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May 2025

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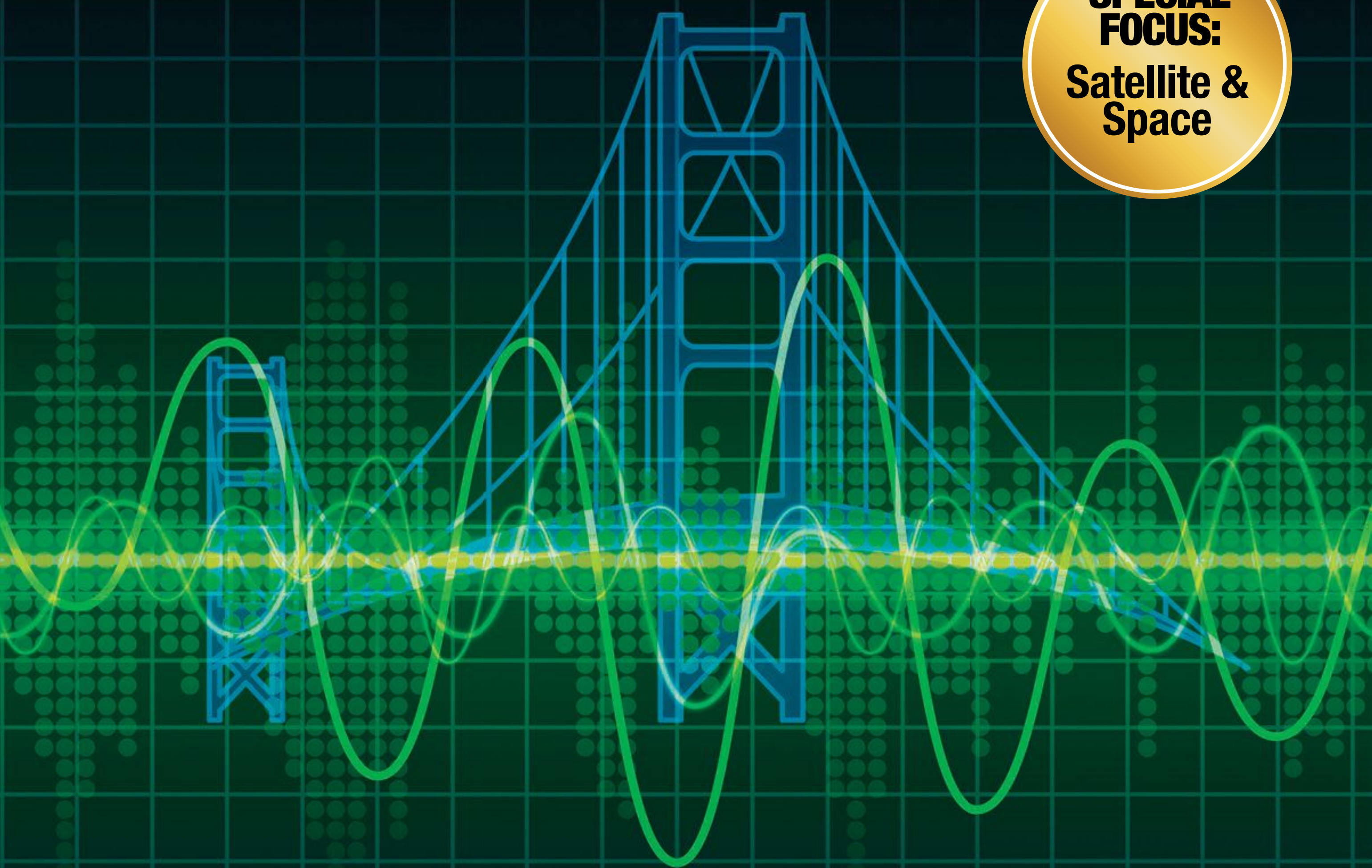

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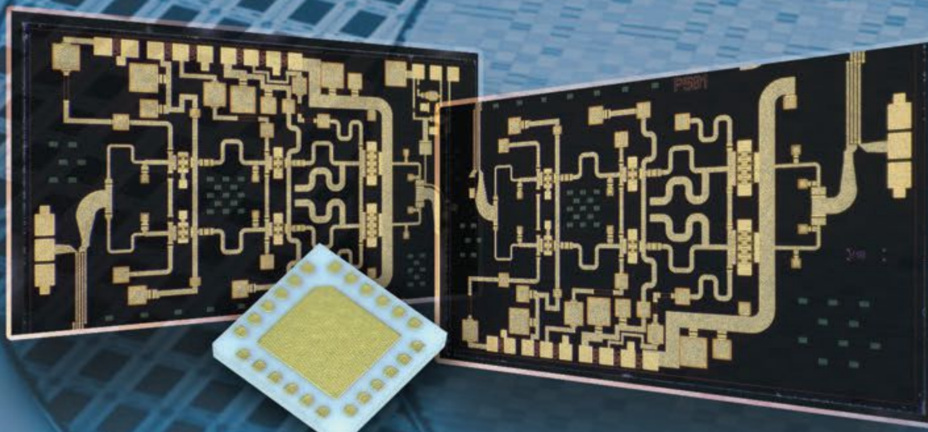

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RF Distributed Low Noise Amplifiers

PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	NF(dB)	P1dB (dBm)	Voltage (VDC)	Current (mA)	Package
MMW001T	DC	20.0	17~19	1~3.5	23 @ 10GHz	8.0	145	die
MMW4FP	DC	50.00	16.00	4.00	24.00	10	200	die
MMW507	0.20	22.0	14.0	4 - 6	28.0	10.0	350	die
MMW508	DC	30.0	14.0	2.5dB @ 15GHz	24.5	10.0	200	die
MMW509	30KHz	45.0	15.0		20.0	6.0	190	die
MMW510	DC	45.0	11.0	4.5	15.5	6.0	100	die
MMW510F	DC	30.00	20.00	2.50	22.00			die
MMW511	0.04	65.0	10.0	9.0	18.0	8.0	250	die
MMW512	DC	65.0	10.0	5.0	14.5	4.5	85	die
MMW5FN	DC	67.00	14.00	2.00	19.00	4.5	81	die
MMW5FP	DC	67.00	14.00	4.00	21.00	8	140	die
MMW011	DC	12.0	14.0		30.5	12.0	350	die

Low Noise Amplifiers

PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	NF(dB)	P1dB (dBm)	Voltage (VDC)	Current (mA)	Package
MML040	6.0	18.0	24.0	1.5	14.0	5.0	35	die
MML058	1.0	18.0	15.0	1.7	17.0	5.0	35	die
MML063	18.0	40.0	11.0	2.9	15.0	5.0	52	die
MML080	0.8	18.0	16.5/15.5	1.9/1.7	18/17.5	5.0	65/40	die
MML081	2.0	18.0	25/23	1.0/1.0	16/9.5	5.0	37/24	die
MML083	0.1	20.0	23.0	1.6	11.0	5.0	58	die

RF Driver Amplifier

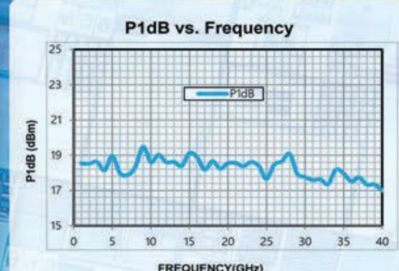
PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	NF(dB)	P1dB (dBm)	Voltage (VDC)	Current (mA)	Package
MM3006	2.0	20.0	19.5	2.5	22.0	7.0	130	die
MM3014	6.0	20.0	15.0	-	19.5	5.0	107	die
MM3017T	17.0	43.0	25.0		22.0	5.0	140	die
MM3031T	20.0	43.0	20.0		24.0	5.0	480	die
MM3051	17.0	24.0	25.0	-	25.0	5.0	220	die
MM3058	18.0	40.0	20/19.5	2.5/2.3	16/14	5/4	69/52	die
MM3059	18.0	40.0	16/16	2.5/2.3	16/15	5/4	67/50	die

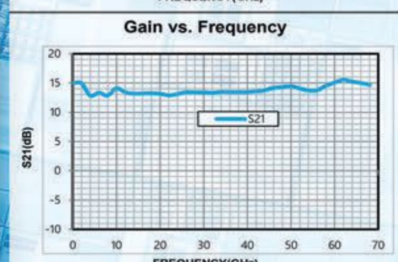
GaAs Medium Power Amplifier

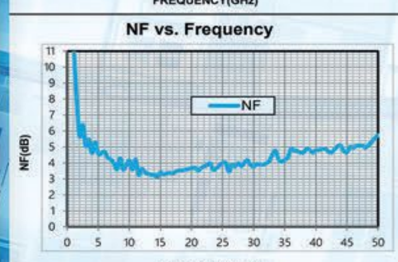
PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	P1dB (dBm)	Psat (dBm)	Voltage (VDC)	Current (mA)	Package
MMP107	17.0	21.0	19.0	30.0	30.0	6.0	400	die
MMP108	18.0	28.0	14.0	31.5	31.0	6.0	650	die
MMP111	26.0	34.0	25.5	33.5	33.5	6.0	1300	die
MMP112	2.0	6.0	20.0	31.5	32.0	8.0	365	die
MMP501	20.0	44.0	15.0	27 -- 32	29 - 34	5.0	1200	die
MMP502	18.0	47.0	14.0	28.0	30.0	5.0	1500	die

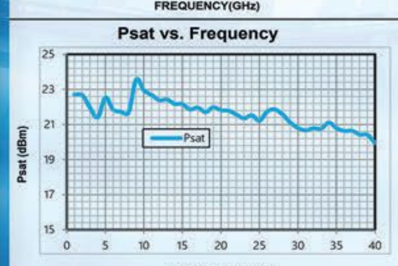
PN : MMW5FP

RF GaAs MMIC DC-67GHz









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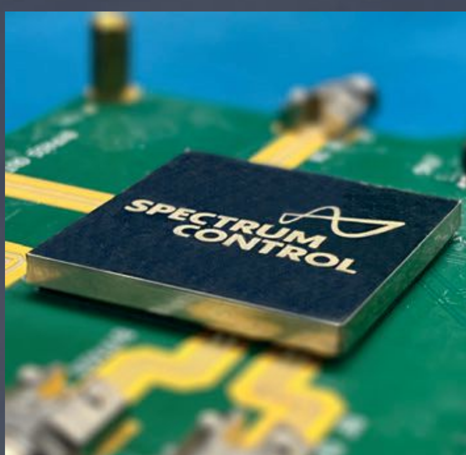

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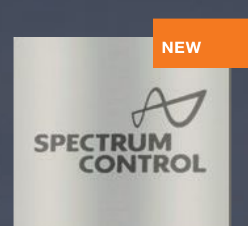


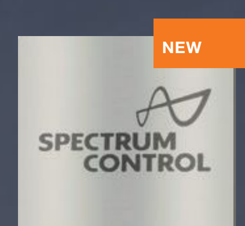
mmWave UpConverter

CH1 IN: 6.25-14.25 GHz

CH2 IN: 3-17 GHz

CH1 OUT: 18-26 GHz

CH2 OUT: 26-40 GHz



mmWave DownConverter

CH1 IN: 18-26 GHz

CH2 IN: 26-40 GHz

CH1 OUT: 6.25-14.25 GHz

CH2 OUT: 3-17 GHz

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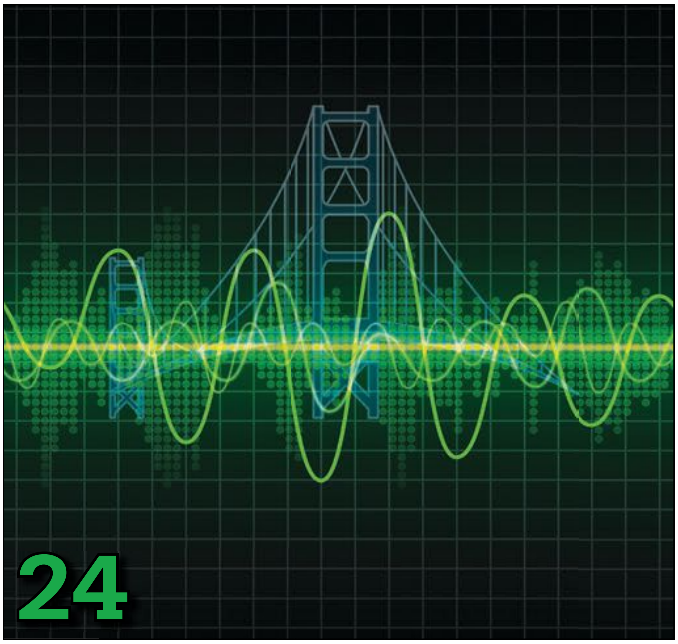

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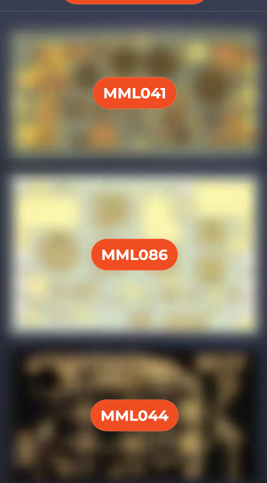
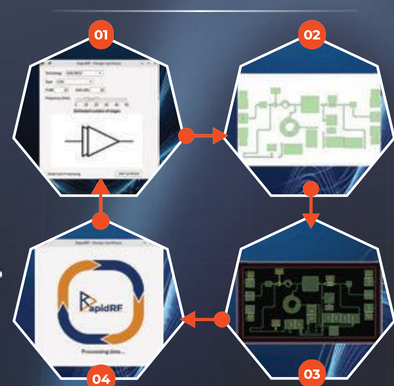
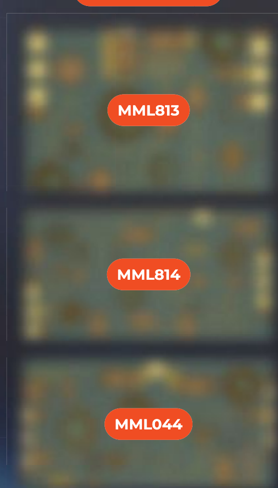


AI MMIC Design Process

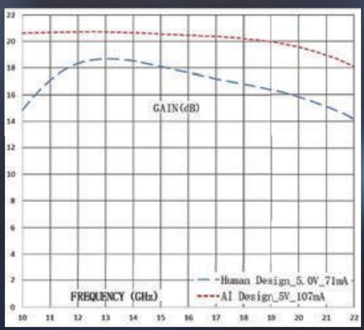


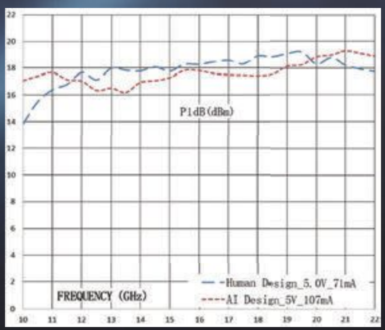
Design Done by RapidRF AI Platform

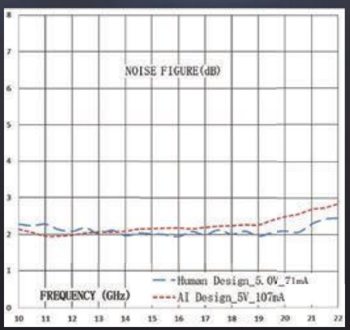
≈5 Hours/Design



Performance Comparisons: RapidRF AI vs Human Engineer Designs







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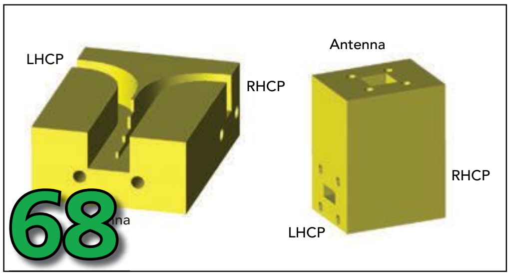

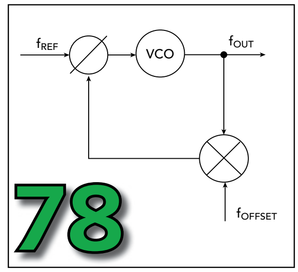

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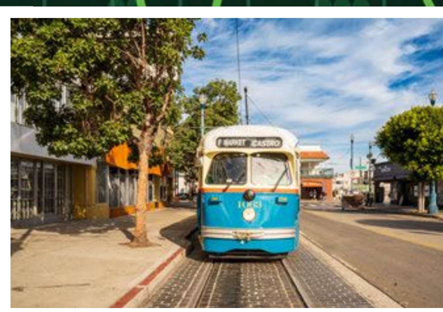
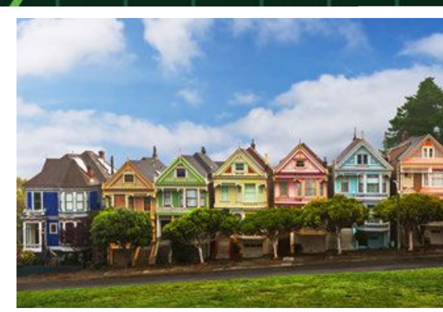

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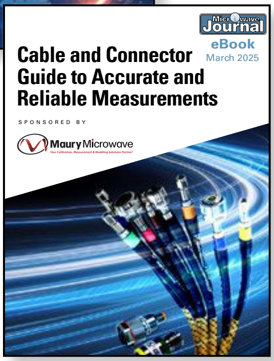

Executive Interview

Dermot O'Shea, co-founder and CEO at Taoglas, discusses his background, some of the innovative technology and products being developed at Taoglas, along with the trends he is seeing and his vision for the company's future.

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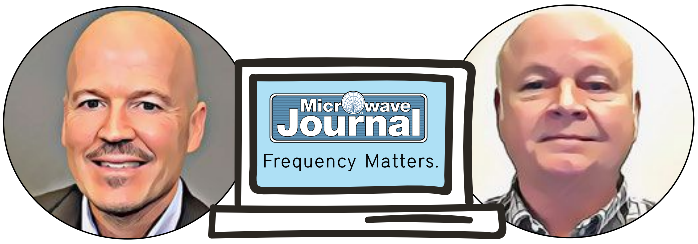

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Recognizing Heinrich Hertz at Kiel University

TIME TRAVEL

Giacomo Giannetti
University of Florence, Florence, Italy
Ludger Klinkenbusch
Kiel University, Kiel, Germany

The electronics industry owes a significant debt of gratitude to Heinrich Hertz. Hertz, born in 1857, was the first scientist to prove the existence of electromagnetic waves, confirming James Clerk Maxwell's theory and paving the way for understanding wave phenomena and modern technologies like radio communications. After completing his doctorate at the Friedrich-Wilhelms-Universität, which was renamed Humboldt-Universität in 1949, in Berlin, he won a two-year post-doctoral scholarship in Kiel. He then spent time at the Christian-Albrechts-Universität zu Kiel, also known as Kiel University, in northern Germany, near Hertz's birthplace and family in Hamburg.[1] While in Kiel, Hertz completed his Habilitation thesis on experiments with electrical discharges that he had conducted in Berlin. Due to the lack of an experimental laboratory in Kiel, he concentrated on the theory. He was fascinated by the recently proposed but still not widely accepted Maxwell's formulas on electromagnetic waves. The most important and brilliant theoretical contribution he made in Kiel[2] was to bridge the gap between Maxwell's theory and the opposing "gegnerische" electrodynamics, mainly developed in continental Europe. In his paper,[2] Hertz derived the following system of equations in free space:

$$\begin{cases} A\dfrac{dL}{dt} = \dfrac{dZ}{dy} - \dfrac{dY}{dz}, A\dfrac{dX}{dt} = \dfrac{dM}{dz} - \dfrac{dN}{dy} \\ A\dfrac{dM}{dt} = \dfrac{dX}{dz} - \dfrac{dZ}{dx}, A\dfrac{dY}{dt} = \dfrac{dN}{dx} - \dfrac{dL}{dz} \\ A\dfrac{dN}{dt} = \dfrac{dY}{dx} - \dfrac{dX}{dy}, A\dfrac{dZ}{dt} = \dfrac{dL}{dy} - \dfrac{dM}{dx} \end{cases}$$

Where:
X, Y, Z (L, M, N) are the x, y, z components of the magnetic (electric) field t = time, and A = the inverse of the speed of light.

This system of equations represents the current form of the two Maxwell's curl equations in the CGS system. In addition, it describes a vacuum with only one medium constant, the speed of light, A^{-1}, instead of two constants, ε_0 and μ_0, as Maxwell's equations require. Consequently, no "ether" is needed for electromagnetic wave propagation in a vacuum.

Recently, Hertz's time in Kiel has received proper attention.[3] One of the lecture halls in the new engineering building, as shown in **Figure 1**, is now known as the Heinrich Hertz-Hörsaal. The plaque, dedicated to Hertz, shown in **Figure 2**, has been relocated from the television tower in Kiel to the building at Kiel University.

HEINRICH HERTZ
PHYSICIST
1857-1894

DISCOVERER
OF THE
ELECTROMAGNETIC
WAVES

FOUNDER OF THE
WIRELESS
COMMUNICATION
ENGINEERING

1883-1885
KIEL UNIVERSITY

Fig. 1 (top) The new Faculty of Engineering building at Kiel University housing the Heinrich Hertz Lecture Hall. (Source: www.uni-kiel.de/en/tf)

Fig. 2 (bottom) Plaque dedicated to Hertz in the new lecture hall and translation of the inscription.

References

1. A. Fölsing, "Heinrich Hertz - Eine Biographie," Hamburg, Germany: Hoffmann und Campe, 1997.
2. H. Hertz, "Über die Beziehungen zwischen den Maxwell'schen electrodynamischen Grundgleichungen und den Grundgleichungen der gegnerischen Electrodynamik," Annalen der Physik, Vol. 259, No. 9, 1884, pp. 84–103.
3. G. Giannetti and L. Klinkenbusch, "The contributions to electromagnetism achieved by Heinrich Hertz at Kiel University," IEEE History of Electrotechnology Conference, Sept. 2023, pp. 1–3.

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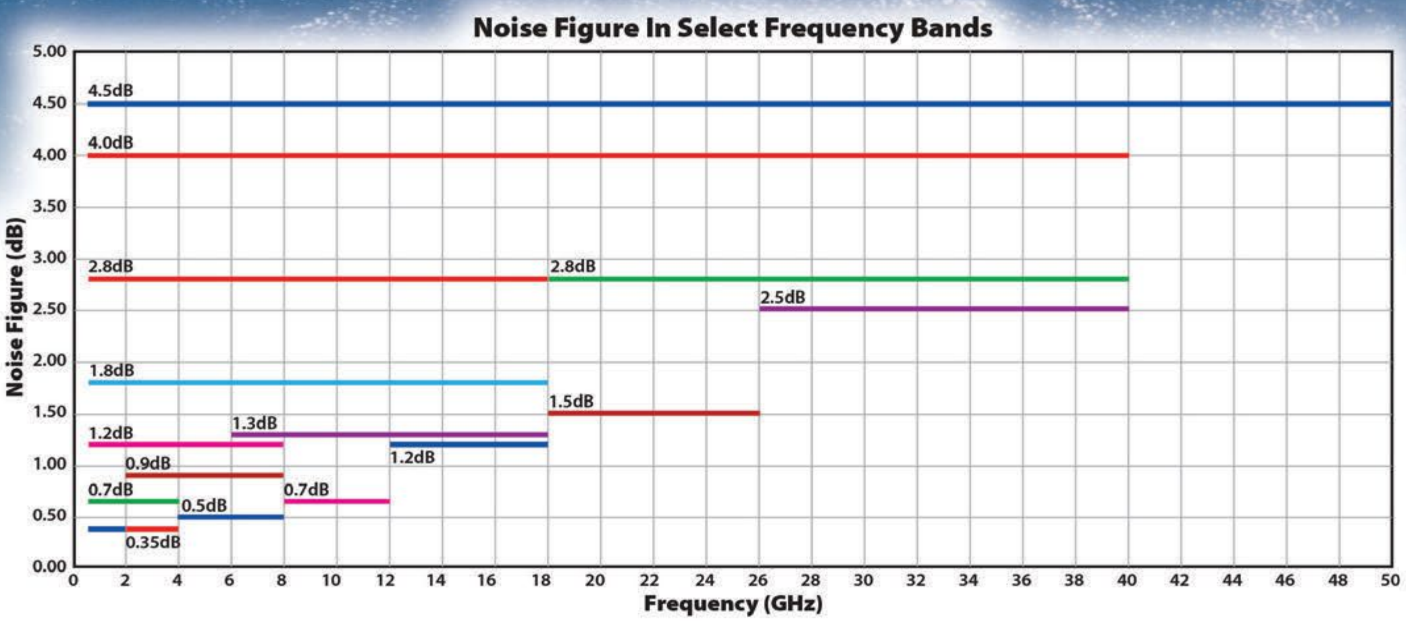

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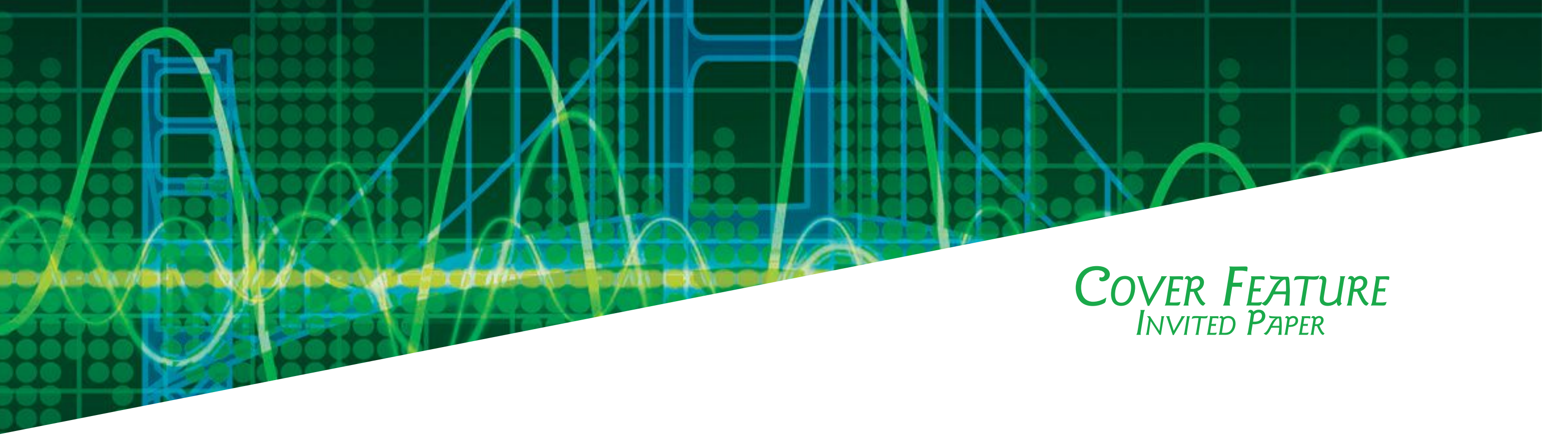

Cover Feature
Invited Paper

Overcoming the Limitations of Modern Signal and Spectrum Analyzers: A Look into the Future

Wolfgang Wendler
Rohde & Schwarz, Munich, Germany

As mobile and wireless communication applications demand ever-increasing data rates, the corresponding need for wider modulation bandwidths and higher modulation orders continues to grow. These requirements dictate a better signal-to-noise ratio to hit the right point in the constellation diagram. Consequently, key components used for these applications must demonstrate a performance close to their physical limit. However, the dynamic range of contemporary signal analyzers falls short when measuring the performance of these components over a wide frequency and power range. Current strategies to overcome these limitations include IQ averaging or cross-correlation signal processing techniques.

TODAY'S WORKAROUNDS

IQ averaging is a technique commonly used for noise cancellation, but this method requires a repetitive signal. Averaging the same IQ data several times reduces the random Gaussian noise, whereas the signal or the IQ vector remains consistent across all captures. This strategy enhances the dynamic range and minimizes the noise added by the measurement instrument. Despite being implemented in current analyzers, this method has limitations.

When there are no repetitive signals, cross-correlation techniques are employed to overcome limitations in the dynamic range. This technique requires two signal analyzers, which must be time-aligned, necessitating additional signal processing for cross-correlation calculations. Unfortunately, this not only increases measurement complexity but also test costs.

Other instruments, such as oscilloscopes, may offer two or even more inputs for this application. However, oscilloscopes typically have a restricted dynamic range. The analog-to-digital converters are optimized for wideband digitization of signals, a characteristic that does not improve the situation, even when cross-correlation techniques are applied. PXI modules with multiple inputs typically have a wider dynamic range; however, the lack of preselection limits the dynamic


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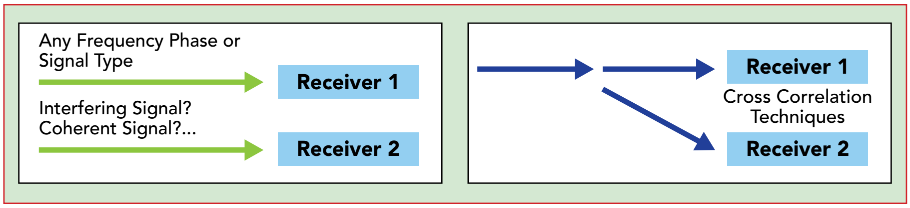


Fig. 1 New architecture opens possibilities for new levels of performance.

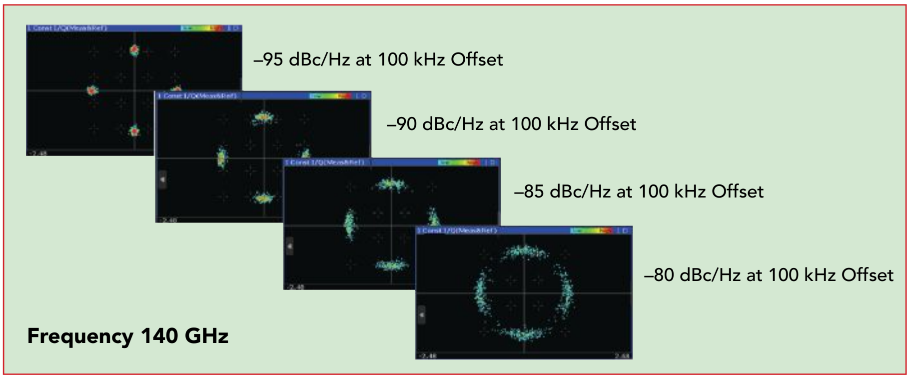


Fig. 2 Phase noise performance is critical to achieving high data rates.

range when unwanted signals are located at the image frequency or unwanted mixing products fall within the band of interest.

ENVISIONING NEW ARCHITECTURES AND NEW POSSIBILITIES

What if signal analyzers were designed to have two internal receive paths? Such an architecture could suppress unwanted signals at the image frequency or unwanted mixing products via preselection at the input. The two paths, including the splitter, could be aligned, calibrated and equalized by the instrument manufacturer. Cross-correlation can be activated with a simple button push, eliminating the need for external splitters and additional calibration steps. If the internal splitter is not used and the two RF input ports are directly routed to the receive unit, multiple receive paths can be used for all modern mobile or wireless communication standards, such as WLAN or 5G, as well as radar applications. ***Figure 1*** illustrates the potential of a new architecture featuring two receive paths for enhanced performance.

CROSS-CORRELATION TECHNIQUES DRAMATICALLY ENHANCE PHASE NOISE ANALYZERS

The implementation of cross-correlation could have implications beyond the dynamic range. It could also yield measurement results unattainable with traditional signal and spectrum analyzers. Already known from professional phase noise testers, such as the Rohde & Schwarz FSWP and the Rohde & Schwarz FSPN, cross-correlation techniques are used in phase noise measurements to suppress the phase noise of the internal local oscillators in the phase noise tester. This is relevant since modern communication applications often operate at higher frequencies, where the phase noise of the oscillators scales with the frequency, f, by 20 log (f). This phase noise impacts EVM performance directly as the frequency increases. An unstable phase reading makes it difficult to detect the correct constellation point in the constellation diagram. As a result, the system may have to switch to a lower-order modulation scheme, reducing the data rate. For this reason, the synthesizers or oscillators must be measured accurately to ensure optimized phase noise performance. Consequently, modern communication applications often require expensive phase noise testers and a good signal and spectrum analyzer. This is due to the limited measurement performance of the analyzer caused by the internal local oscillator.

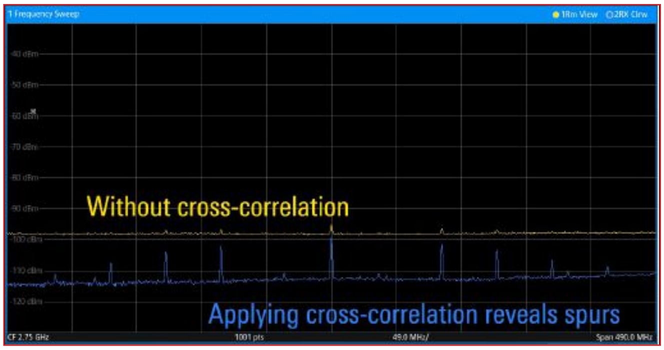
Figure 2 shows how the performance degrades on a QPSK signal with a sample rate of 20 MHz as the phase noise increases. The transmitted information is quite clear with a phase noise of -95 dBc/Hz at a 100 kHz offset. However, the information deteriorates with increasing phase noise. At -80 dBc/Hz, it becomes quite difficult to decode the correct data from the signal. The system must step back to BPSK modulation, which reduces the data rate. A phase noise performance of at least -90 dBc/Hz is needed for QPSK, which is quite challenging at a 140 GHz center frequency. This illustrates the need for test and measurement equipment with cross-correlation capabilities to accurately measure phase noise, enabling optimization of oscillators and synthesizers.

FINDING HIDDEN SPURS QUICKLY

For modern radar applications, detecting targets with a small radar cross-section (RCS), such as drones, is becoming increasingly important. This necessitates an enhancement of test equipment sensitivity for these applications. A key to this effort is lowering the receiver's wideband noise floor and improving the local oscillator's phase noise performance. This will help reveal the RCS reflection of a small target that is no longer hidden by clutter reflection after a slight Doppler frequency shift.

Beyond reducing phase noise and suppressing wideband input noise, the ability to detect small unwanted spurs and interferers in the system is also crucial. These small signals could be misinterpreted as targets, limiting the application's sensitivity as the trusted level for detecting real targets would need to be increased. Currently, signal and spectrum analyzers detect these small unwanted interferers. However, to see spurs close to the noise floor, the spectrum analyzer's resolution bandwidth (RBW) needs to be reduced to just a few hertz. This significantly slows down the sweep due to the prolonged settling time of the filters. Consequently, this technique requires a long measurement time to characterize the system and detect unwanted interferers.

What if the architecture of a re-



▲ Fig. 3 **Measurement results using RMS detector (top) and cross-correlation techniques (bottom).**

ceiver included two paths, allowing users to apply cross-correlation? This could suppress the inherent noise floor of the signal analyzer down to the physical limit without the need to reduce the RBW. This would enable faster sweeps at very low intrinsic noise levels compared to an analyzer, where a small RBW must be applied, which again limits the sweep speed due to the settling time of the RBW.

In ***Figure 3***, the bottom trace displays the measurement obtained when a cross-correlated detector is employed. For comparison, the top trace shows the measurement using an RMS detector. At an RBW of 1 MHz, the spurs are barely detectable, if at all, by the RMS detector. These results show that cross-correlation techniques can lower the test noise floor with only a slight increase in measurement time.

OVERCOMING THE PREVIOUS WIDEBAND CHALLENGE OF YIG VERSUS PRESELECTION FILTERS

Standard signal analyzers attempting wideband modulation analysis currently lack preselection for IQ analysis at microwave frequencies. Up to a specific frequency of several GHz, the signal is up-converted to a high intermediate frequency with the image at much higher frequencies. A lowpass filter is used to suppress the image. However, at frequencies above 5 to 10 GHz, depending on the instrument used, up-conversion for image suppression adds too much noise. Therefore, YIG filters are used for preselection at these frequencies to suppress unwanted images. These YIG filters have a limited bandwidth of 50 MHz, maximum, depending on the frequency range. They also exhibit a strong ripple, in the range of several dB, which prevents them from being used for IQ analysis. For IQ analysis, the YIG filter must be bypassed and noise or unwanted signals at the image frequency will cause the measurement results to deteriorate.

What if this challenge could be overcome by using filter banks? Filter banks for preselection have wide bandwidths and show a flat frequency response. This provides high-level accuracy, making it ideal for IQ analysis. Wideband IQ analysis with image suppression would be possible at an analysis bandwidth much wider than 50 MHz. This analysis bandwidth could range to several GHz, depending on the IF frequency and the analog-to-digital

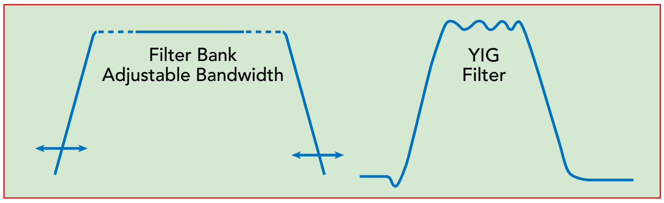


Fig. 4 Comparison of filter bank and YIG filter frequency response.

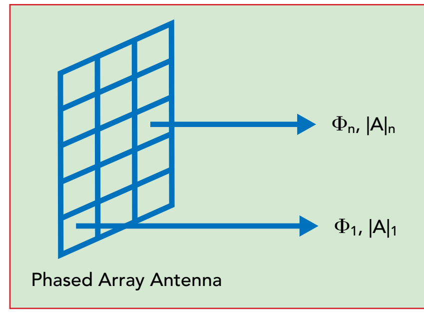


Fig. 5 Comparing one element to the n^{th} element in a phased array antenna being tested under modulated conditions.

converters. This would increase the dynamic range and reduce the error due to interferers at the image frequency. In addition, with a flat frequency response, the absolute error for level measurement of CW carriers or spurs would be significantly smaller, as the YIG filter ripple would cause no deterioration. Level measurement uncertainties in the range of 1 dB or even better would be possible in the microwave range with preselection, making an additional power sensor unnecessary for certain applications. This would enable the accurate specification of spur levels for radar applications. ***Figure 4*** visualizes the difference between filter banks and YIG filters. From the diagram in Figure 4, it is evident that, despite less out-of-band signal suppression, a filter bank offers wider, adjustable bandwidths and a flatter frequency response compared to YIG filters.

YIG filters can be quite slow and inaccurate for spectrum analysis, where users sweep over a wide frequency range. Filter banks for preselection could make the analyzer 10x to 20x faster for spectrum analysis, as they can be switched much faster than a YIG filter can be swept. However, the signal suppression in the stop band is more than 20 to 40 dB lower than that of the YIG filters.

A combination of both would be the most effective solution. The analyzer could use the YIG when narrowband spectrum analysis is required to detect the smallest unwanted interferers. Then, the analyzer could use the filter banks for IQ analysis or to improve measurement speed. Filter banks, in combination with a multipath receiver structure, can also be a helpful tool for spur searches. This is because inherent LO-related spurs of the spectrum analyzer can be easily suppressed when measuring with different IF receive path frequencies, as the spurs appear at different frequencies. A simple NAND operation can suppress these inherent unwanted emissions.

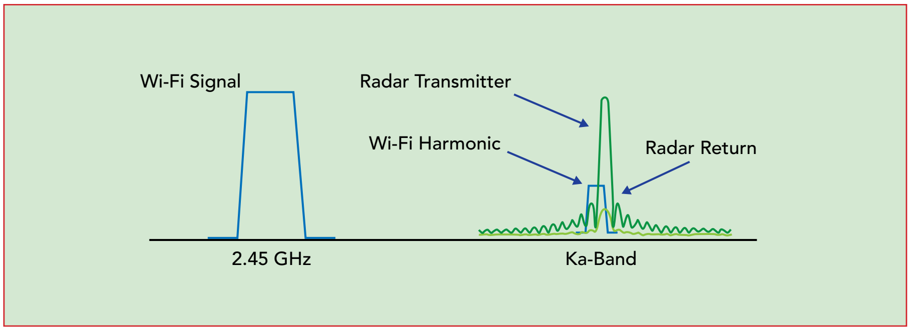


Fig. 6 Analyzing the effect of a Wi-Fi signal at 2.45 GHz on a radar signal at 6 GHz.

SIMPLIFYING THE SETUP FOR PHASED ARRAY ANTENNA TESTING

Beam steering applications in aerospace and defense, as well as mobile communications and automotive radar, often use phased array antennas. The phase between different transmit paths needs to be well-aligned and tested for these antennas. What if a signal analyzer setup could measure these scenarios with multiple phase-coherent paths during the calibrated initial phase? Each channel must be phase-coherent to determine the beam accuracy precisely. It would also help evaluate a phased array antenna under modulated conditions, where one element needs to be compared to the n^{th} element, as illustrated in ***Figure 5***.

A vector network analyzer (VNA) can be used in this scenario, but the process can become slow when stitching is required for modulated conditions. Alternatively, an oscilloscope can be used, but this comes with the limitation of a restricted dynamic range. PXI modules, which share the same local oscillator, offer a wider dynamic range, but neither solution typically applies preselection. Without preselection, signals at the image frequency may further restrict the dynamic range and overcoming these limitations requires setups that can become quite complex and prone to errors.

RADAR TEST: IMPACT OF SIGNAL INTERFERENCE

To effectively capture the entire scenario and analyze the mutual interference created by signals governed by different communications standards at various frequencies or between communications and radar signals, requires an analyzer with a very wide bandwidth. Alternatively, an analyzer with different inputs or with one input and different receivers can also be used. With oscilloscopes or PXI-based signal analyzers, special input settings, such as attenuation or preamplifier gain for the other signal receive paths, cannot be adjusted. This restricts the dynamic range for a measurement scenario, where, for instance, the small higher harmonic levels of a radar application need to be detected

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with a strong mobile communication signal present. Additionally, the available analysis bandwidth limits the frequency range that the analyzer can capture.

Consider the potential of a signal analyzer with multiple inputs or a multipath structure, where different frequencies can be set for the local oscillators or various levels of gain or attenuation can be set at the input. Such a setup could even trigger at a completely different frequency than the frequency at which the measurement is done. Imagine being able to trigger on a Wi-Fi burst at 2.45 GHz and observe whether the radar signal is affected, as illustrated in the example in ***Figure 6***.

MODULATED COMPONENT ANALYSIS: A BETTER WAY?

What if the ability to measure two signals simultaneously, at different frequencies or even the same frequency, could also be used to characterize components? Users could compare the signal-to-noise ratio or EVM performance at the input and output of an amplifier. This could also be done for up- and downconverters with different frequency settings. Both signals would be captured simultaneously and the modulation of the input signal would not even need to be known; the user could compare the IQ data.

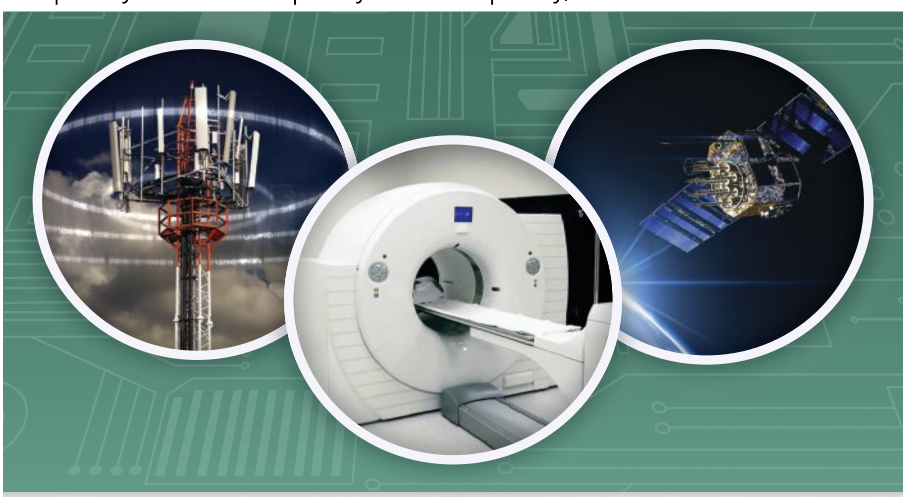
TESTING ELECTRONIC WARFARE DRFMS

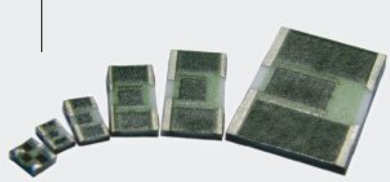
This future scenario also holds promise for electronic warfare applications. Users could examine their application's input and output and analyze the signal's phase and amplitude in real-time. What if modulated pulsed radar signals before and after the digital RF memory could be captured simultaneously, allowing for the characterization of amplitude and phase variations to optimize the system for effective jamming applications?

Again, these measurements could be performed on a VNA, but these instruments typically have a restricted analysis bandwidth. Oscilloscopes could also be used, but their dynamic range is limited and may not reveal the necessary phase and amplitude modulation details. Furthermore, oscilloscopes typically do not provide internal analysis tools to perform this effectively, necessitating the use of external software solutions.

CONCLUSION

Contemporary signal and spectrum analyzers have considerable limitations when addressing emerging technologies. This article proposes a new architecture and possibilities that could overcome these limitations. By implementing two internal receive paths, preselection at the input and built-in cross-correlation in signal analyzers, the dynamic range can be enhanced, measurement speed increased and test setups significantly simplified. The potential of these advancements can revolutionize the way we analyze signals and spectra. At Rohde & Schwarz, we actively explore these possibilities and work toward making them a reality. ■





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DefenseNews
Cliff Drubin, Associate Technical Editor

Breakthrough Manufacturing Process for High Frequency Amplifiers

Traveling-wave tubes (TWTs) are a type of vacuum tube critical for many high performance applications, including deep space missions, satellites and electronic warfare. For decades, their ability to efficiently amplify high frequency signals across wide bandwidths has ensured reliable, long-range communication and radar capabilities.

Supported by Small Business Innovation Research (SBIR) program funding at DARPA, Elve, a deep-tech hardware manufacturing startup, developed a new approach to TWT manufacturing. DARPA's SBIR programs guide small businesses through a structured three-phase process to advance their innovations: feasibility demonstrations, full-scale research and development and transition to commercialization. This framework enables them to move from concept to deployment, ensuring significant impact on both national security and commercial markets.

Through its participation in the SBIR program, Elve developed a novel additive manufacturing process called Layered Additive Multi-Material Manufacturing – Digitized (LAM3D). This breakthrough reduces TWT production times from over a year to just weeks.

The approach developed by Elve during its DARPA program represents a leap forward. The LAM3D process combines additive manufacturing techniques with advanced inspection and alignment features to fabricate TWT circuits with unprecedented speed and precision. This not only shortens production timelines but also reduces costs, enabling rapid prototyping and high-yield manufacturing.

Building on the success of its DARPA work, Elve has since expanded the capabilities of its LAM3D technology to manufacture circuits at frequencies above 200 GHz, pushing the boundaries of TWT performance to the cutting edge of current RF applications. As future defense and commercial systems demand even higher frequencies to support emerging applications, such as next-generation communications, advanced sensing and energy beaming for sustainable power transfer, Elve's innovation positions TWT technology to meet these evolving needs.

TWTs (Source: DARPA)

Elve's rapid progress exemplifies how DARPA's integrated approach — pairing SBIR-driven technological innovation with EEI's commercialization support — fosters transformative solutions from small businesses, from concept to market. Through SBIR investments, DARPA provides critical early-stage funding to drive high-risk, high-reward research and development, enabling companies like Elve to push the boundaries of what is possible.

Further information about SBIR programs and EEI can be found on DARPA's Small Business Programs Office and Embedded Entrepreneur pages, respectively.

Resilient GPS Satellite Technology for National Security

Sierra Space recently announced a successful demonstration of the company's Resilient GPS (R-GPS) technology for the U.S. Space Force (USSF). This major accomplishment, generating all GPS navigation signals required for the R-GPS mission, was achieved in collaboration with General Dynamics Mission Systems. This technology targets the increased need for more R-GPS systems that protect the U.S. against adversarial threats like jamming and spoofing of the current GPS infrastructure.

GPS technology plays a crucial role in daily life, supporting everything from civilian services such as smartphone map applications to vital military and defense uses. However, as adversarial threats become more advanced, there is an increasing need for more R-GPS infrastructure. To address this, the USSF's Quick Start program is developing concepts for integrating a layer of smaller and more affordable satellites into the existing GPS framework. This R-GPS layer of smaller GPS satellites would be capable of rapid fielding to counter evolving threats. Sierra Space's expertise in small satellite technology provides a competitive edge in achieving this goal.

Satellite Constellation (Source: Sierra Space)

The demonstration focused on the satellite's hardware, firmware and software that generates 'YMCA' waveforms, including P(Y), M-code and C/A signals at L1 and L2 frequencies. This achievement is a significant step forward in ensuring that the GPS navigation signals generated by R-GPS satellites will be accurate, secure and compatible with the devices that millions of people use every day.

CACI and the USMA to Advance EW Technologies

CACI International Inc. recently announced that it has entered into a five-year Cooperative Research and Development Agreement

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(CRADA) with the U.S. Military Academy (USMA) at West Point to collaboratively advance electronic warfare (EW) technologies to support future U.S. Army missions.

CACI, a signals intelligence (SIGINT) and EW technology provider to the U.S. Army and other government customers, has the largest signals threat coverage in the world and is unrivaled in collecting and countering more than 1,000 unique global signals. CACI has designed and deployed this technology globally across more than 2,000 EW systems, providing customers with the necessary capabilities to dominate the electromagnetic spectrum and maintain significant battlefield advantage in this critical warfighting domain.

As software-defined radios are becoming more prevalent in technology, the ability to create new waveforms will continue to rise. The U.S. Army must be able to rapidly detect and counter these waveforms from adversaries in real time to protect systems or attack adversary systems in the future. The first project under this CRADA will focus on extending the applicability of the GPU RFIQ Dataplane (GRID) technology stack as developed for the Program Executive Office – Intelligence, Electronic Warfare & Sensors. GRID is a cutting-edge technology used by the U.S. Army for EW systems, enhancing real-time signal processing, threat detection and electromagnetic spectrum dominance on the battlefield.

The USMA will bridge theory and practice by validating GRID data processing outside of a research lab and in the field. Cadets will test GRID firsthand by building RF blocks to showcase its performance while developing a modular framework and methods for extending GRID to support future waveforms. This hands-on experience will reinforce technical expertise in software-defined radio and EW applications and help shape the evolution of GRID for emerging operational needs.

By showcasing its innovations and capabilities, CACI aims to strengthen the pipeline of future SIGINT and EW operators while also improving relationships with future customers and partners to support ongoing national security mission objectives, while West Point provides input as a leader in military innovation and education.

CACI (Source: CACI International Inc.)


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Global 5G Adoption Skyrockets to 2.25 B Connections, Four Times Faster Than 4G

The global wireless telecommunications industry achieved a historic milestone in 2024, with 5G connections reaching 2.25 billion worldwide. This remarkable growth highlights 5G's rapid adoption, far outpacing previous wireless generations. According to 5G Americas and Omdia, 5G has expanded 4x faster than 4G LTE did in a comparable period, when LTE had just surpassed 500 million connections at the end of 2014. The global mobile ecosystem continues to expand, with 1.5 wireless connections per person worldwide by the end of 2024 — up from one connection per person in 2014.

The momentum is expected to continue, with forecasts indicating 8.3 billion 5G connections by 2029, representing 59 percent of all global wireless technologies. Meanwhile, IoT saw unprecedented expansion, adding 438 million new connections in 2024, bringing the global total to 3.6 billion.

North America remains a global leader in 5G adoption, closing 2024 with 289 million 5G connections, representing a 67 percent year-over-year increase from 196 million connections at the end of 2023. North America also has 77 percent of the region covered by 5G. For comparison, 4G LTE adoption in North America had only reached 47 percent regional coverage by the equivalent point in 2014.

Beyond adoption rates, North America is also the first region in the world to reach parity between the number of commercial 5G and 4G LTE networks, reflecting the maturity and pace of next-generation network deployment. This leadership is fueled by robust industry investment, collaborative innovation and a regulatory environment that continues to foster cutting-edge applications in areas like industrial automation, telehealth, smart infrastructure and AI-powered connectivity.

"North America continues to showcase rapid 5G growth, outpacing previous generations and setting the bench-mark for global adoption," said Kristin Paulin, principal analyst at Omdia.

Latin America also witnessed a significant surge in 5G adoption, doubling its 5G connections in one year to 76 million by 2024 year-end — up from 38.5 million in 2023. While 5G expansion accelerates, 4G LTE remains the dominant technology, with 593 million users, accounting for 74 percent of all wireless connections in the region.

The pace of 5G network deployments also continues to exceed that of 4G LTE at a similar stage of its rollout. As of March 17, 2025, there are 354 commercial 5G networks globally, with North America leading in parity, being the only region where the number of 5G and LTE networks are equal. Europe follows, where 5G deployments have reached 72 percent of LTE networks.

ATIS' Next G Alliance Maps Component Technologies for the 6G Future

The Alliance for Telecommunications Industry Solutions' (ATIS) Next G Alliance (NGA) announced the release of the 6G Component Technologies White Papers Series, four pieces that address critical technologies that will contribute to North American leadership in the 6G future:

Antenna, Packaging and Testing — A white paper covering emerging technologies and challenges for antenna, packaging and testing of 6G wireless communication systems.

Circuits and Subsystems — To efficiently support innovative services on a massive scale, 6G must cover challenges related to RF circuits and subsystems. "Circuits and Subsystems" illustrates a baseline transceiver architecture to set the stage for subsequent much-needed discussions on this topic. Transceiver design challenges such as carrier frequency, local oscillator frequency generation, link budgets, high order modulation, beamforming, integrated sensing and communication, non-terrestrial network and AI/EDA tools are covered.

Next G Displays — A white paper highlighting challenges for immersive displays in the 6G future, covering hardware and video content challenges. The paper also introduces solutions and future development directions in the areas of software and content innovations as well as augmented reality development. Key recommendations are provided.

Semiconductor Technology — A white paper addressing the need for further development of semiconductor technologies critical to the successful development of 6G transceivers. This is not a one-size-fits-all approach, as these transceivers are complex systems and 6G covers multiple frequency bands. This paper covers the transceivers' main building blocks and analyzes the need for further technology development.

"The Component Technologies White Papers Series is a critical contribution toward defining the key technologies comprising the National 6G Roadmap's technology layer." said NGA Managing Director Jaydee Griffith.

6G White Papers (Source: ATIS' NGA)

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"Each component covered will be a key building block for North American leadership in the 6G future."

Access each of the white papers in the 6G Component Technologies White Papers Series in the NGA's 6G Library.

Adopter Spending on UHF RFID to Surpass U.S. $10 B in 2030

Item-level tagging with ultra-high frequency (UHF) radio frequency identification (RFID) is starting to evolve rapidly. According to a new dataset from ABI Research, spending on UHF RFID technology will surpass U.S. $10 billion in 2030.

"What is changing in the UHF RFID market is that it is expanding into new end markets and applications," explained Tancred Taylor, senior analyst at ABI Research. "While we have seen growth in the use of RFID tags in the apparel retail industry for years, now there are two defining recent changes. The first is data exploitation by companies that have already tagged items with RFID and want to increase their ROI by using tag data across more workflows in their operations. The second is end market diversification, as massive programs outside the apparel retail industry ramp up and expand, such as UPS' smart package/smart facility, Walmart's item-level supplier mandate or Kroger's bakery tagging."

As a result of this greater breadth of end markets and the more attractive return on investment, ABI Research expects around 118 billion UHF RFID inlays to be shipped in 2030 — nearly 3x the volume shipped in 2024. Leading inlay manufacturers like Avery Dennison, Arizon and Tageos have invested significantly over the past two years to expand their production capacity to meet this growing demand. While new retail industries present the most significant opportunity for expansion, UHF RFID is also being embraced by the logistics and mail industries, various manufacturing industries and service industries like healthcare and hospitality.

Changing operating environments are at the heart of the growing wave of investment. Labor costs and staff retention issues, waste and sustainability targets, theft and inventory shrinkage throughout supply chains and the desire to offer better customer purchasing experiences are a few of the reasons driving new projects. More fundamentally, the lower cost and easier implementation of RFID systems, with the growth of off-the-shelf solution providers and integrators, lowers the barrier to entry for customers and removes the need for complex and time-consuming in-house projects. Nedap, SML and Sensormatic are key examples of suppliers driving the market into its next stage.

Around the Circuit

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Siemens announced that it has completed the acquisition of **Altair Engineering Inc.**, a leading provider of software in the industrial simulation and analysis market, for an enterprise value of approximately USD 10 billion. With this acquisition, Siemens extends its leadership in simulation and industrial artificial intelligence (AI) by adding new capabilities in mechanical and electromagnetic simulation, high performance computing, data science and AI. The addition of the Altair team and technology to Siemens will further enhance the most comprehensive Digital Twin and make simulation more accessible, so companies of any size can bring complex products to market faster.

Teradyne Inc. announced it has entered into a definitive agreement to acquire privately held **Quantifi Photonics**, a leader in photonic IC testing. The acquisition is expected to close in the second quarter of 2025, subject to customary closing conditions and regulatory approval. This acquisition will enable Teradyne to deliver scalable photonic integrated circuit (PIC) test solutions. PIC technology is leveraging wafer-based manufacturing, multi-die integration and advanced packaging with high speed I/O interfaces to enable the rapidly evolving high performance computer market to support AI workloads.

Qualcomm Technologies Inc. announced the entry into an agreement to acquire **Edge Impulse Inc.**, which will enhance its offering for developers and expand its leadership in AI capabilities to power AI-enabled products and services across IoT. The closing of this deal is subject to customary closing conditions. This acquisition is anticipated to complement Qualcomm Technologies' strategic approach to IoT transformation, which includes a comprehensive chipset roadmap, unified software architecture, a suite of services, developer resources, ecosystem partners, comprehensive solutions and IoT blueprints to address diverse industry needs and challenges.

COLLABORATIONS

During NVIDIA GTC, **NVDIA** announced a series of partnerships with industry leaders, including **T-Mobile**, **MITRE**, **Cisco**, **ODC** and **Booz Allen Hamilton**, to advance the development of AI-native wireless networks and 6G technology. These collaborations aim to integrate AI into next-generation network hardware, software and architecture, setting new benchmarks in spectral efficiency, network performance and telco innovation. NVIDIA's collaborations will be anchored in an AI-native wireless network stack built on the NVIDIA AI Aerial platform, enabling software-defined RAN on NVIDIA's accelerated computing infrastructure.

NTT Corporation, **NTT DOCOMO INC.** and **NEC Corporation** announced that they demonstrated a real-time bidirectional wireless transmission in the mmWave band between 71 and 86 GHz that achieved a bit rate of 140 Gbps, unprecedented for sub-100 GHz frequencies. The test demonstrated that Orbital Angular Momentum (OAM) mode multiplexing transmission technology can increase the capacity of wireless transmission. The OAM-mode control technology can increase wireless transmission distances by using reflected paths. The achievement is expected to help realize high-capacity wireless transmissions to meet future demand anticipated in the 2030s.

Sivers Semiconductors AB announced a partnership with **WIN Semiconductors** to enhance production of Sivers Semiconductors' proprietary high-power DFB lasers and laser arrays technology. This strategic collaboration paves the way for high volume manufacturing of critical components for coarse wavelength division multiplexing and dense wavelength division multiplexing applications. WIN Semiconductors will serve as an outsourced manufacturing partner for Sivers Semiconductors, enabling the company to scale production and meet the growing demand for its cutting-edge photonic solutions. This collaboration marks a significant milestone for Sivers, combining WIN Semiconductor's extensive expertise in compound semiconductor manufacturing with Sivers Semiconductors' advanced laser chip technology.

Ericsson and **Drei Austria** are collaborating to enhance urban 5G connectivity by testing W-Band frequencies. Their goal is to prove the usage of microwave links in high frequency band especially in densely populated areas, ultimately paving the way for advanced technological solutions in urban environments. The two partners have recently completed a field trial of W-Band microwave technology, successfully showing its potential as a high-capacity backhaul solution in urban areas where E-Band networks might face congestion. In dense urban areas, where transport networks face very high-capacity demands, end users will benefit from enhanced 5G performance made possible by deploying W-Band technology to complement the existing E-Band spectrum.

Space42, the UAE-based AI-powered SpaceTech company, and **Viasat Inc**, a mobile satellite services (MSS) operator in L- and S-Band spectrum, signed a Memorandum of Understanding to explore ecosystem partnership options for developing a 5G non-terrestrial network initiative. This collaboration between Space42 and Viasat is a major step toward expanding global satellite connectivity, enabling both companies to address the growing opportunities in direct-to-device satellite communications to smartphones, narrowband IoT, as well as existing and next-generation MSS services.

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Around the **Circuit**

NEW STARTS

Intellian Technologies USA Inc., a provider of global satellite communication (satcom) antennas and ground gateway solutions, announced that its ARC-M4 Block 1 (AN/USC-75) is now being manufactured at Intellian's U.S. headquarters, in Irvine, Calif. Intellian is intensifying its commitment to the U.S. Government's mission-critical objectives and supply chain resiliency, by manufacturing the ARC-M4 Block 1 satcom terminal in the U.S. Intellian has implemented a meticulous component-level supply chain control system to ensure that no components are used from vulnerable nation states, which enhances national security and protects against supply chain disruptions.

ACHIEVEMENTS

Altum RF, a leading supplier of high performance RF to mmWave semiconductor solutions for next-generation markets and applications, announced the expanded scope of its ISO 9001:2015 registration for its quality management system. In addition to its headquarters in Eindhoven, the Netherlands, Altum RF's design center in Sydney, Australia, has now also achieved ISO 9001 certification. This milestone underscores the company's commitment to delivering high-quality, reliable and high performance semiconductor products, while maintaining excellence across design, development, manufacturing and sales processes.

CONTRACTS

Anduril has been awarded a $642 million, 10-year indefinite delivery/indefinite quantity (IDIQ) program of record by the **U.S. Marine Corps** to deliver, install and sustain installation-counter small, unmanned aircraft systems (I-CsUAS). Anduril's comprehensive I-CsUAS solution leverages the power of AI and advanced autonomy, equipping the U.S. Marine Corps with hardware and software capabilities required to address evolving aerial threats and protect installations worldwide over the next decade. This program validates Anduril's CUAS advantage, enabling 24/7 autonomous operations powered by Lattice, Anduril's advanced software platform. Lattice uses AI to autonomously detect, track, identify and neutralize aerial threats, empowering human operators to rapidly make critical decisions with minimal manpower.

EnSilica, a leading chip maker of mixed signal application specific integrated circuits (ASICs), announced that it has been awarded an $18 million design and supply contract by a leading European based supplier of electromechanical products for a Cortex M series Arm-based mixed signal sensor interface ASIC to be used across a range of automotive and industrial applications. The total value of the contract is estimated to exceed $18 million over seven years. EnSilica has been selected due to its significant experience in developing mixed signal design ASICs, alongside a proven track record of bringing automotive and industrial chips to high volume production.

Raytheon, an RTX business, has been awarded a follow-on contract from the **U.S. Army Futures Command, Futures and Concepts Center** to continue to utilize its Rapid Campaign Analysis and Demonstration Environment (RCADE) modeling and simulation capability. During the initial contract, Raytheon developed large-scale theater scenarios to assess concepts of operations in a multi-domain conflict. In this follow-on effort, Raytheon will establish a continuous experimentation environment with RCADE to enable the U.S. Army's concept developers and Battle Labs to inform strategic force design decisions. Raytheon's RCADE capabilities enable analysts from the Raytheon Advanced Technology team to work with the U.S. Army team to ensure a continuous feedback loop between modeling and simulation and emerging real-world threats.

REP APPOINTMENTS

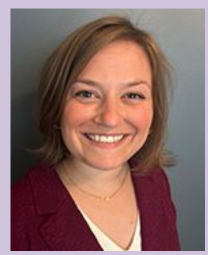
Electro Rent, a global leader in test and measurement equipment rental solutions and services, announced a distribution agreement with **Antennex**, a leading innovator in antenna measurement solutions. This agreement enables Electro Rent to sell new Antennex test chambers in North America. Electro Rent customers can now purchase new Antennex equipment to support their ongoing testing initiatives. Electro Rent is a global leader in test and technology solutions that enable customers to accelerate innovation and optimize investments. Electro Rent's rental, leasing, sales and asset management solutions serve leading innovators in communications, aerospace and defense, automotive, energy, education and general electronics.

Insulated Wire Inc (IW), the innovative specialists in manufacture of microwave cable and cable assemblies, announced **Ward/Davis** as their new representative for California. Ward/Davis is a long-established manufacturer's representative with a strong engineering-focused sales team. They have significant experience in RF and microwave design and cable products in both commercial and defense industries. IW's experience across a worldwide customer base has aided in developing their capability in the high-power segment with ultra-low loss and commensurate high rated coaxial cable and cable assembly products. IW can support applications where high RF power levels need to be reliably transmitted including EMC/EMI testing, rapid microwave de-frosting, communications, semiconductor manufacturing and defense systems.

After more than 16 years as a dedicated **Pasternack** channel partner in the U.K., **Spectech** has announced its retirement and closed business operations on March 31, 2025. To ensure continued high-level channel support in the U.K., Pasternack announced the addition of **RFMW** as its preferred franchised channel partner in the region. RFMW is a globally recognized distributor specializing in RF and microwave components. With a strong technical support team and a commitment to exceptional service, RFMW will provide Pasternack customers in the U.K. with enhanced product availability,

responsive delivery and expert guidance backed by Pasternack's full resources.

Richardson RFPD Inc., an Arrow Electronics company, announced that it has entered into a franchise agreement with **Crescend Technologies LLC**. Crescend Technologies leverages decades of engineering expertise to empower industrial sectors to replace outdated systems with innovative solid-state microwave technology designed to increase throughput, minimize downtime and enhance sustainability. The agreement with Crescend makes Richardson RFPD an authorized global distributor for Crescend's standard industrial microwave generator products.



Microwave Journal announced the retirement of Eric Higham at the end of April and the hire of **Del Pierson** to replace him as technical editor. During his tenure, Higham made significant contributions to the editorial process, notably automating and streamlining workflows to enhance efficiency and accuracy. He is well known for his eloquent writing style, complemented by a keen business sense that enriched his technical writing. We extend our heartfelt thanks to Eric for his dedication and contributions to *Microwave Journal* and wish him all the best in his well-deserved retirement. He will be deeply missed.

Del Pierson is the technical editor of *Microwave Journal* responsible for the editorial content in each month's issue, covering conferences and exhibitions, moderating webinars and co-hosting Frequency Matters. Del joins *Microwave Journal* following her role as a sales engineer and product manager at XMA Corporation, an Amphenol company. At XMA, she developed, marketed and sold new hardware solutions designed for harsh environments and led successful grant applications to support new R&D initiatives. Del is knowledgeable about passive components, nanomaterials, high-density electronics, space communications and quantum computing technologies. With a foundation in physics and product development, Del brings technical depth and fresh energy to the industry. Del holds a B.A. in physics from Colby College in Waterville, Maine.

Bridging the Gap Between Theory and Practice: Collaborating to Transform RF Engineering Education

Pat Hindle
Microwave Journal, Norwood, Mass.

Professor Francesco Fornetti, associate professor of Radio Frequency Engineering at the University of Bristol,[1] has worked tirelessly over the past 12 years to bridge the industry-academia gap. He is an internationally recognized educator known for pioneering engineering education contributions and holds a prestigious National Teaching Fellowship. This highly selective award is conferred to only 55 academics each year in the U.K. It recognizes individuals who have made an outstanding impact on student outcomes and the teaching profession. Professor Francesco Fornetti is shown in ***Figure 1***.

Fig. 1 **Professor Francesco Fornetti of the University of Bristol.**

There has been a longstanding collaboration between Cadence® and the University of Bristol under Professor Fornetti's leadership. This relationship has recently gained momentum with the release of a series of novel online open courses.[2] These courses on Radio Frequency Engineering[3] and the Foundations of Electric Circuits[4] are designed to prepare students for the real-world challenges of an increasingly connected world.

To build on his existing partnership with Cadence and further enhance the material offered in his courses, Professor Fornetti embarked on a collaboration with Rohde & Schwarz in July 2023. Drawing on Rohde & Schwarz's hardware design expertise, the primary goal of the partnership is to modernize the teaching methods for RF engineering, both at university and in continuing professional development (CPD) courses. The vision is simple yet ambitious: make RF education more practical, engaging and relevant to the industry, equipping learners with the real-world skills essential for the workforce.

RF engineering is notoriously challenging for students. Courses are often taught in a highly theoretical, mathematical and abstract way. This is one of the reasons behind the shortage of RF engineers in the electronics industry. To address this, Professor Fornetti had previously developed virtual laboratories (VLs) using the Cadence AWR® simulation software. These VLs allowed him to create instructional material, like video tutorials and demonstrations, which were both conceptual and practical, making complex subjects more intuitive and accessible. VLs enable students to design and experiment with virtual circuits and instruments that closely resemble their physical counterparts, empowering them to take a more empirical, self-directed and exploratory approach to learning.

While this was a significant advancement, Professor Fornetti realized that hands-on physical laboratory experience was still es-

sential. However, traditional RF labs require expensive equipment and without the insights of industrial designers, it becomes difficult to fully bridge the gap between theory and real-world practice. This is where Rohde & Schwarz has become an invaluable partner.

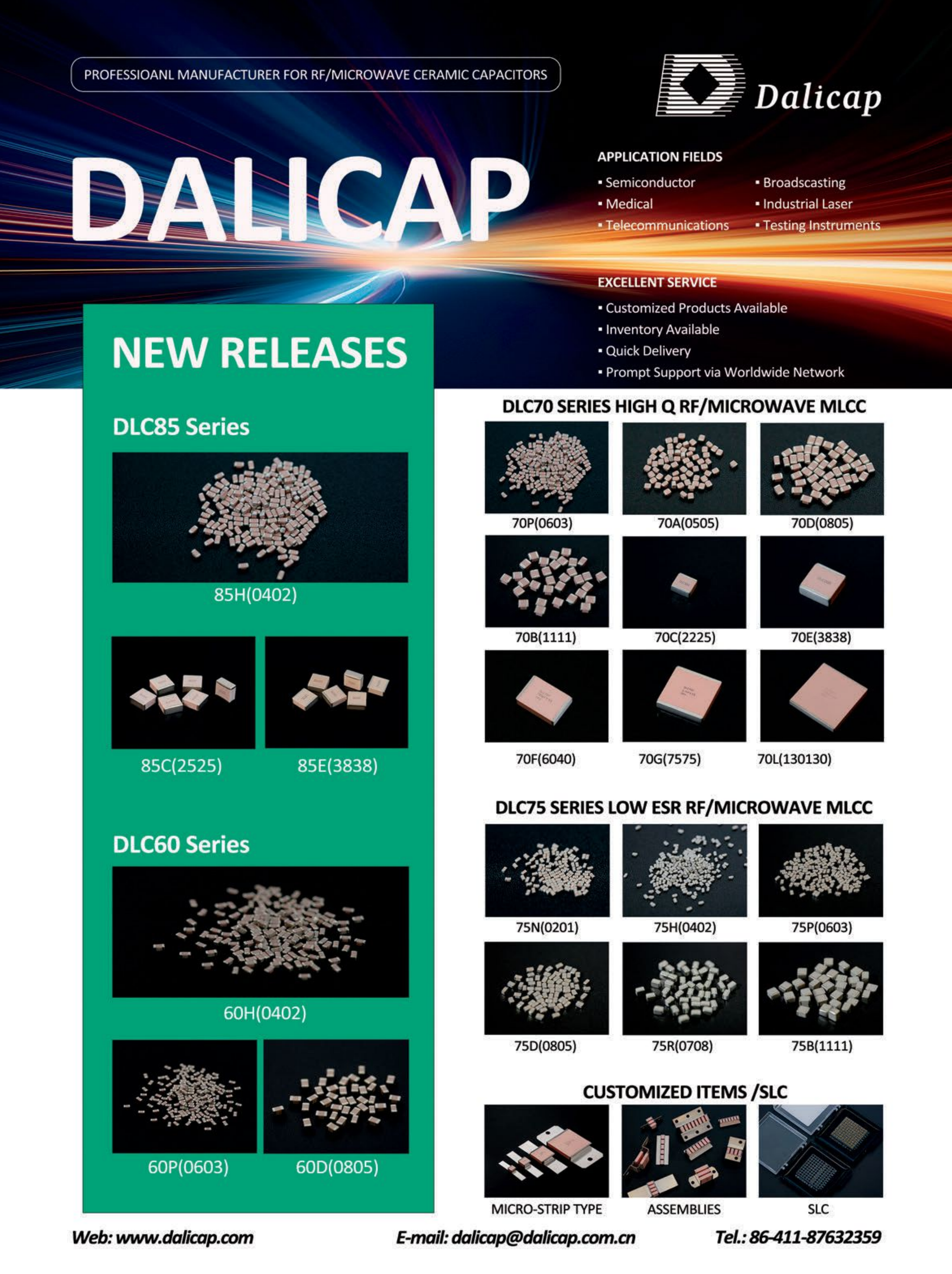
When Rohde & Schwarz released the FPC1500, a versatile, cost-effective instrument that functions as a VNA and a spectrum analyzer, it solved the significant hurdle of equipment affordability. Collaborating with Markus Lang and his team at Rohde & Schwarz has allowed Professor Fornetti to merge the practical design expertise at Rohde & Schwarz with his academic background to create innovative and affordable RF lab exercises. The partnership successfully blends diverse perspectives from academia and industry, consistently finding creative solutions to drive the project forward. The two teams have demystified some of the "black magic" of RF design, using scientific methods to address problems that even seasoned engineers have accepted without question for years.

A key success of this collaboration is the seamless integration of practical lab work with the VLs. The techniques and design processes taught in lectures and supported by the VLs are directly applied to circuit designs implemented in physical labs. The agreement between simulation and practical implementation is excellent. Professor Fornetti has found that with proper understanding and by keeping the frequency of operation below 1 GHz, simulated results can closely match experimental measurements. One particularly valuable solution emerging from the collaboration with the Rohde & Schwarz engineers is the creation of homemade calibration kits using the same board-edge connectors employed in the experiments. A purely academic approach might not have considered this, but this practical solution removes the need for de-embedding experimental data and ensures that the simulation and practical results remain closely aligned. A YouTube video shows more details about this homemade calibration kit.[5] A screenshot from this video is shown in ***Figure 2***.

Fig. 2 **Designing a homemade VNA calibration kit.**

It was also very advantageous that the Cadence AWR software used for the VLs is one of the main tools Rohde & Schwarz employs for their RF circuit designs. This makes collaboration on the simulation aspect of the work seamless. The labs ranged from simple tasks using copper tape and FR4 substrates[6] to more complex design challenges such as two- and three-element matching networks[7] and amplifier design[8] requiring custom PCBs. These labs were particularly engaging because many of the exercises had no single solution, mirroring real-world engineering challenges. Students were free to explore different design approaches, each with its trade-offs.

One of the main objectives in designing these courses is to move away from the traditional, passive forms of learning and create an environment where students are actively engaged in their education. Professor Fornetti aims to foster independent, self-paced learning, allowing students to take more control of their progress in a pressure-free environment catering to neurodiverse individuals. Another primary objective is to promote an exploratory, inquiry-based approach to learning that will not be constrained by the rigid boundaries of a set syllabus, thus encouraging students to tap into their creativity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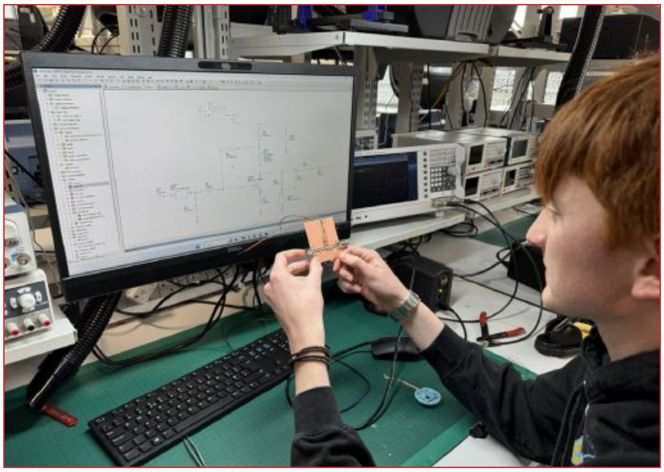

Fig. 3 Amplifier design.

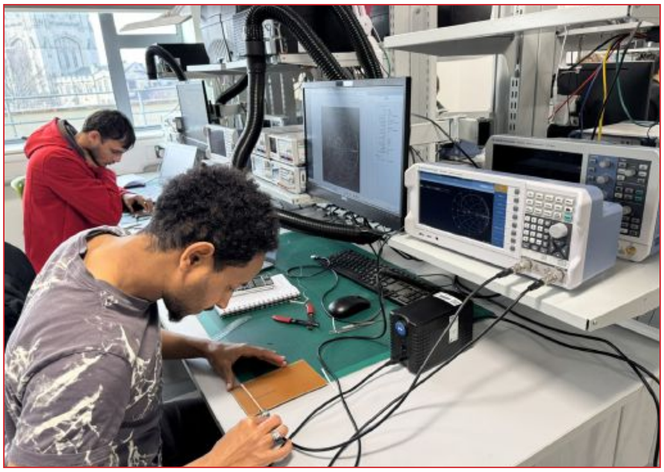

Fig. 4 Transmission line design.

and imagination. These courses enable students to develop "functioning" knowledge that empowers them to tackle real-world problems. It helps them understand the roles of theory, simulation and practical implementations in achieving the desired goals during the electronic design process. Further, the courses provide relevant examples, challenges and instructions for using a powerful simulation tool like Cadence AWR as a virtual laboratory, along with guidance for practical experiments supported by simulations that align with the course content and learning objectives.

Professor Fornetti offers practical workshops on campus to complement his online RF course. These sessions are open not only to students at the University of Bristol but also to those from other universities and industry professionals, provided they pass a free online test. This novel approach to technical CPD is rooted in a blended, self-paced learning model: participants study the online RF course at their own pace and then sit for an exam. Only those who pass the exam are eligible to attend the workshop. As a result, attendees arrive well-prepared, having already designed several RF cir-

Fig. 5 **Matching network design.**

cuits using Cadence AWR. In just one and a half days, attendees can complete all three workshop activities as detailed in this blog post.[9] ***Figure 3*** shows a student working on an amplifier design. ***Figure 4*** shows students working on a transmission line design and ***Figure 5*** shows a student working on a matching network design in a workshop. These workshops also offer valuable, hands-on experience with RF instruments and equipment, further enhancing practical skills and improving industry readiness.

Working with Rohde & Schwarz and Cadence, Professor Fornetti has created a complete experience for students that combines theory, simulation and practical implementation consistently and cohesively. This helps students contextualize their learning and equips them with skills that will serve them well in their careers. Most importantly, this collaboration strengthens the link between industry and academia, creating a curriculum that better prepares students for the demands of modern RF design. It also has the potential to address the shortage of RF engineers in the industry, as all this work is freely accessible online through Connected Worlds,[2] the novel virtual learning environment. ■

References

1. "Dr. Francesco Fornetti," *University of Bristol*, Web: bristol.ac.uk/people/person/Francesco-Fornetti-791e9015-12fd-40c6-921c-e32f773e5aaf.
2. Connected Worlds Courses, Web: connectedworlds.net.
3. Foundations of Radio Frequency Engineering, Web: connectedworlds.net/course/rf-engineering-fundamentals.
4. Foundations of Electric Circuits, Web: connectedworlds.net/course/foundations-of-electric-circuits.
5. "E1.0 Calibrating a VNA with a Cheap, 'Home-made' Cal-kit," *Explore RF*, Web: youtube.com/watch?v=Ws1mIK-JIrg.
6. Connected Worlds Course, Web: connectedworlds.net/path-player?courseid=rf-engineering-fundamentals&unit=669e73c7c98fc958300619feUnit.
7. Connected Worlds Course, Web: connectedworlds.net/path-player?courseid=rf-engineering-fundamentals&unit=66cb2d29eb4018231f0336afUnit.
8. Connected Worlds Course, Web: connectedworlds.net/path-player?courseid=rf-engineering-fundamentals&unit=66cb7d54f695b5c1100c01edUnit.
9. "Practical Radio Frequency Workshop Welcomes Bristol Uni Students and Industry Professionals—A Great Success!," University of Bristol, January 27, 2025, Web: connectedworlds.net/blog/rf-workshop-jan25.

INVITED PAPER

Enhancing MRI Technology: The Role of PIN Diodes in Medical Imaging

Baljit Chandhoke
Microchip Technology Inc., Chandler, Ariz.

Magnetic resonance imaging (MRI) has become an indispensable tool in modern medical diagnostics, providing detailed images of the internal structures of the body without the need for invasive procedures. ***Figure 1*** shows an example of the technology with a robotic-assisted MRI surgical station. The technology behind MRI systems is complex and relies on various components to function effectively. One such critical component is the PIN diode. This article delves into the applications and uses of PIN diodes in MRI devices and their broader impact on the medical market.

UNDERSTANDING PIN DIODES

A PIN diode is a semiconductor device consisting of three layers: a p-type (P) layer, an undoped intrinsic (I) layer and an n-type (N) layer. The intrinsic layer, sandwiched between the p-type and n-type layers, sets PIN diodes apart from other types of diodes. When a PIN diode is forward-biased, a positive voltage is applied to the p-type layer with respect to the n-type layer. When this bias exceeds the PIN diode's threshold voltage, holes and electrons are injected into the I-region. These charge carriers will recombine, but as the forward-bias voltage increases, the magnitude of these injected charge carriers will overwhelm the recombination process. This establishes a current flow through the device, lowering the resistivity of the intrinsic region and the PIN diode becomes a small resistance. Conversely, when the voltage on the n-type layer of the junction is higher than the voltage on the p-type layer, the PIN diode is reverse-biased. In this condition, free charge carriers are swept out of the intrinsic region and the reactance of the diode becomes quite large. This reverse-biased reactance is determined by the capacitance and parallel resistance of the PIN diode structure. This unique structure allows PIN diodes to operate efficiently at high frequencies and handle significant power levels, making them ideal for various applications, including those in MRI systems. ***Figure 2*** shows a simple PIN diode chip diagram.

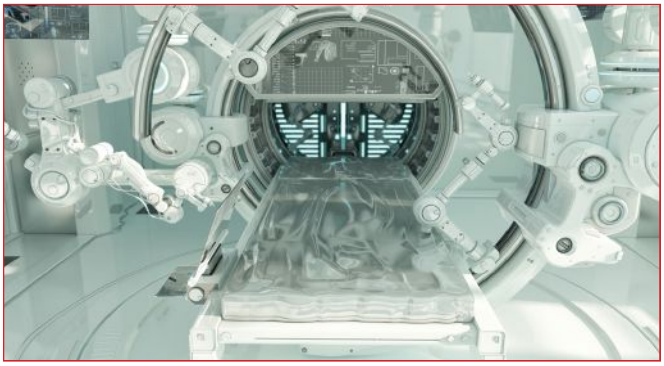

Fig. 1 **Robotic-assisted MRI surgical station.**


VNA400
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40 MHz - 40 GHz
PORT 1
P1
P2
STATUS
PORT 2
Signal Hound

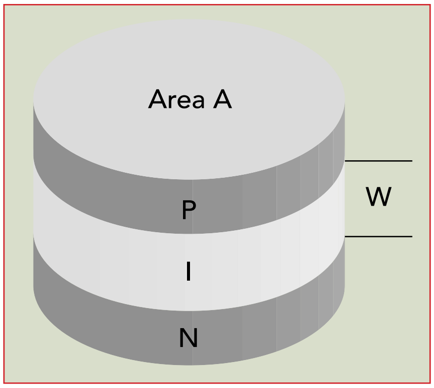

Fig. 2 **PIN diode chip.**

APPLICATIONS FOR MRI SYSTEMS

The RF power supply frequency of an MRI machine depends on the strength of the magnetic field used for the scan and can be calculated according to the Larmor frequency. The Larmor frequency, named after Joseph Larmor, is the frequency at which the magnetic moment of a proton, electron or nucleus precesses around a magnetic field. This is the essential phenomenon leveraged by nuclear magnetic resonance and MRI technology. This is fundamental to the operation of MRI as it governs the frequency of oscillation of hydrogen nuclei (protons) in the human body when subjected to high magnetic fields. The Larmor frequency is given by ***Equation 1***:

$$\omega_0 = \gamma B_0 \qquad (1)$$

Where:

ω_0 = Larmor frequency

γ = the gyromagnetic ratio of the proton, which is approximately 42.58 MHz/T

B_0 = strength of the external magnetic field applied in Tesla (T) units.

Therefore, from Equation 1, a 1.5 T machine would have a Larmor frequency of 42.58 MHz/T × 1.5 T or 63.87 MHz.

One of the primary applications of PIN diodes in MRI systems is for RF switching and attenuation. MRI machines use RF pulses to excite hydrogen nuclei in the body, which then emit signals that are detected and used to create images. PIN diodes are employed to switch these RF signals on and off rapidly and to control their amplitude. Their ability to handle high power and operate at high frequencies makes them particularly well-suited for this purpose.

In MRI systems, the same RF coil is often used for both transmitting the RF pulses and receiving the emitted signals. PIN diodes play a crucial role in transmit/receive (Tx/Rx) switches, which alternate between the transmit and receive modes. When the system is in transmit mode, the PIN diode allows the RF pulse to be sent to the coil. Conversely, when the system switches to receive mode, the PIN diode isolates the receiver from the transmitter, thereby preventing damage to the sensitive receiver components.

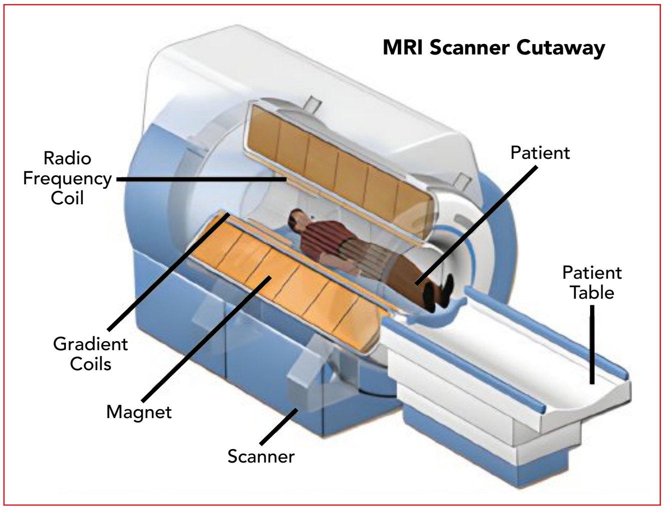

Fig. 3 **MRI scanner cutaway.**

Fig. 4 **Commercial MRI machine installation.**

Modern MRI systems often employ phased array coils, which are composed of multiple smaller coils arranged in an array. These coils can be individually controlled to enhance image quality and reduce scan times. PIN diodes play a crucial role in these coils, enabling the switching of individual elements on and off. This precise control of the RF fields significantly improves the overall performance of the MRI system. RF coils function as resonant circuits tuned to the resonance frequency of proton spins within a given magnetic field. During a scan, RF pulses and magnetic gradients are applied and RF energy is exchanged with the patient to generate images.

The quality of MRI images is heavily dependent on the homogeneity of the magnetic field within the imaging volume. PIN diodes are used in shim coils, which are auxiliary coils designed to correct inhomogeneities in the magnetic field. By adjusting the current in these shim coils, the magnetic field can be made more uniform, resulting in clearer and more accurate images. ***Figure 3*** shows a cutaway of an MRI scanner that illustrates some of these functions and ***Figure 4*** shows a commercial MRI machine installation.

ADVANTAGES IN THE MEDICAL MARKET

The use of PIN diodes in MRI systems offers several advantages that extend to the broader medical market. One of the most significant benefits is their high speed switching capability. PIN diodes can switch on and off very rapidly, which is essential for the fast-paced operation of MRI systems. This high speed switching ensures that the RF pulses are delivered and received with precise timing, leading to high-quality images that are crucial for accurate diagnosis.

Another advantage is the high power handling capability of PIN diodes. MRI systems require compo-


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nents that can manage high levels of power without degrading performance. PIN diodes are well-suited for this task, as they can operate efficiently at high power levels, ensuring the reliability and longevity of the MRI system. This reliability is particularly important in the medical market, where equipment downtime can have serious implications for patient care.

The intrinsic layer in PIN diodes helps to minimize signal distortion, which is crucial for maintaining the integrity of the RF signals used in MRI. Low distortion ensures that the images produced are accurate and free from artifacts, which is essential for effective diagnosis and treatment planning. This level of accuracy and reliability makes PIN diodes an invaluable component in the medical market, where precision is paramount.

Furthermore, the versatility of PIN diodes allows them to be used in various parts of the MRI system, from RF switching to magnetic field correction. This versatility makes them an essential component in the design and operation of MRI machines. These characteristics make PIN diodes invaluable contributors to the advancement of MRI technology and, by extension, the medical market. ***Figure 5*** shows a PIN diode diagram like that of Figure 2. However, in this case, the PIN diode is shown in an axial-leaded package with the anode and cathode connections identified. This points to the packaging flexibility of PIN diodes.

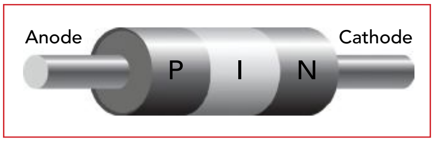

Fig. 5 **Typical packaged PIN diode construction.**

NON-MAGNETIC PACKAGING

The use of non-magnetic packaging for PIN diodes is essential when these components are deployed in environments with high magnetic field strength. Magnetic materials can compromise the performance and reliability of diodes. Non-magnetic materials ensure that the diodes operate correctly without interference from surrounding magnetic fields. This is particularly critical in applications such as medical imaging equipment, scientific instruments and specific communication systems. Employing non-magnetic packaging preserves the integrity and efficiency of PIN diodes, resulting in more accurate and dependable performance in high magnetic field conditions.

MMSM NON-MAGNETIC PACKAGING

Monolithic microwave surface-mount (MMSM) packaged non-magnetic diodes are engineered for direct mounting onto printed circuit boards (PCBs), offering several key advantages. Their non-magnetic nature makes them ideal for applications where minimizing magnetic interference is critical, such as in medical imaging equipment, precision instrumentation and aerospace technology. The MMSM packaging significantly reduces the physical footprint of the diodes on the PCB,

which is advantageous for modern electronic devices that require compact and lightweight designs. Additionally, surface-mount technology (SMT) streamlines the manufacturing process by enabling automated placement and soldering of components onto the PCB, thereby increasing production speed and consistency while reducing human error. This combination of smaller component sizes and automated assembly processes enables lower production costs through reduced material usage and faster assembly times. By eliminating magnetic materials, these diodes help maintain the integrity and accuracy of sensitive systems, which is crucial in applications where magnetic fields can interfere with electronic circuits. Furthermore, MMSM-packaged diodes are designed to withstand the rigors of modern electronic environments, ensuring long-term reliability and durability even in challenging conditions.

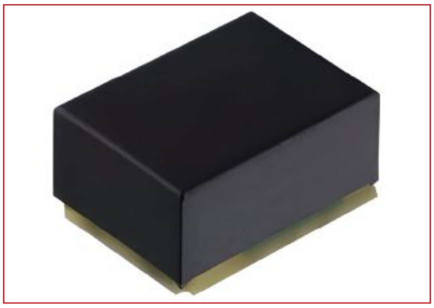

Fig. 6 PIN diode in MMSM package.

Overall, MMSM-packaged nonmagnetic diodes leverage SMT to provide significant benefits in terms of space efficiency, manufacturability, cost reduction, performance and reliability, making them an ideal choice for a wide range of high-precision and space-constrained applications. ***Figure 6*** shows a PIN diode in a nonmagnetic package.

FUTURE MARKET TRENDS

Recent advancements in neurological imaging are being driven by several key trends, notably the development of 7T MRI machines. These high-field MRI systems are breaking new ground in the diagnosis and study of neurological conditions such as Parkinson's disease. The increased magnetic field strength of 7T machines offers significantly higher resolution images compared to the more commonly used 1.5T and 3T MRI systems. This enhanced imaging capability allows for more detailed visualization of brain structures and abnormalities, which is crucial for early diagnosis and treatment planning in neurological disorders.

Typical peak RF powers for 1.5T MRI machines generally range from 10 to 15 kW. The required power is determined by a complex calculation that depends on several factors, including the body tissue being imaged, the type of coils in use, whether the coils are configured in series or parallel and the total magnetic power. For a 3T system, the power requirement can exceed 30 kW. With the advent of 7T systems and experimental 10T and 11T systems, the total RF power required can approach 70 to 80 kW. The RF power amplifier technologies used in these RF supply subsystems can be selected from various options, including VDMOS, LDMOS and GaN. Despite the availability of

high-power individual transistors, these systems often need to combine the power of 30 to 100 transistors to achieve the necessary total peak output power for the MRI machine.

7T machines are also being used for improved imaging, especially in the emerging segment of MR-guided surgery. These high-field MRI systems are particularly beneficial for detailed imaging of knees and other specific body parts. Moreover, they are becoming increasingly important in the growing field of MR-guided surgery, where precise imaging is crucial for successful surgical outcomes.

There is a fair amount of frequency and application diversity in the MRI industry, in addition to field strength. Whole-body MRI systems operating up to 7 T can have RF signals up to 300 MHz. Head-only MRI systems operating at these same field strength levels up to 7 T or greater use RF signals that can be up to 400 MHz. Many of the lower signal strength 3T MRI systems operate at a 127.74 MHz frequency range, while some of these 3T MRI systems operate at 123.2 MHz, which means they are slightly lower in terms of magnetic strength.

Another important trend in the MRI industry is the shift toward helium-free or reduced-helium MRI machines. Helium is traditionally used as a cryogenic coolant for the superconducting magnets in MRI systems. However, helium is both expensive and increasingly scarce, a situation exacerbated by geopolitical factors such as the Russia-Ukraine war. The scarcity and high cost of helium have driven the demand for new MRI machines that use significantly less helium or eliminate the need for it.

This shift not only addresses the supply chain challenges associated with helium but also reduces the operational costs and environmental impact of MRI systems. As a result, there is a growing market for these advanced machines, leading to the replacement of older 1.5T systems with more efficient and sustainable alternatives. These trends underscore the ongoing transformation in the MRI industry, driven by technological innovation and changing market demands. While these developments do not directly impact the use and value of PIN diodes, they do reflect the growing need for new and advanced MRI machines, which in turn influences the overall market landscape.

CONCLUSION

PIN diodes play a vital role in the functionality and efficiency of MRI systems. Their applications in RF switching, Tx/Rx switches, phased array coils and magnetic field homogeneity contribute to the high-quality imaging capabilities of modern MRI machines. The advantages of high speed switching, high power handling, low distortion and versatility make PIN diodes an essential component in the advancement of MRI technology and the broader medical market. As MRI technology continues to evolve, the importance of PIN diodes in enhancing image quality and diagnostic accuracy will only grow, further solidifying their place in the field of medical imaging. ■

Evaluating Polarizer Performance

Andrew Laundrie
Eravant (formerly Sage Millimeter Inc.), Torrance, Calif.

Waveguide polarizers are often used in radar and communication systems operating at microwave and mmWave frequencies. When a circular polarizer is paired with a suitable antenna, such as a conical horn or a feed horn, it enables the transmission and reception of circularly polarized waveforms. System designers can benefit from understanding how polarizers work and how their performance is commonly described and measured.

Circular waveguide polarizers are passive components that accept linearly polarized input signals. They produce output waveforms with circular or near-circular polarization. The output polarization is generally not circular but slightly elliptical due to various design compromises or manufacturing limitations. Choosing the best polarizer depends on practical considerations such as the importance of polarization purity, operating bandwidth, size and cost. ***Figure 1*** shows an example of an Eravant V-Band linear-to-circular polarizer operating from 50 to 75 GHz.

Fig. 1 **Eravant circular polarizers are commonly used in radar and communication systems.**

In many applications, a high degree of polarization purity is essential. For example, satellite communication networks often use both right- and left-hand circular polarizations (RHCP and LHCP). ***Figure 2*** shows a vector diagram for the electric field of RHCP (Figure 2a) and LHCP (Figure 2b) waves. The individual electric field vectors, as well as their combined vector, have a constant magnitude, but the phase angle changes with time. This changing phase angle means the electric (and magnetic) field vector rotates in a clockwise direction for RHCP and a counter-clockwise direction for LHCP when viewed along the direction of propagation, the z-axis in Figure 2.

The phase difference of the components of a circularly polarized electromagnetic wave allows a single transmission channel to carry two signals simultaneously. In some applications, good polarization purity is desired for the transmitted signals and the receiving antennas to control interference between the channels. Additionally, instruments like polarimetric radars and radio telescopes often require high levels of polarization purity. In contrast, some applications function well with only moderate polarization purity. For example, many communication systems transmit circular

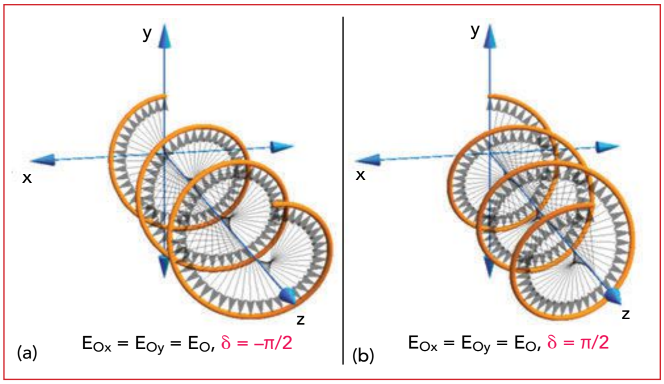

Fig. 2 **RHCP (a) and LHCP (b) wave propagation of a circularly polarized wave.**[1]

polarization to reduce signal fading. Circularly polarized signals can be received by linearly polarized antennas having vertical, horizontal or diagonal orientations. Limited deviations from circular polarization do not worsen signal fading appreciably.

POLARIZER OPERATION

Many polarizer designs have been realized with various advantages and disadvantages. ***Figure 3*** shows a septum polarizer. This type of polarizer has two rectangular waveguide input ports and a square waveguide output. A thin conducting wall separates the two rectangular waveguide inputs. The wall height decreases over a short distance to increase coupling between

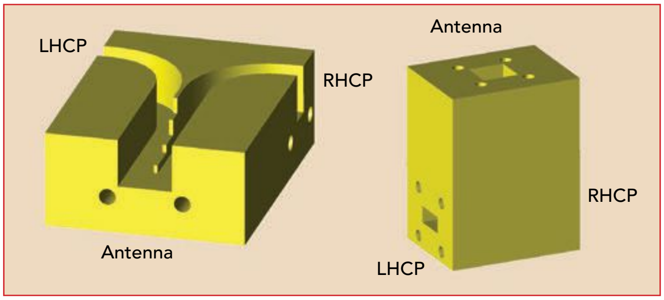

Fig. 3 **Septum polarizer construction illustration.**

the waveguide sections until the signal reaches a single, square waveguide aperture at the output. Applying a signal to one of the inputs produces an RHCP signal at the output. If the signal is applied to the other input, the output is an LHCP signal. This architecture enables septum polarizers to support two communication channels over a single wireless link while sharing a common frequency band.

Circular polarization is generated using an orthomode transducer (OMT). An OMT has two rectangular waveguide ports coupled to a square or circular common port. The H port produces horizontal polarization at the common port, while the V port generates vertical polarization. To obtain circular polarization, signals applied to the H and V ports must have equal amplitude and a phase difference of ±90 degrees when they reach the common port. An example of an Eravant OMT is shown in ***Figure 4***.

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Part	Freq. Range (GHz)	Gain (dB)	NF (dB)	P1dB (dBm)	Bias Voltage (V)	Bias Current (mA)	Package
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ARF1201Q2	22–31.5	24	2.4	15	3.3	40	2.5 × 2.5 QFN
ARF1202Q2	37–43.5	21.5	2.5	7	3.3	15	2.5 × 2.5 QFN
ARF1203Q2	37–43.5	21	2.7	12.5	3.3	40	2.5 × 2.5 QFN
ARF1205Q2	13–25	23	1.9	16	4	65	2.5 × 2.5 QFN
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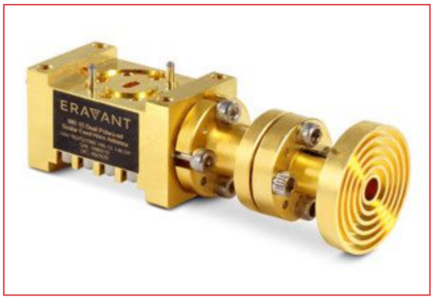

Fig. 4 **Orthomode transducers can transmit and receive circular polarization.**

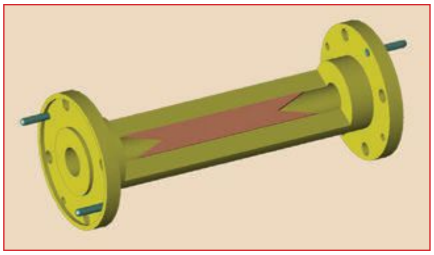

Fig. 5 **A dielectric vane is used to generate circular polarization.**

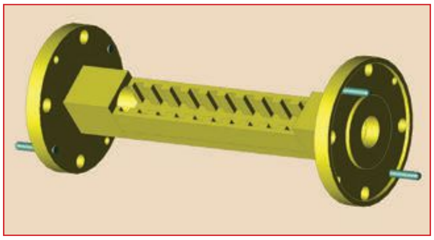

Fig. 6 **A corrugated waveguide assembly can generate circular polarization.**

A variety of single-input polarizers are also available. A typical design approach uses a tapered transition that takes the signal from a rectangular waveguide to a square or circular profile. The polarizing section contains structural features that affect one-half of the applied signal differently than the other half. The two signal components are nominally shifted in phase by ±90 degrees with respect to each other, producing near-circular polarization at the output. Ideally, the two signal components have precisely the same amplitude when they are combined at the output of the polarizer. In practice, impedance mismatches and other limitations cause amplitude and phase imbalances that impact polarization purity.

A variety of phase-shifting structures can be employed to achieve the desired polarization outcome. A typical configuration of this architecture is shown in ***Figure 5***. The illustration of this approach has a dielectric vane oriented at approximately 45 degrees with respect to the input electric field. Dielectric loading effects will cause one-half of the applied signal to propagate slower than the other half. The difference in signal delay will create a 90-degree phase shift between the two signals when they reach the output of the polarizer.

A square waveguide with corrugated surfaces on opposing walls can also generate circular polarization. The corrugated walls will provide different propagation characteristics than the smooth walls and the output signal will depend on the orientation of the applied signal. When the electric field of the input waveform is oriented at a 45-degree angle with respect to the waveguide walls, half of the applied signal travels at a slower speed than the other half, which will affect the polarization. An il-

▲ Fig. 7 **Adjustable polarizers provide RHCP, LHCP and linear polarization.**

▲ Fig. 8 **An OMT is an effective polarization filter for measuring the axial ratio.**

lustration of this type of waveguide structure is shown in ***Figure 6***.

Adjustable polarizers enable the user to rotate the polarizing structure. Using this approach, the resulting polarization can be continuously varied among RHCP, LHCP and linear polarization. These types of adjustable polarizers are often utilized in antenna test ranges to match the polarization of the transmitted signal to that of the receiving antenna. ***Figure 7*** shows an example of an adjustable polarizer.

CHARACTERIZING POLARIZER PERFORMANCE

A polarization ellipse is commonly used to indicate the polarization state of an electromagnetic waveform. It is also used to describe the measured performance of a circular polarizer. As the phase angle of an RF signal advances with time, the polarization ellipse traces the magnitude and direction of the E-field vector in an x-y plane. The ellipse has an axial ratio (AR) and a tilt angle (τ), referenced to the x-axis. The direction of rotation is either right- or left-handed.

The AR is equal to or greater than 1. Perfect circular polarization, for which AR = 1, occurs when the magnitude of the E-field vector remains constant over time. Because of its impact on the performance of many radar and communication systems, the AR is an important figure of merit for polarizers and circularly polarized antennas.

Directly measuring the AR usually involves probing the electric field produced by an antenna or a polarizer. The test measures signal strength versus the tilt angle. In many antenna test ranges, AR and τ are measured by rotating a linearly polarized probe antenna while recording the received signal strength. AR is calculated as the ratio of the maximum and minimum E-field measurements.

Another standard test obtains the amplitude and phase of the electric fields measured in two orthogonal directions, typically horizontally and vertically. The measurements produce the complex quantities E_θ and E_φ in spherical coordinates or E_X and E_Y in rectangular coordinates. The method is described in IEEE Standard 149-2021, Recommended Practice for

Antenna Measurements.[2]

An effective measurement technique for waveguide polarizers uses an OMT as a linear polarization filter. An example of the setup for this technique is shown in ***Figure 8***. The V port is terminated with a matched load to absorb the signal component entering the OMT's common port. During measurements of both E_X and E_Y or, equivalently, S_{21X} and S_{21Y}, the H port remains connected to Port 2 of a vector network analyzer (VNA). The input of the polarizer is connected to Port 1 of the VNA through a rectangular-to-circular waveguide transition. Between measurements of S_{21X} and S_{21Y}, the OMT is disconnected from the polarizer, rotated 90 degrees and reconnected. The procedure ensures phase and amplitude coherence between S_{21X} and S_{21Y} measurements.

For many polarizer designs, the measured AR can be impacted by impedance mismatches. Septum and OMT polarizers are generally less sensitive to load mismatches when compared to those using dielectric vanes or corrugated waveguides. To minimize the effects of source and load mismatches, the rectangular-to-circular waveguide transition connected to the polarizer input should have an internal mode suppressor. The suppressor is usually a thin horizontal vane that absorbs cross-polarized signals reflected by the polarizer or the load, thereby reducing measurement errors caused by standing waves.

CONCLUSION

With radar and communication systems increasingly moving into microwave and mmWave frequencies, waveguide polarizers are seeing more use. Implemented correctly, the phase difference of the components of a circularly polarized electromagnetic wave allows a single transmission channel to carry two signals simultaneously. This improves the spectral efficiency of a wireless signal, enabling higher channel data rates. This article has described the theory and implementation of circular polarization. It has also discussed some of the important parameters that determine the performance of polarizers. In particular, the AR of a waveguide polarizer can significantly impact the performance of radar and communication systems. The article has given insight into understanding what AR represents and how it can be measured accurately to help system designers select the best polarizer for a given application. ■

References

1. "What is Circular Polarization in Antennae?," *Stack Exchange*, Drones and Model Aircraft, April 2020, Web: drones.stackexchange.com/questions/120/what-is-circular-polarization-in-antennae.
2. "IEEE Recommended Practice for Antenna Measurements," *IEEE Standards Association*, February 18, 2022, Web: standards.ieee.org/ieee/149/6667.

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INVITED PAPER

Phased-Locked Loops: Breaking Integers

Alexander Chenakin
Anritsu Company, Morgan Hill, Calif.

The ideal frequency synthesizer should preferably be broadband with fine frequency resolution, allowing the device to address many potential applications. Aside from frequency coverage and resolution, phase noise and spurs are critical parameters that impose the ultimate limit on the system's ability to resolve signals of small amplitude. These requirements of wide frequency coverage, small step size and good spectral purity are the key drivers in the development of modern frequency synthesizers.[1]

SYNTHESIZER CHARACTERISTICS

Synthesizer characteristics depend heavily on a particular architecture.[2] For decades, an indirect phase-locked loop (PLL) synthesizer was the most common and popular technique. As of today, PLL architectures still dominate. A generic single-loop PLL has the architecture shown in ***Figure 1***. It includes a tunable voltage-controlled oscillator (VCO) that generates a signal in a desired frequency range. This signal is fed back to a phase detector through a frequency divider with a variable frequency division ratio, *N*. The other input of the phase detector is a reference signal divided down to a desirable step size. The phase detector compares the signals at both inputs and generates an error voltage. After filtering and optional amplification, the voltage slews the VCO until it acquires the lock frequency given by: $f_{OUT} = N\,f_{PD}$, where f_{PD} is the comparison frequency at the phase detector inputs. Thus, the frequency tuning is achieved in discrete frequency steps equal to f_{PD} by changing the division coefficient *N*.

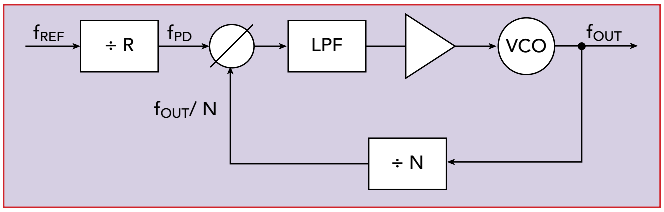


Fig. 1 **Functional diagram of a single-loop PLL synthesizer.**

The main advantage of the PLL synthesizer is the excellent spur rejection resulting from the inherent lowpass filter capabilities of the loop. Note that the spurs are located at multiples of the phase detector comparison frequency and can be easily filtered out, as depicted in the diagram in ***Figure 2***. However, this simple PLL synthesizer exhibits various limitations and tradeoffs. The main impact on the synthesizer performance is the reality of large division ratios required to provide a high frequency output with a

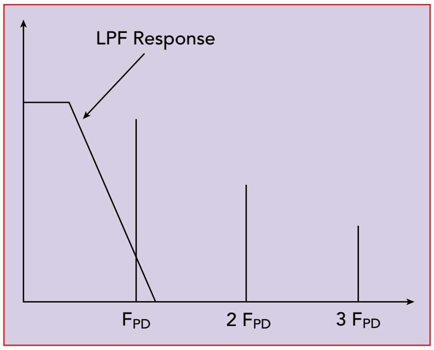


Fig. 2 PLL spurs are located at multiples of the phase detector comparison frequency.

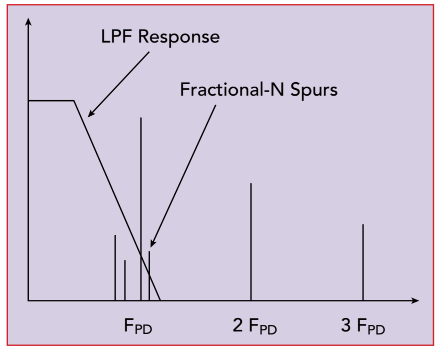


Fig. 3 Fractional-N spurs can be located within the PLL loop bandwidth.

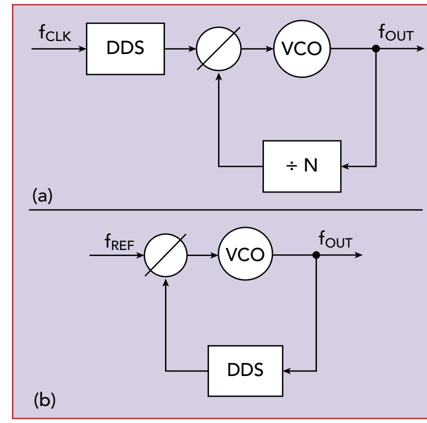


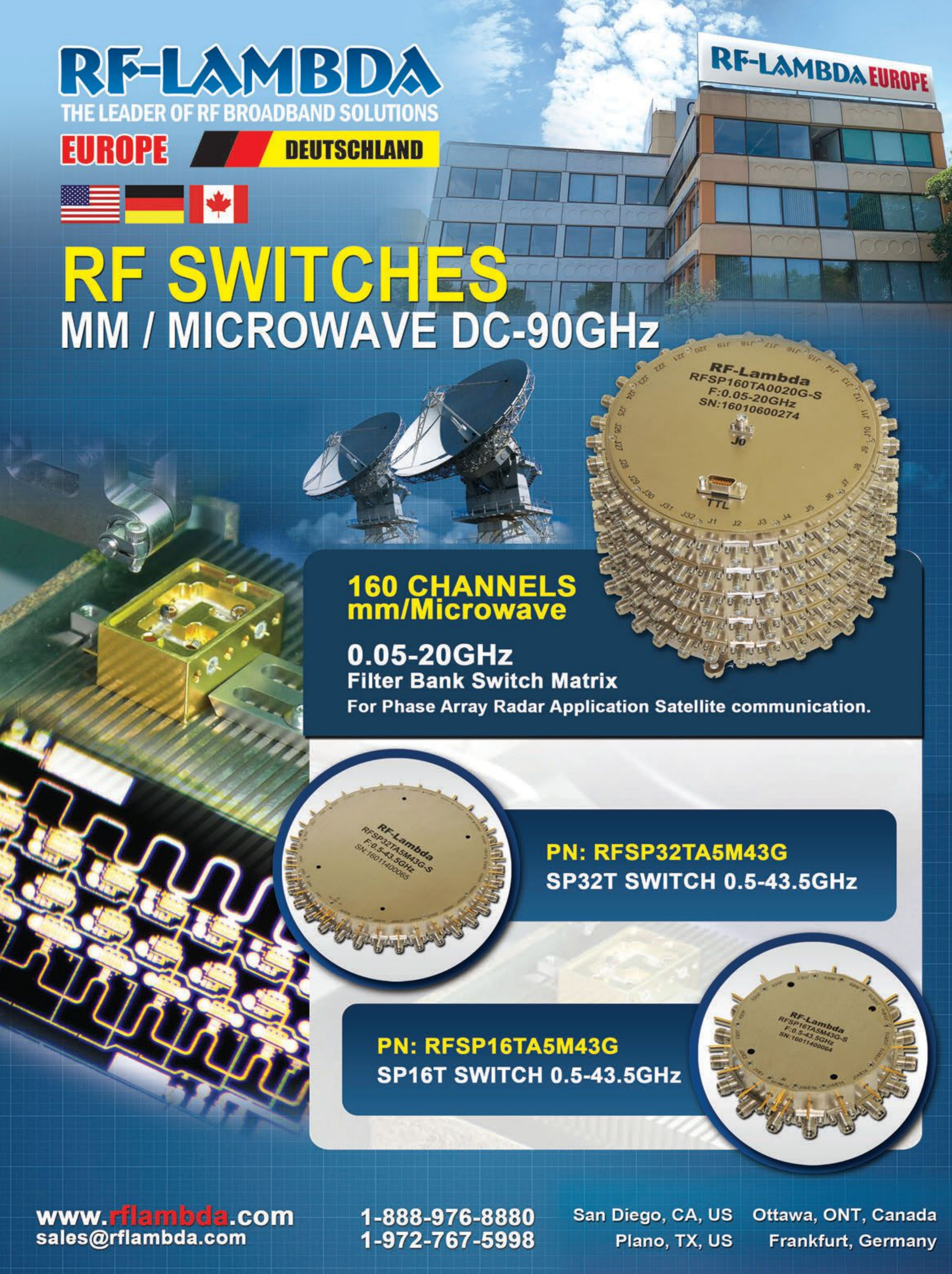
Fig. 4 (a) DDS as a high frequency reference in a PLL synthesizer. (b) DDS as a fractional divider in a PLL synthesizer.

fine resolution. Note that any noise generated by the PLL components is degraded at a rate of 20*logN*, where *N* is the division ratio. The division ratio is large in conventional integer-*N* PLLs operating at small step sizes because the step size must equal the comparison frequency at the phase detector. As a result, significant phase noise degradation occurs. Thus, this simple single-loop architecture suffers from mutually exclusive design goals.

Fractional-*N* synthesizers use fractional division ratios to break this coupling between frequency resolution and other characteristics. This allows a higher comparison frequency for a given step size. Fractional ratios are possible by alternating two or more division ratios, for example, *N* and *N+1* and averaging the output frequency over a certain period.

Another way to look at this process is to calculate the number of pulses delivered by such a complex divider for a given time interval. The average division coefficient will be between *N* and *N+1* depending on how many pulses are processed by each divider. The biggest concern associated with this scheme is that the instantaneous frequency at the fractional-*N* divider output is not constant. An abrupt change in the division coefficient leads to a phase discontinuity that produces a voltage spike at the phase detector output. Since the frequency division change occurs periodically with the same rate, it appears as discrete spurs in the synthesizer's output spectrum. Furthermore, these spurs do not follow the integer relationship with respect to the phase detector comparison frequency and can be within the loop filter bandwidth. This situation is shown in ***Figure 3***.

The direct digital synthesizer (DDS) is another effective solution to provide very fine frequency resolution without the standard penalty of the phase detector comparison frequency reduction. The DDS can serve as a fine-resolution, high frequency reference, as shown in ***Figure 4a***, or be employed as a fractional divider, as illustrated in ***Figure 4b***. While a DDS provides excellent frequency resolution, its spurious levels are usually quite high and do not follow the integer relationship. Moreover, the spurs further degrade because of the PLL multiplication mechanism. Although the two schemes in Figure 4 look different, they affect DDS spurs similarly. The ratio between the VCO output



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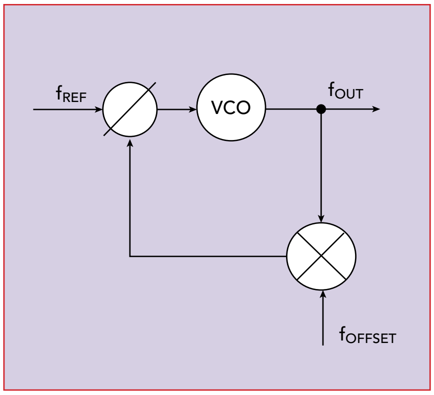

Fig. 5 **Frequency mixing improves PLL performance.**

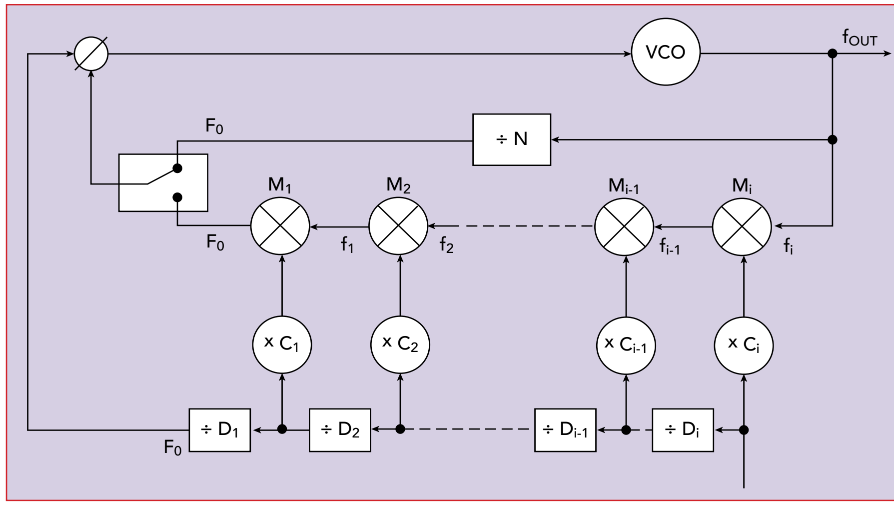

Fig. 6 **Mixer chain in the PLL feedback path.**

and phase detector comparison frequencies in both cases defines the overall loop division coefficient.

The synthesizer's main characteristics can be drastically improved using frequency conversion (mixing) within the synthesizer feedback path, as shown in ***Figure 5***. The idea is to convert the VCO output to a much lower frequency with a mixer and an offset frequency source. In specific scenarios, for example, when the operating frequency range is narrow, it is possible to eliminate the feedback frequency divider. In this case, the loop division coefficient equals one and no phase noise degradation occurs. However, inserting a mixer brings another spur generation mechanism due to the mixer intermodulation products. Unfortunately, these spurs do not follow the integer relationship either. They can also fall within the loop filter bandwidth, meaning the loop filter cannot filter them.

A clever solution is to use a chain of mixers within the PLL feedback path.[3] Individual offset signals can be obtained from a standard high frequency variable reference using dividers and/or multipliers, as depicted on a general block diagram in ***Figure 6***. In this block diagram, mixers M_1 to M_i convert a VCO output signal to the phase detector comparison frequency, F_0, equal to the synthesizer step size. The comparison frequency and mixer LO signals are produced from a common, high-stability and low phase noise reference signal using frequency dividers with frequency division ratios D_1 to D_i and frequency multipliers with multiplication factors C_1 to C_i, respectively.

A phase detector compares the signals at both inputs and generates an error voltage, which slews the frequency of the VCO to a lock frequency given by ***Equation 1***:

$$f = f_i \pm f_{i-1} \pm \ldots \pm f_2 \pm f_1 \pm F_0 \quad (1)$$

After simple manipulations, the result is shown in ***Equation 2***:

$$f = F_0 \left(\begin{array}{l} D_1 D_2 \ldots D_{i-1} D_i C_i \pm \\ D_1 D_2 \ldots D_{i-1} C_{i-1} \pm \ldots \\ \pm D_1 D_2 C_2 \pm D_1 C_1 \pm 1 \end{array} \right) \quad (2)$$

Since all the division and multiplication coefficients are integer num-

bers, we can write f as ***Equation 3***:

$$f = F_0 \times N \quad (3)$$

Where $N = (D_1 D_2 ... D_{i-1} D_1 C_i \pm D_1 D_2 ... D_{i-1} C_{i-1} \pm ... \pm D_1 D_2 C_2 \pm D_1 C_1 \pm 1)$ is an integer.

A desired output frequency can be chosen using an additional coarse-tuning divider with a programmable division ratio, N, inserted into the synthesizer loop. The divider loop provides a simple and reliable mechanism to pre-tune the VCO to the correct frequency. Then, the switch turns off the divider feedback path and connects the mixer chain to ensure no phase noise degradation occurs. An essential feature of this method is that the mixers do not generate undesired products within the synthesizer loop bandwidth. The output of every mixer includes many products, including the fundamentals of the mixer's RF and LO signals and their harmonics, along with the sums and differences of the RF and LO and their harmonics. This relationship is given by ***Equation 4***:

$$f_{MIX} = \pm m f_{RF} \pm n f_{LO} \quad (4)$$

which can be written for the mixer, M_i, as ***Equation 5***:

$$f_{MIX\,i} = \pm m F_0 N \pm n F_0 D_1 D_2 \ldots D_{i-1} D_i C_i \quad (5)$$

Assuming that all the coefficients are integers, the mixer products are given by ***Equation 6***:

$$f_{MIX\,i} = k F_0 \quad (6)$$

Where k is an integer number. Similarly, it can be shown that all harmonic and intermodulation products generated by the mixer chain are multiples of the phase detector frequency, F_0, which a PLL loop filter can easily reject.

Moreover, the residual noise of the PLL can be further reduced by inserting a frequency multiplier instead of a divider into the feedback path. This architecture is depicted in the functional block diagram of ***Figure 7***. Putting the multiplier within a PLL suppresses phase noise at a 20*logN* rate, operating exactly the opposite way to a frequency divider.

CONSTRUCTING A PLL

In general, there can be three basic scenarios for constructing a PLL. These are as follows:

- $N>1$: A frequency divider within the PLL loop (residual phase noise is degraded at 20*logN*)
- $N=1$: No division within the PLL loop (residual phase noise is not degraded)
- $N<1$: A frequency multiplier with-

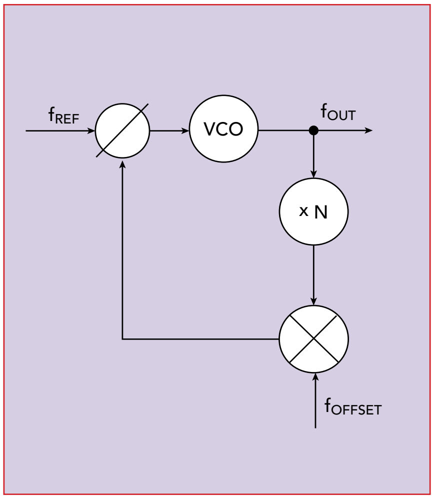

Fig. 7 **Inserting a multiplier into the PLL feedback path.**

in the PLL loop (residual phase noise is improved at 20*logN*).

Thus, the proposed scheme allows minimal phase noise degradation beyond the fundamental 20*logN* rule. This keeps the integer relationship and phase-locked loops' excellent spur rejection capabilities. Do we still need to break the integer relationship? If a design requires an infinitely small size, then yes, the integer relationship must be broken by introducing fractional-*N* or DDS techniques. However, in this case, it should be done within a relatively small band to fill in the gaps in the frequency plan. This certainly helps optimize the architecture and efficiently use other techniques, such as frequency up-conversion followed by frequency division, to minimize any additional spur intervention. Note that the phase noise of the available reference source still limits the synthesizer phase noise. Thus, having a reference with the lowest possible noise is essential in any frequency synthesizer architecture.

SUMMARY

The principles presented in this article can be highlighted to aid in modern PLL synthesizer design:

- Use integer-*N* techniques to employ PLL filtering capabilities for efficient spur suppression
- Use multiple conversions within the loop to minimize phase noise and spur degradation while keeping integer relationships for all phase detector and mixer products
- Use frequency multiplication within the loop for additional phase detector noise suppression
- Break the integer relationship at a single point with the smallest possible bandwidth, together with additional spur suppression techniques.

These principles are used in the Rubidium™ signal generator from Anritsu Company. This device demonstrates phase noise better than -140 dBc/Hz at 10 GHz output and 10 kHz offset and excellent spurious performance.[4,5] Further improvements are possible using better reference sources such as sapphire-loaded cavity oscillators or optoelectronic methods. ■

References

1. A. Chenakin, "Frequency Synthesis: Current Status and Future Projections," *Microwave Journal*, Vol. 60, No. 4, April 2017, pp. 22–36.
2. A. Chenakin, *Frequency Synthesizers: Concept to Product*, Artech House, 2010.
3. A. Chenakin, "Low Phase Noise PLL Synthesizer," U.S. Patent No. 7,701,299, April 2010.
4. A. Chenakin, "Frequency Synthesizers Having Low Phase Noise," U.S. Patent No. 11,817,871, November 2023.
5. A. Chenakin, S. Ojha and S. Phadnis, "Rubidium™ Signal Generators Redefine Industry Standards for Spectral Purity and Stability," *Microwave Journal*, Vol. 64, No. 11, November 2021, pp. 40–42.

How Hot Do Those Isolation Resistors Get?

Steve Huettner, Chris Hermanson, Andrew Gooden, Jonathan Lamb, Justin Sayres and Ben Cannon
Nuvotronics, Durham, N.C.

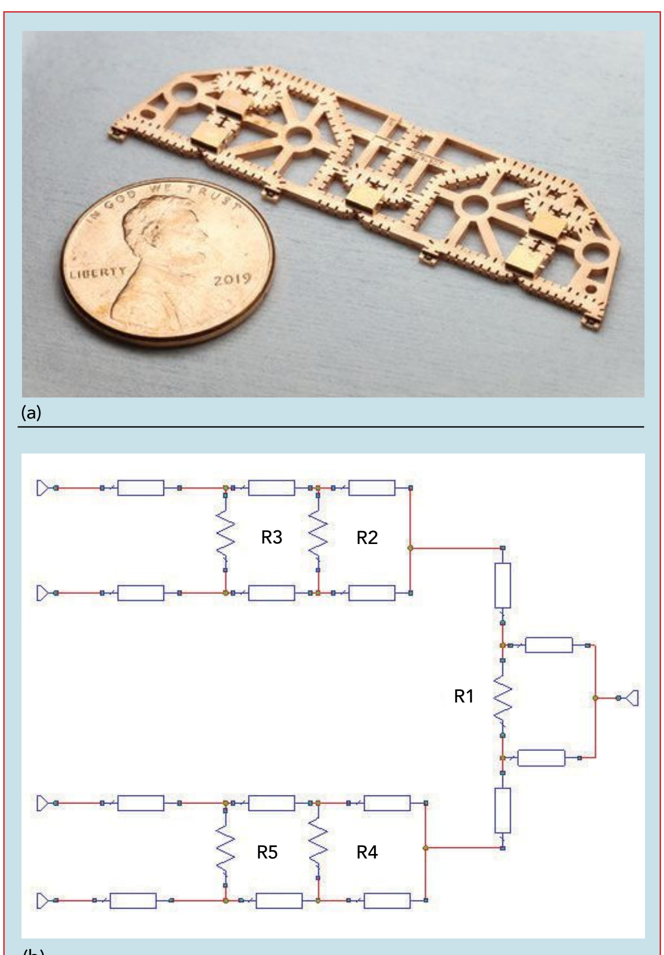

Fig. 1 (a) Nuvotronics combiner. (b) Simplified combiner schematic.

This article describes how isolation resistor temperatures are affected by phase imbalances in a real-world power combiner, followed by the results of power testing a modified back-to-back (B2B) combiner that stresses the resistors without causing a failure. A photo of a Nuvotronics 80 W, 6 to 18 GHz, four-way air-coax power combiner is shown in ***Figure 1a***. This network serves as the foundation for the examples presented in this article. As shown in the simplified schematic of ***Figure 1b***, the combiner is a cascaded Wilkinson design featuring five 100 Ohm isolation resistors that provide a minimum of 13 dB of isolation between inputs across the entire band. It is rated for temperatures up to 85°C and exhibits a loss of just 0.34 dB at the center frequency. This combiner uses the PolyStrata® manufacturing process to create its air-coaxial transmission lines.

In a Wilkinson power combiner, removing heat from isolation resistors can be a challenge. Typically, improving the thermal path adds capacitance to the structure, which can detune the RF performance. This is especially true in air-coax structures. In the 6 to 18 GHz combiner, the thermal resistance of the isolation resistors was evaluated to be 28°C/W using ANSYS software. Future designs have identified a path toward 3°C/W and these designs may become available in 2025.

The isolation resistors that are used in the PolyStrata combiners are CVD diamond thin film products from Smiths.[1] These resistors are typically configured in a 0402 package and rated to 20 W dissipation when attached to a suitable heat sink. According to the manufacturer, the resistors are rated to full power at a film temperature of up to 125°C, but they must be derated linearly to 0 percent power at 150°C. This derating curve is shown in ***Figure 2***. The temperature and power capability of the isolation resistors limit the allowable out-of-balance conditions

when a combiner is used in a solid-state power amplifier (SSPA).

HFSS/MWO "HYBRID" COMBINER MODEL

The 3D HFSS model for the five-port, four-way power combiner was reconfigured to remove the resistors. This was done to model the power combiner as closely as possible to the actual configuration while allowing access to resistors to evaluate their power dissipation under different configurations. RF ports were added to the resistor sites, resulting in a 15-port network. The HFSS model is illustrated in ***Figure 3a***, where Ports 6 through 15 are not depicted in the overall model. ***Figure 3b*** is an example resistor, showing where Ports 6 and 7 have replaced the resistor film.

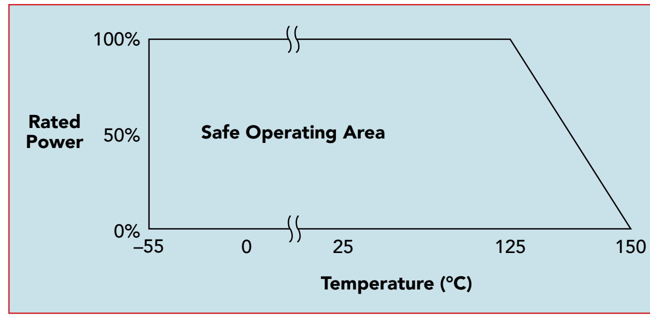

Fig. 2 **Safe operating area for diamond thin film resistors.**

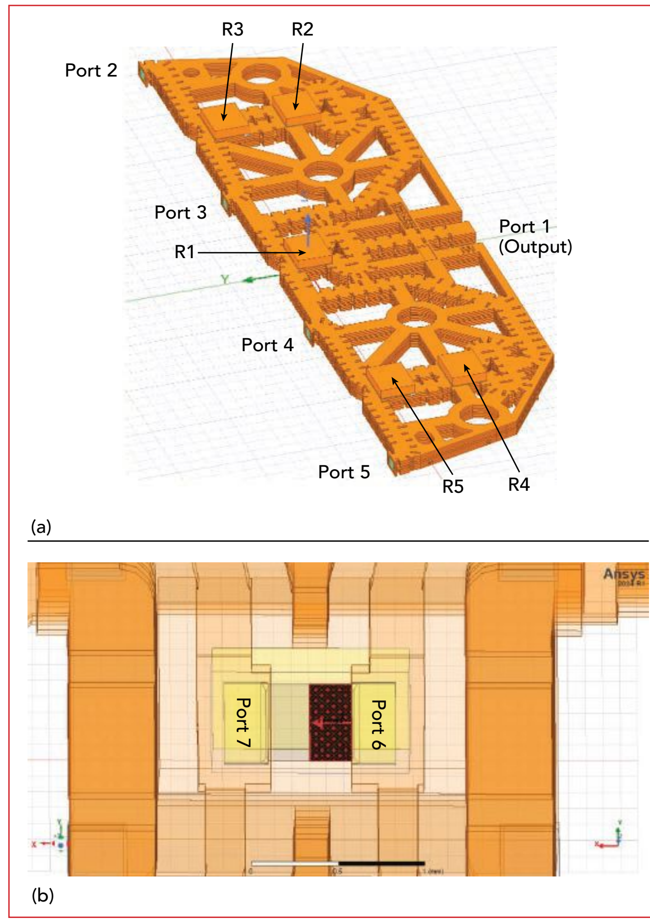

Fig. 3 **(a) 3D circuit model showing Ports 1 to 5. (b) Port definition at R1 resistor interface.**

Using Microwave Office (MWO), resistors were reintroduced into the network in a "hybrid" HFSS/MWO model. MWO enables the convenience of harmonic balance for quickly assessing power performance. An MWO schematic of the rebuilt combiner is shown in ***Figure 4a***. The block diagram in ***Figure 4b*** maps the positions of the five resistors within the network. For example, resistor R1 is closest to the common port or the output of the combiner.

The 6 to 18 GHz power combiner can use available 20 W GaN power amplifiers to achieve a 75 W SSPA power stage. A very simple linear model of such a power stage is shown in ***Figure 5***. In this model, the A1, A2, A3 and A4 amplifiers are fed from a lossless four-way divider, providing 20 dB of linear gain to feed power into the hybrid combiner model. With 29 dBm (800 mW) of input power to the network, the output power is predicted to be approximately 74 W at 10 GHz. This is slightly less than the available 80 W, as the combiner network has an insertion loss of 0.34 dB. Lossless


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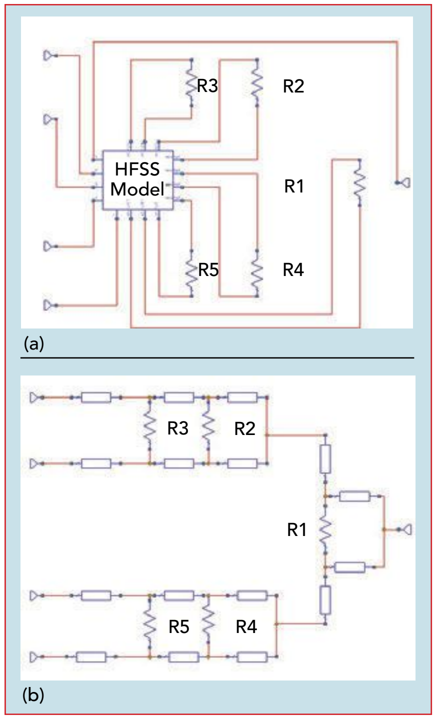

Fig. 4 **(a) HFSS model with five external resistors. (b) Power combiner block diagram.**

phase shifter elements, Φ1, Φ2, Φ3 and Φ4, are in the model to vary transmission phases between amplifiers, as they will not be ideally matched in real-world conditions. In this study, amplitude imbalances are neglected because they create less mismatch.

PHASE MISMATCH EXAMPLE 1

In this example, amplifiers A1 and A2, as well as amplifiers A3 and A4, are assumed to be phase-matched pairs. When there is a phase difference between these pairs, all the mismatched power dissipates in a single resistor, R1, as shown in the schematic of Figure 4b. For this example, the phase difference between the pairs was set to 0 degrees for the in-phase case and then 20 degrees for the out-of-phase case.

The output power drop resulting from these phase conditions is shown in ***Figure 6***. When the phases are aligned and the phase difference between the amplifiers is 0 degrees, the output power is 74.2 W at the band center of 12 GHz. When the amplifier pairs are out of phase by 20 degrees, the output power decreases to 72 W.

Figure 7 illustrates the power dissipated in the R1 resistor during CW operation. For the in-phase condition, no power is dissi-

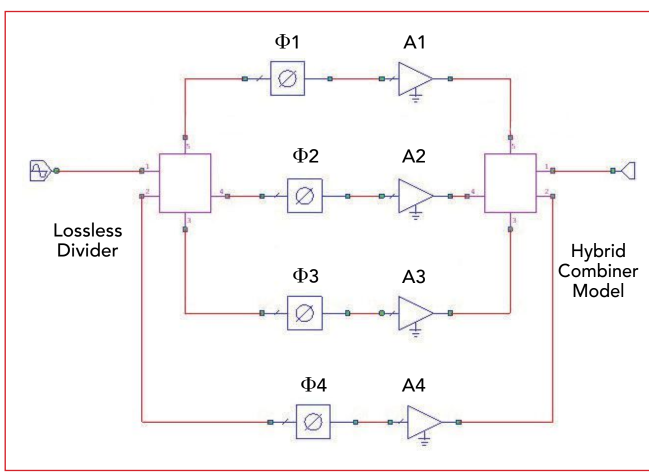

Fig. 5 **75 W power stage model.**

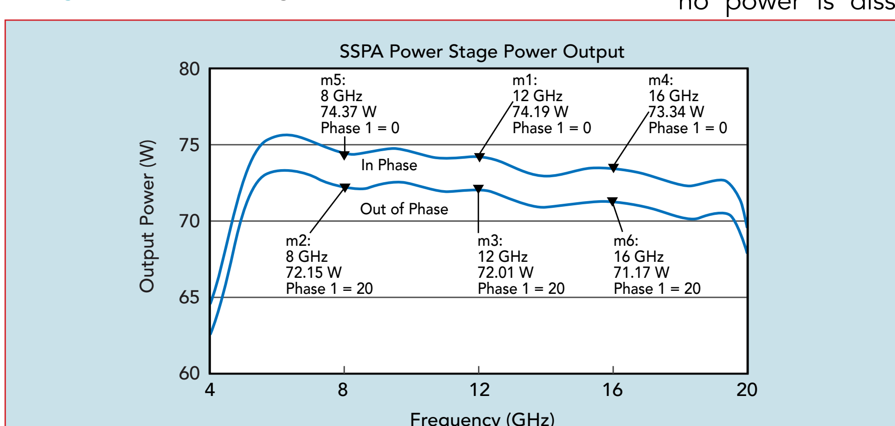

Fig. 6 **Example 1 power output response resulting from phase mismatches.**

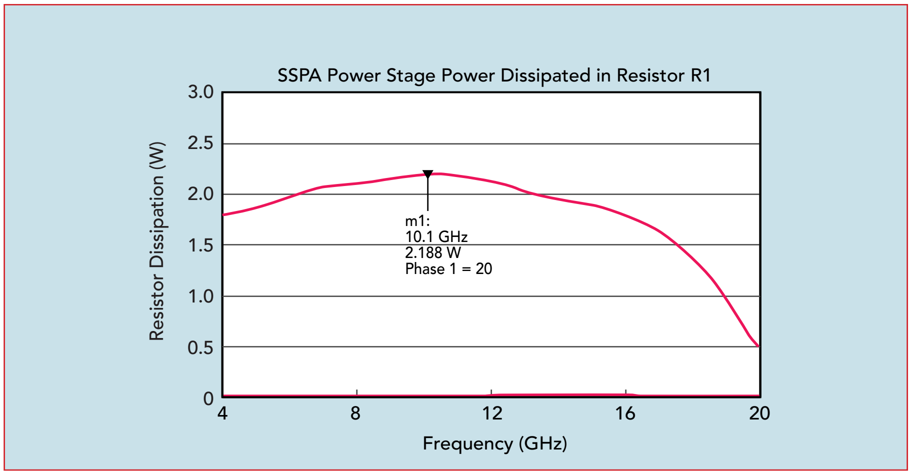

Fig. 7 R1 power dissipation for the Example 1 phase mismatch conditions.

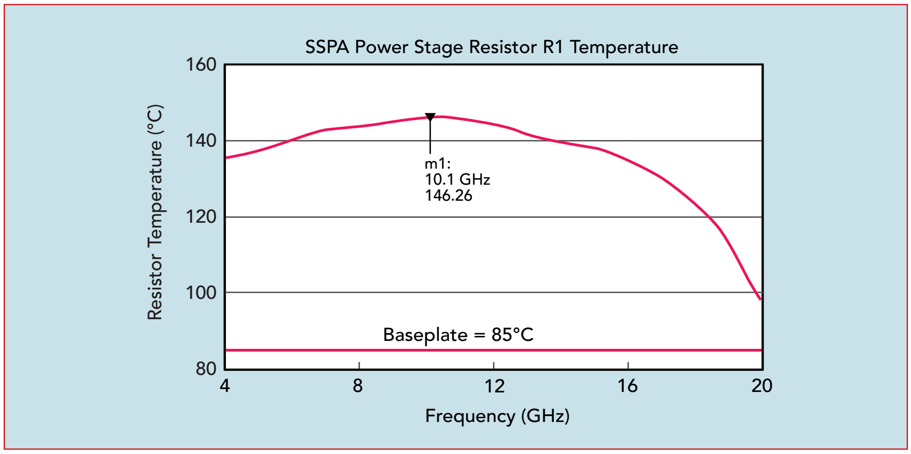

Fig. 8 R1 film temperature profile caused by a 20-degree phase mismatch.

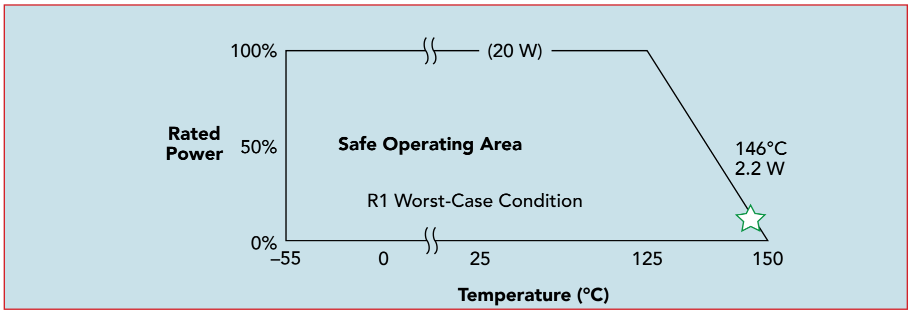

Fig. 9 The worst-case condition for Example 1.

pated in R1. However, in the case where the amplifiers are 20 degrees out of phase, R1 would dissipate 2.2 W at the worst-case value of 10.1 GHz over the 4 to 20 GHz frequency band.

Using the power dissipation response and the 28°C/W resistor thermal resistance of the resistive film calculated earlier, the temperature increase in the isolation resistor in the model can be calculated. Assuming an 85°C baseplate temperature, the 20-degree phase difference creates the thermal profile shown in ***Figure 8***. The maximum temperature increase is 146°C at 10.1 GHz.

Figure 9 superimposes this worst-case temperature increase for R1 onto the derating response shown in Figure 2. While the temperature/power point remains within the safe operating area for the resistor, there is not much room for error. This means the R1 resistor cannot be stressed much further while maintaining reliable operation.

PHASE MISMATCH EXAMPLE 2

In this second example, amplifiers A1 and A3 were paired together, as were amplifiers A2 and A4. In this case, the phase difference was set to 30 degrees, which is 50 percent higher than in Example 1. This results in a more severe power degradation scenario, as shown in ***Figure 10***. Now, the output power for the out-of-phase case decreases by approximately 5 W. Dissipating 5 W in a single resistor at an 85°C baseplate temperature in this combiner would result in failure. Fortunately, in this example, the dissipated power is spread across isolation resistors R2, R3, R4 and R5 as shown in the schematic of Figure 4b.

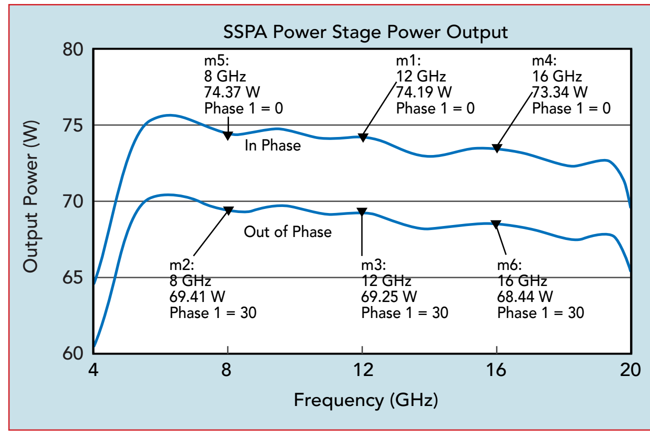

Fig. 10 Power output profile from Example 2 phase mismatch.

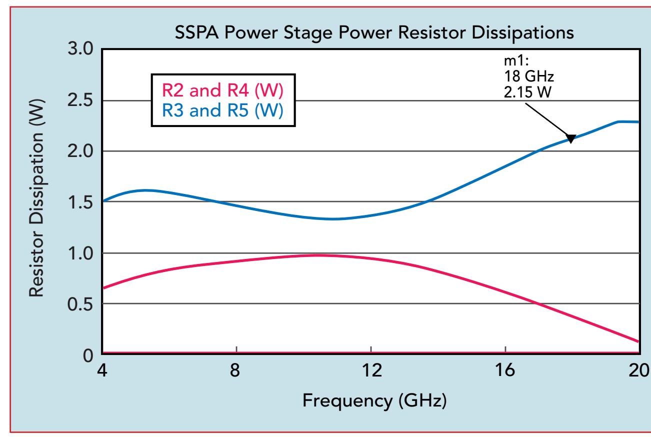

Fig. 11 Power dissipated in resistors R2, R3, R4 and R5 from Example 2 phase mismatch.

The power dissipation profiles for the four "hot" resistors are shown in ***Figure 11***. The power dissipation in these resistors is not equal. The worst-case dissipation across the 6 to 18 GHz operating band of the four-way combiner occurs at 18 GHz, where R3 and R5 dissipate 2.15 W. However, Example 1 has shown that this is a safe level of dissipation at an 85°C baseplate temperature.

These results suggest several key conclusions. First, phase mismatches should be minimized. This is especially true for phase mismatches that affect R1. This is most critical because R1 does not share its thermal load with a second resistor, unlike the R2/R3 and R3/R4 resistor pairs.

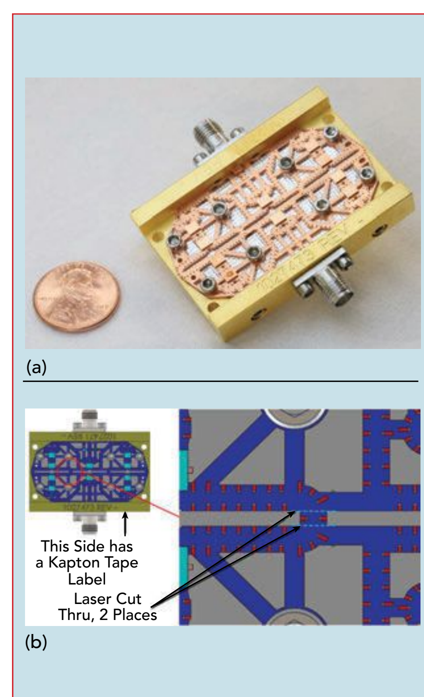

Fig. 12 (a) B2B combiner with cut path. (b) Laser-cut circuit diagram to replicate failed amplifier.

EXPERIMENTAL VERIFICATION OF RESISTOR SURVIVAL

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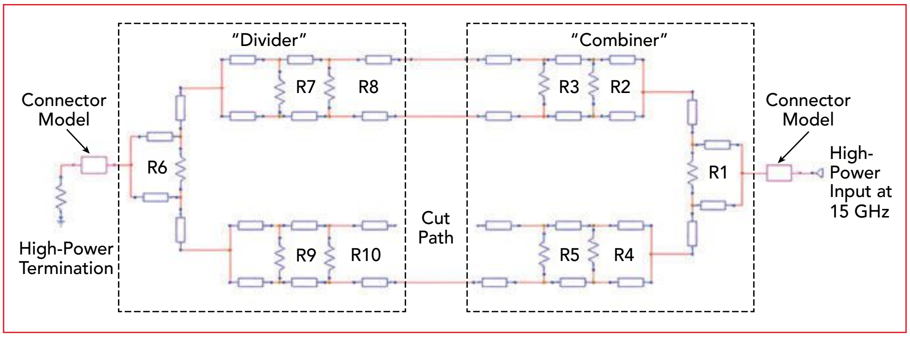

Fig. 13 **Schematic of B2B combiner with cut path.**

test the resistor temperature model could be a costly and complicated endeavor. Additionally, measuring resistor temperatures inside a combiner would require removing the isolation lids, which would negatively impact RF performance. As a result, a simpler, indirect method was developed to stress the combiner resistors to the edge of their safe operating area and demonstrate survivability.

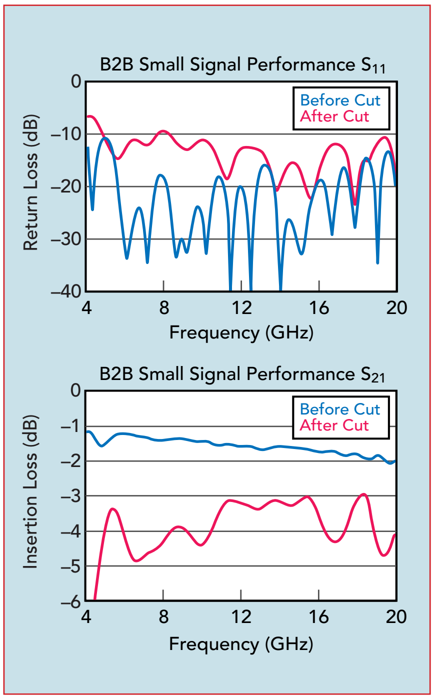

Fig. 14 **B2B S_{11} (top) and S_{21} (bottom) combiner performance before and after cutting the path.**

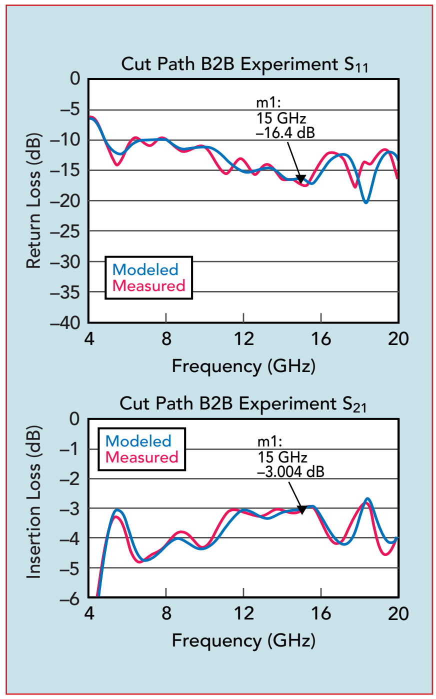

Fig. 15 **Small-signal modeled and measured S_{11} (top) and S_{21} (bottom).**

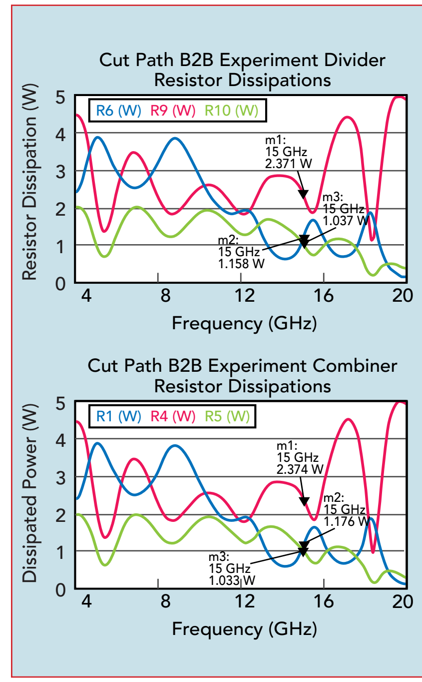

Fig. 16 **Predicted resistor dissipations in cut B2B combiner for divider resistors (top) and combiner resistors (bottom).**

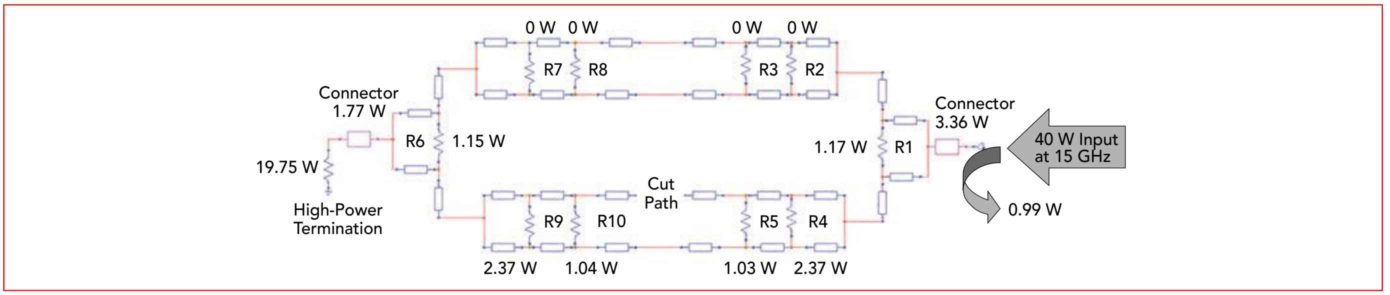

Fig. 17 **Predicted cut B2B combiner power dissipation.**

This method involved modifying a B2B combiner to simulate a graceful degradation of a failed amplifier. The B2B combiner is illustrated in ***Figure 12a***. The diagram in ***Figure 12b*** illustrates an RF path that has been laser-cut to create an open circuit, simulating a failed amplifier.

A simplified schematic of the B2B network with the circuit cut is shown in ***Figure 13***, which identifies the resistor nomenclature. The left side of the structure is designated the "divider," while the right side is the "combiner" function. To measure the heating effects, a high-power CW signal was injected into the combiner input port on the right side of the diagram. RF connectors on the evaluation board introduce loss, but this is accounted for using a connector model with loss proportional to the square root of the frequency.

Two-port S-parameters of the B2B network were evaluated before and after the modification, as shown in ***Figure 14***. Disconnecting one path reduced return loss and increased insertion loss as expected. Much of the increased loss is due to power being dissipated in the isolation resistors.

Figure 15 compares the small-signal response of the cut B2B network with that of the hybrid HFSS/MWO model. There is a close correlation between the modeled and measured S_{11} and S_{21} magnitudes. This serves to illustrate the accuracy of the hybrid modeling approach.

Resistor dissipation is strongly dependent on frequency. For this experiment, a 40 W signal was injected at 15 GHz and the HFSS/MWO model was used to predict resistor dissipation. ***Figure 16*** shows the modeled results, with R4 and R9 dissipating 2.37 W at 15 GHz. This is more than double the dissipation seen in R1, R5, Talent Microwave

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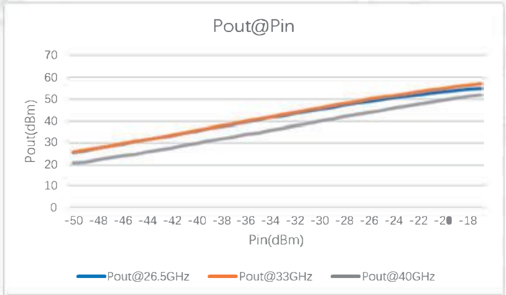

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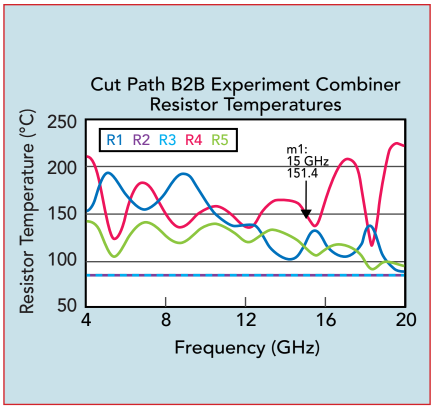
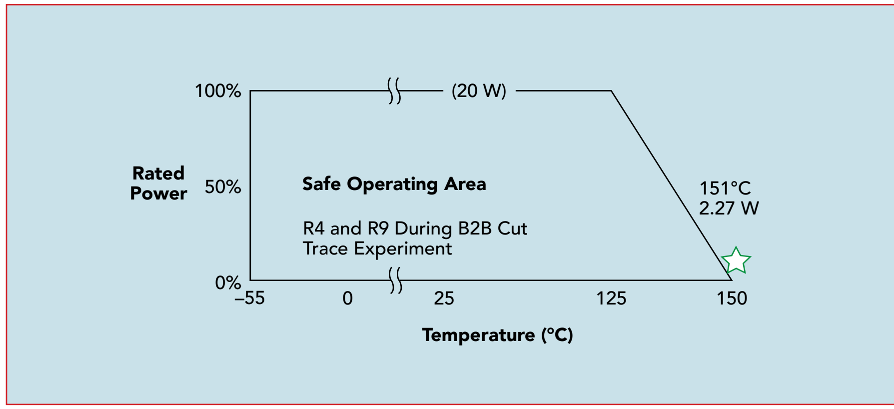


▲ Fig. 18 **Predicted combiner resistor temperatures.**



▲ Fig. 19 **R4 and R9 results are just outside the safe operating area.**

R6 and R10. Resistors R2, R3, R7 and R8 are not in line with the cut path and therefore do not dissipate any power.

A summary of the modeled power dissipation during the cut B2B experiment is shown in ***Figure 17***. The total power dissipation for the resistors is 9.13 W, while the connectors dissipate 5.13 W. Accounting for a reflected power of 0.99 W, since S_{11} is not perfectly matched and 19.75 W power output, this means 5 W is dissipated in the PolyStrata coax transmission lines. These lines can easily handle this thermal load.

The network was heated to a baseplate temperature of 70°C and subjected to increasing power levels at 15 GHz. The resulting resistor temperatures, subjected to an input power of 40 W CW to the cut path B2B combiner for 30 minutes, are shown in ***Figure 18***. R4 in the combiner and R9 in the divider sections dissipate an equal amount of power and these two resistors show a worst-case temperature of 151°C in response to the 40 W input power.

Performing the same analysis as earlier, ***Figure 19*** plots the R4 and R9 temperature and power conditions against the safe operating area. At 150°C, the resistor is rated at zero power, so the cut B2B operating condition of 151°C is outside the safe operating range of the resistor. After the power exposure, the part was re-evaluated and no change in performance was observed. Although it did not fail, continued operation at this point would constitute a reliability concern.

SUMMARY

This article examines the impact of phase imbalances on power dissipation in Wilkinson power divider and combiner architectures. Using a Nuvotronics PolyStrata combiner as an example, a straightforward, inexpensive method is presented for predicting the temperature increase of an isolation resistor using a physical model of a power combiner. The article also presents the modeled results when the PolyStrata combiner/divider is subjected to various input powers and phase imbalance relationships. Rather than an exercise in modeling and matching modeled results to actual results, the experiments described in the article highlight constraints and potential challenges that arise when isolation resistors are stressed to the limit of their safe operating range.

References

1. "Diamond RF Resistives® Family," *Smiths Interconnect*, pp 69–70.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Key Considerations for Space-Grade RF Coaxial Interconnects

Peter McNeil
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The past 15 years have seen an upheaval in space technology trends. Now, there is a mix of legacy or "Old Space" applications from organizations such as NASA and ESA with incredibly stringent requirements and low volume expectations and "New Space" applications with a more commercial and mass market approach from emerging space technology companies.[1] There is a multitude of small research, science and more recently founded national space organizations undertaking a diverse range of missions at an incredible pace.[2] What is true for all these applications is that RF, microwave and mmWave technologies are still essential for communications and sensing missions. These technologies enable important features for spacecraft systems and payloads. Higher frequency and higher-density applications mean more RF systems with even smaller footprints and more interconnections. Coaxial cables, connectors and assemblies are necessary for connecting space systems and payload components. However, they may also introduce a host of failure modes to some of the most sensitive space equipment. This makes ensuring that coaxial interconnections meet space standards for performance and reliability a high priority for designers and systems. These satellite platforms and payloads have many different form factors, which create distinct challenges for each application. ***Figure 1a*** shows the 1U PhoneSat spacecraft. ***Figure 1b*** is the 12U CAPSTONE spacecraft. ***Figure 1c*** is the 3U CLICK spacecraft and ***Figure 1d*** is the 6U PTD-3 spacecraft. These spacecrafts have all flown in orbit and are classified as CubeSats, but the size and footprint mean that interconnection considerations and requirements can differ substantially.

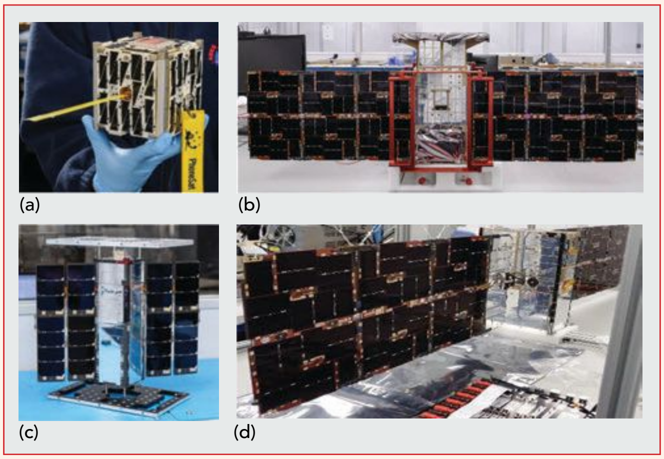

Fig. 1 **(a) 1U PhoneSat spacecraft. (b) 12U CAPSTONE spacecraft. (c) 3U CLICK spacecraft. (d) 6U PTD-3 spacecraft.** ***Source:*** **NASA and Terrain Orbital.[2]**

WHAT IS SPACE-GRADE?

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- Deep space exploration
- Space stations
- Satellites in various orbits
- Launch vehicles
- Rover vehicles, along with other sampling and experimental mobile platforms
- Lunar base and exploration vehicles and habitats
- Mars missions and habitats.

For legacy applications, classifying components as space-grade has historically meant that these components meet extremely rigorous materials, sourcing, processing, quality control, verification and manufacturing requirements. These requirements are typically determined by the space agencies or governments of countries that actively operate space programs. These efforts have created a large body of knowledge addressing how various materials, material combinations and fabrica-

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tion methods operate in space environments and microgravity. While many of the newer space programs and applications do not include the same highly exacting standards and requirements as legacy space programs, the knowledge gained from these programs is still instrumental in determining what works best in space.

New Space programs generally do not operate with the same expectations as legacy space applications. Missions are shorter and the purpose of the mission may not be as critical. This may relax quality standards and widen the viable material selection and fabrication approaches for these missions. This approach will generally reduce the cost of most components since the rigorous standards of critical space programs lead to higher costs, even at volume. With New Space programs able to relax some quality requirements and standards and increase volumes, systems can use traditional space-grade components like coaxial assemblies and connectors. The advantage of this approach is that higher volumes and relaxed quality control requirements translate to lower costs.

Regardless of the mission, there are intrinsic hazards in space and steps that must be taken to ensure a component fulfills the mission requirements. The first consideration is whether the component survives the shock, vibration and acceleration stresses associated with launch. Next, the materials and construction must handle space's vacuum and microgravity conditions. Almost all materials release gases when in low-pressure environments. The rate of gas release and the composition of these released gases significantly impact the viability of a material in space. An important consideration is how long before material outgassing begins to affect the component or the operation of other components.

Although the ambient temperature in a vacuum is extremely low, there are several ways that an RF component may be heated. These include solar radiation or waste heat from other space platform or payload components. As a result, space-grade components must operate reliably and survive over wide temperature variations and repeated cycling over these temperature ranges. Temperature fluctuations are one of the significant causes of failure for many components since thermal cycling causes dimensional changes in the component materials and structure. For space-based systems, radiational cooling may be the only method of removing heat. This cooling method is slower and less effective than conduction or convection at removing heat, raising concerns about how long a component experiences extreme temperatures.

One of the most significant concerns for space survivability is the ability of a component or system to withstand cosmic radiation and solar weather, often referred to as "space weather." This space weather can consist of storms of high-energy particles, wideband electromagnetic (EM) radiation and intense electric/magnetic field phenomena. One of the main concerns with EM radiation is high-energy X-ray and gamma-ray radiation penetrating shielding and reacting with internal system components. Generally, this is a more significant concern for active electronic components that use semiconductors and integrated circuits. This radiation, at high enough levels, can trigger internal faults and may destroy active devices if these devices are not adequately radiation hardened. This concern extends beyond active devices as high-energy EM radiation can degrade and damage passive RF component materials and structures.

The orbit's distance from the Earth's surface heavily influences the actual space environment. Most legacy space missions are in outer, lunar, highly elliptical orbit (HEO) or geosynchronous orbit (GEO). These orbits are relatively far away from the Earth's surface. Space platforms and payloads in these orbits are farther outside the protection of Earth's magnetosphere, making these missions more susceptible to space weather.

Many of the newer space missions are in medium Earth orbit (MEO) and low Earth orbit (LEO),

which are much closer to the Earth than outer orbit or GEO missions. This closer proximity to Earth results in greater protection from some space weather. However, these vehicles must travel much faster and need greater positioning precision to maintain orbit. The most cluttered orbit is LEO, which has a high concentration of active satellites and space debris. This means a higher likelihood of a collision that could damage a LEO mission than GEO and outer orbit missions. ***Figure 2*** shows the range of distances for some of the orbit designations.

WHAT IT TAKES TO SUCCEED IN SPACE

The orbital slot, expected mission lifetime, performance, mission control standards and regional regulatory agencies largely determine mission requirements. The performance and organizational standards are generally demanding with NASA, ESA and other national space agencies. There are many small and short-lived educational, scientific exploration and government-sponsored missions. These include CubeSats and small-satellite (SmallSat) projects. These missions often involve collaborations among many institutions with various requirements and usually limited budgets. New Space companies frequently provide another wrinkle. These companies are often commercial enterprises focusing on introducing new services previously unavailable to consumer, non-government and government users. These New Space companies typically have internal requirements and quality control programs that may not be transparent to the public. Their procurement models tend toward screening many commercial products to determine what will support their missions. This paradigm differs from the traditional legacy approach of ordering custom-designed parts from approved vendors.

Some of the essential requirements to consider for products going into space:

- Footprint and weight
- Physical ruggedness
- Temperature range
- Cosmic radiation and space weather
- Flashover
- Outgassing
- Residual magnetism
- Materials and traceability
- Manufacturing environment
- Quality (IPC Standards Class 3)
- Electrical characteristics.

A satellite platform or payload may have size restrictions that can influence the choice of technology and architecture. The miniaturization resulting from higher microwave and mmWave frequencies is advantageous for footprint- and weight-constrained applications. These size and regulated-spectrum considerations explain why microwave and mmWave frequencies are attractive for terrestrial-to-space and space-to-space communications. However, with smaller electrical components and elements, care must be taken in the design and manufacturing process to ensure each element can withstand the shock, vibration and acceleration forces associated with launch and survivability.

Operating and storage temperature ranges also factor into part suitability for space applications. Depending on the orbit and exposure of the electrical parts, even the

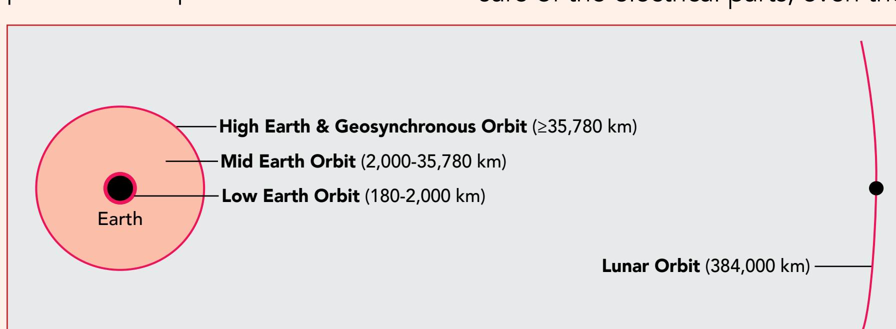

Fig. 2 Orbit designations. *Source:* NASA illustration by Robert Simmon.[3]


From Ground
to Deep Space
A spectrum of solutions
for RF & Microwave
Commercial off-the-shelf
rad tolerant parts
Space-grade RF/MW PCBs
Space-qualified RF components
and integrated solutions
Switching solutions for space
High voltage connectors and
cable assemblies for space
High performance microwave
interconnects and cable assemblies
for space
IMS
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-550°C to 125°C military temperature range may not be adequate. A more acceptable temperature range for space-grade components is -65°C to 150°C and some applications exceed even this range. The materials and construction methods must be carefully selected to operate reliably over such a wide range. Moreover, burn-in or other methods of operating temperature stabilization may need to be considered. These considerations may include matching the coefficient of thermal expansion of various materials and construction stack-ups to ensure operating requirements can be met.

Silver and gold plating over copper/beryllium copper is common for space-grade components due to the superior electrical conductivity of silver and the reduced reactivity of gold. These metallic platings must conform to stringent quality requirements to ensure reliability and effectiveness, often with industry standard methods, quality testing and contact plating thickness expectations. Stainless steel parts must frequently be passivated for corrosion resistance and made from non-magnetic compositions.

A flashover is an unintended electrical discharge that occurs across an insulator. This phenomenon can occur in enclosed spaces in electronic components, such as coaxial cable assemblies with air-gaps and minimal dielectrics. The most common cause of flashover is low-pressure arcing. Avoiding this condition requires careful part selection and system design to prevent the conditions that cause arcing or combustion to occur. Materials and construction methods for space are often governed by outgassing standards such as ASTM E-595. This standard outlines test methods for measuring total mass loss (TML) and collected volatile condensable materials (CVCM) percentages. A low TML and CVCM percentage is often desirable for space applications because it means the build-up of particles and debris, along with outgassing, is low. If these factors are not adequately considered, the result could be performance changes or destructive events such as flashover. To minimize this possibility, many space applications require facility and production process quality control methods to limit component exposure to particles in the manufacturing environment.

IPC-A-620 is an important standard, particularly for coaxial and other cable and wire harness assemblies. This standard addresses practices and requirements for manufacturing these electrical components. IPC-A-620 is generally considered the gold standard for workmanship for such components. Class 3 of the specification is the highest level and most likely to coincide with space criteria. Other factors this standard considers are the materials used and the traceability of the component material composition. Some space applications require approved vendor lists and materials, while others require only selected traceability and compatibility levels. Manufacturers often consider Ethylene tetrafluoroethylene (ETFE) a suitable jacket material for space-grade coaxial cable. This material exhibits a high melting temperature, good chemical resistance, superior electrical performance and resistance to high-energy radiation. High-energy radiation resistance is a key consideration for coaxial assemblies as some materials will degrade in the presence of high-energy radiation, which can lead to interconnect failure.

ELECTRICAL CHARACTERISTICS

Like most electrical components, coaxial cable assemblies, connectors and cables are specified for performance under nominal and operational conditions. With coaxial components for space applications, the operational conditions are usually more rigorous than those of military or industrial applications. This is why space-grade or components intended for space applications will often have more detailed datasheets with more complete tables and plots depicting the behavior of the components over broader operating parameters than typical components.

Some key electrical characteristics to consider for space applications:

- Phase stability

- Phase velocity
- Shielding effectiveness
- Insertion loss.

Phase stability over physical and environmental conditions is especially critical for coaxial assemblies in space. While this parameter is typically only a consideration for test and measurement applications, the wide operating temperature range and other factors make phase stability a critical requirement for many space applications. The phase velocity through a cable or an assembly can directly influence signal delay and timing in a system and these characteristics are critical for space networks. Because of the radiation environment in space, the potential for high-energy particles and external electrical interference, the need for electrical shielding is much greater than in terrestrial applications. RF shielding measures the amount of external signal energy penetrating a component over the operating frequency range. RF shielding effectiveness for space applications must often be 100 dB or more.

Launch costs are related to mass, so the restrictions on RF and DC power budgets are strict in space applications. This places a premium on low loss, high-efficiency components to minimize the power source's size, weight, DC power consumption and RF transmit power. Low loss space-grade coaxial interconnections help minimize the transmit power for the mission, along with component heating issues.

WORKMANSHIP

While the performance of the coaxial cables, connectors and other devices is critically important for space applications, manufacturing techniques and workmanship cannot be overlooked. If devices are not properly manufactured, they may affect the performance and longevity of the mission. NASA has released workmanship standards for space-based components with examples of unacceptable manufacturing processes for coaxial cables and connectors in space applications.[4]

Figure 3a shows an unacceptable solder joint as indicated by the arrow. In this case, the solder termination between the connector and the rigid/semi-rigid cable sheath does not exhibit a thoroughly wetted, concave, smooth and continuous fillet extending entirely around the termination periphery. ***Figure 3b*** shows an unacceptable center contact assembly as defined in NASA-STD-8739.4 [19.6.2.f.3]. As can be seen from the diagram, the center contact location/orientation does not meet the requirements for proper mating.

Figure 3c shows a cable assembly assembled incorrectly per the manufacturing or engineering documentation. As the red arrows indicate, the connector body has been excessively crimped in manufacturing by the center pin crimp tool, crushing the dielectric material. ***Figure 3d*** shows a cable with an unacceptable bend radius. In this case, the cable has been bent below the minimum recommended radius, resulting in ripples and stretching the cable sheath. This may cause a cold-flow of the dielectric, resulting in increased loss and/or shorting of the cable assembly.

SPACE-GRADE COAXIAL INTERCONNECT IS MORE ACCESSIBLE THAN EVER

In the recent past, procuring space-grade coaxial cable assemblies and connectors required contract negotiations with a coaxial cable assembly and connector manufacturer. This process could be time-consuming, with procurement lead time and qualification often taking years. While long, this timescale was acceptable for legacy space applications. However, this is no longer sufficient for New Space or agile space programs. Many New Space applications depend on very large LEO constellations. Multiple satellites are included in each launch vehicle, and the period between launches has become very

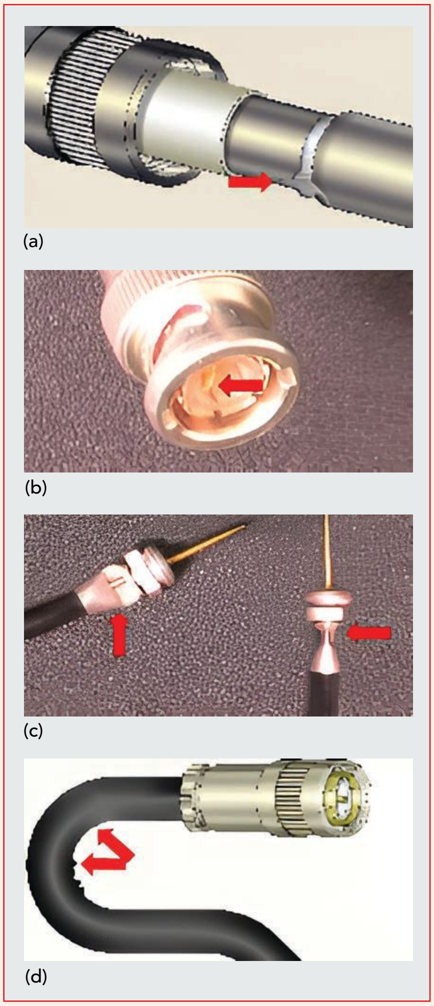

Fig. 3 **(a) Unacceptable solder joint. (b) Improper center contact assembly. (c) Improper connector assembly. (d) Improper cable bend radius.**

short. The performance of these orbiting satellites will drive upgrades and changes for subsequent satellites and launches. This process of experimentation and qualification on the fly puts enormous pressure on development and qualification timescales. The results from this process also contribute to the relaxation of the more stringent requirements that characterize legacy space applications.

The result is a growing demand for coaxial interconnects and other space-grade components that can be ordered at the pace of e-commerce. Having more standardized coaxial interconnects that meet space-grade standards means that the prices of these coaxial cable assemblies and connectors have the economy of scale benefit and the high cost of dedicated contracts does not burden them. These coaxial interconnect components can also be purchased as needed and with very short shipping times, even same-day in some cases. This accessibility enables engineers and scientists developing space platforms and technologies to iterate rapidly without the extended lead times associated with typical contract manufacturing for space-grade components.

CONCLUSION

Advances and increased investment in space technology are enabling the rapid development of the space segment. More commercial enterprises, newly-formed space agencies and scientific organizations are joining the legacy large space agencies. This provides a valuable piece of the connectivity puzzle to consumers and businesses and enables the stars, nearby asteroids, the moon and Earth phenomenon to be studied. Coaxial interconnects, such as coaxial cable assemblies and connectors, are critical for many modern space communications and sensing systems for both space platforms and payloads. Fortunately, as space applications increase in popularity, the accessibility of space-grade coaxial interconnects also grows to meet the needs of a new era in space exploration and services. ■

RESOURCES

1. "Payload Test Requirements," *NASA*, Web: standards.nasa.gov/standard/NASA/NASA-STD-7002.
2. "2.0 Complete Spacecraft Platforms," *NASA*, March 3, 2024, Web: nasa.gov/smallsat-institute/sst-soa/platforms/.
3. H. Riebeek, "Catalog of Earth Satellite Orbits," *NASA Earth Observatory*, September 2009, Web: earthobservatory.nasa.gov/features/OrbitsCatalog.
4. "NASA Workmanship Standards," *NASA*, Web: workmanship.nasa.gov/lib/insp/2%20books/links/sections/404%20Coaxial.html.


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Agility and Smart Sourcing Drive New Space Frontier Success

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Market projections indicate that by 2030, over 60,000 satellites could be operational in low Earth orbit (LEO), a significant increase from the approximately 8000 in orbit today.[1] This surge in activity is defining how companies approach component sourcing, manufacturing and system integration. This article describes some thoughts about how companies can enter this "New Space" market and find the right suppliers for their mission-critical systems. ***Figure 1*** shows an artist's conception of a satellite orbiting over Europe.

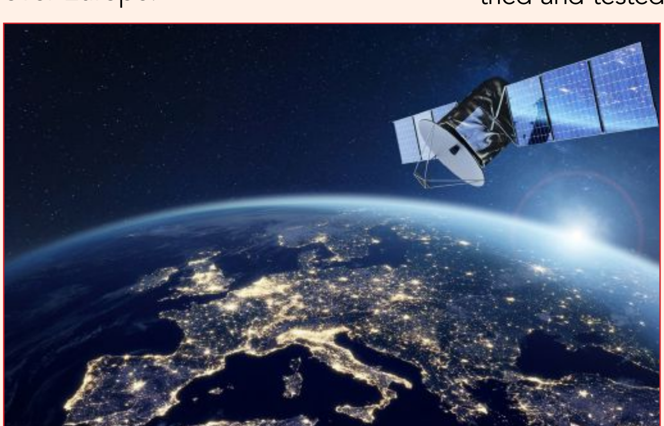

Fig. 1 **Satellite in orbit.**

LEO AND GEO REQUIREMENTS

Traditionally, geostationary orbit (GEO) satellites have dominated space-based communications. Operating at approximately 35,786 km above the equator, GEO satellites maintain a fixed position relative to the Earth's surface, providing consistent coverage over specific areas. Due to their high altitude and extended operational lifespans, ranging from 15 to 30 years, GEO satellites require components with exceptional reliability, often backed up by redundant systems. The high costs associated with launching and maintaining these satellites necessitate the use of tried-and-tested technologies with extensive heritage.

In contrast, LEO satellites orbit at altitudes between 200 and 2000 km, resulting in shorter orbital periods and the need for larger constellations to ensure continuous coverage. This proximity to Earth reduces signal latency, benefiting applications like real-time communications and Earth observation. However, the shorter lifespan of LEO satellites, often between five to 10 years, combined with the scale of deployments that often involve thousands of satellites, demand a different approach to component sourcing.

COTS COMPONENTS

For companies stepping into the LEO sector, the traditional approach to satellite component sourcing no longer applies. In the GEO market, reliability has always been the top priority, with space-grade components rigorously tested and used in nearly identical applications for years. GEO satellites are incredibly expensive to launch, so redundancy is built into the systems, ensuring each satellite can function flawlessly for as long as possible. LEO satellites, on the other hand, operate on a different cost model. The shorter lifespans and higher replacement rates mean companies must strike a balance between quality and affordability while maintaining the ability to scale production rapidly.

One of the biggest game-changers in this new era of satellite technology is the increasing reliance on commercial off-the-shelf (COTS) components. The industry is rec-

ognizing that shorter mission lifetimes can be achieved without needing parts screened to exceptionally high quality levels. This means that high performance components originally developed for industries like telecommunications and defense can offer suitable alternatives.

These sectors demand reliability at scale, making them a natural fit for the LEO market. Using COTS components allows satellite manufacturers to significantly reduce costs, shorten lead times and incorporate the latest technological advancements without the years-long development cycles associated with traditional space hardware. That being said, not all commercially available components are ready for space. Satellites endure extreme conditions, including intense radiation, temperature fluctuations and the vacuum of space. This means that while COTS components offer cost and scalability advantages, they must still be tested and, in many cases, adapted to survive in orbit. Companies looking to source complex assemblies for LEO need to work with suppliers who have experience in both volume manufacturing and space qualification processes.

COLLABORATION AND COMPETITIVENESS

The key to success in the space industry lies in finding partners who understand how to adapt commercial components for space applications without inflating costs to traditional space-industry levels. The European Space Agency has recognized this challenge and is actively investing in programs that support the commercialization of space technology. An example of this is a recent success story at Filtronic, which secured a €3.7 million contract under the ARTES program to develop advanced mmWave products for satellite payloads and gateway links. These products, essential for high frequency bands like Ka-, Q-/V- and W-Band, are crucial for enabling faster, higher-capacity data transfer between space and ground stations that are key to next-generation satellite communications. This win allows Filtronic to build on its 40 years of RF expertise and expand its technologies into the LEO market, further strengthening Europe's competitive edge in the rapidly evolving satellite sector.

As the LEO sector matures, competition among satellite operators is only intensifying. SpaceX's Starlink constellation has set the benchmark for large-scale deployment, but other operators are quickly advancing their own networks. The merger of Eutelsat and OneWeb, in particular, is a significant development that strengthens Europe's position in satellite broadband, providing a viable alternative to U.S.-led systems. In regions where geopolitical tensions complicate reliance on certain satellite networks, having diverse providers is crucial to ensuring global connectivity.

AGILITY

For suppliers and manufacturers, agility has become one of the most important factors in remaining com-

petitive. The ability to rapidly iterate designs, respond to shifting market demands and produce components at scale without compromising on reliability is now just as important as technological innovation itself. Traditional space-industry timelines, where new technologies could take a decade to develop and launch, are no longer viable in the fast-moving LEO market. Instead, companies that can quickly adapt and scale up production will be the ones driving the next generation of satellite communications. As LEO satellite networks scale, higher frequencies are becoming essential for meeting the growing demand for data capacity. Operators are increasingly pushing beyond Ka- and Q-/V-Bands into bands that operate up to and above 100 GHz. However, these higher frequencies introduce new engineering challenges.

THE CHALLENGES

One of the main issues is signal attenuation, which becomes more severe as frequency increases. Atmospheric absorption, particularly due to oxygen and water vapor, is much more pronounced at these frequencies, meaning signals weaken over shorter distances. This requires sophisticated techniques to compensate for signal degradation, such as adaptive power control, beamforming and advanced error correction methods.

Another challenge is the precision required in component manufacturing. As frequencies increase, the tolerances for RF components become much tighter. Even the slightest imperfections in antennas, for instance, can cause significant signal loss or distortion, meaning that manufacturing processes must be incredibly precise, often requiring advanced materials and fabrication techniques to ensure performance consistency.

Heat management is also a critical issue. At higher frequencies, power amplifiers and other active components generate more heat and efficient thermal dissipation becomes essential to prevent performance degradation. In space, where there is no natural convection to dissipate heat, engineers must design innovative cooling solutions, like heat spreaders and radiative cooling systems, to manage thermal loads effectively.

Ultimately, success in the New Space market depends on striking the right balance between performance, cost and scalability. Companies sourcing components for LEO need to think beyond the traditional space-industry playbook and instead look for partners who understand both the commercial and technical challenges of mass-producing high-reliability components. The days of building one-off, ultra-expensive satellites are fading. In their place, a new approach that values flexibility, efficiency and innovation is dictating the route that space technology takes. ■

References

1. "The Future Space Environment," *GOV.UK*, May 2024, Web: www.gov.uk/government/news/the-future-space-environment.

Space Situational Awareness Issues and Challenges

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Space is big, mindbogglingly big even, but suitable orbits around Earth are in limited supply. Due to increased congestion from satellites, traffic in space is becoming an issue. Already, there are thousands of operational satellites and hundreds of millions of pieces of space debris of various sizes. Thousands more satellites are expected to add to the situation as the offer of and demand for new and improved services increases. These new services range from communications, financial transactions, urban planning and mobility to transportation, national security and environmental monitoring. Unless existing and planned traffic and debris are managed better and soon, the challenges of space situational awareness (SSA) will endanger the very use of space. The sovereignty, societies and economies of many nations rely upon this critical, space-based infrastructure. What needs to be done is clear: eliminate the creation of new debris, improve the tracking and characterization of existing active satellites and debris and remediate debris that has already been generated. To get a better understanding of this situation, this article describes the most pressing issues, challenges to be solved and recent initiatives for SSA.

INCREASINGLY CONGESTED SPACE

There are about 13,000 satellites in orbit, 10,000 of which are active. With the announced mega constellations, experts estimate that there will be 60,000 to 100,000 active satellites in space a decade from now. Those numbers only consider satellites. The consensus is that there are 30,000 unique pieces of space debris orbiting the Earth, including satellites, which are larger than 10 cm. If the minimum size of the debris considered drops to larger than 1 cm, the number increases to 670,000. Including debris larger than 1 mm, still large enough to damage orbiting satellites, the number of pieces of debris in orbit around the Earth is estimated to be more than 170 million. ***Figure 1*** shows an artificial intelligence (AI)-generated image that puts the number of satellites and the amount of space debris in different orbits and orbital slots into context.

These numbers are increasing every year and any one object poses the threat of a potential conjunction. In space, a "conjunction" refers to a situation where two satellites or a satellite and a piece of space debris appear to be very close to each other in space, meaning they are passing within a relatively small distance, potentially raising the risk of a collision if not properly managed. All these conjunctions carry risk with the implications for operational efforts as well as the threat of loss of service or assets.

Spacecraft fragmentation events, collision events and anti-satellite weapons (ASATs) are by far the most significant contributors to orbital space debris. While these events are localized when they occur, they do not remain stationary and they begin to affect adjacent orbital regimes as time progresses. The effects of solar activity can accentuate these challenges. An increase in solar activity decreases atmospheric density. With lower density, there is less drag on the debris and the time to re-entry increases. This effect slows the re-entry process and makes the debris situation even more acute. This increases the likelihood of a conjunction, making the problem of the debris field even more acute. According to "The

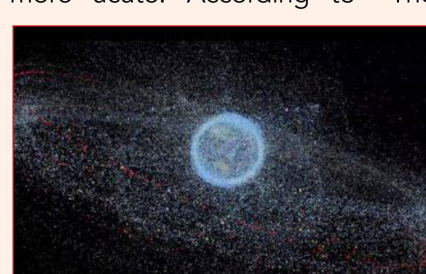


Fig. 1 **AI representation of space congestion. *Source:* Neuraspace.**

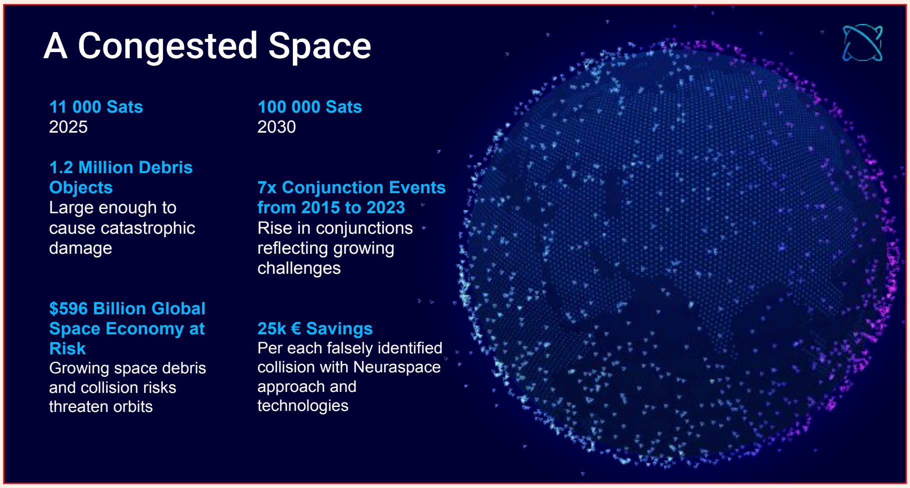


Fig. 2 **Space is a congested environment.** ***Source:*** **Neuraspace.**

Fig. 3 **Neuraspace satellite tracking antenna.** ***Source:*** **Neuraspace.**

Satellite Situation Report" from Space-Track,[1] an estimated 22,723 conjunctions occurred from May 30, 2023 to June 30, 2023.

This concern extends beyond debris interacting with satellites. In June 2023, SpaceX filed a report with the FCC stating that they conducted more than 25,000 maneuvers of its Starlink constellation between December 1, 2022 and May 31, 2023. This equates to approximately 12 maneuvers per satellite. In addition to actions taken to avoid identified debris, these numbers include a substantial number of maneuvers for Starlink-on-Starlink conjunctions. The Starlink example is for one operator and constellation, but the number of maneuvers illustrates the increasingly important need for operator-to-operator coordination. ***Figure 2*** shows a Neuraspace slide that summarizes some of the data, along with the challenges that describe congestion in space.

INCOMPLETE DATA OF OBJECTS IN SPACE

To ensure orbits are safe, it is crucial to have accurate and comprehensive data for all the objects in space. This allows objects in orbit to be monitored, mapped and cataloged. Having this data will enable the development of improved methodologies and algorithms for nowcasting and forecasting the behavior of objects in space.

These activities are underway, but many of the current solutions rely on manual processes, traditional technologies and sensors. The concern in the industry is that these algorithms will not cope with the projected 15x increase in space assets. Plans for this rapid increase in space assets must be tempered by the fact that existing data sets are incomplete and there are millions of pieces of debris smaller than 10 cm that are not being tracked but pose a threat to satellites.

The solution to this challenge is to expand the catalog of tracked objects. However, the scale and speed needed for this task require additional data sources. Even if those data sources are made available, the effort will also need to coordinate and effectively process data from large-scale networks of observation systems on the ground and in space. The evidence that this threat has risen to national and global levels is apparent simply by seeing the increasing number of space nations who are contributing to improve SSA.

To aid in these efforts, Neuraspace installed and activated the optical telescope in Chile, shown in ***Figure 3***. This new telescope expands Neuraspace's satellite tracking coverage to both hemispheres through two telescopes, in addition to data from partner networks. This new telescope can acquire more than one image per second for low orbits and track objects as small as 10 cm in diameter. The two telescopes reduce the uncertainty level for positional errors to less than 20 meters within a single orbital revolution, outperforming the 2023 ESA Space Debris Mitigation Requirement by a factor of five.

The measurement output is impressive. Both telescopes support horizon-to-horizon multi-orbit tracking, allowing rapid target switching. They produce measurements ranging from a few seconds to tens of minutes, enabling scalable data acquisition for multiple purposes such as collision avoidance, debris tracking, pattern-of-life analysis and launch and early orbit phase. This new telescope is expected to produce more than 300,000 measurements of space objects in orbits from low Earth orbit to geostationary orbit within the first three months of operations.

However, with the scope of the issue, it is unlikely that a single entity will be able to track all the objects in space. Allowing satellite operators to plan maneuvers and avoid risky conjunctions based on existing and new data from a synthesis of these diverse sources is a step toward more comprehensive conjunction screening. This will generate a vast amount of information that has to be analyzed pre-launch. The results of this analysis will be used to determine safe lift-off windows for launch vehicles to avoid collisions, the proximity of space objects to operational spacecraft, the algorithm to execute collision avoidance maneuvers and constellation management, including end-of-life disposal.

TECHNOLOGICAL ASPECTS AND METHODS OF KEEPING SPACE SUSTAINABLE

The space industry is starting to demonstrate the commercial and

technological viability of space sustainability by developing systems to address active debris removal, collision avoidance, hardening and operational lifetime extensions.

Manufacturing Measures

Addressing ways to improve debris avoidance should start long before the satellite is in orbit. Building "space-hardened" satellites and equipping all satellites, including CubeSats, with propulsion systems is a measure that will help satellites avoid debris. CubeSats make up a sizable portion of the predicted increase in space assets and they have not traditionally had a means of propulsion. More focus on quality assurance and reducing the number of objects that are released as launch and early operations unfold are additional measures that could help mitigate the challenge if implemented.

Collision Avoidance

It will be impossible for humans to collect, organize and analyze the data to make decisions in real-time without relying on automation that makes use of AI and machine learning (ML) capabilities. AI and ML are powerful tools for identifying patterns where classical methods fall short. Explainable AI will enable the satellite industry to process data, predict object behavior, forecast conjunction-related parameters and support smart decision-making. Having access to the data and finding patterns can help in effectively managing collisions, improving maneuver planning, especially for swarm and constellation satellites and making space activities safer, more sustainable and more efficient. To address some of these challenges, Neuraspace is integrating the improved satellite tracking and analysis capabilities into their Space Traffic Management (STM) Platform, which incorporates AI and ML to provide services such as conjunction monitoring and collision avoidance to over 400 satellites. ***Figure 4*** shows the output of a conjunction analysis from the STM platform. To underscore these trends, RAND, the nonprofit, nonpartisan research organization, has reported that satellite operators are starting to realize the benefits of commercial STM systems as a means of keeping their spacecraft operational while saving time and cost.[2]

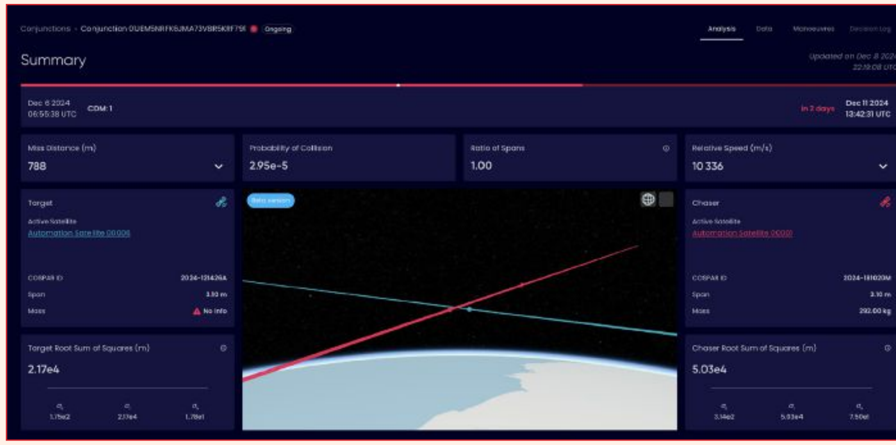


Fig. 4 **Conjunction details analysis display. *Source:* Neuraspace.**

Active and Passive Debris Removal

The first two topic areas have addressed how to reduce the likelihood of generating new debris and how to avoid existing debris. However, removing defunct satellites or other larger pieces of debris that do not have de-orbiting capabilities requires active debris removal capabilities. Active debris removal means a spacecraft must be able to safely approach and then capture an orbiting object and actively de-orbit the object. The industry had been conducting technology developments for active debris removal

and on-orbit servicing for decades. It is only recently that developments in the field of active debris removal have begun to accelerate, with contracts placed by governments and space agencies to prove the viability of being able to remove debris.

The technologies under consideration and in various stages of development and testing for capturing space debris include robotic arms and end effectors, tethered harpoons, electrodynamic tethers, lasers, magnetism and tethered net systems. Before a capture technique can be implemented, there are a number of significant issues to solve. These issues include understanding the object to be captured and its behavior, along with the best way to approach and conduct close-proximity operations safely. For instance, the approach and close-proximity challenges may entail developing algorithms to match rotation and spin rates.

At present, Europe and Japan have been leading these efforts, with industrial players stepping up. Even more significantly, these efforts are now partially backed by venture capital funds, showing the possibility of a workable business model with these efforts. While removing all objects from orbit would be ideal, that does not seem practical with the limited capabilities and resources within the industry. However, it has been widely reported that concentrating on the 50 most statistically concerning low Earth orbit objects and planning to remove these objects at a rate of at least three per year will yield substantial benefits for the satellite industry.

End-of-Life Measures

For low Earth orbit applications, the industry is exploring and developing several passive debris removal concepts. These include using tethers or drag sails as a means of mitigating end-of-life debris. Other options include on-board de-orbiting kits that can assume control in the case where the spacecraft experiences failures that incapacitate it from de-orbiting.

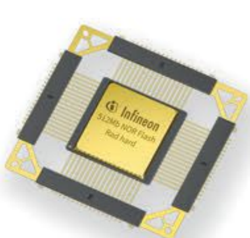
Extended Lifetime

The concept of extended lifetime is simple to understand, but the implementation is more complicated. Extending the lifetime of a satellite typically involves methods like on-orbit servicing, fuel management optimization and advanced component design. On-orbit services took a first big step toward broader adoption in 2020, when Northrop Grumman Innovation Systems' MEV-1 spacecraft successfully rendezvoused and docked with the Intelsat 901 satellite. The MEV-1 successfully re-positioned the spacecraft and it has performed station-keeping since.

ECONOMICS OF ORBIT SAFETY

As governments have realized how crucial space systems and the services they provide are for economic growth, national security and scientific research, orbital safety has evolved to become a significant economic factor. Forecasts and growth projections for the space economy vary widely, with revenue forecasts ranging from $1.8 trillion by 2030 to more than $10 trillion by the mid-2030s. Some of the forecast variability depends on what new and emerging market segments are included under the umbrella of the "space market." Despite the variability, the revenue numbers are significant. The emergence of the "New Space" industry presents a transformative opportunity for non-space activities, unlocking potential across various sectors like agriculture, healthcare, communication and environmental management. By leveraging space innovations, industries far removed from traditional aerospace applications can achieve breakthroughs in efficiency, sustainability and global impact that will foster economic growth and address some of the world's most pressing challenges. Companies need a coherent space strategy for their continued competitiveness.

This boost to the space economy is reflected in each segment of



the space market: manufacturing, launch, operations and services. The emergence of the New Space segment, with its increased exposure to non-space business needs and drivers, increases the pressure for disruptive innovation and increased profitability. Fortune Business Insights projects the global SSA market to grow from $1.97 billion in 2023 to $3.01 billion by 2032.[3] According to ResearchandMarkets, the space debris removal market is expected to see growth from $282 million in 2023 to reach $1.77 billion in 2030.[4] Analysys Mason estimates the cumulative revenue from satellite refueling will exceed $6 billion between 2023 and 2033.[5] Zion Market Research estimates that the global space logistics market size will grow from $5.12 billion in 2023 to reach $21.14 billion by 2032.[6] Global space defense and security investments will also see a continued growth trend over the coming decade.

The numbers are impressive, but there are challenges to making these forecasts a reality. This growth of the space safety, security and sustainability market must be driven by companies worldwide, realizing that only by supporting the development of a commercial space safety ecosystem and market can the full innovation potential be unleashed. To take full effect, all these existing and planned initiatives require some overarching governance.

NATIONAL AND INTERNATIONAL REGULATION AND PUBLIC SECTOR FOUNDATIONAL SERVICES

Space sustainability is a sine qua non. It is the responsibility of governments to understand the urgent need to propose and implement regulations into national and international policies and laws. Regulation will play a positive role in fostering a market for space domain awareness (SDA) by establishing clear standards, encouraging data-sharing and setting industry benchmarks for accuracy and reliability.

Recognizing these issues, the last couple of years have seen some new developments. In 2022, the FCC adopted new rules changing the maximum time limit for de-orbiting defunct low Earth orbit satellites from 25 years to five years after their end of mission. The consequences of this ruling became apparent in 2023 when the FCC issued the first fine ever for space debris. U.S. satellite operator Dish had to pay $150,000 for failure to move one of its satellites into a safe orbit. As a direct result, the company's share price dropped almost four percent that day, reducing the company's $3 billion valuation by $100 million.

Also in 2023, the U.S. Senate Committee on Commerce, Science and Transportation passed the Orbital Sustainability Act. The same year, ESA published its non-binding Zero Debris Charter. The char-

ter emphasizes the importance of debris tracking and particularly mentions the need for "access to timely and accurate data on space objects down to a size of 5 cm or smaller in low Earth orbit."

Public sector SDA services like the U.S. Space Force's Traffic Coordination System for Space and the European Union's Space Surveillance and Tracking provide foundational data and essential safety services that commercial providers can enhance to offer tailored solutions to government and commercial end-users alike. Space agencies like NASA and ESA have recognized the increasing danger posed by the growing population of objects in space and the inadequacy of legacy systems and are looking for service providers. Regulatory frameworks will further incentivize commercial SDA services. Well-defined regulations will reduce uncertainties, enabling a robust commercial SDA ecosystem.

FINAL COMMENTS AND OUTLOOK

The satellite market is proving to be one of the more dynamic opportunities for hardware and services. The market opportunity is significant, with new mega constellations promising to enable and enhance a full range of services to improve communication, transportation, security, sensing and connectivity applications. Despite the vastness of space, it is becoming increasingly congested with satellites and orbital debris and the rapid expansion of satellite launches will only exacerbate this challenge. This article has discussed some of the issues and challenges surrounding SSA topics, along with some of the solutions that are being developed and implemented. The growing number of players will have profound implications for the future SSA market and the broader space industry. With all the opportunities and challenges, the commercial market of space safety and sustainability is wide open for business. ■

References

1. "The Satellite Situation Report" *Space-Track*, Web: www.space-track.org.
2. B. McClintock, D. C. Ligor, D. McCormick, M. Herron, K. Jukneviciute, T. Van Bibber, K. Feistel, A. Rao, A. Rao, T. Grosso, et al., "The Time for International Space Traffic Management Is Now," *RAND*, June 5, 2023, Web: rand.org/pubs/research_briefs/RBA1949-1.html.
3. "Space Situational Awareness (SSA) Market Size, Share & Industry Analysis," *Fortune Business Insights*, March 2025, Web: https://www.fortunebusinessinsights.com/space-situational-awareness-ssa-market-105446.
4. "Space Debris Removal Market Size, Share & Forecast to 2030," *ResearchandMarkets*, March 2025, Web: https://www.researchandmarkets.com/report/space-debris-removal.
5. D. Kasaboski, "Refuelling Providers Need Strategies to Match Changing Demand for In-orbit Satellite Services," *Analysys Mason*, April 2024, Web: analysysmason.com/contentassets/9e0735b31acb4233950b2a5c6e8fdbf5/analysys_mason_refuelling_strategy_change_apr2024_nsi011.pdf.
6. "Space Logistics Market Size, Share, Demand, Growth Analysis 2024-2032," *Zion Market Research*, March 2024, Web: https://www.zionmarketresearch.com/report/space-logistics-market.

Satellite Communications Market Trends and Forecasts

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A new era of space exploration and innovation opens transformative possibilities for governments and companies in the satellite communications (satcom) sector. Satcom services provide vital global connectivity by transmitting data, voice and video signals via satellites. This ensures access to communication networks in remote and underserved areas lacking terrestrial infrastructure. These services are essential across various sectors, including broadcasting, military, maritime and enterprise, offering reliable high speed connections that support real-time data transfer, high-definition content distribution and critical communications during emergencies and disasters. As demand for seamless connectivity grows, driven by the expansion of IoT, the need for broadband internet in rural regions and the increasing reliance on digital services, satcom continues to evolve with advancements such as high-throughput satellites (HTS) and low Earth orbit (LEO) constellations. These innovations are enhancing capacity, speed and coverage, making satcom an indispensable component of the global communications infrastructure, particularly in regions where other forms of connectivity are not feasible. According to MarketsandMarkets, the satcom market is estimated to reach $33.2 billion by 2029 at a compound annual growth rate (CAGR) of 14.5 percent.[1] **Figure 1** shows a brief

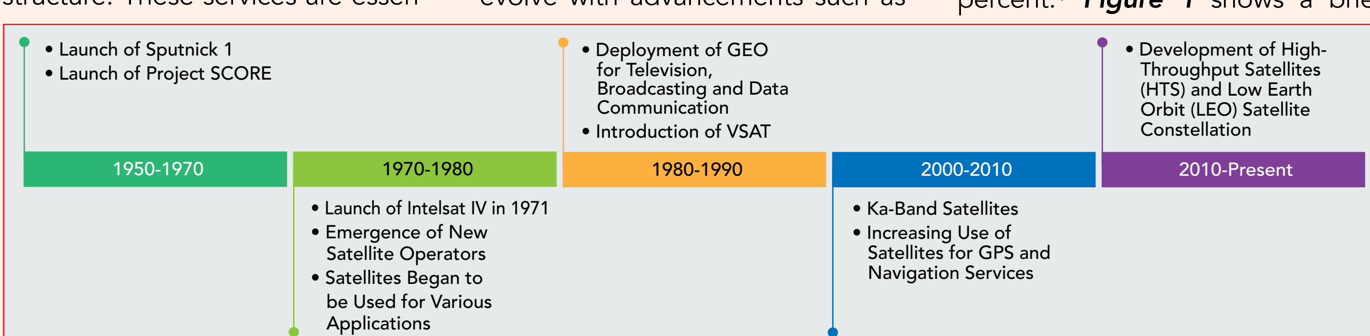

Fig. 1 **The evolution of the satellite communications market.** ***Source:*** **Secondary research, interviews with experts and MarketsandMarkets analysis.**

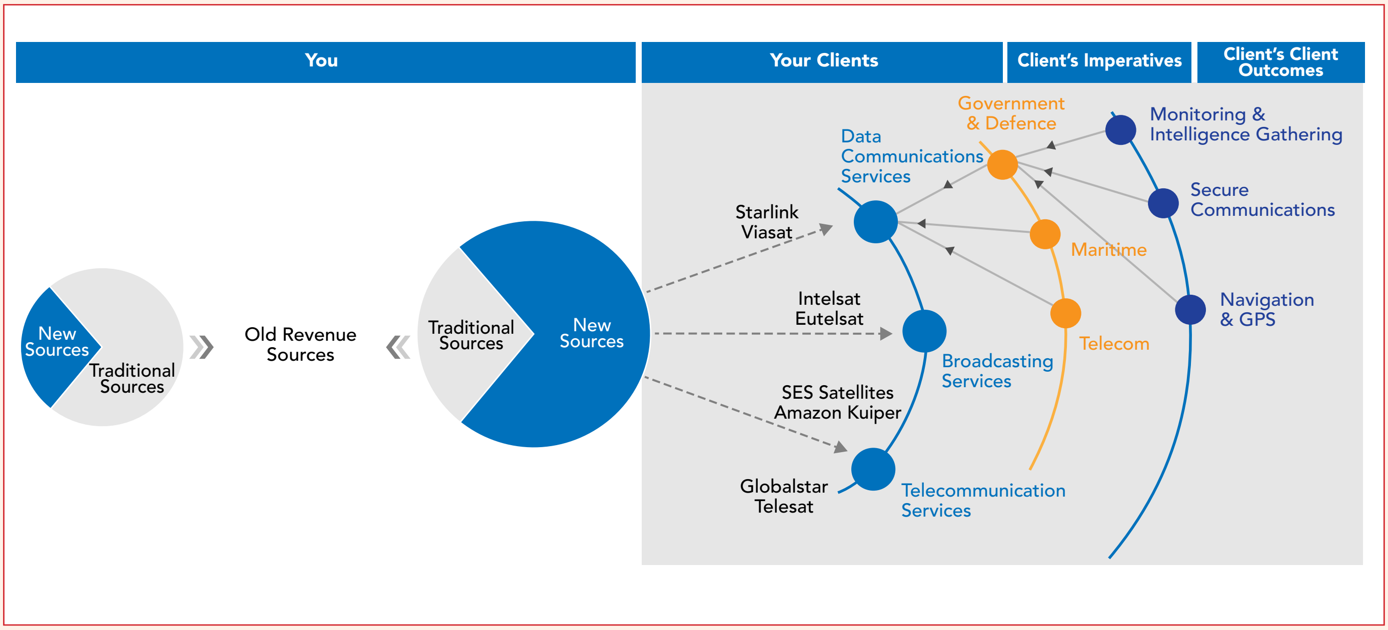

Fig. 2 **Satellite communications market.** ***Source:*** **Secondary research, interviews with experts and MarketsandMarkets analysis.**

history of some of the most critical developments in the evolution of the satcom market.

In the short term, the satcom market is expected to witness steady growth driven by increased demand for connectivity in remote and underserved areas. Providers will focus on enhancing service quality and expanding coverage to meet rising maritime, aviation and emergency service needs. Technological advancements will be centered around improving data transmission speeds and network reliability. Innovations will likely involve better integration of satellite services with existing terrestrial networks to enhance overall performance and service delivery.

MID-TERM ROADMAP (2026 TO 2028)

The mid-term period will witness a significant evolution in satcom services, with a greater emphasis on leveraging emerging technologies. The integration of services with advanced technologies, such as IoT and 5G, will be a key trend, enabling more seamless and efficient communication. Providers will focus on enhancing service customization and adaptability to meet diverse user needs and applications. Technological advancements will include improved signal processing and dynamic bandwidth management, contributing to more robust and flexible service offerings. ***Figure 2*** shows MarketsandMarkets' thoughts on some of the satcom market participants, segments and applications, with typical interconnections shown for Starlink and Viasat.

LONG-TERM ROADMAP (2029 AND BEYOND)

Looking ahead, the satcom market is set for exciting changes driven by advancing technologies. As satellite services merge with next-generation innovations, new applications and use cases will emerge that can reshape connectivity. Services will become more flexible, offering tailored solutions that integrate seamlessly with smart infrastructure and real-time data insights. The focus will shift toward making everything run more smoothly and efficiently, thanks to AI-driven management and automation improvements. This evolution will solidify satcom services as a fundamental component of global connectivity in a more interconnected world.

Ground stations are the essential hubs of communication between satellites and the Earth. They consist of large antennas, often called parabolic dishes, responsible for transmitting and receiving data to and from orbiting satellites. These stations are complex facilities equipped with tracking systems to maintain alignment with the fast-moving satellites. Modern ground stations incorporate technologies like adaptive coding and modulation, which adjust signal quality in response to changing atmospheric conditions to ensure data reliability. With advances in automation, many ground stations can now operate with minimal human intervention, continuously communicating with satellites across various orbits from LEO to geostationary orbit (GEO). Essentially, ground stations are the terrestrial link in the satcom chain, managing massive amounts of data and ensuring it reaches its intended destination efficiently.

FREQUENCY BANDS

Frequency bands play a crucial role in satcom services. Each of the satellite bands has unique properties that affect data transmission between satellites and ground stations. The L-Band, from 1 to 2 GHz, is valued for its ability to penetrate weather conditions like rain and fog, ensuring reliable communication in adverse weather. The disadvantage of L-Band is lower data transfer rates. The S-Band, between 2 and 4 GHz, offers a balance between coverage and data rate. This band is suitable for sat-

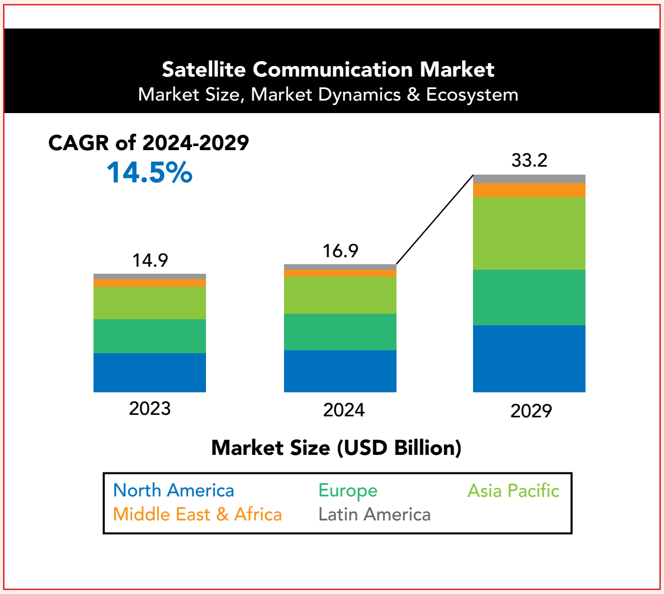

Fig. 3 **Satellite communications market forecast.**
Source: **Secondary research, interviews with experts and MarketsandMarkets analysis.**

ellite and mobile applications requiring better performance than L-Band can provide but with less capacity. The C-Band, ranging from 4 to 8 GHz, is commonly used for satellite TV and communication, providing stable coverage and data rates with less susceptibility to rain fade than higher frequencies. The X-Band, from 8 to 12 GHz, is mainly used for military and government communications, offering higher data rates and precision. However, this band is affected by rain and atmospheric interference more than lower frequency bands. The Ku-Band, covering 12 to 18 GHz, supports high data rate communications, making this band ideal for broadband and satellite TV. However, this band is more prone to rain fade effects. The Ka-Band, from 18 to 40 GHz, is used for high-capacity applications like high speed internet. This band enables very high data rates and bandwidth but is significantly impacted by atmospheric conditions such as rain and humidity. Dynamic spectrum management is essential in today's satcom environment to optimize these bands, reduce data congestion and ensure that diverse applications, from TV broadcasts to internet services, function efficiently without interference.

TERRESTRIAL NETWORKS

Terrestrial networks are integral to satcom services, acting as the essential infrastructure that connects satellite signals to end users and integrates them with broader communications systems. These networks encompass a range of technologies, including fiber optics, microwave links and other high-capacity transmission mediums that ensure efficient data flow from satellite ground stations to various endpoints. Fiber-optic cables provide high speed, high bandwidth connections crucial for handling the large volumes of data transmitted from satellites. In areas where fiber deployment is not feasible, microwave links are the preferred technology for point-to-point connections. Additionally, terrestrial networks incorporate advanced networking technologies like software-defined networking and network function virtualization, enhancing flexibility and efficiency by allowing dynamic management and optimizing data traffic. This integration ensures that satellite-delivered data can be effectively distributed to homes, businesses and mobile devices, supporting a seamless and reliable communications experience across diverse applications and geographical locations.

MARKET FORECASTS

The satcom market is expected to reach $33.2 billion by 2029 from $16.9 billion in 2024, at a CAGR of 14.5 percent from 2024 to 2029. The Asia-Pacific segment of the satcom market will be the largest in 2029, followed by North America and Europe. Africa and the Middle East are constantly in flux due to different developments and strategic initiatives. However, while remaining small, these regions will present opportunities for higher growth rates in the next five years. The expected increase in the market, along with regional segmentation, is shown in ***Figure 3***.

CONCLUSION

Whether consumers or businesses, users are showing an insatiable desire for connectivity and data-intensive services. As the demand grows for seamless connectivity, satcom networks are playing a vital role in evolving data, voice and video networks. The drivers for the evolution of satellite networks' role in connectivity include increased demand from remote, underserved areas, an expansion of IoT and M2M communications, increasing service demand from maritime, aviation, broadcasting and security applications and partnerships with 5G operators.

While the opportunity is significant and the drivers are strong, challenges still remain. The industry is characterized by high initial investment and operational costs. Like terrestrial wireless networks, there are regulatory and spectrum allocation challenges and the satellite networks must develop an approach that allows them to coexist with terrestrial networks. From a technology standpoint, latency performance and bandwidth availability will not be sufficient for some applications. Paradoxically, the success of the satellite network may pose the most significant challenge. As more satellites are launched into larger and denser constellations, space debris and satellite failures pose an increasing risk to all satellites. However, MarketsandMarkets' forecast shows revenue in the satellite market nearly doubling in five years, the industry will see success in solving these challenges and capitalizing on the benefits and advantages that satcom networks will provide users. ■

References

1. "Satellite Communication Market by Type, Application and Region - Global Forecast to 2029," *MarketsandMarkets*, August 2024, Web: marketsandmarkets.com/Market-Reports/satellite-communication-market-32381348.html.

Unlocking K-/Ka-Band Satellite Communications with Embedded Encryption

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The NSR-SDR-K/Ka-HDR-NEM from Vulcan Wireless redefines high data throughput at K-/Ka-Band for space-based satellite communications. It combines advanced software-defined radio (SDR) technology with high data throughput, robust encryption, radiation tolerance and seamless waveform compatibility. Designed for mission-critical satellite operations, this state-of-the-art radio delivers superior performance, security and adaptability, making it a top choice for both military and commercial space missions.

Operating across a range of uplink and downlink frequencies within the specified Ka-Band spectrum, the NSR-SDR-K/Ka-HDR-NEM supports data rates up to 600 Mbps. Its full-duplex capability and 5 W linear RF output ensure reliable communication links, even in challenging environments. The integrated low-noise amplifier (LNA) and power amplifier (PA) enhance signal integrity and minimize noise, providing a robust connection for data-intensive applications. Including the RF front-end with the SDR and encryption subsystems makes for a highly compact communications solution that enables high-rate satellite manufacturing and reduces the need for integration on space vehicles. ***Figure 1*** illustrates a block diagram of the radio architecture, highlighting key integrated components.

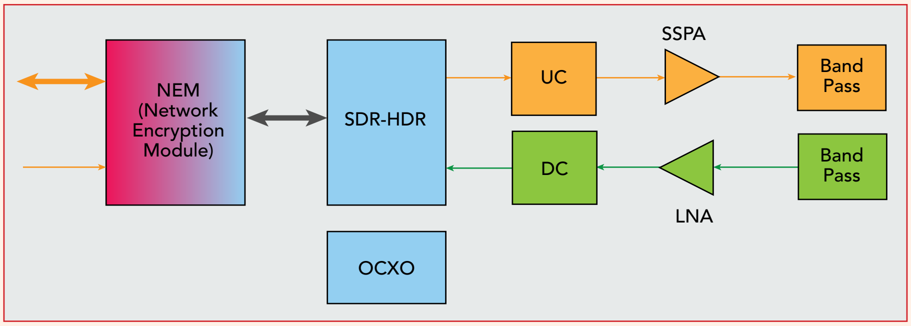

Fig. 1 **NSR-SDR-K/Ka-HDR-NEM block diagram.**

The radio is fully compliant with DVB-S2 modulation and coding standards and adheres to the relevant Consultative Committee for Space Data Systems space communications protocols. The NSR-SDR-K/Ka-HDR-NEM integrates seamlessly with existing ground station infrastructure, reducing the need for custom systems and simplifying mission planning. The radio's adaptive spectral shaping optimizes bandwidth usage while staying within emission limits, maximizing data throughput without compromising regulatory compliance. ***Figure 2*** illustrates a DVB-S2 signal operating at a symbol rate of 270 Msym/sec with 8-PSK modulation. The spectral plot demonstrates the occupied bandwidth of the signal, which is consistent with the expected characteristics of 8-PSK modula-

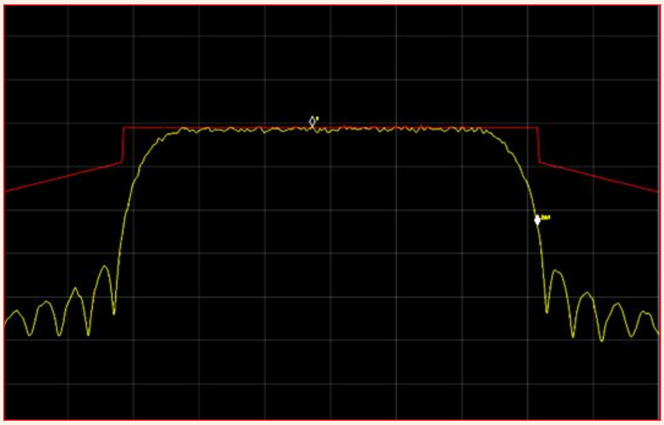

Fig. 2 **Spectrum analysis of a DVB-S2 signal.**

tion at this symbol rate. The band power has a clean spectrum, suggesting efficient utilization of the available bandwidth with minimal interference or spurious emissions. This configuration is optimized for high data rate transmission while maintaining spectral efficiency.

Cyber security remains at the core of the NSR-SDR-K/Ka-HDR-NEM. The system features an integrated NEM-ETH encryption module, capable of providing information assurance up to top secret classification levels. Unlike traditional solutions that require classification throughout production, this SDR can be configured as unclassified during manufacturing and testing. This modular approach simplifies logistics, reduces handling costs and allows for efficient production integration across a wide range of facility types. This flexibility is a significant departure from legacy systems, which often impose rigid classification requirements throughout the production cycle, leading to increased costs and extended lead times. The NSR-SDR-K/Ka-HDR-NEM streamlines this process, offering both efficiency and adaptability.

Customers operating in unclassified environments can integrate and test the unit without requiring specialized infrastructure or personnel clearances. Classified keys can be loaded during final customer deployment, enabling secure communication channels for applications such as defense satellite networks, intelligence, surveillance and reconnaissance missions and telemetry, tracking and command systems. The flexibility that the Vulcan Wireless NSR-SDR-K/Ka-HDR-NEM offers versus legacy systems in production processes is shown in the flow diagram of ***Figure 3***. The highly compact system also provides rigorous EMI/EMC filtering and control, minimizing unwanted emissions.

Designed for seamless spacecraft integration, the NSR-SDR-K/Ka-HDR-NEM is a true plug-and-play solution. Its compact, modular architecture integrates essential components such as RF channel filtering and amplification directly into the unit, eliminating the need for external hardware. This design significantly reduces size, weight and power (SWaP), making it ideal for small satellites and CubeSats where resource optimization is paramount. ***Figure 4*** shows the compact size and efficient design of the NSR-SDR-K/Ka-HDR-NEM that optimizes the utilization of available space on the vehicle.

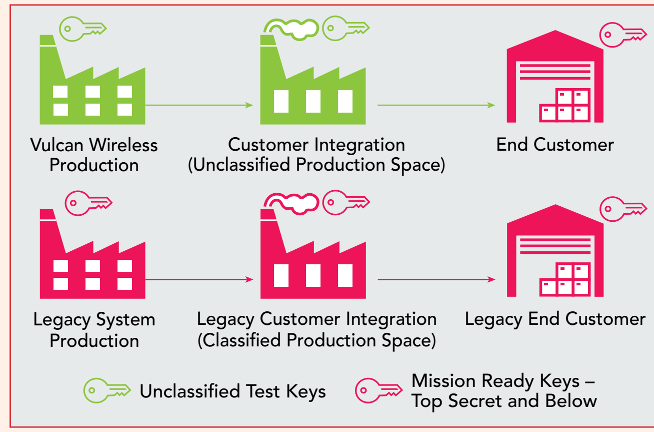

Fig. 3 **NSR-SDR-K/Ka-HDR-NEM versus legacy systems in production.**

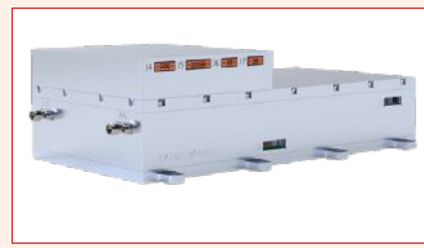

Fig. 4 **The NSR-SDR-K/Ka-HDR-NEM.**

The development of the NSR-SDR-K/Ka-HDR-NEM involved careful consideration of several trade-offs to balance performance, reliability, security and SWaP constraints. One of the primary challenges involved integrating the encryption unit without compromising the compact form factor of the radio. By carefully architecting the unit to optimize thermal management and minimize signal loss, the design team successfully achieved a balance of security, efficiency and reliability, ensuring the system meets stringent performance standards.

The NSR-SDR-K/Ka-HDR-NEM represents a significant leap forward in K-/Ka-Band satellite communication. The encrypted, radiation-tolerant SDR offers a high performance, secure and versatile solution for modern space missions. The integration of advanced encryption, waveform adaptability and streamlined spacecraft computability positions the NSR-SDR-K/Ka-HDR-NEM as a leading choice for government and commercial operators alike.

Vulcan Wireless continues to lead in satellite communication technology, consistently advancing its capabilities to meet the evolving needs of secure, reliable connectivity. By embracing innovation and delivering proven solutions, the company remains at the forefront of the industry, supporting critical communications in challenging environments. Through ongoing development and a commitment to excellence, Vulcan Wireless ensures that its technologies enable robust, efficient communication systems for its customers.

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Radiation-Tolerant MOSFETs for the New Space Market

Infineon IR HiRel
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International Rectifier (IR) HiRel and its parent company, Infineon Technologies, have over 50 years of combined experience designing and manufacturing best-in-class semiconductors for commercial and high-reliability applications. IR HiRel's portfolio of radiation-tolerant power MOSFETs is ideal for low Earth orbit (LEO) missions, typically lasting two to five years. These products are a testament to the company's expertise in the automotive and space industries. Qualified for space applications under the automotive AEC-Q101 standard, IR HiRel offers N- and P-channel devices with a linear energy transfer of 46 MeV·cm^2/mg, total ionizing dose (TID) rating of 30 krad (Si) and single event effect (SEE) tolerance. The radiation-tolerant New Space portfolio can be used in LEO space applications and constellations, such as proton tests, without further radiation tests, helping customers go to market faster and more cost-effectively.

OVERVIEW

IR HiRel's rad-tolerant power portfolio comprises both N-channel and P-channel devices. While P-channel MOSFETs require a negative voltage from gate to source (V_{GS}) to activate, N-channel devices need a positive VGS to activate, as illustrated by ***Figure 1***.

IR HiRel's rad-tolerant MOSFETs enable engineers to select power solutions that suit various needs without compromising size, weight and cost constraints. IR HiRel's New Space power portfolio includes four N-channel MOSFETs and one newly-released P-channel variant, all identified in ***Table 1***. All five IR HiRel devices are available in plastic packaging with further testing, such as outgas and salt atmosphere tests, guaranteed by the product's qualification.

AWARD-WINNING RAD-TOLERANT N-CHANNEL MOSFETS

IR HiRel offers four different radiation-tolerant N-channel MOSFETs based on Infineon's industry-leading and patented CoolMOS™ superjunction technology, known for its high efficiency, compact design and enhanced thermal management characteristics. Ideal for fast switching applications, the N-channel MOSFETs are offered in

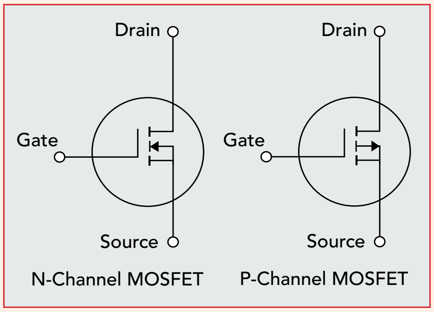

Fig. 1 **A comparison of N-channel and P-channel construction.**

60 V and 150 V voltage options in two plastic package options: the surface-mount TO-263 and the through-hole TO-247, illustrated in ***Figure 2***. The N-channel MOSFETs support 28 V and 54 V bus voltages, which are most common in LEO satellites. Their $R_{DS(on)}$ values start at 15 mΩ and range to 60 mΩ, as shown in Table 1.

The surface-mount TO-263 package enables easy assembly and reflow soldering, while the through-hole TO-247 package promotes an optimized cooling concept well-suited for higher current applications. Both packages have matte tin-plated leads to reduce whisker growth. With an operating temperature of -40°C to +125°C, these

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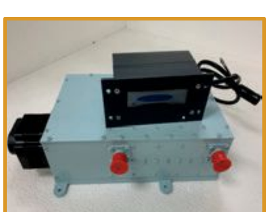
Telonic Berkeley **Fixed Filters** are known and used worldwide. Our impressive array of fixed filter types has evolved over the years in responding to the demanding needs of the electronic industry while offering performance parameters tailored specifically to each customer's unique requirements.

Telonic Berkeley Engineers are ready and anxious to provide innovative solutions for your RF multi-channel or **Multiplexer** needs. Our Diplexer, Triplexer or Quadraplexer designs in lumped element or combline/cavity designs may be the solution you are looking for.

Telonic Tubular Bandpass Filters are available in 2 to 12 sections. Three different and frequency sizes ranges allow for the selection of an optimal design for each requirement. Almost any type of input or output connection is available as a standard item.

Tunable Filters including Manually Tuned Bandpass Filters, Manually Tuned Bandstop Filters, Digitally Tuned Bandstop Filters, and Multi-Octave Digitally Tuned Filters up to 36 Gigahertz are available.

Telonic Berkeley offers a full range of **RF Cable Assemblies,** Flat Ribbon Cables, Grounding Cables, Wire Harnesses, Discrete Harnesses, and Power Cords



Network Managed Tunable RF Filters provide remote management, monitoring and diagnostic capabilities. High Power Tunable BSF and BPF are available

TABLE 1

A PARAMETRIC TABLE OF INFINEON IR HIREL RADIATION-TOLERANT MOSFETS

Product	V_{DS} max.	Polarity	Package	Qualification	Operating Temperature	I_D at 25°C max.	$R_{DS(on)}$ at 10 V max.
BUP15CN027E-01	150 V	N	TO-247	AEC-Q101	-40°C to +125°C	98 A	27 mΩ
BUP15CN060L-01	150 V	N	D^2PAK	AEC-Q101	-40°C to +125°C	36 A	60 mΩ
BUP06CN015E-01	60 V	N	TO-247	AEC-Q101	-40°C to +125°C	106 A	15 mΩ
BUP06CN035L-01	60 V	N	D^2PAK	AEC-Q101	-40°C to +125°C	52 A	35 mΩ
BUP06CP038F-01	-60 V	P	D^2PAK	AEC-Q101	-55°C to +175°C	-35 A	38 mΩ

Fig. 2 **(a) Surface mount TO-263 D^2PAK (b) Through-hole TO-247 MOSFET packages**

field-effect transistors (FETs) bring reliability and endurance to LEO missions and constellations. The N-channel devices are ideal for all power-related applications, specifically within power conditioning units, power distribution units and DC-DC converters. ***Figure 3*** shows a block diagram of the MOSFET applications.

RAD-TOLERANT P-CHANNEL MOSFET

IR HiRel's newly-released P-channel device brings radiation tolerance and reliability to the New Space market. It is offered in a -60 V voltage class with an $R_{DS(on)}$ of 38 mΩ. Available in the surface-mount TO-252-3 plastic package, the P-channel MOSFET is ideal for short-term missions aboard medium to large satellite constellations. The P-channel MOSFET is specified with a junction temperature of -55°C to +175°C and target applications include protection switches, load switches, power distribution units and battery management systems. The P-channel device addresses the same applications shown in Figure 3. It was added as an extension to IR HiRel's radiation-tolerant power portfolio earlier this year, complementing the 60 V and 150 V N-channel devices. Infineon is working toward expanding its radiation-tolerant portfolio with gate drivers and GaN HEMTs.

ROBUST NEWSPACE MEMORIES

To complete its New Space portfolio, Infineon IR HiRel offers volatile and non-volatile radiation-tolerant memories with a single lot code, 100 percent electrical testing and guaranteed TID radiation performance. The portfolio includes two F-RAM devices, two NOR flash devices and four pseudo-SRAM devices available in various densities, interfaces, packages and ratings. These memories are ideal in systems that do not require traditional military/aerospace certifications but benefit from robust performance and reliability in harsh environments. Like IR HiRel's MOSFETs, the rad-tolerant memories are ideal for LEO applications with mission lifetimes under five years.

CONCLUSION

Infineon IR HiRel's entire New Space radiation-tolerant power product line eliminates component-level testing by the customer due to its SEE and TID performance at the product level. This enables cost and time efficiency in the manufacturing process. IR HiRel's unique experience with automotive and industrial electronics brings unmatched reliability and robust performance to today's space exploration efforts. With high volume and established commercial assembly lines, IR HiRel's N- and P-channel MOSFET manufacturing processes and timelines easily support the growing number of commercial launches fueling the New Space economy.

Infineon IR HiRel
Leominster, Mass.
infineon.com/cms/en/product/high-reliability

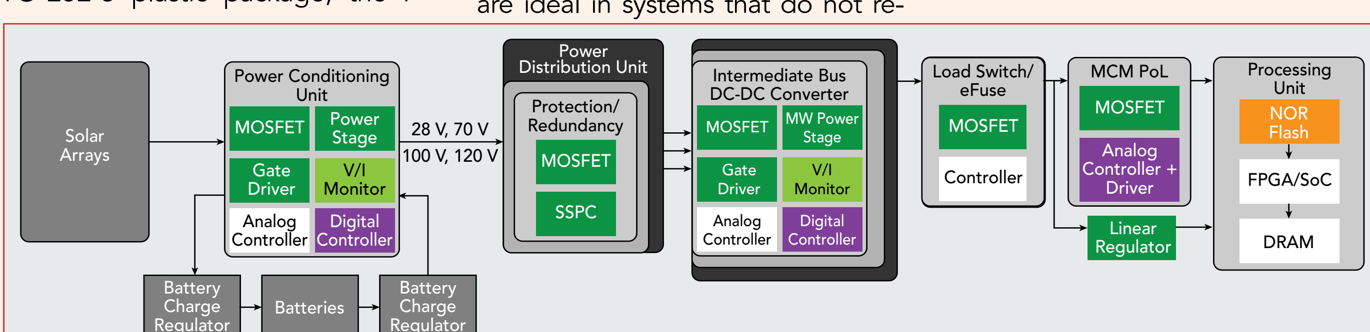


Fig. 3 **IR HiRel's radiation-tolerant MOSFET applications.**

The Fusion of SDR and SoC Technologies Revolutionizes RF Systems

Slipstream Design
Shipley, U.K.

The rapid advancement of RF systems is being driven by the convergence of software-defined radio (SDR) and RF system-on-chip (SoC) technologies. Innovations such as AMD's Versal RF series enable the digitization and miniaturization of RF systems, transforming radar and satellite communications (satcom). Slipstream Design has addressed key challenges in RF miniaturization and digitalization by integrating sensing and communication modes and minimizing size, weight, power and cost (SWaP-C) configurations. Slipstream Design's ASTRO platform enhances digital beamforming and leverages advanced materials and digital techniques for optimized performance.

SDR AND SOC IN RF SYSTEM MINIATURIZATION

SDR has revolutionized RF design by shifting signal processing from analog hardware to digital software. This increases flexibility and reduces the reliance on hardware. AMD's RFSoC technology integrates high speed data converters with programmable logic and embedded processors, which helps streamline RF system design. With AMD's Versal RF series SoC solution, SDR enables compact, reconfigurable and efficient RF systems for radar, satcom and electronic warfare (EW) applications.

Miniaturization is critical as demand grows for space-based and airborne RF systems. Traditional designs, reliant on bulky analog components, require significant space and power. SDR and SoC integration embed processing, digital filtering and beamforming functions within a single chip. This reduces size while enhancing efficiency and adaptability. Digital RF architectures also enable software-controlled hardware reconfigurability, which is crucial for dynamic military and aerospace applications. Slipstream Design's ASTRO platform embodies this approach, combining SDR versatility with an optimized RF front-end.

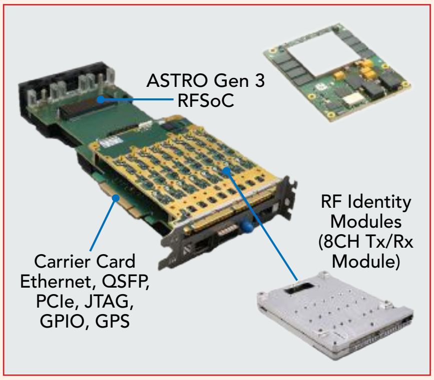


Fig. 1 **The ASTRO Nova direct RF processor module.**

ASTRO: A TECHNICAL OVERVIEW

Built on AMD's Gen 3 RFSoC, ASTRO is a compact, direct RF processor module optimized for accelerated digital beamforming. It is designed by radar engineers to ensure tactical superiority through rapid mode switching between radar (beamforming and steering) and communication. ASTRO features reconfigurable clocking for onboard or external RF sample clocks along with a multichannel, multimodule sync controller. It also features eight Tx (10 GSPS digital-to-analog con-

verters) and eight Rx (5 GSPS analog-to-digital converters). Harnessing AMD's RFSoC within an FPGA Mezzanine Card (FMC) form factor of 96 × 69 × 16.6 mm that incorporates high PCB layer counts and optimizes RF transitions achieves a low SWaP SDR platform with superior RF performance. ***Figure 1*** shows a view of the ASTRO Nova module with some functional elements expanded for better clarity.

OVERCOMING RF FRONT-END CHALLENGES

The RF front-end, situated ahead of the SDR, has traditionally been fixed and static. However, this is at odds with the flexibility of the SDR. Advances in circuit techniques and the adoption of wideband GaN devices are helping RF front-ends unleash the power of SDR in real-world systems. ***Figure 2*** shows the fully-assembled ASTRO Nova module and its ability to operate over the 3300 to 4200 MHz frequency range, encompassing the n78 and upper n77 bands.

Several key challenges must be addressed:

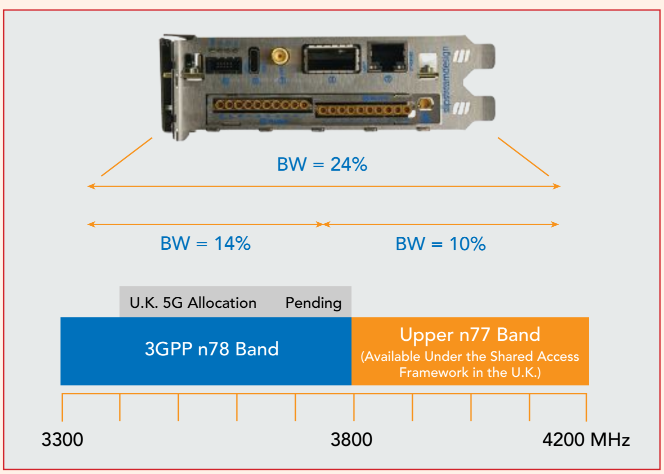


Fig. 2 **Wide bandwidth capability of the ASTRO Nova module.**

Wideband SDR versus narrowband and fixed RF: SDRs operate across wide bandwidths, while front-end components are typically optimized for specific, narrower bands. Tunable components are essential for wideband efficiency.

Dynamic impedance matching: SDRs frequently adjust frequencies and bandwidths, which requires real-time impedance tuning of power amplifiers (PAs).

Linearity versus efficiency: Maintaining efficiency when using complex modulation schemes.

Interference and filtering: Wideband SDRs are susceptible to interference, creating the need for adaptive filtering solutions.

Thermal management: SDRs and RF circuitry generate heat, demanding effective cooling strategies.

There is a gap between the agility of an SDR and the limitations of RF front-ends. Tunable RF filters, reconfigurable matching networks and AI-driven adaptive control are being developed to bridge this gap. GaN-based PAs using digital load modulation and digitally-controlled front-ends are being developed to improve efficiency and adaptability.

The ASTRO Nova exemplifies this innovation, leveraging GaN technologies for enhanced wideband opera-

Fig. 3 **ASTRO Nova switching between radar and OFDM waveforms.**

tion. Traditionally, sensing and communications applications required separate RF hardware. Integrating SoC and digitally-controlled GaN technologies enables seamless multifunctional operation, which allows a single hardware variant to switch between 5G New Radio waveforms and radar pulse generation. As an example of this capability, ***Figure 3*** shows the output when the ASTRO Nova switches between a pulsed radar chip generation and an orthogonal frequency-division multiplexing (OFDM) waveform generation.

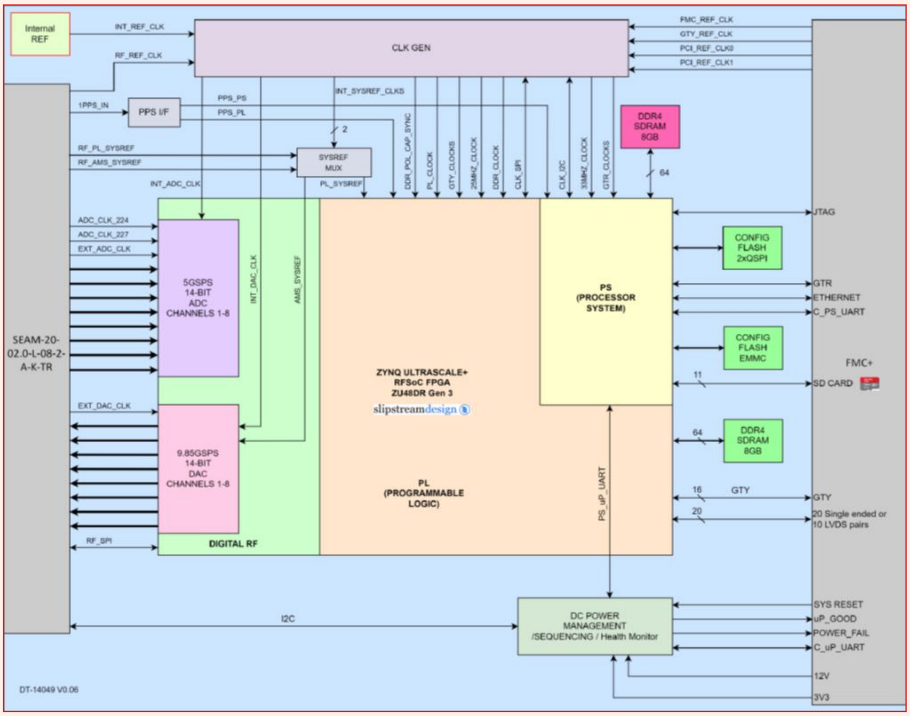


Fig. 4 **ASTRO Nova functional block diagram.**

THE EVOLUTION OF RF FRONT-END SUBSYSTEMS

GaN technology offers superior power density, efficiency and thermal performance compared to silicon-based alternatives. These features make the technology ideal for compact, high-power RF solutions in space and airborne applications. Digital optimization further enhances RF front-end efficiency. Real-time digital control of PAs and filters reduces manual interventions and improves system agility, crucial in satcom where remote reconfigurability is essential. ***Figure 4*** shows the functional diagram of the ASTRO Nova.

THE FUTURE OF NEXT-GENERATION RF SYSTEMS

The integration of SDR and SoC technologies is redefining radar, satcom and EW applications. Miniaturization, digitalization and advanced materials drive highly efficient, adaptable and cost-effective RF solutions. Fully digital RF architectures enhance system flexibility, enabling rapid prototyping, iterative improvements and seamless software updates. Combining sensing and communication functions within compact platforms will drive advancements in applications ranging from autonomous vehicles to deep-space exploration.

Slipstream Design is at the forefront of these innovations, leveraging GaN PAs and digitally optimized RF front-ends to meet evolving demands. As SDR, SoC and GaN technologies advance, they will shape the next wave of RF system innovation. These developments will enhance performance, efficiency and adaptability in an increasingly complex and interconnected world.

Slipstream Design
Shipley, U.K.
https://slipstream-design.co.uk/

MiCable

SSMP 40GHz Female Right Angle

C25F Series MILLIMETER WAVE CABLE ASSEMBLY

Ideal for connection and jumper requiring extremely limited installation space and high reliability

NEW

3mm Min. Bend Radius

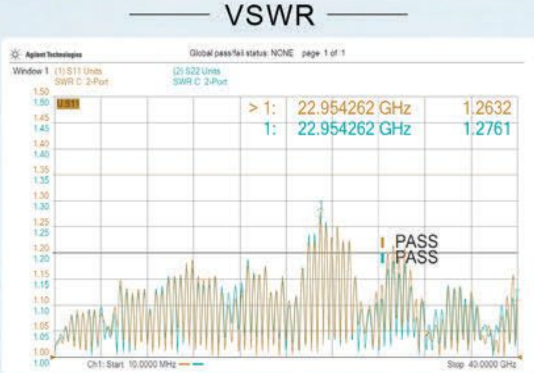
Excellent Phase Stability vs. Temp.

Excellent Mechanical/Temp. Stability

High Freq. Low Loss Low VSWR

Small Size for High Density Arrangement

VSWR



Cable Diameter	1.42mm
Frequency	DC~40GHz
Cable Attenuation	7.69dB/m@40GHz
VSWR	<1.40@40GHz
Shielding Effectiveness	<-90dB
Phase Stability vs. Flex.	<±4°@40GHz
Phase Stability vs. Temp.	<200ppm@-15°C~+35°C <400ppm@-40°C~+70°C
Amplitude Stability vs. Flex.	<±0.1dB/m@40GHz

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Precision Frequency Control and Timing from PLDROs

Quantic MWD's (Microwave Dynamics) new Whisper Series phase-locked dielectric resonator oscillators (PLDROs) provide precision frequency control and timing for demanding RF and microwave applications. Engineered for exceptional frequency stability and ultra-low phase noise, these oscillators operate across X-Band and Ku-Band frequencies from 8 to 18 GHz. They offer fully customizable options, including phase-locked loops, frequency tuning and external reference pairing with Quantic Wenzel's oven-controlled crystal oscillators (OCXOs).

With ruggedized and space-qualified versions available, Whisper Series PLDROs perform reliably in extreme environments, making them ideal for radar, satellite communications, test equipment and defense applications.

PERFORMANCE CHARACTERISTICS

- Frequency Range: Covers fixed frequencies from 8 to 18 GHz
- Phase Noise Performance: Delivers low phase noise of -110 dBc/Hz at a 10 kHz offset and -105 dBc/Hz at a 1 kHz offset, ensuring clean signal generation for high performance RF and microwave systems
- Customization and Tuning: Available with phase-locked loop options and fine-tuning capabilities to optimize system integration
- Environmental Resilience: Built to withstand challenging conditions, with space-qualified versions available
- Frequency Stability: Compatible with external reference sources, including Quantic Wenzel's high performance OCXOs, for enhanced frequency accuracy and long-term stability
- Compact and Versatile Design: Engineered for seamless integration into radar systems, satellite payloads, test equipment and portable transceivers.

Founded in 1993, Quantic MWD designs and manufactures free-running and phase-locked oscillators, amplifiers, frequency converters and frequency multipliers focusing on the singular characteristic that matters most: performance. Quantic MWD offers a portfolio of best-in-class solutions that maximize stability and minimize noise under extreme environmental conditions, ensuring optimal precision and reliability for mission-critical and industrial defense applications.

VENDORVIEW

Quantic MWD (Microwave Dynamics)
Irvine, Calif.
quanticmwd.com

RF/MICROWAVE FILTER SOLUTIONS

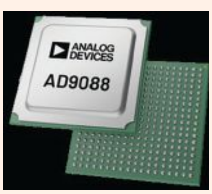
VENDORVIEW

3H Communication Systems is an AS9100 and ISO9001:2015 certified wireless infrastructure and microwave solutions company with decades of expertise in RF filters and front-end systems, offering RF/microwave filter solutions that are innovative, high quality, cost-effective, DC to 50 GHz and have a five-year warranty.

3H Communication Systems
www.3hcommunicationsystems.com

DISRUPTIVE TECHNOLOGY, TRANSFORMATIVE SOLUTIONS

VENDORVIEW



The Apollo mixed signal front-end (MxFE®) is a highly integrated device with a 16-bit, 16 GSPS maximum sample rate, RF digital-to-analog converter (DAC) core and 12-bit, 8 GSPS maximum sample rate, RF analog-to-digital converter (ADC) core. The AD9088 supports eight transmit channels and eight receive channels. The AD9088 is well suited for applications requiring both wideband ADCs and DACs to process signal(s) having wide instantaneous bandwidth.

Analog Devices
www.analog.com

SPACE QUALIFIED PRODUCTS

Crane designs and manufactures high performance, space-qualified passive products for defense and commercial satellite customers. We can readily meet your specific space program needs with a selection of pre-qualified products that provide proven high-reliability design, shorter delivery and reduced costs. Products include power dividers, directional couplers, mixers, modulators, iso-dividers/combiners and beamformers. Find your solution with our easy-to-use Product Finder at www.cranemicrowave.com.

Crane Aerospace & Electronics
www.craneae.com/space-solutions

MMWAVE AMPLIFIERS

Experience Elve mmWave amplifiers risk-free with Elve's new two-month free hardware "First Light" product demo program. Elve unlocks access to high power and high efficiency mmWave amplifiers with advanced materials and additive manufacturing processes. Their products enable Gbit speeds for next-gen multi-domain connectivity with large-scale production of TWTAs at significantly lower costs in Ka-, Q-, V-, E- and W-Bands.

Elve
www.elvespeed.com

4 KW L-/S-BAND SSPA FOR SATCOM UPLINK

VENDORVIEW

Empower's model 2176 is a compact, high-power GaN on SiC solid-state CW amplifier is 27 in. tall, less than half the size of typical legacy Klystron uplink HPAs that it replaces. The slightly broader band allows transmitting in either of the two L/S uplink channels. The 2176 is based on Empower's established and field proven next-generation architecture that is tactically deployed and operating on multiple levels in support of critical DOD missions.

Empower RF
www.empowerrf.com

MMWAVE THERMAL VACUUM TESTING SERVICES

VENDORVIEW

Introducing Eravant's mmWave thermal vacuum component testing services. Simulate the extreme temperature ranges and vacuum conditions required for mmWave component testing for space qualification. The 24 × 24 × 24 in. chamber allows for testing from -160°C to +250°C with an operating vacuum pressure up to 1 × 10^{-6} torr. In addition, a variety of in-house test equipment and components from DC to 110 GHz are available for customer use, including specialized coaxial vacuum RF feedthroughs from SMA to 1 mm.

Eravant
www.eravant.com

V-BAND WR19 WAVEGUIDE DIPLEXER

VENDORVIEW

V-Band WR19 waveguide diplexer with steep rejection on both bands, rejecting 50.2 to 50.4 GHz, the space research frequency band. Return loss on both channels is 15 dB minimum with insertion loss of 0.6 dB at the center of the band. The housing is made with invar to provide stable performance over temperature. Exceed Microwave, an AS9100D/ISO9001:2015 ITAR-registered company, provides custom-designed passive components.

Exceed Microwave
www.exceedmicrowave.com

SPACE-QUALIFIED TXCO

The T1354 temperature-compensated crystal oscillator (TCXO) is available from 20 to 100 MHz and features an extremely rugged, 20.3 × 12.7 mm DIP package, clipped Sine output and supply voltage of +3.3 or +5.0

VDC. The T1354 is radiation tolerant to 100 krad (Si) TID, and an ultra-low g-sensitivity option is available for appropriate applications. Frequency stability versus temperature is ± 1.0 ppm (-20°C to 70°C). The T1354 Series has been designed for low orbit satellite applications (nano/micro satellites), RF telemetry systems, multiband terminal and up-converter applications.
Greenray Industries
www.greenrayindustries.com

COST-EFFECTIVE POWER MOSFETS

Infineon IR HiRel's radiation-tolerant power portfolio combines decades of space and automotive experience to bring highly reliable, cost-effective power MOSFETs to the commercial space market. HiRel's N- and P-channel variants, available in 60 V and 150 V voltage classes, are AEC-Q101 qualified for space applications and optimized for two- to five-year low Earth orbit missions. The power devices feature durable plastic encapsulated packaging with surface-mount and thru hole options and a TID of 30 krad(Si).
Infineon IR HiRel
www.infineon.com

MULTIDISCIPLINARY MICROWAVE COMPONENTS AND SUBASSEMBLIES

KRATOS Microwave Electronics Division is a globally recognized leader in the design and manufacture of high performance, state-of-the-art multidisciplinary microwave components and subassemblies used in defense, commercial and space applications. With over 50 years of proven expertise and an unwavering commitment to quality and reliability, KRATOS continues to set industry standards. To meet the specific needs of customers, they offer cutting-edge technologies. These include embedded DSP, mixed-signal processing, system-on-chip devices, high-power amplifiers, FPGA and other advanced digital technologies.
KRATOS
www.kratosmed.com

HIGH PERFORMANCE COMPONENTS FOR SPACE & THERMAL VAC

VENDORVIEW

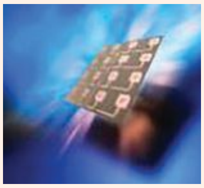
KRYTAR specializes in the design and manufacturing of ultra-broadband, high performance microwave components operating from 0.5 to 40 GHz for commercial and military space applications: directional couplers, power dividers, hybrid couplers and coaxial terminations. KRYTAR's successful space heritage offers qualities you can depend on, offering innovative products, quick-reaction capability, design responsiveness, flexibility, fast production turn-around and partnerships with our customers. KRYTAR can provide customized solutions to meet your application-specific requirements.
Krytar
www.krytar.com

SPACE-QUALIFIED HIGH POWER SPDT & DPDT TNC COAXIAL SWITCHES

The two-decade Logus space legacy offers the satellite integrator many options including these high power TNC coaxial switches, in addition to Logus's space-qualified SPDT, DPDT and R-type waveguide switches. These high performance TNC switches are designed for low VSWR, low insertion loss and high isolation. Multipactor free tested over many frequency bands and high RF power levels, they are proudly operating in orbit over 15 years/failure free.
Logus Microwave
www.logus.com

ADVANCED DIRECT LASER PROCESSING FOR SPECIAL MATERIALS

LPKF's latest nano and picosecond ProtoLaser systems enable direct material processing for flexible, rigid-flex, and RF/microwave substrates with patented rapid



metal removal, precise drilling and cutting, controlled engraving and customizable settings. Advanced software allows on-demand production of precision devices in minutes within your lab.

LPKF
www.lpkfusa.com

18 – 86 GHZ GAAS MMIC CHIP SCALE PACKAGE DOUBLE BALANCED MIXER

VENDORVIEW

The MM1-1886HCSP2 is a highly linear passive GaAs double balanced MMIC mixer suitable for both up- and down-conversion applications from 18 to 86 GHz. As with all Marki Microwave mixers, it features excellent conversion loss, isolation and spurious performance across a broad bandwidth and in a small form factor. The MM1-1886HCSP2 is available in a lead-free, RoHS-compliant 2.5 × 2.5 mm chip scale surface-mount package and is compatible with standard leaded and lead-free PCB reflow soldering processes.

Marki Microwave
www.markimicrowave.com

ACE9000 ADVANCED CHANNEL EMULATOR

The Maury Microwave ACE9000 can emulate the effects of naturally occurring disturbances in a non-terrestrial communication environment. Reducing the effects of these impairments can extend network reach, improve capacity and ensure reliable connectivity even in geographically remote or underpopulated hard-to-reach areas, such as the open ocean or large desert regions.

Maury Microwave
www.maurymw.com/dbm

PERSONAL ANTENNA ARRAY OTA TEST SYSTEM FOR MMWAVE AND THZ APPLICATIONS

MilliBox offers a range of compact anechoic chambers and 3D positioners specifically designed for antenna radiation pattern and beam steering measurements above 10 GHz. Having a personal benchtop setup greatly increases productivity

and scalability by eliminating downtime and setup time commonly impacting shared resources. Modularity, flexibility and affordability are the defining principles behind all MilliBox products.

MilliBox
www.millibox.org

WIDEBAND SYNTHESIZER

The MI-WAVE 958 Series wideband synthesizer is a high performance, GUI-controlled solution for ultra-wideband applications. It supports CW, frequency sweep, frequency hop, and external trigger modes, with remote operation via Wi-Fi or Ethernet. Key features include internal filtering, low phase noise, adjustable charge-pump current, remote RF on/off control, and single supply operation (8 to 15 V). Compatible with 10 to 250 MHz references and featuring temperature monitoring, it ensures precision and reliability. Perfect for ATE, telecom, satellite, embedded systems, secure communications and electronic warfare applications.

Millimeter Wave Products
www.miwv.com

EW TUNER

Engineered for next-gen EW missions, MPG's new EW tuner is a compact, high-performance wideband superheterodyne tuner delivering 0.5–18 GHz RF input with 1 GHz instantaneous bandwidth. Ideal for ELINT, SIGINT, and RESM applications, it offers fast 10 µs tuning, 50 dB SFDR, and SOSA-aligned OpenVPX integration. Advanced filtering, a DDS-based LO, and phase-coherent multi-channel options ensure exceptional signal clarity and system scalability. This tuner matches the performance of larger receivers in a rugged, single-slot 3U form factor—empowering mission-critical intelligence with precision and speed.

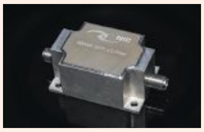
MPG
www.mpgdover.com

MULTIPACTION TEST

Mtron has over 125 design wins across satellite and manned spacecraft. Higher data rates are driving the need for higher frequency and higher power space-level RF solutions. Mtron acts as an extension of their customer's engineering design department, reviewing design trade-offs, mitigating multipaction risk and other risks that could lead to premature system failure. By combining Spark3D simulations and in-house high RF power altitude testing, Mtron mitigates risks early in the design phase to ensure reliable performance in orbit.

Mtron
www.mtronpti.com

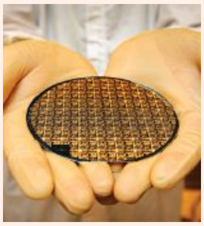
UHF FILTER



NIC expands its space-qualified RF portfolio with a new UHF filter designed to deliver exceptional selectivity and stability in high-radiation, low-gravity environments. Fully compliant with MIL-PRF-38534, EEE-INST-002 and TOR Standards, the filter is ideal for use in spaceborne payloads, telemetry and satellite communication systems. With over three decades of experience and space heritage, NIC remains a trusted provider of RF solutions for commercial, scientific, defense and governmental space missions.

Networks International Corporation
www.nickc.com

FUELING INNOVATION.



Powering America's technology. MMIC sales, foundry services, design and test services, wafer bumping, IC packaging and RF units.

Northrop Grumman
www.ngc.com/micro

ACTIVE ANTENNA TEST SUITE

VENDORVIEW

NSI-MI Technologies' Active Antenna Test Suite (SYS-AATS) gives you the tools to fully characterize system-lev-

el parameters for satellite payloads and antenna systems. SYS-AATS has been optimized to characterize active electronically scanned arrays (AESA) and transponders on all types of antenna measurement systems. This approach expands the role of the antenna measurement system to include radiated, system-level characterization of critical payloads. Measure antenna patterns, equivalent isotropic radiated power, gain-over-noise-temperature, group delay and more using SYS-AATS.
NSI-MI Technologies
www.nsi-mi.com

BROADBAND AMPLIFIER 20-1000 MHZ

The 5127 is a 200 W broadband amplifier that covers the 20 to 1000 MHz frequency range. This amplifier utilizes class A/AB linear power devices that provide an excellent third-order intercept point, high gain and a wide dynamic range. This series has been updated to deliver more power with less consumption in a compact package. Power levels range from 20 to 1000 W. Suitable for all EMC, EW, pulse and other lab testing needs. Includes a five-year warranty.
Ophir RF
www.ophirrf.com

RF/MICROWAVE PASSIVE COMPONENTS

Passive Plus leads the way in manufacturing high performance RF/microwave passive components providing cutting-edge solutions for the medical, semiconductor, military, broadcast or telecommunications industries. PPI's components are engineered for ground-based satellite communication equipment, delivering unmatched reliability and precision for satellite transmission and receiving systems. Designed to withstand the demanding conditions, PPI's products ensure optimal performance, exceptional signal integrity and robust durability, making them the ideal choice for mission-critical applications in satellite operations. Visit their website for full component details.
Passive Plus
www.passiveplus.com

NEW SPACE TO FULL SPACE CRYSTAL OSCILLATORS FROM Q-TECH/AXTAL

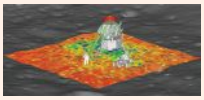
Q-Tech/AXTAL offers a wide selection of oscillators (XOs, TCXOs, VCXOs, OCXOs, MCXOs, TCXOs and SAWs) for the entire spacescape, new space (LEO) satellite clusters to

full space (GEO) and beyond. Wide range of frequencies, exceptionally low phase noise, wide temperature range, excellent single event effects performance, TIDs ranging from 50kRad (LEO) to over 100kRad (full space).
Q-Tech Corporation
www.q-tech.com/brochures

HIGH-POWER K-BAND SSPA

QuinStar QBP-21014750: K-band high-power SSPA designed for space and airborne applications, the QBP-21014750 is a high-efficiency GaN SSPA operating at 20.2–21.2 GHz. Delivering 49 dBm saturated output with 5 dBm drive, it ensures reliability with over-temperature protection and advanced thermal management. Precision-crafted in our modern facility, it offers superior RF performance. Learn more at IMS2025, Booth 1735, or via sales@quinstar.com.
QuinStar Technology
www.quinstar.com

WIRELESS INSITE®
VENDORVIEW



Remcom's Wireless InSite® includes new features to predict the performance of 4G/5G and Wi-Fi systems in the complex landscape of the moon, ensuring robust communications for NASA's Artemis missions. Wireless InSite ensures accurate simulation of RF propagation on the moon by providing the ability to import LRO LOLA terrain datasets and accurately transform the coordinates of RF mobile systems upon lunar terrain. By capturing the reflection and refraction characteristics inherent to the moon's landscape, these capabilities will be essential for future lunar missions.
Remcom
www.remcom.com

SMART AMPLIFIERS

Renaissance Electronics is introducing GaN-based SWaP-C amplifiers with high linearity and efficiency

across various power levels. Power and temperature monitoring enclosed in a 3 × 3 × 1 in. robust package optimized for outstanding thermal performance. Features include a wide input voltage range (5 to 32 V), 1 to 8 W variable output port at S-Band, 12 W option available for UHF and In-built AGC supporting wide input power range and output power.
Renaissance
www.rec-usa.com

PHASE & INSERTION LOSS STABLE CABLE ASSEMBLIES

Samtec's Nitrowave™ high performance microwave cable offers improved phase and amplitude stability over flexure. Performance is optimized at frequencies that go beyond traditional industry targets to support emerging applications in the aerospace/defense, test and measurement and instrumentation markets.
Samtec
www.samtec.com

RF SOURCE

The SC5531A is an RF source covering the frequency range of 100 kHz to 23 GHz with fast frequency switching, milli Hertz tuning resolution, and low phase noise. It accepts 10 MHz, 100 MHz and 1.6 GHz reference signals and outputs its internal 1.6 GHz reference signal that could be used to synchronize multiple SC5531A devices, greatly improving their relative phase stability. The product features fine amplitude adjustment in the range of -40 to 15 dBm.
SignalCore Inc.
www.signalcore.com

THE ULTIMATE RF CONNECTOR FOR SPACE APPLICATIONS

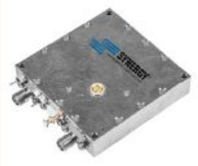
Smiths Interconnect (SINT) draws on decades of military/aerospace experience to offer SMPM Mini-Lock connectors. Patented technology provides the ultimate reliability and excellent RF performance in harsh environments.

More than 50 lbs. of pull strength is assured with an audible click while delivering low insertion and return loss up to 110 GHz. In addition, the connectors are small, compact and blind-matable for easy integration. SINT's RF cable assemblies are trusted by industry leaders around the world.
Smiths Interconnect
www.smithsinterconnect.com

SOLID-STATE POWER AMPLIFIER MODULE

Stellant leads in delivering high-power solid-state and TWT-based MPM RF modules. Utilizing proven RF GaN amplifier designs and TWT MPMs, Stellant's compact, efficient solutions offer RF power density across 20 MHz to 40 GHz. Perfect for communication, electronic warfare and radar systems with space, cooling and power constraints, these advanced designs excel across ground (mobile and fixed), surface and airborne platforms, setting the standard for RF performance and amplifier innovation.
Stellant Systems
www.stellantsystems.com

ULTRA-LOW PHASE NOISE PLDROS



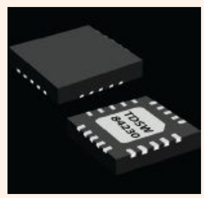
The KSFLOD series of ultra-low noise phase locked dielectric resonator oscillators (PLDROs) offer unmatched phase noise performance in a variety of optimized CW signal source applications in satellite converters, radar and RF/microwave test and measurement equipment. The output power in standard products is available up to +20 dBm. Accompanying reference frequency multipliers are also available to supply reference frequencies up

to 1600 MHz from an external 100 MHz standard reference source. The loop bandwidth can be several 100 kHz wide, allowing for fast acquisition, locking and higher stability.
Synergy Microwave Corporation
www.synergymwave.com

OCXO (NA-100M-6700) FOR SATELLITE COMMUNICATION LANDING STATIONS

Taitien's NA-100M-6700 OCXO delivers ultra-low phase noise, exceptional frequency stability and low g-sensitivity (as low as 0.05 ppb/g), ensuring precise timing in satellite communication landing stations. Its wide temperature tolerance allows reliable operation in harsh environments, maintaining signal integrity for seamless data transmission. With superior performance in frequency stability and vibration resistance, the NA-100M-6700 enhances uplink and downlink accuracy, making it an ideal choice for ground stations, gateways and critical satellite infrastructure.
Taitien
www.taitien.com

GAN HIGH-POWER SPDT RF SWITCH, 30 MHZ TO 5 GHZ



Teledyne HiRel Semiconductors TDSW84230EP GaN high-power SPDT RF switch operates from 30 MHz to 5 GHz and features 20 W CW power handling, low insertion loss of 0.2 dB and high port isolation of 45 dB. Housed in a compact QFN package, it replaces traditional PIN diode switches and is optimized for aerospace and applications. The GaN HEMT process ensures high breakdown voltage and saturation current, making it ideal for military communication systems. Commercial devices are available now for shipment.
Teledyne HiRel Semiconductors
www.teledynedefenseelectronics.com

MOUNTED ROTARY STEP ATTENUATORS

These Telonic Berkeley step attenuators are available in nine different models with attenuation ranges from 1 to 100 dB, in steps of 1 to 10 dB. There are two basic case designs, both 1.31 in. diameter with lengths of 1.50 in. (subminiature) and 2.29 in. (miniature). This mechanical configuration reduces panel mounting space to a minimum and also permits incorporation of these attenuators into many existing designs.
Telonic Berkeley
www.telonicberkeley.com

HIGH-PERFORMANCE PCB LAMINATES

With 30+ years' expertise, Transline Technology specializes in working closely with engineering innovators that push RF, microwave and mmWave PCB boundaries. Their hands-on approach makes them an extension of your engineering team. Transline stocks a wide variety of high performance PCB laminates, enabling rapid prototype delivery.

Transline Technology
www.translinetech.com

FROM EARTH TO ORBIT, REDEFINING THE LIMITS OF COMMUNICATION

The WAVEPIA WPGC0912020 is designed to enable high performance short- and long-range transmissions for radar and satellite communication systems. Operating across 9 to 12 GHz, it delivers exceptional efficiency (48 percent PAE) and saturated output power (43.2 dBm) at 20 to 22 V. Engineered for precision ground surveillance, critical military applications and dependable space communications, it offers unparalleled stability and durability. Trust WAVEPIA for cutting-edge solutions that enhance accuracy, power and reliability in mission-critical operations.

WAVEPIA
www.wavepia.com

SPACE & MIL-QUALIFIED TO 50 GHZ

Weinschel Associates is a leading manufacturer of broadband RF and microwave products for space, military and commercial markets from DC to 50 GHz. Products include high-power and high frequency attenuators, terminations, power dividers and splitters, adapters, DC blocks and more. Problems with other vendors' part obsolescence? Weinschel Associates is your solution with cross-referenced replacements or build to form, fit and function if needed. Visit them at IMS booth #630 or contact sales@weinschelassociates.com for more information.

Weinschel Associates
www.weinschelassociates.com

Mobile GHz Signal Acquisition and Generation

Spectrum Instrumentation GmbH
Grosshansdorf, Germany

Spectrum Instrumentation has released a new series of ultrafast arbitrary waveform generators (AWGs) and digitizers that can be controlled easily over Ethernet. These NETBOX instruments are ideal for automated and/or remote applications. They connect directly to PCs, laptops or even the company network, using a simple Ethernet/LXI cable. Small and compact, they can be placed almost anywhere, running as standalone units or, as they are fully programmable, integrated into sophisticated automated testing systems. ***Figure 1*** shows the NETBOX, weighing less than 7 kg.

The new instruments offer test engineers, scientists and designers a cost-effective means of producing and acquiring electronic waveforms up to microwave frequencies, with high purity and low distortion. For signal acquisition, the DN2.33x series of digitizers offers sampling rates of up to 10 GSPS, bandwidths of up to 4.7 GHz and uses the latest 12-bit analog-to-digital converter technology. The DN2.63x series of AWGs makes an excellent companion product line, generating waveforms at rates up to 10 GSPS with bandwidths up to 2.5 GHz, utilizing 16-bit digital-to-analog converters. Single- and dual-channel models are available, offering a choice of maximum sample rates and bandwidths to create perfect-fit solutions.

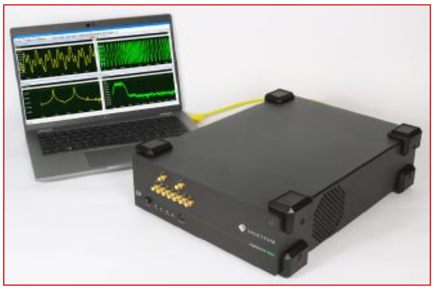


Fig. 1 **The NETBOX offers mobile and easy operation.**

Along with their ultrafast sample rates and wide bandwidths, the products feature onboard waveform memories of up to 8 GS (16 GB) per channel. Large memories enable the acquisition and generation of long and complex signals. For example, running at 10 GSPS, single-shot or transient waveforms can be captured or generated over a full 800 milliseconds with a sample resolution of just 100 picoseconds. If required, the large memories can also be partitioned and combined with different trigger, acquisition and generation modes. This enables optimized memory usage, allowing the products to capture or replay multiple signals.

For easy system integration, the NETBOX products include a host of signal inputs and outputs via standard front panel connectors. These connector functions include channel, trigger and clock signals, lines for multi-

Fig. 2 NETBOX front plate.

purpose digital I/O and status flags. If needed, there is even a high speed Digital Pulse Generator option. NETBOX products have a variety of connectors on the front plate, making it easy to integrate a NETBOX into any test application. ***Figure 2*** shows the front plate of a NETBOX unit.

Each NETBOX product is shipped with Spectrum's graphical user interface (GUI), SBench 6 Pro, which provides local, interactive control, waveform acquisition, creation, display, signal analysis and documentation. It also includes useful data import and export functions, making it easy to transfer data between different NETBOX instruments, as well as third-party hardware and software products. If you wish to run your own application-specific code, the units are fully programmable when running on Windows or LINUX operating systems. All NETBOX products come with software development kits for programming in a host of different languages, including C++, Python, MATLAB and LabVIEW.

In general, Spectrum Instrumentation offers over 110 variants of NETBOX products, allowing customers to pay only for the speed, channels and features they truly need. Working together, the NETBOX digitizer and AWG products form a formidable team that is perfect for stimulus-response or closed-loop type applications.

MULTITONE TESTING FOR AMPLIFIER LINEARITY

This section contains a real-world example of the advantages and benefits of the NETBOX product line. Multitone testing is a common way of assessing the linearity of amplifiers. Tests are frequently conducted using dual sinusoidal signals with high signal purity. The two signals are applied to the input of an amplifier and the distortion resulting from the nonlinearities in the amplifier is measured. The Spectrum DN2.63x series AWGs can generate a dual-tone signal in a single chan-

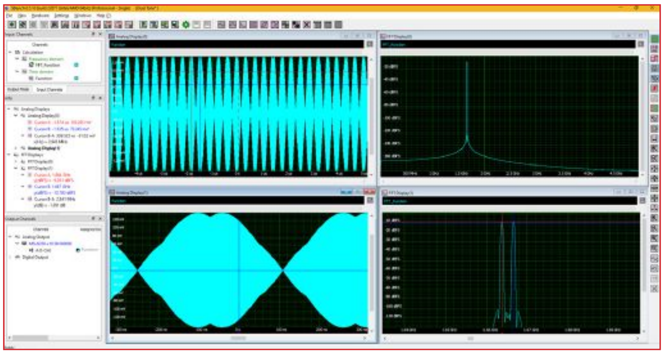


Fig. 3 A dual-tone test signal consisting of the sum of two sine waves.

nel with very low distortion, as shown in ***Figure 3***.

The software tool, SBench 6 Pro, can create the data for the required dual-tone waveforms by summing two sine waves. In this case, the Spectrum DN2.636 series AWG is producing sine waves at frequencies of 1.664 and 1.667 GHz. The data is created using a formula in the GUI's function generator. The resultant waveform shows a beat pattern equal to the frequency difference between the two sinusoidal components. This is shown in the top and bottom left quadrants of Figure 3. The FFT of the signal, as shown in the upper right quadrant of Figure 3, reveals a combined frequency peak at 1.66 GHz. Horizontally expanding the FFT shows the two frequency components measured by the cursors. The data is transferred to the AWG memory and the output signal is then applied to the amplifier under test. A DN2.336 digitizer is then used to acquire and measure the amplifier's output. ***Figure 4*** shows the two-tone input signal on the left and the acquired time signal on the right. The figure shows that the acquired time signal retains the beat frequency of the two carriers.

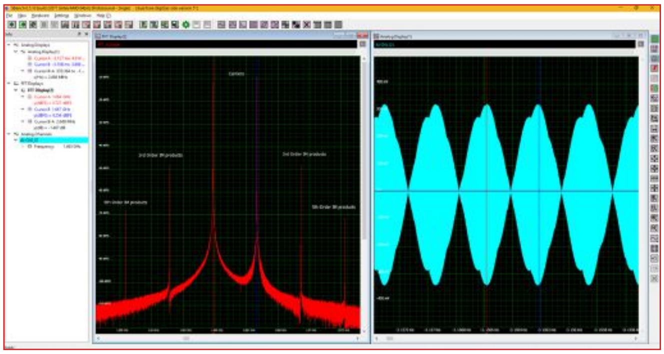


Fig. 4 **Two-tone test input and results.**

The frequency spectrum of the acquired signal is expanded about the carriers to show the classic intermodulation mixing components. Cursors mark the carrier frequencies in the spectrum trace and the beat frequency in the time domain view. The third-order mixing products result from mixing a second harmonic of one of the carrier signals with the other carrier. Other mixing products, such as the second- and fifth-order products, occur due to the similar mixing of harmonics and the carrier signals. The amplitudes and frequencies of these harmonic and mixing components are used to compute several amplifier performance figures of merit. The purity of the signals from the source determines the limits of this type of measurement. As shown in the example, the Spectrum NETBOX instruments offer a straightforward method for generating and acquiring high frequency, high purity and low distortion waveforms.

VENDORVIEW

Spectrum Instrumentation GmbH
Grosshansdorf, Germany
www.spectrum-instrumentation.com

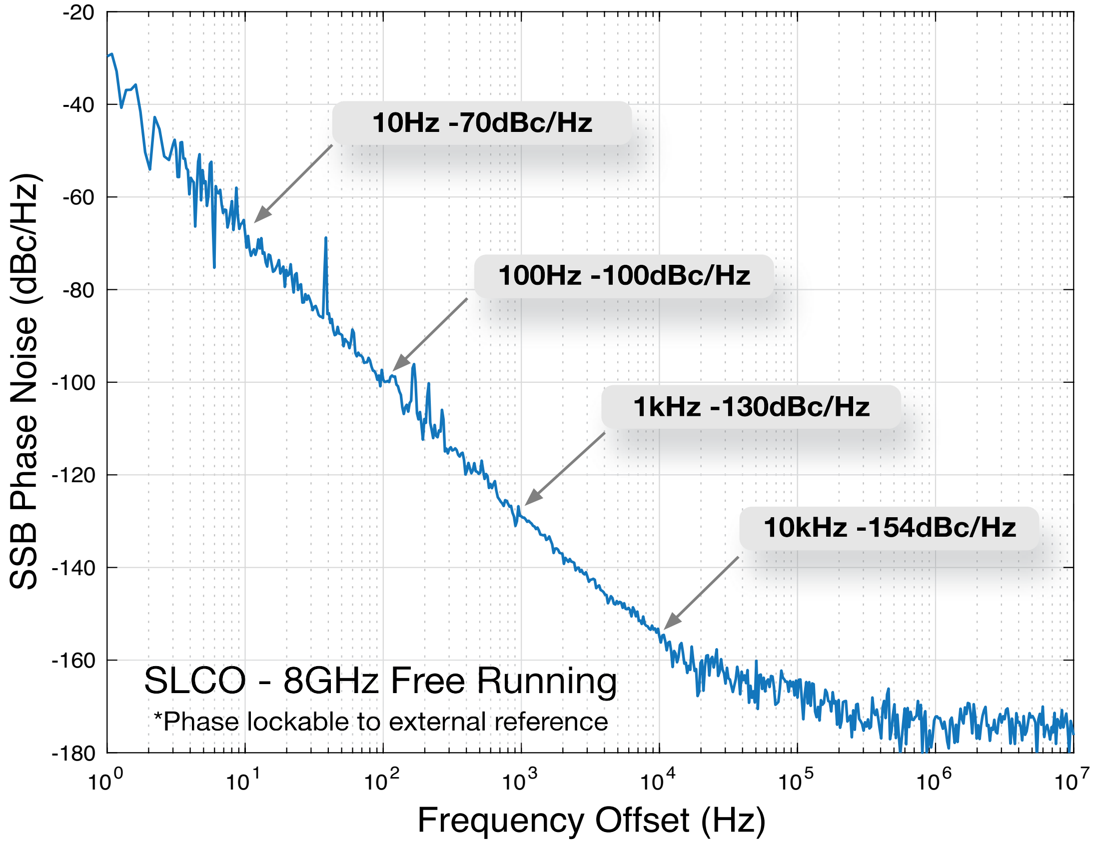
saetta labs

Boulder, Colorado USA

saettalabs.com

- Thermally Stabilized
- Ext Ref Input (PLL)
- Status Display
- Lock Detect

Sapphire Loaded Cavity Oscillators
X-Band



Solid-State/Magnetron Weather Radar Transmitters

Pulse Systems
Easton, Mass.

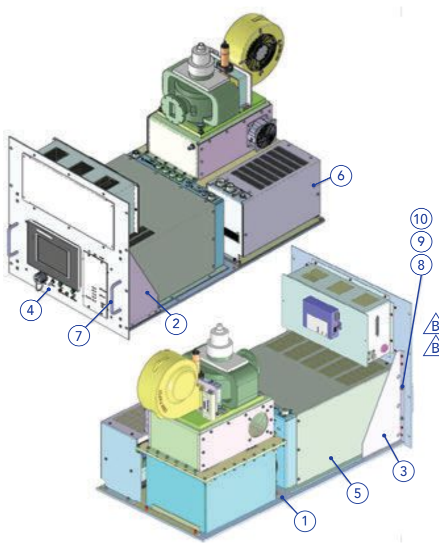
Providing early warning for extreme weather has become an increasingly important requirement for weather radar systems as populations have become larger and denser. A recent report from the International Chamber of Commerce[1] predicts that extreme weather events will cost the global economy more than $2 trillion over the next decade. When the loss of life is added to the economic impacts, the need for more powerful and sophisticated weather radar systems becomes apparent.

Since the early 1970s, Pulse Systems has been a globally recognized leader in the development, design and manufacture of magnetic components, radar subsystems and RF sources. These reliable, high-quality, high performance products range from solid-state and tube-based transmitters to power supplies for a variety of radar-based applications in defense and industrial markets. To support the evolving needs of the weather radar market, Pulse Systems has released the TR-2900. The complete weather radar system is shown in ***Figure 1***.

As shown in Figure 1, the TR-2900 weather radar system is large and complex. It consists of a high-voltage power supply, a control panel and a pulse modulator system comprised of circuitry and RF driver stages powering a CPI magnetron as an output stage. The magnetron provides a minimum of 250 kW of peak power at the output flange from 5.2 to 5.9 GHz. The system is designed to be connected directly to an antenna as a single polarization system. It can be configured for dual-polarization applications by incorporating some additional microwave components. ***Figure 2*** shows an assembly drawing of the mechanical considerations along with these electrical functions.

Conventional weather radar

Fig. 1 **TR-2900 weather radar system.**



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TR2900RevB-001-001	Transmitter MTG Plate	1
2	TR2900RevB-001-002	Control Panel Right Support Bracket	1
3	TR2900RevB-001-003	Control Panel Left Support Bracket	1
4	TR2900RevB-010-000	Control Panel Assy	1
5	PS2900RevB-000-000	Power Supply Assy	1
6	MG2900RevB-000-000	Modular Assy	1
7	7146	Keystone Round Handle	2
8	91735A830	Screw #10-32 5/8"	4
9	93852A101	Washer #10	4
10	92147A430	Lock Washer #10	4

Fig. 2 **Mechanical assembly drawing showing electrical functions.**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1.0mm Connector
DC to 110GHz, VSWR≤1.2
1.35mm Connector
DC to 90GHz, VSWR≤1.2
1.85mm Connector
DC to 67GHz, VSWR≤1.2
2.4mm Connector
DC to 50GHz, VSWR≤1.2
2.92mm Connector
DC to 40GHz, VSWR≤1.15
3.5mm Connector
DC to 34GHz, VSWR≤1.15
1.35mm Series up to 90GHz
Test Cables up to 110GHz
Frontlynk Technologies Inc.
www.frontlynk.com
Tel: +886-6-356-2626
Fax: +886-6-356-6268
E-mail: info@frontlynk.com

TABLE 1

TR-2900 PERFORMANCE SPECIFICATIONS

Parameter	Min.	Max.	Typical	Notes
RF frequency (GHz)	5.2	5.9		
Output power (kW)	250			
Input voltage (V_{AC})			220	50/60 Hz single phase
Pulse width (μSec)	0.5	2.0		
Power factor correction (V_{DC})			+/-360	Bus voltage
Control panel voltage (V_{DC})			24	
Input line current (A)		7.5		
Peak cathode current (A)			24	

systems use a line-type modulator system, where the pulse width is determined by the characteristics of the system's pulse-forming network. This approach creates tuning challenges for the user. To mitigate this issue, the Pulse Systems TR-2900 has been designed with a programmable logic controller (PLC) to provide variable pulse widths. The pulse width of this system can be set anywhere from 0.5 to 2.0 µsec with a 0.1 percent (0.001) duty cycle. An Allen Bradley integrated PLC with pre-selectable pulse widths at 0.5 µsec, 0.8 µsec, 1.0 µsec and 2.0 µsec allows for the variable pulse width capability.

The complete modulator system consists of a supervisory control circuit governing the operating conditions of the two drive circuits and the output section. The output section consists of a solid-state switch assembly, a high-voltage step-up pulse transformer, a DC filament power supply and a pulse-shaping network. To generate the narrow pulses that weather radar applications may require, the rise and fall times of the RF signal must be short. Achieving the necessary pulse rise and fall times places stringent considerations on the magnetic material that is used in the pulse transformer design and the proper winding configuration. These are two areas that benefit from Pulse Systems' long heritage and expertise in magnetic material and components.

Pulse Systems' heritage and expertise also come into play with the magnetron-based output stage. To prevent magnetron modding, the rate of change for the cathode voltage must be controlled. We have determined that the cathode voltage rate of change must be kept in the 60 to 70 kV/µsec range. The high-voltage section of the modulator, including the pulsed-voltage control of the magnetron cathode, is in an oil-filled section of the weather radar system. The control function for the modulator includes a solid-state switch assembly

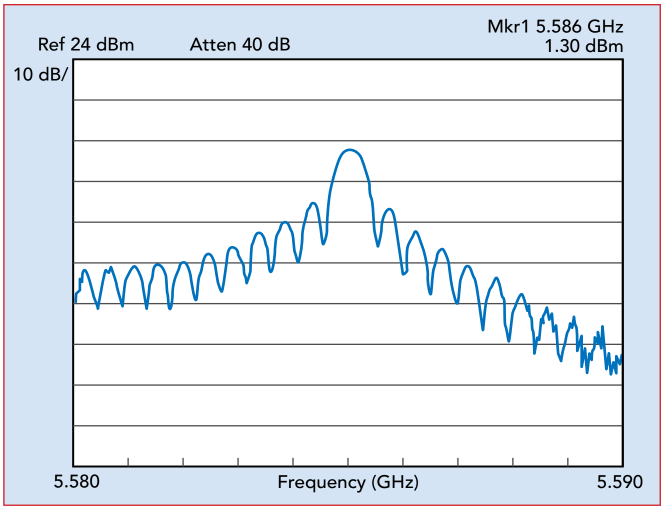


Fig. 3 **TR-2900 output power.**

mounted on a heat sink for easy access. This switch assembly is turned on during the positive portion of the drive pulse and kept off when the drive pulse goes to a negative bias level. The high-power switching capability of these devices and their high efficiency make them well-suited for weather radar systems. The output pulse width of the system bears a close relationship to the drive pulse of the switch driver.

The power supply for the system is also an important design consideration. In this case, the high-voltage power supply has a series resonance full-bridge configuration that uses SiC FETs as the main switching elements. This power supply configuration operates at an 80 KHz clock frequency with a pulse width modulation regulation scheme. Some representative performance characteristics of the TR-2900 weather radar system are shown in ***Table 1***.

Figure 3 shows the output power of the TR-2900 weather radar transmitter. To safely accommodate the power levels, the output signal has been attenuated by 40 dB. The trace shows the output power at a center frequency of approximately 5.586 GHz with a 2.0 µsec pulse width.

With a long heritage and history designing transmitters for radar applications, Pulse Systems has introduced the TR-2900 weather radar system. This system incorporates solid-state technology, in addition to magnetron technology, to address some of the challenges created by previous solutions in the segment. The result is a high performance, high-power system that supports the evolution of weather radar system capabilities.

Reference

1. "New report: extreme weather events cost economy $2 trillion over the last decade," *International Chamber of Commerce*, Nov. 11, 2024, Web: "https://iccwbo.org/news-pA recentublications/policies-reports/new-report-extreme-weather-events-cost-economy-2-trillion-over-the-last-decade."

Pulse Systems
Easton, Mass.
pulsesystem.com

Small Form Factor Power Sensor

LadyBug Technologies announced the expansion of its small form factor power sensor product line by introducing the new LBSF09L. This advanced power sensor operates across a frequency range of 4 kHz to 9 GHz and features an excellent dynamic range, making it ideal for a wide array of embedded and automated test equipment (ATE) applications. This new addition to the LBSF product line is the smallest power sensor in the world with traceability.

The LBSF09L embodies LadyBug's commitment to precision and integration, encapsulated in their tagline: "Designed for metrology, built for integration." It offers standard USB HID and USBTMC interfaces plus optional HiSLIP LAN, SPI and I2C interfaces. These interfaces enable seamless integration into various systems, allowing the self-contained power sensors to be used without additional equipment. Its compact design suits embedded applications requiring traceability, facilitating easy integration into ATE systems.

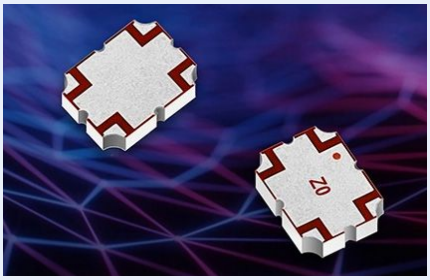
Key benefits include high accuracy for reliable measurements, fast acquisition speed and patented No-Zero No-Cal thermal characterization that maintains performance and accuracy under varying temperature conditions. Option LTX extends the low-temperature operating range to -50°C for operation in cold environments, making the sensor ideal for satcom, space and defense applications. Additionally, the LBSF09L provides superior dynamic range and sensitivity, accurately measuring signals with any modulation bandwidth.

With a width of 0.8 in. and a height of 1.6 in., the LBSF09L can comfortably fit multiple units within a 1 RU rack space. Programmatic measurements can be performed using standard SCPI power meter commands and queries, such as Read? or Fetch?, across any of the LBSF09L's interfaces.

Please visit LadyBug's website for more information on the LBSF09L power sensor and the complete product line.

VENDORVIEW

LadyBug Technologies
Boise, Idaho
www.ladybug-tech.com



High-Power RF Coupler for Wireless Applications

Johanson Technology's 0850HC47A0300001E is a 300 W, 90-degree hybrid RF coupler designed for high-power applications in the 700 to 1000 MHz range. This hybrid coupler is ideal for LTE/4G/5G base stations, DCS, AMPS and other wireless system applications. The 0850HC47A0300001E has a maximum insertion loss of 0.4 dB, minimum isolation of 23 dB and a hybrid phase balance of 90 ±3 degrees, which enables superior signal integrity.

Some of the key features of the 0850HC47A0300001E include:

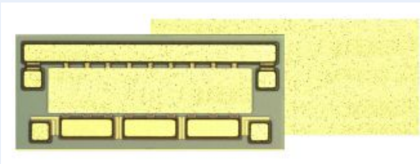
- Handles up to 300 W (CW) for high-power RF systems
- Low insertion loss and high isolation for improved efficiency
- Operating temperature range of -55°C to +125°C
- Optimized for PCB integration with Ni/Sn termination.

The 0850HC47A0300001E can be customized for applications in the 400 to 9000 MHz range. The electrical characteristics can also be tailored for specific system requirements. The hybrid RF coupler is designed for seamless integration and PCB layout guidelines are available to optimize impedance matching. The robust construction ensures reliable operation in demanding environments.

Managing power levels, thermal efficiency and signal integrity are critical in high-power RF applications. This coupler helps solve RF design challenges by providing a rugged, low loss solution to help engineers optimize system performance. Contact Johanson for PCB layout files and customization options.

Johanson Technology has over 60 years of experience specializing in designing and manufacturing high-quality RF and microwave ceramic chip capacitors, inductors and integrated passives.

Johanson Technology
Camarillo, Calif.
www.johansontechnology.com/contact/request-a-sample/



DC to 6 GHz 50 W GaN-on-SiC Transistor

The GRF0030D from Guerrilla RF is a bare die, high performance GaN-on-SiC HEMT. It supports DC to 6 GHz applications requiring pulsed, CW and linear operation modes. The GRF0030D is also suitable for operation using 50 V or 28 V supply rails.

GaN has many desirable characteristics compared to alternative transistor technologies. These include higher power density, lower output capacitance and increased breakdown voltage. These characteristics combine to improve efficiency and bandwidth in compact application-level footprints. The transistor delivers up to 50 W peak power and greater than 60 percent peak drain efficiency when operated from a 50 V supply rail. The transistor exhibits a 150 V breakdown voltage, 225°C maximum junction temperature and a 10:1 VSWR capability, suitable for operation in demanding environments.

The GRF0030D is supported with S-parameter and load-pull data measured in a 3 mm x 3 mm QFN16 package from 1 to 6 GHz at 50 V and 28 V drain voltages. The GaN-on-SiC bare die transistor is well-suited for compact, rugged, high-efficiency applications. This makes the device ideal for S-Band (2 to 4 GHz) and lower C-Band (4 to 6 GHz) radar, communications and instrumentation applications.

Guerrilla RF provides high performance MMICs and their cores form the backbone of today's state-of-the-art RF and microwave communication systems. Each RFIC is tailored to meet the demanding requirements of wireless infrastructure-grade applications found in 5G, automotive connectivity, cellular boosters and DAS, military radios and wireless audio. Guerrilla RF's passion for creating the very best RFICs has led directly to their success as one of the fastest-growing semiconductor firms in the industry.

VENDORVIEW

RFMW
San Jose, Calif.
www.rfmw.com

Guerrilla RF
Greensboro, N.C.
www.guerrilla-rf.com

IMS2025 – The Wireless Golden Gateway

Pat Hindle, *Microwave Journal*

Taking place in San Francisco, Calif., this year, IMS2025 will be the largest gathering of RF and microwave engineers with about 9000 attendees and 500+ companies in the exhibition. There is a lot going on during the week so here are some of the highlights in chronological order to help with your planning.

SUNDAY

The Workshops start at 8 a.m. on Sunday and go through Monday covering various topics. The half-day Quantum Bootcamp also starts at 8 a.m. on Sunday, with the AI/ML Bootcamp starting in the afternoon.

Sunday evening is the RFIC reception, forum and plenary talks featuring Dr. John Smee, senior vice president of engineering at Qualcomm, discussing RFICs for 6G and Maryam Rofougaran, CEO and co-founder of Movandi, talking about next generation ICs for data centers and AI.

MONDAY

The RFIC Technical Sessions start Monday morning at 8 a.m. and run through Tuesday. There are panel sessions each day starting at noon Monday through Thursday. The half day Wireless Power Technologies Bootcamp and full day RF Bootcamp also start at 8 a.m. on Monday.

The IMS plenary session is Monday evening featuring talks by Arogyaswami J. Paulraj, Emeritus Professor at Stanford University, discussing Antenna Arrays for Communications, Positioning, and Sensing and Jin Bains, CEO of Mini-Circuits, discussing the Next Generation of RF Systems. Following that is the IMS Welcome Reception, which will be hosted at the San Francisco Museum of Modern Art (SF MOMA).

TUESDAY

The IMS Technical Sessions start Tuesday morning at 8 a.m. and run through Thursday covering field, device and circuit technology, passive and active devices/components, emerging technical areas, focus and special sessions and systems and applications.

The exhibition opens at 9:30 a.m. on Tuesday and runs through mid-afternoon on Thursday. There will be about 9000 total attendees with about 500 exhibiting companies. The Startup Pavilion will also be on the exhibition floor with a program of panel sessions and talks. The MicroApps typically given by industry experts on the exhibition floor also starts Tuesday morning and run through Thursday. The Startup panels sessions and talks will be mixed into the MicroApps sessions Tuesday through Thursday. The Industry Workshops start Tuesday morning and run through Thursday, covering practical simulation, test and device/component sessions.

The HAM Radio Social Networking Reception is on Tuesday starting at 6:30 p.m. The Women in Microwaves and Young Professionals affinity groups will also have events on Tuesday starting at 7 p.m. At the time of writing, the location of these events was not available.

WEDNESDAY

The Future G Summit will feature four sessions throughout the day, each focusing on a different theme: standards and regulatory progress towards the next G, AI in wireless communications, technologies for mmWave to THz and non-terrestrial networks. The Interactive Forum is Wednesday afternoon.

The IEEE Entrepreneurship Hard Tech Venture Summit is an innovation event that recognizes the unique challenges faced by early-stage hard tech startups. The Hard Tech Summit starts Wednesday and runs through Thursday at the Marriott Marquis.

There is an industry hosted reception on the exhibition floor starting at 5 p.m. on Wednesday and the MTT-S Awards Banquet will be hosted at the Marriott Marquis starting at 6:30 p.m.

THURSDAY

The IMS Closing session is Thursday afternoon featuring David F. Welch, founder and CEO of AttoTude, discussing Next Generation Networking in the Data Center.

FRIDAY

The ARFTG conference takes place on Friday.

IMS typically sets records for attendance and number of companies in the exhibition whenever it is located in San Francisco or Boston, so don't miss this opportunity to learn, network and catch up with old friends.

EXHIBITION DATES AND HOURS:	
Tuesday, 17 June 2025	09:30-17:00
Wednesday, 18 June 2025	09:30-18:00
Thursday, 19 June 2025	09:30-15:00

IMS WEEK AT A GLANCE:	
Sunday, 15 June 2025	• Workshops • Quantum Bootcamp • RFIC Technical Lecture • AI/ML Bootcamp • RFIC Plenary Session • RFIC Symposium Showcase • RFIC Reception
Monday, 16 June 2025	• Workshops • RF Bootcamp • WPT Bootcamp • RFIC Technical Sessions • RFIC Panel Session • Three Minute Thesis • IMS Industry Showcase • IMS Plenary Session • IMS Welcome Reception
Tuesday, 17 June 2025	• RFIC Technical Sessions • IMS Technical Sessions • IMS Student Design Competitions • IMS/RFIC Joint Panel Session • IMS Exhibition • MicroApps • Industry Workshops • RFIC Industry Chip Chat • MTT-S Journals Reception • HAM Radio Social • Young Professionals (YP) Reception • Women in Microwaves (WIM) Reception
Wednesday, 18 June 2025	• IMS Technical Sessions and Interactive Forum • Hands On Experiential Activity • IMS Panel Session • IMS Exhibition • MicroApps • Industry Workshops • Future Networks Summit • Industry Hosted Reception • MTT-S Awards Banquet
Thursday, 19 June 2025	• IMS Technical Sessions • Hands On Experiential Activity • IMS Panel Session • IMS Exhibition • MicroApps • Industry Workshops • WIM/YP Joint Panel Session • IMS Closing Session
Friday, 20 June 2025	• 105th ARFTG

Welcome to IMS2025

Steven Rosenau, *IMS2025 General Chair (R)*
Jay Banwait, *IMS2025 General Co-Chair (L)*

It is our great pleasure to welcome you to San Francisco, Calif., for the 2025 IEEE Microwave Theory and Technology Society (MTT-S) International Microwave Symposium (IMS2025), taking place on 15-20 June 2025 in the City by the Bay. Co-located with the IEEE Radio Frequency Integrated Circuits Symposium (RFIC) and the Automatic Radio Frequency Techniques Group (ARFTG) Conference, IMS2025 offers an unparalleled platform for learning, networking and collaboration. Over the past several years, a dedicated team of volunteers has worked tirelessly to design a truly unique and enriching experience. It is both a privilege and an honor to lead this team in organizing the MTT-S's premier event.

San Francisco has long captivated visitors with its iconic landmarks, including the Golden Gate Bridge, Fisherman's Wharf and Ghirardelli Square. Hop aboard the city's famed cable cars to explore world-class museums, theaters and cultural treasures that reflect San Francisco's innovative spirit. IMS2025 will be hosted at the newly renovated Moscone Center, which offers expanded spaces for technical sessions, engaging social events and an impressive exhibit hall showcasing the latest advancements in our field. Situated in the heart of San Francisco's vibrant SoMa (South of Market) district, the Moscone Center provides easy access to the city's renowned cultural and culinary attractions. Whether you join us for the technical program or the exhibition, IMS2025 promises to be a remarkable experience-set against the unforgettable backdrop of one of the world's most dynamic cities. IMS2025 in San Francisco is the place for professionals who are pushing the boundaries of microwave and RF technology.

Just as the Golden Gate is the gateway to San Francisco Bay, San Francisco is the gateway to Silicon Valley and the Bay Area-global innovation hubs in RF and microwave technology. This dynamic region is at the forefront of breakthroughs in wireless communication, radar systems and high frequency electronics, driven by a unique synergy of startups, established industry leaders and world-class research institutions. The Bay Area is shaping the wireless future, from pioneering advancements in 6G and satellite communications to transformative solutions in defense systems and IoT.

Collaborations with universities such as Stanford and UC Berkeley have propelled groundbreaking developments in semiconductors, spectrum management and energy-efficient design, directly influencing industries ranging from telecommunications to autonomous vehicles. Whether revolutionizing compact, high-power RF amplifiers or unlocking the potential of next-generation radar systems, the Bay Area continues to lead the way in RF and microwave innovation. IMS2025 invites you to join this dynamic ecosystem, where cutting-edge research and real-world applications converge to create a smarter, more connected world.

For the first time at IMS, IMS2025 will be co-located with the IEEE Hard Tech Venture Summit, a groundbreaking event designed to connect hard tech startup founders with visionary investors and manufacturers, fostering the growth of next-generation companies. This exciting addition to Microwave Week offers a unique platform for innovation and collaboration, featuring a series of panels and talks led by leaders in the venture capital and small business innovation research communities on Wednesday. Complementing these sessions, the Hard Tech Pavilion, strategically located near the StartUp Pavilion and MicroApps Theater on the exhibit floor, will provide an engaging networking space and showcase emerging technologies. The Hard Tech Venture Summit is a must-attend for anyone looking to engage with the vibrant startup ecosystem and drive the future of hard tech innovation.

IMS2025 will feature innovative and disruptive technologies through various thematic areas, including Systems and Applications; Aerospace and Security; Chips for Critical Infrastructure; and Emerging Technologies, Innovations and Entrepreneurship. This includes the co-located, industry-focused Future G Summit, jointly sponsored by the MTT-S and the IEEE Antennas and Propagation, Communications, and Photonics Societies. You can also look forward to industry-focused initiatives, such as the Industry Showcase, Best Industry Paper Award, and technical session keynotes, ensuring a deep connection between academic research and practical application.

Microwave Week kicks off on Sunday, 15 June 2025 with various informative workshops and bootcamps designed to keep participants at the forefront of industry trends or refresh their understanding of microwave fundamentals. Sunday also marks the start of our technical symposia, with the RFIC symposium leading the way. The IMS formally opens on Monday, 16 June with the Industry Showcase, highlighting cutting-edge technical advancements from participating companies, immediately followed by the Plenary Session.

The IMS Plenary Session will feature two talks. Jin Bains, CEO of Mini-Circuits and a global leader in the design and manufacturing of RF, intermediate frequency and microwave components, will present "Powering the Next Generation of RF Systems," exploring the evolving role of RF in modern technology. Arogyaswami Paulraj, Professor Emeritus at Stanford University and a pioneer of multiple input, multiple-output wireless technology, will deliver "Antenna Arrays for Communications, Positioning, and Sensing: Emerging Applications and Challenges," sharing insights into the breakthroughs that have shaped wireless systems worldwide.

After the plenary session, you are invited to the IMS Welcome Reception at the San Francisco Museum of Modem Art, just a short walk from the Moscone Center. With access to all five floors of this cultural landmark, you can enjoy works from iconic artists, such as Jackson Pollock, Andy Warhol, Diego Rivera and Frida Kahlo. Highlights include the breathtaking Living Wall, a vertical garden of more than 4,400 ft^2 and the open-air sculpture garden, offering a serene backdrop to stunning city views.

Throughout the week, various networking events provide opportunities to connect with colleagues and peers. Receptions for Women in Microwaves, Young Professionals, amateur radio enthusiasts and MTT-S journal reviewers will be held at exclusive venues on Tuesday evening.

The MTT-S Awards Banquet, a hallmark of the symposium, will take place on Wednesday, 18 June (registration is required). Finally, IMS2025 will close on Thursday, 19 June, with a special presentation titled, "Next Generation Networking in the Data Center," which explores the exciting convergence of wireless and optical technologies. This presentation is by David F. Welch, who is chief strategy officer at Infinera and an industry leader with more than 40 years of experience in the fiber-optics and optical communications industries. Microwave Week concludes with the 105th ARFTG Microwave Measurement Symposium on Friday, 20 June, to round out an incredible week of collaboration, discovery, and innovation.

With more than 550+ companies participating in the exhibition, the IMS is the world's largest gathering of the RF and microwave community. The IMS2025 Exhibition will take place in Halls A through E of the Moscone Convention Center, spanning more than 100,100 ft^2 of dedicated space. The exhibition will be open from the morning of Tuesday, 17 June, through the afternoon of Thursday, 19 June.

In addition to the extensive industry exhibition, you can look forward to various engaging events held within the exhibit hall throughout the week. Tuesday will feature the Student Design Competitions, while Wednesday will include the Interactive Forum. The MicroApps Theater will host continuous presentations featuring the latest advancements from participating companies.

Building on past success, IMS2025 will continue the StartUp Pavilion, first introduced in 2019, to spotlight emerging RF/microwave startups. The StartUp Pavilion will be near the MicroApps Theater and the new Hard Tech Pavilion.

On Wednesday afternoon, there will be a dedicated time slot for the exhibition, with no technical sessions scheduled, allowing you to fully explore the exhibit floor. The day will culminate in the Industry Hosted Reception on the exhibit floor. This event offers a chance to network and express gratitude to our Diamond, Platinum, Gold and Silver Prestige Sponsors for their generous support in making Microwave Week a success!

In closing, we are thrilled to welcome you to IMS2025 in San Francisco for Microwave Week, 15-20 June 2025!

MAKING WAVES

Disruptive Technology, Transformative Solutions

Accelerate design cycles, reduce costs and future-proof designs with Apollo MxFE™.

Analog Devices
https://players.brightcove.net/706011717001/VwMdg0a0kC_default/index.html?videoId=6328949464112

New Short Form Catalogue

Insulated Wire Inc. (IW) announced the availability of a new short form catalogue providing information on their market-leading range of products. The new brochure features information of IW's broad range of cables including low loss/phase stable, reflex, semi-rigid and non-RF products.

Insulated Wire Inc.
www.insulatedwire.com

Logus Space Qualified Waveguide Switches

Logus presents a small glimpse of their two decade space legacy right here.

Logus Microwave
logus.com/space/

Mtron Celebrates 60 Years

MtronPTI, now rebranded to Mtron, unveiled its evolved brand identity as part of its 60th anniversary celebration, marking 60 years of innovation, growth and transformation.

Mtron
www.mtronpti.com

Qorvo Technical Forums: Connect. Collaborate. Solve

Tired of Googling for solutions or waiting for an answer from tech support? Join Qorvo's Tech Forums to exchange ideas, troubleshoot issues and collaborate with engineers who speak your language.

Qorvo
Forum.qorvo.com

Quantic Wenzel Moves to New Facility

Quantic Wenzel has moved to a new 45,000-square-foot facility in Austin, Texas. Located just over a quarter mile from the previous site, the new facility features a state-of-the-art cleanroom, expanded engineering labs and optimized manufacturing areas to enhance production.

Quantic Wenzel
www.quanticwenzel.com

Agile Microwave Technology Inc.
Power Amplifier (PA)

Agile MwT's broadband 15 W PA, operating from 2 to 18 GHz, is offered in a compact module configuration. AMT-A0350 provides Psat of 15 W typical with flat small signal gain of 43 dB typical, ± 1 dB typical gain flatness with VSWR of 1.8:1 typical. Family of these PAs are competitively priced and ship from stock or short lead time. The new 20 W, 2 to 18 GHz model will be available in September 2025.

www.agilemwt.com

Analog Devices
Wideband Mixed-Signal Front-End Platform

VENDORVIEW

Apollo MxFE™ is a recently released wideband mixed-signal front-end platform offering instantaneous bandwidths as high as 10 GHz per channel while directly sampling and synthesizing frequencies up to 18 GHz (Ku-Band). This monolithic 16 nm CMOS device utilizes state-of-the-art high dynamic range ADC and DAC cores with the best spurious free dynamic range and noise spectral density available on the market today.

www.analog.com

Anoison
PT Cables

Anoison challenges the perception that top-quality test cables are always expensive and bulky. What is essential when choosing test cables? Low insertion loss, high phase stability, good RF shielding, proper connector selection, durability and flexibility. Why are high-quality test cables necessary? Accurate measurements, calibration impact and repeatability. Anoison PT family of test cables achieves these requirements with equal to or better specifications, less bulk and weight and at a significantly lower price than you are used to.

www.anoison.com

Anritsu
Compact Microwave Synthesizer Module – EcoSyn Lite MG36021A

Anritsu MG36021A 10 MHz to 20 GHz Microwave Synthesizer Module offers outstanding signal purity, best-in-class output power range and ultra-fast switching speed in a very small form factor of 3.94 × 3.94 × 0.79 in. It is powered with an external 12 V DC power supply and can be controlled through USB or SPI interfaces. MG36021A supports SCPI commands over USB interface. MG36021A is ideal for use as a LO for clocking and other embedded applications.

www.anritsu.com/en-us/

Cadence
AI-Enabled Computational Software

VENDORVIEW

Cadence enables engineers to drastically reduce turnaround times for RF to mmWave components and systems targeting 5G/6G, radar and other wireless applications. AI-enabled computational software supports next-generation design, analysis and front-to-back workflows for III-V and silicon MMICs/RFICs, PCBs, packages and systems implemented through multi-fabric heterogeneous integration.

www.cadence.com

Cernex Inc.
Rack Mount Broadband GaN High Power Amplifiers

VENDORVIEW

This line of GaN rack mount amplifiers is high power, efficient and can be customized to your project's needs. The model CBP-G30404040R-01 has a large band from 30 to 40 GHz, a high 40 dB gain and an output of 40 dBm. It is packaged in a 4U rack mount with cooling apparatus included and runs on standard AC power, so it will always be ready to strengthen your RF signal whenever you need it.

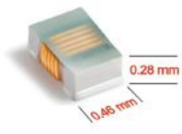
www.cernex.com

Ciao Wireless Inc.
Amplifiers

Standard models include units with instantaneous bandwidths covering 10 MHz to 6 GHz and 24 to 43 GHz (designs for 52 GHz available) to support both the uplink/downlink bands for 5G NR. Designs are available with O/P levels up to +33 dBm P1 dBPT and functions including detectors, switched/RF bypass (TTL), variable gain (digital and VVA) or full rack mount with Ethernet control. Multiple gain levels from 10 dB and up are available, with typical noise figures in the 3 to 5 dB range.

www.ciaowireless.com

Coilcraft
Wirewound Chip Inductors



With a maximum height of just 0.28 mm, Coilcraft's 0201HT Series wirewound chip inductors offer the industry's lowest profile in a 0201 size (metric 0603). They have significantly higher Q and lower DCR than similarly sized thin-film types and are optimized for high frequency impedance matching in applications such as cell phones, wearable devices, Wi-Fi, Bluetooth, GPS and LTE/5G IoT networks. As with all Coilcraft products, free samples of the 0201HT Series are available at www.coilcraft.com.

www.coilcraft.com

Copper Mountain
SN0916 16-Port 9 GHz Analyzer

VENDORVIEW

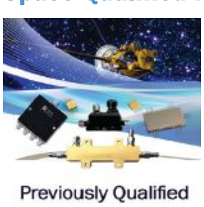
SN0916 is a versatile 9 GHz multiport solution with excellent dynamic range (140 dB typical) and measurement speed (24 μs). This VNA enables dependable, accurate testing of various DUTs: multiport antennas, integrated circuits, switches, interconnects, cable assemblies, diplexers, etc. SN0916 has a streamlined calibration process for reduced test times. The hardware can fit a 19 in. rack and utilizes robust, durable port connectors with ergonomic positioning for simplified cable connection.

Additional models are available in 6-, 8-, 10-, 12- and 14-port configurations.
www.coppermountaintech.com

CPI Electron Device Business
Electronic Components and Subsystems

CPI Electron Device Business (CPI EDB) is a manufacturer of electronic components and subsystems focused primarily on the defense market. The company develops, manufactures and globally distributes innovative and reliable technology solutions used in the generation, amplification, transmission and reception of microwave signals for commercial and military applications. CPI EDB serves customers in the communications, defense, medical, industrial and scientific markets.
www.cpi-edb.com

Crane Aerospace & Electronics
Space Qualified Products



Crane designs and manufactures high performance space qualified passive products for defense and commercial satellite customers. Crane can readily meet your specific space program needs with a selection of pre-qualified products that provide proven high-reliability design, shorter delivery and reduced costs. Products include power dividers, directional couplers, mixers, modulators, isodividers/combiners and beamformers. Find your solution with Crane's easy-to-use Product Finder at www.cranemicrowave.com.
www.cranemicrowave.com

Empower RF Systems
1212 Module

Empower RF Systems' 1212 module is a popular choice for fielded C-UAS applications. This SSPA operates from 2000 to 6000 MHz with 50 W minimum output

and showcases Empower RF's expertise in designing compact and reliable HPAs for EW systems. The 1212 is part of Empower's smart module family, offering digital controls and reporting, simplifying integration for cutting-edge C-UAS solutions. Its compact design, utilizing GaN technology, ensures high reliability and performance in demanding electromagnetic response scenarios.
www.empowerrf.com

Eravant
Frequency Extenders Boost VNA Measurement Capabilities

Frequency-extendable VNAs are increasingly vital for measuring components and antennas at mmWave and sub-THz frequencies. The STO series of transmit/receive frequency extenders supports bi-directional VNA measurements covering waveguide bands from 50 to 330 GHz. Internal frequency multipliers generate higher frequency RF and LO signals from lower frequency outputs provided by the VNA. Sensitive down-converters and effective noise filters yield dynamic range as high as 120 dB. Accessories include Proxi-Flange™ contactless waveguide adapters that eliminate the need for waveguide screws during tests.
www.eravant.com

ERZIA
Low Noise Amplifier

Covering a wide bandwidth of 1 to 40 GHz, ERZIA's ERZ-LNA-0100-4000-45-5 low noise amplifier is ideal for applications requiring broad frequency coverage, high data throughput and low distortion for optimal system performance across a range of demanding environments. It provides a gain of 45 dB with a noise figure of 5 dB and is designed to be compact and lightweight, making it ideal for your next system.
www.erzia.com

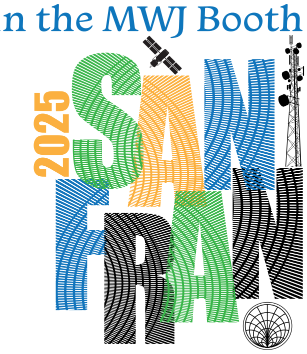
Exodus Advanced Communications
Exodus AMP40007, 8.0-12.0 GHz, 200 W

Exodus AMP40007 is designed for replacing aging TWT technology. A broadband, rugged EMC Class A/AB linear design for all modulations and industry standards. Covers X-Band 8.0 to 12.0 GHz, 200 W minimum/250 W typical with a minimum 53 dB gain. Excellent flatness, optional monitoring parameters for forward/reflected power, VSWR, voltage, current and temperature sensing for superb reliability. Exodus advanced technology in our compact 6U-chassis.
www.exoduscomm.com

Flann
USB Control Variable Attenuators Series 024

The Flann Series 024 USB control variable waveguide attenuator expands upon its range of variable attenuators to provide a compact, low-cost solution. An improved RF design enables an attenuation flatness of ±10 percent across the full waveguide band, within its guaranteed attenuation range. USB control provides quick and repeatable change in attenuation while also allowing the possibility to seamlessly incorporate the unit into larger and/or OEM systems.
www.flann.com

Pick Up Your T-Shirt in the MWJ Booth 935



Hasco

Redefining Flexibility and Performance with Littlebend® Cables

VENDORVIEW

HASCO's ultra-flexible cable line is the perfect solution for tight-space RF installations where performance cannot be compromised. Designed with a tight bend radius, low insertion loss and high shielding effectiveness, Littlebend® Cables deliver reliable signal integrity in even the most compact systems. Ideal for telecom, aerospace, medical and IoT applications, these cables provide the strength of traditional coaxial solutions with unmatched flexibility. Choose Littlebend® for space-efficient, high performance RF connectivity — where precision meets adaptability.

www.hasco-inc.com/littlebend

Reliable Solution for GPS Signal Splitting

The WM8PD-GPS-ACT-S 8-way power divider from Werbel Microwave delivers consistent performance from 0.9 to 2.2 GHz. Built in the U.S. with SMA female connectors, active circuitry and a durable aluminum case, it's designed for long-term reliability and precise signal output. When performance and trust matter, this is the smart choice for your RF setup. Explore seamless integration with trusted Werbel's quality active splitters, couplers and power dividers.

www.werbelmicrowave.com

Herotek, Inc.

Limiter

Herotek offers a wide range of mmWave limiters. Model LP18-40A is a limiter operating from 18 to 40 GHz with a 1 W CW power handling capability. It has an insertion loss of 4 dB maximum and 2:1 VSWR with a maximum leakage of +20 dBm at 1 W CW input power. This limiter comes in a hermetically sealed package with removable connectors for drop-in assemble and designed for both military and commercial applications.

www.herotek.com

JFW Industries

Five New USB Attenuator Models

VENDORVIEW

JFW has just added five USB attenuator models to the website. All five models are four-channel USB attenuators. Each attenuator is individually controlled using our GUI test software. They are the 50P-2089 SMA (0 to 95 × 1 dB, 200 to 6000 MHz), 50P-2137 SMA (0 to 95 × 1 dB, 30 to 3000 MHz), 50P-2138 SMA (0 to 95 × 1 dB, 1 to 1000 MHz), 50P-2141 SMA (0 to 63 × 1 dB, 200 to 6000 MHz) and the 50P-2142 SMA (0 to 63.5 × 0.5 dB, 30 to 3000 MHz) models.

www.jfwindustries.com

JQL Technologies

Isolators & Circulators

VENDORVIEW

JQL continues to expand the product base through innovation and launched a unique design of coaxial isolator and circulator in the frequency 27 to 31 GHz. This design has an integral housing with connectors. This device has extremely low insertion loss over the broad band, stable over temperature range and almost zero RF leakage, making it ideal for applications such as space, airborne terminals, man-pack radios and satcom-on-the-move.

www.jqltechnologies.com

Kratos

Multidisciplinary Microwave Components and Subassemblies

KRATOS Microwave Electronics Division is a globally recognized leader in the design and manufacture of high performance, state-of-the-art multidisciplinary microwave components and subassemblies used in defense, commercial and space applications. With over 50 years of proven expertise and an unwavering commitment to quality and reliability, the company continues to set industry standards. To meet the specific needs of its customers, Kratos offers cutting-edge technologies. These include embedded DSP, mixed-signal processing, system-on-chip devices, high-power amplifiers, FPGA and other advanced digital technologies.

www.kratosmed.com

Krytar

KRYTAR is Celebrating its 50-year Anniversary

VENDORVIEW

Founded by Thomas J. Russell in 1975, KRYTAR specializes in the high performance design and manufacture of ultra-broadband mmWave, microwave and RF components and test equipment for both commercial and military wireless communications, radar, space and thermal vacuum applications. Products cover DC to 110.0 GHz, including directional couplers and detectors, 3 dB hybrids, MLDD power dividers, terminations, coaxial adapters, bias tees, Butler matrices, Butlers with phase shift and monopulse comparators. The KRYTAR booth 1635 will be showcasing many new innovative products.

www.krytar.com

KVG Quartz Crystal Technology GmbH

Vibration Isolated OCXO D-RUG Module

This module features an ultra-low g-sensitivity OCXO encapsulated in a specially developed mechanical vibration damping system, with a package size of 80 × 80 × 50 mm. It demonstrates outstanding dynamic phase noise performance under harsh environmental conditions — including temperature, altitude, vibration and shock — as specified by MIL-STD-810G Change Notice 1 and RTCA DO-160G. The effective g-sensitivity is improved by a factor of 10 at 100 Hz and by a factor of 100 at 1 kHz.

www.kvg-gmbh.de

LadyBug Technologies

Spectrum of Power Sensor Products

VENDORVIEW

Visit LadyBug at booth 1731 to explore its wide selection of power measurement solutions. The company's sales engineers will demonstrate the LBSF09A, the world's most compact traceable power sensor, alongside its new LAN power sensor interface system featuring an embedded web-based power meter and interactive IO control. You'll also see its new waveguide power sensors, expanding LadyBug's measurement capabilities. Its engineers will be on hand to discuss these innovations as well as its custom thermocouple sensors, tailored to meet your specific needs.

www.ladybug-tech.com

Logus Microwave

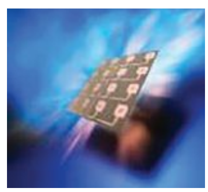
DC to 40 GHz 2.92mm SP6T Terminated Coaxial Switch

The Logus Microwave SP6T terminated coaxial switch sets a benchmark for RF/microwave applications with TTL control and fast switching. Supporting seamless signal routing across DC to 40 GHz, it features a latching design, single set of indicators, low 0.9 dB insertion loss, 50 dB isolation and 2.0:1 VSWR. Built for reliability, precision and durability, this switch excels in demanding environments requiring high frequency signal integrity.

www.logus.com

LPKF Laser & Electronics

Advanced Direct Laser Processing for Special Materials



LPKF's latest nano and picosecond ProtoLaser systems enable direct material processing for flexible, rigid-flex and RF/microwave substrates with patented rapid metal removal, precise drilling and cutting, controlled engraving and customizable settings. Advanced software allows on-demand production of precision devices in minutes within your lab.

www.lpkfusa.com

Luff Research

Fast-Switching Frequency Synthesizer

Mu-del Electronics, LLC, a Luff Research/Ironwave Technologies company, has developed a new fast-switching frequency synthesizer (Model FSFS) for modern ATE and EW systems. These synthesizers offer broadband (0.5 to 20 GHz), fast switching (less than 1 µsec) and exhibit low phase noise. These units operate on internal reference. The new product will be available June through August 2025.

www.ironwavetech.com/luff-research

Marki Microwave

Surface-Mount Quadplexer

VENDORVIEW

The MMPX-00002PSM is a MMIC surface-mount quadplexer capable of multiplexing DC to 6 GHz / 8 to 10 GHz / 12 to 14 GHz / 16 to 18 GHz signals. Passive GaAs MMIC technology allows production of smaller filter constructions that replace larger form factor circuit board constructions. Tight fabrication tolerances allow for less unit-to-unit variation than traditional filter technologies.

The MMPX-00002PSM is available as a 6 x 6 mm QFN. Low unit-to-unit variation allows for accurate simulations using the provided SnP files taken from measured production units.

www.markimicrowave.com

Massachusetts Bay Technologies Inc. (MBT)

Active and Passive Products

Do you have trouble meeting that RF/microwave diode, chip capacitor or resistor specification? Has cost been a factor? By going the extra mile, MBT's active and passive products are Class K ready to meet the growing need for your mission-critical application. Motivated by Performance, Focused on Reliability®

www.massbaytech.com

Maury Microwave

Characterization Solutions, Components and Services

Maury Microwave

Maury Microwave's mission is to give its customers confidence in their RF through THz measurements and models. They accomplish this by providing best-in-class and fully proven characterization solutions, components and services. Visit Maury Microwave at IMS booth #727 to learn about InsightPro™, the industry's premier unified software suite, designed to accelerate the component and subsystem measurement and model extraction workflow for research and development, design verification and small-scale production testing. Visit Maury's other booth #1032 to learn about its cables and interconnect solutions.

www.maurymw.com

Mercury
AM9018 Miniature Receiver Module

AM9018 is a fully integrated tuner module that provides high dynamic range coverage from 0.9 to 18 GHz. The analog IF output frequency is centered at 2 GHz with a 1 GHz bandwidth and a bypass path from 10 MHz to 6 GHz delivers direct spectrum capture capabilities. It can be mountable to a host circuit board for use in multi-channel receiver applications and multiple tuner sets can be configured to work together for coherent operation and N-channel applications.

www.mrcy.com

MIcable Inc.
2-8 GHz, 30/40 dB, 400 W, High Power Dual-Directional Coupler

VENDORVIEW

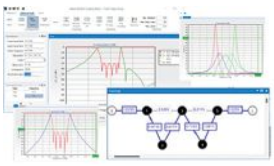
MIcable 2 to 8 GHz, 30/40 dB, 400 W, high-power dual-directional coupler has DC pass capability. It has excellent main-line/coupling VSWR (1.4:1/1.4:1 maximum), low insertion loss (0.4 dB maximum), excellent coupling (30/40±0.8 dB maximum) and flatness (±0.9 dB maximum), high directivity (14 dB minimum) and 400 W CW power handling capability. It can be widely used in 5G, testing, instrumentation, PA, transmitter and other fields.

0.5-6 GHz, 100 W, Surface-Mount 90° Hybrid

MIcable just released the new 0.5 to 6 GHz high power surface-mount 90-degree hybrid. It has low insertion loss (1.2 dB maximum), low VSWR (1.5:1 maximum) extremely good amplitude unbalance (±1 dB maximum) and phase unbalance (±6 degrees maximum), high isolation (15 dB minimum) and 100 W power handling capability with excellent stability and heat dissipation ability in a small package. It is suitable for power amplifier, power combining network, antenna feed network, modulator and phase shifter applications.

www.micable.cn

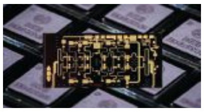
MICIAN
µWave Wizard Coupling Matrix



The all-new coupling matrix synthesis feature enables the fast design of filters with inline, folded, triplet, quadruplet, dual-mode or user-defined topologies. The tool provides precise control with real and pairs of complex frequency transmission zeros. Users will take advantage of integrated non-resonating node for synthesizing extracted pole filters and can monitor return loss, rejection, insertion loss, group delay and resonator Q-factor in real time. Coupling issues in measured or simulated filter responses can be identified and adjusted by manually manipulating coupling parameters via intuitive slider controls. The tool also supports the extraction of the coupling matrix from simulated or measured S-parameter data for bandpass filters with a given topology.

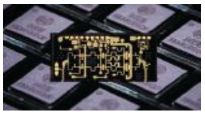
www.mician.com

Miller MMIC
GaN Power Amplifier 13-16 GHz 40 W 24 V 1.6A



The MMGP526 from Miller MMIC is a high performance GaN PA operating from 13 to 16 GHz, delivering up to 40 W saturated output. Designed for X- and Ku-Band systems, it offers high efficiency, linearity and ruggedness. Ideal for radar, satcom, EW and RF modules, it supports CW and pulsed modes. Built on GaN-on-SiC, it ensures excellent thermal handling, reliability and compact integration — making it a strong choice for demanding microwave and high-power RF applications.

Distributed Broadband Amplifier DC-70 GHz Gain 14 dB P1dB +18 dBm



The MMW5FP from Miller MMIC is a high performance distributed amplifier covering DC to 70 GHz. It offers 14 dB gain, +18 dBm P1dB and 4 dB noise figure. Designed for ultra-wideband applications, it ensures low noise, flat gain and excellent linearity. Ideal for high speed communications, optical transceivers, test systems, broadband EW and mmWave subsystems requiring compact, consistent performance.

www.millermmic.com

MilliBox
Benchtop mmWave Radar Testing Setup

MilliBox has a range of OTA test setups (MBX33R) specifically designed for mmWave radar measurements. They feature MBX3x large cavity benchtop anechoic chamber, GIM04 3-Axis DUT positioner and up to nine fixed or oscillating wall-mounted trihedral corner reflectors. Radar target simulators can be mounted inside the chamber for controlled parametric testing. 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.
Wideband Synthesizer

The MI-WAVE 958 Series wideband synthesizer is a high performance, GUI-controlled solution for ultra-wideband applications. It supports CW, frequency sweep, frequency hop and external trigger modes, with remote operation via Wi-Fi or Ethernet. Key features include internal filtering, low phase noise, adjustable charge-pump current, remote RF on/off control and single supply operation (8 to 15 V). Compatible with 10 to 250 MHz references and featuring temperature monitoring, it ensures precision and reliability. Perfect for ATE, telecom, satellite, embedded systems, secure communications and EW applications.

www.miwv.com

Mini-Circuits

3.5 W MMIC Power Amplifier, 8 to 12 GHz

VENDORVIEW

Mini-Circuits' new 3.5 W MMIC PA provides high dynamic range with significant headroom for high PAPR signals from 8 to 12 GHz. Nearly 30 dB of gain and 43.8 dBm OIP3 make the PMA5-123-3W+ an excellent driver stage for pulsed or linear systems. This model comes in a 5 × 5 mm QFN-style package, ideal for shoehorning into dense board layouts and meeting demanding SWaP targets. This model is ideally suited for X-Band radar, wireless and VSAT systems and more.

Dual-Band Signal Generator for X-Band Test Applications

Mini-Circuits' SSG-8N12GD-RC is a dual-band synthesized signal generator capable of producing signals from 8 to 12.5 GHz over a dynamic range from -55 to +23 dBm. The two channels can operate independently in coherent and non-coherent modes with 360-degree phase control. Controlled via USB, Ethernet and PoE interfaces, the generator offers CW, pulsed, AM, FM and chirp modulation options, automated sweep and hop sequences over frequency and power and daisy-chain connection to control multiple modules on one control line.

Suspended Substrate Diplexer Combines DC to 3 GHz and 4 to 20 GHz Channels

Mini-Circuits' ZDSS-3G4G-S+ is a suspended substrate diplexer with a low-pass channel from DC to 3 GHz and a high-pass channel from 4 to 20 GHz. Capable of handling up to 3 W RF input power with 1.5 dB insertion loss on both channels, this model has become popular for combining wideband or multiband signals into a common port without the losses of a traditional combiner. This model features SMA connectors at all ports and rugged construction for reliable performance in harsh environments.

1 kW Turnkey Signal Source for ISM RF Energy

Mini-Circuits' RFS-2G42G51K0+ is a turnkey high-power signal source for 2.4 to 2.5 GHz ISM applications. Capable of delivering up to 1 kW of RF power, this water-cooled system incorporates four Mini-Circuits SSPAs with built-in signal source, control and power supply in a 2U, 19 in. rack-mountable chassis. Controlled via USB, Ethernet, EtherCAT and RS-485, the unit features built-in monitoring and protection for temperature, current, forward and reverse power. A Windows®-based GUI and front-panel touch screen provide access to the signal source and monitoring functions.

Phase-Stable Flex Cables, DC to 26.5 GHz

Mini-Circuits has introduced the CBN-series of phase-stable flexible cables supporting a wide range of precision test applications from DC to 26.5 GHz. CBN-series models provide exceptional phase and amplitude stability (±6 degrees, ±0.08 dB) in bend radii as small as 50 mm. 90 dB shielding effectiveness and 74 percent velocity of propagation ensure outstanding transmission efficiency for outstanding measurement integrity and consistency. These high performance cables are available from stock in lengths from 1 to 5 ft., with custom lengths available.

www.minicircuits.com

MPG

Hercules™ Switch Line™

MPG's Hercules™ switch line is precision-engineered for performance, reliability and future-ready automation. Designed for exceptional RF performance up to 27 GHz, Hercules™ offers minimal insertion loss, high isolation and rugged durability. Developed using advanced metrology and material science, it ensures data-driven consistency across SPDT, SP6T and SP12T models. With TTL logic control, a long lifecycle and robust environmental ratings, Hercules sets a new standard for high frequency switching in mission-critical and demanding applications.

www.mpgdover.com

Mtron

e-Vibe™ Series of Electronically Compensated OCXO, XO5503-100 MHz

The Mtron XO5503 Series e-Vibe™ OCXO incorporates an SC-cut resonator and electronic vibration compensation, resulting in 0.02 ppb/g G-sensitivity. The e-Vibe™ OCXO replaces bulkier mechanically vibration-compensated products and improves system performance while reducing size to 2.0 × 1.5 × 0.8 in. and weight to 70 g. Other features: a wide temperature range (-45°C to +85°C) and stability down to ±200 ppb. Mtron offers a broad line of precision RF components and solutions. MtronPTI is an ISO 9001:2015 and AS9100 Rev. D certified organization.

www.mtron.com

Networks International Corp.

Surface-Mount Cavity Filter

Introducing the NIC X-Band surface-mount cavity filter, built with high-temperature (Sn95Sb05) solder to endure standard PCB reflow profiles of up to 215°C. This advanced filter delivers impressive performance with a passband insertion loss of less

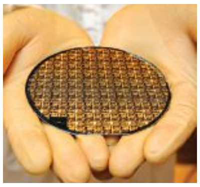
than 1 dB and exceptional out-of-band rejection greater than 60 dB, even up to 3x the center frequency. Its compact and durable SMT design makes it the ideal choice for demanding applications in radar, EW and space missions. Visit us at IMS2025 booth 627 for more information.
www.nickc.com

Norden Millimeter
Custom Transceivers
VENDORVIEW

Norden designs custom transceivers for military and commercial applications, including airborne, UAV and EW. They have "catalog" models that provide wideband RF and up to 1.5 GHz IF with low phase noise. Norden can provide custom designs that 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

Northrop Grumman
Fueling Innovation

Powering America's technology. MMIC sales, foundry services, design and test services, wafer bumping, IC packaging and RF units.



www.ngc.com/micro

Nxbeam
8 W Ka-Band Surface-Mount PA
VENDORVIEW

Nxbeam expands its Ka-Band PA portfolio with the release of a surface-mount 8 W GaN PA. The NPA2040-SM operates from 27.5 to 31 GHz and provides an average saturated output power of 8 W, 25 percent power-added efficiency and 22 dB linear gain. This part is ideal for satellite communication ground terminals and point-to-point communication links and can be used as a driver for its higher power 20 W and 35 W GaN PA MMICs.
www.nxbeam.com

Ophir RF
Broadband Amplifier 20-1000 MHz

The 5127 is a 200 W broadband amplifier that covers the 20 to 1000 MHz frequency range. This amplifier utilizes class A/AB linear power devices that provide an excellent third-order intercept point, high gain and a wide dynamic range. This series has been updated to deliver more power with less consumption in a compact package. Power levels range from 20 to 1000 W. Suitable for EMC, EW, pulse and other lab testing needs. Five-year warranty provided.
www.ophirrf.com

Passive Plus
RF/Microwave Passive Components

Passive Plus leads the way in manufacturing high performance RF/microwave passive components providing cutting-edge solutions for the medical, semiconductor, military, broadcast or telecommunications industries. Its components are engineered for ground-based satcom equipment, delivering unmatched reliability and precision for satellite transmission and receiving systems. Designed to withstand the demanding conditions, its products ensure optimal performance, exceptional signal integrity and robust durability, making them the ideal choice for mission-critical applications in satellite operations.
www.passiveplus.com

Pivotone
Tower Antenna Mounts

Tower Antenna Mounts (TAMs) from Pivotone are designed to allow an equipment pole to be offset and tiltable from a parent pole or tower leg, which makes it possible to compensate to get a vertical pole on an inclined tower. The TAMs can be installed on masts as well as conical towers and they can handle a wide range of all common frame leg designs: L-profile, round and square.
www.pivotone.com

Q-Tech Corporation
Frequency and Timing Products

Q-Tech Corporation and its German affiliate, AXTAL, deliver technology leadership with an extensive selection of frequency and timing products for aerospace, defense, avionics, high-temperature, instrumentation and master clock applications. The Q-Tech and AXTAL product portfolios combined offer a full range of crystal oscillators: XOs, TCXOs, MCXOs and OCXOs, plus additional technologies for complex modules, oscillators with multiple outputs and those with optimized performance under vibration. Stop by booth 4215 at IMS2025 to learn more about Q-Tech's product offerings.
www.q-tech.com

Qorvo
Learn How Qorvo Is Powering the Future of Satcom
VENDORVIEW

Qorvo's latest integrated BFICs provide a competitive edge with the lowest noise figure, enhanced temperature stability and simplified system integration. They eliminate external LNAs, reduce calibration complexity and improve cost-effectiveness. Designed for high channel efficiency, these BFICs optimize link budgets and reduce power consumption — delivering superior performance for next-generation satcom networks. Built on decades of RF leadership, Qorvo delivers the performance, scale and innovation trusted by top satcom providers worldwide. Learn more at IMS booth #543.
www.qorvo.com

Quantic Corry
Multi-Line Filters

Quantic Corry's multi-line filters offer efficient, cost-effective EMI/RFI isolation for multi-compartment systems. Customize assemblies for optimal "clean" power and interference-free control signals. The company provides cross-referencing for existing specifications or designs custom filters to meet precise requirements. Its solutions ensure reliable performance, minimizing electromagnetic interference and maximizing system integrity.

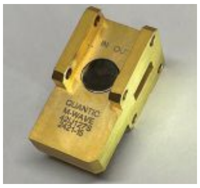
www.quanticcorry.com

Quantic Eulex
3-Terminal Ceramic Gap Capacitor

Quantic Eulex has just released a groundbreaking 3-terminal ceramic gap capacitor engineered for superior high frequency and ultra-stable performance. By leveraging a unique ultra-thin, single-layer design, it minimizes equivalent series inductance (ESL) while eliminating the need for wire bonding, unlike traditional single-layer capacitors (SLCs). This innovative design combines the high frequency performance of SLCs with the exceptionally low mounting inductance of 3-terminal configurations, resulting in superior effectiveness for power supply bypassing, filtering and noise suppression. The surface-mountable package ensures ease of integration into your circuit designs.

www.quanticeulex.com

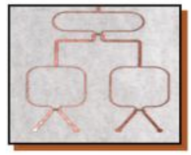
Quantic M-Wave
Ultra-Low Insertion Loss Isolators



Quantic M-Wave has 30+ years of passive ferrite product design experience in low loss applications. Its proprietary processes provide extremely high efficiency in its waveguide and coaxial isolator and circulators. The highlighted model #42IJ127S provides 0.08 dB typical insertion loss and a 0.12 dB maximum over the customer-specified bandwidth in WR42. With M-Wave now part of the Quantic team, we are even better positioned to support your needs for high performance components.

www.mwavedesign.com

Quantic Ohmega Ticer
Embedded Resistive Material

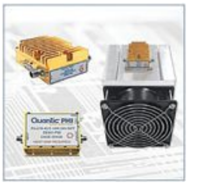


Quantic Ohmega Ticer's embedded resistive material replaces solder joints and discrete resistors in power dividers like Wilkinson, enabling easier integration and superior high frequency performance due to reduced parasitics and shorter signal paths. This boosts reliability by eliminating solder joints and allows for smaller, more efficient designs with improved signal integrity.

www.quanticohmega.com

Quantic Planar Monolithics Inc.
Broadband High Power Amplifiers

VENDORVIEW



Mission-ready broadband high power amplifiers (SSPAs) from Quantic PMI offer high gain and low noise figure performance for pulsed airborne, naval and ground radar applications, as well as found in weather forecasting Doppler radar systems and utilized in air traffic control and precision approach radar systems. These PAs offer remarkably high gain up to +53 dB and saturated output power above 40 dBm (10 W). Available in custom or standard configurations.

www.quanticpmi.com

Quantic Wenzel
Multiplied Crystal Oscillators

VENDORVIEW

Quantic Wenzel's Multiplied Crystal Oscillators (MXOs) combine ultra-low noise OCXOs with low noise multiplier stages and are customizable between 200 MHz and 12 GHz. The series offers phase-locking options to external references like rubidium, cesium, GPS or OCXOs. The Golden Multiplied Crystal Oscillator (GMXO) Series delivers enhanced phase noise performance by up to 10 dB compared to the MXO series. Contact Quantic Wenzel today to learn how their MXO and GMXO solutions can enhance your RF system's performance.

www.quanticwenzel.com

Quantic X-Microwave
Layout Tool

Quantic X-Microwave's layout tool is an interactive design environment enabling part selection and layout of signal chains using X-MWblocks. This tool aims to simplify the design process, whether for prototype plates or standard connectorized housing, by providing a visual environment for users to construct their designs, selecting and placing XMWblocks from an extensive component library onto a virtual canvas. Now with a library of over 6000 components, redesigned user interface, automated wall algorithm and export capabilities to help you get to market faster.

www.quanticxmw.com

Quinstar
High-Power K-Band SSPA

The QBP-21014750 is a high efficiency K-Band GaN SSPA designed for space and airborne applications. Operating from 20.2 to 21.2 GHz, it delivers 49 dBm saturated output with just 5 dBm drive. Engineered for reliability, it features integrated over-temperature protection and optimized thermal management. Custom built-in its state-of-the-art facility, it ensures superior RF performance. Visit IMS2025 booth 1735, or contact sales@quinstar.com for details.

www.quinstar.com

Reactel Incorporated
Filters, Multiplexers & Multifunction Assemblies

VENDORVIEW

Reactel will feature its full line of filters, multiplexers and multifunction assemblies covering up to 67 GHz at IMS2025. Supporting military, commercial, 5G, industrial and research needs, we can design a unit that is right for you. From small, lightweight units suitable for flight or portable systems to high-power units up to 25 kW, connectorized or surface-mount, large or small quantities — our talented engineers can design a unit specifically for your application. Visit us in booth 632 to discuss your requirements and meet our engineers.

www.reactel.com

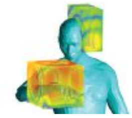
RelComm Technologies Inc.
1P2T Coaxial Relay

RelComm Technologies introduces to its product line a RRDL-4.3-10 Series. A high performance 1P2T coaxial relay configured with 4.3-10 type connectors providing excellent RF performance and power ratings up to 6 GHz. Its operating temperature range is -30°C to +70°C. The relay measures 3.50 × 1 × 2.13 in. This relay is fully RoHS compliant. This series is available in both failsafe and latching configurations with 12 to 48 Vdc operation available. Standard options include auxiliary position indicators, suppression diodes, TTL input, moisture seal and D-Sub header.

www.relcommtech.com

Remcom Inc.
Analyze Mobility and Performance of Body-Worn Devices

VENDORVIEW

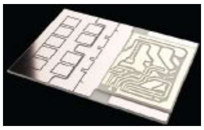


Turn to Remcom for challenging on-body propagation test and measurement. Capture the performance of antennas and interactions with people, vehicles and structures in the near-field of the antenna with high fidelity using XFdtd®. Transfer this domain into Wireless InSite® to further refine the simulation of complex EM interactions with the body or nearby structures for technologies such as 6G, GNSS, WLAN, lunar missions and on-body communication while in motion.

www.remcom.com

Remtec
Metallized Ceramic Solutions

VENDORVIEW



Whether you require a reliable substrate to dissipate heat, a custom circuit with tight tolerances or a high-density, multilayer solution with vias, interconnects or interposers — consider Remtec's metallized ceramic solutions. They offer approaches for high-power applications including direct bond copper, active metal braze, or thick film, single-layer boards; multilayer dielectric ceramic circuits; copper conductor layer thickness from 5 to 12 mil, unsurpassed wire bondability, solderability and conductor adhesion and alumina; aluminum nitride and silicon nitride solutions. To learn more, schedule a high-power capabilities presentation and ask about onshoring with Remtec.

www.remtec.com

Renaissance Electronics
Custom BUC and BDC for Satcom

Renaissance Electronics specializes in high frequency BUC and BDC solutions for satcom. Its converters feature fixed and programmable LO, with up-converters offering an integrated power amplifier option. A prime example is its Ka-Band BUC and BDC, designed for high reliability with customized output power, low noise figures and flexible frequency plans. Key features include an integrated 25 W PA BUC, fixed frequency plans for simplicity and BDC band switching from 18 to 40 GHz. Optimize your communication systems with Renaissance.

www.rec-usa.com

RF-Lambda

600 W, 2-6 GHz, EMC Power Amplifier

This wideband EMC power amplifier spans an impressive frequency range of 2 to 6 GHz while delivering 600 W of CW output power. This advanced solution is built to provide engineers and researchers with a single broadband solution, offering high power-amplified signals over a wide frequency range without the need to source several amplifiers. Applications include test and measurement, EMC/EMI, wireless commercial communications, aerospace and military, as well as research such as particle physics.

300 W, 2-20 GHz, EMC Power Amplifier

This 300 W CW EMC AC-powered amplifier is optimized to cover a broadband frequency of 2 to 20 GHz. This unit is packed with comprehensive protection features such as built-in temperature compensation, automatic calibration, as well as over current, temperature, VSWR, current imbalance and RF input protection. The unit also supports Ethernet control and monitoring. Applications include test and measurement, EMC/EMI, wireless commercial communications, aerospace and military, as well as research such as particle physics.

18-26 GHz, Hermetically Sealed Power Amplifier

Our ultra-wideband power amplifier spans 18 to 26.5 GHz with 51 dBm output power. The DC-powered series offers a compact package, easily integrated into RF systems or test setups. Any of RF Lambda's DC amplifiers can be provided in an AC-powered unit (RAMPXXX series). Hermetic Seal, including 100 percent leak testing as per MIL-STD-883, is available for outdoor and harsh environments.

1-18 GHz, Hermetically Sealed SP2T Switch

RF Lambda's 1 to 18 GHz SP2T high-power 20 W switch combines robust power handling with rapid switching. Ideal for radar or TDD systems, it boasts low 1.8 dB insertion loss and a maximum 200 ns switching time. Our comprehensive range of active RF switches — from SP2T to SP160T — supports power handling up to 1 KW, ensuring longevity without cycle limitations. Perfect for sustained, reliable switching in demanding systems.

www.rflambda.com

RFMW

Butler Matrix Family is Highly Reliable Option for Accurate MIMO Testing

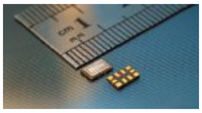
VENDORVIEW

Spectrum Control's Butler Matrix family simplifies Wi-Fi MIMO testing by delivering consistent, high-quality results with minimal setup time. Unlike traditional methods, which require manual alignment for each frequency range, the Butler Matrix provides a well-conditioned test channel with low condition numbers, ensuring the highest achievable speeds. Offering excellent phase accuracy, amplitude balance and port-to-port isolation, it's an ideal solution for Wi-Fi, cellular and RF/microwave MIMO testing. With 4-, 8- and 16-channel units, it covers 0.5 to 7.25 GHz for reliable, efficient testing. Available at RFMW.

High Performance 5-1225 MHz 75 Ohm 12 dB Coupler

The MiniRF MRFCP5753 Coupler is a small, low-cost and highly reliable surface-mount component ideal for broadband, wireless and communications systems. This 5 to 1200 MHz, 12 dB coupler comes in a compact 4x4 mm package, offering a 75 Ohm characteristic impedance and RoHS-compliant, lead-free construction. Perfect for applications like broadband/CATV and wireless systems, it ensures optimal performance with ease of integration. S-parameters are available on request for enhanced design flexibility. Available at RFMW.

60-220 MHz, ±50 ppb, Endura™ Series Ultra-precision Super-TCXO



Available now from RFMW, the SiT5349 is a ruggedized ±50 ppb precision MEMS Super-TCXO designed for high-reliability applications in defense, space, avionics and precision GNSS systems. With superior shock survivability (> 30,000 g), 0.009 ppb/g acceleration sensitivity and excellent dynamic performance, it ensures optimal stability in extreme environments. Featuring programmable frequency options and digital control via I2C, the SiT5349 offers unmatched flexibility and performance, making it ideal for mission-critical timing in challenging conditions. Engineered for precision, durability and efficiency.

www.rfmw.com

Richardson RFPD
Design Accelerators
VENDORVIEW

Start developing radio projects in minutes instead of months. Design accelerators are standardized, off-the-shelf, hardware development platforms that help RF and radio product developers reduce risk and speed time to market. Each design accelerator includes full documentation, open source or licensable software and technical support. Design files of select design accelerators may also be available via license. RadioThorium and RadioOxygen design accelerators were developed by Richardson RFPD to support high-power software-defined radio, troposcatter, satcom and 5G mmWave communications.
www.richardsonrfpd.com

RLC Electronics
High Frequency Highpass Filters

RLC Electronics' high frequency highpass filters are provided with coaxial interfaces but internally are designed/machined as a ridged waveguide filter, which allows for extremely sharp rejection, low loss and fantastic repeatability. The filter shown passes 28 to 40 GHz, while rejecting over 70 dB less than 700 MHz from the passband edge (it is the equivalent of a 22-section interdigital filter response), all while handling over 100 W input power.
www.rlcelectronics.com

Rohde & Schwarz USA
Network Analyzers

The analyzers of the R&S®ZNB3000 family combine fast measurement speed, wide dynamic range and high temperature stability with excellent raw data to deliver performance and measurement throughput that meets even

the greatest challenge in high volume production applications and environments with short ramp-up times. The R&S®ZNB3000 is especially well suited for development and large-scale production of RF components and has a frequency range from 9 kHz to 4.5 GHz, 9 GHz, 20 GHz and 26.5 GHz.
www.rohde-schwarz.com/us

Safran Electronics & Defense
Advanced Atomic Clock

The Ground Active Hydrogen Maser (GAHM) is Safran's advanced atomic clock, offering exceptional frequency stability for applications like deep space tracking, geodesy and radio astronomy. With a frequency stability of less than 1.5E-13 at 1 second and under 2.5E-15 at 1 day and phase noise below -130 dBc/Hz at 1Hz, the GAHM ensures precise and reliable timekeeping. Designed for a maintenance-free operation over a 20-year lifespan, it supports critical infrastructures requiring unparalleled accuracy.
www.safran-group.com

Samtec
Phase & Insertion Loss Stable Cable Assemblies

Samtec's Nitrowave™ high performance microwave cable offers improved phase and amplitude stability

over flexure. Performance is optimized at frequencies that go beyond traditional industry targets to support emerging applications in the aerospace/defense, test and measurement and instrumentation markets.
www.samtec.com

Santron
Precision Field Replaceable Connectors

Santron introduces their new generation of high performance field replaceable connectors. Offered in connector series SMA, 2.92 mm, 2.4 mm and 1.85 mm and designed to be optimally matched to most connectorized assemblies for low VSWR, rugged dependability and exceptional repeatability. Available in both female or male with multiple size mounting options in 2-hole or 4-hole flange configurations. Santron also offers a wide variety of launch accessories, including glass-to-metal feedthroughs, launch pins and PTFE insulators.
www.santron.com

SignalCore Inc.
RF Source

The SC5531A is an RF source covering the frequency range of 100 kHz to 23 GHz with fast frequency switching, millihertz tuning resolution and low phase noise. It accepts 10 MHz, 100 MHz and 1.6 GHz reference signals and outputs its internal 1.6 GHz reference signal that could be used to synchronize multiple SC5531A devices, greatly improving their relative phase stability. The product features fine amplitude adjustment in the range of -40 to 15 dBm.
www.signalcore.com

Signal Hound
Vector Network Analyzer (VNA)

The VNA400, Signal Hound's new 40 GHz, two-port, USB-powered VNA, samples incident and reflected signals on both ports simultaneously. With excellent dynamic range (up to 125 dB), sub-Hz resolution, ± 1 ppm internal TCXO accuracy and fast sweeps (2000 points per second at 30 kHz RBW), the VNA400 is optimized for testing two-port devices, such as filters, amplifiers and attenuators, as well as one-port devices like antennas or VSWR testing in the lab or out in the field.
www.signalhound.com

Smiths Interconnect
The Ultimate RF Connector for Mil/Aero Applications

Smiths Interconnect (SINT) draws on decades of mil/aero experience to offer SMPM Mini-Lock connectors. Patented technology provides the ultimate reliability and excellent RF performance in harsh environments. More than 50 lbs. of pull

strength is assured with an audible click while delivering low insertion and return loss up to 110 GHz. In addition, the connectors are small, compact and blindmatable for easy integration. SINT's RF cable assemblies are trusted by industry leaders around the world.
www.smithsinterconnect.com

Southwest Microwave
Thread-In Connector

Visit us at IMS booth 859 to discover our groundbreaking 0.8 mm (145 GHz) high performance thread-in connector. This cutting-edge design ensures exceptional signal integrity while delivering the industry's lowest VSWR, RF leakage and insertion loss. Also presenting our 0.8 mm vertical launch connector for microstrip and CPW, currently in the prototyping phase. The outlook is bright. Southwest Microwave remains committed to surpassing previous milestones, cementing our reputation as the performance leader in microwave connectors.
www.southwestmicrowave.com

Stellant Systems
Microwave Power Module M1245

Stellant leads in delivering high-power solid-state and TWT-based MPM RF modules. Utilizing proven RF GaN amplifier designs and TWT MPMs, our compact, efficient solutions offer RF power density across 20 MHz to 40 GHz. Perfect for communication, electronic warfare and radar systems with space, cooling and power constraints, these advanced designs excel across ground (mobile and fixed), surface and airborne platforms, setting the standard for RF performance and amplifier innovation.
www.stellantsystems.com

Teledyne Relays
Coaxial Switches

Teledyne Relays' broadband SPnT coaxial switches offer repeatable and stable broadband performance up to 53 GHz. The CCR-38U is a normally open multi-throw switch, while the CCR-39U is a latching switch. Both models withstand harsh environments up to 65°C for commercial and 85°C for elite models. Applications include switching mmWave signals for 5G, routing RF signals to antennas and amplifiers for jammers and setting up test environments for RF components like beamformers.

www.teledynedefenseelectronics.com

Telonic Berkeley
Mounted Rotary Step Attenuators

These Telonic Berkeley step attenuators are available in nine different models with attenuation ranges from 1 to 100 dB, in steps of 1 to 10 dB. There are two basic case designs, both 1.31 in. diameter with lengths of 1.50 in. (subminiature) and 2.29 in. (miniature). This mechanical configuration reduces panel mounting space to a minimum and also permits incorporation of these attenuators into many existing designs.
www.telonicberkeley.com

Trans-Tech
Materials and Components

Trans-Tech manufactures dielectric and ferrite materials and components, thermal barrier coating materials, RF bandpass filters, RF circulators and isolators, medical materials, patch antennas, phased array radar elements, RF absorber and numerous other custom solutions for RF, microwave, thermal and high-power, temperature-stable and low dielectric loss uses.
www.trans-techinc.com

Transline Technology
High Performance PCB Laminates

With 30+ years' expertise, Transline Technology specializes in working closely with engineering innovators that push RF, microwave and mmWave PCB boundaries. Our hands-on approach makes us an extension of your engineering team. We stock a wide variety of high performance PCB laminates enabling rapid prototype delivery.

www.translinetech.com

Trexon EZ Form Cable
Cables and Connectors

EZ FORM CABLE
AS9100 CERTIFIED

EZ Form Cable, a Trexon Company, is an AS9100D-certified manufacturer of coaxial cable, coaxial cable assemblies, RF connectors and coaxial delay lines. EZ Form's RF, microwave and mmWave transmission line solutions offer proven performance for critical applications in mil/aero, cryo/quantum computing, telecommunications, medical, instrumentation and test.

www.ezform.com

WAVEPIA
Power Amplifier

Designed for the battlefields, networks and skies of the future, WAVEPIA's WP-GM0204250M delivers uncompromising performance in the most demanding environments. From secure military communications to multi-functional radar, it provides the reliability mission-critical systems require. Optimized for 2.6 to 3.8 GHz operation, the WPGM0204250M delivers 54.7 dBm saturated output power with 48.9 percent PAE at 48 to 50 V, ensuring high efficiency and robust performance. At WAVEPIA, reliability isn't just a specification — it's our commitment.

www.wavepia.com

Weinschel Associates
High-Power Attenuators and Loads

Weinschel Associates offers an improved line of high-power attenuators and loads to complement their current high-power line-up. The WA70/6 and WA1470/6 are a 1 KW attenuator and termination performing from DC to 6 GHz and are available with a variety of connector options, including N-Type, 4.3/10 and 7/16 DIN. Please visit us at IMS booth #630 or contact us at sales@weinschelassociates.com for more information.

www.weinschelassociates.com

Pick Up Your
T-Shirt
in the MWJ Booth 935

Werlatone
In-Phase Connectorized Combiner

Werlatone's model D9706 is a 16-way radial, in-phase connectorized combiner that covers the 2700 to 3500 MHz band. This is a high-power model rated to 2000 W CW and operates with less than 0.35 dB of insertion loss. The D9706 operates as a non-isolated combiner. Choose your specific connector configuration from a list of options. Visit our website to see more radial combining options or reach out to our experts with custom N-Way requirements. Above all, Werlatone RF combiners handle the most stringent operating conditions.

www.werlatone.com

West Bond
7KF Bonder

The 7KF bonder with our new 7 in. capacitive touch sensing LCD display is designed with a gantry style chassis enabling unlimited part size capacity. Our exclusive 8:1 ratio, purely orthogonal X-Y-Z Micromanipulator allows the operator to place bonds very precisely and is convertible between Ball Bonding and Wedge Bonding, presenting bond wire at both 45 and 90 degrees for deep access and ribbon bonding capabilities. It is an excellent tool for RF, microwave, semiconductor, hybrid and medical device field applications.

www.westbond.com

Z-Communications
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Bookend

Introduction to LabVIEW FPGA for RF, Radar and Electronic Warfare Applications

By: Terry Stratoudakis

Terry Stratoudakis' "Introduction to LabVIEW FPGA for RF, Radar and Electronic Warfare Applications" is a solid, practical guide that connects rapidly advancing field-programmable gate array (FPGA) technology and applications in RF, radar and electronic warfare (EW). What stands out most is how the book simplifies a highly technical subject, making it approachable for professionals with backgrounds in both FPGA development and RF engineering. The blend of theory and hands-on practical advice makes it a must-read for those working in these specialized areas.

The book focuses on LabVIEW FPGA, a powerful tool that can be complex to learn, especially when applied to systems such as radar and EW. Stratoudakis provides a clear and structured path for learning LabVIEW FPGA, starting with foundations in Chapter 2. This chapter is particularly useful because it provides a step-by-step learning process that guides readers, regardless of their prior experience.

Chapter 3 does an excellent job of covering FPGA fundamentals. For engineers already familiar with FPGAs but looking to improve their understanding in the context of RF and radar applications, this chapter points to resources for deeper exploration. The explanation of how FPGAs are used in large-scale applications adds real-world context, highlighting the practical relevance of the technology.

Chapters 4 and 5 are where the book truly shines. Chapter 4 dives into LabVIEW FPGA itself, providing practical examples and case studies. The case studies in Chapter 5, which cover various RF and radar systems, are especially engaging. They not only demonstrate how LabVIEW FPGA can be applied but also provide insights into the design considerations and challenges faced in developing high performance systems for defense and communication applications.

In summary, this book is ideal for engineers working in RF, radar and EW who are looking to deepen their knowledge of FPGA development using LabVIEW. Its practical approach, combined with a clear educational path, makes it accessible while still offering valuable insights for advanced users.

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FABS and LABS

Massachusetts Bay Technologies: Motivated by Performance; Focused on Reliability




The term "Massachusetts Bay" comes from what became known as the Massachusetts Bay Colony. The Massachusetts Bay Company, an English trading company, was tasked with colonizing and establishing trade in the area outside Boston. This effort began nearly 150 years before the American Revolutionary War, so the term has deep roots in the Massachusetts area and symbolizes the region's perseverance, efforts and growth.

Massachusetts Bay Technologies (MBT), located in Stoughton, Mass., embodies those qualities. The privately held company was founded in 1999 by the Fallon brothers, Brian and Charlie. Having just celebrated MBT's 26th anniversary, Brian holds the role of president, and Charlie serves as vice president of the company. Over the past 26 years, MBT has evolved into one of the leading manufacturers of RF and microwave semiconductors and passive components.

The evolution and growth of MBT have created several decision points for the company. Befitting a start-up company, MBT adopted a fabless manufacturing model from its inception in 1999. However, in 2008, the company recognized that the fabless model was not a reliable growth strategy. The best solution to enable the Fallon brothers' growth vision for MBT was to build a wafer fab facility. Despite this being a herculean task, MBT's 20,000+ sq. ft. state-of-the-art wafer processing fab was up and running in 2010, less than two years after the decision was made. The company maintains a value-added assembly capability, where it performs assembly, die attach, wire and ribbon bonding and packaging of various devices. They also provide reliability testing of devices up to and including space-level reliability. These capabilities, combined with the wafer processing fab, enable MBT to provide all fabrication, manufacturing and reliability testing under one roof.

The company boasts an impressive set of capabilities, including diffusion, LPCVD and oxidation furnaces. Fabrication starts with metalization, photolithography and etching capabilities. Once fabricated, MBT can plate, dice, laser trim, test and inspect its products. These standard and custom products, along with build-to-print efforts, can be tested to 40 GHz and environmentally screened in MBT's in-house facilities. All these activities take place in the company's ISO 9001:2015-certified and ITAR-compliant manufacturing facility.

As the company has grown, it has expanded its product portfolio both organically and through acquisitions. In 2016, MBT acquired MACOM Technology Solutions' point-contact diode product line. These diode products support both commercial and mission-critical defense applications and devices. In January 2019, the company launched a thin film product line, producing both standard and custom products. Later that year, in October 2019, MBT began production of single-layer ceramic (SLC) capacitors. The addition of thin film and SLC capabilities complements and expands MBT's existing semiconductor and passive product portfolio.

After 26 years of effort, perseverance and growth, MBT has evolved into a company specializing in the design and manufacture of current, obsolete and discrete silicon and GaAs RF and microwave semiconductor diodes, as well as passive components and thin film products. These products range from 100 Hz up into the mmWave frequency range. The MBT products are used in consumer, telecommunications, medical, industrial, space, aerospace and defense applications. The company prides itself on being a customer-service-oriented organization motivated by performance and focused on reliability.

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Compact IPD Bandpass Filter Uses Transformer for High Rejection and Low Loss

Yanzhu Qi, Yazi Cao, Qixiang Ren, Bo Yuan, Shichang Chen and Gaofeng Wang
MOE Engineering Research Center of Smart Microsensors and Microsystems, School of Electronics and Information, Hangzhou Dianzi University, Hangzhou, China

This article discusses the design of a compact integrated passive device (IPD) bandpass filter (BPF) with high out-of-band rejection that features a transformer-based circuit topology to achieve low insertion loss. High out-of-band suppression in the Wi-Fi 5 (5.15 to 5.875 GHz) and Wi-Fi 6 (5.925 to 7.125 GHz) bands is achieved by serially adding a seventh-order lowpass filter to the transformer circuit. A prototype is fabricated using silicon-based IPD technology. The measured bandwidth is 2.4 to 2.5 GHz, insertion loss is less than 1.75 dB and out-of-band suppression is greater than 27.7 dB and 35 dB in the Wi-Fi 5 and Wi-Fi 6 frequency bands, respectively. The fabricated BPF area is only 1 mm × 0.5 mm.

Requirements for RF front-ends in highly integrated and high performance communication systems are becoming more stringent.[1] Compact, low insertion loss and high out-of-band suppression filters play significant roles in RF systems. Compared to filters based on low-temperature co-fired ceramic (LTCC)[2] and printed circuit board (PCB)[3] processes, IPD filters offer advantages in terms of size, precision and profile.[4] Consequently, new types of filters and synthesis methods for high performance and miniaturized IPD filters have emerged in recent years.[5-10]

In this work, a miniaturized silicon-based IPD BPF with low insertion loss and high out-of-band rejection is described. A transformer design with inductive loading is analyzed to reduce insertion loss. High out-of-band rejection is achieved by serially adding a lowpass filter.

DESIGN AND ANALYSIS

Transformer with Inductive Loading

Figure 1 is a typical equivalent circuit for a transformer design with inductive loading. An inductor, L_{load}, is connected in parallel to both ends of the transformer. The equivalent circuit includes ground capacitance, C_1, coupling inductance, L_1, coupling capacitance, C_T and mutual inductance, M. The element values of the transformer circuit can be calculated with ***Equations 1*** through ***6***:[8]

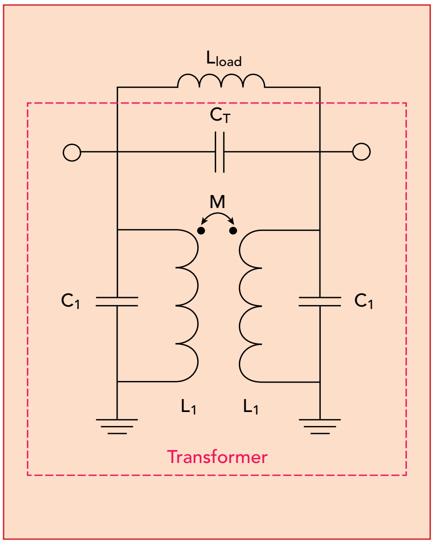

Fig. 1 **Inductively-loaded transformer equivalent circuit.**

$$C_1 = \frac{\sin\theta}{\omega Z_e} \quad (1)$$

$$L_1 = \frac{Z_e \tan\left(\frac{\theta}{2}\right)}{2\omega} + \frac{1 - \cos\theta}{2\omega^2 (C_1 + 2C_r)} \quad (2)$$

$$C_T = \frac{(Z_e - Z_0)\sin\theta}{2\omega Z_e Z_0} \quad (3)$$

$$M = \frac{Z_e \tan\left(\frac{\theta}{2}\right)}{2\omega} - \frac{1 - \cos\theta}{2\omega^2 (C_1 + 2C_r)} \quad (4)$$

$$k = \frac{Z_e - Z_0}{Z_e + Z_0} \quad (5)$$

$$Z_i = \frac{Z_e - Z_0}{2} \quad (6)$$

Based on Equations 1 through 6, for $\theta = \pi/2$ at f_0 = 2.45 GHz, k = 0.7 and Z_i = 50 Ω, the component values of the transformer can be calculated as: $C_1 = C_T$ = 1 pF, L_1 = 5 nH and M = 2 nH. Therefore, the S-parameter response can be computed with the results shown in ***Figure 2***, which shows that the transformer has a bandpass filtering characteristic. Since the two coils in the transformer design are nested together, it is difficult to adjust the inductance and coupling independently. To overcome this issue, an inductor is connected in parallel at both ends of the transformer to separately control the coupling between the transformer coils without affecting other parameters. When the inductance is added, the passband of the transformer shifts higher in frequency.

To study the effect of L_{load}, simulation results with various values are shown in Figure 2. When L_{load} decreases, the bandwidth of the transformer increases. Moreover, compared to the case without inductive loading, insertion loss with inductive loading improves.

BPF Design

To improve out-band suppression at the high frequency end, a seventh-order elliptic function lowpass filter is implemented. The filter circuit topology is shown in ***Figure 3a*** and the simulated S-parameters are shown in ***Figure 3b***. The cutoff frequency is 3 GHz and the component values calculated using the filter synthesis method[6] are: $L_3 = L_4$ = 2.22 nH, L_5 = 3.3 nH, $C_3 = C_8$ = 0.64 pF, C_4 = 0.86 pF, C_5 = 0.17 pF, C_6 = 1.27 pF, C_7 = 1.46 pF and C_9 = 0.96 pF. The filtering circuit provides three transmission zeros, denoted as TZ1, TZ2 and TZ3, which are controlled by Resonators 2, 1 and 3, respectively.

The final circuit comprises the inductively loading transformer connected in series with the lowpass filter circuit and the resulting topology is shown in ***Figure 4***. To achieve better impedance matching, C_9 is removed. The values of the remaining BPF circuit components are further optimized and the final values for operation at 2.45 GHz are listed in ***Table 1***.

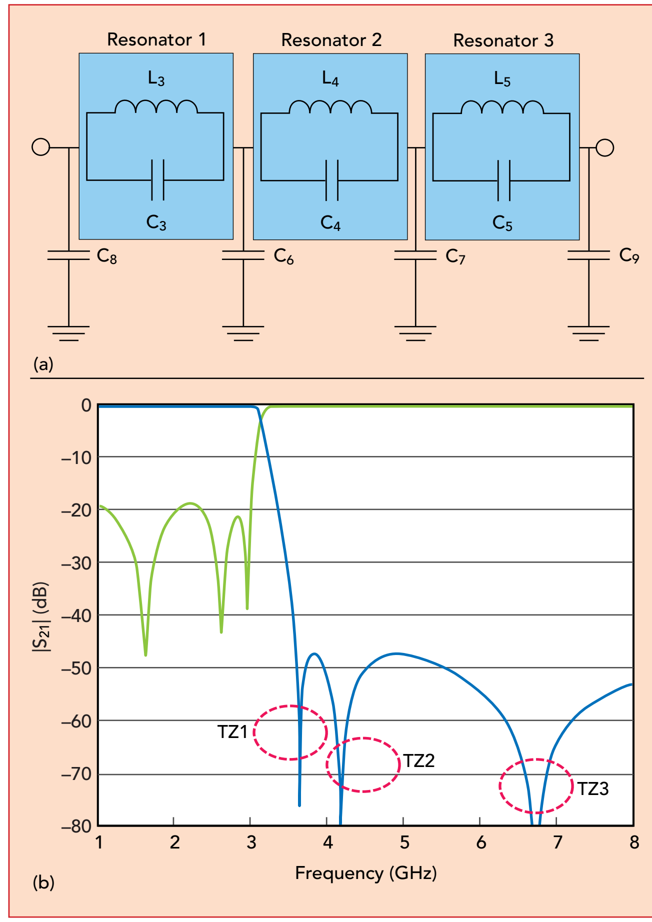

Fig. 3 **Seventh-order elliptic function lowpass filter circuit topology (a) and simulated S-parameters (b).**

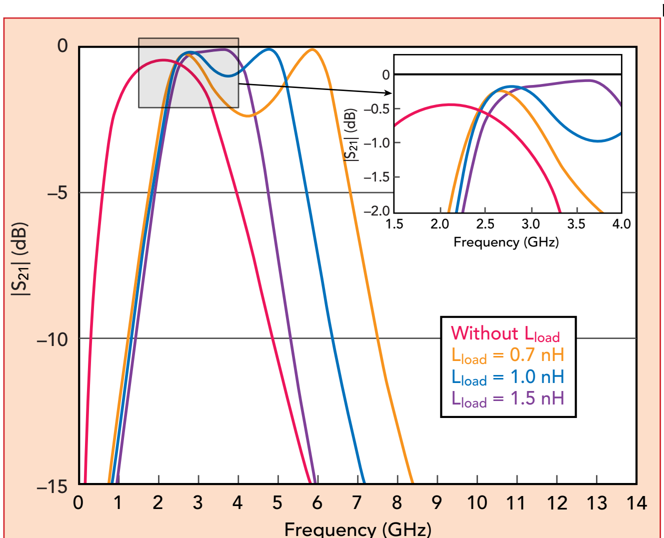

Fig. 2 **Calculated $|S_{21}|$ of the inductively loaded transformer.**

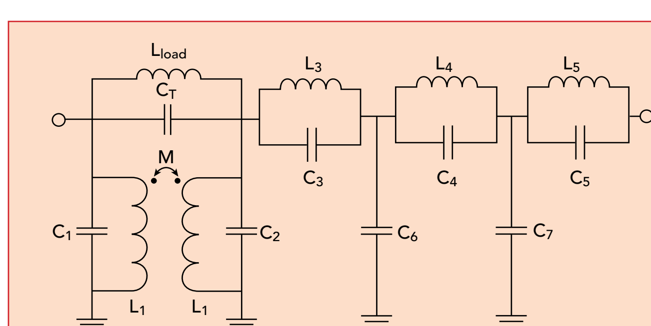

Fig. 4 **BPF circuit topology.**

TABLE 1

BPF COMPONENT VALUES

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_T	Units
1.68	3.6	0.66	0.48	0.54	0.69	0.3	1	(pF)
L_1	L_{load}	L_3	L_4	L_5	M			
5	0.3	1.8	0.35	0.47	2			(nH)

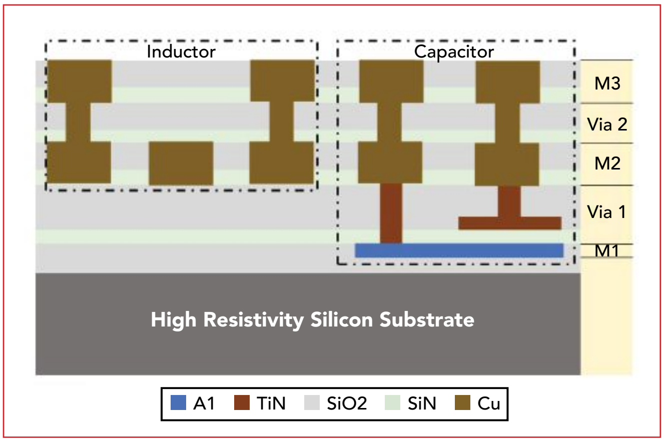

Fig. 5 HRS substrate stack-up.

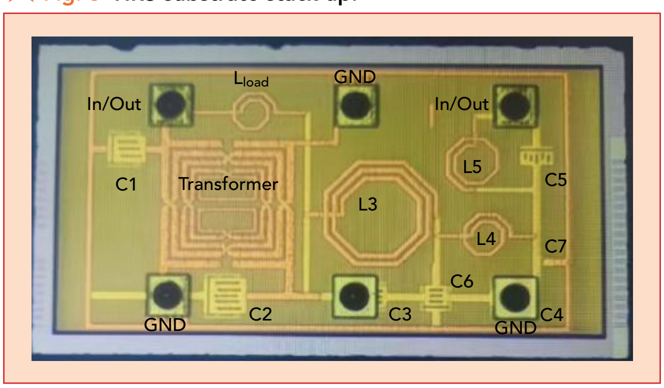

Fig. 6 IPD BPF prototype.

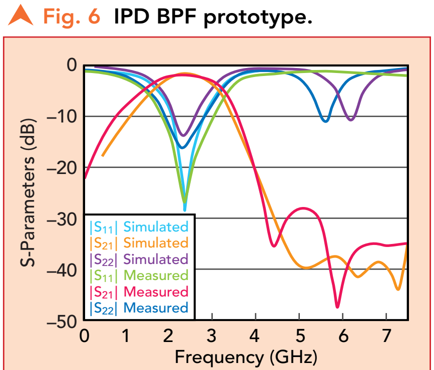

Fig. 7 Simulated and measured S-parameters.

Note that an inductor with a smaller inductance generally occupies a smaller area. Although this may lead to an increase in transformer bandwidth, it can be filtered out and thus compensated through the lowpass filtering circuit connected in series.

TABLE 2

COMPARISON WITH OTHER RECENT WORK

Reference	f_0 (GHz)	Insertion Loss (dB)	FBW (%)	Size (λ_0^2) x10^{-4}	Process
4	3	3.1	20	1.55 × 0.92	GaAs
6	3.35	2.05	56.7	1.68 × 0.67	GaAs
7	3.05	1.9	23	8.8 × 6.9	LTCC
8	4	2.12	111	3.2 × 0.8	GaAs
9	2.83	1.2	143	2.7 × 0.9	GaAs
10	4.2	3.2	29	2.7 × 1.77	GIPD
This work	2.45	1.75	73.9	0.87 × 0.43	HRS

*FBW: Fractional 3 dB Bandwidth
**λ_0: Wavelength in air at f_0

FABRICATION AND MEASUREMENT

The IPD BPF shown in ***Figure 5*** is fabricated on high-resistivity silicon (HRS) using a thin-film process. The substrate thickness is 200 µm after wafer thinning, with a relative dielectric constant, ε_r, of 11.9 and a loss tangent of 0.003. The IPD technology includes three thick metal (Cu) layers, M1, M2 and M3, with thicknesses of 0.55, 3 and 3 µm, respectively. Each via has a thickness of 3 µm. ***Figure 6*** shows the fabricated BPF chip with a size of 1 mm × 0.5 mm (8.7 × 10^{-3} λ_0 × 4.3 × 10^{-3} λ_0).

Simulated results, using the Ultra-EM® 3D full-wave EM simulator and measured S-parameters, are shown in ***Figure 7***. Good agreement is observed. Specifically, in the operating frequency band of 2.4 to 2.5 GHz, insertion loss is lower than 1.75 dB and return loss is higher than 14 dB. Its out-of-band rejection is greater than 30 dB at 1.74x the center frequency. Out-of-band rejection is greater than 27.7 dB and 35 dB in the frequency bands of 5.15 to 5.875 GHz (Wi-Fi 5) and 5.925 to 7.125 GHz (Wi-Fi 6), respectively. There is a minor frequency shift between the simulated and measured results attributed to fabricated tolerances. A comparison of the results of this design with the results from other designs is listed in ***Table 2***. This filter is more compact and its insertion loss is lower than the filters in references 4, 6, 7, 8 and 10. It has higher selectivity than the filters in references 8 and 9.

CONCLUSION

A miniaturized silicon-based IPD BPF design has been fabricated with low insertion loss and high out-of-band rejection. Adding an inductively-loaded transformer has reduced the insertion loss. The addition of a lowpass filter in series with the transformer increases the rejection in the Wi-Fi 5 and Wi-Fi 6 bands. A prototype measuring only 1 mm × 0.5 mm (0.87 × 10^{-2} λ_0 × 0.43 × 10^{-2} λ_0) was fabricated using silicon-based IPD technology. Measurements demonstrate a 2.4 to 2.5 GHz bandwidth with insertion loss less than 1.75 dB and return loss greater than 14 dB. It shows potential, due to its size and performance, for application in Wi-Fi communication systems. ■

ACKNOWLEDGMENTS

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References

1. C. H. Chen, C. H. Huang, T. S. Horng and S. -M. Wu, "Highly Miniaturized Multiband Bandpass Filter Design Based on a Stacked Spiral Resonator Structure," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 5, May 2012, pp. 1278–1286.
2. W. Zhao, Y. Wu, Y. Yang and W. Wang, "LTCC Bandpass Filter Chips with Controllable Transmission Zeros and Bandwidths Using Stepped-Impedance Stubs," *IEEE Transactions on Circuits and Systems II: Express Briefs*, Vol. 69, No. 4, April 2022, pp. 2071–2075.
3. S. Marín, J. D. Martínez, C. I. Valero and V. E. Boria, "Microstrip Filters with Enhanced Stopband Based on Lumped Bisected Pi-Sections with Parasitics," *IEEE Microwave and Wireless Components Letters*, Vol. 27, No. 1, January 2017, pp. 19–21.
4. F. J. Chen, X. Cheng, L. Zhang, Y. L. Tian, Y. Tang and X. J. Deng, "Synthesis and Design of Lumped-Element Filters in GaAs Technology Based on Frequency Dependent Coupling Matrices," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 67, No. 4, April 2019, pp. 1483–1495.
5. A. Taslimi and K. Mouthaan, "Design of Optimized Minimum Inductor Bandpass Filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 65, No. 2, February 2017, pp. 484–495.
6. X. H. Luo, X. Cheng, L. Zhang, F. J. Chen X. L. Xia, J. -A Han and X. J Deng, "A Miniaturized On-Chip BPF With Ultrawide Stopband Based on Lumped Pi-Section and Source-Load Coupling," *IEEE Microwave and Wireless Components Letters*, Vol. 29, No. 8, August 2019, pp. 516–519.
7. W. Feng, X. Gao, W. Che, W. Yang and Q. Xue, "LTCC Wideband Bandpass Filters with High Performance Using Coupled Lines with Open/Shorted Stubs," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, Vol. 7, No. 4, April 2017, pp. 602–609.
8. B. G. Liu, Y. J. Zhou and C. H. Cheng, "Miniaturized Ultra-Wideband Bandpass Filter with Ultra-Wide Stopband Using π-Type Unit with Inductive Loading on Integrated Passive Device," *IEEE Transactions on Circuits and Systems II: Express Briefs*, Vol. 68, No. 11, November 2021, pp. 3406–3410.
9. Y. P. Lyu, Y. J. Zhou, L. Zhu and C. H. Cheng, "Compact and High-Order On-Chip Wideband Bandpass Filters on Multimode Resonator in Integrated Passive Device Technology," *IEEE Electron Device Letters*, Vol. 43, No. 2, February 2022, pp. 196-199.
10. Y. C. Tseng and T. G. Ma, "On-Chip GIPD Bandpass Filter Using Synthesized Stepped Impedance Resonators," *IEEE Microwave and Wireless Components Letters*, Vol. 24, No. 3, March 2014, pp. 140-142.

PLAYBOOK

LEO Satellites: Driving the Future of SATCOM

THE SATELLITE COMMUNICATIONS (SATCOM) INDUSTRY IS EXPERIENCING RAPID GROWTH.

Overview

The SATCOM industry is experiencing rapid growth, driven by advancements in low Earth orbit (LEO) satellite technology and the increasing demand for low-latency, high-speed connectivity. With LEO constellations expected to make up 70% of the commercial satellite market by 2029, this shift presents significant opportunities for innovation across telecommunications, Internet of Things (IoT), defense and disaster recovery.

Key enablers of this transformation include active electronically scanned array (AESA) antennas and beamforming technologies, which enhance performance, agility and reliability. These systems enable seamless communication across various orbits, supporting high-speed data transmission and global coverage. Additionally, the emergence of non-terrestrial networks (NTNs) is extending connectivity to remote and underserved areas. Enabled by 3GPP Release 17 and upcoming enhancements in Release 18, NTNs support applications such as direct-to-smartphone connectivity, real-time IoT communications and emergency response.

As SATCOM technologies continue to evolve, they will play a critical role in next-generation wireless networks. Qorvo's SATCOM portfolio is positioned to meet these demands, offering scalable RF solutions that enhance connectivity for both terrestrial and space-based applications.

The LEO satellite market is skyrocketing, with projections showing it will soar from $12.6 billion in 2024 to an impressive $23.2 billion by 2029. This rapid growth, at a CAGR of 13.0%, reflects surging demand for next-generation connectivity and the race to revolutionize global communication networks.[1]

THE FUTURE HAS NEVER LOOKED BRIGHTER FOR SATELLITE OPERATORS

given the record-setting number of satellite launches in recent years, the growing number of satellite-based applications and the huge capital investments being made in a host of planned space ventures.

SATCOM Market Drivers

Large investments in new communications satellite constellations are driving the demand for new technologies at lower price points and more capabilities. In addition to new technologies, the growth in satellite deployments is driving the need for more power efficient, compact and reliable components used throughout the signal chain, from RF power amplifiers to low-noise amplifiers to beamforming ICs.

There are a wide range of SATCOM applications across a variety of market segments. Often these terminals have varying requirements depending on the constellation(s) on which they operate and the markets in which they address.

The four major markets include **consumer, commercial mobility, enterprise and government**. Many requirements overlap in these markets, including performance requirements, size, weight, power draw, throughput performance, cost and ruggedness. Generally, the consumer market has the least overlap as their requirements are the most unique, with very limited viability outside their intended market.

The other three markets have more significant overlap in requirements with ruggedness being a key differentiator from consumer applications. With this typically comes higher prices, ability to sustain higher power draw and often the demand for higher throughput performance. Although many requirements overlap, each market has its own unique class set of criteria as shown in Figure 1 on page 4.

[1] Markets and Markets LEO Satellite Market Report, May 2024.

FOUR MAJOR MARKETS OF SATCOM USER TERMINALS:

1. **Consumer:** Home internet users, vehicle and private maritime users.
2. **Enterprise:** Data centers, mid-to-large businesses and satellite-to-ground teleports.
3. **Government:** Aviation, ground mobile, maritime and ground transportable.
4. **Commercial Mobility:** Agriculture, construction, mining, maritime, aviation and ground transport.

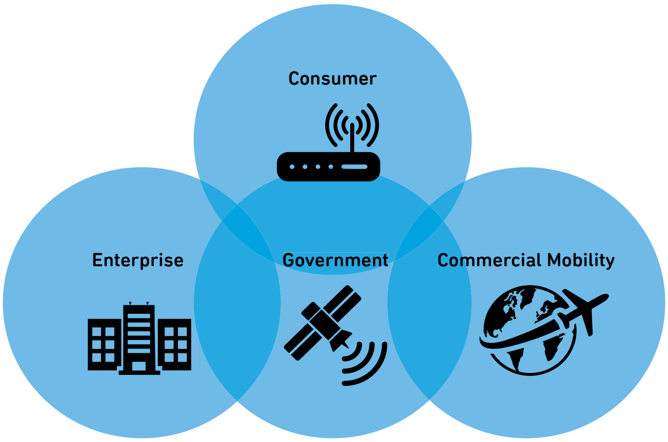


Figure 1: Primary markets have overlapping requirements for terminals dominated by enterprise, government and commercial mobility with consumer terminals nearly standing on their own.

The constellation(s) with which the systems operate can also drive required performance capabilities and requirements. Orbits can be divided into two categories: traditional geostationary Earth orbit (GEO) and non-geostationary orbit (NGSO). NGSO includes low Earth orbit (LEO), medium Earth orbit (MEO) and highly elliptical orbit (HEO), all of which bring unique terminal performance requirements.

The LEO mega-constellations are projected to provide **100x increase in bandwidth** from the legacy GEO satellites with reduced latency by 10x, while serving significantly more users.

MEO satellites also provide lower latency, higher throughputs and service more users than GEO, but with less global footprint than LEO. HEO satellites are being used to fill the "gaps" in GEO and MEO systems, providing higher latitude and polar coverage.

MEO satellites, like GPS, are commonly used for navigation. MEO satellites have their advantages, but like GEO satellites, they do have high launch and maintenance costs. Both GEO and MEO satellites serve a purpose, but they come at the cost of latency and data speeds. Figure 2 on page 5 describes the coverage areas for each of the satellite types.

Parameter	LEO: 500-1,200 km	MEO: 5,000-20,000 km	GEO: 36,000 km
Altitude	Very low	Low	High
Earth Coverage	Small	Large	Very large
Satellites Required	Thousands	Six	Three
Data Gateways	Local numerous	Regional flexible	Few fixed
Antenna Speed	10-minute fast tracking	1-hour slow tracking	Stationary

Figure 2: LEO, GEO, MEO satellite coverage areas. LEO satellites have ushered in a new era of global connectivity and data accessibility.

LEO satellites offer distinct advantages over their geostationary and medium Earth orbit counterparts. They provide low-latency (30 times more responsive than GEO) and high-speed internet connectivity to remote and underserved regions of Earth. LEO satellites require hundreds to thousands of units to cover the Earth's surface, enabling a cross-linked mesh network. This mesh networking not only improves global coverage but also improves connection reliability – for example, if one satellite goes offline, another one can step in to support any signal loss. Currently, most LEO satellite deployments are driven by private companies and government agencies. Companies like SpaceX, OneWeb, Amazon's Project Kuiper and Telesat have invested heavily in LEO satellite deployment. This has ushered in a new era of global connectivity and data accessibility.

SATCOM ORBITS DEFINED

- **GEO:** 35,786 km above Earth. Application connection:
  - Telecommunication, broadcasting, weather forecasting, remote sensing, navigation.
- **MEO:** 5,000-20,000 km above Earth. Application connection:
  - Telecommunication, GPS and other navigation applications.
- **LEO:** 500-1,500 km above Earth. Application connection:
  - Latency critical applications, financial transactions, autonomous vehicles, remote video surgery.

Satellites play a big role in connecting the world. As shown in Figure 3, they do two main things: talk directly to Earth supporting multiple end user terminals across various industries and backhaul that data to Earth either directly or through inter-satellite links (ISLs). With more LEO satellites being launched, communication is getting even faster and covers more area, making it easier to send information from space to Earth with less delay.

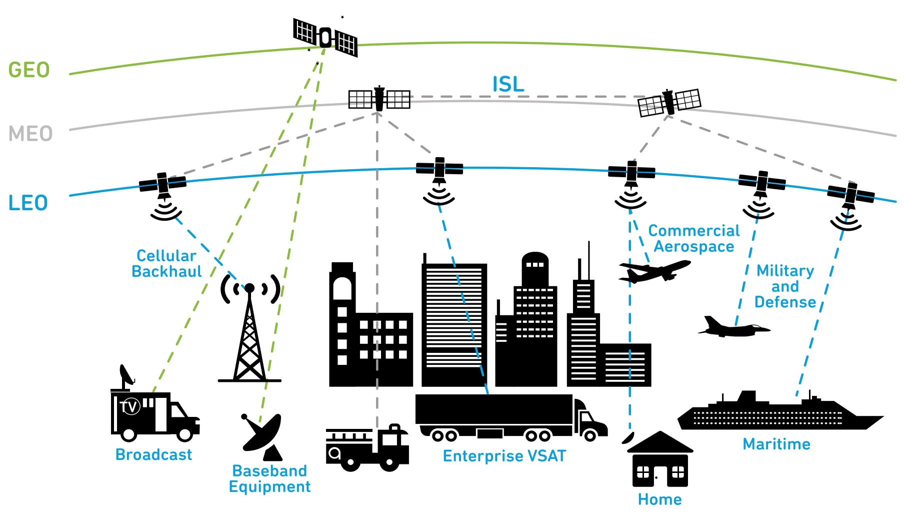


Figure 3: Satellite networks, including terrestrial ISL. The LEO mega-constellations are projected to provide 100x increase in bandwidth from the legacy GEO satellites with reduced latency by 10x, while serving significantly more users.

Looking at the top 4 LEO constellations in consideration today, Amazon (Project Kuiper), Eutelsat OneWeb, Starlink and Telesat, together, they plan for a combined total of over 30,000 satellites when the constellations are fully deployed. The aggregate data capacity of these constellations is staggering, especially compared to the current capabilities of the GEO satellites. As of March 2025, 8,712 communications satellites were in orbit, an increase of over 200% since December 2020, dominated by the LEO launches of OneWeb and Starlink.

A comparison of the constellation sizes is shown in Table 1. This massive growth in capacity combined with a growing demand in the government and commercial mobility markets is leading to a 6-12% CAGR of growth through 2030. In 2021, the market was $3,877 million and is projected to be over $6,000 million by 2028[2]. This demand and growth mean great opportunities for terminal manufacturers who can develop, manufacture and certify terminals at a reasonable price.

System	GEO	Kuiper	OneWeb	Starlink	Telsat
Frequency	Ku & Ka	Ka	Ku	Ku	Ka
Number of Satellites in Orbit	563	2	660	8,050	0
Number of Planned Satellites	700 by 2030 (~15-20 per year)	3,232	7,088	20,000	300
Altitude (km)	35,786	590-630	1200	540-570	1,015-1,320
Latency (ms)	560	~30	~40	~30	~40-50
Satellite Life (Years)	–	7	~5	5-7	10-12
Capacity at Full Plan	3 Tbs	~30-32 Tbs	~50 Tbs (~7.5 Gbps/Sat)	~75 Tbs (~17 Gbps/Sat)	~12 Tbs (~20-50 Gbps/Sat)
Target Markets	Consumer, Enterprise, Mobility, Gov	Consumer, Enterprise, Mobility, Gov	Enterprise, Mobility, Gov	Consumer, Enterprise, Mobility, Gov	Consumer, Enterprise, Mobility, Gov

Table 1: Top 4 LEO Satellite Constellations.[3]

[2] Market Research.com Satellite Communication Terminal Market Forecast to 2028, January 2022.

[3] Jonathan McDowell, astronomer at the Harvard-Smithsonian Center for Astrophysics and leading watcher of most things orbital. March 8, 2025.

Frequency Spectrums for Satellite Communications

Most satellite deployments are L to Ka-band. However, there are more modern satellites moving toward higher frequency bands like Q/V and E spectrums, as shown in Table 2. To serve 5G non-terrestrial network application, 3GPP also allocated NTN bands. Table 3 shows both the current NTN bands in L&S band as well as the newly proposed bands in the K and Ka band.

SATCOM Frequency Band	Downlink Frequency GHz	Downlink Bandwidth GHz	Uplink Frequency GHz	Uplink Bandwidth GHz	Description
L-Band	1.535-1.56	0.025	1.635-1.66	0.025	Provides real-time visibility to monitoring the status of equipment for a remote location and machine-to-machine communications
S-Band	2.5-2.54	0.04	2.65-2.69	0.04	Used for weather radar, surface ship radar and NASA communications, satellite television, mobile broadband services, radio broadcasting and inflight connectivity
C-Band	3.4-4.2	0.8	5.8-6.725	0.925	Provides voice and data transmissions from ship to shore
X-Band	7.25-7.75	0.5	7.9-8.4	0.5	Used for SATCOM, military SATCOM and radar applications
Ku-Band	10-13	3	14-18	4	Used for SATCOM, fixed satellite services and broadcast satellite services
Ka-Band	17.7-21.2	3.5	27.5-31	3.5	Used for SATCOM, military SATCOM, 5G telecommunications
Q/V-Band	37.5-42.5	5	42.5-51.4	8.9	Used for voice, data and video communications
E-Band	71-76	6	81-86	5	Provides very high throughout satellite communications

Table 2: Allocated frequency spectrum for SATCOM communications.

NTN Bands

NR Operating Band	Uplink Operating Band Base Station Receive User Equipment Transmit	Downlink Operating Band Base Station Transmit User Equipment Receive	Duplex Mode	Region	Nicknames
	FDL_low-FDL_high	FDL_low-FDL_high			
n255	1626 MHz-1660.5 MHz	1525 MHz-1559 MHz	FDD	All	MSS L-Band
n256	1980 MHz-2010 MHz	2170 MHz-2200 MHz	FDD	All	MSS S-Band

Proposed 3GPP NTN FR2-1 for K-Band and KA-Band (VSAT)

NR Operating Band	Uplink Operating Band Base Station Receive User Equipment Transmit	Downlink Operating Band Base Station Transmit User Equipment Receive	Duplex Mode	Region	Nicknames
	FDL_low-FDL_high	FDL_low-FDL_high			
n510	17.7 GHz-20.2 GHz	27.5 GHz-28.35 GHz	FDD	All	MSS K & Ka-Band
n511	17.7 GHz-20.2 GHz	28.35 GHz-30 GHz	FDD	All	MSS K & Ka-Band
n512	17.7 GHz-20.2 GHz	27.5 GHz-30 GHz	FDD	All	MSS K & Ka-Band

Table 3: Current and proposed NTN bands.

The Integration of Satellites in the 5G Network

There's a growing adoption globally of broadband internet services offered by large LEO satellite constellations. This interest, along with the integration of satellite networks into the 5G ecosystem, is further propelling satellite market growth.

Moreover, cellular communications are becoming part of the satellite ecosystem. The introduction of 3GPP 5G wireless technology in Release 17[4] has made it possible to adapt 5G systems for NTNs. NTNs aim to expand network coverage worldwide, especially in rural and remote areas, and facilitate direct connections between mobile devices, the IoT and commercial autonomous vehicles to satellites. This integration enables the satellite industry to leverage the 5G ecosystem's economy of scale.

The 3GPP Release 17 specified both 5G new radio (NR) NTN and 4G IoT NTN, as described in Figure 4. It focuses on utilizing satellite transparent payload architecture and User Equipment (UE) with GNSS capabilities. Figure 4 shows the expected use cases for 5G NTN.

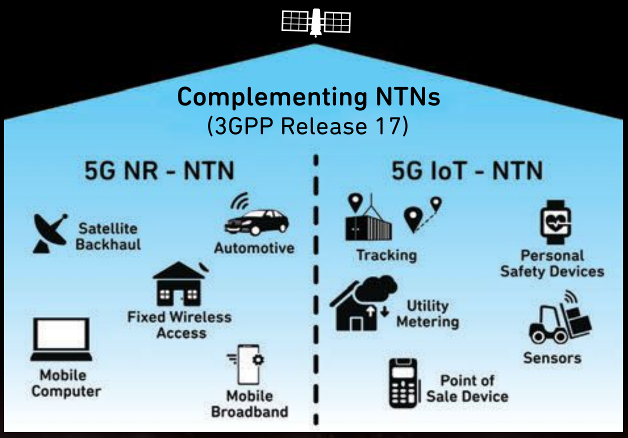


Figure 4: NTN 5G NR and IoT use cases that complement each other.

Additional 5G NTN uses include:

- Under-covered areas such as agriculture, mining and forestry.
- Disaster communications when land communication networks are damaged.
- Broadcasting information over a very wide area.

[4] 3GPP Release 17

Advancing Communication: The Role of LEO Satellites in the Wireless Expansion

In the previous section, we explored the many aspects of the satellite marketplace and began to touch upon the impact it's having on 5G NR cellular and IoT networks. In this section we dig a bit more into this convergence of satellite mesh with NTNs and how they are changing the communication landscape of tomorrow.

NTN satellites function as relays to extend wireless coverage and capacity of terrestrial networks. These networks provide communication services for emergencies, disasters and other services such as IoT network devices. Moreover, companies are offering agreements to add satellite connectivity to the latest high-end smartphones. Enabling global two-way emergency messaging, low-cost internet services to remote locations, remote texting and other phone-based communications, all powered by LEO satellite networks.

Moreover, the 3GPP's Release 17 adds new 5G satellite network uses, covering GEO, MEO and LEO satellite technologies. The 5G NTN NR satellite network includes two communication links – one between the satellite and users and the other between the satellite and the ground station connected to the data network on Earth. It will provide both NTN-IoT and 5G NR communications – linking smartphones and other 5G enabled devices to the NTN service network.

Advancements in 5G NR NTN and Satellite Technology

As shown in Figure 5 below, GEO satellites, positioned at 35,000 km above the Earth, have a latency of 280 milliseconds (ms), whereas LEO satellites, orbiting at altitudes between 500 to 1,200 km, can reduce latency to just 6 to 30 ms. Therefore, the maximum one-way propagation delays from UE to LEO satellites have a much shorter delay than their MEO and GEO counterparts.

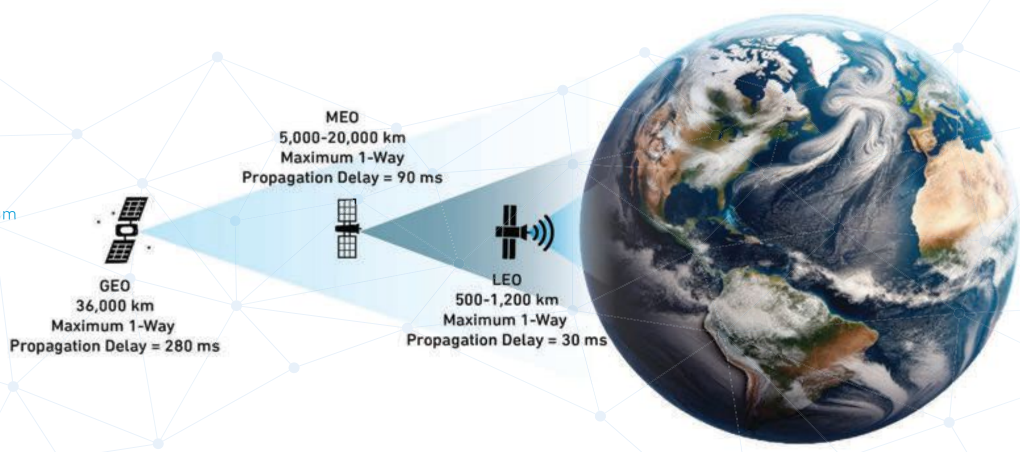


Figure 5: 3GPP-TS 22.261 maximum one-way propagation delays from UE to satellite comparison.

The 5G NR NTN architecture, incorporating satellite technology, promises global cellular wireless connectivity. The 3GPP Release 17 focuses on enhancing 5G NTN and IoT NTN services worldwide, it also introduces low latency direct-to-cellular services, improving speeds to tens of Mbps in the sub-6 GHz band.

Additionally, Release 18 aims to improve coverage and mobility by using frequencies above 10 GHz, specifically the Ku and Ka bands. This allows speeds of hundreds of Mbps, benefiting smaller AESA antennas, such as those used by SpaceX's Starlink. These advancements boost speeds, support disaster recovery efforts and extend coverage to remote areas previously unreachable by traditional networks.

As discussed in the previous section, detailed in table 3, the evolution of 5G NTN under 3GPP standards involves expanding the spectrum to include the L, S, K and Ka bands, enhancing uplink coverage and supporting mobility services. Release 18 specifically targets the introduction of three new NTN bands above 10 GHz (n510, n511 and n512) to further refine the 5G NTN design for improved performance and broader accessibility.

Another key objective of NTN networks is to enhance the efficiency of the limited radio frequency spectrum, which often becomes congested. Recent technology studies are finding better ways to manage this congestion, like using time division duplexing (TDD) for space networks, a change from the usual method that assigns different paths for sending and receiving signals. The use of TDD bands as shown in Table 4, helps mobile carriers free up more space on the busy under-6 GHz spectrum. These improvements are pushing satellite technology forward, making it smarter and more in line with ground-based networks.

Band Details	Band	Uplink (GHz)	Downlink (GHz)	Duplex
Existing 3GPP FR2 Bands	n257	26.5 to 29.5	26.5 to 29.5	TDD
	n258	24.25 to 27.5	24.25 to 27.5	TDD
	n259	39.5 to 43.5	39.5 to 43.5	TDD
	n260	37 to 40	37 to 40	TDD
	n261	27.5 to 28.35	27.5 to 28.35	TDD
	n262	47.2 to 48.2	47.2 to 48.2	TDD

Table 4: Future TDD NTN bands are pushing satellite technology forward, making it smarter and more in line with ground-based networks.

3GPP NTN GOALS:

Release 17: Enhancing 5G NTN and IoT NTN services.

Release 17: Introduce low latency direct-to-cellular services in the sub-6 GHz band.

Release 18: Improve coverage and mobility by using frequencies in the Ku and Ka-bands allowing speeds of hundreds of Mbps, benefiting smaller AESA antennas.

Comparison of One-Way and Two Way Satellite Communications

Satellite communications are categorized into one-way and two-way systems. One-way communication involves signals being transmitted from the satellite to the ground, utilized in services such as GPS, satellite TV and radio. In contrast, two-way communication facilitates interactive signal exchange between satellites and ground stations, supporting internet services and phone calls. Figure 6 illustrates the differences between one-way and two-way communications involving Earth stations and a satellite.

As shown, one-way communications (left) like direct broadcast satellite (DBS) services, traditionally rely on GEO satellites. GEO satellites match the planet's rotation and only orbit Earth's equator. From the ground perspective GEO satellites appear in a fixed position in the sky. GEO satellites are a type of geosynchronous orbit (GSO), and both are used in telecommunications and Earth observation.

Non-geostationary orbit (NGSO) refers to a type of orbit used by satellites where it is not stationary relative to the surface of the Earth. NGSOs orbit the Earth at a lower altitude than GEO satellites and complete an orbit in a much shorter time. NGSOs constantly move across the sky and can provide better coverage for mobile satellite services and improve global connectivity. There are several types of NGSO orbits, including LEO, MEO and HEO – with LEO being the closest to Earth.

Two-way LEO satellite architectures further enhance the overall satellite communications. These two-way satellite communications advance beyond the old one-way "bent-pipe" approach, incorporating technologies like AESA antennas. The bent-pipe architecture behaves like a repeater, while the two-way architecture moves beyond this one-way communications style. These advanced systems are crucial for enhancing communication between ground and satellite.

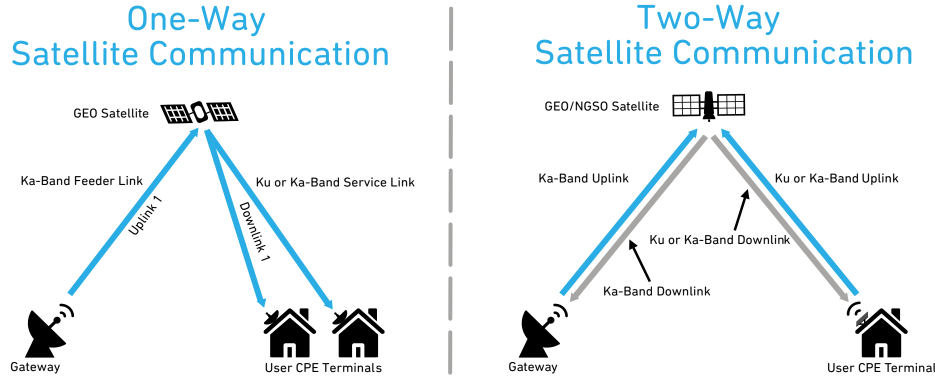


Figure 6: Example of one-way and two-way satellite use cases. Two-way architectures are crucial for enhancing communication between ground and satellite.

NTN Transparent and Regenerative Architectures

The new generation of ground-station systems is moving towards flexible and interconnected infrastructures with smaller flat panel user terminals, like cellular networks. To integrate satellite access networks into 5G, 3GPP TR38.821 introduced two types of satellite-based NG-RAN architectures: transparent and regenerative.

As shown in Figure 7 (left), the transparent payload architecture, the 3GPP 5G NR base station (gNB) is on the Earth, while the satellite plays the role of the bent-pipe repeater. In transparent payload communications, RF filtering, frequency conversion and amplification are performed on the satellite. In the regenerative payload architecture shown in Figure 7 (right), full gNB or part of gNB is implemented on the satellite. Therefore, in regenerative payload communications, the RF filtering, frequency conversion and amplification, demodulation, coding/decoding, switching or routing and modulation are done on the satellite. This is like having all or part of the gNB traditional ground base cell site function on board the satellite. These regenerative system architectures used for LEO satellites have many advantages over the traditional bent-pipe transponders. This is the architecture of the future as the current LEO constellations have their own proprietary waveforms and on-board processing systems.

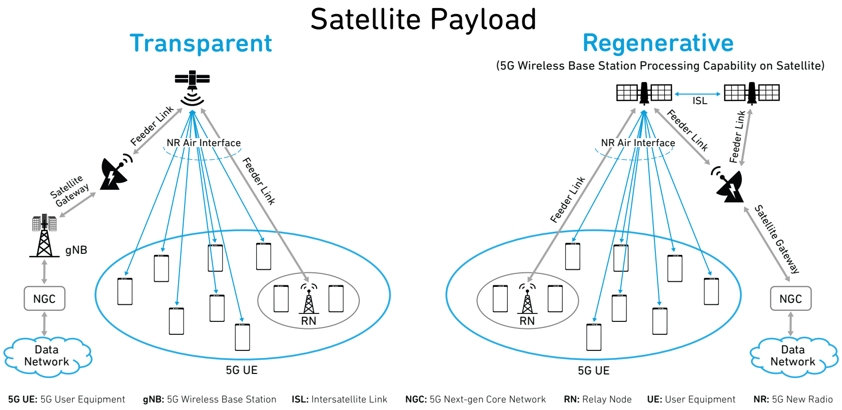


Figure 7: Satellite payload transparent and regenerative networks. Regenerative satellite architectures offer significant advantages in terms of performance, flexibility and efficiency, making them ideal for modern, data-intensive applications

AS DEMAND FOR CONNECTIVITY INCREASES

satellites will serve areas outside highly networked cities for purposes such as connection on the move, critical emergency services, edge networking and connected devices (IoT).

Satellite Technologies

Satellite communications is a growth market, both for the satellites in orbit and the associated ground terminals. Both require a broad range of RF signal chain components, from low noise amplifiers (LNAs) and RF power amplifiers (PAs). Other key components include filters and switches. As demand for LEO SATCOM advances, so does the focus on the satellite's size, weight and power attributes. Also, the availability of lightweight fixed and portable SATCOM user terminals is driving the industry to deliver creative answers to existing technologies, such as antennas.

The Entrance of AESA and Beamforming

The growth of SATCOM user terminals is responsible for a major shift in antenna technology.

Traditional parabolic (dish type) antenna limitations are unable to keep up with current requirements, leading a transition to electronically steered antennas such as AESA or phased-array types. AESA antennas can change the direction of their signal electronically, without needing to move physically, offering a big improvement over the mechanically steered antennas' agility. Moreover, AESA can create and send out its signals, using beamforming techniques for fast and accurate beamsteering adjustments. This enables connectivity to satellites in any orbit with fast handoff between satellites.

As shown in Figure 8 below, user CPE terminals are the direct link between the user and the satellite. These units are lower cost, easy to set up and can be stationary or mobile (i.e., mobile SATCOM, maritime, etc.). They use AESA antennas to integrate various technologies into a more compact and lightweight design. This includes beamforming technology for agile tracking and steering, and they also utilize readily available commercial off-the-shelf (COTS) components. Moreover, they support faster data transmission methods.

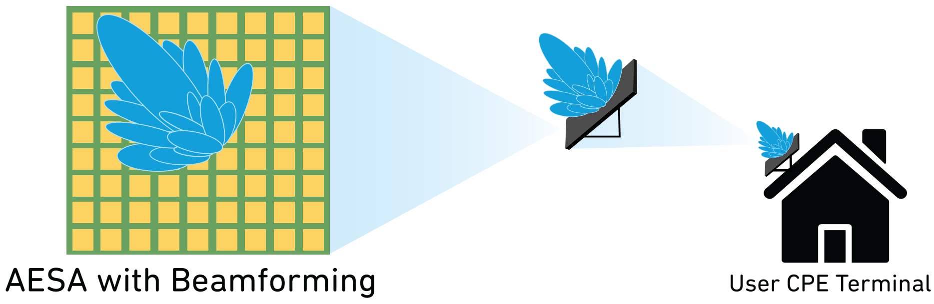


Figure 8: AESA beamforming terminal. AESA technology improves the speed in which data can be sent and the efficient use of the available frequencies. This makes internet connections faster, reaching wider areas and provides more dependable service, even in remote locations.

The Role of Beamforming and AESA Antennas in SATCOM Communications

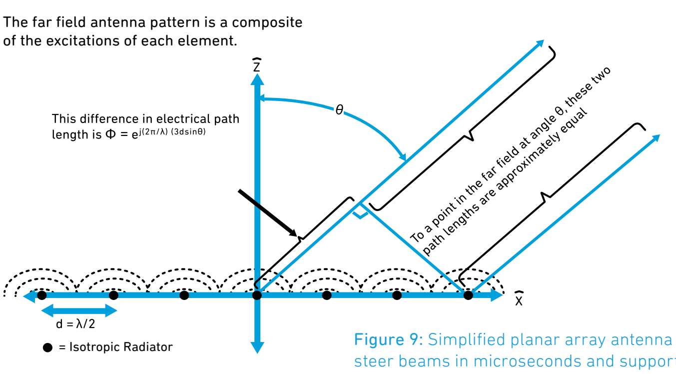
In the previous sections, we explored the many aspects of the satellite marketplace and introduced ways in which beamforming and AESA technologies are advancing satellite NTN. This section delves into how beamforming and AESA antennas are shaping satellite communication design trends and benefiting engineers in the field.

Beamforming is a signal processing technique used in antenna arrays for directional signal transmission or reception. This technology is crucial in wireless communication systems as it improves signal power, leading to enhanced performance and efficiency.

Beamforming along with multiple-input multiple-output (MIMO) and AESA are foundational technologies in modern wireless communication, offering significant benefits in terms of signal quality, network efficiency and user experience. Their applications span from mobile networks and Wi-Fi to satellite communications and radar, making them a critical tool in the advancement of wireless technologies.

What is an AESA or Active Antenna?

An active antenna, also known as a phased array antenna, consists of multiple stationary elements fed coherently. To form an electronic beam, each element is energized by the appropriate phase, then a beam can be formed coherently in the far field for the desired direction. It uses variable phase control at each element to scan a beam to specific angles in space, as shown in Figure 9 below. This electronic beam steering, with no moving parts, is managed by ICs at each radiating element.



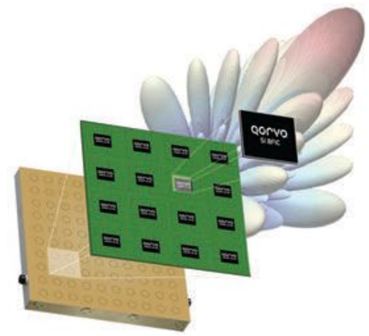


Figure 9: Simplified planar array antenna with a row of isotropic radiators. Active antennas can steer beams in microseconds and support multiple, simultaneous, independently steerable beams.

Active antennas with beamforming ICs have the advantage known as a soft failure mechanism, which means that the failure of a few elements typically has little impact on overall performance. Moreover, these AESA beamforming antennas can steer beams in microseconds and support multiple, simultaneous, independently steerable beams. With no mechanical parts, they are low-profile and reliable. Additionally, they can steer nulls and have high degrees of freedom to block interferers and jammers, enabling precise radiating aperture patterns.

For most NTN communications, antennas operate at mmWave in the GHz frequency ranges, like 24, 26, 28, 37 or 39 GHz. These high frequencies have short wavelengths, allowing many antenna elements to fit into a compact, highly directive aperture, offsetting high path loss, as shown in Figure 9 on page 15. The highly directive beams also offer spatial diversity, enabling multiple beams to reuse the same frequency spectrum, which significantly increases system capacity.

What is Beamforming?

Beamforming can be executed in an analog or digital format, depending on the system requirements. We'll dig more into the individual architecture types later.

Beamforming involves manipulating the phase and amplitude of the signal at each radiating element in the array. This technique causes signals at specific angles to experience constructive interference, while others experience destructive interference. This results in the RF energy being "focused" in specific directions, creating a beam-like pattern, as shown in Figure 10. In this figure, we can see the steered beam in the antenna array creates a main lobe at a given angle and minimizes the side lobes. Beamforming increases the signal-to-noise ratio (SNR) at the receiver end, reduces multipath fading and minimizes interference from other directions.

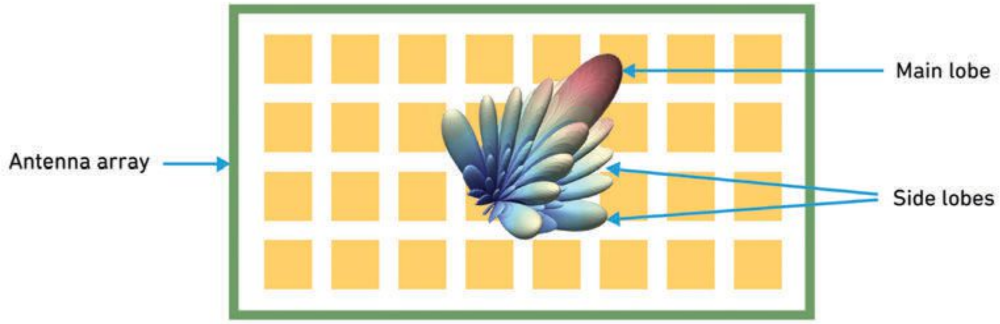


Figure 10: Beamforming signal lobes in an AESA antenna. The signal beam is steered using phase shifters of TDUs.

AESA antennas can steer the signal beam using either phase shifters or TDUs, each with its tradeoffs. For systems operating with a larger instantaneous bandwidth, TDUs may be a better choice to avoid beam distortion, known as squinting, as shown in Figure 11 below. However, for lower operating bandwidth systems, phase shifters are sufficient and are the most broadly implemented solution. Note, there are also architectures that incorporate both TDU and phase shifters into the same system. This also helps reduce squinting.

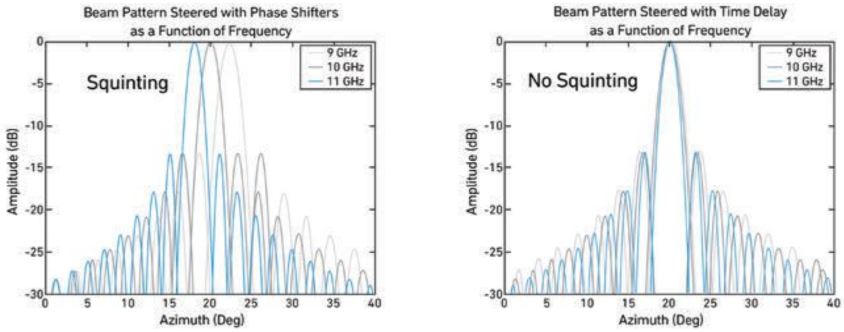


Figure 11: Beam squinting/distortion.

TDUs exhibit a constant phase slope over frequency range and therefore, remove beam squinting effects. While phase shifters exhibit constant phase over the operating frequency range; therefore, a phase shifter setting may result in different beam steering angles for different frequencies. Which is the reason phase shifters work best for narrower system bandwidths.

Phase shifters electrically steer a beam by approximating time delay, resulting in an optimal beam at the center frequency. However, phase shifting can cause understeering at the maximum operating frequency and oversteering at the minimum operating frequency. Phase shifter architectures are significantly more cost effective and thus more commonly used.

Ultimately, both methods work but engineers must make tradeoffs for the best implementation. First by evaluating the array size and instantaneous bandwidth requirements to determine if phase shifters are sufficient. Second, by evaluating whether a hybrid solution is sufficient where phase shifters are used at the elements and TDU is implemented behind some subset of elements within a larger array. If the instantaneous bandwidth and/or array size is large enough, TDUs may be required at every antenna element.

BEAMFORMING ENHANCES SIGNAL QUALITY AND EFFICIENCY

by directing electromagnetic energy, which is crucial for mobile networks, Wi-Fi and satellite communications.

Today's systems offer precise and reliable beam steering to improve network performance, signal coverage and data throughput in modern communications.

Types of Beamforming

Three general beamforming architectures are used in active antennas: analog beamforming, digital beamforming and hybrid beamforming. This section describes each approach from a high level and then compares the pros and cons of each approach.

Analog Beamforming: Requires an RF signal adjustment at each antenna element to steer the beam in the desired direction. This is simpler, often cheaper and lower power but less flexible compared to digital beamforming.

Digital Beamforming: Each antenna element is connected to its own digital signal processor. The beam is formed and steered by digitally manipulating the signals. This can allow for more precise control and the ability to form multiple beams simultaneously from the same array. This is practical only at low frequencies, such as S-band, where the lattices are large and there is plenty of room to place the required hardware on the array.

Hybrid Beamforming: Combines both analog and digital techniques, often used in systems where a purely digital approach would be too costly or complex and is popular in 5G mmWave networks. This technique mitigates the complexity inherent to using digital beamforming and reduces the RF chain components, thereby simplifying the overall system.

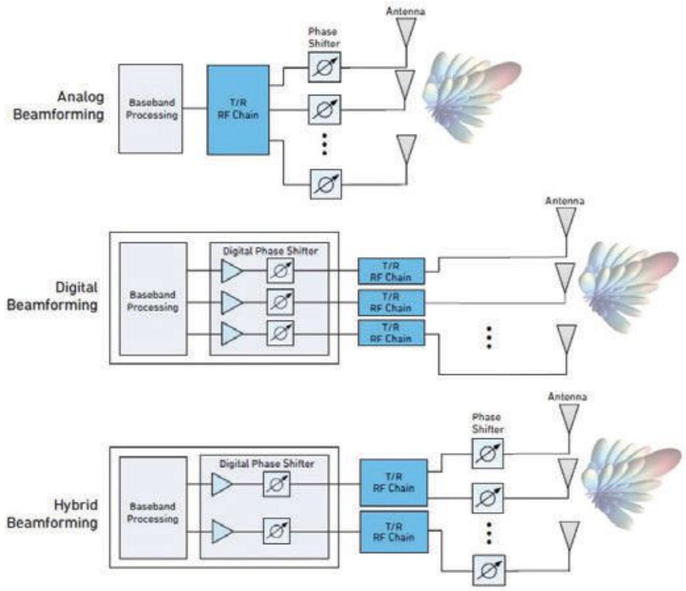


Figure 12: Comparison between analog, digital and hybrid beamforming architectures.

Parameter	Analog	Digital	Hybrid
Phase Shift Control	Analog phase shifters	Digital signal processing	Combination of analog and digital
Carrier Bandwidth	Narrower	Widest	Wider
Complexity	Lower complexity	Higher complexity	Moderate complexity
Cost	Lowest	Highest	Moderate
Power Consumption	Lowest	Highest	Moderate
Application	Broadest market	Exquisite market	High-performance market

Table 5: Comparison of beamforming types.

A Brief Look at Beamforming Wireless Applications

The wireless marketplace is beginning a move towards more beamforming SATCOM applications, to provide higher throughput enabled by wider bandwidth frequencies. In cellular networks, beamforming can be used to improve bandwidth efficiency and coverage by enabling base stations to focus signals on individual users, reducing interference and increasing data rates. In Wi-Fi networks, beamforming can be used to enhance signal quality and range, particularly in crowded environments with many user devices. Moreover, satellite communications, using beamforming is shaping the coverage area of satellite signals, allowing for targeted broadcasting and communication with specific regions. In radar system applications, beamforming is enhancing resolution and range by focusing transmitted pulses in the direction of interest improving the detection of objects.

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Qorvo is your trusted partner for satellite communications. We bring innovation and scale to SATCOM applications. Our system level support and broad portfolio of solutions for both user terminals and LEO/GEO/MEO satellites are connecting the world through space.

Webinars:

- Innovations in Satellite Communications & Emerging ESA Technologies
- Key Components for LEO Satellite Systems
- Navigating the SATCOM User Terminal Trade Space

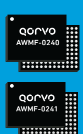
Sponsored eBook:

- RF Technology Trends for LEO Satellite Systems

Additionally, you can find more information on this subject by visiting our SATCOM solutions page, or email us at **beamforming-sales@qorvo.com.**

GROUND APPLICATIONS

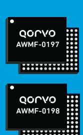
Flat Panel Arrays



Ku-Band

Rx: 10.7 to 12.75 GHz; Tx: 13.75 to 14.5 GHz

Ku-Band Quad Beamformer ICs
AWMF-0240[NEW], AWMF-0241[NEW]
AWMF-0146, AWMF-0147
New Quad 4x2 Tx and Rx integrated ICs advancing efficiency and performance.
Recommended Rx Gain Stage: CMD264P3
Recommended Tx Driver: CMD264P3

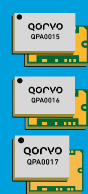


Ka-Band

Rx: 17.7 to 21.2 GHz; Tx: 27.5 to 31.0 GHz

Ka-Band Quad Beamformer ICs
AWMF-0197, AWMF-0198
Quad 4x2 Tx and Rx highly integrated ICs simplifying active antenna design.
Recommended Rx Gain Stage: QPA2626
Recommended Tx Driver: QPA2628

SATCOM Terminals



Ku-Band

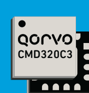
Rx: 10.7 to 12.75 GHz; Tx: 13.75 to 14.5 GHz

8, 15 or 25W GaN Tx Power Amplifiers
QPA0015, QPA0016, QPA0017
SMT package

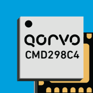
Ka-Band

Rx: 17.7 to 21.2 GHz; Tx: 27.5 to 31.0 GHz

25W GaN Tx Power Amplifier
QPA2212D



Ultra-Low Noise Rx Amplifier
CMD320C3
Market leading NF=1.07 dB, 18 dB gain with no external DC blocks or RF matching required. Low power dissipation.



GaAs Rx Low Noise Amplifier
CMD298C4
Market leading NF=1.07 dB, 18 dB gain with no external DC blocks or RF matching required. Low power dissipation.

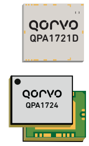
SPACE APPLICATIONS

Space Payload

Ku-Band

Rx: 13.75 to 14.5 GHz; Tx: 10.7 to 12.75 GHz

17.5 or 35W GaN Tx Power Amplifiers
QPA1006D, QPA1009D



Ka-Band

Rx: 27.5 to 31.0 GHz; Tx: 17.7 to 21.2 GHz

20 or 30W GaN Tx Power Amplifiers
QPA1721D, QPA1724

GaAs Rx Low Noise Amplifier
QPA2628
Market leading NF=1.6 dB, 23 dB gain with no external DC blocks or RF matching required.

GaAs Rx Low Noise Amplifier
QPA2735
Market leading NF=1.3 dB, 25.5 dB gain with no external DC blocks or RF matching required.

Visit qorvo.com/go/satcom for more information