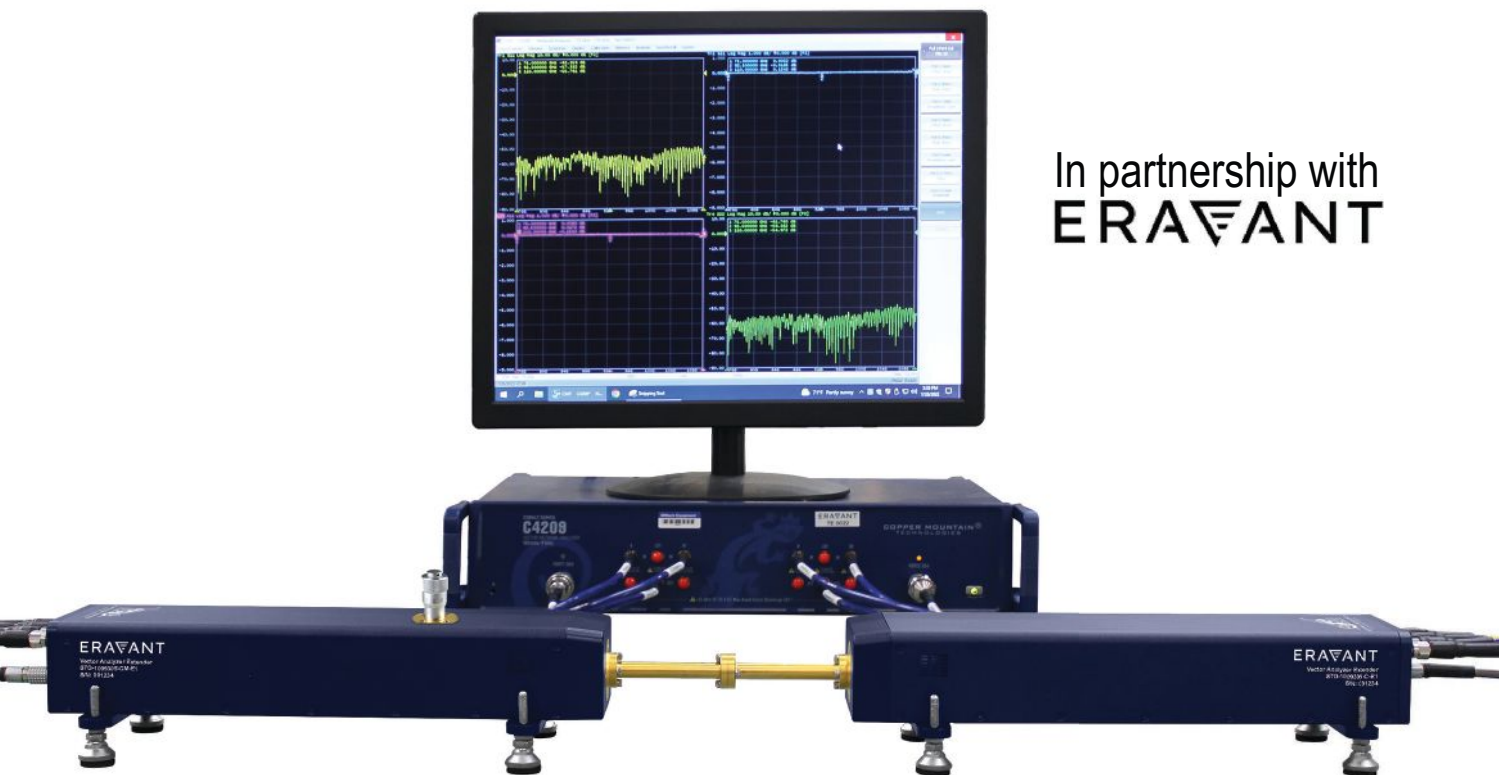
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MMWAVE TESTING SOLUTION

ANCHORED BY 9 GHz VNA

Copper Mountain Technologies and Eravant have partnered to deliver co-branded frequency extender modules with options for output power adjustment and high power output anchored by a 9 GHz VNA.

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Mini-Circuits

Low Noise Amplifier



Mini-Circuits' model ZX60-14LN-S+ is a low noise amplifier (LNA) with bandwidth of 50 MHz to 10 GHz. Noise figure is typically 2.2 dB to 8 GHz and 3.62 dB to 10 GHz. Gain is typically 20.6 dB to 8 GHz and 18.2 dB to 10 GHz with full-band gain flatness of ± 2.2 dB and within ± 1 dB to 8 GHz. Well suited for communications, radar and test, the LNA features SMA female connectors and operates from a single +6 VDC supply.

Highpass LTCC Filter



Mini-Circuits' model HFCV-2002+ is a low temperature co-fired ceramic (LTCC) highpass filter with passband from 19.6 to 47.0 GHz. Passband loss is typically 1 dB to 26.5 GHz and 2.2 dB or less to 47.0 GHz. Rejection is 17.8 dB or better across a stopband of 0.1 to 15.0 GHz. Ideal for cellular communications and test applications, the surface-mount technology (SMT) filter handles input power levels to 1 W. The 50 Ω filter measures 0.126 $\times$ 0.098 in. (3.20 $\times$ 2.50 mm).

Coaxial Amplifier



Mini-Circuits' model ZVA-24443G1+ wideband coaxial amplifier covers 24.0 to 43.5 GHz with 43 dB or more typical gain. The typical full-band noise figure is 1.75 dB or better, with output power at 1 dB compression of typically +21 dBm or better. The typical third-order intercept is +27 dBm. Available with or without a heat sink, the rugged amplifier has built-in over-voltage and reverse-voltage protection and incorporates 2.92 mm female coaxial connectors. It operates from a single supply of +9 to +15 VDC.

Low Loss SMT Thru-Line



Mini-Circuits' model TPCG-183+ SMT thru-line features low loss from DC to 18 GHz. Typical insertion loss is 0.5 dB from DC to 15 GHz rising only to 0.6 dB through 18 GHz. Return loss is typically 10 dB to 15 GHz and 9 dB to 18 GHz. The 50 Ω thru-line is a good fit for communications, radar and test systems and serves as a handy "place holder" in printed circuit boards for 0805 SMT LTCC filters. It handles as much as 7.5 W of power.

Cavity Bandpass Filter



Mini-Circuits' model ZVBP-16R3G-S+ is a cavity bandpass filter with insertion loss of typically 0.5 dB and return loss of typically 21 dB across a passband of 15.9 to 16.7 GHz. It accompanies the outstanding loss characteristics with lower-band rejection of typically 58 dB from DC to 14.7 GHz and upper-band rejection of typically 39 dB from 17.4 to 28.0 GHz. Outfitted with SMA female coaxial connectors, the RoHS-compliant filter is ideal for isolating signals of interest in test setups.

www.minicircuits.com

Molex

5G 4 $\times$ 4 Band 7 RF Cavity Filter



This filter represents the best in performance across many parameters. It offers low insertion loss (< 1 dB), high filter-to-filter isolation (> 70 dB) and tough rejection profile. This filter can be designed for 8T8R as well. IP67-rated 4.3-10 connectors and powder coating make it suitable for extreme outdoor conditions. Size, shape and weight in die cast versions are optimized for network operators and integrators.

www.molex.com

MPG

Printed Filters



Covering a frequency range of 2 to 30 GHz, 2 to 40% relative bandwidth and 1.5:1 VSWR these products offer an extremely small footprint and low profile. Incorporates the 50 Ω matching network giving the best performance when installed. Highpass, lowpass, bandpass and notch designs are available. These filters are suitable for the highest reliability requirements. For more information contact support@mpg-dover.com or visit our website to contact an engineer today.

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MtronPTI

(Represented by Bradford RF Sales in New England)

Electronically Vibration Compensated OCXO

MtronPTI's XO5503-100 is an electronically vibration compensated OCXO designed for applications where dynamic phase noise performance is critical. It incorporates an SC-cut quartz resonator and electronic vibration compensation technology, resulting in a G-





Featured GaN Power Amplifiers



FEATURES

- Wide bandwidth from 1.8 to 6.2 GHz
- Psat 42 dBm, Gain 46 dB
- Input / Output matched to 50 Ohms
- TTL control
- Temperature monitor
- Thermal Shutdown for Temp > 95°C

AMCOM's AM186242MD-4H is a broadband GaN Power Amplifier module designed for general purpose applications. It operates from 1.8 GHz to 6.2 GHz and typically delivers 15 watts (42dBm) of CW output power and 46 dB small signal gain. The amplifier module has 4 screw slots for mounting to a heat sink. This amplifier module is compact and light weight at 2.2" (L) x 2.2" (W) x 0.65" (H).



FEATURES

- Wide bandwidth from 4 to 8 GHz
- Psat 47.5 dBm, Gain 55 dB
- Input / Output matched to 50 Ohms
- TTL control

AMCOM's AM408047SF-5H is a broadband GaN Power Amplifier module designed for general purpose applications. It operates from 4 GHz to 8 GHz and typically delivers 55 watts (47.5dBm) of CW output power and 55dB small signal gain. The amplifier module has 6 screw slots for mounting to a heat sink. This amplifier module is compact and light weight at 6" (L) x 4" (W) x 0.75" (H).

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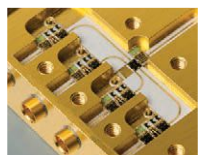


sensitivity of 0.02 ppb/g. The XO5503 Series OCXO measures $2.0 \times 1.5 \times 0.8$ in. and has a maximum weight of 70 g which is significantly smaller and lighter than the bulkier mechanically vibration compensated products and supports a wide temperature range of -45°C to $+85^{\circ}\text{C}$ with stability down to ± 200 ppb.

www.mtronpti.com

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Naprotek provides unique capabilities including RF/microwave electronics manufacturing and PCB assembly, in-house semiconductor and thin film foundry capabilities and performance testing with a focus on defense,

space, satcom and advanced technology applications. We offer a comprehensive RF product line of passive and active semiconductor components, from attenuators to complex thin film circuits that meet the highest industry standards. Our two U.S.-based centers of excellence provide end-to-end manufacturing solutions for prototyping and batch production, integration and test and RF microelectronics assembly.

www.naprotek.com

Networks International Corp.

Ultra-Low Profile LC Filters



NIC's engineering expertise in high-reliability RF products includes low profile (< 0.1 in.) LC filters that span from 10 MHz to 11 GHz. These compact high performance filters are built on industry standard printed circuit boards, such as Rogers 4350 or 4003, and have high selectivity with an out-of-band rejection of > 60 dB. These products can be customized to meet passband requirements from 1 to 100% and pass a wide range of environmental requirements as well. Please stop by booth 1124 at IMS2023 for additional information.

www.nickc.com

Norden Millimeter

Custom Transceivers



Norden designs custom transceivers for military and commercial applications including airborne, unmanned aerial vehicle and electronic warfare. They have "catalog" models which provide wideband RF and up to 1.5 GHz IF with low phase noise. Norden can provide custom designs which incorporate temperature compensation, variable gain and meet military environmental requirements. Norden also offers models in a low SWaP 3U VPX module which includes a built-in LO. Norden engineers utilize proven designs to provide low risk, cost-effective solutions.

www.nordengroup.com

Nxbeam

3.5 W V-Band GaN Power Amplifier MMIC



Nxbeam expands its MMIC portfolio with the release of a new GaN V-Band power amplifier MMIC. The NPA4010-DE operates from 47 to 52 GHz and provides an average saturated output power of 3.5 W, average power-added efficiency of 23% and average linear gain of 24 dB. The output power level of this MMIC makes it ideal for point-to-point V-Band communication links and satellite communications ground terminals.

www.nxbeam.com

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Excellent Phase Accuracy, Amplitude Unbalance

Low VSWR / Low Insertion Loss / High Isolation



P / N	Structure	Freq. Range (GHz)	VSWR Max. (:1)	Insertion Loss* Max. (dB)	Amplitude Unbal. Max. (dB)	Amplitude Flatness Max. (dB)	Phase Accuracy Max. (Deg.)	Isolation Min. (dB)
SA-07-4B006050	4x4	0.617~0.821	1.4	8.2	±1.1	±0.8	±10	16
		0.832~0.96	1.4	8.2	±1.1	±0.7	±9	16
		1.427~1.71	1.5	8.3	±0.9	±0.7	±9	15
		1.71~2.2	1.5	8.5	±0.9	±0.8	±10	14
		2.496~2.69	1.5	8.7	±0.9	±0.7	±9	13
		3.3~4.2	1.6	8.9	±1.0	±0.7	±12	13
SA-07-4B020080	4x4	4.4~5	1.6	9.2	±1.0	±0.8	±12	13
		2.4~2.5	1.4	7.3	±0.5	±0.3	±4	14
		5.18~5.83	1.5	7.7	±0.6	±0.4	±5	13
SA-07-8B020080	8x8	5.9~7.25	1.5	7.8	±0.7	±0.5	±6	13
		2.4~2.5	1.5	11.2	±0.6	±0.4	±8	13
		5.18~5.83	1.5	11.6	±0.8	±0.5	±10	12
SA-07-4B240430	4x4	5.9~7.25	1.55	11.8	±0.9	±0.7	±12	12
		24~43	2.0	12.4	±1.2	±2.0	±15	10

*Theoretical 6dB Included

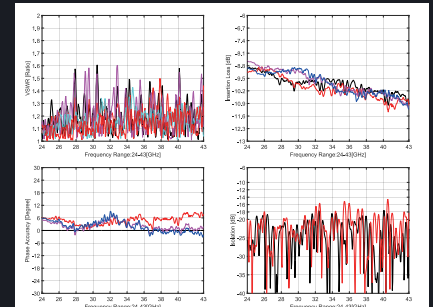
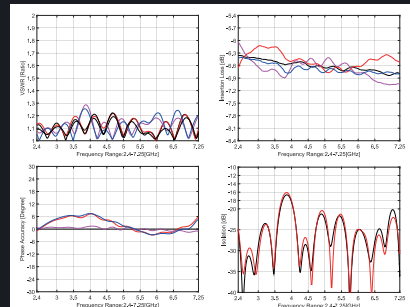
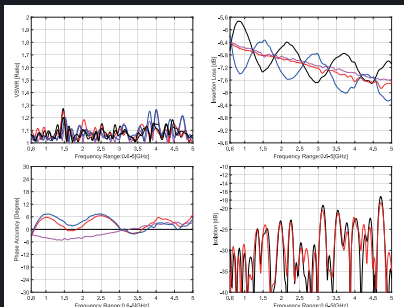
 **Note:** The connected components are available from MiCable which include the phase matched assemblies & low loss high isolation phase matched switches.

— Typical Test Curve** —

SA-07-4B006050

SA-07-4B020080

SA-07-4B240430



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bility. Due to robust engineering and employment of the most advanced devices and components, this amplifier achieves high efficiency operation with proven reliability. Like all Ophir RF amplifiers, the 4147 comes backed by Ophir RF's commitment to total customer satisfaction.

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Defining an RFIU signal routing and distribution system can be challenging. Pickering Interfaces has a long history of providing RF/microwave switch solu-

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1.0-4.0 GHz	0.35	± 0.75 dB	23	1.20:1	CS*-04
0.5-6.0 GHz	1.00	± 0.80 dB	15	1.50:1	CS10-24
2.0-8.0 GHz	0.35	± 0.40 dB	20	1.25:1	CS*-09
0.5-12.0 GHz	1.00	± 0.80 dB	15	1.50:1	CS*-19
1.0-18.0 GHz	0.90	± 0.50 dB	15 12	1.50:1	CS*-18
2.0-18.0 GHz	0.80	± 0.50 dB	15 12	1.50:1	CS*-15
4.0-18.0 GHz	0.60	± 0.50 dB	15 12	1.40:1	CS*-16
8.0-20.0 GHz	1.00	± 0.80 dB	12	1.50:1	CS*-21
6.0-26.5 GHz	0.70	± 0.80 dB	13	1.55:1	CS20-50
1.0-40.0 GHz	1.60	± 1.50 dB	10	1.80:1	CS20-53
2.0-40.0 GHz	1.60	± 1.00 dB	10	1.80:1	CS20-52
6.0-40.0 GHz	1.20	± 1.00 dB	10	1.70:1	CS10-51
6.0-50.0 GHz	1.60	± 1.00 dB	10	2.00:1	CS20-54
6.0-60.0 GHz	1.80	± 1.00 dB	07	2.50:1	CS20-55

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Q Microwave

RF Wideband Converter, 0.5 to 18 GHz



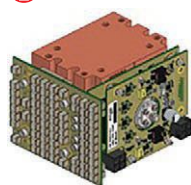
Q Microwave's RF wideband converter is a frequency-agile RF converter, capable of converting RF frequencies between 0.5 and 18 GHz, with 500 MHz of instantaneous bandwidth, for an IF range centered at 1200 MHz (950 to 1450 MHz).

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Q Microwave's RF wideband converter is a frequency-agile RF converter, capable of converting

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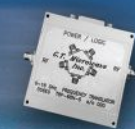
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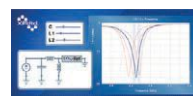
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100 W, 18 to 40 GHz, EMC Power Amplifier



This 100 W CW EMC 18 to 40 GHz enables customers to cover from 6 to 40 GHz and 100 to 400 W with only two rack-mount units. Like the lower frequency model above, this unit contains all the same protection features, gain control and remote Ethernet connectivity. EMC amplifiers also include automated calibration and bias compensation to correct for any changes over time and temperature. Applications include test and measurement, EMC/EMI, wireless commercial communications, aerospace, military as well as research such as particle physics.

20 to 54 GHz, Broadband Solid-State Power Amplifier



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0.5 to 43.5 GHz, SP8T Switch



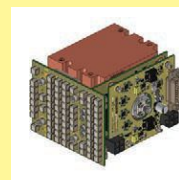
RF-Lambda's SP8T 43.5 GHz switch can be used in a variety of RF applications where broadband high frequency fast switching is required. This RF switch provides 70 dB of isolation, a switching time of 100 ns and an insertion loss of 5 dB. RF-Lambda has a full catalog of active switches from SP2T to SP160T and power up to 1 kW. Active switches do not have a cycle lifetime when compared with electro-mechanical switch offerings so are suitable for systems requiring highly reliable switching over a long period of time.

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VENDORVIEW



An excellent alternative to traveling wave tube amplifiers, Qorvo's Spatium™ QPB2040N is a solid-state, spa-

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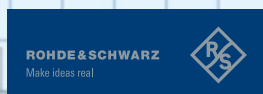


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www.signalcore.com

Signal Hound High Performance Spectrum Analyzer/ Monitoring Receiver



Signal Hound's SM435C is a high performance spectrum analyzer/monitoring receiver tuning from 100 kHz to 43.5 GHz. This next-generation SM-series analyzer includes a 10 Gb Ethernet SFP+ port, enabling communication with a PC over long distances using a fiber optic cable. Designed for affordable, remotely located, accurate RF data analysis, the SM435C is perfect for 5G mmWave monitoring and analysis, 24 GHz ISM frequency monitoring, complete Ka-Band spectrum testing and analysis of emerging and new high frequency RF signals.

www.signalhound.com

Signal Microwave TDR/VNA Probes



Signal Microwave, in partnership with DVT Solutions, is introducing the DVT-FPPXX, a 100 Ω true differential probe with bandwidths of 40, 50 and 70 GHz series to support the industry's demand for higher data rates over differential traces. The new differential probe satisfies the need to probe PCB designs that have wide pitch test pads up to 70 GHz with a test pad pitch center to center around 1 mm.

www.signalmicrowave.com

Smiths Interconnect Fixed Chip Attenuators VENDORVIEW



Smiths Interconnect's new fixed chip attenuators offer proven high performance in commercial applications. The AT Series is available in various styles from DC to 6 GHz for lower frequency requirements covering DC to



20 GHz for the broadband requirements of higher frequency, commercial, high volume applications. It provides excellent attenuation accuracy and flatness by maintaining an efficient RF power transmission. It offers a proven, robust, thick film construction in a cost-effective, easy to implement solution.
www.smithsinterconnect.com

Stellant Systems K-Band Quad Space nanoMPM®



Stellant Systems' K-Band Quad Space nanoMPM® is a state-of-the-art RF power amplifier for use in satellite downlink applications, specifically designed to enable the next generation of software-defined satellites utilizing phased-array antennas for increased flexibility while on-orbit.

This product delivers the ultimate performance by leveraging the best of solid-state and TWT vacuum technology. Utilizing a high gain predistortion solid-state linearizer, wideband high-power mini-TWT and proprietary compact nanoMPM® EPC designs, the B3400H series bridges the gap between solid-state amplifiers and traditional space linearized channelized TWTs.
www.stellantsystems.com

SV Microwave VITA RF 67 For Embedded Computing



Amphenol SV Microwave's VITA 67.1/2 and .3 product lines are the latest addition to the RF section of the VPX platform. These modular solutions include contacts, cable assemblies, adapters and connector backplane and plug-in modules that support

the entire RF signal path of your embedded system. Designed for implementation with other VITA connector standards. SV Microwave is an associate member of The Open Group and an active participant of the SOSA Electro-mechanical hardware group. In stock through distribution.
www.svmicrowave.com

Tabor Electronics 40 GHz Signal Generators



Introducing the new Lucid X-Series of microwave signal generators from Tabor Electronics. The LSX family of signal generators have 8, 20 and 40 GHz frequency ranges. With phase noise better than -120 dBc/Hz at 1 GHz, fast and high-resolution frequency switching and +15 dBm of standard output power – these instruments matched some of the industries toughest requirements. Built



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on Tabor's modular technology platform, the LSX family is available in PXIe, USB-modular, rack, benchtop and portable formfactors.
www.taborelec.com

Taitien USA OCXO



The new NF-16M384-7000 series is the latest addition to Taitien OCXO product line. With ultra-

low power consumption of just 75 mW (typical), this series is designed to save energy without compromising on performance. It boasts a tight frequency stability of 10 ppb under the operating temperature range from 0°C to 50°C, ensuring precise and reliable timing. The low phase noise and fast warm-up time make it an ideal choice for critical applications like seismic. Choose NF-16M384-7000 series for unbeatable

accuracy, efficiency and performance.
www.taitien.com

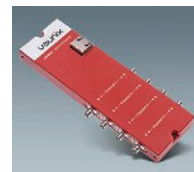
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www.us.tecdia.com

Vaunix Programmable Digital Attenuator



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pendently controlled attenuator paths. It provides calibrated attenuation from 200 to 8,000 MHz with an amazing step size of 0.1 dB and typical accuracy < 0.25 dB over 60 dB of control range. For more information, visit our website.

www.vaunix.com

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Fairview Microwave

Bias Tees



Fairview Microwave, an Infinite Electronics brand and a provider of on-demand RF, microwave and mmWave components, has introduced an innovative series

of bias tees. The new line addresses a variety of applications, including research and development, satellite communications, test and measurement, optical communications and more. Fairview's expanded bias tee offering includes an assortment of coaxial packaged configurations, featuring DC Pin, SMA and BNC DC ports as well as SMA, 2.92 mm and N-type RF ports.

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OML introduces a new family of precision compact mmWave waveguide band fixed attenuator, xxFAyy

series, in 1 in. length. Fixed attenuators are available in WR-19, WR-15, WR-12, WR-10, WR-08, WR-06, WR-05 and WR-03 band. Standard fixed attenuation values are 3, 6, 10, 13, 16, 20, 30, 40, 45 and 50. Custom attenuation value is also available. They are ideal for test and instrumentations, laboratory uses and subsystem integrations.

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Peraso Inc. has been a leader in providing RF solutions for more than 10 years, with a focus on 5G FR2 licensed bands and the 60 GHz unlicensed band. The company's Perspectus series of modules utilize Peraso's high power X720 chipset and are supported by Peraso's Perspectus Infrastructure software and firmware packages. With a variety of integrated antenna options, and the ability to add a high gain parabolic reflector, the Perspectus system can achieve gigabit data rates at ranges exceeding 20 km.

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3U Rack-Mountable Amplifiers



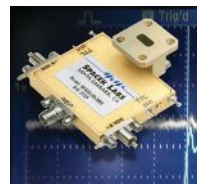
The new 9103 series is offered as 3U rack-mountable amplifiers, with standard models

providing frequency coverage of 2 to 8 GHz and 6.5 to 18 GHz, with output power ratings of 300 W CW or 1.5 to 2 kW pulsed. All of Quarterwave's amplifiers feature low noise, high PRF, optional touch screen interface and are fully customizable. Other models of amplifiers are capable of covering 0.8 to 40 GHz, with an output rating of up to 50 kW.

www.quarterwave.com

Spacek Labs

Ka-Band Power Amplifier



The high power amplifier, SP352-25-38W, is designed for use from 32 to 38 GHz. 100 nSec switching speed is controlled using TTL. Saturated output power is 6 to 7 W typi-

cal, suited for communication and radar applications. Nominal gain is 35 dB with VSWR < 2:1 at both ports. Bias voltage is +8 VDC with 4.5A quiescent current, 8A at saturated output. Switching speed shown; 100 nSec includes propagation delay of trigger cabling.

www.spaceklabs.com

Spectrum Instrumentation

Optimal GHz Signal Acquisition and Analysis



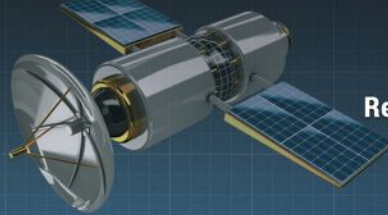
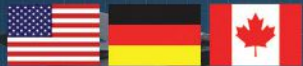
Spectrum Instrumentation launched two new PCIe digitizer cards which offer a

stunning combination of ultra-fast 10 GSps sampling speed, 12-bit vertical resolution, market-leading 12.8 Gbps data streaming over the PCIe bus, 3 GHz bandwidth and up to 16 Gb (8 GS) of on-board memory. These cards are perfect for scientists and engineers dealing with today's most challenging GHz-range electronic signals.

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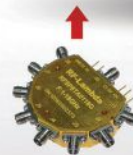
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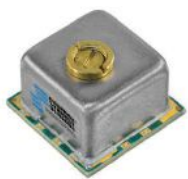
ExpressRF™ is Swift Bridge Technologies' economical RF cable product line. These flexible and low loss cable assemblies offer excellent

performance to ensure accurate and repeatable measurements on the device under test. ExpressRF is available as individual cables and phase matched pairs, matched to within 1 ps, at operating frequencies of 40, 50 and 65 GHz. Male and female 2.92, 2.4 and 1.85 mm precision RF connector configurations are available. All assemblies are 100 percent tested to assure S-parameters meet or exceed their specified performance.

www.swiftbridgetechnologies.com

Synergy Microwave

Surface-Mount Dielectric Resonator Oscillators



Synergy Microwave introduces three new surface-mount dielectric resonator oscillators with extended temperature range and ultra-low phase noise. These

products are ideally suited for free running and phase locked applications in radar and high data rate clocking converters for military communications, test instrumentation and 5G and 6G. The SDR01000-8XT operates at 10 GHz and the SDR015000-8XT operates at 15 GHz, with phase noise of -104 and -99 dBc/Hz, respectively, at 10 KHz offset. The GSDR01000-8XT is the introductory product of the "gold series."

www.synergymwave.com

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The new LSS-20B series broadband limiting amplifiers cover a wide

frequency range of 0.5 to 20 GHz. LSS-20B products can accept a wide range of input power levels, with a limited range of output power variation between 15 and 21 dBm and a saturated power output deviation of ± 0.5 dB over the frequency range. The LSS-20B series broadband limiting amplifiers produce > 11 dBc output harmonic separation from -25 dBm to +12 dBm input power.

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Copper Mountain Technologies' Cyprus R&D location is now offering repair and annual verification services for global CMT customers.

Copper Mountain Technologies
<https://coppermountaintech.com/>



POLATIS' 576 Optical Circuit Switch: Mike Bitting Interview

In their latest video, Mike Bitting, head of global government sales for POLATIS at HUBER+SUHNER discusses the ins and outs of the new POLATIS 576 all-optical circuit switch. Watch the video to learn more!

HUBER+SUHNER

www.youtube.com/watch?v=NPHXX5X-G_A



Ironwave Integration

In order to best serve its customers superior alternatives in solving electronic warfare, secure communication and sensor forward challenges, Ironwave Technologies announced its integration of Mu-Del Electronics, American Microwave, Luff Research and Syntronics.

Ironwave Technologies

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1.7 kW Amplifier and 4-Channel Driver for 27 MHz RF Energy Applications

This video covers the latest additions to Mini-Circuits, RF and microwave energy amplifier portfolio, the RFE-24M30M1K7X+ and RFE-24M30M075X+.

Mini-Circuits

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Eye on IMS Episode 18

In Episode 18 of Eye on IMS, technical editor for Microwave Journal, Eric Higham, is joined by Jasmin Grosinger, IMS2023 WIM Co-Chair, and Jonas Urbonas, IMS2023 YP Co-Chair, to discuss the activities planned for San Diego.

MTT IMS

www.youtube.com/watch?v=7Jrx6reBZwU



Panasonic Video on PCB Materials

MEGTRON and XPEDION support high speed, high frequency and stable operation of networking equipment: low dielectric constant (Dk), low dissipation factor (Df), enables low transmission loss in PCBs.

Panasonic

<https://industrial.panasonic.com/ww/products/pt/megtron/megtron8>



3.5 mm Coaxial Cable Adapters Overview

The 3.5 mm coaxial connector is a widely used standardized coaxial connector type with some interesting features, including its design to be relatively rugged and uses an air-dielectric as opposed to physical dielectric.

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Maximize Your Precious Metal Returns

QML has compiled this list of 12 fundamental, but often overlooked tips, to getting the highest returns on your precious metal.

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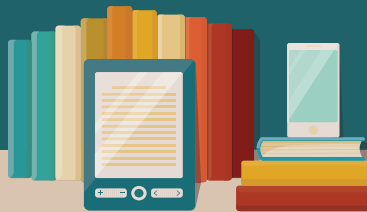
SCAN ME



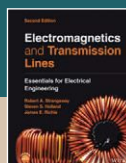
New PCI Digitizers with Ultra-Fast 10 GSPS

Spectrum Instrumentation launched the fastest digitizers in its 33-year history. The cards offer a stunning combination of ultra-fast 10 GSPS sampling speed, 12-bit vertical resolution and market-leading 12.8 Gbps data streaming over the PCIe bus.

Spectrum Instrumentation
www.spectrum-instrumentation.com/news/202303_New_PCIe_digitizer_with_10GSPS_and_12bit.php



Review by:
Whitney Lohmeyer



Bookend

Electromagnetics and Transmission Lines

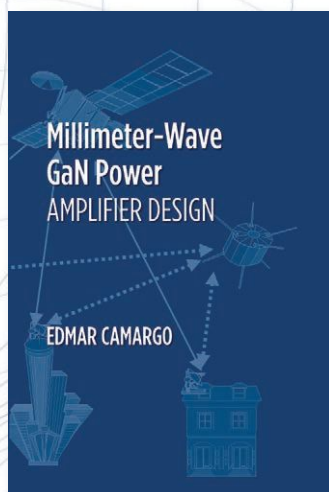
Robert Alan Strangeway, Steven Sean Holland and James Elwood Richie

The strengths of this book are in its clarity of the examples, exercises and the provided solutions, as well as the content in transmission lines, antennas, links and signal integrity (Chapters 6 through 9). The book would have benefited from focusing and diving deeper into these four chapters. For example, separating signal integrity and power integrity and then EMI and EMC with the inclusion of material covering FCC Part 15, Part 18 and SAR as opposed to some of the other material which is covered at a surface level. The section on the dos and don'ts of decibels stood out as practical content that all engineers could benefit from understanding. For completion, the inclusion of microstrips and striplines, two of the most commonly used transmission lines in PCB design, is necessary. Furthermore, expanding this style of description in additional sections, like when to use a spectrum analyzer versus a vector network analyzer, or how to characterize video bandwidth versus resolution bandwidth in a spectrum analyzer would have also been helpful. The link budget section deserves a whole chapter with the possible inclusion and expansion on topics like satellite communications, spread spectrum techniques, thermal noise, Eb/No, Es/No, signal-to-noise ratio, signal to interference and noise ratio and other figures of merit that impact communications systems. With these modifications, future iterations of this book will be better suited to target a more cohesive audience of hobbyists and engineers.

ISBN 13: 978-1-119-88190-2

Pages: 304 Pages

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Millimeter-Wave GaN Power Amplifier Design

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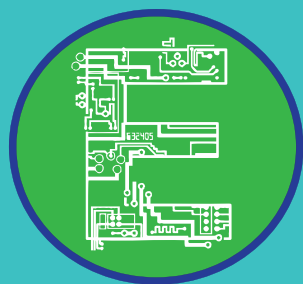


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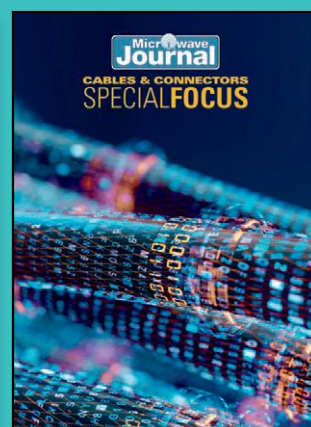
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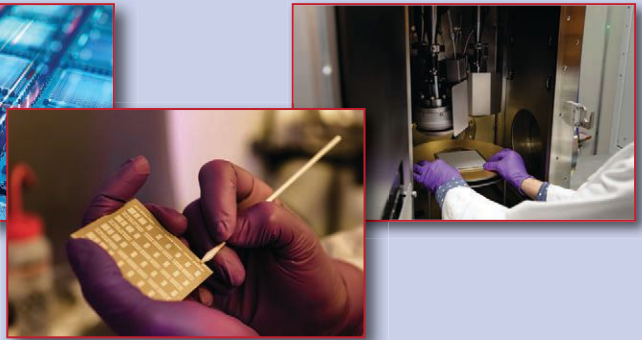
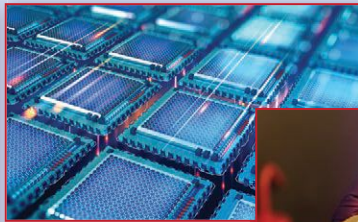
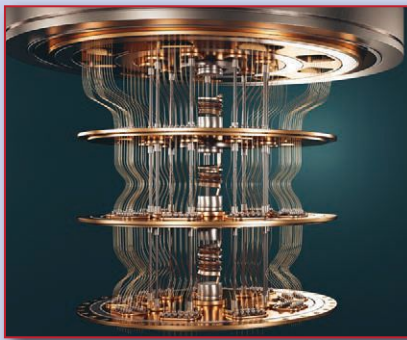
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FAB\$ and LAB\$

XMA is FAB: One Connection at a Time!



In 2003, Bruce Cooper and Fred Goodrich, entrepreneurs with RF, microwave and mmWave component, system and distribution experience, founded XMA Corporation and acquired key coaxial RF inventory, including capital equipment from MACOM, an industry leader in RF products. In 2008, XMA acquired the branding rights to the name Omni Spectra, a significant milestone in XMA's historic past. At the time of the brand acquisition, Omni Spectra had more than 45 years of heritage and XMA's goal was to continue Omni Spectra's legacy of high performance, state-of-the-art RF products. That homage to its early roots is evident in the company's logo, which includes "powered by Omni Spectra," 20 years after the original acquisition from MACOM.

From the beginning and up to the time of the Omni Spectra acquisition, the primary focus was to continue developing the passive coaxial product portfolio, along with the sale and support of attenuators, terminations, DC blocks, power dividers, equalizers and other legacy passive devices. Those products served as a launching pad for XMA, increasing name recognition and revenue. This allowed the company to accelerate its growth by developing new products in higher frequency bands with a stated goal of shaping the future of passive RF technology.

As the company celebrates its 20th anniversary, they are headquartered in Manchester, New Hampshire with another facility in Asia. The legacy product lines remain core parts of XMA's product portfolio, but the company is expanding the breadth of its products with some going into the V-Band frequency range, along with its application focus. Since the beginning, XMA has differentiated its products by refining its resistive thin film hybrid technology. This company believes that this proprietary resistor process provides a valuable performance edge for its components, particularly under extreme environmental conditions.

Leveraging core products and this proprietary resistive thin film technology, XMA focuses on a variety of key market applications. Space heritage is an example of these markets, with XMA products first used in space in 2011. For this application, the company offers thermal vacuum-rated and cryogenically compatible products, and XMA is also included

in NASA's Approved Vendors Database.

XMA is well-positioned for emerging quantum opportunities, with a focus on cryogenic capabilities. The company has been shipping components into quantum applications since 2014 and attributes success in these cryogenic solutions to an understanding of non-superconducting materials and tight tolerancing of components. In these applications, XMA leverages its in-house resistive chip manufacturing capabilities into standard as well as custom designs.

XMA also focuses on military/aerospace and 5G communications applications with a variety of product families. The product development trends take products higher in frequency with unique mechanical designs. In military/aerospace applications, XMA is seeing interest in integrated RF assembly and sub-system solutions.

Marc Smith joined the company in 2013 as president and CEO. Marc came to the company with an aerospace background, so he understood the importance and value of a robust quality management system (QMS). Having these systems in place, along with the required company culture was a key enabler for the new market applications that XMA was targeting.

In 2014, XMA obtained AS9100 certification for the aerospace industry. In 2016, the company enrolled in AS9100D onsite training to upgrade its QMS to the new revision. This upgrade incorporated new information addressing counterfeit parts, attention to the human factors influencing manufacturing quality, product safety and ethics training. XMA also meets the Class K and Class H qualification standards of MIL-PRF-38534 for its space-qualified activities.

With this commitment to quality and technology, XMA offers new coaxial components to disrupt the industry and advance RF technology. They continue improving components created more than 60 years ago to provide standard and customized solutions into the most advanced high frequency communications, cryogenic, quantum, space and defense applications. And as they say, they continue to deliver those new solutions to their customers "one connection at a time."

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D8454	8-Way	370-450	10,000	50,000	0.25	1.30:1	3 1/8" EIA, N-Female
D5320	12-Way	470-860	500	5,000	0.30	1.30:1	All N-Female
D10119	4-Way	700-4200	2,000	15,000	0.30	1.35:1	13-30 DIN-Female, N-F
D10603	32-Way	900-925	50,000	150,000	0.15	1.25:1	WR975, 7/16-Female
D10795	32-Way	900-930	25,000	150,000	0.25	1.20:1	WR975, 4.3-10-F
D9710	8-Way	1000-2500	2,000	10,000	0.30	1.40:1	1 5/8" EIA, N-Female
D8182	5-Way	1175-1375	1,500	25,000	0.40	1.35:1	1 5/8" EIA, N-Female
D6857	32-Way	1200-1400	4,000	16,000	0.50	1.35:1	1 5/8" EIA, N-Female
D11896	4-Way	2000-2120	4,000	40,000	0.25	1.40:1	WR430, 7/16-Female
D11828	4-Way	2400-2500	3,000	25,000	0.20	1.25:1	WR340, 7/16-Female
D10851	8-Way	2400-2500	8,000	50,000	0.20	1.25:1	WR340, 7/16-Female
D11433	16-Way	2700-3500	2,000	20,000	0.30	1.35:1	WR284, N-Female
D11815	16-Way	2700-3500	6,000	40,000	0.30	1.35:1	WR284, N-Female
D12101	6-Way	2750-3750	2,000	20,000	0.35	1.40:1	WR284, N-Female
D9582	16-Way	3100-3500	2,000	16,000	0.25	1.50:1	WR284, N-Female
D12102	6-Way	5100-6000	850	4,500	0.35	1.35:1	WR159, N-Female
D12484	6-Way	8200-8600	600	700	0.35	1.25:1	WR112, SMA-Female
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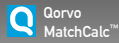
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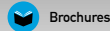
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RF Accelerator >>>

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