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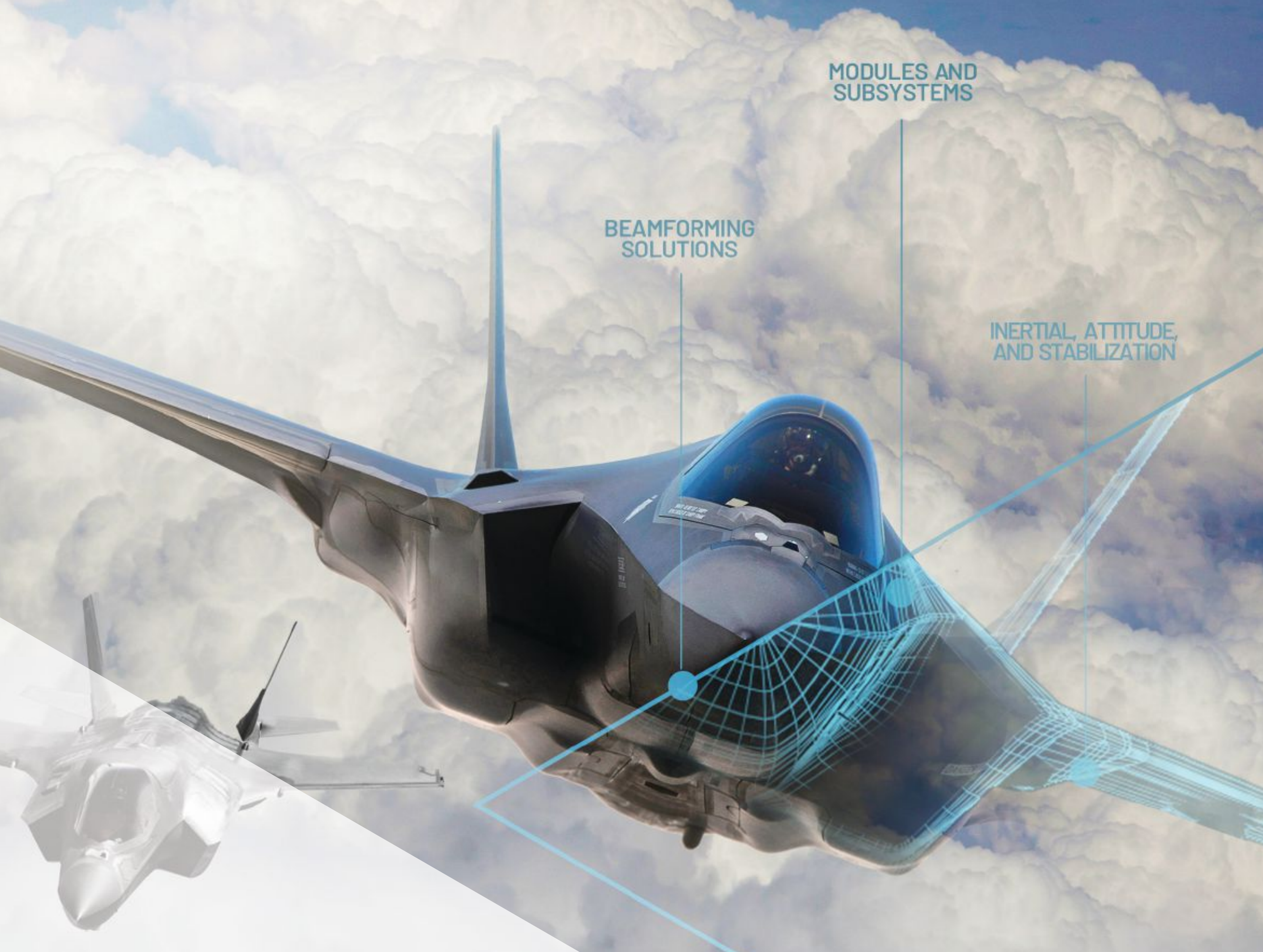
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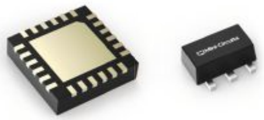

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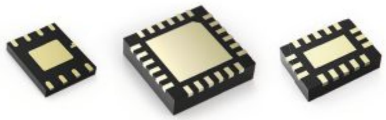

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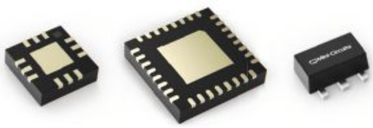

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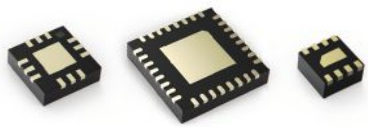

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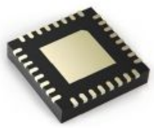

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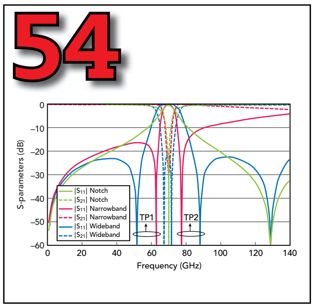

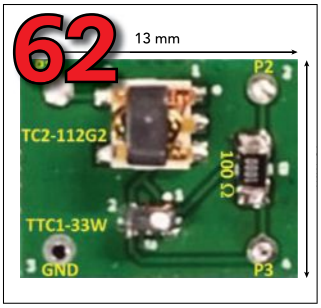

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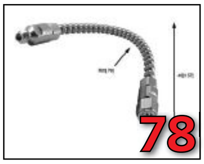

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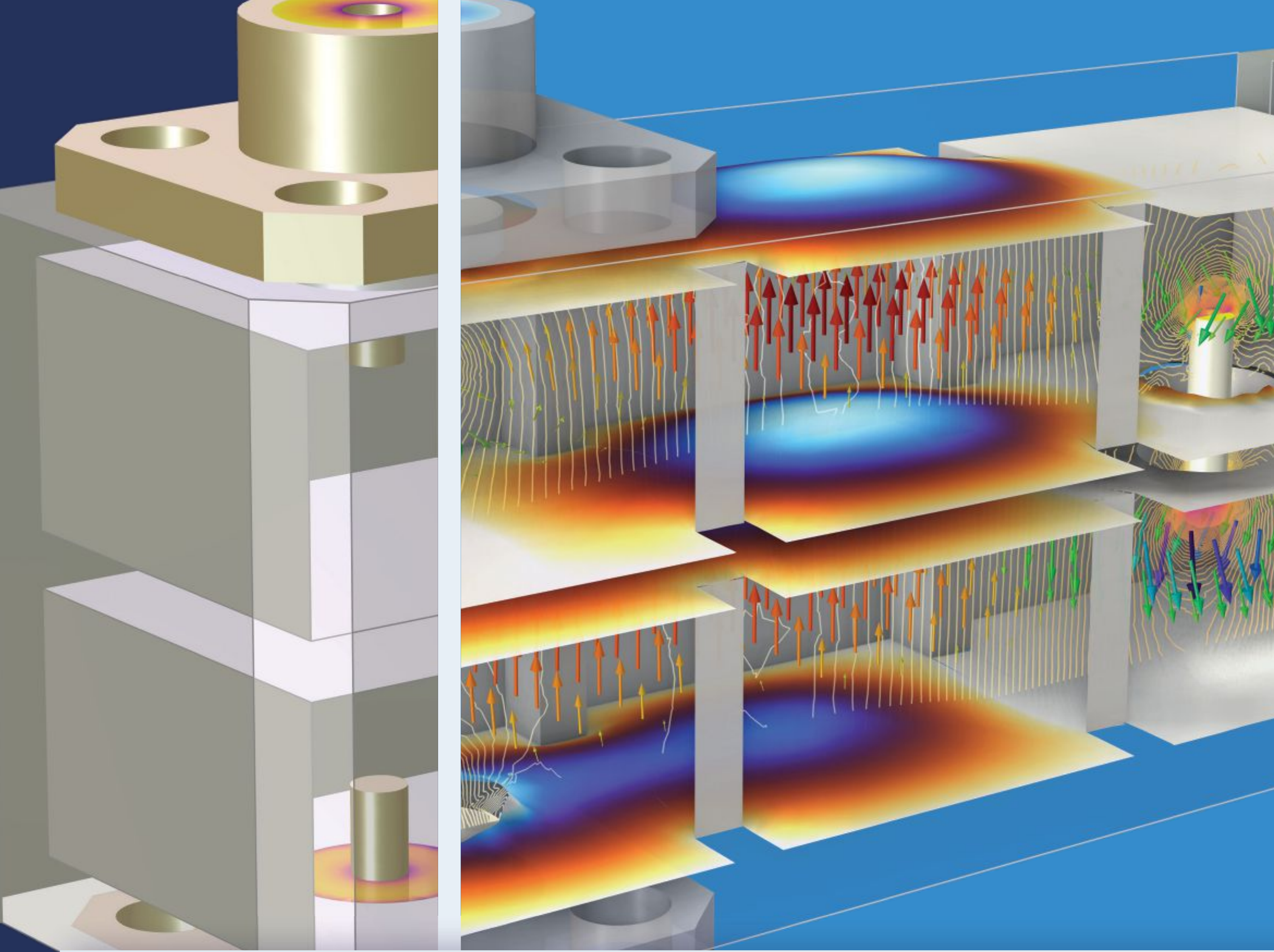

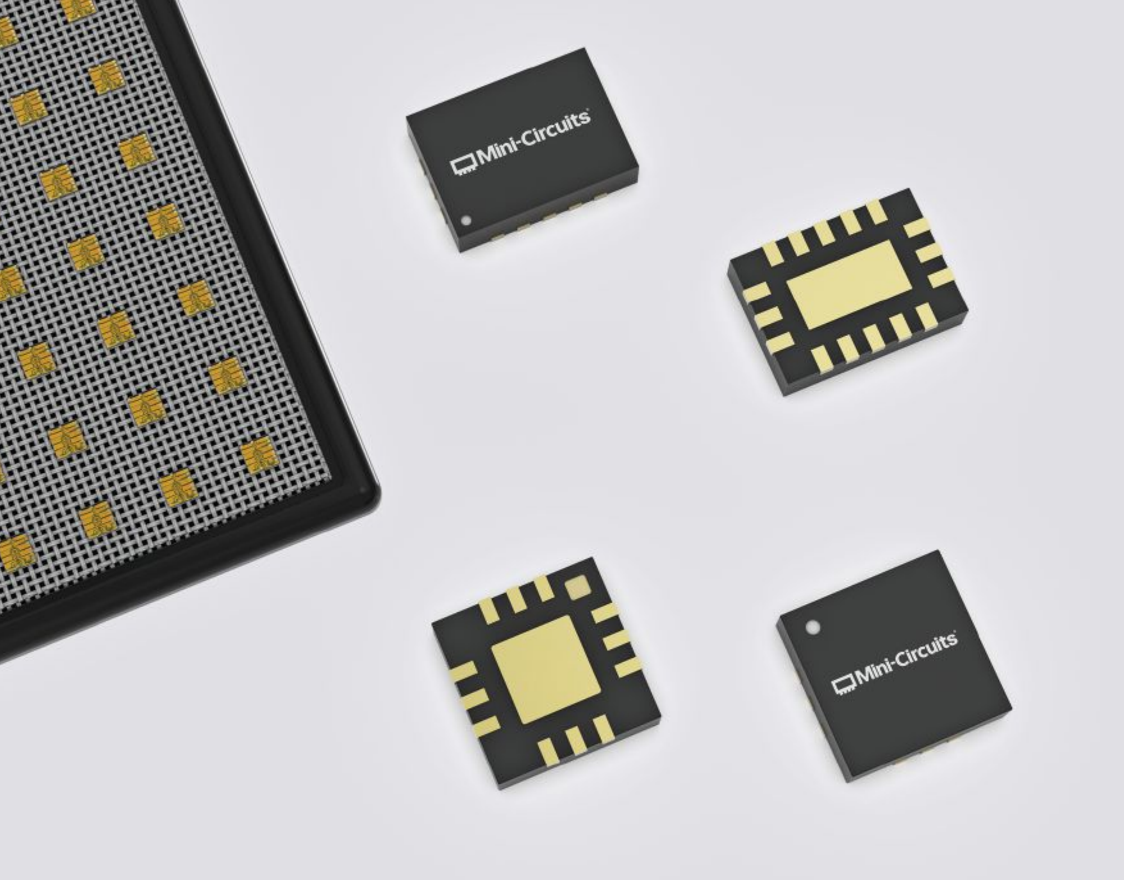

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InP HBT Technology: Advantages, Applications and Future Challenges

Scott DeMange and Barry Wu
Keysight Technologies, Santa Rosa, Calif.

In the semiconductor RF world, indium phosphide (InP) heterojunction bipolar transistors (HBTs) have historically been a niche technology. High substrate costs and a lack of manufacturing expertise have contributed to limited adoption throughout the electronics industry. InP is, however, an ideal technology for many high speed electronic applications. With superior peak electron velocity compared to Si and GaAs and a higher breakdown voltage than SiGe, InP has the potential to benefit many microwave, mmWave and even terahertz (THz) applications. It has been used successfully in the electronic design, emulation and test industry for nearly two decades, enabling some of the highest performing instruments, including a 110 GHz real-time oscilloscope. Increasingly, InP HBTs are used or being considered for next-generation aerospace and defense, automotive and 5G/6G platforms. Capitalizing on the benefits of InP HBTs will require advanced packaging techniques to maintain high frequency performance and an industry-wide effort to reduce substrate prices.

INP HBT ADVANTAGES FOR RF DEVICES

Although the advantages of InP have been covered in many articles and white papers,[1,2,3] ongoing research continues in both academia and industry to exploit the performance capabilities of this material for high frequency applications. InP's most notable advantage is its electron velocity. This feature gives InP and its associated lattice-matched material systems, like indium gallium arsenide (InGaAs) or gallium arsenide antimonide (GaAsSb) an inherent advantage over other HBT device technologies. These systems can have peak electron velocities around 2.5 × 10^7 cm/s or higher, while GaAs-based systems have peak velocities of ~1.8 × 10^7 cm/s as shown in ***Figure 1***. These peak velocities and the ability to engineer the transistor junctions with various material systems have resulted in a maximum frequency

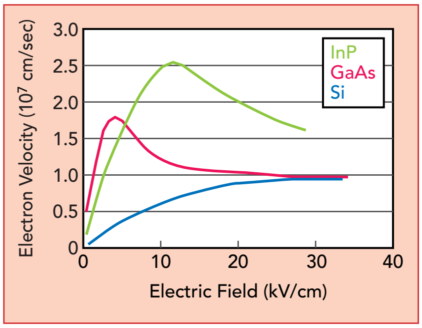


Fig. 1 **HBT electron velocities.**

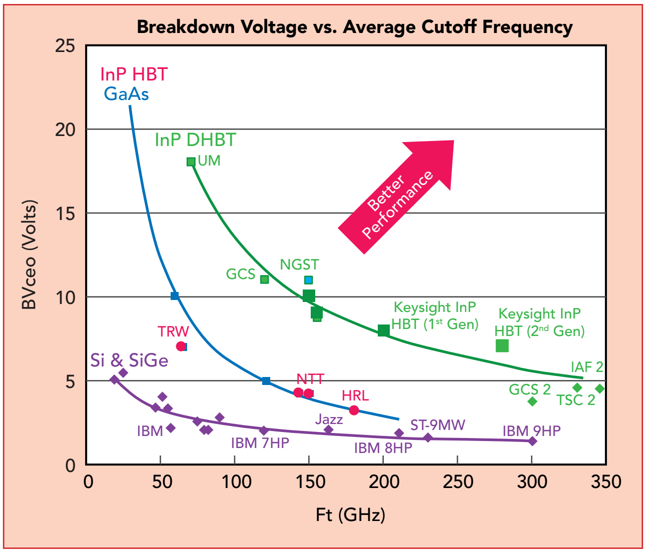


Fig. 2 Breakdown voltage vs. cutoff frequency.

(f_{max}) greater than 1 THz with Arabhavi et al. reporting an f_{max} of 1.2 THz.[4]

A second important advantage of InP is the ability to manufacture high breakdown voltage devices at high frequencies. For MMIC designs, the product of breakdown voltage between the collector and the emitter when the base is open (BV_{CEO}) and cutoff frequency (f_t) is a good metric for a semiconductor process. Higher BV_{CEO} results in higher device power capabilities. The frequency where current gain goes to unity is f_t and generally, the bandwidth of a MMIC increases with increasing transistor process f_t. InP's $BV_{CEO} \times f_t$ product is also a key advantage versus SiGe even though SiGe technology also produces devices exceeding 100 GHz. Cutoff frequency characteristics for various breakdown voltages are shown in ***Figure 2***. While a 100 GHz SiGe circuit may have a breakdown voltage of ~1.6 V, a similar 100 GHz InP circuit can have a breakdown voltage of ~7 V.

Designing InP HBTs to capitalize on the breakdown voltage and speed advantages requires a process utilizing a heterojunction (an interface of two dissimilar materials) at the emitter-base junction and the base-collector junction. This is known as a double heterojunction bipolar transistor (DHBT). By carefully choosing the junction materials, bandgaps and band lineups, performance can be optimized for many applications. In an InP DHBT, a wide bandgap (1.35 eV) InP collector will provide a high breakdown voltage. In addition, as a binary material (two elements), it has better thermal properties compared to ternary material (three elements) alternatives.

A narrow bandgap material such as InGaAs (0.75 eV) or GaAsSb (0.72 eV) is typically used for the base. These materials, which have peak electron velocities like InP, enable a transistor turn-on voltage of typically ~0.6 V. This enables high frequency performance in situations where only low voltages are available. This can translate into lower heat dissipation and longer battery operation for handheld applications.

Compared to InGaAs, GaAsSb has the advantage

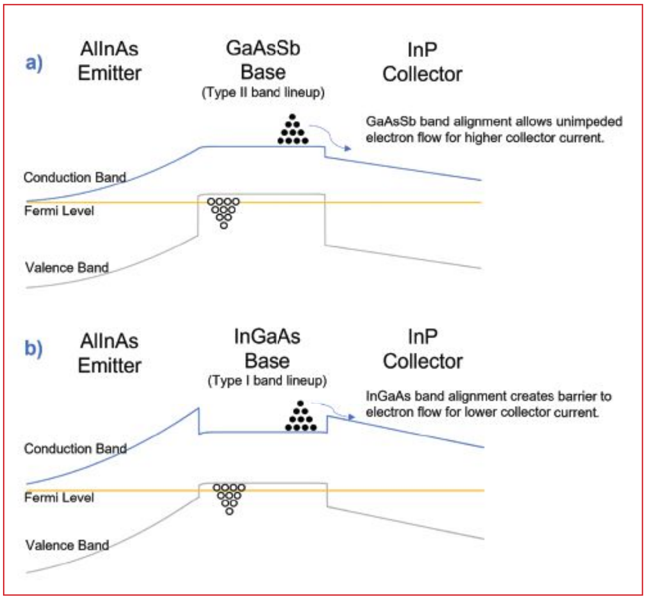


Fig. 3 Type II band lineup with GaAsSb base (a). Type I band lineup with InGaAs base (b).

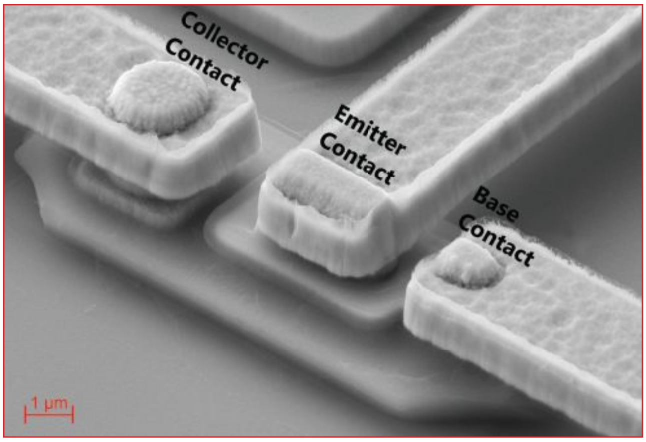


Fig. 4 InP HBT SEM image.

of a Type II (staggered gap) conduction band lineup to the collector. This eliminates the electron barrier at the base-collector heterojunction, allowing for increased electron flow to the collector and higher collector current (I_c) as shown in ***Figure 3a*** and ***Figure 3b***. With higher I_c, the amplification factor of the transistor ($\beta = I_c/I_B$) increases, where I_B is the base current. In addition, a paper from Iverson et. al. demonstrated an electron mobility of 1970 $cm^2/(V\text{-}s)$ for GaAsSb. The paper states, "For comparison, the value quoted for p-InGaAs in InGaAs/InP DHBTs at the same doping value was about 1500 $cm^2/(V\text{-}s)$."[5] That said, the InGaAs material system allows a higher doping and a lower base resistance, which allows for slightly higher frequency operation than GaAsSb.

Like the collector, the emitter also uses a wide bandgap material such as AlInAs or InP. By using an emitter material with a wide bandgap relative to the base, hole flow from the base to the emitter can be partially blocked by the bandgap discontinuity formed at the interface. This reduces I_B, increasing β. With holes not materially participating in current flow across the emitter-base junction, higher doping of the base can occur,

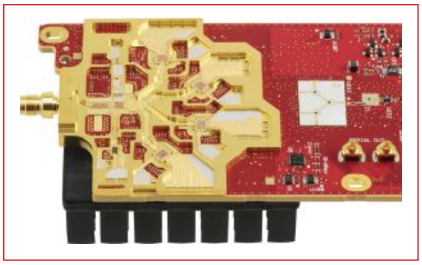


Fig. 5 110 GHz oscilloscope front-end.

Fig. 6 Microwave handheld analyzer.

lowering the base resistance value and allowing for increased operating frequencies.

Another important note is that InP HBT technology simultaneously enables high frequency operation and high breakdown voltage while maintaining good broadband linearity and noise performance. This combination is key in the development of high frequency, broadband architectures.

INP HBT IN THE ELECTRONIC DESIGN, EMULATION AND TEST MARKET

The InP material system has enjoyed commercial success in the optical sector for nearly three decades. As a direct bandgap material with emission/detection > 1000 nm, InP-based devices have been used in telecom and datacom markets as laser diodes, modulators, photodiodes, mixers and more. In a 2019 Yole report outlining InP substrate use, telecom and datacom optical applications accounted for nearly 75 percent of an estimated $77 million market in 2018, while RF applications accounted for only 12 percent.[6]

In the RF sector, InP HBTs have been successful in the electronic design, emulation and test market. ***Figure 4*** shows a representative InP HBT transistor structure. In 2012, Keysight's predecessor, Agilent, shipped a 63 GHz oscilloscope.[7] While this was not the company's first oscilloscope utilizing InP (a 33 GHz model shipped a few years prior), it was the first oscilloscope that utilized the full capabilities of the InP HBT process, enabling a true 60+ GHz bandwidth front-end.

In 2018, Keysight used its second-generation InP HBT process to develop a 110 GHz real-time oscilloscope.[8] By utilizing the high speed, broadband performance and high breakdown voltage of InP HBTs, Keysight designed an oscilloscope front-end with 110 GHz of analog bandwidth. This oscilloscope has exceptional noise performance and dynamic range without using frequency interleaving techniques that degrade signals. This oscilloscope front-end is shown in ***Figure 5***. The scope utilizes six InP MMICs, including a 110 GHz pre-amp, a multi-GHz sampler and a limiting amplifier for NIST traceable calibration.

InP HBTs have also been used successfully in handheld analyzer applications. In 2008, Agilent introduced a new line of handheld RF analyzers with an example shown in ***Figure 6***.[9] Primarily targeted at installation and maintenance, these GaAs-based units operated up to 6 GHz without the need for fans or vents. The design challenge was to create a product with better performance that maintained the same portable form factor. Handheld products at higher bandwidths existed, but they compromised the handheld form factor by increasing the size, adding fans/vents and/or adding external heads for additional bandwidth coverage. Higher power consumption reduced battery life or required larger batteries to maintain the same operating time.

In 2012, Agilent introduced an InP HBT-based unit operating up to 26.5 GHz.[10] Utilizing the bandwidth and low turn-on voltage characteristics of the InP transistors enabled innovative design architectures. This allowed the high bandwidth models to fit the same handheld form factors as the lower bandwidth models. The RF board and associated InP MMICs are shown in ***Figure 7***.

With further advancements in InP technology, Keysight augmented the handheld lineup with a 50 GHz model in 2015.[11] The broadband linearity and noise performance of InP technology enabled lab-grade performance in handhelds, rivaling that of benchtop instruments. As a result, handhelds have become more than an installation and maintenance solution. Handheld instruments are used in wide-ranging applications in communications, aerospace and defense and even in the medical field for research into early breast cancer detection.[12]

InP HBT usage in the design, emulation and test market is not limited to the two previous applications. This technology permeates a significant percentage of high-end test and measurement solutions in the industry. This will continue to be the case in the future.

INP MATERIAL AND PRODUCTION CHALLENGES

Despite the advantages of InP technology, adoption of RF applications has not been widespread. The primary reason for this is cost. Cost is driven largely by raw material availability, difficulty procuring

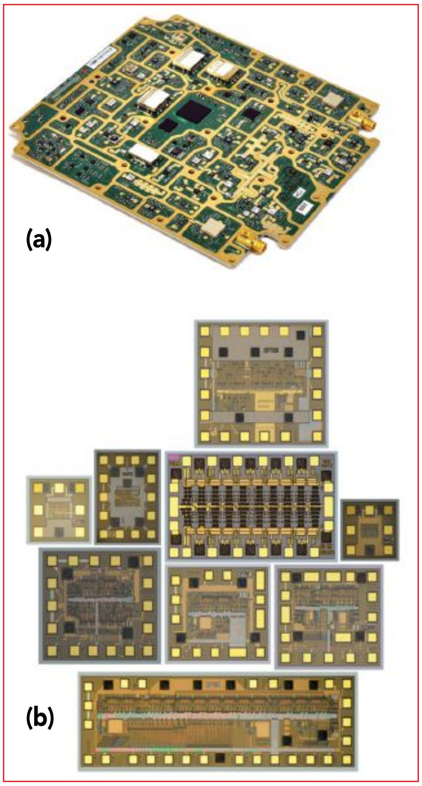
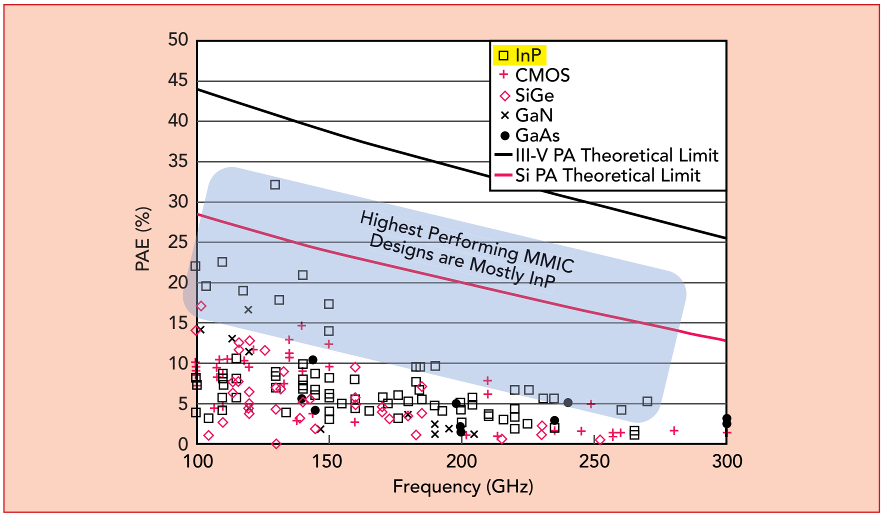


Fig. 7 Handheld RF board (a) and associated InP MMICs (b).



▲ Fig. 8 Reported PA PAE results for Si CMOS, SiGe HBTs, GaAs pHEMTS, GaN HEMTs and InP HBTs. Figure from DARPA ELGAR BAA and attributed to Buckwalter, private communication, 2021.[18]

quality large-diameter wafers and challenges in MMIC fabrication.

Indium is produced exclusively as a byproduct of processing other metal ores, mainly sulfidic zinc. China is the leading producer, followed by South Korea, Japan and Canada.[13] With these limited sources of production, indium is on the list of critical minerals for the U.S., Canada, Australia and the European Union.[14] According to the European Chemical Society, the indium supply will be exhausted in 50 years at the current rates of use.[15] Solving these raw material supply issues requires the discovery of previously unknown reserves or finding new ways to collect or recycle and then purify the element.

The availability of high-quality, large-diameter substrates also influences the price of InP RF devices, with most InP wafers being 3 or 4 inches in diameter. As early as 2002, 6-in. InP wafers were announced,[16] but these larger diameter wafers still prove difficult to produce, limiting supply. In contrast, 6-in. diameter GaAs wafers are standard with some 8-in. wafers being shipped commercially.[17] From a cost-per-area standpoint, InP wafers can cost 10x to 20x more than GaAs wafers by the time epitaxial layers are grown on substrates.

A third factor contributing to the cost of InP for RF applications is the difficulty of manufacturing MMICs. InP substrates are very brittle when compared to GaAs substrates and even more so when compared to silicon. In wafer processing steps, extreme care must be taken when handling and managing the layer stresses to avoid wafer fractures. With these difficulties, very few InP RF device fabs exist, especially at a commercial level. Though not exhaustive, a 2019 report from Yole lists only six fabs worldwide.[6]

INP HBT FUTURE APPLICATIONS AND CHALLENGES

Despite the challenges, numerous industries are using InP RF devices in narrow applications and continue to investigate future use cases. An appealing property of InP HBTs is their ability to enable high frequency power amplifier (PA) designs with exceptional power-added efficiency (PAE). The performance advantages of InP HBTs enable high frequency circuits operating at large current and power densities that achieve world-leading PAEs. A survey of PAE versus frequency for amplifiers operating over 100 GHz is dominated, almost exclusively, by InP HBT-based designs. These results are shown in ***Figure 8***.[18]

For over a decade, researchers contemplated using InP HBTs as GaAs PA replacements for handsets,[19] but high cost and lack of availability thwarted this effort.

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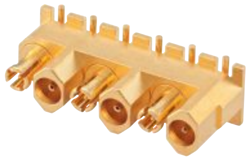

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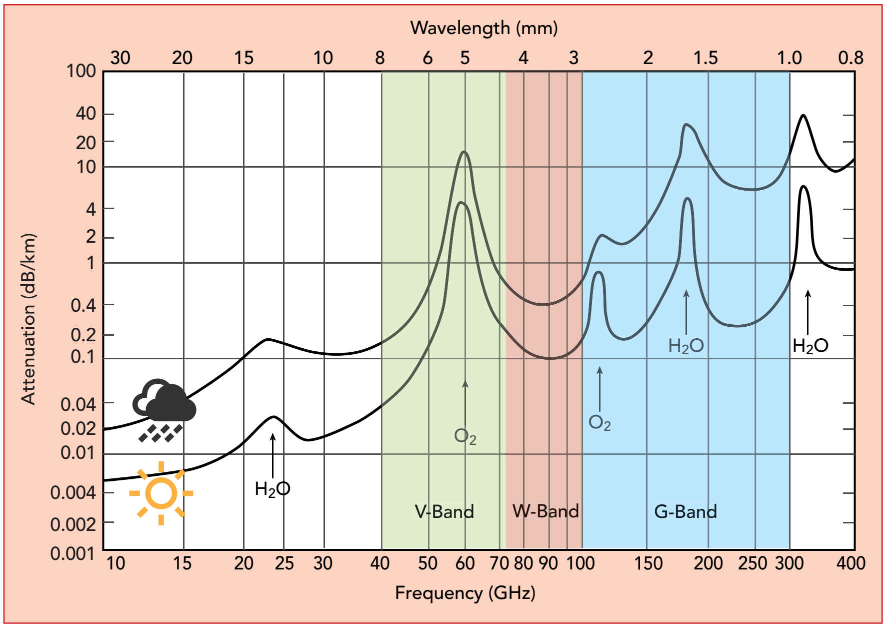

Fig. 9 Atmospheric attenuation in rain and sun.[20]

These amplifiers operate below 7 GHz. With more applications requiring frequency bands well above 7 GHz, researchers are once again considering InP.

One example is next-generation, G-Band (110 to 300 GHz), high speed wireless communication. G-Band is advantageous because it is a mostly unused portion of spectrum. While some commercial applications and associated components operate at these frequencies, the vast majority are at lower frequencies. A second advantage is that these frequencies support extremely high data rates. With a higher carrier frequency, more bandwidth can be allocated to a communication channel, enabling higher data rates. Lastly, there are local minima in the atmospheric absorption of microwave radiation at 140 and 220 GHz as shown in ***Figure 9***. Using these windows, a communication system can transmit signals farther.

In 2021, DARPA initiated the ELectronics for G-band ARrays (ELGAR) program targeting high data rate communications.[18] This program has a goal of producing a 200 mW PA operating at 30 percent PAE. InP HBT technology is a prime candidate for this PA performance. Achieving these goals requires InP semiconductor processing advances that allow on-chip interconnect chassis to support the full native transistor performance. The ELGAR Broad Agency Announcement states that current III-V on-chip interconnects are "large and inefficient, leading to passive circuits…that are physically large and lossy."

Even with advances in the InP HBT interconnect chassis, the challenge of integrating a MMIC into a system with minimal performance impact still exists. At 100 GHz and above, traditional chip and wire and PCB technologies do not work well due to parasitics. Even short wire bonds add inductance that adversely affects high frequency performance. To overcome this limitation, manufacturers are using flip-chip technology with solder bumps to attach the die.

Technologies that allow high frequency signal propagation to signal conditioning or processing blocks with minimal degradation extend beyond flip-chip attachment. These technologies include chip stacking and high performance interposers. While both technologies are used in low frequency applications, operation above 100 GHz has not been realized commercially. Besides maintaining signal integrity, these technologies will be important to meet integration challenges. For the ELGAR program targeting 220 GHz operation, an antenna array with associated transmit/receive electronics spaced on a λ/2 grid would require ~0.68 mm spacing.[18] This constraint demands progress beyond the most advanced technologies to date.

CONCLUSION

While numerous challenges have limited the widespread adoption of InP HBT technology, its applicability in the design, emulation and test market has been a success story. The technology has enabled state-of-the-art instruments that have provided a giant leap in performance. With future wireless technologies looking to higher frequency V-, W- and G-Bands, InP HBTs are poised to make a broader commercial breakthrough.

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RAMP05M80GC 0.5-80GHZ

REMC02G06GE 2-6GHZ 500W

REMC08G11GE 8-11GHZ 400W

To realize the potential of InP HBTs, economic challenges need to be overcome and fabrication, packaging and integration technologies need to evolve. Perhaps in a decade or less, InP HBT usage in RF devices will expand beyond the design, emulation and test market to play a larger role in products we use every day. ■

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INVITED PAPER

Unlocking the Potential of AI to Enable the Next Generation of Wireless Systems Design

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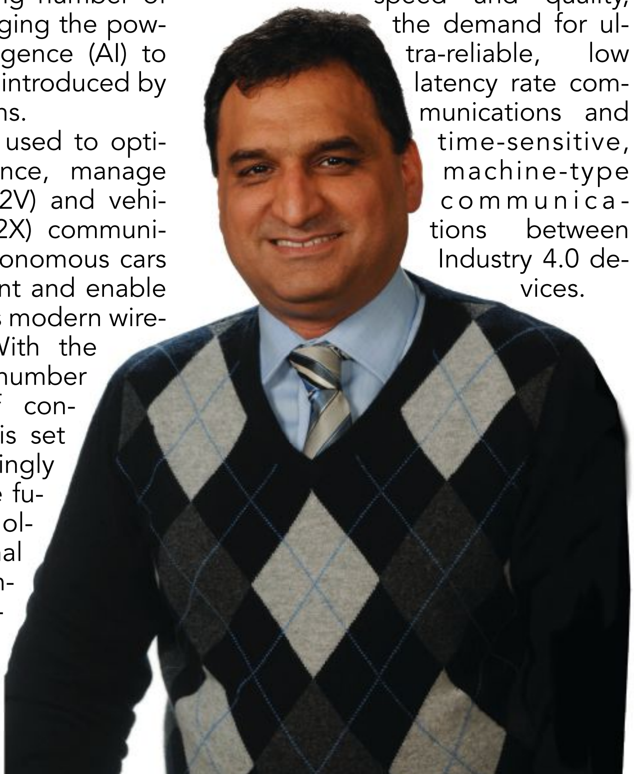
Within the last two decades, mobile wireless technology has undergone significant evolution from 3G to 4G to the advanced use cases of 5G and Industry 4.0. As a result, the design of wireless systems has become increasingly complex. To tackle this complexity, a growing number of engineers are leveraging the power of artificial intelligence (AI) to solve the challenges introduced by these modern systems.

AI is now being used to optimize call performance, manage vehicle-to-vehicle (V2V) and vehicle-to-everything (V2X) communications between autonomous cars and their environment and enable the growth of today's modern wireless applications. With the expansion in the number and capabilities of connected devices, AI is set to play an increasingly important role in the future of wireless technology. To ensure optimal implementation, engineers must consider the key benefits and best practices for AI in wireless systems.



THE USE CASES FOR AI FOR WIRELESS

The evolution of mobile networks to 5G has been driven by three primary use cases; the optimization of broadband network speed and quality, the demand for ultra-reliable, low latency rate communications and time-sensitive, machine-type communications between Industry 4.0 devices.

Furthermore, the growing complexity of wireless systems can be attributed to the increasing number of devices vying for the same network resources and an expanding user base. Traditional linear design patterns that were once handled by human-based rules and data processing are no longer sufficient. By contrast, AI techniques can effectively tackle non-linear problems by automatically and efficiently extracting patterns that surpass the abilities of human-based approaches.

Integrating AI in a wireless environment enables machine learning and deep learning systems to recognize patterns within communications channels. These systems then optimize the resources given to a link in order to improve performance. As applications of a modern network compete for the same resources without the use of AI methodologies, managing these networks becomes a near-impossible task.

The sophistication of AI also enables more efficient project management through features such as reduced order modeling. By incorporating simulated environments into an algorithmic model by estimating the behavior of source en-

vironments, engineers can quickly study a system's dominant effect using minimal computational resources. This leaves more time to explore design and carry out more iterations faster, cutting time in production cycles, along with their associated costs.

DEPLOYING AI IN WIRELESS SYSTEMS: BEST PRACTICE

Data quality is vital for the successful and effective deployment of AI. AI models need to be trained with a comprehensive range of data to adequately deal with real-world scenarios. By synthesizing new data based on primitives or by extracting them over the air, applications like MathWorks' 5G Toolbox[1] provide the data variability necessary for 5G network designers to train AI robustly. Failure to explore a large training data set and iterate on different algorithms based on limited data could result in a narrow local optimization instead of an overall global one, compromising the reliability of AI in real-world scenarios.

A robust approach to testing AI models in the field is similarly critical to success. If signals to test AI are captured only in a narrow and localized geography, the lack of variability in that training data may negatively impact how an engineer may approach and optimize their system design. Without comprehensive field iterations, the parameters of individual cases cannot be used to optimize AI for specific locations, which will adversely impact call performance.

EMBRACING DIGITAL TRANSFORMATION: THE INCREASING ADOPTION OF AI ACROSS INDUSTRIES

Digital transformation has been embraced across various industries, from telecommunications to automotive applications. This, in turn, has necessitated the widescale adoption of AI and is one of the primary drivers for its application. Incorporating electronic communications sensors generates large amounts of data in applications like smart homes, telecommunication networks and autonomous vehicles that rely on connectivity. The large quantity of data generated by these applications facilitates the development of future AI techniques to accelerate the process of digital transformation, yet it also stretches the resources of the joining networks.

In telecommunications, AI is deployed at the physical layer (PHY) and in above-PHY applications. The application of AI for improving call performance between two users is referred to as operating at PHY. Applications of AI techniques to PHYs include digital predistortion, channel estimation and channel resource optimization, as well as autoencoder design that spans automatic adjustments to transceiver parameters during a call.

Channel optimization is the enhancement of the connection between two devices. This applies, principally, to the network infrastructure and the user equipment or handsets. Using AI helps to overcome signal variability in localized environments through processes such as fingerprinting and channel state information compression.

With fingerprinting, AI is used to optimize positioning and localization for wireless networks by mapping disruptions to propagation patterns in indoor environments caused by individuals entering and disrupting the environment. AI then estimates the position of the user, based on these individualized 5G signal variations. In doing so, traditional obstacles associated with localization methods using comparisons between received signal strength indication and the received signal strength in providers' databases can be overcome. Channel state information compression, on the other hand, uses AI to compress feedback data from user equipment to a base station. This ensures that the feedback loop informing the base station's attempt to improve call performance does not exceed the available bandwidth, leading to a dropped call.

Above-PHY uses occur primarily in resource allocation and network management applications. As the number of users and use cases on the network increase exponentially, network designers are looking to AI techniques to respond to allocation demands in real-time. Applications such as beam management, spectrum allocation and scheduling function are used to optimize the management of a core system's resources for the competing users and use cases of the network.

In the automotive industry, using AI for wireless connectivity is making safe autonomous driving possible. Autonomous vehicles and V2V/V2X vehicular communications rely on data from multiple sources, including LiDAR, radar and wireless sensors, to interpret the environment. The hardware present in autonomous vehicles must manage data from these competing sources to function effectively. AI enables sensor fusion, which in this case means merging competing signals to enable the vehicle's software to make sense of its location and establish how it will interact with its environment by understanding omnidirectional messages. This approach to communications allows the vehicle to establish a 360-degree field of awareness of other vehicles and potential crash threats within its proximity. Whether through informing the driver of the vehicle or driving autonomously, the utilization of AI is leading to improved road traffic safety and reducing the number of crashes at intersections.

THE INCREASING IMPORTANCE OF AI IN WIRELESS SYSTEMS DESIGN

As the use cases for wireless technology expand, so does the need to implement AI within those systems. From 5G to autonomous vehicles to IoT, these applications would not have the sophistication necessary to function effectively without the use of AI. AI's place in the engineering landscape, particularly wireless system design, has been growing exponentially in recent years and this pace of change can be expected to continue and even speed up as the use cases and the number of network users expand in the modern age.

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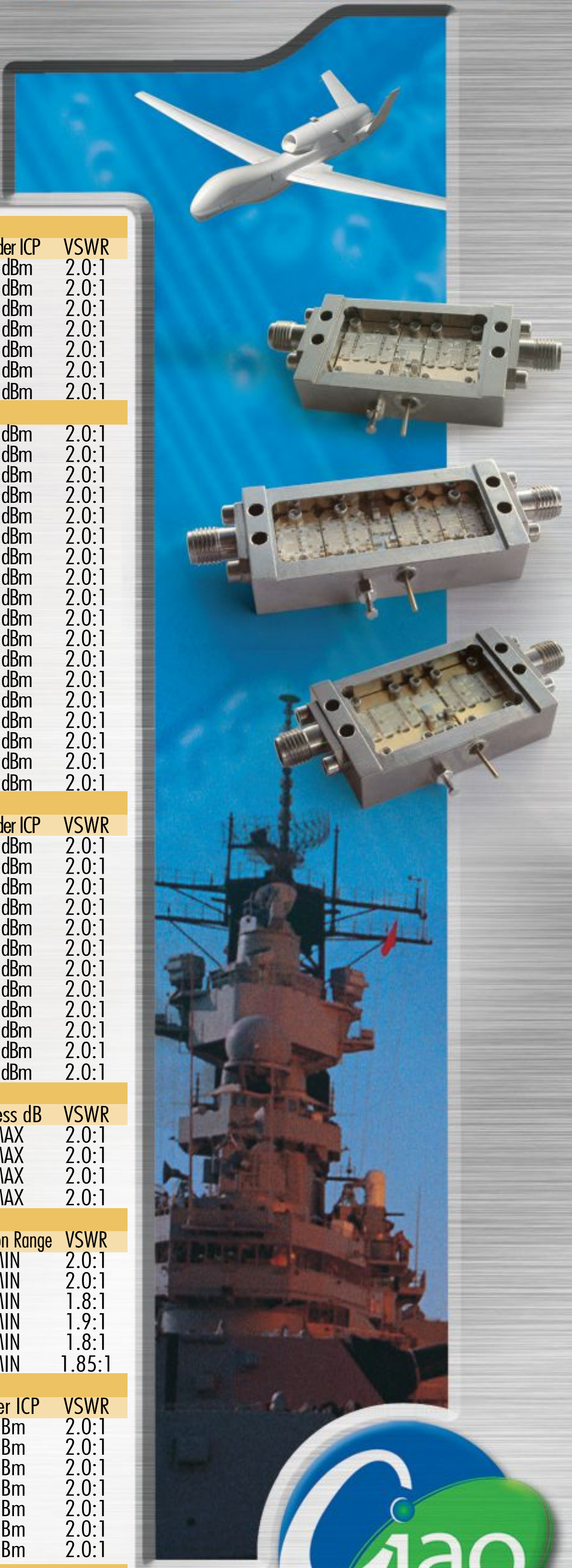

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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Rising Above the Battlefield: The Booming Market of Loitering Munitions and Their Game-Changing Impact on Modern Warfare

The war in Ukraine has highlighted the value of loitering munitions, which in spite of their existence and use for several years are now coming to the surface. The market is projected to grow to U.S.$6.85 billion by 2031, at a CAGR of 12.6 percent in the 2023-2031 period.

The market is still at its early stages and can offer several opportunities for manufacturers and suppliers who consider entering or expanding in it. With unmanned aerial vehicles (UAVs) being essentially the platform, the technological risk is constrained and most of the risks currently come from the limited capacity of the industries and the obstacles in the supply chain. As they are expected to be resolved in the next one to two years, the market will increase at a higher pace.

There are several trends and drives supporting the market's growth. In the current great power politics and military force structures, long-range fires are key in modern operations. Until now that has only been feasible with the use of artillery systems and other precision-guided weapons. However, these have not always been organic to the frontline units but were assigned in support or operational command on an ad-hoc basis.

Mini Harpy (Source: Israeli Aerospace Industries)

Loitering munitions are changing this landscape as they offer a reduction of collateral damage, the ability to abort a mission and recover the munitions, especially when it comes to missions in urban environments, affordability over precision-guided bombs or guided missiles, an ability to loiter over a designated area, as well as strike and intelligence, surveillance and reconnaissance capabilities combined in one system.

Most importantly, they bring long-range firepower to the lower echelons of command, allowing them to operate more efficiently and independently. They are not expected to replace conventional and missile artillery systems, but rather complement them. In that aspect what the military is currently missing is established concepts of use of these systems. Apart from the U.S. Marine Corps which has resolved these issues, almost no other military force until now has outlined its plans on whether they will be allocated to units.

The Loitering Munition Market and Technology Forecast to 2031 study is an important tool for those that are currently in the market, those that manufacture UAVs and would like to expand their business, those that manufacture platforms and systems such remotely operated weapons stations, as well as suppliers of parts. Although the market is at its first steps, it is expected to become more fragmented and competitive in the next two to four years.

IBCS Achieves Initial Operational Capability

Northrop Grumman Corporation's integrated battle command system (IBCS) has achieved initial operational capability from the U.S. Army. With this declaration, the system is now ready to be fielded to U.S. Army units to further support the development of the system's capabilities.

IBCS is the cornerstone of the Army's air and missile defense modernization strategy, replacing the multiple current air and missile defense command and control systems with a single system. The system has completed rigorous and demanding Initial Operational Test and Evaluation and numerous successful development and operational flight tests. During these demanding assessments, IBCS demonstrated its ability to deliver decision-quality fire control data across joint networks, increasing situational awareness and time for decision making.

IBCS (Source: Northrop Grumman Corporation)

"IBCS has the leading role in the Army's air and missile defense modernization strategy because its ability to integrate multi-domain sensors to create fire quality fused data enables the warfighter to quickly decide on the best shooter to defend against incoming threats," said Rebecca Torzone, vice president and general manager, combat systems and mission readiness, Northrop Grumman. "With its mature, proven and ready capabilities, IBCS transforms and extends the battlespace for the U.S. and its allies."

This groundbreaking step toward putting multi-domain capabilities in the hands of the warfighter comes on the heels of the program's recent approval for full rate production. These milestones are the result of the successful completion of critical testing, and development of logistics, support and training. To date, IBCS has integrated or demonstrated integration on numerous sensors and shooters from all U.S. service branches and allies. IBCS can quickly integrate additional systems given its open architecture – enabling the U.S. and its allies to move beyond interoperability to achieve the

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high level of multi-domain integration required today and in the future.

IBCS implements a modular, open and scalable architecture that integrates available assets in the battlespace onto a common, integrated fire control network, regardless of source, service or domain. Its architecture enables the efficient and affordable integration of current and future systems and extends the battlespace by disaggregating sensors and effectors. By enabling this high level of network integration, the warfighter is given unprecedented time to make accurate decisions.

New Investment to Boost Technologies for the UK's Future Combat Aircraft

The U.K. Ministry of Defense (MOD) has awarded a contract extension worth £656 million to BAE Systems – on behalf of British defense firms; Leonardo UK, MBDA UK and Rolls-Royce – to progress the concepting and technology of the next generation combat aircraft, known as Tempest, in the U.K.

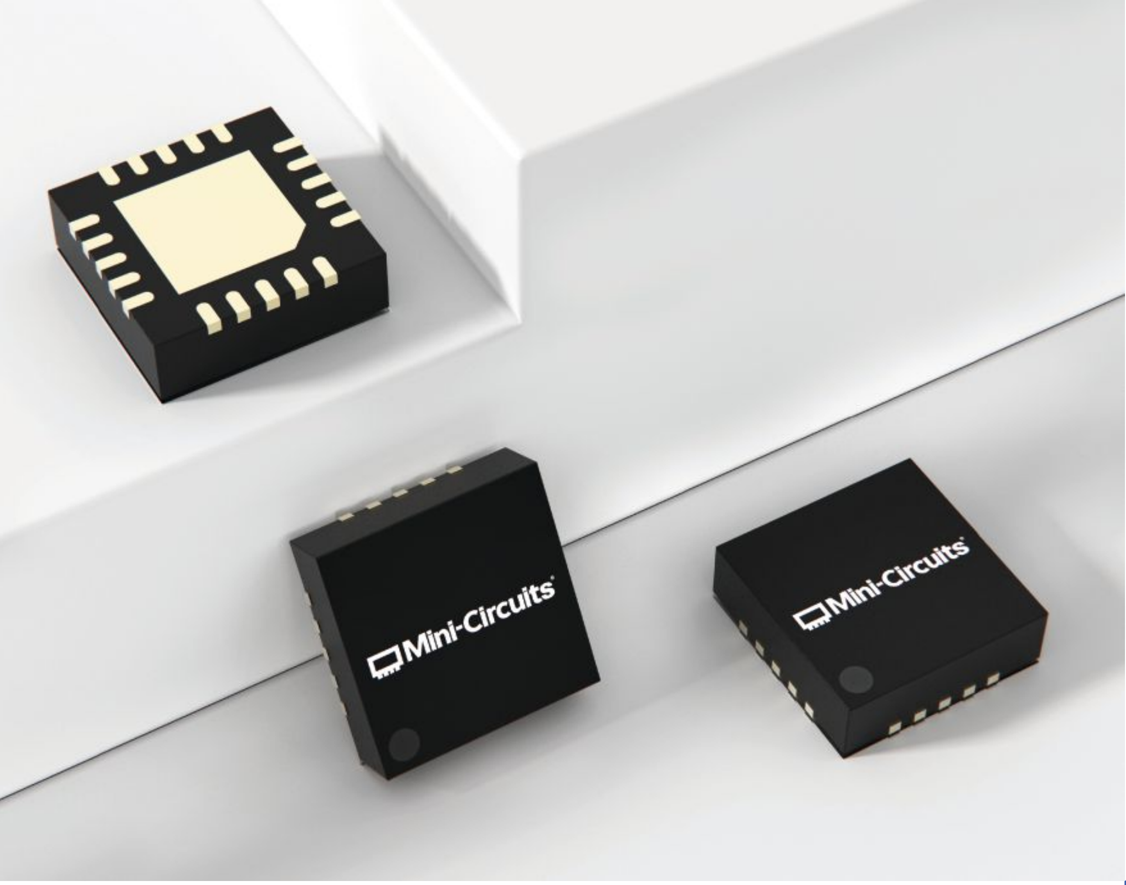
The new funding will build on the ground breaking science, research and engineering already completed under the first phase of the contract delivered by U.K.

GCA (Source: BAE Systems)

Tempest partners BAE Systems, Leonardo UK, MBDA U.K. and Rolls-Royce in partnership since 2018.

The U.K. Tempest partners, working in close collaboration with the UK MOD, will now progress the maturity of more than 60 cutting-edge technology demonstrations, digital concepts and new technologies. These are critical to the U.K.'s sovereign defense capability and will help shape the final requirements, with the Global Combat Air Programme (GCAP) partners in Japan and Italy, for the combat air platform, due to enter service with the Royal Air Force by 2035.

The aircraft is designed to be an innovative stealth fighter with supersonic capability, equipped with cutting-edge technologies, including state-of-the-art sensing and protection capabilities. This will make the aircraft one of the world's most advanced, interoperable, adaptable and connected fighter jets in service, delivering battle-winning, next-generation weapons to protect the U.K. and its allies.



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Models In Stock

Model	Freq. Range (MHz)	Gain (dB)	NF (dB)	P1dB (dBm)	OIP3 (dBm)	Voltage (V)	DC Current (mA)
AVA-0233LN+	2000-30000	17	2.2	13.5	25.7	5	65
AVA-24A+	5000-20000	11.8	5.7	18.4	25	5	120
AVA-2183+	2000-20000	16.4	5.2	19.3	24.7	4	210
AVA-5R183+	500-18000	14.4	3.4	16.8	27.9	5	85
AVA-183A+	5000-18000	14	5	19	26	5	131
AVA-183P+	500-18000	8.1	4.8	11.7	21.5	5	46
AVA-183MP+	50-18000	16.5	1.8	23.8	31.1	8	160

Mini-Circuits®

What Drives the Automotive Radar Industry?

Original equipment manufacturers (OEMs) are ramping up the equipment rate for radar in their cars. Multiple developments are happening or are expected to happen. This includes a switch from 24 to 77 GHz, a move from legacy radar without elevation capability and a limited tracked object list to 4D radar as a baseline and imaging radar in premium cases. There is also a trend toward centralizing radar computing and transitioning from planar printed circuit board antennas to 3D waveguides. According to Yole Intelligence, part of Yole Group, the exterior radar market was US$6.7 billion in 2022 and is poised to grow to US$12.9 billion by 2028.

Cédric Malaquin, team lead analyst for RF activity within the power and wireless division at Yole Intelligence said, "Besides exterior radar sensors for driving assistance, our car interiors are becoming more monitored. The first implementation was a driver monitoring system to ensure the driver focused on the road ahead. A car occupant monitoring system is a natural extension for passenger safety, starting with child presence detection (CPD), though it also finds application in improving the user experience. Next on the list will be object monitoring, such as the position of a seat or headrest."

A CPD system has been in demand in many markets since 2022/2023 (ASEAN New Car Assessment Program (NCAP) and Euro NCAP), though the system itself is not regulated. In most cases, an indirect method is used (door opening cycle tracking and driver alerts). However, from 2025 a direct sensing method will be mandated in Euro NCAP, which is likely to change the market dynamics for in-cabin monitoring. Radar is particularly well suited for this task as it can detect a child in a turned-back baby seat. It can also be used in vital sign monitoring.

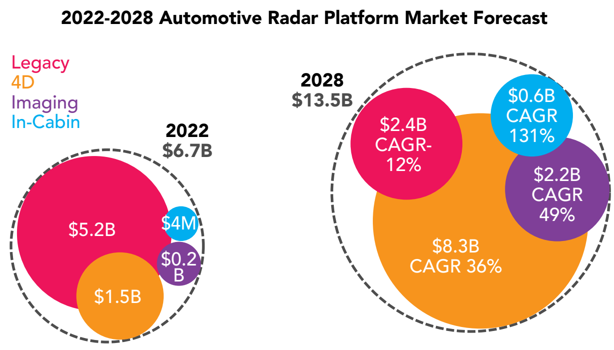
The market opportunity is estimated at US$600 million by 2028, and market uptake is expected in 2025. In this context, Yole Intelligence has recently released its new market and technology report: Radar for Automotive 2023. This study provides key market metrics and forecasts for the automotive radar market. It analyzes the drivers and challenges for the radar technologies' adoption, and presents the main technical trends and ongoing developments with a focus on imaging radar and centralized vehicle architecture. Yole Intelligence's analysts also review the leading players across the automotive radar supply chain and analyze how business models and supply chains are evolving.

The first breakthrough improvement was enabling elevation measurements with radar modules (the "fourth D" of radar). This was key to deciding on whether or not to drive over road debris and drive under bridges and has been the focus of fifth-generation radar from the leading players.

However, the most significant breakthrough required is the order of magnitude angular resolution improvement needed for proper target separation. The first so-called imaging radar achieved a 1-degree angular resolution by scaling the MIMO concept. The principle is to increase the number of transmit and receive antennas to get a bigger virtual antenna array aperture.

But there are physical limits to antenna scaling, starting with the size of the array. Another limiting factor is the necessary computing power and memory resources. A solution could be computing centralization. With a centralized architecture, the computing part of the radar is likely to be removed and delocalized to a zonal engine control unit. As a result, radars will be cheaper and smaller, and their computational power will increase, thus improving their performance. Vehicle centralization is the new trend among OEMs and should become a reality around 2030 to 2035.

There have been substantial performance improvements in the RF sensor itself. Key figures of merit have improved, along with better temperature stability. Meanwhile, integration has been further enhanced thanks to a move toward mature complementary metal oxide semiconductor technologies.



Automotive Radar Market Forecast (Source: Yole Intelligence)

5G's Global "Tipping Point" Reached

VIAVI Solutions Inc. released new industry data revealing that 5G connectivity has reached a tipping point globally as 5G networks are now active in 47 of the world's 70 largest economies by GDP.

In its seventh annual "The State of 5G," VIAVI revealed that there are 2,497 cities with commercial 5G networks across 92 countries. 23 countries have pre-commercial 5G trials underway and 32 countries have announced their 5G intentions. This leaves 48 countries that have not publicly announced plans for 5G.

A total of 18 countries announced their first 5G deployments in 2022. The new 5G countries include two of the largest developing economies, India and Mexico, as well as other emerging economies such as Angola, Ethiopia and Guatemala. The data also revealed several other major trends relating to 5G deployments:

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U.S. Tops 5G Cities Leaderboard

The U.S. has topped the 5G cities leaderboard for the first time, displacing China, which was the leader in previous VIAVI State of 5G updates since 2021. In the U.S., the number of cities with 5G networks has grown significantly to 503, compared with just 297 in May 2022, a 69 percent increase. In contrast, the number of 5G cities in China has remained static at 356 since the June 2021 update.

Manufacturing Sector Emerges as Leader in Private 5G

The manufacturing sector has emerged as the clear leader for private 5G networks globally, with 44 percent of the publicly announced deployments, followed by logistics, education, transport, sports, utilities and mining. This trend suggests a clear pragmatism about how the business world is tackling private 5G, where organizations with the biggest connectivity pain points and greatest opportunities for smart applications are naturally emerging as the private 5G front-runners.

Standalone 5G Gains Momentum with 45 Operator Networks

5G Standalone (SA) networks are rapidly gaining momentum around the world. As of January 2023, there were 45 5G SA networks in place across 23 countries. This contrasts with January of 2022, when there were just 24 Non-Standalone (NSA) networks globally.

Often considered to be "true" 5G, 5G SA networks offer a wider array of use cases and monetization models compared to NSA, which are limited in their applications beyond eMBB. With a near doubling of 5G SA networks, more operators will start to realize more of the long-promised commercial benefits of 5G, while consumers and businesses in those countries may start to notice improved network speeds.

Diverse and Widespread Interest in mmWave

Spectrum for 5G in the mmWave band, generally considered to be 24 GHz and above, has garnered a lot of interest from diverse countries. The spectrum range offers significant benefits with the highest speeds, lowest latency and highest capacity. However, it also comes with downsides such as shorter ranges, higher equipment costs and the need for dense deployments.

Countries that have made the mmWave spectrum available span every continent and represent a mix of population sizes, economies and levels of technological advancement. Several of the largest mobile markets in the world have made mmWave available as well as those with tiny populations such as Seychelles and Guam. The same pattern of diversity holds true across developed markets such as Germany and Japan through to emerging economies like Indonesia and Vietnam.

The diversity of countries licensing mmWave shows that there is a clear appeal from regulators combined with a natural interest from spectrum-hungry operators. Nonetheless, with clear benefits and drawbacks, the mmWave story is likely to have many twists and turns over the coming years.

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Nxbeam's suite of Ka-band PA MMICs offers customers an unparalleled combination of power, gain, and efficiency with proven reliability.

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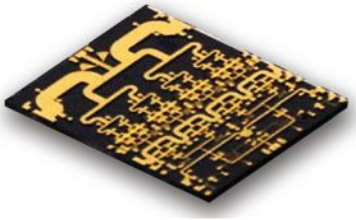

Packaged MMICs to 35W

Nxbeam offers its Ka-band MMICs in leaded flange packages for easier system integration

PRODUCTS:
NPA2001-FL
NPA2002-FL
NPA2003-FL
NPA2030-FL

Module Products to 60W

For higher levels of power and integration, Nxbeam offers modules that combine multiple Nxbeam MMICs to achieve higher performance in an easy-to-use form factor. Custom designs available

PRODUCTS:
NPM2001-KW
NPM2002-KW
NPM2003-KW

Around the Circuit

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

RFMW announced the closing of its acquisition of **MRC Gigacomp (MRCG)** and **MRC Components (MRCC)** in Germany. RFMW will add the MRCC components to its power management offerings and the MRCG products to its RF and microwave product portfolio. The acquisition of MRCG and MRCC expands RFMW's capabilities in Europe, adding a warehouse facility in Germany and a team of experienced professionals with a deep understanding of RF, microwave and power technologies. This acquisition strengthens RFMW's position in the European market and gives customers access to a broader range of products and services.

iNRCORE LLC announced the acquisition of **Sentran Corporation**, a manufacturer of instrument transformers and transducers for energy conservation, monitoring and control markets. As the latest addition to iNRCORE's exclusive family of brands, Sentran Corporation will continue to operate as a wholly owned subsidiary of iNRCORE with its existing leadership reporting directly to Andrew Abbott, general manager, Custom Magnetics. Sentran will retain its headquarters in Salem, Ore. The acquisition, backed by iNRCORE majority owner The Jordan Company, comes on the heels of the prior acquisition of Vanguard Electronics, a manufacturer of catalogue and custom high-reliability magnetics for high-reliability applications.

Gapwaves made a strategic investment in the radar sensor market by acquiring a minority stake in **Sensrad**. Sensrad is a recent spin-out venture from Qamcom's radar division since January 1, 2023, and offers a unique 4D imaging radar sensor based on sophisticated software and hardware technology, including the leading radar chipset from Arbe. Through the investment, Gapwaves addresses several new and structurally growing end-user markets in 4D imaging radar utilizing its antenna technology and industrial know-how outside the traditional automotive market. Qamcom has established Sensrad as a frontrunner in advanced imaging radar sensors based on the high performing Arbe chipset.

Sunshine Global Circuits (SGC) announced the acquisition of **Vision Industries Sdn. Bhd**. in Penang, Malaysia. This acquisition is an important step in extending Sunshine's manufacturing capabilities into southeast Asia and will enhance Sunshine's product offerings in microwave and RF circuit boards. The combination further establishes SGC as a premier international PCB manufacturer after the establishment of Sunshine USA in 2011 and the acquisition of Sunshine Germany in 2013.

COLLABORATIONS

Modelithics and **Inter-Continental Microwave**, designer and manufacturer of microwave test fixtures, announced their collaboration to offer custom and standardized coaxial test fixtures to today's design engineers. As part of the collaboration, Modelithics will continue to advance its offering of test fixtures and accessories products, including legacy parts from J Micro Technology for a family of thin film Alumina substrate components to adapt the benefits of coplanar waveguide wafer probe test methods to the measurement of devices suited for connection to microstrip circuits.

Enhanced disaster response, environmental monitoring, agricultural productivity and infrastructure planning has been made available to businesses in Thailand thanks to a new partnership announced between Tokyo-based SAR satellite data and solutions provider, **Synspective Inc.**, and Asia's leading satellite operator and space technology service provider, **Thaicom**. Synspective and Thaicom will supply a joint solution to government, defense, agriculture and finance sectors in Thailand that enhances disaster response, environmental monitoring, agricultural productivity and infrastructure planning. The collaboration will combine Synspective's expertise in SAR technology and Thaicom's knowledge in the satellite and space technology in Thailand.

Curiosity Lab at Peachtree Corners, one of the U.S.'s first smart cities powered by real-world connected infrastructure and 5G, has launched a collaboration with **Spoke**, a company that aims to transform roadway safety and rider connectivity by delivering the first-ever connected IoT ecosystem for vulnerable road users (VRUs). This technology provides insight and contextual awareness to drivers by connecting VRUs to the mobility ecosystem around them, ensuring VRUs are seen and protected. This partnership allows Spoke to continue testing and developing their VRU2X technologies using Curiosity Lab's living smart city ecosystem where real drivers, pedestrians and autonomous vehicles use the public roadways each day.

Cadence Design Systems has collaborated with **TSMC** to optimize the Cadence® Virtuoso® platform for the 79 GHz mmWave design reference flow on TSMC's N16 process. With this latest development in Cadence and TSMC's long history of collaboration, joint customers now have access to a complete 79 GHz mmWave design reference flow on the N16 process for developing optimized, highly-reliable, next-generation RFIC designs for use in radar, 5G and other wireless applications for the mobile, automotive, healthcare and aerospace markets. Customers have already started using the corresponding TSMC PDKs for RFIC design work.

NEW STARTS

Tabor Electronics announced their global research

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and development center has opened in India, located at Ahmedabad, the Heritage City of India. The facility will focus on the software development activities for the complete product ranges of Tabor Instruments. The grand opening of this facility took place on April 23, 2023. The office has been inaugurated by Nilesh Desai, director of space applications, Tabor Electronics president and CEO Ron Glazer, CRO Paul Nurflus and India GM Nikhil Mitaliya. During the inaugural function, Desai took a tour of the complete facilities and saw the developmental stage of Proteus Arbitrary Waveform Transceivers and Lucid family RF signal generators.

J.A.M.E.S, a frontrunner in the field of additively manufactured electronics (AME), announced the launch of its new website. Following insightful feedback from partners, users and enthusiasts, J.A.M.E.S has leveraged this feedback to construct a contemporary website that will appeal to larger numbers and promote knowledge of AME technology. The new website encompasses various features and improvements that make it more intuitive, user-friendly and informative. The main objective of launching the new website is to captivate a wider audience, raising awareness about the latest advancements in 3D printed electronics and AME technology.

Pharrowtech announced its expansion into North America with the creation of its new subsidiary, Pharrowtech Inc. With this news, Pharrowtech continues to consolidate its position as a leader in the high speed mmWave wireless industry. The company has appointed semiconductor veteran Christian Plante as general manager to lead its North American business growth and foster relationships with customers and partners. Plante will head up the U.S. division and will oversee building a team in the region.

ACHIEVEMENTS

On the long journey of the **Juice** spacecraft to Jupiter, more than 100 **Rosenberger** connectors of SMP, SMA and RPC-2.92 series are also on board. The Jupiter Icy Moons Explorer (Juice) spacecraft of the European Space Agency consists of various components such as thrusters, communication units, power supply, scientific measuring instruments. The Rosenberger connectors provide reliable and high-precision service in the spectrometer sub-mmWave instrument, which investigates the atmospheric composition of Jupiter and its moons, and in the particle spectrometer particle environment package, which measures neutral and charged particles in the Jupiter system.

Echodyne announced that **ANRA Technologies** has integrated Echodyne's radar data into its Single Integrated Operating Picture (SIOP) platform. Customers use ANRA's SIOP application for a single integrated visualization that detects, locates and tracks cooperative and non-cooperative aircraft. ANRA wanted to expand its portfolio of drone detection sensors by adding Echodyne radar, providing their SIOP customers with a premier situational awareness option that can be used independently or fused with other sensors for a complete and correlated airspace picture for all sizes of aircraft. ANRA's platform provides airspace management for drones, spanning mission planning, strategic deconfliction, tracking, monitoring and more.

Sensor specialist **HENSOLDT** has successfully concluded the modernization of core test systems of the artillery location radar COBRA which is in service with several NATO armies. Under a contract worth several million euros awarded by the Organisation for Joint Armament Co-operation Organisation Conjointe de Coopération en matière d'Armement, on behalf of Germany and France, HENSOLDT has replaced the radar target generator (RTG) and the COBRA Radar Environment Simulator, key elements of the test environment of COBRA indispensable for determining optimum deployment and testing system performance. The RTG is designed to generate primary radar returns and can be placed in the radar's far field to simulate target trajectories.

SES announced the successful launch of two additional O3b mPOWER satellites from Cape Canaveral Space Force Station in Florida, U.S. The satellites were launched aboard a SpaceX Falcon 9 rocket, marking a significant milestone for the O3b mPOWER constellation. The second pair of O3b mPOWER satellites will join the first two satellites launched in December 2022, which have arrived at their target medium earth orbit and are currently undergoing in-orbit check out. The O3b mPOWER system will offer high performance network services delivering industry-best throughput, predictable low latency and ultra-reliable service availability.

CONTRACTS

Raytheon Technologies was awarded a $237 million contract for Ku-Band Radio Frequency Sensors (KuRFS) and Coyote® effectors to detect and defeat unmanned aircraft systems. As part of the U.S. Army's low, slow, small-unmanned aircraft integrated defeat system (LIDS), KuRFS provides advanced 360-degree threat detection, while Coyote low-cost effectors defeat drones. The contract includes a combination of fixed-site and mobile systems as well as a quantity of effectors, designated to support the Army's U.S Central Command operations. As part of the U.S. Army's LIDS, KuRFS provides advanced 360-degree threat detection, while Coyote low-cost effectors defeat drones.

Israel Aerospace Industries (IAI) through its defense electronics subsidiary, **ELTA Systems**, announced that it has been awarded with a contract to provide airborne signals intelligence (SIGINT) solutions to an international customer. The contract size including systems delivery and maintenance will surpass $100 million. Under the contract, ELTA will provide SIGINT systems and airborne communications suites for installation both on manned and unmanned aircraft. The SIGINT capabilities are designed to cope with the challenges of modern, dense communications and electronic environments, to analyze complex signal formats and to build a real-time electronic order of battle providing time-critical intelligence.

Around the **Circuit**

L3Harris Technologies received a **U.S. Air Force** contract award to develop a common tactical edge network (CTEN) providing an aerial military IoT to support advanced battle management system and Joint All-Domain Command and Control initiatives. The system will include a meshed network of defense and commercial resources, enhancing aerial interoperability for U.S. and allied forces by incorporating commercial-like, high speed data processing and sharing at the tactical edge. CTEN will initially connect Air Force aerial platforms that currently operate with incongruent network architectures with the potential to improve connectivity across the entire joint force. CTEN's data fusion will enable warfighters controlling multiple platforms to think and operate as one, greatly shortening the decision cycle.

Quantic™ X-Microwave, a business of **Quantic® Electronics**, announced they have been awarded a multi-million-dollar contract by a leading U.S. defense contractor. This initial order is for the delivery of 3U OpenVPX card assemblies to be used in a major airborne electronic warfare application. Given the harsh and rugged environments that many electronic warfare applications must operate in, defense contractors are now adopting the 3U OpenVPX platform as the primary format for housing critical circuits. Quantic X-Microwave has developed a revolutionary 3U OpenVPX card assembly, capable of meeting customers' stringent requirements for these mission-critical applications while expediting time to market.

PEOPLE

▲ *Alexander Chenakin*

Dr. Alexander Chenakin, chief technology officer at **Anritsu US**, Morgan Hill, Calif., oversees the development of various test and measurement instruments. He leads a team of talented engineers and has a proven track record in developing and implementing solutions that deliver results. Dr. Chenakin previously held a range of technical and executive positions that include serving as vice president of advanced technologies at Micro Lambda Wireless, Inc. and vice president of Phase Matrix.

▲ *Maddiel Gonzalez*

MegaPhase announced that **Maddiel Gonzalez** has accepted the new role of vice president, chief technology officer at the company. Gonzalez will be a key leader of MegaPhase's operation and continue to foster a culture of innovation, securing their position as a leader in the ever-evolving high-reliability military and space markets. Gonzalez initially joined MegaPhase in 2017 after working for a competitor. He is a key designer of state-of-the-art RF connectors and cables for space, military and commercial applications. Gonzalez has over 10+ years of experience in the interconnect industry providing innovative solutions to customer challenges.

▲ *Mark Pierpoint*

Keysight's Vice President of Strategic Innovation and Partnerships **Mark Pierpoint,** Ph.D., has been appointed to serve on the Visiting Committee on Advanced Technology (VCAT) of the National Institute of Standards and Technology (NIST) for a three-year term that began April 1. VCAT reviews and makes recommendations for NIST's policies, organization, budget and programs within the framework set forth by the President and the Congress of the United States. NIST is a non-regulatory agency of the U.S. Department of Commerce that promotes the innovation and industrial competitiveness by advancing measurement science, standards and technology.

REP APPOINTMENTS

Anritsu Company announced that it has named **Pylon Electronics Inc.** as an authorized service center for select Anritsu test solutions. The agreement allows Anritsu to continue to best serve Canadian customers. Pylon Electronics operates the largest Canadian-owned calibration company and offers a true coast-to-coast solution. Pylon will service the majority of Anritsu handheld instruments, along with designated benchtop solutions, including bit error rate testers, vector network analyzers and synthesizers in its Ottawa location.

Picocom and **iCana** have announced a new strategic partnership aimed at leveraging their respective capabilities to jointly develop a 5G Open RAN Small Cell radio unit reference platform. The 5G NR FR1 small cell RU reference designs will enable customers to bring their products to market faster, with greater efficiency and more cost-effectively. The combination of Picocom's innovative digital predistortion (DPD) technology, specifically crafted for small cells, and iCana's DPD-friendly 4 W, 8 W and 20 W power amplifiers, realized in GaAs and GaN technologies, provides an efficient solution with reduced power consumption, complexity, size and cost while maintaining high performance and reliability.

Richardson Electronics Ltd. announced a technology partnership agreement with **VINATech**. VINATech products enhance the company's current technology offerings and expand the product range, driving growth opportunities within the power management and green energy solutions business segments. Established in 1999, VINATech designs and manufactures energy storage ultracapacitors as well as hybrid lithium capacitors. These ultracapacitors are excellent for numerous applications including smart-grids, solar power, automatic meter reading, automotive, UPS, solid-state drives, medical, automated guidance vehicles and lighting.

INVITED PAPER

Innovation and Pricing Pressures Drive 5G Base Station Power Amplifier Trends

Cyril Buey and Cédric Malaquin
Yole Intelligence, part of Yole Group
Lyon-Villeurbanne, France

To keep up with the exponential growth of mobile traffic globally, mobile network operators (MNOs) are massively deploying 5G networks. At the same time, they are shutting down their 3G and 2G services to free up the cell site spectrum for 4G and 5G. Globally, 5G is being deployed at two different paces, with China supporting half of the base transceiver station (BTS) market while the rest of Asia, Europe, the U.S. and late 5G entrant India dominate the balance of the market. ***Figure 1*** shows our latest base station forecast by region.

We estimate that 5G comprises more than 70 percent of the investment from the MNOs. MNOs are expected to continue investing massively in 5G in the upcoming years and this will continue to expand the 5G footprint. The first wave of investment mainly focused on 5G Non-Standalone (NSA), involving only new radios, to ensure a fast time to market and a smooth cohabitation with 4G. The second wave is now focusing on the baseband and core networks, where evolution is critical to provide 5G Standalone (SA) that enables new use cases and levers for monetization. There are big expectations for RAN and RF front-end (RFFE) market opportunities in 2023, primarily due to an ambitious launch of 5G networks in India. The question becomes; will it last over the next few years?

MARKET DRIVERS COME OUT OF MNO REQUIREMENTS

5G is bringing massive network capacity improvements by using new spectrum in the sub-6 GHz frequency band while reusing legacy 4G bands. 5G architectures leverage traditional remote radio heads (RRHs) and active antenna systems (AAS). The use of massive MIMO (mMIMO) is a crucial technology to improve AAS spectral efficiency and throughput. Mainstream mMIMO systems use 32 or 64 streams and this has a huge impact on the number of RF lines compared to legacy RRHs that typically had 2 to 8 TRx. Although the mMIMO architecture is much more efficient than an RRH architecture in terms of gigabits per kilowatt, AAS consumes much more power than legacy RRH. With the increase in mMIMO penetration, the trend toward higher-power radio units

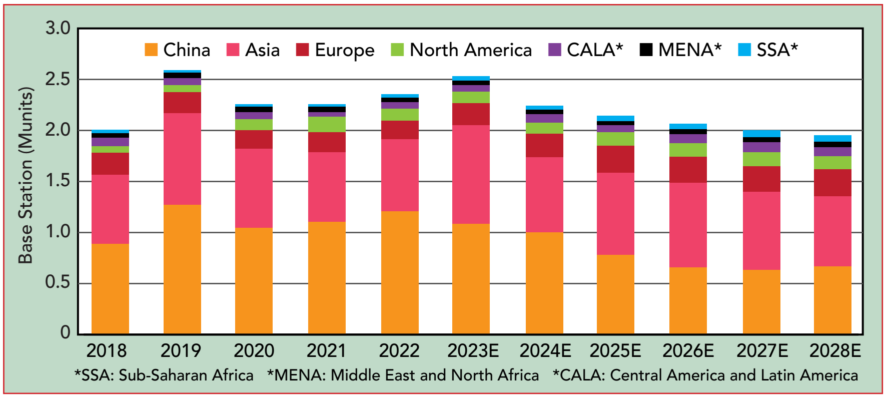

Fig. 1 **Macro/Micro regional BTS forecast. *Source:* RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.**

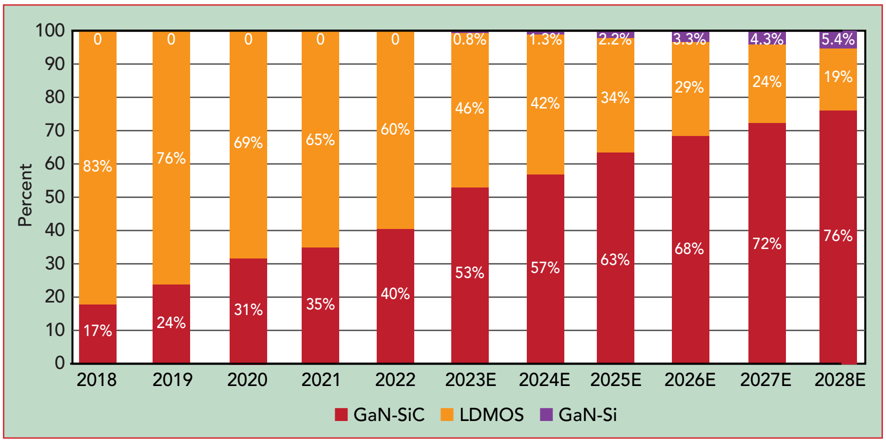

Fig. 2 **Forecast of final PA technology in BTS RAN. *Source:* RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.**

(RUs) with transmit power above 300 W is becoming the norm.

This rising concern about energy consumption is a serious challenge for MNOs. This is becoming increasingly problematic as energy prices are rising and sustainability is becoming important for consumers, politicians and investors. Various sources estimate that BTS energy consumption is between 20 and 40 percent of an operator's OPEX, representing one of the highest contributors to that expense. Addressing this energy issue is critical because MNOs cannot deal with increasing OPEX on one hand and increasing CAPEX to support expensive 5G hardware deployment on the other.

To address the energy issue, original equipment manufacturers (OEMs) are focusing on power amplifiers (PAs). These devices consume the most power in the radio and drive high transmit power levels but they suffer from limited efficiency. Huawei was the first to trade the low-cost laterally-diffused metal-oxide semiconductor (LDMOS) power transistor technology for the better power-added efficiency of GaN technology solutions. With the increasing need to optimize power consumption, the transition toward GaN-based RUs is accelerating. The supply chain has adapted accordingly to support the growing demand for GaN devices. Our market share forecast for the various PA technologies is shown in ***Figure 2***.

The most significant example of the growing importance of GaN in BTS applications is probably NXP, a key historical LDMOS player. In 2020, they opened a 6-in. GaN fab in the U.S., showing the strategic need to internalize GaN production and to compete with other long-time GaN manufacturers in the BTS market. Sumitomo Electric Device Innovation (SEDI) and NXP, the top two GaN players in this market are seeing increasing competition from Qorvo and Wolfspeed in the U.S. and a few growing players in China, such as Dynax, Bowei and WaTech Electronics.

With the ongoing trade conflict between the U.S. and China, the supply chain tends to be polarized. This is a tough challenge for Chinese players, system and device makers, as well as foundries, because it turns the Chinese ecosystem against the rest of the world. China has been forced to accelerate the development of a local supply chain and with massive support from the government, more companies are emerging in the RFFE field.

The second important lever to improve energy efficiency is artificial intelligence (AI), which is set to play a critical role in dynamic power management. AI is expected to power significant breakthroughs in the telecommunication field as it is now used by many manufacturers to reduce energy consumption. To make the best use of this new feature, PAs will have to support dynamic control of the threshold voltage for low or high traffic modes, optimizing the power consumption as a function of the traffic. To perform smoothly, AI also requires a very low latency network to control traffic and power management in real-time.

With the RAN market expected to peak in 2023, the telecom industry is now looking for new growth drivers. While MNOs are looking toward 5G SA and monetizing their 5G networks, OEMs are getting ready for the second phase of deployment involving sub-6 GHz small cells and mmWave RUs. Thanks to the massive amounts of bandwidth available, potential 5G mmWave use cases are numerous, but as of today, the technology has had difficulty penetrating the market outside the U.S. and Japan. The growth has been slow because the industry is focusing on C-Band mMIMO deployment and the need for mmWave in consumer devices remains to be proven. The mmWave ecosystem is counting on fixed wireless access applications emerging as a killer use case to encourage MNOs to deploy this technology. In the same way, the opportunity for sub-6 GHz small cells remains limited as the cost of installation, which requires fiber at each access point, and the cost of the radios is still too high.

Nevertheless, there is a lot of activity around mmWave and sub-

6 GHz small cells from both established RF component makers and emerging companies. For mmWave communication, the industry has chosen to use a hybrid architecture, combining digital and analog beamforming. This architecture requires beamforming integrated circuits (BFICs) integrating four to 32 complete RF chains. These RF chains contain PAs, LNAs, filters, switches and phase shifters and several technology platforms are suitable for these functions. The first BFICs were designed using SiGe or CMOS, but we now see several players turning to RF-SOI for its scalability and good performance. Tier 1 OEMs like Samsung, which has an important mmWave footprint in the U.S., are using in-house designed BFICs.

5G MARKET STATUS

After the RAN market slowed down in 2021 due to COVID restrictions and a tight supply chain, it regained strength in 2022, with more than 2.3 million BTS deployed. In 2023, we expect to see a peak of 2.5 million BTS, with 35 percent of those BTS using mMIMO AAS. The penetration rate of this type of architecture has continuously increased since the beginning of the 5G era. The demand for infrastructure hardware is mainly supported by operators in India deploying 5G networks with lofty ambitions and a sustained rollout in China. India is a new and important market for 5G and the country has chosen to turn toward the Western supply chain, with Nokia and Ericsson as the main suppliers.

The growth in the RAN market is mainly supported by the five big established players: Huawei, Ericsson, Nokia, ZTE and Samsung. These suppliers are trying to consolidate their leading positions by innovating in their RAN portfolio to optimize system size and power efficiency. Huawei and ZTE increased their market share thanks to massive deployments in China and Samsung is capitalizing on its early adoption of virtual RAN (v-RAN) and open RAN (O-RAN) strategies.

Nevertheless, O-RAN and network virtualization represent a major opportunity for other players, such as NEC and Fujitsu, or even smaller players, like Mavenir or Airspan. Companies like Samsung and NEC are showing their ambitions to capture an important part of this market, which is expected to reach up to 25 percent of the annual RAN market by 2025. The small cell and mmWave markets also present an exciting opportunity for small players and newcomers.

The RF component market is directly benefiting from the mMIMO penetration. We estimated the RFFE market at $3.3 billion in 2022 and this opportunity is forecast to exceed $4.2 billion in 2023, including sub-6 GHz small cells and mmWave RUs. In terms of volume, the RFFE market represented almost 1.2 billion RF components in 2022 and it will account for almost 1.5 billion components in 2023. The market is expected to keep growing in volume over the next five years as mMIMO becomes increasingly dominant.

THE BTS PA

In the RFFE market, the final stage PAs attract most of the attention because these devices account for 45 percent of the overall market, split between LDMOS and GaN-SiC technology platforms. GaN-SiC devices are emerging as winners in this market, but the cost of the technology remains an issue when compared to LDMOS. Under pressure from OEMs and with the GaN-SiC process constantly improving, the technology cost is slowly decreasing. Chip makers are refining their value propositions by proposing multi-chip PA modules, along with integrating more amplification stages and power management features. This offering is well accepted by OEMs as it saves manufacturing and testing time, leading to benefits for manufacturers and system OEMs. From the technology standpoint, PA modules are becoming more complex and diversified; they are monolithic or multi-chip and sometimes combine several technology platforms inside a module. LDMOS is becoming a supporting technology as it provides easy impedance matching when used as a driver, for example. Finally, GaN-on-silicon, expected to bridge the cost/performance gap between LDMOS and GaN-SiC, is

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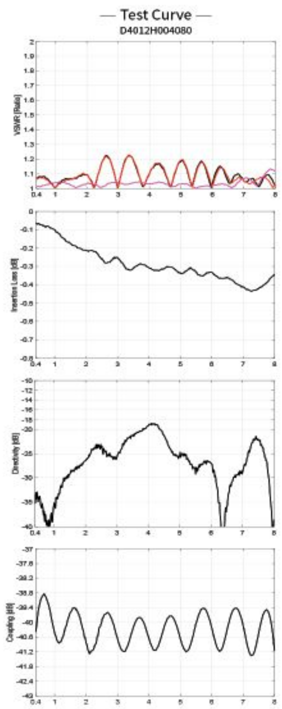
P/N	CW Power Max.(W)	Nominal Coupling (dB)	Main Line VSWR Max.(:1)	Coupling VSWR Max.(:1)	Insertion Loss* Max.(dB)	Coupling Max.(dB)	Flatness Max.(dB)	Directivity Min.(dB)
0.4-8GHz Directional Coupler								
D3002H004080	120	30	1.3	1.3	0.8	30±1.0	±0.8	18
D4002H004080	120	40	1.3	1.3	0.8	40±1.0	±0.8	18
D3005H004080	250	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4005H004080	250	40	1.4	1.4	0.7	40±1.0	±1.4	14
D3008H004080	400	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4008H004080	400	40	1.4	1.4	0.7	40±1.0	±1.4	14
D3012H004080	600	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4012H004080	600	40	1.4	1.4	0.7	40±1.0	±1.4	14
0.4-8GHz Dual-Directional Coupler								
D3002HB004080	120	30	1.3	1.3	0.8	30±1.0	±1.0	18
D4002HB004080	120	40	1.3	1.3	0.8	40±1.0	±1.0	18
D3005HB004080	250	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4005HB004080	250	40	1.4	1.4	0.7	40±1.0	±1.6	14
D3008HB004080	400	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4008HB004080	400	40	1.4	1.4	0.7	40±1.0	±1.6	14
D3012HB004080	600	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4012HB004080	600	40	1.4	1.4	0.7	40±1.0	±1.6	14

*Theoretical I.L. Included



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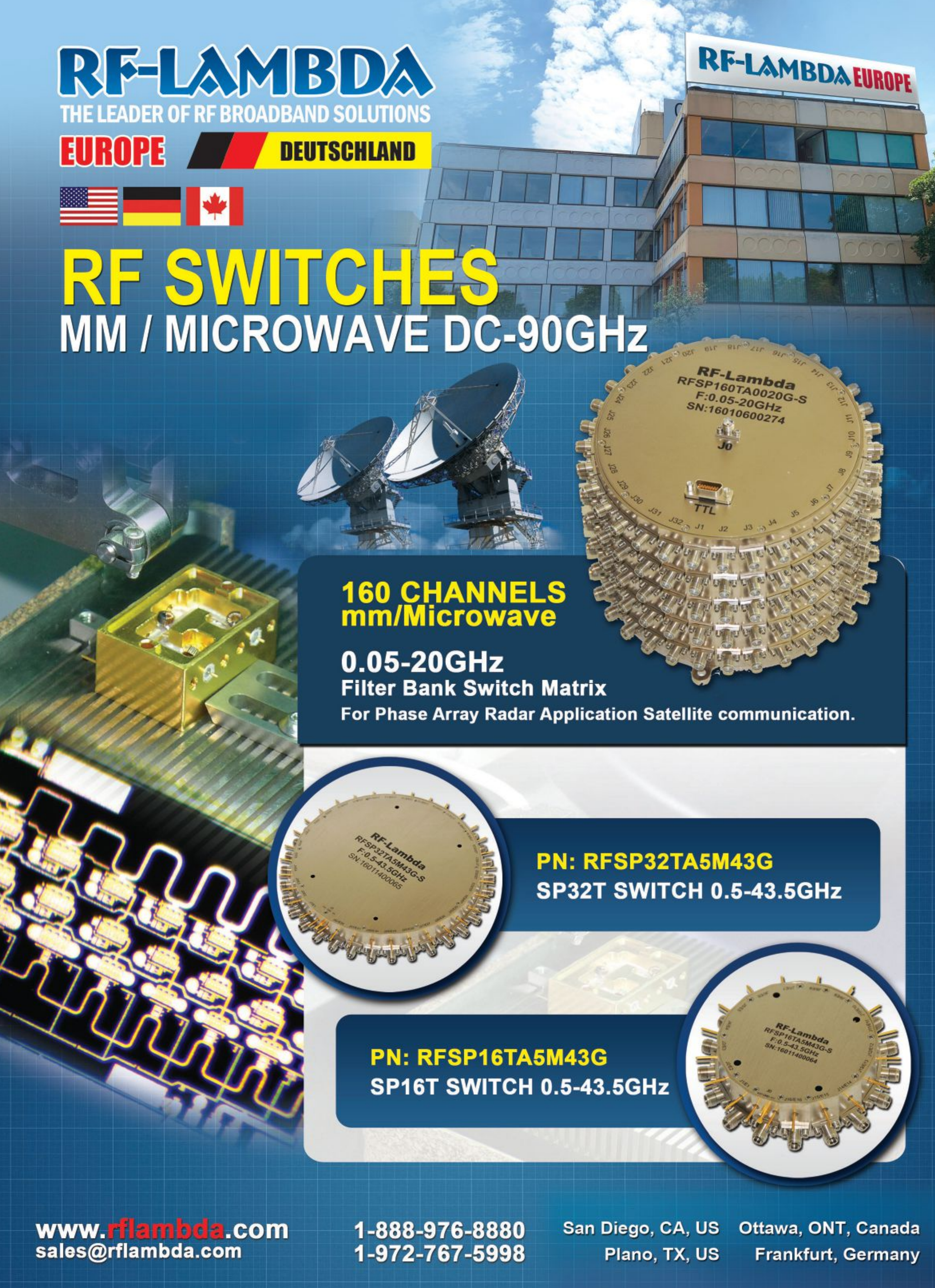
likely to enter the market in 2023 for mid-band mMIMO AAS, driven by Infineon. A snapshot of the RF final PA supply chain and market share for all technologies used in RAN applications is shown in ***Figure 3***. ***Figure 4*** shows our estimate for the share of device technology and the evolution toward integrated modules for the final PA stage in RAN applications.

A wide variety of semiconductor technologies are used in the RAN RFFE, not only for the final PA but also for drivers, switches and filters. The diversity in terms of power levels, frequency and architecture among systems creates a need for complementary solutions to adequately address the demand. This results in a complex technological ecosystem. The industry's recent technological disruption caused by 5G has created a fragmented market with many players involved. A few players, like NXP, Qorvo, SEDI and Analog Devices, stand out in this market with large market shares. NXP is the uncontested leader with a 35 percent share of the overall RFFE component market. With the expected market growth in the next several years, we will likely see other players generating significant revenue in BTS applications.

CONCLUSION AND PERSPECTIVES

Innovation continues for 5G and the next generation of wireless networks, but price pressure from the

Fig. 3 2022 RF final PA supply chain and market share. *Source:* RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.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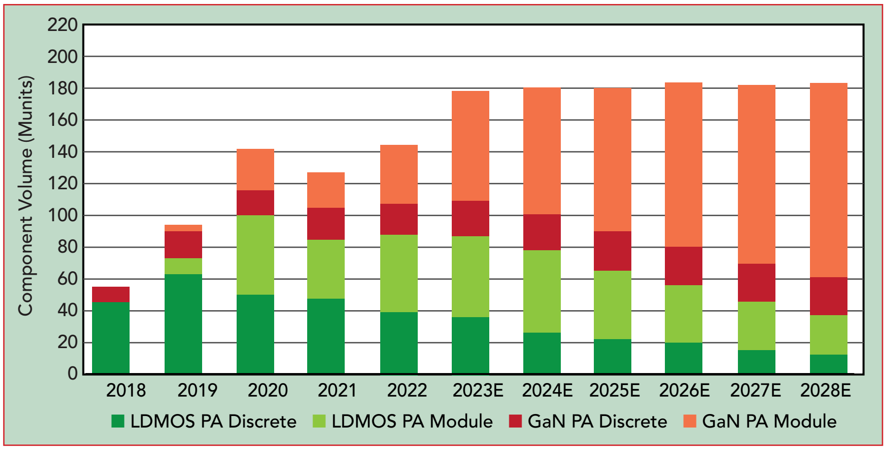

Fig. 4 RAN PA technology and integration forecast. *Source:* RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.

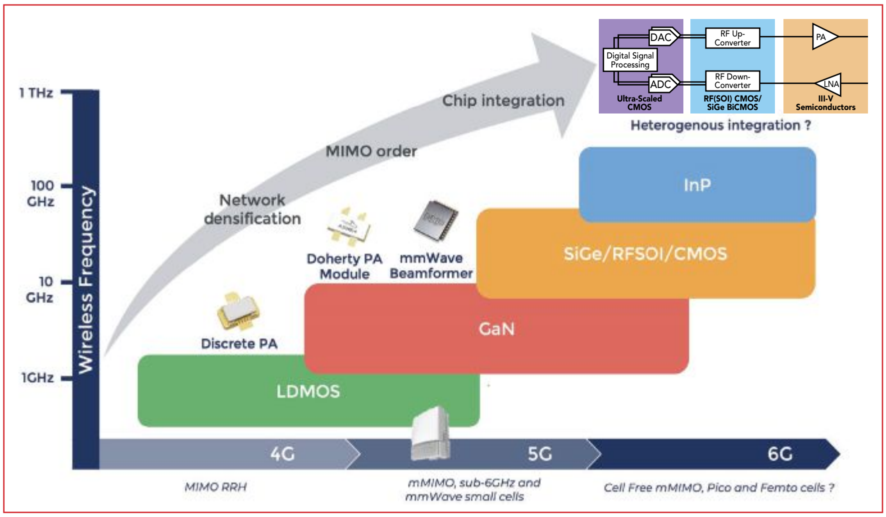

Fig. 5 A 6G technology roadmap. *Source:* RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.

MNOs is becoming more challenging for OEMs and chip makers. Fragmented spectrum assets, coupled with an increasing number of available frequency bands are compelling operators to push to combine several bands inside a radio. In response, leading chip makers are designing PAs with very large bandwidths that also support higher transmit powers.

The next step for the 5G standard, 3GPP Release 18, is expected in the second calendar quarter of 2024, and will be considered the first release of 5G Advanced. This new standard will enhance 5G functionalities from the core network to RUs. Beyond 5G Advanced, the industry has begun 6G research, in parallel with many research and development initiatives around the globe. Some of the main challenges for 6G will be how to incorporate sub-THz and THz frequencies. Initial areas of interest are focusing on transmission in 100 to 300 GHz sub-THz bands. Activities in these and higher bands are likely to result in the development of new materials for semiconductors and antennas, novel packaging techniques and advanced semiconductor processes. InP and SiGe are considered potential elements to enable these higher frequency ranges being envisioned for 6G applications. With 5G mmWave applications struggling to find a market, the question of whether 6G will be beneficial if it requires even higher frequencies is legitimate. If 6G does have a path forward, compound semiconductors will play a big role in enabling that future. Our thoughts on a technology roadmap that takes us from 4G to 6G are shown in ***Figure 5***. ■

A Compact Dual-Mode mmWave Bandstop Filter in 0.13 µm SiGe Technology

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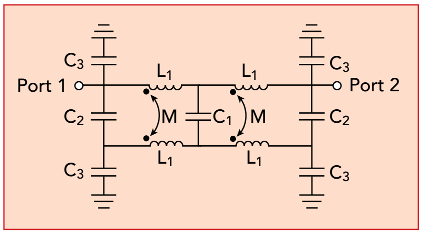
A compact mmWave on-chip dual-mode bandstop filter (BSF) is proposed and implemented in this work. The proposed BSF is realized with a broadside-coupled electromagnetic (EM) structure. Using this structure enables dual-mode operation, which helps to increase the attenuation bandwidth and the stopband attenuation level. As practical validation, a 72 GHz on-chip BSF is implemented in 0.13 µm SiGe technology and tested. There is close agreement between simulated and measured results for this on-chip BSF circuit. The measurement results show that the attenuation is better than 10 dB from 60 to 79 GHz, with 40 dB attenuation recorded at the optimized frequency. The passband insertion loss is better than 2.2 dB from DC to 50 GHz and 90 to 110 GHz. Excluding the pads, the size of the designed BSF is only 0.027 mm^2.

On-chip passive components operating at mmWave frequencies are critical building blocks that can be found in many wireless systems, ranging from motion detection radar to high speed wireless data transmission. In particular, the compact passive components implemented in low-cost, silicon-based technology, including both CMOS and SiGe, are the ones that have drawn the most attention in the past few years.[1-7] These passive components, like filters, baluns and couplers can be used as standalone building blocks or they can be codesigned with transistor circuits to further enhance the performance of active components.[8-13]

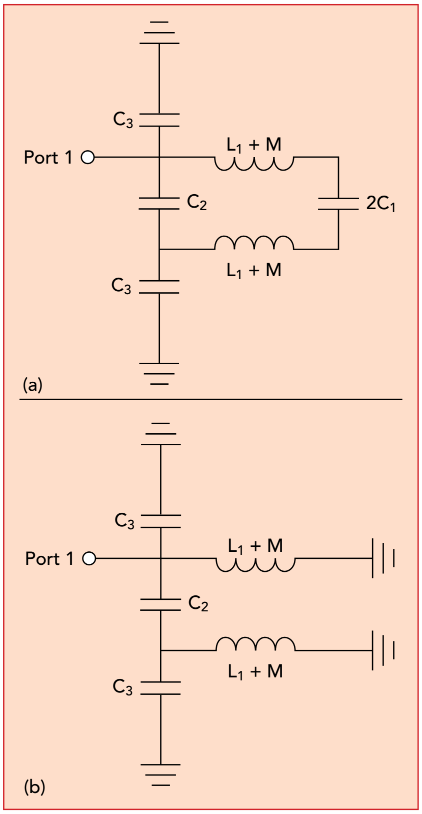


▲ Fig. 1 **LC-equivalent circuit of the dual-mode BSF.**

For filter design, the primary focus is on bandpass filters (BPFs). Although many novel EM structures have been presented for BPF design in the literature,[1-7,14] the works that address the design issues related to BSF are limited. In addition, most of the previously published BSF works address narrowband applications.[15-18] Another issue of on-chip mmWave BSF designs is the limited in-band attenuation that can be achieved, with attenuation levels of more than 30 dB desirable. This is difficult to achieve using the existing approaches, resulting in a knowledge gap when it comes to effectively designing a wideband on-chip BSF. In this paper, an innovative EM structure is proposed that takes advantage of dual-mode operation to increase the stopband bandwidth and attenuation of the designed BSF.

SIMPLIFIED CIRCUIT MODEL USING LUMPED ELEMENTS

To understand the proposed dual-mode BSF design concept, this section will pres-



▲ Fig. 2 **Even-mode LC-equivalent circuit (a) and odd-mode LC-equivalent circuit (b).**

ent a theoretical analysis. A simplified circuit model using ideal lumped elements is given in ***Figure 1***. This model is composed of two pairs of inductors with a value of L_1 with a mutual inductance of M and multiple capacitors with capacitances of C_1, C_2 and C_3. To investigate the transmitting characteristics of the device, the even- and odd-mode analysis method can be applied. The even- and odd-mode equivalent circuits are displayed in ***Figure 2(a)*** and ***Figure 2(b)***, respectively.

For the even-mode circuit, the input admittance can be expressed as:

$$Y_{even} = j\omega C_3 + \cfrac{1}{\cfrac{1}{j\omega C_2 + \cfrac{1}{\cfrac{1}{j2\omega C_1} + 2\omega\left(L_1 + M\right)}} + \cfrac{1}{j\omega C_3}} \quad (1)$$

For the odd-mode circuit, the input admittance can be expressed as:

$$Y_{odd} = j\omega C_3 + \cfrac{1}{j\omega\left(L_1 + M\right)} + \cfrac{1}{\cfrac{1}{j\omega C_2} + \cfrac{1}{j\omega C_3 + \cfrac{1}{j\omega\left(L_1 + M\right)}}} \quad (2)$$

To create transmission poles (TPs) at the two edges of the stopband, the following equations should be satisfied:

$$\frac{1}{j\omega C_2} + \cfrac{1}{j\omega C_3 + \cfrac{1}{j\omega + \left(L_1 + M\right)}} = 0 \quad (3)$$

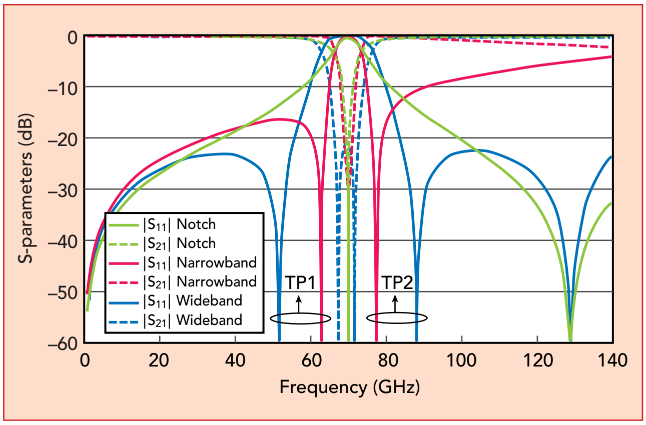
$$\cfrac{1}{j\omega C_2 + \cfrac{1}{\cfrac{1}{j2\omega C_1} + 2\omega\left(L_1 + M\right)}} + \frac{1}{j\omega C_3} = 0 \quad (4)$$

By solving equations (3) and (4), the positions of TP1 and TP2 are located at:

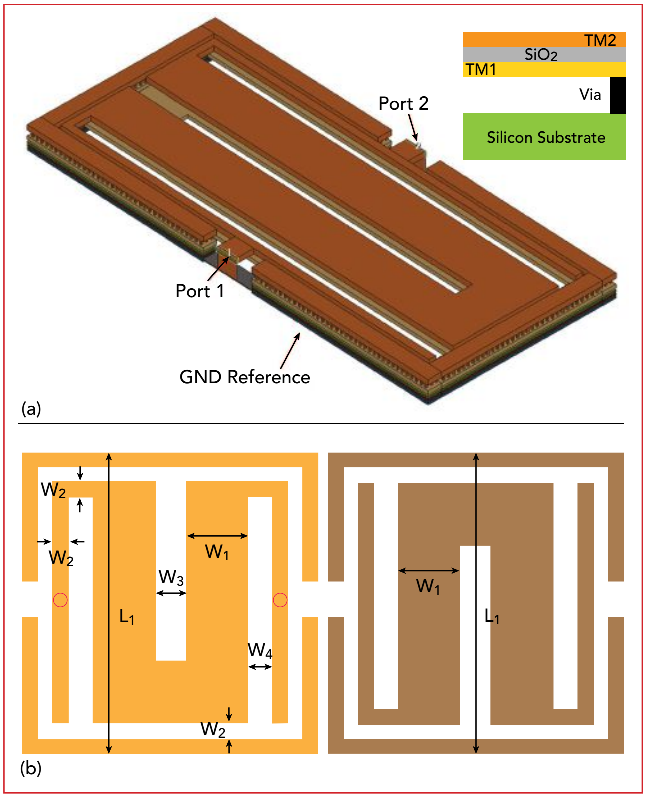
$$f_{TP1} = \frac{1}{2\pi}\sqrt{\frac{1}{\left(C_2 + C_3\right)\left(L_1 + M\right)}} \quad (5)$$

$$f_{TP2} = \frac{1}{4\pi}\sqrt{\frac{2C_1 + C_2 + C_3}{C_1\left(C_2 + C_3\right)\left(L_1 + M\right)}} \quad (6)$$

When the resonators are fixed, the positions of the TPs are affected by the mutual capacitance between the two inductors, which also determines the bandwidth of the stopband. ***Figure 3*** shows the calculated S-parameters of three different cases. The first case is



▲ Fig. 3 **Synthesized S-parameters of a notch filter, a narrowband BSF and a wideband BSF.**



▲ Fig. 4 **3D view of the BSF EM structure (a). 2D view of the BSF EM structure with physical dimensions (b). Note: W_1 = 26 mm, W_2 = 4 mm, W_3 = 10 mm, W_4 = 10 mm and L_1 = 248 mm.**

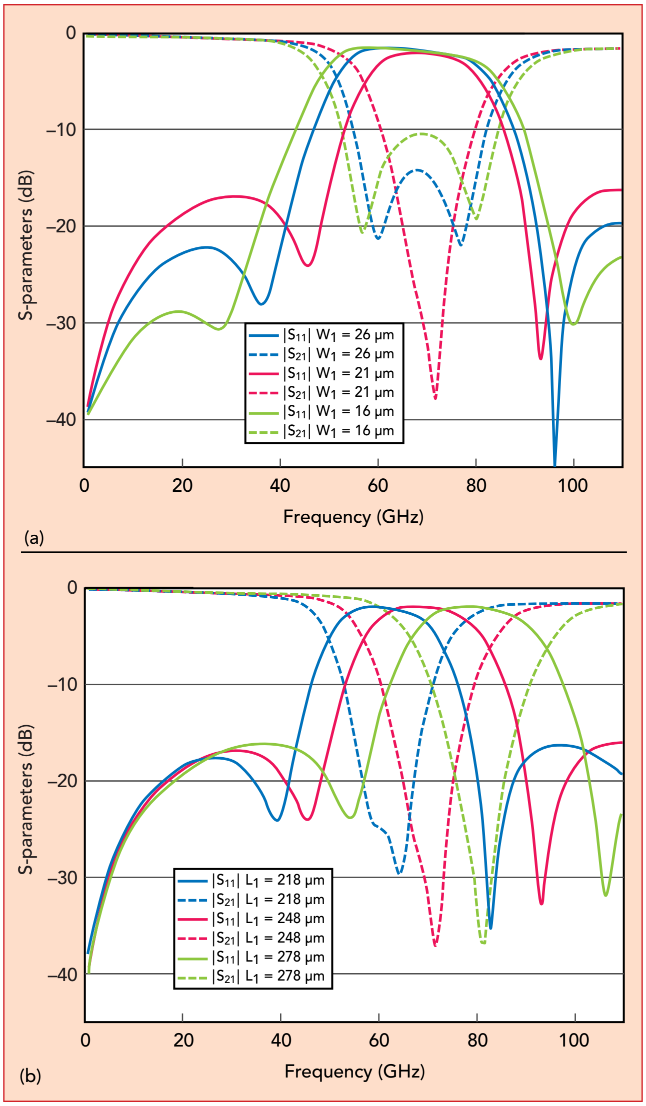


Fig. 5 **EM simulation results sweeping W_1 (a). EM simulation results sweeping L_1 (b).**

a notch filter with no mutual inductance between the two inductors. In this case, only one zero is realized at the center frequency without any TPs at two edges (in green). The second and third cases represent a dual-mode BSF with two TPs at two edges and the bandwidth of the stopband can be controlled in a certain range.

IMPLEMENTATION OF THE DESIGNED BSF

The lumped-element model presented in Figure 1 is implemented using a 0.13 µm SiGe technology. This process provides seven metal layers, including two thick aluminum layers shown as TM1 and TM2 in ***Figure 4(a)***. These two layers are isolated by an SiO_2 layer that has a dielectric constant of 4.1 and a thickness of 3 µm. The thickness of these two aluminum layers are 3 µm and 2 µm, respectively. In this design, these two metal layers are extensively used to construct the core of the BSF. The lower layer metals are thin and mainly used as the ground reference. The 2D view of the designed BSF is shown in ***Figure 4(b)***. This figure shows the adjustable dimensions of the bandstop filter design. To demonstrate that the designed bandwidth and stopband attenuation can be effectively controlled, a parametric study was conducted using EMX, an EM simulation tool from Cadence. Although multiple physical parameters can be used to control the performance, only two parameters were chosen in this study to limit the analysis to a reasonable length.

As demonstrated in ***Figure 5(a)***, the two TPs can be controlled by keeping L_1 constant and varying the value of W_1. This process helps to determine an optimized bandwidth in the design. In ***Figure 5(b)***, reducing the value L_1 from 278 to 218 µm results in the notch frequency shifting from 64 to 80 GHz. These results indicate that the frequency bandwidth of operation can be fully controlled in addition to the bandwidth. More importantly, the stopband attenuation level can also be optimized by adjusting the locations of the two TPs. Depending on the design specifications, the design trade-offs between high stopband attenuation and wide stopband bandwidth can be controlled by simply tuning these two variables.

MEASUREMENTS

To evaluate the performance of the presented dual-mode BSF, a prototype was fabricated in 0.13 µm SiGe technology. The die microphotograph is shown in ***Figure 6***. Excluding the testing pads, the die size is only 0.11 × 0.248 mm. The S-parameter measurements were conducted with on-wafer ground-signal-ground (GSG) probes up to 110 GHz using an N5290A vector network analyzer from Keysight and 100 µm pitch GSG Infinity Probes with 1 mm connectors from FormFactor, Inc. The on-wafer calibration was made by using a conventional short-load-open-thru (SLOT) method to move the reference plane from the connectors of the equipment to the tips of the RF probes.

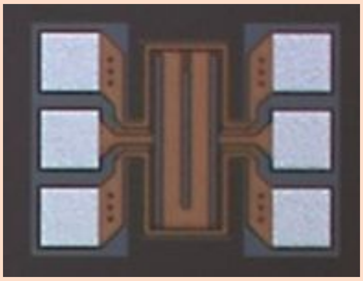


Fig. 6 Die microphotograph of the designed dual-mode BSF.

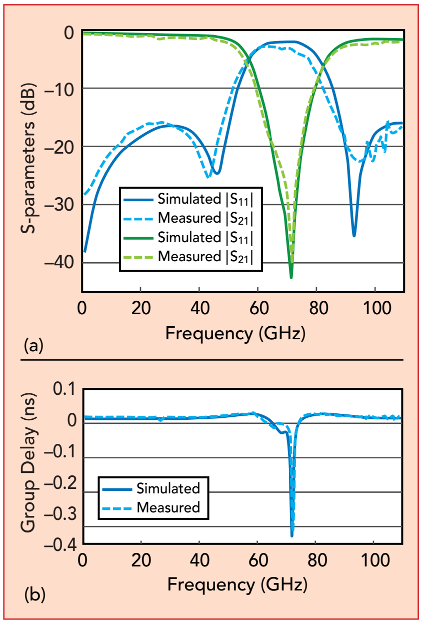


Fig. 7 Measured S-parameters results for the dual-mode BSF (a). Measured group delay results for the dual-mode BSF (b).

The simulated and measured power transmission and the group delay responses of the prototype are compared in ***Figure 7(a)*** and ***Figure 7(b)***. As observed, there is close agreement between predicted and experimental results. The minor discrepancies observed between simulated and measured power-reflection levels are attributed to the probes and GSG pads, which were not considered in the simulation process due to the increased computational cost.

Table 1 compares the results of this work to other similar efforts. As shown, this design has achieved the highest stopband attenuation and the widest stopband bandwidth while still maintaining a small footprint. These comparisons to other state-of-the-art designs demonstrate the overall performance improvement of the designed BSF.

CONCLUSION

An mmWave dual-mode BSF has

TABLE 1

PERFORMANCE SUMMARY OF THE ON-CHIP NOTCH FILTER DESIGN VERSUS OTHER REPORTED RESULTS

	(4)	(5)	(6)	(7)	(15)	(18)	This work
f_c (GHz)	59	59	46	67	24.5	19	72
#Insertion loss (dB)	1.8	1.9	2	2.4	0.5	0.6	2.2
Attenuation (dB)	15.7	20	28	25	23.1	37	40
3 dB Bandwidth (GHz)	> 20	27	20	> 24	5	6	31
*Selectivity (dB/GHz)	1.27	1.26	2.5	0.92	8	11.3	1.95
Area (mm^2)	0.024	0.039	0.023	0.012	0.038	0.028	0.027

Note: #Out-of-band (passband range) loss.
*Calculated as: (attenuation at f_3 dB – peak attenuation) / (f_c – f_3 dB).

been designed using 0.13 μm SiGe technology. The theoretical analysis of this design has been presented and validated through EM simulation. In addition, the fabricated BSF shows close agreement between EM simulation and measured results. These measured results show that the presented design has in-band suppression of more than 30 dB and low out-of-band insertion loss. ■

ACKNOWLEDGMENTS

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A Ferrite Transformer-Based Power Divider with 400:1 Bandwidth

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A wideband very high frequency (VHF) power divider for IoT uses commercially available off-the-shelf ferrite transformers. The measured operating frequency range is from 1 to 400 MHz (a bandwidth of 400:1). Measured insertion loss is less than 0.6 dB and return loss is greater than 18 dB over the entire band. Measured amplitude and phase imbalance are within 0.05 dB and 1.75 degrees, respectively. Isolation is better than 20 dB over the band.

Power dividers are vital components in electronic communication systems and are widely used in high-power solid-state amplifiers, antenna feeder networks, IQ receivers and test and measurement applications. The frequency spectrum allocated for IoT applications has renewed research interest in the VHF Band.[1] However, there has been little research in vital components such as power dividers at these frequencies.

A Mini-Circuits application note[2] is one of the few references available to designers. However, it uses autotransformers that are not commercially available as off-the-shelf components. In addition, there is no DC isolation between input and output ports in such a circuit. Recently, a magnetic circuit using ferrite transformers has been used to realize a power splitter operating from 200 Hz to 10 KHz (50:1 bandwidth) for power and energy measurements of the smart grid.[3] One of its limitations is that it is a custom circuit; it is not possible with this design to employ commercially available off-the-shelf ferrite transformers.

The design described in this article addresses that issue with a wideband power divider using commercially available ferrite transformers (ordinary two-winding ferrite transformers).

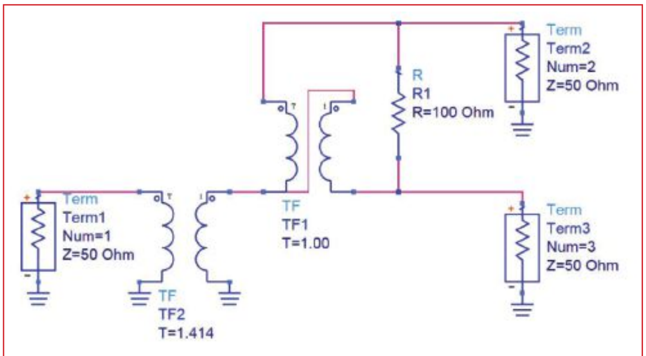


Fig. 1 **Wideband ferrite transformer-based power divider schematic. (T = turns ratio).**

POWER DIVIDER CONCEPT

The wideband ferrite transformer-based power divider schematic (see ***Figure 1***) uses only two transformers, one with a turns ratio of 1:1 (i.e. impedance ratio of 1:1) and the other with a turns ratio of 1.414:1 (i.e. impedance ratio of 2:1). Such transformers are available as off-the-shelf components. A lumped resistor with a resistance of 100 Ω between the output ports (Ports 2 and 3) provides the required isolation. Such an ideal

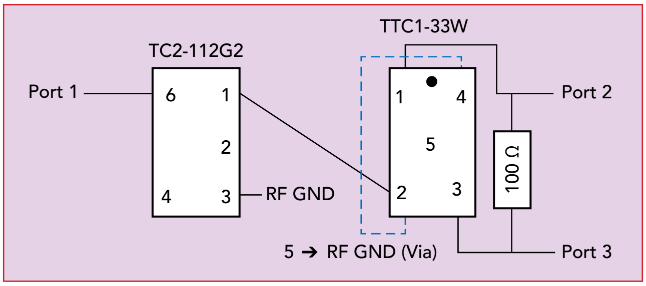


Fig. 2 Proof of concept.

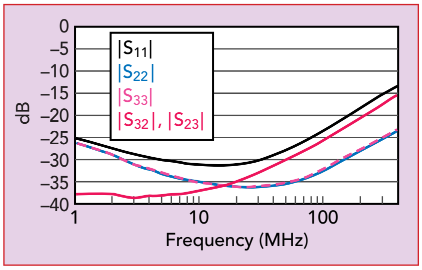


Fig. 3 Simulated $|S_{11}|$, $|S_{22}|$, $|S_{33}|$ and $|S_{23}|$.

network provides perfect impedance matching, power division and isolation; hence, theoretical performance is not plotted.

PROOF OF CONCEPT

A ferrite transformer-based power divider is designed for operation in the VHF Band with the following specifications: operating frequency range from 1 to 400 MHz, return loss greater than 10 dB, insertion loss less than 1 dB, isolation greater than 20 dB, amplitude imbalance less than 0.2 dB and phase imbalance less than 2 degrees.

Design and Simulation

To realize the power divider, two commercially available ferrite transformers from Mini-Circuits: TC2-112G2 (with an impedance ratio of 2:1) and TTC1-33W (with an impedance ratio of 1:1) are employed (see ***Figure 2***).[4,5] Measured S-parameters of the transformers are used to obtain the power divider's simulated response with the Keysight ADS simulator.[6] ***Figure 3*** plots the simulated reflection coefficients at the three ports as well as output port coupling. Return loss is greater than 14 dB and isolation is greater than 16 dB over the entire band. ***Figures 4*** and ***5*** plot the magnitudes and phases of the transmission coefficients respectively, as well as amplitude and phase imbalance. Insertion loss is less than 0.8 dB, amplitude imbalance is better than 0.05 dB and phase imbalance is better than 0.2 degrees over the entire bandwidth. Owing to the symmetry in the simulation environment, both amplitude and phase imbalance are excellent. It is expected that the asymmetry caused by layout in PCB and assembly of components will degrade the amplitude and phase imbalances in the measurement results.

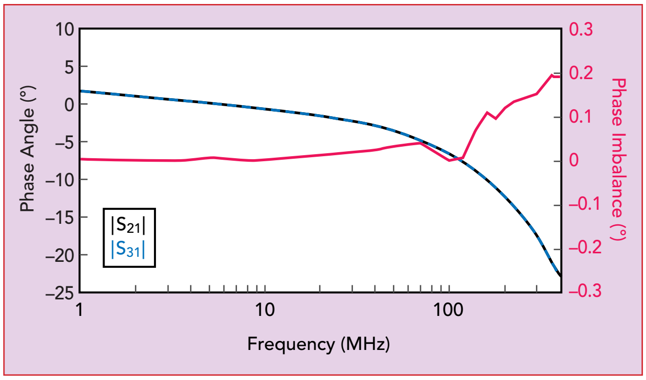


Fig. 5 Simulated S_{21} and S_{31} phase and phase imbalance.

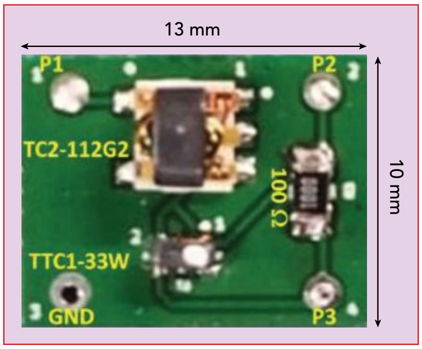


Fig. 6 Prototype VHF power divider.

Fabrication and Measurement

The power divider is fabricated on a 60 mil 2-layer FR4 PCB (see ***Figure 6***). ***Figure 7*** plots the measured reflection coefficients and output port coupling. Return loss is greater than 11 dB and isolation is greater than 15 dB over the entire band. ***Figures 8*** and ***9*** plot the magnitudes and phases of the transmission coefficients respectively, as well as amplitude and phase imbalance. Measured insertion loss is less than 1 dB, amplitude imbalance is better than 0.05 dB and phase imbalance is better than 1.5 degrees over the entire band. Note that the power

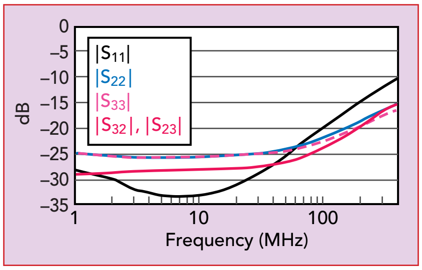


Fig. 7 Measured $|S_{11}|$, $|S_{22}|$, $|S_{33}|$ and $|S_{23}|$.

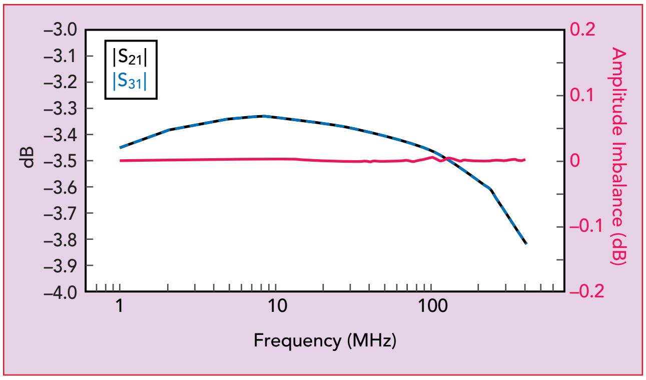


Fig. 4 Simulated $|S_{21}|$, $|S_{31}|$ and amplitude imbalance.

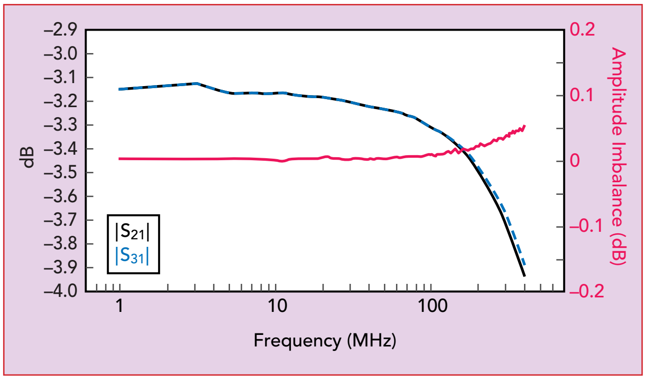


Fig. 8 Measured $|S_{21}|$, $|S_{31}|$ and amplitude imbalance.

divider demonstrates excellent amplitude and phase imbalance over the entire band even though the layout is not symmetrical. This equates to a power combining the efficiency of better than 99.5 percent, excluding insertion loss.[7]

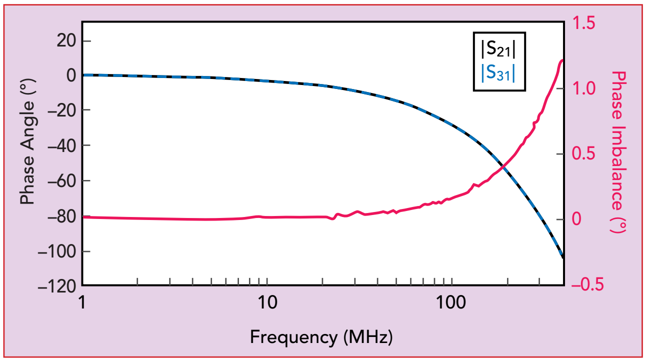


Fig. 9 Measured S_{21} and S_{31} phase and phase imbalance.

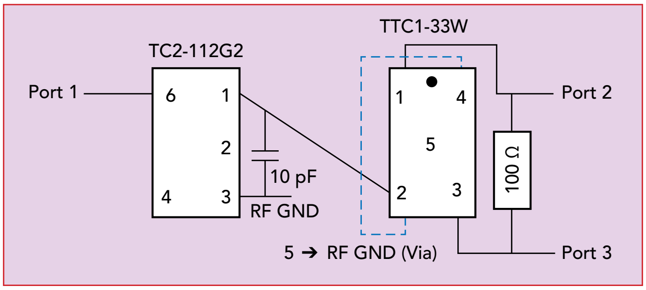


Fig. 10 VHF power divider with enhanced performance.

PROOF OF CONCEPT – ENHANCED DESIGN

To enhance return loss and isolation performance, a 10 pF capacitor is introduced between the transformers to absorb parasitic inductance (see ***Figure 10***). The prototype power divider is shown in ***Figure 11***. ***Figure 12*** plots the measured reflection coefficients as well as output port coupling. Return loss is greater than 18 dB and isolation is greater than 20 dB over the entire band. ***Figures 13*** and ***14*** plot the magnitudes and phases of the transmission coefficients respectively, as well as amplitude and phase imbalance. Measured insertion loss is less than 0.6 dB, while amplitude imbalance is better

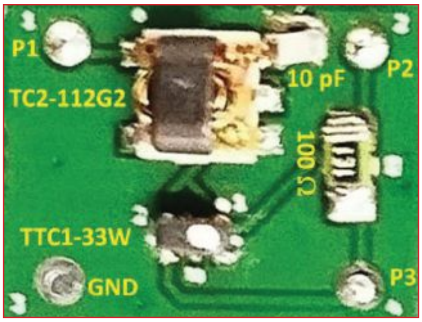


Fig. 11 Prototype enhanced-performance VHF power divider.

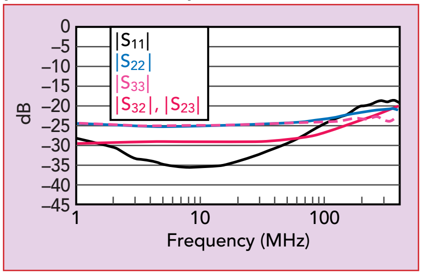
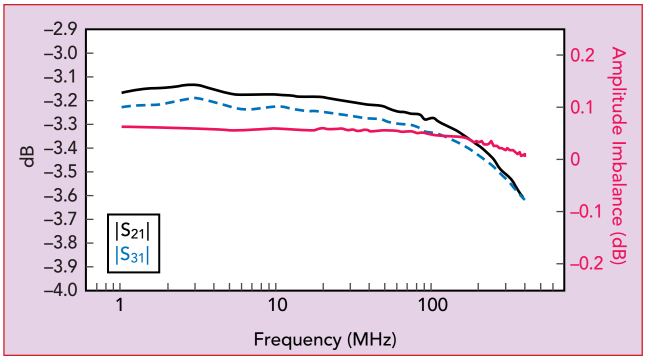
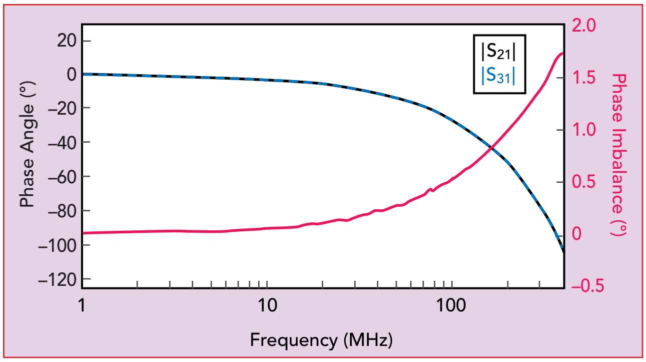


Fig. 12 Measured $|S_{11}|$, $|S_{22}|$, $|S_{33}|$ and $|S_{23}|$.



▲ Fig. 13 Measured $|S_{21}|$, $|S_{31}|$ and amplitude imbalance.



▲ Fig. 14 Measured S_{21} and S_{31} phase and phase imbalance.

than 0.05 dB and phase imbalance is better than 1.75 degrees over the entire band.

CONCLUSION

A novel broadband VHF power divider uses commercially available off-the-shelf ferrite transformers. The measured operating frequency range is from 1 to 400 MHz with a bandwidth of 400:1. Measured insertion loss is less than 0.6 dB and return loss is greater than 18 dB over the entire band. Measured amplitude and phase imbalance are within 0.05 dB and 1.75 degrees, respectively, and isolation is better than 20 dB over the band. ■

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Asymmetric Surface Plasmon Polariton Defected Ground Structure with Triple-Band Rejection and its Application in a Gysel Power Divider with Harmonic Suppression

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Asymmetric spoof surface plasmon-defected ground structures (ASSP-DGSs) are developed from conventional dumbbell-shaped DGSs (DB-DGSs). By loading comb-shaped periodic SSP structures in the two rectangular defected areas and reducing the size of one side, the ASSP-DGS can produce three transmission zeros. Moreover, by changing the loaded SSP structure, the transmission zeros can be easily adjusted to obtain the desired rejection. The ASSP-DGS is incorporated in a Gysel power divider with triple-band rejection. Suppression bandwidths ($|S_{21}| < -15$ dB and $|S_{31}| < -15$ dB) at the second, third and fourth harmonics are 26.4, 23.8 and 12.5 percent, respectively.

In many modern wireless communication systems RF front-ends, harmonic rejection is important because harmonics interfere with desired signals. Various structures and techniques have been proposed to suppress them.[1-9] Lowpass or bandstop filters can be used in many designs;[1-3] however, both size and insertion loss often increase. Different filter structures with improved harmonic rejection have been proposed at the cost of increased design complexity and insertion loss.[4-6]

DGSs are employed to suppress harmonics as well.[7-9] Because DGSs can provide only one or two transmission zeros, multiple cascaded DGSs of different sizes must be employed to obtain rejection at several frequencies. The cascaded DGS configuration, however, increases insertion loss and circuit size.

In this work, a DGS with three transmission zeros is developed by combining a dumbbell-shaped DGS and SSP structures. HFSS and ADS simulations as well as parametric analyses are provided. It is found that the new DGS exhibits a response with three transmission zeros, rejecting multiple harmonics simultaneously. A Gysel power divider with triple harmonic rejection is designed. Experimental results agree closely with the simulation.

DGS WITH MULTIPLE TRANSMISSION ZEROS

SSP-DGS with Two Transmission Zeros

A DGS with two attenuation poles is first developed (see ***Figure 1***). The SSP-DGS is created by loading comb-shape periodic SSP structures within the two rectangu-

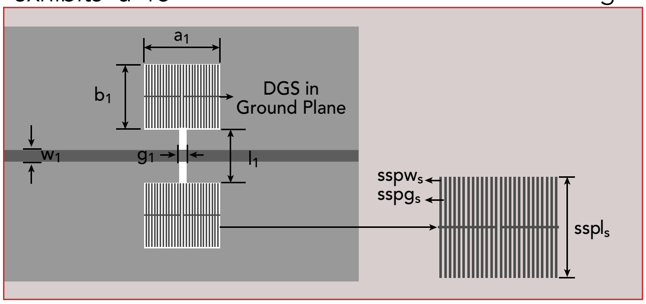
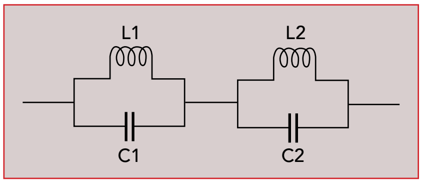


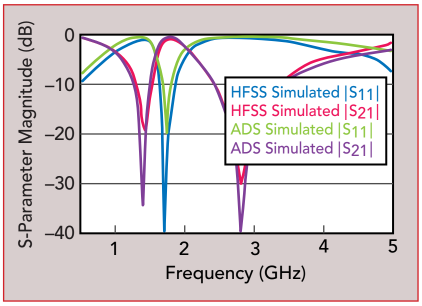
Fig. 1 SSP-DGS.

lar defected areas of a conventional DB-DGS. The SSP groove depth and strip width are $sspl_s$ and $sspw_s$, respectively, and the spacing between two adjacent strips is $sspg_s$. The number of periodic unit cells is n_s. The substrate is 0.8 mm thick with $\varepsilon_r = 4.4$.

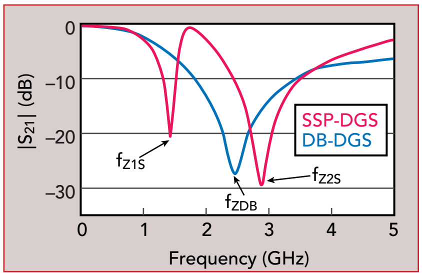
The equivalent circuit of Figure 1 is analyzed, and the circuit parameters are extracted. A conventional DGS is equivalent to a single parallel LC circuit that blocks the signal at resonance. The SSP-DGS in this work is equivalent to two LC circuits in series (see ***Figure 2***). ***Figure 3*** shows simulation results of the SSP-DGS in both HFSS and ADS, demonstrating close agreement over a wide frequency range.



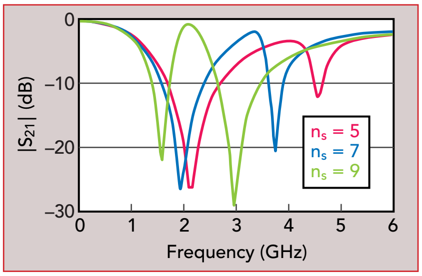
▲ Fig. 2 **SSP-DGS equivalent circuit.**



▲ Fig. 3 **HFSS and ADS simulations.**



▲ Fig. 4 **Simulated DB-DGS and SSP-DGS $|S_{21}|$ (w_1 = 1.5, g_1 = 0.5, l_1 = 5.5, a_1 = b_1 = 12, $sspl_s$ =11.6, $sspw_s$ = 0.25 and $sspg_s$ = 0.2 mm).**



▲ Fig. 5 **Simulated $|S_{21}|$ of SSP-DGSs with different periodic number n_s (w_1 = 1.5, g_1 = 0.5, l_1 = 5.5, a_1 = b_1 = 12, $sspl_s$ = 11.6, $sspw_s$ = 0.25 and $sspg_s$ = 0.2 mm).**

Figure 4 compares the HFSS simulated $|S_{21}|$ of the conventional DB-DGS and the SSP-DGS. When the SSP structure is introduced, two transmission zeros at f_{z1s} and f_{z2s} appear on the $|S_{21}|$ plot. The location of the zeros can be adjusted by changing the loading of the SSP structure. As shown in ***Figure 5***, when n_s increases, the upper and lower frequency transmission zeros are both drawn lower in frequency. Similarly, as shown in ***Figure 6***, the transmission zeros can be adjusted with different groove depths.

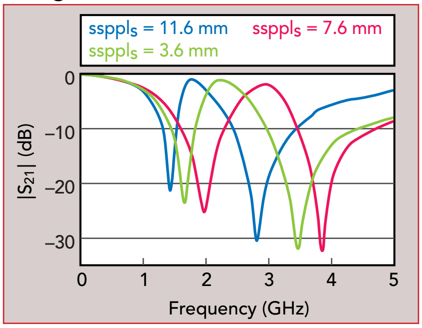
ASSP-DGS with Three Transmission Zeros

As shown in ***Figure 7***, an ASSP-DGS is developed from a symmetrical SSP-DGS by reducing the size of the defect structure on one side. The ASSP-DGS is equivalent to three shunt LC resonant circuits in series as shown in ***Figure 8***. ***Figure 9*** shows simulation results of the ASSP-DGS in HFSS and ADS, demonstrating close agreement over a wide frequency range.

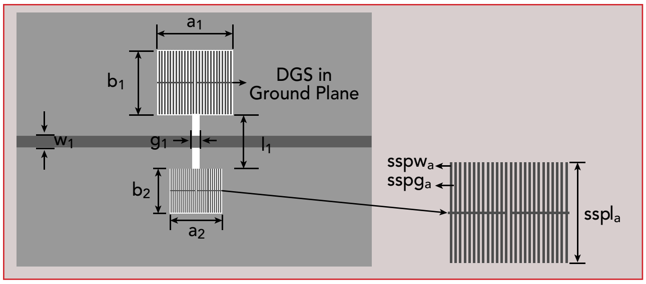
Figure 10 compares the HFSS simulated S-parameters of the SSP-DGS and ASSP-DGS. Three transmission zeros at f_{z1a}, f_{z2a} and f_{z3a} appear on the $|S_{21}|$ plot of the ASSP-DGS.

Figures 11 and ***12*** compare simulated transmission responses of the ASPP-DGS with different periodic numbers n_a and groove depths $sspl_a$. The location of the transmission zero f_{z1a} is insensitive to the change of the smaller defect structure. The zeros at f_{z2a} and f_{z3a}, however, are both drawn lower in frequency when either n_a or $sspl_a$ is increased.

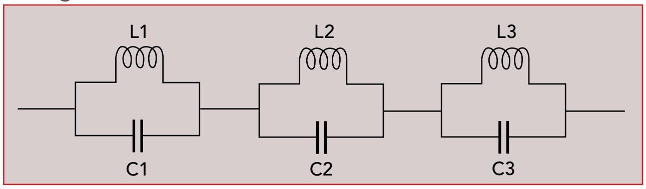
An ASSP-DGS with triple-band rejection is constructed by first defining the transmission zero frequencies f_{z1}, f_{z2} and f_{z3} as well as the required rejection. A DB-DGS is designed with a transmission zero at



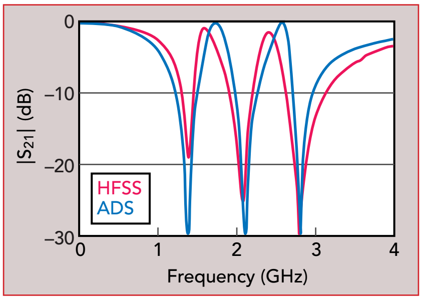
▲ Fig. 6 **Simulated $|S_{21}|$ of SSP-DGSs with different groove depth $sspl_s$ (w_1 = 1.5, g_1 = 0.5, l_1 = 5.5, a_1 = b_1 = 12, $sspw_s$ = 0.25 and $sspg_s$ = 0.2 mm). n_s = 13.**



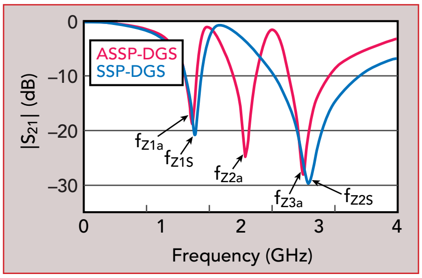
▲ Fig. 7 **ASSP-DGS.**



▲ Fig. 8 **ASSP-DGS equivalent circuit.**



▲ Fig. 9 **HFSS and ADS simulations.**



▲ Fig. 10 **Simulated $|S_{21}|$ of SSP-DGS and ASSP-DGS compared (w_1 = 1.5, g_1 = 0.5, l_1 = 5.5, a_1 = 12, b_1 = 13.8, $sspl_{a1}$ = 13.4, a_2 = 11, b_2 = 8.7, $sspl_{a2}$ = 8.3, $sspw_a$ = 0.25 and $sspg_a$ = 0.4 mm).**

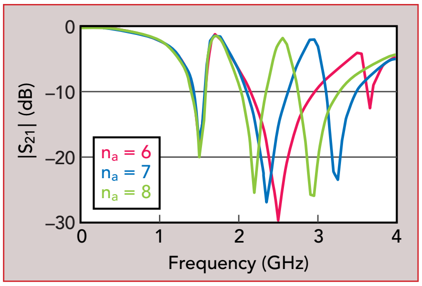


Fig. 11 **Simulated $|S_{21}|$ of ASSP-DGSs with different periodic number n_a (w_1 = 1.5, g_1 = 0.5, l_1 = 5.5, a_1 = 12, b_1 = 13.8, $sspl_{a1}$ = 13.4, a_2 = 11, b_2 = 8.7, $sspl_{a2}$ = 8.3, $sspw_a$ = 0.25 and $sspg_a$ = 0.4 mm).**

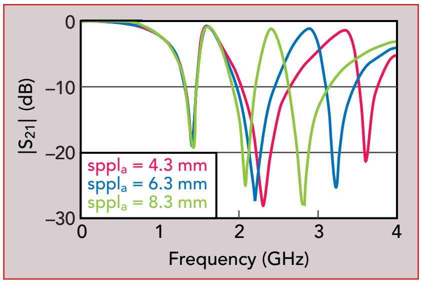


Fig. 12 **Simulated $|S_{21}|$ of ASSP-DGSs with different groove depth $asspl_s$ (w_1 = 1.5, g_1 = 0.5, l_1 = 5.5, a_1 = 12, b_1 = 13.8, $sspl_{a1}$ = 13.4, a_2 = 11, b_2 = 8.7, $sspl_{a2}$ = 8.3, $sspw_a$ = 0.25 and $sspg_a$ = 0.4 mm).n_a = 8.**

around f_{z2}. Then, an SSP-DGS with two transmission zeros f_{z1s} and f_{z2s} is designed with its loading parameters adjusted to make $f_{z1s} \approx f_{z1}$ and $f_{z2s} > f_{z3}$. Finally, the ASSP-DGS is designed, based on the SSP-DGS, with three transmission zeros f_{z1a}, f_{z2a} and f_{z3a} by adjusting the asymmetric defect structure to make $f_{z1a} \approx f_{z1}$, $f_{z2a} \approx f_{z2}$ and $f_{z3a} \approx f_{z3}$.

POWER DIVIDER DESIGN

The power divider (PD) is a device that can divide an RF input signal into two or more output signals. Because it satisfies the reciprocity theorem, it can be used as a combiner as well. PDs are widely used as components in many microwave devices such as mixers, power amplifiers and antenna arrays. In these applications, unwanted harmonics caused by nonlinear circuit properties must be suppressed. A DGS can be incorporated as a harmonic rejection filter. The ASSP-DGSs are used to suppress the second, third and fourth harmonics.

The Gysel PD design with ASSP-DGSs is shown in ***Figure 13***. The fabricated divider is shown in ***Figure 14***. It is constructed on a 0.8 mm thick FR4 substrate with a relative dielectric constant ε_r of 4.4. The dimensions are:

w_{gs1} = 1.9, w_{gs2} = 1.7, l_{gs1} = 10, l_{gs2} = 22, l_{gs3} = 18.5, l_{gs4} = 43.5, l_{gs5} = 15, l_{gs6} = 16, g_1 = 0.5, l_1 = 5.5, a_1 = 12, b_1 = 13.8, $sspl_{a1}$ = 13.4, a_2 = 11, b_2 = 8.7, $sspl_{a2}$ = 8.3, $sspw_a$ = 0.25 and $sspg_a$ = 0.4 mm.

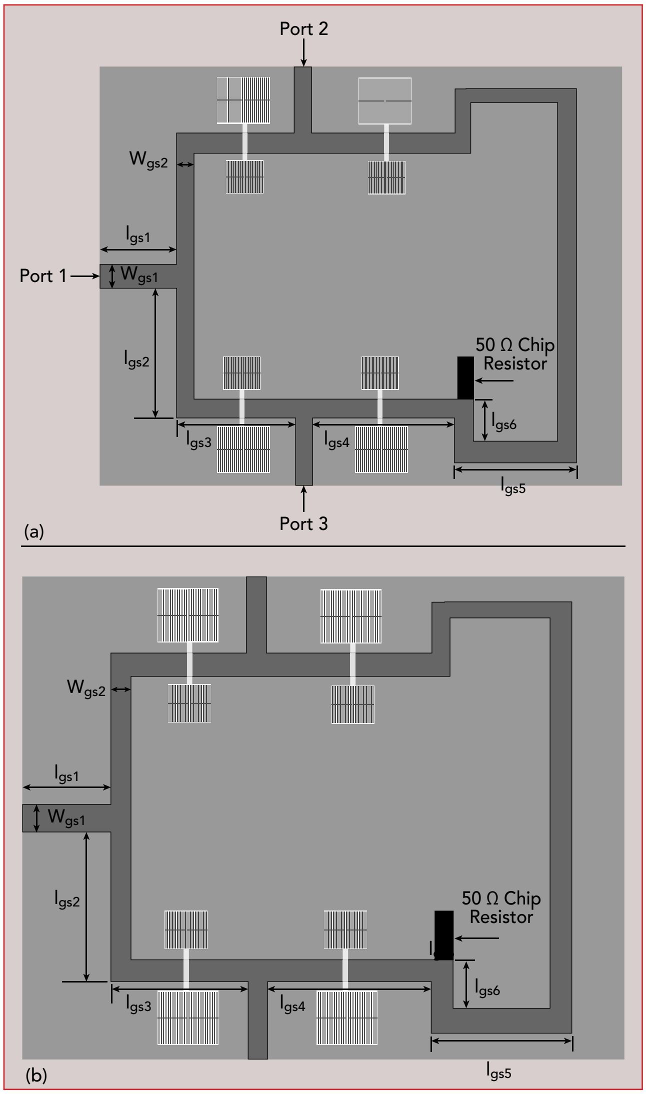


Fig. 13 **Gysel power divider layout with harmonic suppression: top view (a), bottom view (b).**

MEASUREMENTS

Figure 15 shows simulated and measured S-parameters of the fabricated harmonic suppression Gysel PD. The matching bandwidth ($|S_{11}|$, $|S_{22}|$ and $|S_{33}|$

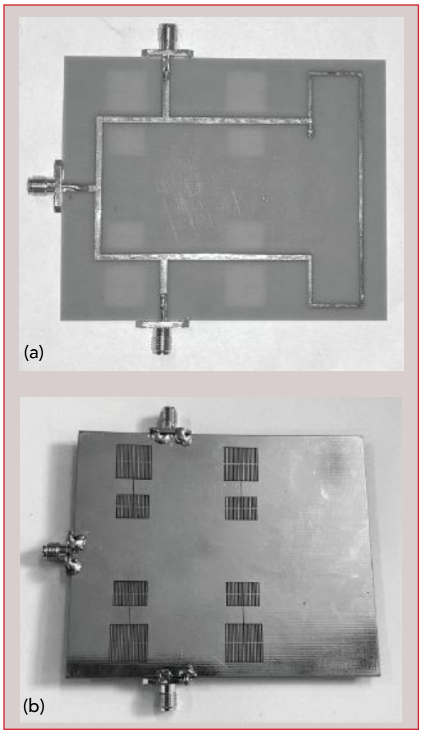


Fig. 14 **Fabricated Gysel power divider with harmonic suppression: top view (a), bottom view (b).**

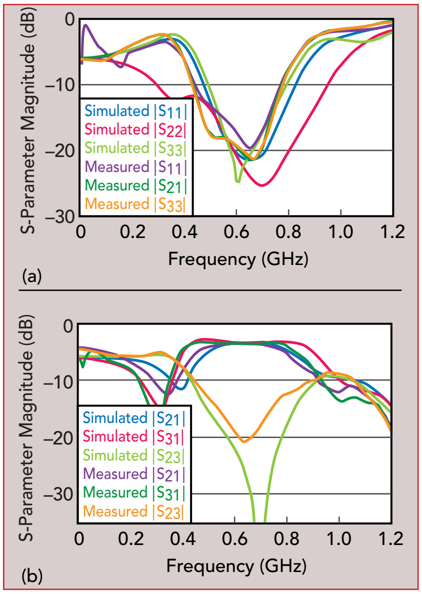


Fig. 15 **Simulated and measured S-parameters of Gysel power divider with harmonic suppression: $|S_{11}|$, $|S_{22}|$, $|S_{33}|$ (a) and $|S_{21}|$, $|S_{31}|$, $|S_{23}|$ (b).**

< -15 dB) around the center frequency of 0.7 GHz is 24.3, 35.7 and 37.1 percent, respectively. The port isolation bandwidth ($|S_{23}|$ <-15 dB) is 30.1 percent. Measured $|S_{21}|$ is -3.6 dB and $|S_{31}|$ is -3.4 dB at 0.7 GHz.

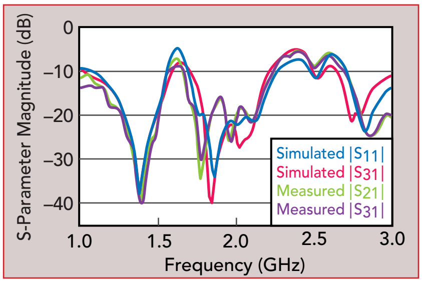


Fig. 16 **Simulated and measured $|S_{21}|$ and $|S_{31}|$ wideband performance of Gysel power divider with harmonic suppression.**

Simulated and measured wideband $|S_{21}|$ and $|S_{31}|$ are shown in ***Figure 16***. The suppression bandwidth ($|S_{11}|$ and $|S_{22}|$ < -15 dB) at the second, third and fourth harmonics is 26.4, 23.8 and 12.5 percent, respectively.

CONCLUSION

The ASPP-DGS described exhibits a response with three transmission zeros. Three harmonics can be suppressed simultaneously by adjusting the sizes of the DB grounds and the sizes of the internally loaded SSP structures. Performance is verified with the integration of four ASSP-DGSs into a Gysel PD providing second, third and fourth harmonic suppression. Both simulations and the measurements show suppression of the second, third and fourth harmonics with little loss at the operating frequency. ■

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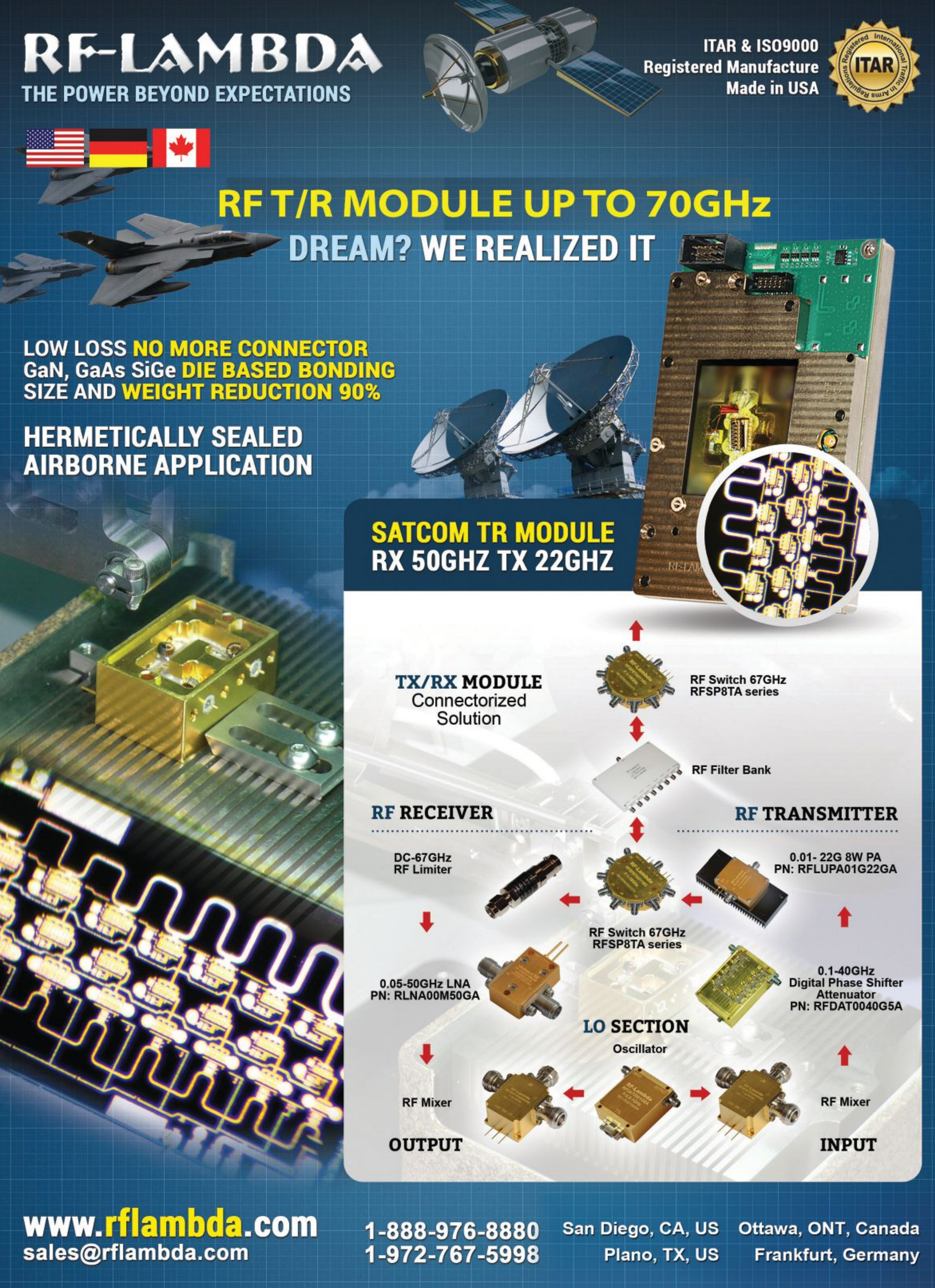
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Contactless Data and Power Transmission

Rosenberger
Hochfrequenztechnik GmbH & Co. KG
Fridolfing, Germany

SEAMLESS CONNECTIVITY

In the smart factory, seamless communication from the "shop floor to the top floor" is the name of the game. This demands reliable, high speed networks when connecting, for example, brownfield as well as new machine and production environments, the so-called operational technologies (OT), with the IT and ERP systems. Real-time data captured by numerous machine sensors must be securely communicated to the cloud, people and machines throughout the organization and the supply chain.

The key to the success of these networks is the connectors that carry power, data and signals. These connectors must ensure high data rates and be able to withstand harsh production environments. However, being frequently plugged in and unplugged means they are at constant risk of a limited lifetime brought about by the contacts being damaged or worn prematurely.

CONTACTLESS DATA AND POWER TRANSMISSION

In response to these challenges, Rosenberger's RoProxCon designers have developed an innovative contactless connector system that provides transmission that is not restricted by physical limits. Such freedom is achieved through a specially developed antenna concept. The focus is on simultaneous and bidirectional data and power transmission without having to compromise on mechanical flexibility.

Power transmission is based on resonant inductive coupling and data transmission is based on 60 GHz radio waves. This allows for a wear-free connection and these techniques can be used by a variety of different media. In this way, data in the Gbit/s range can be transmitted across an air gap regardless of the rotation angle. Moreover, the RoProxCon solution allows an angle deviation and a radial offset.

Typically, in industrial applications, there is no power supply on either side of a communication application. Therefore, in addition to high data rates, sufficient power must be provided for devices like proximity sensors and actuators. Rosenberger is working on a solution called the RoProxCon - Hybrid that can transmit up to 30 W of power while keeping the modules as compact as possible to enable the optimum usage of the installation space. Rosenberger also supports implementation in a particular customer application. Ethernet-based transmissions such as PROFINET, EtherCAT or EtherNet/IP can be easily integrated and implemented using suitable adaptor circuits. In addition, proprietary IO signals or fieldbuses can be utilized. The RoProxCon - Hybrid also offers safety features such as foreign object detection and active receiver detection.

PORTFOLIO OUTLOOK AND VISION

The RoProxCon portfolio from Rosenberger comprehensively addresses the typical limitations of conventional connection solutions in industrial environments. This reflects the company's in-depth market- and customer-oriented product development ethos, combined with more than 60 years knowles PRECISION DEVICES

Streamline your design process and build prototypes quickly with a SLC Design Kit

We understand that improving the efficiency of your development process is critical to delivering quality products on time. That's why Knowles Precision Devices is now offering an all-in-one Single Layer Capacitor (SLC) Design Kit.

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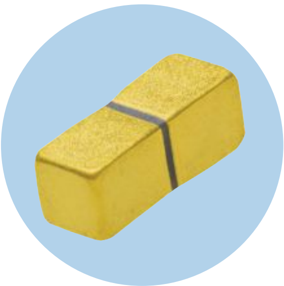
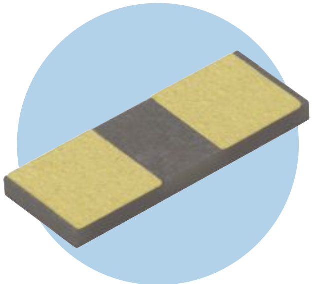




RFMW®

>> Learn more: rfmw.com/dielectric

Contact us today to explore a range of catalog and custom design options: **sales@rfmw.com** of company experience in connector technology. This heritage allows Rosenberger to provide maximum flexibility for easy integration of new application possibilities, which is another important requirement.

With these requirements in mind, Rosenberger offers the RoProxCon System-on-Module (SoM). It can be easily customized to suit individual customer transmission needs, from board to board or device to device. The specially designed antenna that is integrated into the SoM enables new solutions for a range of applications where the use of conventional systems would usually require performance or price compromises. In contrast to conventional systems, a user can twist and rotate this system in any direction.

The SoM is based on the ST60A2 from STMicroelectronics. The ST60A2 is a radio transceiver chip that can transmit data at 60 GHz with speeds up to 6.25 Gbps. This IC allows solutions with very low power consumption and latencies as low as 7 ns to be implemented into networks. These performance levels have become very important for real-time industrial applications. The partnership between STMicroelectronics and Rosenberger makes it possible to integrate the knowledge and strengths of both companies into the product development process.

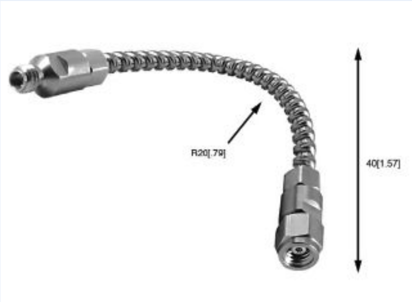
The results of this collaboration are a portfolio of cost-optimized products with maximum functionality for the customer. In addition to solutions for new applications, a cost-effective retrofit solution for a straightforward plug and play upgrade of existing systems can be achieved by using various RoProxCon adaptors and cable connections. This allows existing factory plants and systems to be upgraded with minimal technical and regulatory effort, directly benefiting customer total cost of ownership.

CONCLUSION

Thanks to its innovative mechanical decoupling design and the resulting flexibility, combined with uncomplicated integration, Rosenberger's RoProxCon transmission system offers significant advantages for networking the factory of the future. The new connection system allows endless rotation and opens completely new applications and perspectives for developers. The RoProxCon product portfolio addresses data and power in a hybrid solution and Rosenberger believes that it will become the choice for maximum performance with maximum flexibility.

Rosenberger is one of the world's leading manufacturers of impedance-controlled and optical interconnect solutions. The portfolio includes solutions in high frequency, high voltage and fiber-optic technology for mobile communication networks, data centers, industrial measurement technology, automotive electronics and high voltage contact systems, medical electronics and aerospace applications.

Rosenberger
Hochfrequenztechnik GmbH & Co. KG
Fridolfing, Germany
www.rosenberger.com



Armored Ultra Flexible RF Cables Offer Better Phase Stability

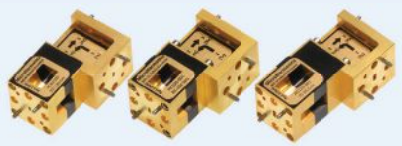
With increased phase stability and power handling capacity, the HLB055 Little-110 GHz armored ultra flexible RF cable is designed for demanding microwave interconnect requirements. This extremely flexible cable is well-suited for dense microwave packaging with a 0.79-in. minimum bend directly at the connector mating point, eliminating the need for right-angle adapters and connectors. The HLB055 Little-110 GHz cable series is constructed with an outer conductor made of silver-plated copper tape and braid.

The Littlebend™ 110 GHz Ultra Flexible RF Cable series offers thermal stability without sacrificing insertion loss and phase stability versus flexure and the series features excellent linearity across a wide temperature range. This armored flexible cable is ideal for applications including air-, sea- and ground-based phased array radars, sensors, mobile backhaul and temperature testing.

Littlebend cables expand HASCO's line of flexible cable assemblies to over 100 unique configurations, including new 1.0 mm, SMA, 2.92 mm, 2.4 mm, SMP and SMPM. Additional configurations are available by special order. The Littlebend cables are RoHS compliant and are in stock and ready to ship daily with new upcoming configurations rolling out over the next six months.

VENDORVIEW

HASCO, Inc.
Moorpark, Calif.
hasco-inc.com/Littlebend



Hybrid Circulator Family Operates From 70 to 133 GHz

Micro Harmonics Corporation has announced the release of three hybrid circulators in WR-12 (70 to 86 GHz), WR-10 (85 to 104 GHz) and WR-8 (107 to 133 GHz) millimeter waveguide bands. These patent-pending hybrid circulators can cover 24 percent fractional bandwidths with less than 1 dB insertion loss and more than 20 dB of isolation. Their wideband performance is verified from the comprehensive test data that Micro Harmonics provides with every component. Greater isolation and bandwidth enable designers to fully capitalize on the mmWave spectrum.

At the higher mmWave frequencies, even a state-of-the-art Y-junction circulator is effective only within a very narrow bandwidth and this can place a severe bandwidth limitation on the entire system. A typical Y-junction circulator designed for operation near 170 GHz has a bandwidth of only 2 GHz, but a hybrid circulator can cover the entire 150 to 190 GHz band. This significant increase in bandwidth is possible because the hybrid circulator's mode of operation is fundamentally different from that of the Y-junction. The hybrid uniquely combines an inherently broadband Faraday rotator with an orthomode transducer to create the circulator function. The hybrid circulator has diamond heat sinks for improved power handling, internal waveguide screw access, anti-cocking waveguide flanges and it is resistant to stray magnetic fields.

These new circulators expand the Micro Harmonics portfolio. The company has already released the hybrid design in WR-15 (54 to 68 GHz) and WR-5.1 (150 to 190 GHz). Under a two-phase Small Business Innovation Research (SBIR) contract awarded by NASA, the company is in the process of completing its entire line of hybrid circulators that will operate up to 333 GHz.

Micro Harmonics
Fincastle, Va.
www.microharmonics.com

Altair Panopticon 2023.0: An Introduction

Altair Panopticon 2023.0 offers new ways to create data tables, new connectors for cloud data sources and numerous improvements to the user experience that allow users to create, manage and deploy their dashboards in less time.

Altair

bit.ly/42XSzgL

EZF Builder & New Website

EZ Form Cable, a Trexon company, announced the launch of its new and improved website and new integrated cable assembly building tool "EZF Builder" for semi-rigid, formable, flexible and standard delay line options.

EZ Form Cable

www.ezfbuilder.com

RF Connector Dust Caps

As RF equipment can be found on platforms from oil rigs and naval vessels to cell towers and aircraft, it is necessary to ensure that the RF ports of the equipment remain undamaged and clean. Learn more in this blog post.

Fairview Microwave

https://blog.fairviewmicrowave.com/2023/04/21/rf-connector-dust-caps/

Radio History: A Pioneering Woman in Broadcast Journalism

Edythe Meserand was a rarity of her time; a prominent female broadcast journalist in the 20th century. She inspired young women to pursue careers and contributed to the evolution of broadcast entertainment and RF technology. Read more in this blog post.

Mini-Circuits

bit.ly/427ngzU

Maryland Filter Guy Blog

There are many filter companies in Maryland, but only one Maryland Filter Guy. Reactel has reimagined its blog about filters, our industry and so much more. Visit marylandfilterguy.com for the latest.

Reactel

www.marylandfilterguy.com

Tabor Electronics Opens India Office

Tabor Electronics' global research and development (R&D) center has opened in India, located at Ahmedabad, the Heritage City of India. The facility will focus on the software development activities for complete product ranges of Tabor Instruments.

Tabor Electronics

www.taborelec.com

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Waveguide Switch

VENDORVIEW

Operating from 110 to 170 GHz, model SWJ-06-T1 is an E-plane bidirectional DPDT waveguide switch that alternately connects each port to one of its two adjacent ports. Often used to achieve component redundancy or configuration agility in radar and communication systems, the four-port switch changes positions within 125 ms typically. Nominal insertion loss is 1.5 dB while port isolation is 45 dB. With typical return loss of 20 dB, the switch requires ±28 VDC at 250 mA and a TTL-level control signal.

Eravant
www.eravant.com

RF Power Dividers and RF Couplers

VENDORVIEW

Fairview Microwave, an Infinite Electronics brand and a leading provider of on-demand RF, microwave and mmWave components, recently released a new offering of RF power dividers and RF couplers with excellent power ratings, a variety of configuration options and greater operating frequency ranges. The RF power dividers and RF couplers in Fairview's portfolio provide greater power and more expansive coverage than ever before, with maximum power ratings up to 30 W and operating frequencies ranging up to 70 GHz.

Fairview Microwave
www.fairviewmicrowave.com

Semi-Rigid Waveguide Sections

Developed last year, this range of seamless semi-rigid waveguide sections provide insertion losses and VSWR comparable to machined waveguide straights but offer possibilities to form complex bend and twist solutions. WM-250 (750 GHz to 1.1 THz) and WM-380 (500 to 750 GHz) straights in lengths of 1 and 2 in. were recently delivered to the National Physical Laboratory, confirming RF performance figures of 16 dB/100 mm in WM-250 and 8 dB/100 mm in WM-380. Get in touch for further information or to discover what's new.

Flann Microwave Ltd.
www.flann.com

2 to 6.8 GHz 100 W Surface-Mount 90-Degree Hybrid

VENDORVIEW

MIcable just released the new 2 to 6.8 GHz high-power surface-mount 90-degree hybrid. It has low insertion loss, low VSWR 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.

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

Filters & Multiplexers

VENDORVIEW

JQL Technologies Corp. has launched ceramic waveguide filters and multiplexers from UHF band to X-Band. The fundamental advantage of this new technology is low insertion loss and higher attenuation and higher power handling capability. JQL has successfully introduced this product for global 5G programs. JQL has also developed space qualified diplexers using ceramic waveguide technology in S-Band. The devices have gone through group B qualification and screening tests.

JQL Technologies Corp.
www.jqltechnologies.com

Splitter/Combiner Channels

VENDORVIEW

Mini-Circuits' model COM-2G42G51K0+ four-way power splitter/combiner handles up to 1.2 kW CW power from 2.4 to 2.5 GHz. Typical insertion loss is just 0.1 dB above the nominal 6 dB split, with typical amplitude imbalance of ±0.15 dB and typical phase unbalance of ±1 degree. Ideal for RF energy generators, S-Band amplifiers and industrial heating systems, it measures 6.116 × 4.803 × 1.339 in. (155.34 × 122 × 34 mm) with one female 7/16 DIN connector and four female N-type connectors.

Mini-Circuits
www.minicircuits.com

Broadband Ceramic Capacitors

Passive Plus (PPI) has expanded its broadband capacitor line to include the industry's smallest .010 × .005 in. broadband part characterized for RF performance. The 01005BB104 series has been expanded and a new part is now offered with a 10 V rating. Always committed to producing the highest quality product on the market, Passive Plus maintains a fully equipped R&D and testing facility ensuring a wide range of superior RF, microwave and broadband components. Passive Plus works with requesting engineers to determine the best component for their applications.

Passive Plus
www.passiveplus.com

Push-Button Attenuators

VENDORVIEW

Pasternack, an Infinite Electronics brand and a leading provider of RF, microwave and mmWave products, has introduced a new series of push-button attenuators to address multiple applications, including test instrumentation and cellular, wireless and satellite communications. Pasternack's new line of continuously variable attenuators features even greater maximum power ratings of 5 and 10 W, an operating frequency range up to 18 GHz and attenuation levels up to 50 dB.

Pasternack
www.pasternack.com

Hybrid Couplers

The SMC90-1032 is a 200 W CW STM 90-degree hybrid with a typical VSWR on all ports of less than 1.25:1 and has an amplitude balance of ±0.4 dB with insertion loss of only 0.2 dB and a phase balance of ±3 degrees and isolation of 24 dB minimum. Its smaller brother SMC90-1031 is rated at 50 W CW and has an amplitude balance of ±0.2 dB with an insertion loss of 0.18 dB with a minimum isolation of 23 dB and a phase balance ± 3 degrees.

Preferred Power Products, LLC
www.p3-rf.com

NewProducts

RF Multifunction Module in 6U or 3U Package

Using its expertise in RF filters, converters, switch filter banks and amplification, Q Microwave manufactures a wide range of multifunction modules that include VITA standard interfaces and FPGA digital controls using UHART or TCP/IP through RS-422 or RS-485.

Q Microwave
www.qmicrowave.com

6-Bit Phase Shifter

VENDORVIEW

Quantic PMI Model No. PDPS-3F-6-AL is a 6-bit phase shifter with a speed of 300 ns maximum, (100 ns typical), designed to operate at a frequency of 2.3 to 3.8 GHz with a VSWR of 2.0:1. This unit has a typical insertion loss of 9.0 dB maximum and a phase accuracy of ±6 degrees maximum, 3 degrees typical, at 3 GHz and a switching speed of 70 ns. The package size is 3.00 × 2.70 × 0.53 in. and has SMA female connectors.

Quantic PMI
www.quanticpmi.com

Multilayer Organic (MLO®) Filters

VENDORVIEW

Richardson RFPD Inc., an Arrow Electronics company, announced the in-stock availability and full design support capabilities for the multilayer organic filters from KYOCERA AVX. KYOCERA AVX's MLO filters utilize high dielectric constant and low loss materials to realize high Q passive printed elements, such as inductors and capacitors, in a multilayer stack. The filters can support a variety of frequency bands and multiple wireless standards and are less than 1.0 mm in thickness. All filters are expansion-matched to most organic PCB materials, resulting in improved reliability over standard silicon and ceramic devices.

Richardson RFPD Inc.
www.richardsonrfpd.com

SP7T and SP8T Switches

RLC Electronics introduced SP7T and SP8T switches with SC connectors (N available as well). These switches operate up to 4 GHz and are designed for high power applications (1.8 kW cW at 1 GHz, 1.1 kW cW at 2 GHz, 800 W cW at 3 GHz) than standard catalog high-power switches. In addition to long life, the switch also features extremely low insertion loss (0.2 dB maximum to 4 GHz) and VSWR over the entire frequency range, while maintaining high isolation (> 70 dB).

RLC Electronics
www.rlcelectronics.com

CABLES & CONNECTORS

Test Port Adapters

Ruggedized test port adapters from SPINNER are quick and easy to attach to your vector network analyzer (VNA) so you can start getting results right away. Plus, they very effectively protect the VNA test port from accidental damage. These so-called port replicators reliably safeguard your equipment's test ports. Extra ball bearings in the coupling nut of the SPINNER ruggedized test port adapter prevent direct grinding and friction between the coupling nut and outer conductor.

SPINNER
www.spinner-group.com

0.8 to 1.0 mm Adapter Series

Withwave's 0.8 to 1.0 mm Adapter Series are manufactured to precise microwave specification and constructed with male and female gender on both sides. The precision microwave connector interfaces ensure an excellent microwave performance up to 110 GHz. Features include frequency range: DC to 110 GHz, VSWR : 1.40 : 1 (maximum) at 110 GHz and stainless steel (passivated).

withwave co., ltd
www.with-wave.com

AMPLIFIERS

AMP2030-LC-1 KW, 1 to 6 GHz, 1000 W

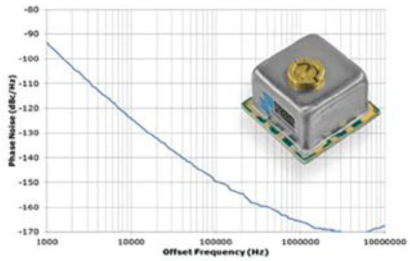
VENDORVIEW

Exodus AMP2030-LC-1 KW is a rack integrated powerhouse. Covering 1 to 6 GHz, produces 1000 W minimum output, > 1200 W typical with 700 W P1db. Excellent gain flatness with a minimum power gain of 60 dB. Included are amplifier monitoring parameters for forward/reflected power in dBm and watts, VSWR, as well as voltage, current and temperature sensing on a large color touchscreen for optimum reliability and ruggedness. Unprecedented 20U total drawer height.

Exodus Advanced Communications
www.exoduscomm.com

SOURCES

Compact Dielectric Resonator Oscillators



Synergy Microwave introduced a line of compact dielectric resonator oscillators (DROs) that come in both SMD and connectorized packages. The DROs have been designed with extremely low phase noise at fundamental frequencies up to 20 GHz. Synergy's state-of-the-art GSDRO 1000-8XT is a testament to its commitment to excellence. It exhibits unmatched performance for a given figure of merit, making it an excellent choice for integration into radar and communications systems.

Synergy Microwave
www.synergymwave.com

Tiny Size High Precision Quartz Oscillator

Taitien Electronics introduced 03 TYPE tiny size high precision crystal oscillator, to fulfill the high precision, tiny size and low-power mobile application requirement. The 03 type package size is 1.65 × 1.25 mm, which is 60 percent smaller than 2.50 × 2.00 mm package. It is easy to adapt to various small-scale design applications. The frequency stability of 03 TYPE is also excellent under extreme operation temperatures, it is as low as ±25 ppm under the range of -40°C to +85°C, or ±50 ppm under the range of -40°C to +105°C. In addition to the fast enable/disable function, it takes as short as 10 ns for the rise and fall times which effectively reduces the product power consumption.

Taitien Electronics
www.taitien.com

SOFTWARE

Modelithics COMPLETE Library™

VENDORVIEW

Modelithics® announced the release of the latest version, v23.1, of the Modelithics COMPLETE Library™ for Keysight Technologies' PathWave Advanced Design System (ADS). The Modelithics COMPLETE Library for Keysight ADS now represents over 900 models that represent more than 26,000 components from 70+ vendors. The release includes compatibility with Keysight ADS 2023 update 2. Version 23.1 adds new

models for five GaAs FET transistors from Microwave Technology: MwT-1F, MwT-3F, MwT-7F, MwT-9F and MwT-11F all validated to 30 or 40 GHz. Each model is validated against I-V, S-parameter and load-pull measurement data.
Modelithics
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Mitigate supply chain issues, accelerate development and safely verify and debug test program code by simulating more than 1000 PXI and LXI modules. Pickering Interfaces, a global supplier of modular signal switching and simulation solutions for use in electronic test and verification. These tools enable test engineers to begin writing and verifying test program code today, freeing them from supply chain constraints.
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www.phoenix-testlab.de

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SSA5000A Series Spectrum Analyzer

The SIGLENT SSA5000A spectrum analyzers are powerful and flexible tools for complex RF spectrum and signal analysis. With the capability of real-time spectrum analysis, the analyzer can provide multi-dimensions data displays and advanced triggering to solve modern RF spectrum challenges, like channel power measurement, hopping frequency, conflict channel and spectrum interference. Applications include broadcast monitoring/evaluation, cellular site, IoT, WLAN and Bluetooth surveying, research and development, education, production and maintenance.
Siglent
www.siglentna.com

MICRO-ADS

Reviewed by: Michael Roberg, Ph.D.
MMIC Design Engineer
Fellow at Qorvo

Bookend

Nonlinear Design: FETs and HEMTs

Peter H. Ladbrooke

"Nonlinear Design: FETs and HEMTs" by Peter H. Ladbrooke should be on the bookshelf of every III-V semiconductor device engineer, modeling engineer and circuit designer. What I particularly like about this book is it focuses more on the practicality of nonlinear device modeling rather than strictly theoretical constructs which are far less digestible to the practicing engineer. Don't let my statement fool you though, there is plenty of meat in this book even for the theoretical junkie! Those looking to "connect the dots" between device characteristics, device modeling and circuit performance should read this book.

Part I discusses commercially available nonlinear models as well as digging into the practical details of device behavior and model parameter extraction. Part II proposes a reformulation of the device model and proceeds to dig into the finer details of parameter extractions as well as presenting some results with practical circuits. Part III is perhaps the most detailed section, providing extreme depth on FET device characteristics, current and charge conservation and charge storage while also introducing macro-cell simulators.

As a MMIC design engineer, I found this book rather useful in understanding the finer details of how accurately (or inaccurately) modeling device characteristics impacts my circuit performance. In addition, I found it useful for understanding the connection of basic device characteristics and circuit performance. I see this being a valuable, frequently consulted reference for those deeply involved in the III-V semiconductor community.

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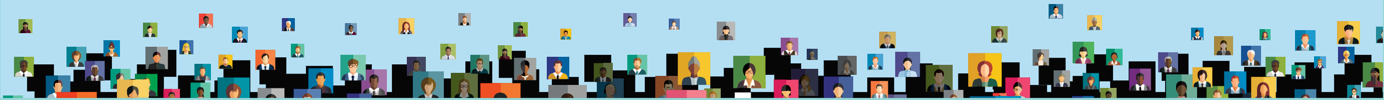

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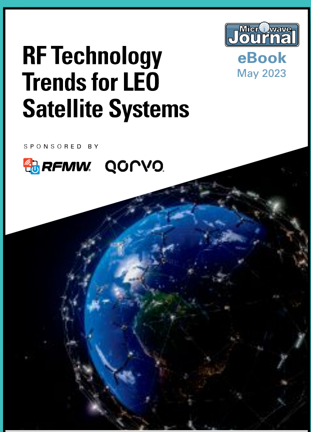

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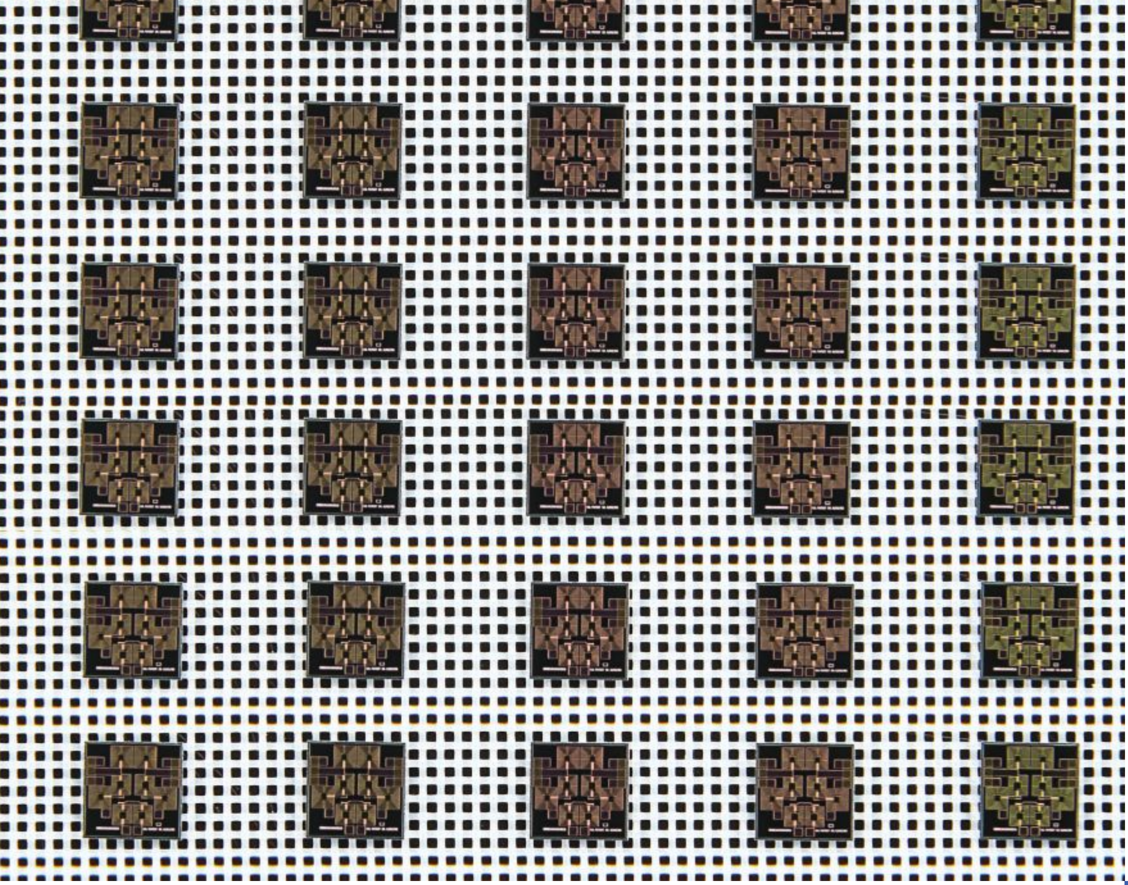
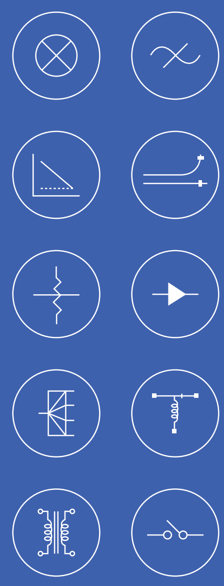
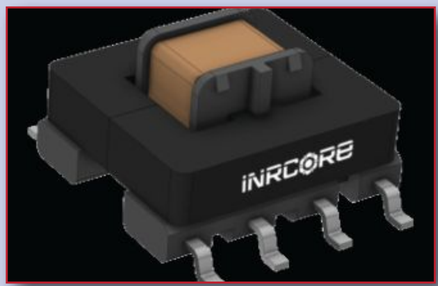




FABS and LABS

iNRCORE: Rugged to the Core



In July 2023, iNRCORE will be celebrating its third anniversary, but the company traces its origin back to 1947, following quite an interesting path to the present. In 1947, four engineering graduates from the University of Pennsylvania founded Technitrol outside Philadelphia. The founders had all participated in the ENIAC (Electronic Numerical Integrator and Computer) development, the world's first electronic computer. These efforts laid the foundation for Technitrol, which became a pioneer in the computer and electronics industries. Technitrol held the first patent for a magnetic disk drive, but the company never manufactured magnetic disk drives out of concern for the high start-up costs.

Instead, Technitrol licensed the disk drive patent and focused on manufacturing other less capital-intensive products. Technitrol pioneered the development of mercury delay lines and magnetic drums for computer-memory storage. Sensing an underserved market opportunity, Technitrol began manufacturing electronic components. Company management used its internal manufacturing capabilities to expand its product offering beyond the emerging computer industry to the broader electronics industry. Organic growth of the customer and product base, coupled with the acquisition of L&O Research and Development Corporation, powered company growth for more than two decades.

In the 1970s, management became concerned that the electronics industry was seeing a rapid and expensive evolution of technology that posed significant threats to Technitrol's core technology and products. Over the next 20 years, Technitrol solved this challenge with a series of acquisitions that broadened its product and manufacturing base. That effort culminated with a change in management in 1995 and the acquisition of Pulse Engineering.

Pulse Engineering developed electronic components and modules used by LAN and telecommunications systems. Pulse's strength was in international markets and this geographic and market diversification was the driving force to combine some of the earlier acquisitions and internal capabilities into a new Pulse organization. With Pulse becoming one of the largest suppliers of magnetic components to data communications and telecommunications industries, Technitrol followed the same blueprint to enhance its metallurgical business.

Over the next decade, Pulse completed 10 acquisitions, with one doubling the size of the Military and Aerospace Division and adding the Power Products line. The success of Pulse ultimately signaled the demise of Technitrol, however. At the end of 2010, Technitrol and Pulse combined to form Pulse Electronics.

This did not end the consolidation and rebranding. At the end of 2018, Japan's Yageo Corporation completed the acquisition of Pulse Electronics. As part of this deal, the Military and Aerospace Division became a stand-alone business known as PulseR. PulseR expanded into larger facilities in the U.S. and Asia. These facilities were certified to AS9100D with expanded in-house qualification testing capabilities and automated production lines. PulseR operated as an independent designer and manufacturer of ruggedized magnetic solutions for military, commercial aerospace, space and high performance industrial applications until early 2020 when it was acquired by The Jordan Company, a private equity firm. A few months later, PulseR rebranded as iNRCORE.

Now headquartered in Bristol, Pa., iNRCORE contains eight brands as the company builds on its 70-year heritage by expanding its portfolio and market share. The rebranded company designs and manufactures power and signal magnetic components that transmit high speed, mission-critical data and power in the harshest operating conditions. iNRCORE prides itself on being a collaborative partner that can respond to unique requirements with reliable and intelligent solutions to power the world's next generation of systems. Whether they are meeting a custom design or screening products to qualify for a critical mission, iNRCORE lives by the credo that their solutions are rugged to the core.

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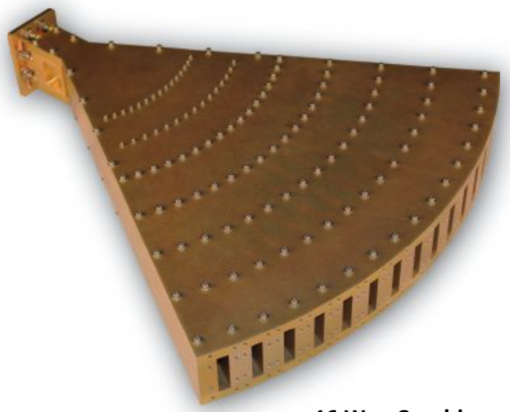

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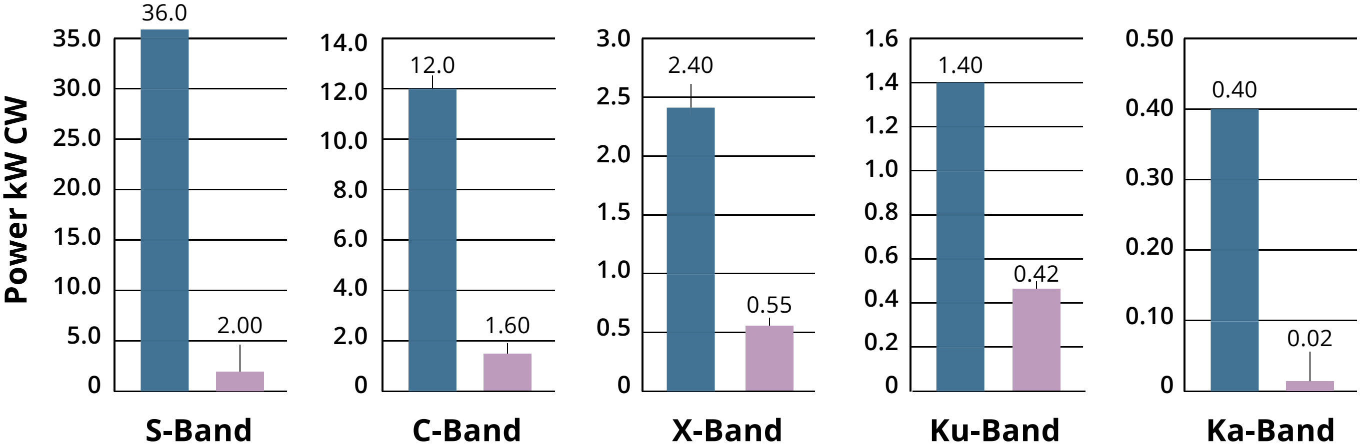

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ERAVANT ENHANCES A&D PRESENCE WITH AS9100 REV. D CERTIFICATION

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

"All credit for this significant milestone goes to our amazing team," said Wendy Shu, CEO. "Becoming one of the few AS9100D certified millimeter wave and sub-THz suppliers signals our commitment to delivering quality products and services reliably and repeatably to our entire customer base. The AS9100 certification ensures that we are holding ourselves to a higher standard of execution year after year."

Becoming AS9100D certified strengthens Eravant's competitive position through systematic continuous improvement and business monitoring processes. AS9100 certification sets the worldwide aerospace quality standards as well as the quality requirements of the Department of Defense (DoD) and National Aeronautics and Space Administration (NASA). The standard provides manufacturing suppliers with a comprehensive quality system for providing safe and reliable products. AS9100 is managed by the International Aerospace Quality Group (IAQG) and based upon ISO 9001.

About Eravant

Eravant, located in Torrance, California, operates from a 60,000-square-foot design, manufacturing, assembly, and testing facility focused on supplying a global customer base with millimeter wave and sub-THz (18 to 330 GHz) components, subassemblies, and test equipment. Eravant is known for supporting the customer every step of the way from lab set-up, to R&D and prototype, and through program or volume production.

We are an AS9100D certified, ITAR-registered, women-owned small business designing and manufacturing in the United States. The company's vision is to make millimeter wave and sub-THz accessible by lowering budget, knowledge, and experience barriers so more engineers and scientists can work to realize the technology of the future.

Space Development Agency: Setting the Pace for Defense Innovation

Erik Luther
CesiumAstro, Austin, Texas

The U.S. Department of Defense's (DOD's) Space Development Agency (SDA) is leading the rapid evolution of military space-based communications and sensing in response to the increasing threat from adversaries. Reliant on a small number of geosynchronous orbit (GEO) communication satellites that are now seen as "large, big, fat, juicy targets," according to Gen. John Hyten, USAF, (Retired), the DOD is building a more robust and defendable solution known as the Proliferated Warfighter Space Architecture (PWSA). Comprised of hundreds of satellites, the PWSA provides expanded capabilities in a more resilient global architecture for communications, tracking and early warning capabilities. To respond to the urgent needs of today's warfighter, SDA is pursuing aggressive timelines with a modest budget by embracing commercial trends like smaller satellites, shorter mission durations and the use of radiation-tolerant commercial components. York Space, Mynaric and CesiumAstro are a few of the non-traditional entities utilizing mass-manufacturing approaches to deliver space capabilities at commercial scale and they have partnered with SDA to deliver technology such as satellite buses, optical inter-satellite links and active electronically steered array (AESA) antennas. With a 2022 budget of $1.4 billion, SDA has gained the traction required to deliver new defense capabilities at the pace, budget and scale required to defend U.S. national interests and support the warfighter.

Enabling Capability in Layers

Architected in functional layers, the PWSA's capabilities are enabled by a mesh network of communications satellites, sensors and data processing. The three primary layers utilizing RF and microwave technologies are the Transport, Tracking and Custody Layers, each of which includes dedicated satellites. Other layers may be hosted on existing satellites or combined with other payloads.

Transport Layer: Serves as the secure communication layer routing data across the network and to the warfighter. Envisioned to consist of 300 to 500 satellites in a high low earth orbit (LEO) ranging from 750 to 1200 km in altitude. High LEO provides a broader view of the earth and satellites in a lower orbit but it presents a more challenging radiation environment. User services will include both Link 16 and the Integrated Broadcast System, providing communications, threat warning and situational awareness.

Tracking Layer: Provides active sensing capabilities enabling real-time warning and battlefield awareness that includes 24/7/365 missile warning, missile tracking and missile defense (MW/MT/MD) capability. The orbits vary, depending on the mission. Data is relayed through the Transport Layer for aggregation and communication to the ground and user segments.

Custody Layer: Includes sensors that aggregate collected data over time, building strategic insights for left-of-launch (before launch) tracking and targeting. Data fusion from many sensors is networked through the Transport Layer to provide real-time insights to the warfighter.

Together, the layers form a cohesive network to provide a clear theater picture to the warfighter. Each layer contains a compatible set of core communications payloads that ensure connectivity to the Transport Layer, including both RF and free-space optical laser communications. ***Figure 1*** shows a diagram of the PWSA architecture and its functional layers. The Transport Layer, Tracking Layer and Custody Layer are the most discrete layers utilizing RF and microwave technologies. Note that not all layers will have dedicated satellites and those functions may be shared across the constellation.

Semper Citius: Move Fast and Launch

Averaging 2.5 years from award to launch, SDA's first batch of satellites is already in orbit. SDA is breaking the cycle of increasing cost and schedule typical of defense infrastructure. Taking a spiral development approach, SDA is deploying the PWSA in stages called tranches, with increasing technical capabilities and quantities of satellites to be delivered in each tranche. ***Figure 2*** shows the timeline and current expectations of this tranche development approach.

Leveraging an agile approach reduces risk while providing a steady flow of opportunities to deploy new capabilities. Strategically focused on proving that the timeline and budgets are achievable, the first 10 Tranche 0 satellites launched on April 2, 2023. Tranche 1 awards were recently completed and are scheduled to launch in 2025, delivering enhanced communications and sensing capabilities enabling initial warfighting capability in specific regions of the globe. The first Tranche 2 satellites launch in 2027, providing full global capability, which will be followed every two years by Tranche 3 onward.

Recognizing the need to evaluate new technologies outside of the core deployment, SDA has established multiple experimental missions between tranches to support the development and evaluation of new approaches and technologies that, once matured, can fold into future tranches at scale. The focus of these technologies in the coming tranches will be alternative pointing, navigation and timing, improvements in target tracking and satellite meshing and advanced waveforms for communication.

As it slices through red tape while holding the line on the budget, the SDA acquisitions process has reduced

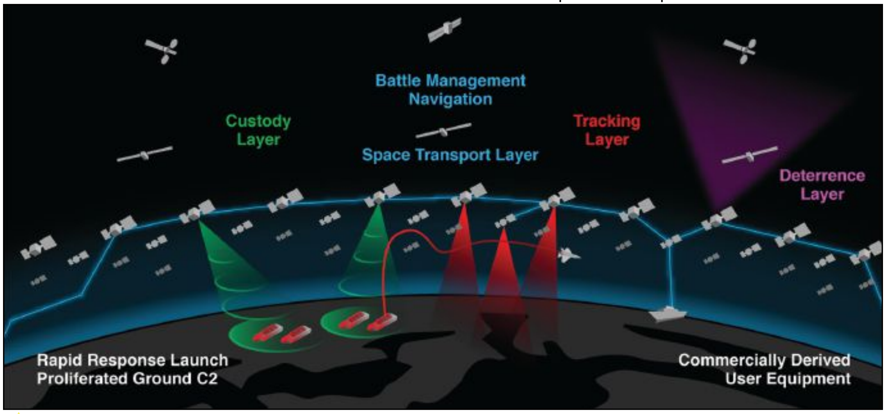

Fig. 1 The PWSA architecture and its functional layers.

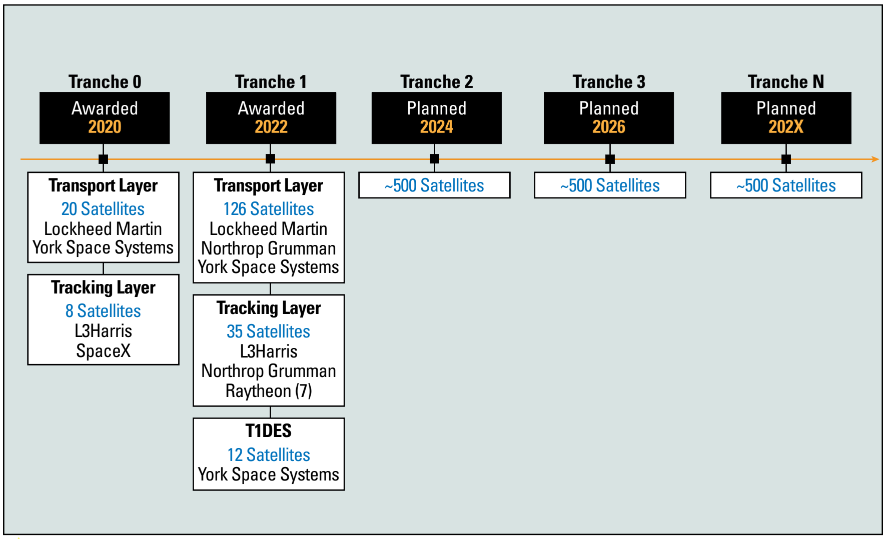

Fig. 2 SDA spiral-based approach to constellation development.

typical acquisition times from years to months. Requirements are rapidly developed and drafts are published for feedback. Request for proposal (RFP) responses, historically due several months after issue, are due in as few as four weeks from publication. Proposals are evaluated and awards are granted at a similar pace, allowing awarded companies to hit the ground running. Earning a reputation for setting a schedule and then keeping it, companies bidding on PWSA RFPs are adapting their bid processes and planning cycles to provide more feedback during the draft phase. To compete, companies must engage their supply chains, build execution teams and rapidly draft responses tailored to the aggressive schedule required by PWSA deployment.

"One thing I can say for certain is that with regards to ideas, the more the better. And if you can look across the broad space ecosystem and pull in as many ideas as possible, regardless of the size of the vendor that's promoting that idea, you're going to be more successful at it putting solid innovative ideas on the plate."
—Gen. B. Chance Saltzman, U.S. Space Force, Chief of Space Operations

Inviting Companies of All Sizes to the Table

To broaden input across the space ecosystem, SDA encourages the participation of non-traditional commercial companies in addition to traditional defense organizations. The goal is to pull in as many new ideas as possible and elevate the best contributions, regardless of the source. To level the playing field, SDA has committed to a multiple-solicitation, multiple-vendor approach to maximize participation, increase the number of meaningful awards and prevent vendor lock. Encouraging competition is intended to enhance supplier diversity, control costs, spur innovation and keep incumbents on their toes. The diversity of awards is impressive and benefits smaller or non-traditional companies, as they can participate and compete both with and against major defense primes with innovative new offerings. With each award announced, SDA provides the entire space community with a window into the schedule and price to win, an intentional move reinforcing its commitment to diversity and broad-based participation.

Communications Payload Technology Evolution

RF and microwave technologies are core to the PWSA by enabling mission

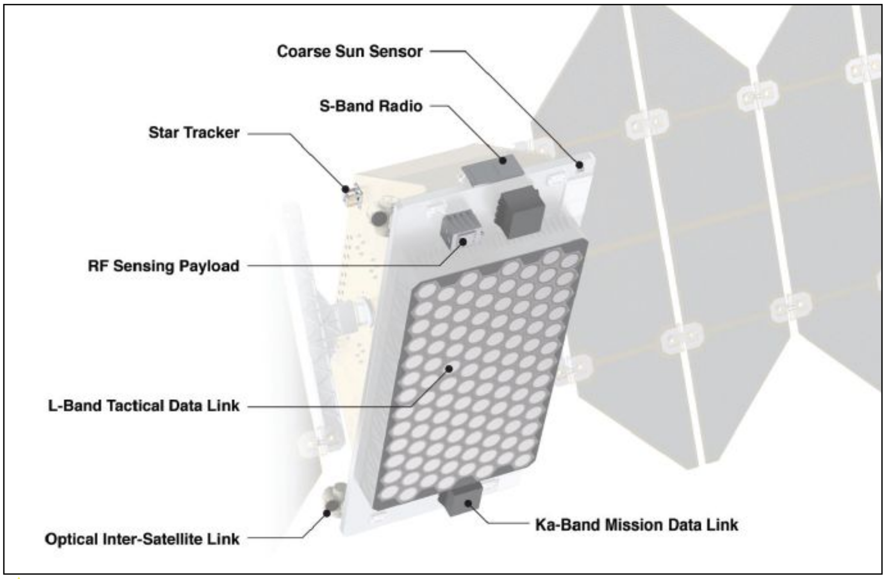

Fig. 3 Example of a Transport Layer satellite configuration with common payload components.

communications, tactical communications and sensing capabilities. ***Figure 3*** shows an architecture for a Tracking Layer satellite payload. This architecture shows several opportunities for digital, RF and optical components and systems.

A payload like that shown in Figure 3 may contain the following systems:

Mission data link: enabled over military Ka-Band radio frequencies that provide focused, high data rate communications. Serving as the primary gateway connection, the mission data link utilizes gimbaled reflectors in early tranches. This limits connectivity to a single beam and it requires a high degree of pointing accuracy on the spacecraft.

Tactical data link: enables direct connectivity to the warfighter using the Link 16 multi-user communications standard on L-Band radio frequencies. To date, Link 16 has been restricted to ground, ship and airborne assets, but SDA is expanding its capabilities by adding payloads compatible with widely-deployed systems. Early tranches baselined fixed antennas requiring body pointing or gimbaled direct-radiating antennas. These capabilities are critical in advancing the first space-deployed Link 16 assets, but modernization through multi-beam phased arrays is needed to better support the needs of the warfighter with enhanced coverage areas, jamming resistance and reduced latencies, among other benefits. A rendering of a satellite-enabled Link 16 tactical data link is shown in ***Figure 4***.

RF sensing: a key technology that is utilized in a wide range of missions and requirements. A deeper discussion on sensing for the SDA mission is available through the agency's program solicitations.

Early tranches of the PWSA have prioritized schedule and cost to validate the entire end-to-end constellation concept. Future tranches will require increased capability. Implementing these new requirements and capabilities will be driven by experimental missions as the primary on-ramp for new technologies.

Enhanced Payload Development

CesiumAstro is currently working to provide SDA with multi-beam AESA capabilities for the Ka-Band mission data link and the L-Band tactical data link. Its Vireo AESA payload will be supplied for integration into seven Raytheon space vehicles as part of Tranche 1's Tracking Layer. Building upon prior efforts, its L-Band Link 16–compatible AESA supports a modular approach utilizing a scalable tactical datalink solution connecting disparate networks. Optimized for space, the communication payload provides fast electronic steering with multiple beams, integration with commoditized buses and it meets associated requirements for size, weight, power consumption and thermal management. It communicates with fielded tactical terminals that were not designed to communicate with LEO. The system is being developed to accommodate large-quantity production in support of the constellation deployment goals while meeting the associated cost and schedule requirements. CesiumAstro's design and production methods directly address the challenges associated with fielding the PWSA. The design leverages industry-wide investment in mobile communication for the cost and performance of ICs, meets requirements for high volume manufacturing and uses software-defined features.

While phased array antennas are being used in terrestrial applications, space introduces a more rigid set of design requirements, beginning with the need for greater power efficiency. Generating power in space is challenging in itself while dissipating the heat produced by the devices that use that power can be even more difficult. Thoughtful system engineering is required to optimize power genera-

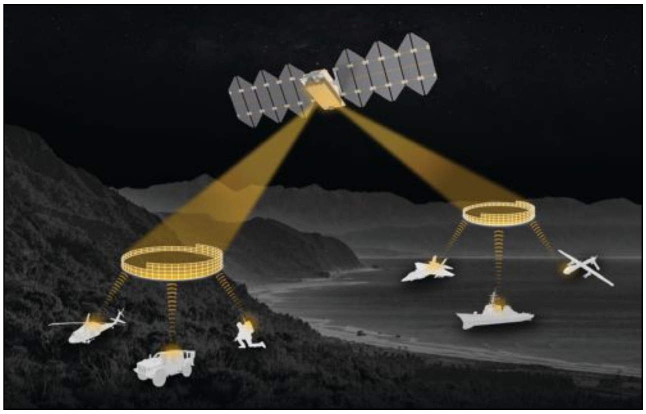

Fig. 4 Satellite-enabled Link 16 supporting multiple battlespaces. Source: CesiumAstro.


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tion and consumption, manage performance over wide temperature swings, maximize RF performance and minimize overall mass. For example, while current SOI, GaN and GaAs processes are naturally radiation-tolerant, their RF performance can vary widely with temperature. These challenges must be addressed with a highly integrated interdisciplinary engineering team that includes systems, RF, electronics, digital, software, thermal, packaging, manufacturing and test engineers that collaborate on a tightly integrated, yet modular design that meets mission requirements and is manufacturable at scale.

AESA Communications Revolution

The use of AESA technology for communications has multiple benefits for the warfighter and the mission. Early tranches favored fixed antennas that required body pointing or gimbaling to provide single beams of connectivity. The use of multi-beam AESAs, once an expensive radar solution, is now a mature communications technology. AESA payload architectures offer several operational benefits:

Multiple simultaneous beams: Maximize capacity and frequency reuse with multiple independent beams from a single aperture.

Fast steering: Rapidly hop and steer beams to improve spectrum utilization and increase user capacity.

Beam shaping: Full amplitude and phase control at each element allows for shaped beams, which optimize coverage area and reduce sidelobes or create nulls for interferers.

Arbitrary polarization: Fully polarimetric elements can be used for isolation between channels, to correct polarization over scan angle or minimize polarization mismatch for ground terminals.

Graceful degradation: Redundancy minimizes the impact of single-component failure on overall performance, extending mission life.

In addition to these direct benefits for communications, AESAs simplify the overall spacecraft architecture by reducing the complexity of the attitude determination and control system (ADCS). In a study of small satellite failures from 2000 to 2016, ADCSs were the second-leading cause of partial or complete mission failures. A gimbaled or body-pointed antenna imposes more stringent requirements on an ADCS, increases the cost and complexity of that system, increases the power requirements and reduces the average vehicle lifetime. Utilizing an AESA reduces the size, cost and complexity of the ADCS while providing pointing redundancy in the event of reduced ADCS performance, which can happen when the spacecraft is in "safe hold" mode. AESAs also allow a spacecraft to implement much simpler and more straightforward pointing control strategies and perform other functions while executing communications tasks. For example, a spacecraft can simply nadir-point, a process of pointing in the downward field of view of that satellite, while tracking one or more ground terminals. This process can result in a significant reduction in programming and operational overhead. Furthermore, a spacecraft can more easily track the sun while communicating with multiple users, simultaneously maximizing quality of service, power generation and energy storage. Because of these benefits, AESA antennas are now being considered for Link 16 communications and other payloads as an approach to optimizing total system lifecycle cost and performance.

Conclusion

SDA's vision has been laid, the path from solicitation to launch has been proven and policymakers have aligned the budget to support its goals. DOD acquisitions reform is taking hold and new capabilities are moving from concept to flight at a record pace. Companies of all sizes are contributing new, innovative capabilities to support the warfighter and defend the nation. SDA's layered function model and tranche-based deployments provide a continuous flow of opportunities to design, evaluate and deploy new capabilities on orbit. Now is the time for the RF and microwave community to deliver the innovative communications systems and sensors needed to enable this ambitious mission set. RF and microwave electronics and antenna technologies are core to the mission of providing enhanced communication capability and situational awareness at scale to today's warfighter. It is increasingly clear that space is vital to our way of life and national security. Maintaining and extending our advantage in space is a national imperative and critical to paving the long-term path to peace and prosperity. ■

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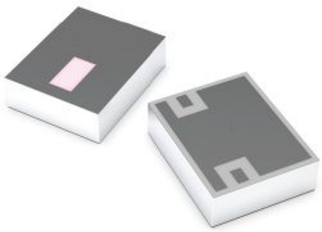

Model Number	Passband (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)
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BFCQ-2872+	27500-30000	100-22200	32	35300-55000	28.4
BFCQ-1932+	17700-21000	DC-14600	30	25600-40000	40
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Adaptive Computing Drives Speed and Innovation in Tactical Edge Computing

Chris Thompson
Mercury Systems, Andover, Mass.

Developing the next generation of mission-critical defense systems, including beamforming, radar and electronic warfare (EW), requires processing higher volumes of sensor data in harsh and size, weight and power (SWaP)-constrained environments. Defining the incoming signal and transforming the accompanying data into actionable intelligence requires more from the sensor and the system. Traditionally, these operations are complex and add significant latency to effectively respond to emerging threats.

As sensors collect ever-increasing volumes of data, the expectations on edge processing technology also increase. This next-generation of processing components must not only be small and rugged, able to function in a fighter jet or on a joint light tactical vehicle, but they must also deliver enough processing power to enable sophisticated artificial intelligence (AI)-based applications like image recognition and cognitive EW. The result is that edge computing has moved data processing far beyond a ground-based command and control center as shown conceptually in ***Figure 1***.

Compute-Intensive Solutions At The Tactical Edge

There is no doubt that processing technology needs to adapt to handle the massive influx of data to create faster, stronger and more capable systems at the edge. Driven by the enormous market forces of worldwide electronics demand, AMD offers the Adaptive Compute Acceleration Platform (ACAP). This platform provides a different type of semiconductor architecture that is fueling a generational leap in edge computing capabilities for defense applications.

Fig. 1 Data processing requirements reach new domains.

Part of the AMD Xilinx Versal portfolio, the Versal AI Core ACAP is more than just another field programmable gate array (FPGA) or system on chip (SoC). It combines multiple styles of computing in a single silicon chip, making it a true heterogeneous processor. It is fabricated with state-of-the-art 7 nm technology, incorporating three different types of compute engines. As an adaptive SoC, an ACAP can be given a new hardware configuration to adapt to application requirements, providing a unique differentiator from CPUs, GPUs and application specific standard products, which all have fixed hardware architectures.

For defense systems, perhaps the most exciting feature of ACAP is that it can support adding AI capability to a host of edge applications. And this new processing technology also helps military systems in several other ways. The AMD Versal AI Core ACAP is shown in ***Figure 2***. It combines multiple styles of computing in a single silicon chip, making it a true heterogeneous processor and it sets the stage for a new wave of compute-intensive defense applications.

Making ACAPs Accessible For Aerospace And Defense Systems

The Versal platform includes software development tools and offers flexibility that matches the device's multiple engine types. There are a range of options, so developers can use familiar tools and languages. Embedded software developers can program in C using the AMD Vitis software platform and hardware engineers can continue to use AMD's Vivado tools to program in VHDL or Verilog.

Additionally, AI developers can use machine

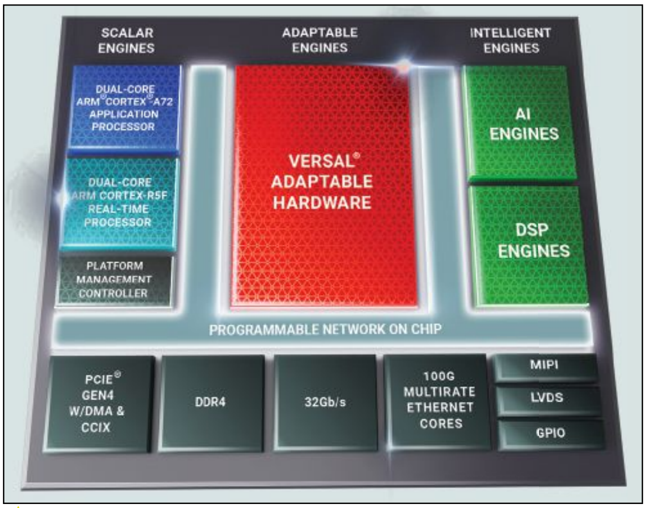

Fig. 2 The AMD Versal AI Core ACAP.

learning (ML) frameworks such as TensorFlow or PyTorch and target their C++ algorithms and Python data flows to the Versal ACAP. This can be done without using the traditional tools needed to write Register Transfer Level (RTL), a design abstraction used to model a digital circuit. In the case of an ASIC or an FPGA, an RTL description can usually be directly translated to an equivalent hardware implementation file.

The industry's first deployable heterogeneous processing module using the Versal AI Core ACAP is the rugged

Fig. 3 The Mercury SCFE6931 ACAP processing module.

SCFE6931. This is a single-slot, 6U OpenVPX form factor product designed to support multiple high-reliability cooling options. With two Versal AI Core devices, it delivers a tremendous level of flexible processing power to edge applications. To jump-start development, the low-cost 6U VPX Model 8258 enables developers to build, run and debug applications on the SCFE6931 Dual Versal ACAP processing module shown in ***Figure 3***. SWaP-optimized and ruggedized deployable ACAP-based solutions, like Mercury's SCFE6931, deliver a tremendous level of flexible processing power to edge applications.

Defining Industry Challenges

Mission-critical defense systems now employ countless sensors. Many collect imaging data, centered on the visual spectrum, but extend into the infrared and ultraviolet ranges. Others track electromagnetic communications or radar input ranging from traditional frequencies through mmWave (100 MHz through 50 GHz) ranges. Still others monitor physical vibrations for sonar or voice recognition. In every one of these areas, applications are requiring expanded capabilities, like more detailed images, the ability to track more targets and a comprehensive view of the radio spectrum.

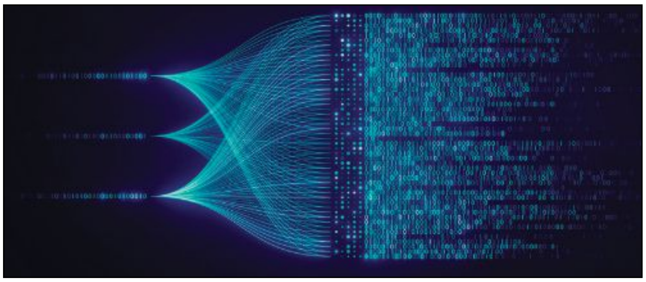

Fig. 4 Complex waveforms require edge data processing.

This data is complex. Both radar and EW sensors are reaching new levels of sophistication and returning large amounts of streaming data. Efficiently exploiting this data requires powerful processing technology to translate incoming signals and extract what is needed most.

The environments are harsh. The demand for processing at the edge, where systems must withstand environmental elements such as extreme temperature, moisture and vibration, is constantly being pushed further. Additionally, this capability must be achieved without sacrificing a SWaP focus.

Processing speed is increasing. GPUs, CPUs and traditional memory schemes are no longer sufficient to handle the increasing high speed data streaming needs and the low latency demands critical for real-time sensor processing. New sensors must operate with greater precision (bit-depth) and speed (data rate) to generate an expanded data stream from each node. When that effect is combined with a continual increase in the number of deployed sensors, the result is a geometric increase in sensor data volumes, to the point where some individual systems must deal with Tb/s of input.

Victory on the twenty-first century battlefield now requires processing vast quantities of information in real-time. More detailed imagery is needed to enable better decision-making in tactical command centers. Radar tracking must be able to monitor more targets across expanded distances and EW systems will need to deal with an increasingly complex range of waveforms, like the one shown conceptually in ***Figure 4***, that will be generated by clever adversaries. Applying edge data in real-time means enhanced decision-making and more successful missions.

True Heterogenous Processing

Incorporating three different types of compute engines, each ACAP device includes scalar engines, programmable logic and intelligent engines, all connected by an extremely high bandwidth network-on-chip (NoC). Multiple compute engine types are designed into the ACAP, because no single style of processing is capable of optimally performing all the tasks involved in a sophisticated edge application.

Scalar engines function like traditional CPUs and they are ideal for complex decision-making and control. The Versal AI Core ACAP includes four of these as well as two low-power Arm Cortex-R5F real-time processors and two full-power domain Cortex-A72 cores, supported by a system memory management unit. These processing engines are vital for managing and responding

Processing Challenges	Processing Solutions	ACAP
Scalar Processing: Complex algorithms, widely branching decision trees and broad library assets.	CPUs	Arm® Cortex™ processors
Vector Processing: Large-scale, parallel computations on high data volumes. Used for signal processing and artificial intelligence applications.	DSPs and GPUs	Adaptable Intelligence Engines (AIE)
Programmable Logic Processing: Real-time, low/no latency and highly-customizable user applications.	FPGAs	FPGA with Network on Chip (NoC)

▲ Fig. 5 How ACAP addresses processing challenges.

to human interfaces, controlling multi-mission system behavior and countless other operations that involve choosing between multiple options.

Programmable logic, also referred to as adaptable engines, adds the flexibility to handle a diverse set of computationally demanding algorithms. Included are FPGA structures, with 1.5x the lookup tables of AMD's high-end Virtex UltraScale+ FPGA, as well as programmable I/O and a customizable memory hierarchy of block RAM and UltraRAM. Just like FPGAs, adaptable engines provide highly efficient signal processing for radar and EW applications.

Intelligent engines are optimized for advanced signal processing, like linear algebra and matrix math, which are well suited for 5G wireless systems and AI inference. The ACAP contains DSP and AI engines. The DSP engines function like traditional digital signal processors and they are optimal for certain kinds of signal processing like routines that use context switching. The AI engines, similar to advanced GPUs, comprise vector processors for fixed and floating-point operations, a scalar processor as well as dedicated program and data memories. The vector processors in the AI engines deliver fast manipulation of image pixels as well as high performance for ML and inference algorithms in AI-based applications. The chart in ***Figure 5*** shows some of the processing challenges and solutions that ACAP addresses. Multiple compute engines designed into the ACAP enable powerful processing in sophisticated edge applications.

Keep The Data Moving

High performance memory access is critical to ensuring that applications can deliver a low latency, deterministic response. The ACAP addresses this with an on-chip, cacheless memory hierarchy consisting of block RAM, UltraRAM and accelerator RAM; all levels of the hierarchy are essentially shared RAM. The accelerator RAM, introduced in the Versal AI Core series, enables multiple application datasets to be stored directly

on-chip, reducing both power consumption and latency by avoiding the need to access off-chip memory.

Having a variety of processing engines is only useful if they are processing data in parallel and not stalled, so managing I/O bottlenecks is critical. The ACAP's hardened NoC can be programmed to support flexible data flows between the full range, high speed I/Os and the various types of computing engines. The NoC programmability extends to addressing different levels of throughputs, latencies and even bit widths, in the event of multiple algorithms on a single chip being optimized for different resolutions.

Functionally, the NoC is a packet switch network that performs high speed, point-to-point hops to move data around the device. Even without exploiting its inherent parallelism, the NoC is capable of data bandwidths exceeding 2 Tb/s, with much greater data transport capacity if the application design mapping exploits parallelism. This level of on-chip bandwidth is critical for low latency performance in applications like active electronically scanned array radars that must process multiple data streams concurrently. It is also important in complex AI-enhanced EW applications that first use FPGA structures to apply signal processing algorithms to a captured signal and then must move the processed data to an AI engine where other algorithms implement analysis and response.

Ensuring System Security

With edge processing comes an increased concern for data safety. Cyberattacks and threats to data integrity are constantly on the rise, so ACAPs are designed with safety features built in from the ground up. The Versal architecture is partitioned with functional hardware features in each domain as well as global resources to monitor and eliminate common cause failures. The robust set of security features within the ACAP architecture includes:

- Hardware root of trust
- Boot time firmware and image authentication
- SCA-resistant crypto engines to decrypt images
- Debug security
- Key management
- Secure and measured boot with remote attestation
- Attack protection
- Tamper detection and protection
- Run-time security
- Trust zone and trusted execution environment
- Memory and peripheral protection

Improved Intelligence in Deployed Applications

Defense applications usually involve multiple processing steps as sensor data is manipulated, analyzed and used to drive a response. For example, in EW systems, multi-step signal processing algorithms are used to extract waveforms from an antenna's input, then those waveforms are analyzed to find signals of interest. New advanced EW systems will add another processing level by using AI to create, in real-time, countermeasures addressing those signals of interest. This type of application is often referred to as cognitive EW.

Optimized execution for each step requires a specific type of processor. In currently deployed systems, this is

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accomplished by using a set of specialized processor boards with data moving between the boards using system backplane interconnects. These types of systems cannot meet the SWaP constraints of small platforms on the edge, while latency limits are dictated by the system-level interconnect.

With an ACAP, this type of application processing can now be implemented within a single chip. All the processing engines can operate in parallel on a pipelined data stream that moves between engines using the NoC. On-chip data movement latency is at a level far beyond the capability of even the fastest multi-board system.

Powerful Processing at the Edge

Similar forms of advanced functionality, powered by AI, can be envisioned across a range of applications. Image recognition located next to the optical and infrared sensors in perimeter security systems is one example. Voice recognition attached to microphones would further enhance these systems.

Another image recognition example involves UAV data collection. For example, a surveillance UAV may fly an 18-hour mission, imaging disputed terrain, with only five minutes of that imaging showing anything of interest to analysts. Having an onboard AI capability that could identify, extract and transmit that small section of collected data would enable better command decisions and faster responses.

Entirely new applications will also become possible. Autonomous ground vehicles are a DOD goal. Achieving this goal will allow supply convoys in future conflicts to operate without human drivers, reducing potential casualties. An ACAP is well equipped to process the data from multiple sensors, combine that sensor data with map data and then use its intelligence engines to execute AI algorithms for navigation and vehicle control.

Meeting the Military's Complex Data Demands

Exploding sensor data volumes, the need for ever-faster response times and sophisticated sensor-fusing applications are all driving the need for powerful processing capabilities placed on the edge, adjacent to the sensors. In addition to the processing of more data at the edge, many next-generation deployed systems will need AI capabilities to maintain dominance on the electronic battlefield. And the next generation of edge processors must also be able to support these AI applications with both low latency and response flexibility. Edge deployment also means operating in exposed and harsh environments. Sensor edge processing systems must be designed and packaged to be extremely rugged and able to withstand shock, vibration and temperature extremes.

With rugged, deployable ACAP-based solutions being brought to market, a new level of computational performance has been unleashed for the next era of specialized computing. By combining multiple types of processing elements into a single architecture, this highly dense, next-generation processing technology enables a whole new category of dramatically faster devices that step beyond the current CPU/GPU/FPGA paradigm. ■

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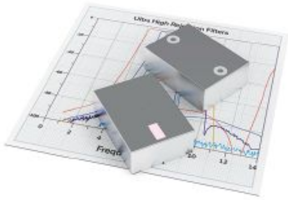

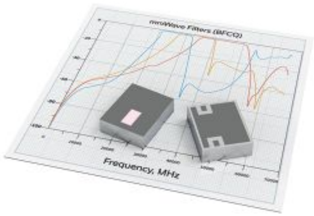

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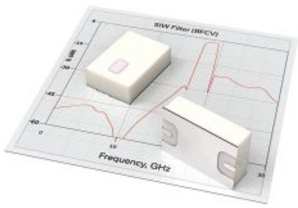

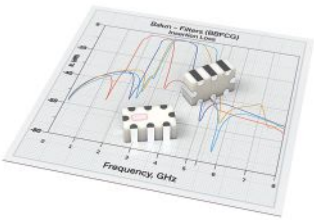

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The recent supply chain issues with chip shortages and long lead times have prompted system makers to turn to second-tier suppliers and distributors to fulfill their semiconductor needs. This, in turn, has put a spotlight on the growing concern of fraudulent or counterfeit ICs. Counterfeit ICs can have many sources of origin. They may be devices manufactured using less stringent quality standards, they may have come from excess inventory and they may also have old date codes or outdated revisions. These counterfeit devices may have failed test procedures or perhaps they were scavenged from recalled or broken system boards. While the method of entry into the supply chain may be murky, the consequences of these devices are much clearer. They may not meet performance specifications, they may also have poor reliability, shorter lifetimes and they may have experienced supply chain security breaches, along with being susceptible to hacking or trojan circuitry.

This, however, is not a new problem. Various publications and researchers have studied this subject over the years and concluded that this is indeed a real and serious problem, causing concern to system makers and especially those involved in mission-critical, security, defense and government applications. In a 2014 IEEE publication,[1] the authors estimated the revenue loss due to counterfeiting to be in the range of $100 billion with up to 1 percent of all semiconductor sales estimated to be counterfeit. A U.S. Chamber of Commerce report[2] cites that the Organisation for Economic Co-operation and Development estimated in 2016 that 2.5 percent of the world trade, or $461 billion, is related to counterfeiting. A 2017 study by the U.S. Air Force[3] (USAF) warns of growing concern about counterfeit devices contaminating the U.S. Department of Defense (DOD) and USAF supply chains. The study goes on to say that these counterfeit devices may be responsible for a loss of USAF personnel and the USAF has called for the DOD to take countermeasures. In response, the DOD and National Security Technology Accelerator (NSTXL) have initiated multiple programs such as RAMP[4] to implement supply chain security in offshore manufacturing environments with commercial participants such as Qualcomm[5] and Intel.[6]

Counterfeit IC Motivation, Sources and Risks

In an economic environment of supply shortage and long lead times, buyers can be tempted to turn to secondary suppliers or distributors to source the ICs needed for their products. This increases their exposure to counterfeit ICs. Even understanding the risks, there can be multiple motivations for suppliers to sell counterfeit ICs. These include:

- Improving gross margins by selling a lower-cost device at a higher price
- Winning a price and availability battle against competing distributors and resellers
- Selling a restricted device in an unapproved region or to a banned application
- Selling a digital rights management-disabled device into a content-sensitive market or application
- Contaminating a sensitive supply chain with hacked devices or with devices containing trojan circuits.

These counterfeit ICs can come from multiple sources:

- Second-source ICs that were manufactured at lower-cost manufacturing facilities or manufac-

turers with lower quality standards

- Recycled ICs that failed production line testing but were salvaged and repackaged as good units
- Retired ICs that were returned to companies as return material authorizations or disassembled from discarded or used system boards
- End-of-life or replaced ICs that were announced as obsolete and replaced with an updated revision
- A hostile entity trying to exploit a vulnerability in the supply chain to inject hacked or trojan devices.

By using counterfeit ICs, system makers and users are exposed to various risks such as:

- Faulty, low performance or buggy ICs that may not perform as expected and can cause permanent or intermittent system failures
- Lower quality products that may fail prematurely in the field
- Backdoors that enable hostile entities to take over sensitive applications and data.

Best-Known Methods and Limitations

Like identification cards or passports that contain a unique ID that distinguishes one person from another, detecting counterfeiting is based on a type of ID and a secured database of legitimate IDs. The most obvious way to track an individual IC is by assigning it a chip ID that is a unique identifier, commissioned to the IC's non-volatile memory. This may be accomplished with an e-fuse or a one-time programmable memory area at the end of the manufacturing line.

A limitation of this method is that offenders may obtain a stock of non-commissioned devices and program them with an ID of a legitimate unit. This is known as cloning a device. Another weakness is that often, the method of commissioning the ID into the device is by burning a bit and modifying its default value. While it is impossible to change a logical one to a logical zero, the converse may be possible. This means that an offender can change logical zero bits into logical ones and turn an illegitimate ID into a seemingly legitimate one.

Like using biometric methods to counter fake ID cards or passports, an inherent identifier that is not dependent on the commissioning of IDs is needed to counter IC supply chain vulnerabilities. Such a method is called a physically unclonable function (PUF). The most common method of PUF is an uninitialized SRAM. Each bit in an SRAM that was not previously written or initialized has a certain tendency to be read as a zero or a one. Research shows that implementing noise cancelation techniques and reading a large enough uninitialized SRAM can result in a very high probability that different devices will read different values but multiple reads from the same device will return the same value on each read.

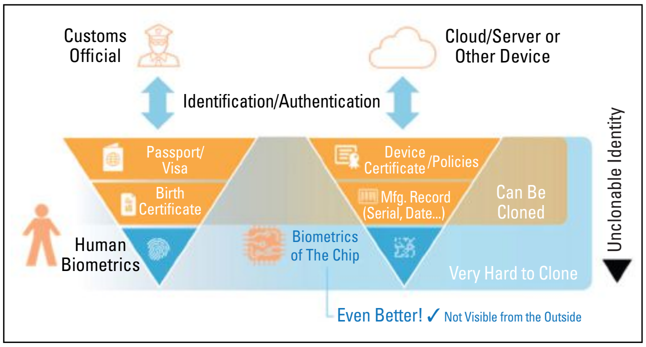


Fig. 1 Root of Trust using an unclonable function.

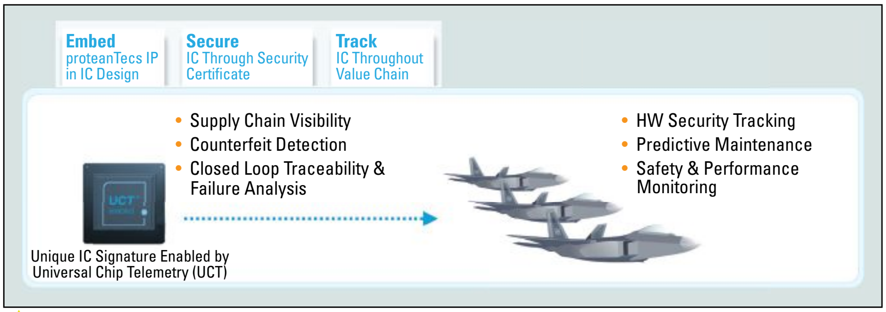
A flow diagram for a Root of Trust system used to provide trusted verification for human and IC identification and verification is shown in ***Figure 1***. This diagram introduces the concept of a PUF. It comes from a work based on an SRAM implementation of a PUF.[7]

Unfortunately, after some amount of time in the field, there is a good chance that this PUF device will experience aging and wear-out. This is likely to affect the PUF signature and the device will start advertising a different value. Another limitation of this approach is that devices that were manufactured at an illegitimate foundry, devices that have had additional circuits inserted or devices with an older revision do not map back to an IC design or process data. This limits the ability of a PUF to detect these counterfeit parts. The solution to this challenge requires a new PUF

method that provides the benefits of an SRAM-based PUF while also offering value for additional use cases and attack schemes.

Some industries are looking to use a split manufacturing concept as a means to segment the silicon manufacturing process into identifiable untrusted and trusted portions.[8] In this concept, the advanced process node foundry for the transistors can be an untrusted generic front-end-of-line foundry process. In this implementation, the back-end-of-line of the process, where the metal interconnect layers turn the transistors into circuits, would be a trusted process. However, this process concept is difficult to manage with limited functionality and it may not be feasible with newer silicon technologies.

As shown in Figure 1, the system needs to do more than just generate unique IDs. There is also a need for a cloud-based and secured data platform to store and maintain the database of valid device signatures. Existing chip ID databases are often not secure enough, siloed or not accessible throughout the supply chain.



▲ Fig. 2 Supply chain security through on-chip visibility and data analytics.

PROTEANTECS UCT-BASED SUPPLY CHAIN SECURITY

Due to inherent process variation, especially in advanced FinFET nodes, each transistor in an IC will manifest a slight variation of its basic electrical parameters even when it is manufactured using the same template. These variations apply to electrical characteristics like threshold voltage, on current and off current. The same is also true for the resistance and capacitance of the conductors inside the chip.

These device parameters represent the DNA of an IC. If a large enough set of such parameters is analyzed, the unique DNA of the chip can be extracted and then used as a PUF. Not only is every IC different, but even more significantly, every wafer, lot and foundry is different. By collecting large manufacturing data sets and by using big data and machine learning (ML) techniques, the signature of the IC can be used to map it back to its original wafer, lot or foundry.

proteanTecs has introduced UCT as a method for collecting large sets of parametric measurements from each IC with supplementary pre-silicon simulations. Proteus, a ML-enabled cloud-based data analytics platform fuses and infers the UCT data and provides a comprehensive, holistic and secured solution for end-to-end supply chain security. Along with counterfeit detection and prevention. Proteus delivers values that are tightly related to the DNA, or the personality, of each unique device. ***Figure 2*** shows a top-level visualization of supply chain security in a system utilizing UCT.

Introduction to UCT

UCT is based on a collection of agents that are small monitors embedded inside an IC during the design process. These agents collect vital parametric information while the IC is tested or used in a system in fully operational mode. UCT-generated data is then loaded into Proteus, a cloud-based data analytics platform, where the data from the entire fleet of chips and systems is analyzed to produce vital insights for the design teams, production groups and fleet operators. These insights help optimize the chip and system performance and reliability during characterization, qualification, high volume manufacturing and in field use. They also provide alerts on faults before they become failures for predictive maintenance. The features of the Proteus platform, along with its integration with UCT are shown in the diagram of ***Figure 3***.

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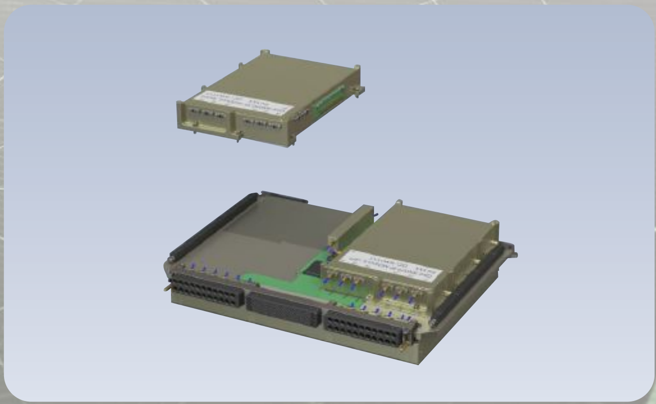

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UCT Agents

UCT agents are on-chip monitors, specifically designed for data analytics. With that in mind, the data they collect

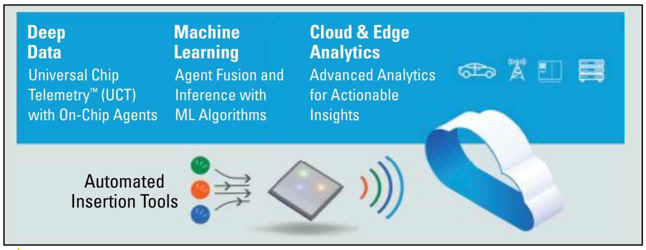


Fig. 3 Proteus provides a holistic deep data solution based on UCT.

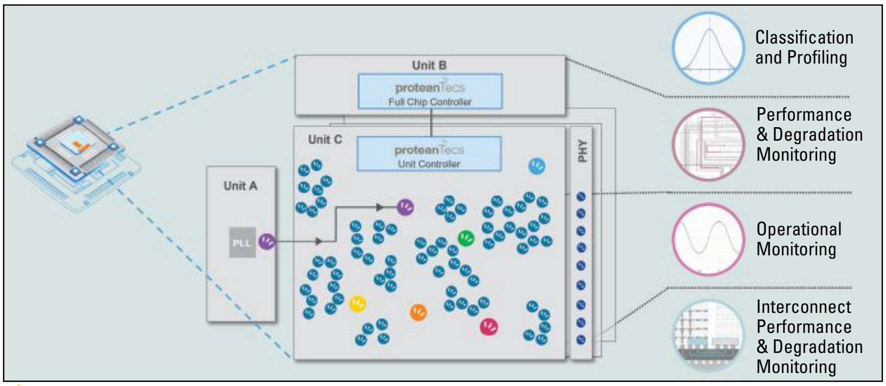


Fig. 4 Four UCT agent categories.

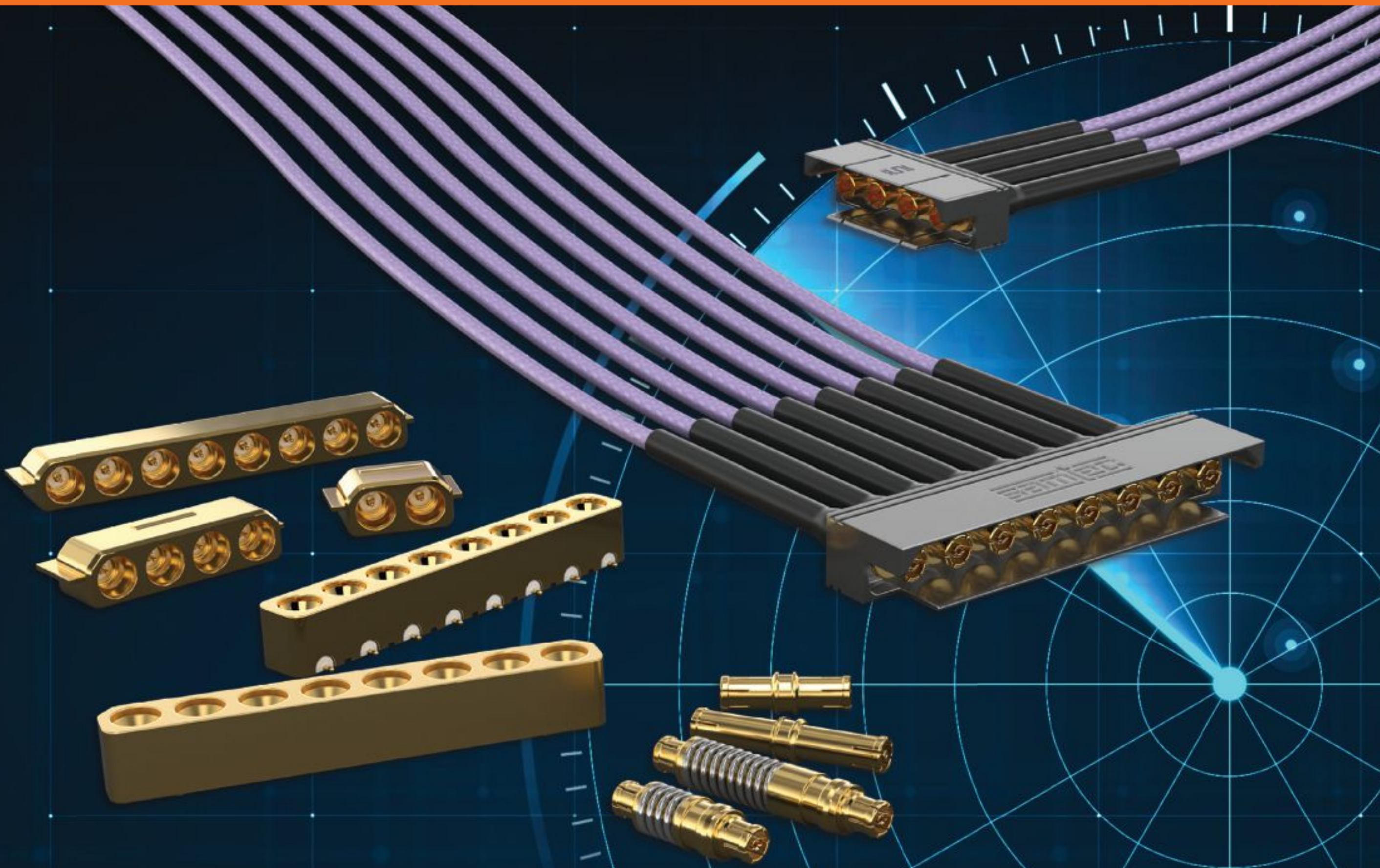
is pre-processed inside the chip and then aggregated and packed for extraction and loading into external cloud software. The agents are extremely small, spread in numbers across the chip and complement each other with the data they collect. They can be used continuously or on demand and can operate in the background while the chip is in full operational mode. They do not require a special test mode or test firmware to operate them. An overview of this UCT agent concept is shown in ***Figure 4***.

The UCT agents are divided into four categories:

Classification and Profiling Agents collect information related to the behavior of the chip's building elements: its basic transistors, standard cells and conductors. They are constructed to be sensitive to the different device parameters and can map a chip or a sub-chip to the closest matching process corner, Monte-Carlo simulation point and RC model. They provide fine-grain visibility of the full distribution at every stage and determine if the issue is by design or a product of process variation.

Performance and Performance Degradation Agents are placed at the end of many timing paths and continuously track the remaining timing margin to the target capture clock frequency. They can be used to pinpoint critical path timing issues as well as track their degradation over time.

Operational Agents provide deep visibility of system, software and environmen-



tal issues, as seen from the chip, as well as diagnostics as to the root cause of problems. They track changes in the DC voltage and temperature across the die as well as information related to the clock jitter, power supply noise and workload. Their information can be used to explain timing issues detected by the performance and degradation agents as well as understand the system environment in which the chip is assembled.

Interconnect Performance and Degradation Agents are located inside a high bandwidth die-to-die interface and are capable of continuously detecting the signal integrity and performance of the critical chip interfaces.

Proteus Data Analytics Cloud Platform

The data collected from the embedded UCT agents as well as information available from other on-chip or off-chip sensors, test results from ATE, environmental and machine conditions and additional data sources are loaded into the Proteus cloud platform for deep data analytics. This highly scalable and secure platform uses ML and dedicated algorithms to process the data and fuse information from various sources, along with the entire fleet of chips and systems. The output from this information is meaningful, useful insights and alerts through a set of pre-configured dashboards. The Proteus platform also offers an open environment for customized algorithm and analytics development.

Proteus UCT-Based Supply Chain Security and Counterfeit Detection

The solution is based on three primary elements:

- **Embed:** Using the proteanTecs agent integration tools, each design is analyzed and a recommended set of agents are inserted to provide optimal coverage for this specific product and technology. A comprehensive set of simulations are then performed to create the baseline or the expected behavior of these agents using the target manufacturing process parameters.
- **Secure:** UCT data from each unit is extracted at the first test station, as early as in the wafer sort process. The Proteus Supply Chain Security module is used to calculate and assign a unique signature for each unit and store it in its secured database. At this phase, alerts can be issued for devices that seem to originate from suspected sources. These

alerts may be triggered in several ways. For example, if the performance is different from the simulations, this may represent an older design revision. An alert will occur if the data does not match the intended manufacturing process models. If the data shows a significant variation from the rest of the population, this may represent counterfeit manufacturing sources or changes in the production process. These alerts are not necessarily catastrophic. If the data source that triggers an alert is deemed legitimate, the calculated signature is stored in the secured database.

- **Track:** At every tracking station along the supply chain, UCT data is extracted to compare and monitor the same device across its lifetime and to detect devices that falsely claim to be legitimate devices. At every test station, devices that are found to be defective, underperforming, showing signs of aging or wear-out or do not meet quality standards are marked accordingly in the secure data-

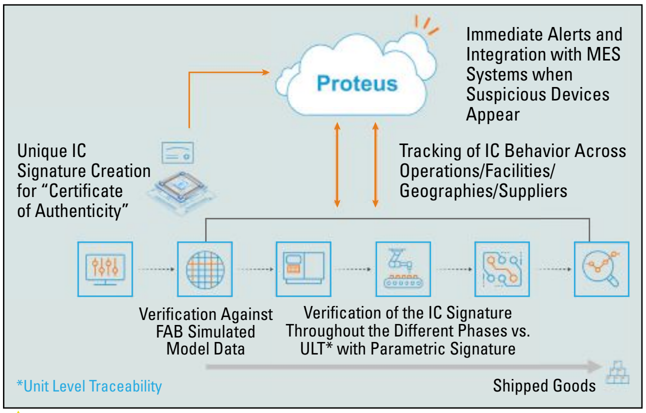
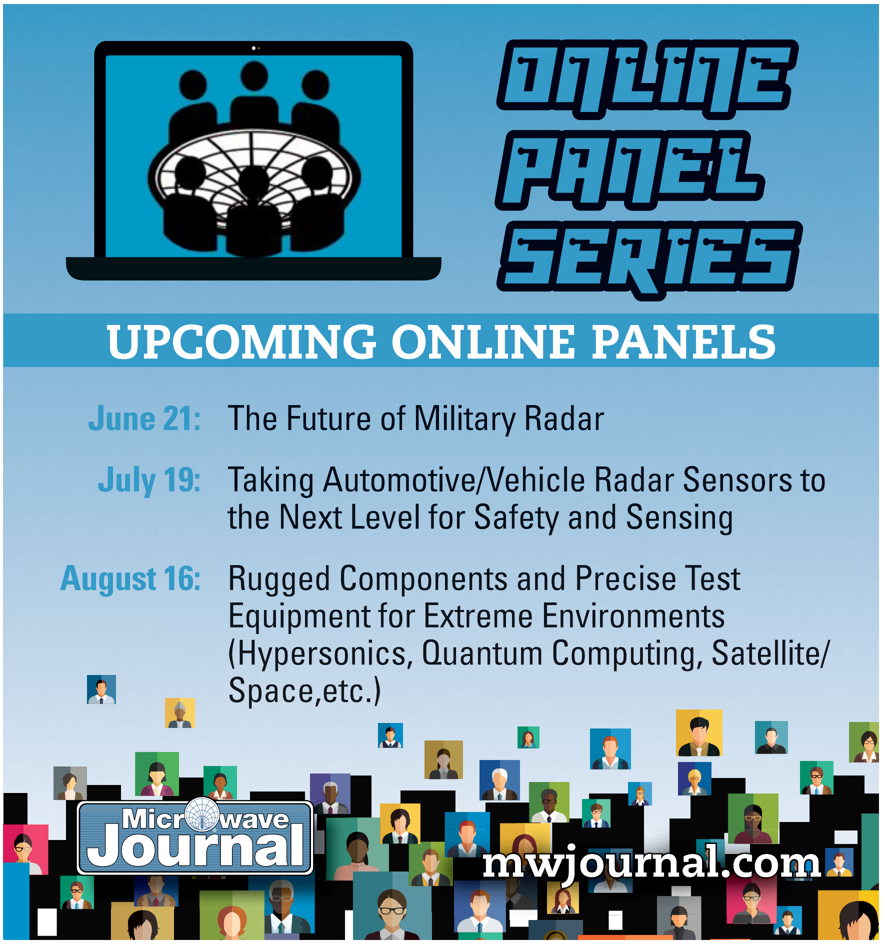


Fig. 5 Signature creation and tracking across the supply chain.

Fig. 6 Embed, Secure and Track details.



base of this product. Tracking and continuously updating the cloud-based secure database identifies devices that were previously considered legitimate but were discarded somewhere along the supply chain. These devices may have failed test or quality requirements, they may be devices that did not meet specific binning criteria or they may be used or recycled devices.

The conceptual implementation for the supply chain is shown in ***Figure 5***. ***Figure 6*** gives additional details on the primary elements of the Proteus platform.

Summary

Proteus deep data analytics based on UCT provides an innovative approach to supply chain security and counterfeit detection. By generating and collecting a large set of parametric measurements from each chip and uploading them to a ML-enabled, cloud-based analytics platform, a comprehensive and secured method of detection can be achieved. This allows for continuous and intrinsic tracking of ICs through the supply chain to allow for device authentication, validation and supply chain integrity. The combination of the hardware of the UCT agents, coupled with the software of the Proteus platform makes a compelling solution for defense and commercial entities concerned with counterfeit parts and supply chain security. ■

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Liquid-Cooled GaN Amplifier Delivers 5 kW at S-Band

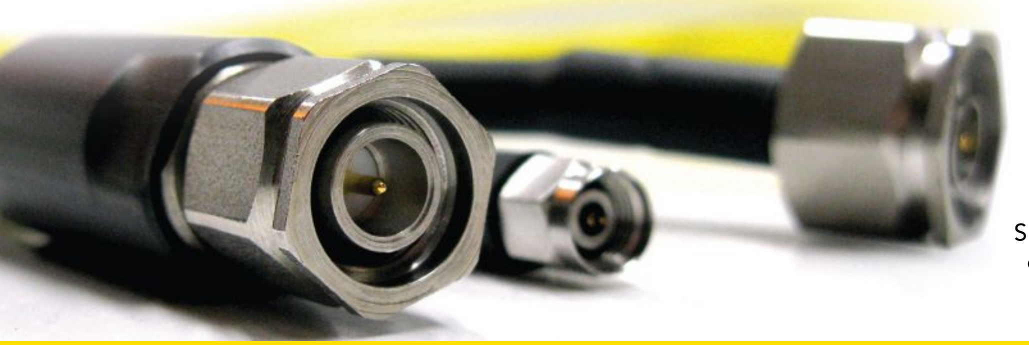
Designed to deliver extreme power and reliability, Empower RF Systems announces its newest GaN-on-SiC amplifier, the model 2245. This liquid-cooled amplifier delivers a minimum of 4100 W CW from 2 to 4 GHz with 5 kW mid-band performance. Reliability is a key feature and the result of its distributed RF architecture. With no single point of RF failure, the 2245 boasts exceptional long-term reliability.

The modular architecture allows hot or muted swapping of the integrated 2U amplifier drawers and cold swapping of the 3U system controller from the front. Swapping time is less than 15 minutes. Repair is modular, fast and easy, bringing lifetime costs down. Specialized technician training is not required and there are no dangerous high voltage supplies to contend with. Because of the architecture, only fractional system spares are needed for a complete backup system. You only need to spare a single amplifier drawer and one controller. The 2245 is the smart choice for those seeking exceptional reliability and the lowest lifetime cost of ownership.

Other power combinations are easily accommodated with the scalable design of the 2245. The amplifier system can be specified with any even number, up to 16, of 2U amplifier drawers. For even higher power, additional racks can be combined. In either case, the amplifier design effort is limited to the combiner. When it comes to delivering high power reliably, efficiently and at a lower cost, Empower RF has a validated, proven track record of fielding high-power CW and pulsed microwave amplifiers to the DOD and major prime contractors.

VENDORVIEW

Empower RF Systems
Inglewood, Calif.
www.empowerrf.com



4 kW Pulsed Solid-State Amplifier Operates from 4 to 8 GHz

Exodus Advanced Communications has developed a high-power solid-state amplifier (HPA) system for C-Band pulsed radar testing applications as well as general radiated susceptibility requirements such as EMI-Lab/RS103 and electronic warfare applications. The AMP2083P-4KW pulse amplifier covers the full C-Band frequency range of 4 to 8 GHz, providing outstanding RF pulse fidelity. The amplifier satisfies pulse requirements for radar applications with narrow or wide RF pulses and duty cycles to 10 percent. To do this, the AMP2083P-4KW produces at least 4000 W of pulsed power across the band with 3 dB peak-to-peak power gain flatness. The HPA uses a class AB linear design and it achieves harmonics of less than -20 dBc at the rated output with -60 dBc spurious levels and an 80 dB on/off ratio.

The pulse HPA has extensive control and monitoring capabilities, including optional calibrated power monitoring. Monitoring can be done via the color display or remote control. The color touchscreen shows forward and reflected power, along with VSWR in real-time. It also displays system voltages and currents as well as the operating temperature of the PA modules, heat sinks and internal system. The amplifier system also includes gain control with more than 20 dB of attenuation accessible through the screen or the remote interface.

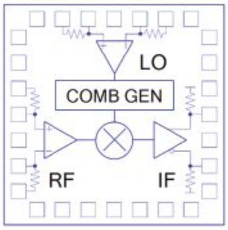
The AMP2083P-4KW is rack-mountable or it may be used on a bench. The HPA uses type N-female connectors for the RF input and optional RF sampling ports. To efficiently handle the high power, the RF output connector is an SC female connector.

Exodus Advanced Communications' products use LDMOS, GaN HEMT and GaAs technology with a large share of these devices manufactured by the company. In addition to high-power amplifiers, Exodus designs low noise amplifiers, modules and multi-band systems for applications ranging in frequency from 10 kHz to more than 75 GHz.

VENDORVIEW

Exodus Advanced Communications
Las Vegas, Nev.
www.exoduscomm.com

DC to 20 GHz Down-Converter Sampler/ Harmonic Mixer IC



HYPERLABS has developed a DC to 20 GHz harmonic downconverter/sampler IC targeted for use in SIGINT and spectrum monitoring applications. The HL9333 delivers excellent linearity, low noise and high LO to RF isolation in a 28-pin 4 mm QFN package. This product is specifically designed for Nyquist folding receiver applications. It extends the analog bandwidth of high speed A/D converters, simplifying the design of network analyzers, spectrum analyzers and sampling oscilloscopes. The RF front-end features 50 Ω terminations to ground and a buffer amplifier. The combined 3 dB bandwidth of the RF amplifier and mixer is typically DC to 17 GHz. The LO to RF isolation is 75 dB.

The LO comb generator produces a broad spectrum of harmonics. Each LO harmonic converts two Nyquist zones from RF to IF baseband. When sampling at the recommended 1 GSPS, 40 Nyquist zones of the DC to 20 GHz RF spectrum are folded and aliased into the IF baseband. Signals from the even Nyquist zones are spectrally inverted. The buffered IF output features 50 Ω terminations to VDD (+6 V). The IF bandwidth is 700 MHz.

The HL9333 can operate at LO frequencies as high as 7 GHz with little effect on RF bandwidth. For broadband applications, the maximum recommended LO is 1.4 GHz. The IF mixing products at 700 MHz are attenuated by 3 dB relative to the lower frequency mixing products due to IF bandwidth limitations. This results in a 3 dB ripple when operated at 1.4 GSPS. For narrowband applications, a higher LO frequency may be selected if the channels of interest fall within the 700 MHz IF range.

Founded in 1992, HYPERLABS sells an array of ultra-broadband components including baluns, bias tees, DC blocks, power dividers, pick-off tees, samplers and more operating up to 110 GHz. HYPERLABS' instrumentation line includes pulse generators, TDRs/TDTs, impedance analyzers and cable skew testers.

HYPERLABS
Louisville, Colo.
www.hyperlabs.com/product/hl9333

Expanded Line of Semi-Rigid Cable Assemblies and Connectors

Fairview Microwave, a leading provider of on-demand RF, microwave and mmWave components, has expanded its offering of semi-rigid cable assemblies and connectors. This expanded offering is designed to negate the need for any custom tooling or jigs in the production process. This new series of semi-rigid cable assemblies features superior shielding compared to their flexible counterparts. Their solid outer conductor semi-rigid coax design guarantees their forms are reliably held after bending, making them desirable for applications involving enclosure and/or box-type layouts. Fairview's customers can enjoy access to a variety of connector options, including Type N, SMA, 3.5 mm and more. There are also in-series and between-series connector options. This expanded offering includes custom lengths for the cable assemblies along with multiple cable type options to address numerous applications. For example, there are smaller diameter options for higher frequencies and smaller housings, as well as larger diameter options for larger housings and lower loss scenarios. Fairview Microwave's customers can tap into one of the most robust portfolios of semi-rigid cable assemblies and connectors available anywhere. Customers can customize assemblies to meet their specific needs and these assemblies no longer require custom tooling or jigs in their production process. Fairview's new semi-rigid coax cable assemblies and connectors are in-stock and available for same-day shipping.

VENDORVIEW

Fairview Microwave
Lewisville, Texas
www.fairviewmicrowave.com/t-semi-rigid-connectors-and-assemblies.aspx

Low-Power Satcom Beamforming ICs

VENDORVIEW

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

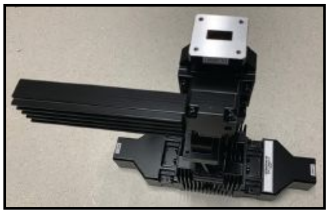
Analog Devices
www.analog.com/en/products/adar3002.html

CAES PIONEERING ADVANCED ELECTRONICS

CAES

CAES is a pioneer of advanced electronics for the most challenging defense and aerospace trusted systems. As a leading provider of advanced RF technology to the U.S. aerospace and defense industry, CAES delivers high-reliability RF and digital solutions that enable our customers to ensure a safer, more secure planet.

CAES
www.caes.com

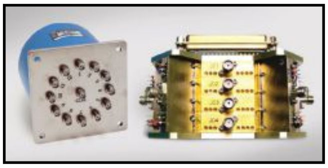


High-Power Waveguide Circulators

VENDORVIEW

Cernexwave's CWC series high-power waveguide circulators are great solutions for directing signals of any strength. They are made to fit your project requirements with small to very large frequency bands and power levels into the kilowatts. The precision internals provide low insertion loss and high isolation while the robust aluminum construction keeps temperature levels manageable.

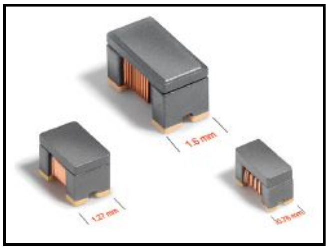
Cernexwave
www.cernexwave.com



Coaxial EM & PIN Diode RF/Microwave Switches from a Single Source

Superior RF performance, reliability and repeatability for defense, commercial and high-power applications. Thousands of fast-delivery coaxial electromechanical switch variations from DC to 40 GHz, including SPDT, transfer (DPDT), multi-position (SP3T-SP12T) and internally or externally terminated models. PIN diode switches tailored to key performance parameters include reflective or absorptive designs with options for SPST through SP24T, low loss, high isolation and fast switching speed.

Charter Engineering, a dB Control/HEICO company
www.rf-switches.com



Outgassing Compliant USB Common Mode Chokes from Critical Products & Services

FRA Family common mode chokes virtually eliminate common mode noise in high speed, differential-mode signal transmission applications such as USB 3.0, HDMI, SATA, IEEE1394 and LVDS, supporting data rates up to 4.8 Gbit/s. They are offered in three standard sizes, 0603 (AR312FRA), 0805 (AR336FRA) and 1206 (AR376FRA), all of which pass NASA low outgassing specifications. The use of a chemically-resistive adhesive also helps these parts withstand aggressive solvents.

Coilcraft
www.coilcraft.com

1 kW GaN Power Amplifier Offers Multi-Mode Radar Solutions

This solid-state power amplifier (SSPA) is an excellent solution for your multi-mode radar applications. Model AGN/095-6064 is a GaN-based SSPA and operates from 9 to 10 GHz, in 500 MHz band segments, with 1 kW pulse power output at 5 percent duty cycle (100 µSec pulse width). The compact SSPA measures just 6.17 x 4.36- x 0.82 in. with type "N" or waveguide output options. Covering markets include: EW radar, shipboard radar, AESA radar, AMDR, SAR, UAVs, VLO/FLO threats and new land radar. Export license may be required.

CTT - KRATOS Microwave U.S.
www.cttinc.com

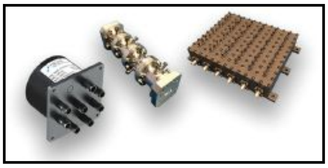
AEROSPACE AND DEFENSE

COMPANY SHOWCASE

1 kW X-Band Long Pulse GaN SSPA for Radar

Operating from 9 to 10 GHz, Empowers model 2241 provides over 1000 W peak power in a compact 3 U chassis. Long pulse capabilities include up to 500 usec pulse widths at full power and a derated long pulse operation up to 2.2 ms at 200 W peak. Duty cycles up to 20 percent and 25 kHz PRFs. Pulse modulated or gated pulse mode. The unit is controlled through the front panel touch screen, M2M SCPI and peer/LAN connected PC and web browser.

Empower RF
www.empowerrf.com/products/display_amplifier.php?sku=2241



High Performance Passive Components

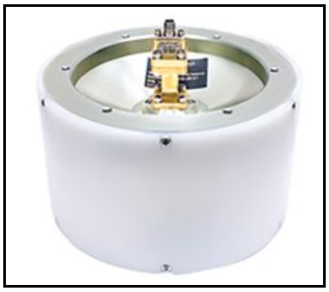
Exceed Microwave provides custom high performance passive microwave component designs up to 110 GHz for defense, space and commercial applications. Exceed Microwave is AS9100 certified and ITAR registered, providing high-quality, high performance passive components. They provide various types of designs, each with its own unique values and are designed and made in the U.S. Many of Exceed's designs offer extremely high Q factor, allowing very low insertion loss and high-power handling.

Exceed Microwave
www.exceedmicrowave.com

Little-110 Armored Flexible RF Cable

A global distributor of 'just-in-time' RF and microwave components, HASCO is expanding their line of flexible cables to include the HLB055 Littlebend 110 GHz flexible cable series. With its low loss, excellent phase stability, low VSWR and high temperature rating, HASCO Little-110, 110 GHz cable assembly is a versatile and reliable solution for satellite communications, radar, aerospace and other high frequency applications. Available in 1.0 mm, SMA, 1.85 mm, 2.4 mm, 2.92 mm, SMP and SMPM connectors.

HASCO Components
www.hasco-inc.com



Omnidirectional Antenna Scans 10° Elevation from 26.5 to 40 GHz

Suitable for electronic intelligence and EW applications, model SAO-2734030810-KF-S1 is a vertically polarized omnidirectional antenna that covers frequencies from 26.5 to 40 GHz with 7.5 dBi gain. Antenna gain variation is within +/-1.0 dB in azimuth with a nominal 3 dB vertical beamwidth of 10 degrees. The waveguide-fed antenna includes a coaxial-to-waveguide adapter with a female Type K connector. The cylindrical radome measures 5.7 in. in diameter with a height of 3.5 in. Maximum power is 75 W with 9 dB minimum return loss.

Eravant
www.eravant.com

Exodus AMP2065G-LC-2KW

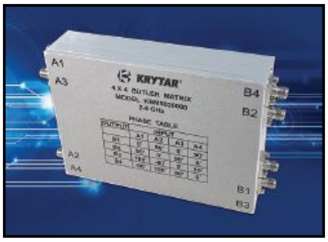
The Exodus AMP2065G-LC-2KW is designed for replacing aging TWT technology. A broadband rugged EMC Class A/AB linear solid-state design for all modulations & industry standards. Covers 6 to 18 GHz, produces > 2000 W minimum, with > 63 dB gain. Excellent flatness, optional monitoring parameters for forward/reflected power in both dBm and watts, VSWR, voltage, current and temperature indication for superb reliability. Gain control is standard and power-Indication accurate to within +/-0.2 dB in rack cabinets incorporating Exodus Quiet-Cool technology for extreme reliability.

Exodus
www.exoduscomm.com

Open Your Eyes

HYPERLABS is a leading provider of high performance, broadband amplifier products including the new HL5897 with a typical bandwidth of 65 kHz to 65 GHz. The flat response of this amplifier supports PAM4 data-driver requirements with a focus on maintaining optimized eye patterns. Since 1992, HYPERLABS has built a reputation as an industry leader in broadband component designs including: baluns, bias tees, DC blocks, power dividers and more.

HYPERLABS
www.HYPERLABS.com



Butler Matrices from 0.5 to 40 GHz with High Accuracy

VENDORVIEW

The new KRYTAR Butler Matrix family uses KRYTAR's high performance 90- and 180-degree hybrid couplers providing superior phase accuracy, amplitude imbalance, stability, high isolation, low insertion loss and VSWR and repeatability. Offering coverage of multiple microwave bands, from 0.5 to 40 GHz, a KRYTAR butler matrix is the ideal choice for antenna array beamforming, 5G New Radio testing, mmWave testing, MIMO testing, multipath simulation and performance evaluation and many other applications.

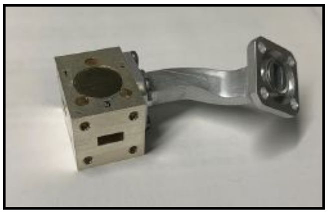
KRYTAR
www.krytar.com

RF Power Sensors

VENDORVIEW

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

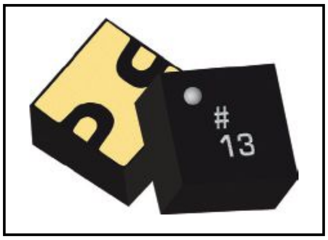
LadyBug Technologies
www.LadyBug-Tech.com



High Performance Components

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

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



MMIC DC to 40 GHz Limiter

Marki Microwave continues to push the frequency envelope with its chip scale packaging portfolio, featuring game-changing, die-level performance in an ultra-compact surface mount package. Compatible with standard pick-and-place assembly, the HLM-8010CSP1 is a MMIC DC to 40 GHz limiter that delivers +8 dBm flat leakage, 0.5 dB insertion loss and 24 dB return loss. Its 1.5 x 1.5 mm package reduces SWaP-C, making it ideal for space constrained applications needing to obtain the highest level of performance.

Marki Microwave
www.markimicrowave.com

Miniature Air Coils for High-Reliability, RF and Microwave Applications

Microwave Components, Inc. (MCI) in Dracut, Mass., is a small, veteran-owned manufacturer of miniature air coils. MCI has proudly been delivering custom, high Q, miniature air inductors to the aerospace, defense and space markets since 1978. Materials include; bare and insulated gold, copper, silver, gold plated copper, nickel copper alloy and aluminum wire. Inductances from 1 to 1000+ nH.

Microwave Components, Inc.
www.mcicoils.com

20 to 36 GHz/28 to 40 GHz YIG-Based Notch Filters for EW and ECM

New breakthrough product line of notch filters that cover mmWave frequencies. This family of new yttrium iron garnet based filters provide superior notch depths over the 20 to 40 GHz frequency range. Two models provide tunable notches of 15 MHz minimum at 40 dB down across the 20 to 36 GHz (MLFR-2036) and 28 to 40 GHz (MLFR-2840) bands. The 3 dB bandwidth is 100 MHz maximum for both models. Typical passband insertion loss: 3 dB, passband range is 20 to 42 GHz.

Micro Lambda Wireless
www.microlambdawireless.com

Cutting-Edge RF & Microwave Subsystems

MPG Solutions combines five decades of experience and proven heritage from BSC, Dow-Key Microwave®, K&L Microwave® and Pole/Zero® brands to deliver high performance subsystems for mission-critical EW and radar platforms under the most challenging conditions. MPG Solutions' push the limits of signal purity, speed, bandwidth, dynamic range, linearity, SWaP and reliability, while establishing close partnerships with its customers that lead to advanced RF and microwave solutions.

MPG Solutions
www.mpgdover.com

See Norden's VPX Transceiver Specs

VENDORVIEW

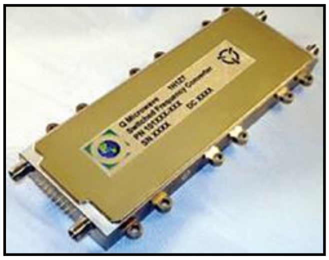
Norden's wideband VPX transceiver is used across military applications. It offers 2 to 18 GHz operation in a versatile OpenVPX platform. The NUDC2-18/1.3-2.3 includes internal LOs which provide an instantaneous IF bandwidth of 1 GHz and exceptional noise figure. The NUDC2-18_1.3-2.3 is currently in production. Please contact the company with your specific requirements and to discuss its custom configurations to meet your specification needs.

Norden Millimeter
https://nordengroup.com/wp-content/uploads/Norden-Transceiver.pdf

New Wearable SDR With Enhanced Ruggedization

Pixus Technologies announced a new compact implementation of its ruggedized enclosure line utilizing NI's Ettus Research™ brand software-defined radio (SDR). The new RB210 is a ruggedized version of NI's small form factor B210 SDR. It currently comes in an IP67 weather resistant style with options for full MIL grade implementations. The compact unit is approximately 87 tall x 156 wide and 300 mm long and weighs under 7 lbs. The RB210 features continuous frequency coverage from 70 MHz to 6 GHz.

Pixus Technologies
https://pixustechnologies.com



RF Wideband Converter, 0.5 to 18 GHz

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

Q Microwave
https://qmicrowave.com/subsystem-products.html

High-Power, Compact (3U) Traveling Wave Tube Amplifiers

The new 9103 series is offered as 3U rack mountable amplifiers, with standard models providing frequency coverage of 2 to 8 GHz and 6.5 to 18 GHz, with output power ratings of 300 Watts CW or 1.5 to 2 kW pulsed. All of Quarterwave's amplifiers feature low noise, high PRF, optional touch screen interface and are fully customizable. Other models of amplifiers are capable of covering 0.8 to 40 GHz, with an output rating of up to 50 kW.

Quarterwave
www.quarterwave.com

Filters, Multiplexers and Multifunction Assemblies

VENDORVIEW

Reactel manufactures a line of filters, multiplexers and multifunction assemblies covering up to 67 GHz. From small, lightweight units suitable for flight or portable systems to high-power units capable of handling up to 25 kW, connectorized or surface mount - the company's talented engineers can design a unit specifically for your application.

Reactel
www.reactel.com

Rosenberger Connectors on the Way into Space

On the journey of the Juice spacecraft to Jupiter, more than 100 Rosenberger connectors of SMP, SMA and RPC-2.92 series are also on board. The Jupiter Icy Moons Explorer spacecraft of the ESA consists of components such as thrusters, communication units, power supply, scientific measuring instruments. The Rosenberger connectors provide reliable and high precision service in the spectrometer sub-mmWave instrument, which investigates the atmospheric composition of Jupiter and its moons, and in the particle spectrometer particle environment package.

Rosenberger
www.rosenberger.com

Threaded Compression with Alignment Features

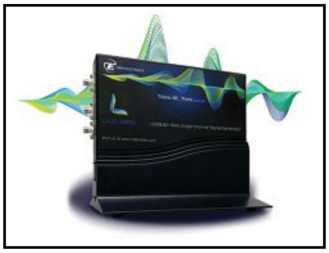
Samtec's threaded compression mount connectors are uniquely designed with alignment grooves milled into the foot of the connector. With the incorporation of fiducials to the PCB footprint, it becomes possible to achieve a level of positional accuracy with vertical compression mount connectors that was previously unattainable, ensuring repeatable, peak connector performance necessary for test and measurement applications.

Samtec
www.samtec.com/RF

High Performance Spectrum Analyzer/ Monitoring Receiver

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

Signal Hound
www.signalhound.com



40 GHz Signal Generators

Introducing the new Lucid X-Series of microwave signal generators from Tabor Electronics. The LSX family of signal generators have 8, 20 and 40 GHz frequency ranges. With phase noise better than -120 dBc/Hz at 1 GHz, fast and high-resolution frequency switching and +15 dBm of standard output power – these instruments matched some of the industries toughest requirements. Built on Tabor's modular technology platform, the LSX family is available in PXIe, USB-modular, rack, benchtop and portable formfactors.

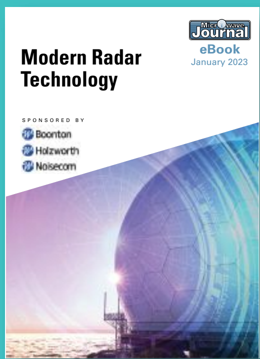
Tabor Electronics
www.taborelec.com

V Series Dielectric Varactor for mmWave Applications

VENDORVIEW

Tecdia has launched the V Series Dielectric Varactor, offering substantial improvements over the H Series varactors. These varactors feature higher Q and better tunability, making them ideal for high linearity and precise tuning in mmWave applications. Tecdia's unique tunable dielectric technology enables the V Series varactors to deliver exceptional performance with low ESR, even at mmWave frequencies. Samples are available upon request.

Tecdia
https://us.tecdia.com



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