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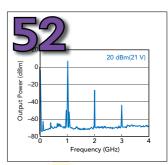
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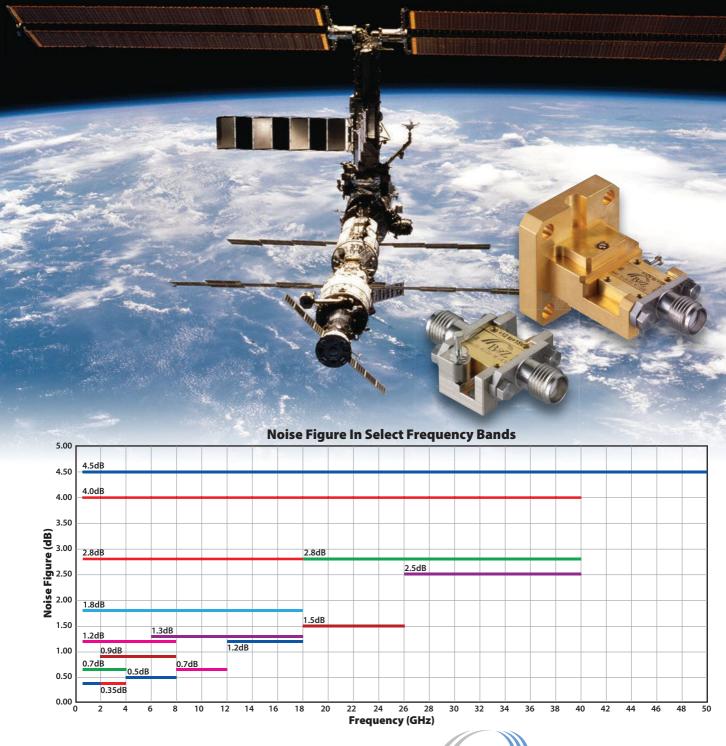
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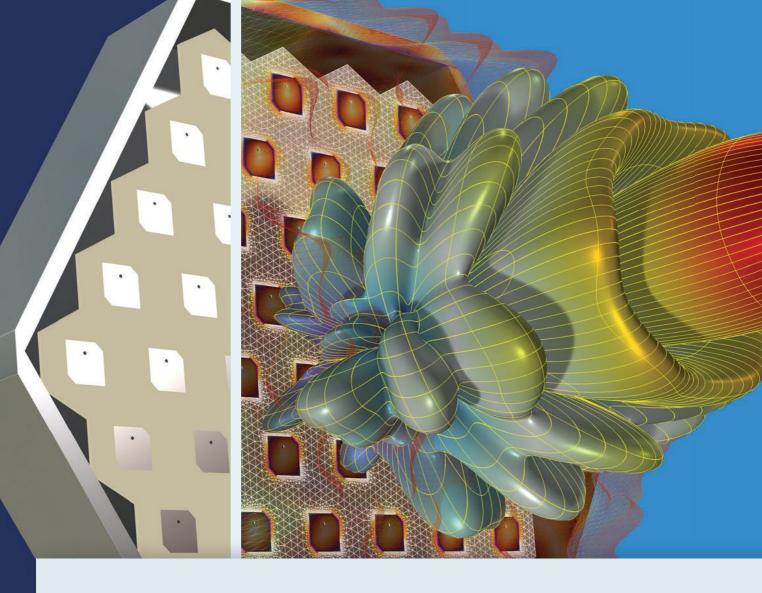


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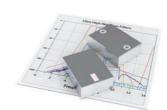
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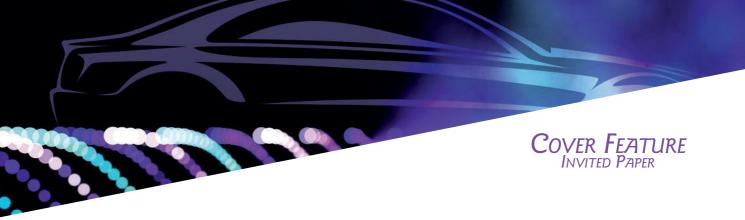
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A Cost-Effective Method to Measure Vehicle Antenna Radiation Patterns and Data Throughput

Jan Carlsson RanLOS AB, Gothenburg, Sweden

lehicles are becoming more dependent on reliable radio communications, whether it be for safety or autonomous driving-related systems or data streaming for software updates or entertainment purposes. The capabilities and performance of these systems and services have become important differentiators in the competition for customers. Even so, only a handful of vehicle manufacturers around the world have invested in test systems to measure antenna performance and connectivity. The main reasons for this are that conventional measuring technologies are complex, often time-consuming to use and require special test facilities, along with large investments. In contrast, the RanLOS test system represents an affordable and easy-to-use alternative solution. The RanLOS system can be used on an ongoing basis during the development process to guarantee reliable and superior performance of the end product. This article explains the ideas and technology behind the RanLOS test system and how it enables vehicle manufacturers to measure both an-

tenna radiation patterns and overthe-air (OTA) data throughput in a cost-efficient way.

BACKGROUND

One way to evaluate the performance of a radio communication system is to measure its performance in the actual environment of use. For vehicles, this is normally referred to as a drive test and this simply means that the vehicle is driven around on public roads. This is how many vehicle manufacturers test their systems today. However, this method poses questions; is the environment the same today as it was the last time the measurements were done and are the results comparable? Does the environment represent typical use? Are all the possible cases covered? The answer to all these questions is, strictly speaking, no, bringing into question the value of the tests. Another problem is that a drive test requires a vehicle that is almost finished, which in many cases cannot be driven around in public, at least not during the daytime, due to secrecy. Due to all the practical problems and the limited value of drive

tests, other approaches have been proposed. One such approach is to mimic the environment in a laboratory setup. This can be achieved by placing several antennas in a circle, a hemisphere or a similar configuration around the vehicle. These antennas are then fed with suitable signals to mimic a real environment. With such a setup, it is possible to generate waves coming from different directions that simulate reflections, diffraction and scattering from objects in a real environment. The guestions then become what environment gets simulated and is this environment the worst case? Another question is how many different types of environments should the test bed emulate to build the confidence level that the test needs have been covered sufficiently.

To begin addressing these questions, the RanLOS founder, Per-Simon Kildal, a professor at Chalmers University of Technology founded Bluetest in 2000. Bluetest made manufacturing reverberation chambers to test mobile devices in rich isotropic multipath (RIMP) environments. The RIMP environment contains many isotropic multipath

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waves with signals coming from all possible directions, amplitudes, phases and polarizations. 1 Professor Kildal began to formulate the idea that to accurately test a communication system, the line-of-sight (LOS) environment must be replicated as well. The LOS environment contains only a single wave incident on the vehicle under test. That environment replicates traditional pointto-point communication links. As he explored these boundary conditions in 2013, Professor Kildal came up with the idea that it would be necessary to test a communication system in both the RIMP and LOS edge environments.²

In 2016, Professor Kildal founded RanLOS to manufacture test systems that accommodated this LOS edge environment. The RIMP environment presents an extreme multipath environment that we rarely see in real life, but which can be emulated in a reverberation chamber. In the LOS edge environment, there is only a single wave incident on the vehicle under test. This is another type of environment that rarely occurs in real life, but Professor Kildal hypothesized that all real environments could be described as something in between these two edge environments. He concluded that if a device is performing well in both edge environments, it will also perform well in a real environment. Also, if a device is not performing

well in either of the two edge environments, it will probably not perform well in a real environment, or at least not as well as a device that does better in both edge environments. Since Professor Kildal's passing in 2016, the theoretical and development work has been carried out by an expert team including his daughter Madeleine.³ Based on these theories, RanLOS has developed OTA measurement systems for vehicular applications as well as for smaller mmWave devices. Figure 1 shows the latest production version of an OTA test system for

RANLOS TEST SYSTEM AND APPLICATIONS

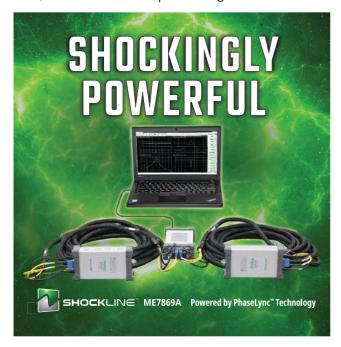
The RanLOS test system consists of a cylindrical reflector fed by a linear array of dual polarized antennas, along with software for controlling measurement instruments and other peripheral devices. Supported measurement instruments include vector network analyzers (VNAs) and communication test instruments. One example of a peripheral device is a turntable that could also be a 3D positioner. The software controls the measurement steps and collects measured data, as well as performing postprocessing and visualizing results in different ways. The feed array is easily exchangeable and it covers an octave bandwidth. To cover the



Fig. 1 The RanLOS test system for vehicular applications.

0.75 to 6 GHz frequency band, the most useful frequencies for vehicular communication systems used today, three feed arrays are needed. RanLOS has developed feed arrays that operate up to 6 GHz. Feed arrays for higher frequencies are on the roadmap, so existing customers can easily upgrade with no need to alter the reflector.

The RanLOS hardware can be viewed as a passive two-port, dual polarized antenna that generates a plane wave at a short distance. In function, it is very similar to the feed horn and spherical reflector used in a traditional compact antenna test



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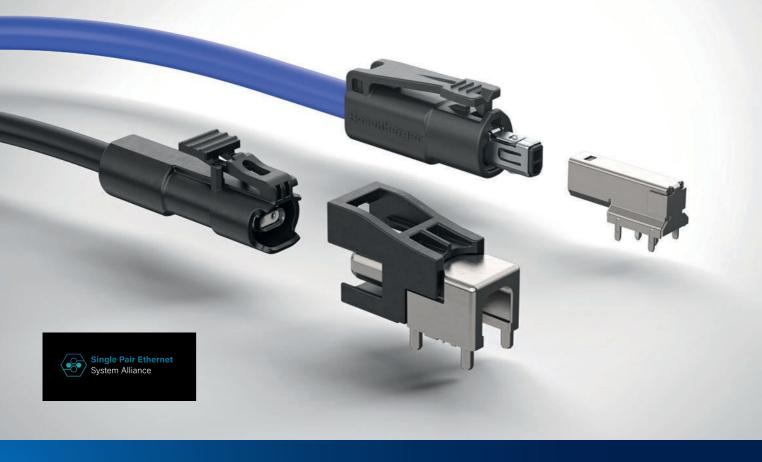


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range. One advantage of the cylindrically shaped reflector is that it is easier and cheaper to manufacture as compared to a double-curved reflector. It is also scalable in width and can be made in sections.

Figure 2 shows a weather-protected outdoor measurement range with the RanLOS test system in front of a vehicle under test. The vehicle is placed on a turntable so that it can be rotated in front of the reflector. The reflector shown in Figure 2 consists of four identical sections and even though the reflector antenna is physically large, it is equipped with wheels to make handling easier. This makes it possible to conveniently roll the reflector in and out of EMC chambers that many automotive manufacturers already have. The RanLOS setup makes it possible to measure antenna performance and connectivity in an existing chamber.

ANTENNA RADIATION PATTERN MEASUREMENTS

As can be seen in Figure 2, the vehicle under test is placed on a

turntable in front of the reflector. By rotating the turntable, the vehicle will experience an incident wave from different directions, emulating the LOS edge environment. Since the generated field is a plane wave, this results in far-field conditions and far-field parameters such as the antenna gain pattern of a vehiclemounted antenna can be measured by the test personnel. The gain pattern is measured by connecting one port of a VNA to the antenna on the vehicle and the other port to the RanLOS system to measure the signal transmission. The test setup, with all connections, is shown schematically in Figure 3. To enable rotation, it is preferable that the turntable be equipped with a rotary joint for the RF cable.

The feed array has two ports, one for each polarization. With a 4-port VNA, it is possible to measure both polarizations simultaneously, for up to two vehicle-mounted antennas. If absolute gain values are desired, a calibration must be done first, using a reference antenna with known

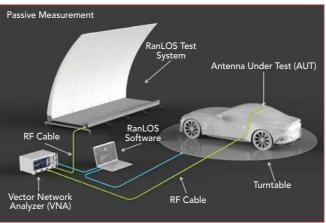
gain.

perfor-

mance comparison with other measurement methods, Figure 4a shows a Polestar body with a monopole antenna placed on the roof in the Ran-LOS measurement setup.4 Figure 4b shows the same Polestar body and antenna combination measured in an advanced accredited near-field to far-field (NF-FF) range in Denmark. Finally, Figure 4c shows the gain pattern for the two test setups measured at 2.6 GHz. The agreement between the two test methods is very good. In the NF-FF measurement of Figure 4b, the field is probed in points on a hemisphere



Fig. 2 The RanLOS test system.



▲ Fig. 3 Measurement setup for an antenna radiation pattern measurement.

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- 200 Watt CW and 1000 Watt Peak
- (1 Microsec pulse width) power handling capability
- Built-in DC block @ input and output
- Hermetically sealed module



| MODEL | FREQ. RANGE (MHz) | MAX 1 INSERTION LOSS (dB) | MAX 1 VSWR | MAX 2 INPUT CW | |
|--------------|-------------------------|------------------------------------|---------------|----------------------|--|
| LS00102P200A | 10-200 | 0.3 | 1.5:1 | 200 | |
| LS00105P200A | 10-500 | 0.8 | 2.2:1 | 200 | |

- 1 Insertion loss and VSWR tested @-10dBm
- 2 Power rating de-rated to 20% @+125°C
- Leakage slightly higher at frequencies below 100 MHz

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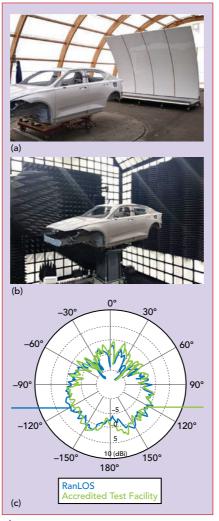


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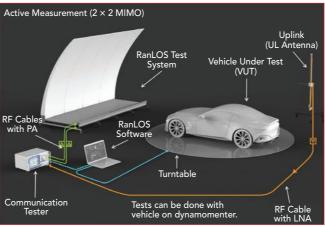
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around the vehicle and later postprocessed to obtain the far-field gain. The time for a measurement using the RanLOS system depends



▲ Fig. 4 (a) RanLOS system measuring a monopole on the roof of a Polestar body. (b) Monopole on the roof of a Polestar body in an accredited NF-FF antenna test range. (c) Measured antenna gain patterns for the Polestar monopole.



▲ Fig. 5 Typical measurement setup when the antenna cannot be accessed.

on the instrumentation and the time to rotate the turntable one revolution. The rotation can be done in discrete steps or continuously, in which case, the measurements are taken on the fly. The measurement in the RanLOS chamber in Figure 4a took less than 10 minutes, implying that the RanLOS system can be used as an engineering tool for investigating how the performance is affected by factors such as antenna position, type or manufacturer.

CONNECTIVITY MEASUREMENTS

In modern vehicles, the antenna is often tightly integrated with the radio module with the consequence that we do not have access to the antenna ports needed for measuring the antenna gain pattern. In such cases, a communication test instrument is connected to the RanLOS system instead of a VNA and OTA measurements of characteristics like the throughput can be performed. A typical measurement setup, in this case for an LTE 2 × 2 MIMO OTA measurement, is shown in *Figure 5*.

In the measurement setup in Figure 5, the communication test instrument, together with the RanLOS system, act as a base station sending a data stream to the antennas and radio modem in the vehicle. This is the downlink. The uplink, which normally is configured to have a lower data speed and modulation scheme, is connected to the instrument via a separate antenna. In *Figure 6*, several measured downlink throughput curves for the 2 × 2 MIMO LTE system as a function of

power for different rotation angles of the vehicle under test are shown.

Each curve corresponds to one angle of rotation of the turntable, representing different incident signal paths as seen by the receiving antennas on the vehicle. As expected, the throughput is at a maximum value for high power levels. When the



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|---|-------------------|---------------|---------------|---------------|----------------|---------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|--------------------|--|
| Dynamic Range (BW=10Hz, dB, typ) (BW=10Hz, dB, min) | 120 110 | 120 105 | 120 110 | 120 110 | 120 110 | 120 110 | 120 110 | 120 110 | 115 110 | 115 105 | 100 80 | 110 100 | 100 80 | 95 75 | |
| Magnitude Stability (±dB) | 0.15 | 0.15 | 0.10 | 0.10 | 0.10 | 0.15 | 0.25 | 0.25 | 0.3 | 0.3 | 0.5 | 0.5 | 0.4 | 0.5 | |
| Phase Stability (±deg) | 2 | 2 | 1.5 | 1.5 | 1.5 | 2 | 4 | 4 | 4 | 6 | 6 | 6 | 4 | 6 | |
| Test Port Power (dBm) | 13 | 13 | 13 | 18 | 18 | 16 | 13 | 6 | 4 | 1 | -10 | -3 | -16 | -23 | |



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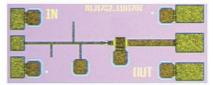
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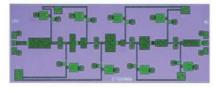
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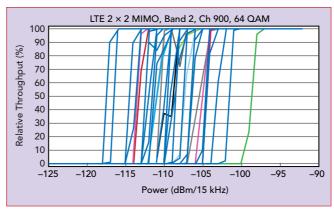




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♠ Fig. 6 Measured downlink throughput as a function of power and vehicle rotation angle.

power is decreased and we approach the sensitivity level of the radio module, the throughput falls to zero very quickly and we lose the connection. From Figure 6, it can also be seen that there is almost a 20 dB difference between the best, leftmost curve and the worst, rightmost curve, cases. In practice, this means that the maximum distance to the base station to maintain connectivity will be different for different orientations of the vehicle to the base station. This delta between best and worst cases translates to a sizable difference in distance. As an example, if the maximum communication distance is 10 km in the best case, it will only be about 1 km in the worst case. This assumes pure LOS communication in free space.

If we have electromagnetic disturbances at the downlink frequency coming from sources in the surroundings or from internal sources in the vehicle, we expect all the curves to be shifted to the right in Figure 6. The consequence of disturbances is that the maximum communication distance will be shorter. The reduction in communication distance will be the same in all directions if the disturbances are coming from the vehicle, but this is not necessarily the case if the disturbances are coming from the surroundings. Due to the large number of electronic control units in modern vehicles, there are many possible sources of disturbances. It is therefore important for vehicle manufacturers to be able to investigate the possible influence of disturbances on the radio communication quality, especially for critical safety systems. Such investigations can be done conveniently in an EMC chamber equipped with a dynamometer so that the vehicle can be run in realistic operation modes. In these cases, the RanLOS test system is a useful tool.

CONCLUSION

RanLOS has developed a unique,

patented OTA test system including both hardware and software for measuring antenna performance metrics as well as connectivity quality. The system is mobile, so it can easily be rolled in and out of an existing semi-anechoic chamber, like EMC chambers that many vehicle manufacturers already have. The system should not be seen as a competitor to advanced specially-tailored antenna test ranges, but rather as an engineering tool that can be used regularly to improve antenna performance and connectivity quality, especially for vehicular applications. The system is future-proof in the sense that the frequency range can be extended simply by exchanging the feed array with testing to 3G, 4G or 5G radio requirements determined by auxiliary instruments. ■

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The Automotive Market Will Be a Growth Engine for the Semiconductor Industry

Asif Anwar Techlnsights, Milton Keynes, England

he macroeconomic challenges posed by the conflict in Ukraine, the Chinese property sector crisis, European energy prices and subsequent global inflationary pressures have served to dampen consumer confidence as disposable income dries up. This has resulted in semiconductor demand from smartphones, data centers and consumer electronics floundering. The automotive sector has to date been relatively resilient and consequently, automotive semiconductor demand is bucking the trend. The TechInsights "Automotive Semiconductor Demand Outlook 2021 to 2030" forecasts continued growth with the global automotive semiconductor market serving as a growth engine for the overall semiconductor industry.¹

AUTOMOTIVE SEMICONDUCTOR DEMAND OUTLOOK

In 2022, the global demand for automotive semiconductors based on original equipment manufacturer (OEM) vehicle production grew by 24 percent year-on-year to reach \$54 billion, averaged across all applications, including sensors. A

combination of strong demand and constrained supply translated into semiconductor pricing increases which also served to further bolster revenues for the automotive semiconductor industry. In 2023, the automotive semiconductor market is forecast to grow by 19 percent and the referenced report forecasts that the global automotive semiconductor market will almost triple by 2030.

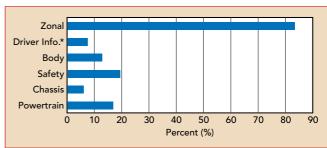
This revenue increase is not being driven by a tripling of vehicle output. Instead, it is the semiconductor content per vehicle that is increasing over this timeframe. This is reflected by growth trends across the vehicle domains of powertrain, body, chassis, safety and driver infotainment, as well as the emergence of a zonal domain. The semicon-

ductor growth rate performance for these domains is shown in *Figure 1*.

Underpinning this growth will be the continued momentum towards electrification. Electrification, in turn, is a core tenet as the

automotive industry moves towards domain-based and zonal electrical/ electronic (E/E) architectures. The goal is to enable vehicle capabilities across advanced driver assistance systems (ADAS) and automated driving (AD), along with advanced infotainment, telematics and vehicle connectivity.

Growth of the "zonal" domain will be predicated upon the move towards new platforms that will be underpinned by battery electric vehicles. Semiconductor demand from zonal controllers will grow at a compounded average annual growth rate (CAAGR) of 83.5 percent from 2022 to 2027. This demand will account for an additional \$84.7 billion of cumulative demand from 2022 to 2030, as it drives up the use of



▲ Fig. 1 Automotive semiconductor growth by domain. *Source:* TechInsights forecast.



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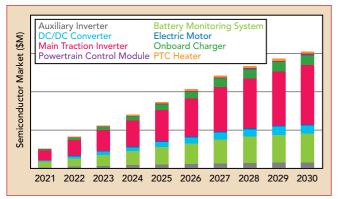
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♠ Fig. 2 xEV powertrain semiconductor demand. Source: TechInsights.

increasingly sophisticated semiconductor processors to support the push toward a software-defined vehicle (SDV).

The continued expansion of OEM electric vehicle (xEV) offerings is driving high levels of semiconductor growth, particularly for power electronics and battery management components within the powertrain domain. The powertrain domain is forecast to grow with a CAAGR of 18 percent from 2022 to 2027. As outlined in the TechInsights "xEV Semiconductor Demand Outlook 2021-2030," xEV light vehicle powertrain production, incorporating mild hybrid, full hybrid, plug-in hybrid and battery electric vehicles, will grow from 21 million units in 2022 to reach 58 million units by 2030.

The push to electrified powertrains is being dictated by consumer awareness and government regulations and mandates related to climate change and the need to reduce emissions and slow the impacts of global warming. With timelines ranging from 2030 to 2040, several countries have put into play policies that effectively ban the sales of internal combustion engine-based vehicles.

The corresponding xEV powertrain semiconductor demand from battery management systems, DC/ DC converters, main traction inverter, electric motor and onboard charger and other systems is forecast to grow at a CAAGR of 24 percent, reaching \$31 billion by 2030. The system segmentation for the total semiconductor revenue in xEV powertrains is shown in Figure 2. Battery electric vehicles will comprise the largest market for semiconductors growing at a CAAGR of 31 percent and accounting for 86 percent of the total xEV powertrain semiconductor market opportunity in 2030. The move to battery electric vehicles will be accompanied by a push towards increasing use of wide bandgap technologies. By 2030, the industry will be approaching a tipping point when silicon carbide (SiC) semiconductor demand starts to exceed that of silicon power semiconductors. There will also be an emerging opportunity for GaN power electronics.

While xEV powertrains become mainstream, the number of ADAS/AD sensors per vehicle will continue to grow. This will mean that the safety domain will grow at a faster CAAGR of 21 percent from 2022 to 2027.



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Safety domain growth is driven by a combination of rapid ADAS adoption in premium and mid-range vehicles, continuing penetration growth of passive safety systems in the emerging markets and the inclusion of additional safety systems to meet safety rating requirements.

A trend toward LED-based lighting and more sophisticated and capable gateway modules will drive automotive semiconductor demand from the body domain. The body domain will grow at a CAAGR of 13.0 percent and will be an early driver for system-on-chip (SoC)based processing requirements, as well as underpinning moves towards Ethernet-based in-vehicle networking from gateway modules. Other growth areas will include adaptive front lighting matrix, LED front lighting and near-field communication enhanced passive keyless entry systems.

Automotive semiconductor demand from the driver info domain will be driven by a move towards centralization of infotainment, driver

instrumentation and other functionality. Fully flat panel and high-end hybrid primary instrumentation clusters are the high growth drivers for semiconductors demand, as vehicle OEMs compete to differentiate the look and feel of their products through innovations in the clusters and A/V infotainment systems. A move towards centralization of infotainment, driver instrumentation and other functionality will drive cockpit-domain controller concepts that start to bleed over into crossdomain territory with ADAS systems. This will further positively impact driver information architectures and semiconductor requirements.

Semiconductor demand from the chassis domain will remain the most conservative over the forecast time-frame, but there are some notable areas of growth in drive-by-wire systems for braking and steering.

This will translate to semiconductor content per vehicle increasing by over 181 percent over the 2022 to 2027 timeframe. By 2030 there will be on average \$1400 of semicon-

ductor content, including semiconductor-based sensors, per vehicle. These trends will be reflected in the breakdown of the automotive semiconductor market by device type, with automotive processor demand accounting for the largest share of the automotive semiconductor market followed by demand for power semiconductors and linear devices.

- Memory exhibits the highest CAAGR from 2022 to 2027 and will be shaped by continued demand for high performance processing in ADAS applications and high-end infotainment graphics.
- Processor demand will also see an increasing shift towards SoCs versus microcontrollers as the market adopts zonal architectures and looks to high performance compute capabilities to meet the needs of the battery electric SDV.
- Power semiconductor growth will be driven by the move towards electrification driving opportunities for SiC and GaN as well as mainstream silicon power semiconductors.
- Linear devices incorporate a broad range of devices. Growth will be driven by demand for RF-ICs from automotive radar applications, ADC-based battery management ICs and demand for in-vehicle network transceivers like CAN/CAN-FD, LIN, Ethernet, MOST, FlexRay, etc.
- Optoelectronic device demand will come from exterior and interior lighting as well as the use of optoisolators in xEV platforms.

ARE WE AT THE END OF SEMICONDUCTOR SHORTAGES YET?

During the global lockdown period, the decision by many automotive OEMs to stop ordering materials as they shuttered production effectively put the industry at the back of the queue. When production started up again, a feeding frenzy placed an excessive strain on automotive-specific semiconductor technologies, especially those based on older process nodes like 28 nm, 40 nm, etc. The fabs running these processes had typically not been upgraded so they filled up very quickly. With little overhead,





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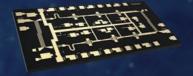
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- NPA2004-DE | 25.0-28.5 GHz | 35 W
- NPA2020-DE | 24.0-25.0 GHz | 8 W
- NPA2030-DE | 27.5-31.0 GHz | 20 W
- NPA2040-DE | 27.5-31.0 GHz | 10 W



V

- NPA4000-DE | 47.0-52.0 GHz | 1.5 W
- NPA4010-DE | 47.0-52.0 GHz | 3.5 W



- NPA7000-DE | 65.0-76.0 GHz | 1 W
- NPA7010-DE | 71.0-76.0 GHz | 4 W*
- * In Fabrication



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these facilities have continued running at full capacity leading to significant bottlenecks and forming one of three contributing factors that resulted in the automotive semiconductor shortage.

While the supply of these more mature products started to close the gap with demand in the second half of 2022, the push towards electrification provided the other two contributing factors to the semiconductor shortage. As automotive OEMs started to follow early leader Tesla into electrification, the premium sector became the primary target as companies looked to retain profitability amidst the significantly higher costs associated with the electrified powertrain. The push to premium sector vehicles brought with it a near doubling of semiconductor content compounding the bottleneck even as overall production volumes remained low.

The third contributor centered around electrification plus the associated trends around ADAS/AD, infotainment systems, connectivity,

domain and zonal/centralized architectures. This shifted focus towards higher performance and specialized semiconductor requirements that were not in place before 2021. This shift in focus represented a supplydemand imbalance that continued to be worked through in 2022 and has rolled over into 2023.

Consequently, suppliers were playing catch-up to demand in 2022 with global automotive semiconductor revenue growth continuing to outstrip year-on-year vehicle production and resultant semiconductor demand from vehicles productor demand per vehicle has also been growing. This combination of strong demand and constrained supply further translated into semiconductor pricing increases which served to bolster revenues.

However, there were signs that the mismatch between automotive semiconductor industry revenues and actual semiconductor demand was closing, with 21 percent year-onyear semiconductor demand from vehicles produced translating to a \$54 billion market in 2022. TechInsights estimates that 2022 automotive semiconductor vendor revenues increased 27 percent year-on-year, growing from \$46 billion in 2021 to \$59 billion. Moving into 2023, analysis on lead times and inventories at companies such as NXP, Renesas and Rohm affirms a trend that shows the overall move towards a more normal supply-demand dynamic. However, TechInsights believes that while we are starting to see the beginning of the end of the semiconductor shortage, a normalization of the supply-demand balance will not start to be observed until the second half of 2023.

AUTOMOTIVE SEMICONDUCTOR MARKET LEADERS

TechInsights' annual "Automotive Semiconductor Vendor Market Share"³ survey and top-down analysis of automotive semiconductor vendor sales revenues and market shares concluded that 2022 automotive semiconductor vendor revenues increased 27 percent year-on-year, growing from \$46 billion in 2021 to \$59 billion. Infineon maintained the top spot in the 2022 automotive semiconductor vendor market share rankings while NXP remained in second place. Renesas, blighted by the effects of a weak Yen, slipped from third position to fifth. STMicroelectronics took third place and Texas Instruments jumped into fourth place. Collectively, these top five vendors accounted for 49 percent of the 2022 automotive semiconductor vendor

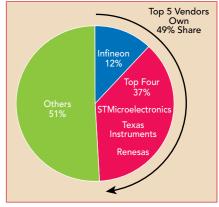


Fig. 3 2022 automotive semiconductor market snapshot. Source: TechInsights.





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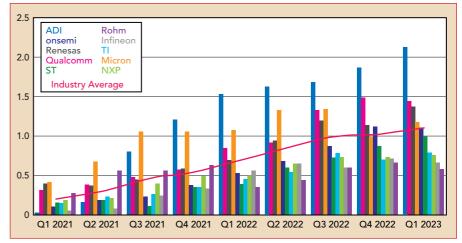


Fig. 4 Automotive semiconductor index. Source: TechInsights.

revenues. The bottom half of the top 10 includes onsemi, Bosch, ADI, Micron and Qualcomm. The top 10 companies grew their collective share of global automotive semiconductor revenues in 2022 to 71 percent versus 69 percent in 2021. *Figure 3* shows the 2022 snapshot of the automotive semiconductor market share.

The automotive sector has, to date, been relatively resilient and consequently, automotive semiconductor demand is bucking the broader consumer electronics trend. This is reflected in the Techlnsights Auto Semi Index shown in *Figure 4* as presented in the quarterly "Automotive Semiconductor Industry Performance Snapshot," This report tracks the automotive revenues for 10 of the leading publicly quoted automotive semiconductor companies and shows continued quarter-on-quarter growth.

CONCLUSION

Despite the headwinds created by geopolitical events like the conflict in Ukraine, property sector issues in China, a global increase in energy prices and the subsequent global inflationary pressures that these and other events have stirred up, the automotive sector has been resilient. In the face of dampened consumer confidence and decreasing disposable income, global demand for automotive semiconductors grew by 24 percent yearon-year to \$54 billion in 2022. A combination of strong demand and constrained supply translated into

semiconductor pricing increases which have bolstered revenues for the automotive semiconductor industry. With these headwinds conspiring to reduce demand for smartphones, data centers and consumer electronics, the automotive sector has been a powerful growth engine for the semiconductor industry.

The TechInsights "Automotive Semiconductor Demand Outlook 2021 to 2030" report forecasts that automotive semiconductor demand will grow by 19 percent in 2023, enabled by the continued momentum towards electrification. This will translate to automotive semiconductor demand serving as the growth engine for the overall semiconductor industry, growing at a CAAGR of almost 17 percent over the 2022 to 2027 five-year period. The result will be automotive semiconductor demand almost tripling to \$144 billion by 2030. ■

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| CA12-2110 | 1.0-2.0 | 30 | 1.0 MAX, 0.7 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA24-2111 | 2.0-4.0 | 29 | 1.1 MAX, 0.95 TYP 1.3 MAX, 1.0 TYP | +10 MIN +10 MIN +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 | 29 27 | 1.6 MAX, 1.4 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA1218-4111 | 12.0-18.0 | 25 | 1.9 MAX, 1.7 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA1826-2110 | 18.0-26.5 | 32 | 3.0 MAX, 2.5 TYP | +10 MIN | +20 dBm | 2.0:1 |
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| CAOLOLL | | | | | | 2.0.1 |
| 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 +10 MIN +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 | I 4 MAX I 2 IYP | +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 | 1.0 MAX, 1.4 TH | +33 MIN | +41 dBm | 2.0:1 |
| CA34-6116 | 3.1 - 3.5 | 30 40 | 4.0 MAX, 3.0 TYP 4.5 MAX, 3.5 TYP | +35 MIN | +41 dBm | 2.0:1 |
| | | 20 | 5 0 MAY 4 0 TVD | | | |
| CA56-5114 | 5.9 - 6.4 | 30 | 5.0 MAX, 4.0 TYP | +30 MIN | +40 dBm | 2.0:1 |
| CA812-6115 | | 30 30 | 4.5 MAX, 3.5 TYP 5.0 MAX, 4.0 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 | | +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-BRO | ADBAND & | MULTI-OC | TAVE BAND AI | MPLIFIERS | | |
| Model No. | Freq (GHz) | Gain (dB) MIN | Noise Figure (dB) | Power-out @ P1-d | 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 |
| CA0108-3111 | 0.1-8.0 | 26 | 2.2 Max, 1.8 TYP | +10 MIN | +20 dBm | 2.0:1 |
| | 0.1-8.0 | 20 | 2.2 Mux, 1.0 III | +10 MIN +22 MIN | | |
| CA0108-4112 | | 32 36 | 3.0 MAX, 1.8 TYP | | +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 22 | 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 | 7.3 | 3.U MAA. 3.3 HT | +23 MIN | +33 dBm | 2.0:1 |
| CA618-6114 | 6.0-18.0 | 35 | 5.0 MAX, 3.5 TYP | +30 MIN +23 MIN +30 MIN | +40 dBm | 2.0:1 |
| CA218-4116 | 2.0-18.0 | 35 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 A | | | 310 111111, 010 111 | | 10 1 ubiii | 2.01. |
| Model No. | | nout Dynamic Ro | ange Output Power | Range Psat Pov | wer Flatness dB | VSWR |
| CLA24-4001 | 2.0 - 4.0 | -28 to ±10 dR | m ⊥7 to ⊥1 | 1 dRm | +/- 1.5 MAX | 2.0:1 |
| CLA24-4001 CLA26-8001 | 2.0 - 6.0 | -20 to +10 db | m +7 to +1 m +14 to +1 | I & dRm | /- 1.5 MAX | 2.0:1 |
| | | 21 to . 10 db | m +14 10 +1 | 10 dDm | +/- 1.5 MAX +/- 1.5 MAX | |
| CLA712-5001 | 7.0 - 12.4 | -21 to +10 dB | m +14 to +1 | 19 dBm - | / 1.5 MAN | 2.0:1 |
| CLA618-1201 | 6.0 - 18.0 | -50 to +20 dB | | 1 4 apm - | + / - 1.5 MAX | 2.0:1 |
| AMPLIFIERS V | | | | | Au r D | VCMB |
| Model No. | Freq (GHz) | Gain (dB) MIN | Noise Figure (dB) Pov | ver-out@P1-dB Gair | | |
| CA001-2511A | | 21 5 | | +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 | $\overline{25}$ $\overline{2}$ | .2 MAX, 1.6 TYP | +16 MIN | 20 dB MIN | 1.8:1 |
| CA1518-4110A | 15.0-18.0 | | .0 MAX, 2.0 TYP | +18 MIN | 20 dB MIN | 1.85:1 |
| LOW FREQUE | | | 2.0 111 | | | |
| Model No. | | 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 |
| CAOO 1-2 1 1 U | 0.01-0.10 | 24 | 2 E MAY 2 2 TVD | | | |
| CA001-2211 | 0.04-0.15 | 24 | J.D MAX, Z.Z IYP | +13 MIN | +23 dBm | 2.0:1 |
| CA001-2215 | 0.04-0.15 | 23 | 3.5 MAX, 2.2 TYP 4.0 MAX, 2.2 TYP 4.0 MAX, 2.8 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 | 2/ | 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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New Radar, Game-Changing Capability

n a sign of further confidence in the future of the Eurofighter Typhoon program, the UK Ministry of Defence has awarded BAE Systems a £870 million contract to deliver a new radar to enhance the Royal Air Force's Typhoon fighter jet fleet.

Lyndon Hoyle, head of Typhoon Delivery Team, Ministry of Defence DE&S, said the funding will to lead to initial flight testing in 2024 and the overall objective of project to turn the ECRS Mk2 prototype into something that is operationally capable over the next five years.

The radar will strengthen the aircraft's control of the airspace and provide cutting-edge electronic warfare capabilities. The contract is part of the U.K. Government announcement, made in July 2022, to invest £2.35 billion in the continued technology advancements in Typhoon capabilities, as recognition of its long-term role supporting national security and defense priorities.

BAE Systems leads the overall design, development, manufacture and upgrade of the Typhoon aircraft for the U.K. and Leonardo is the lead for the aircraft's main



Eurofighter (Source: Eurofighter)

sensing and survivability systems including its radar and defensive aids subsystem.

BÁE Systems received the prototype ECRS Mk2 radar from Leonardo

in April and has already clocked up hundreds of hours of 'flying' without ever once leaving the ground.

Some might have assumed that the ECRS Mk2 would go straight into a development aircraft and then into the skies. However, the fact is one of the world's most sophisticated radars is being tested in a unique building on the edge of the runway at BAE Systems' Warton base, known as the Integrated Test Facility (ITF). It is being initially put through its paces there to help save time, money and manpower as well as the environmental damage from countless flights.

A test Typhoon aircraft BS116 is already being prepared by the BAE Systems team at Warton so that it is ready to receive the prototype radar ready for flight trials once it has been through a series of tests in the ITF. Typhoon is a highly capable and extremely agile multirole combat aircraft. It is capable of being deployed for the full spectrum of air operations, including air policing, peace support and high intensity conflict.

James Glazebrook, deputy director – Europe, BAE Systems, told a media briefing at BAE Systems Integration and Test Facility that the ECRS Mk2 will take Typhoon's capability to the next level. He said, "It will bring new electronic attack and electronic warfare capabilities, enabling the aircraft to simultaneously detect,

identify and track multiple targets in the air and on the ground."

As an electronic attack and warfare tool the ECRS Mk2 will be incredibly capable — able to carry out sophisticated electronic warfare functions while performing its primary role as an air-to-air radar sensor.

The Safe Integration of Drones into Airspace is Getting Closer

ensor solutions provider HENSOLDT is taking the development of its collision warning system for civil and military drones to a new level. The demonstrator study for a detect-and-avoid (DAA) radar, commissioned by the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw), enables a further step toward the safe integration of drones into controlled airspace.

The German customer has drawn up requirements for an investigation into the implementation of a gradual and full-scale airspace integration of the EU-RODRONE. For this, a DAA system is foreseeably nec-

essary, which is to be advanced in a gradual series development.

In the run-up to this future development of a DAA system, HENSOLDT—as a long-standing partner of the German Armed Forces in the field of radar technology—has car-



DAA Radar (Source: Hensoldt)

ried out risk-minimizing national and European studies regarding the concept and design of a special radar sensor system for such a DAA system. The flight test campaigns carried out and the results obtained in the course of these studies in preparation for development are already proving the functional capability.

The DAA radar is one of the decisive sensors in a complex DAA system on board unmanned aerial vehicles. It supports the calculation of evasive maneuvers for collision avoidance by detecting, classifying and forming complete tracks of approaching objects in the airspace. Due to the multifunctional design of this radar, the requirements for integrating a weather radar function and a possible perspective regarding the support of a separate landing aid will also be considered.

The currently commissioned study for the DAA radar includes the investigation of the technical feasibility for the EURODRONE project, the verification with a near-series demonstrator as well as risk mitigation for a future series development. Since the novel DAA radar is a flight- and mission-critical component, the study deals, particularly, with the implementation of safety requirements and the approval strategy at national and inter-

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national aviation safety authorities (EASA, LBA) as well as military organizations.

NGC to Design an Autonomous Vertical Takeoff and Landing Aircraft

orthrop Grumman Corporation (NGC) has been awarded a contract by the Defense Advanced Research Project Agency's (DARPA) Tactical Technology Office to design an autonomous vertical takeoff and landing (VTOL) uncrewed aircraft system capable of operating from a moving Navy ship

The AdvaNced airCraft Infrastructure-Less Launch And RecoverY (ANCILLARY) demonstrator will be designed as a cost-efficient, multiple-mission capable vehicle built on an agile platform that is runway independent.

It will be capable of carrying a large 60-pound sensor payload with greater endurance of 20 hours' time on station and mission radius range of 100 nautical miles, which is more than current systems, without using significant additional infrastructure aside from what is on board the air vehicle. The system will also have the capability to land on a ship in adverse weather conditions.



ANCILLARY (Source: Northrop Grumman)

The aircraft will be capable of performing intelligence, surveillance, reconnaissance and targeting missions, supporting expeditionary missions for special operations forc-

es and logistical missions with significant affordability impacts for ship-to-shore transition of parts and supplies.

DARPA's ANCILLARY program aims to develop and flight demonstrate an X-plane with the critical technologies required for a leap-ahead in long endurance, VTOL unmanned air system (UAS) performance. The UAS will be able to launch and recover from ship flight decks and small austere land locations in adverse weather without additional infrastructure equipment, thus enabling expeditionary deployments. Unlike large VTOL systems, the small UAS size will enable many aircraft to be stored and operated from one ship creating a tactical beyond-line-of-site, multi-intelligence sensor network capability.

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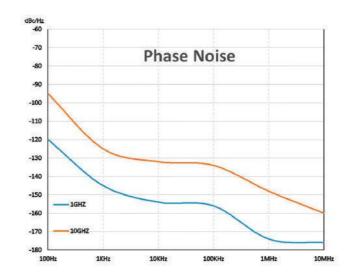
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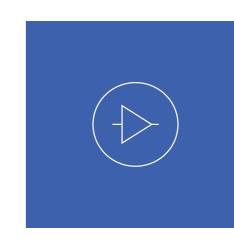




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Cliff Drubin, Associate Technical Editor

Overview of the Semiconductor Devices Industry

ole Intelligence released its "Overview of the Semiconductor Devices Industry 2023" report. According to the report, the trillion dollar semiconductor industry is poised for a new cycle of growth fueled by breakthroughs in artificial intelligence (AI), quantum computing, 5G and specialized applications.

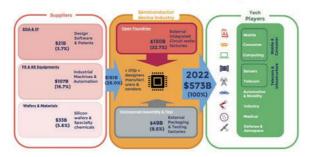
Semiconductor device revenue peaked in 2022 at \$573 billion and is expected to retreat 7 percent to \$534 billion in 2023. This industry plays a critical role in enabling technological advancements across various sectors, including mobile and consumer, infrastructure, automotive and industrial. Over the past few decades, the industry has experienced a sustained 6.4 percent compound annual growth rate, driven by increasing demand for mobile and consumer electronics, the rise of internet applications such as social media and the rapid digitalization of most industries.

ICs are becoming smaller, more powerful and capable of handling complex tasks, paving the way for new technology advancements such as AI, machine learning and edge computing. This evolution presents both opportunities and challenges for companies in the industry, requiring them to invest massively in research and development and capital expenditure for new foundries to maintain significance in this fast-paced ecosystem.

The semiconductor device industry relies heavily on global ecosystems, making supply chain resilience and risk mitigation crucial for sustained success. Recent disruptions and geopolitical tensions have highlighted the vulnerabilities of the semiconductor supply chain.

The semiconductor industry is geographically concentrated in a few places, primarily the U.S., Taiwan, Korea, Japan, Europe and mainland China. The dominance of U.S.-based semiconductor device companies is historical; in the last five years, they have maintained a 53 percent market share. If we combine all types of semiconductor company business models, i.e., adding the open foundries, OSAT, equipment and material companies, the market share of U.S. companies drops

SEMICONDUCTOR INDUSTRY VALUE CHAIN



Semiconductor Industry Value Chain (Source: Yole Intelligence)

to 41 percent; and if only the added value is considered, then the U.S. share becomes 32 percent, and this number has been diminishing at a rate of 1 percentage point per year in the last five years.

At the center of competition is the More Moore node race in the manufacturing process, currently 7, 5 and 3 nm, as well as future smaller nodes. These cutting-edge processes enable higher transistor density, improved performance and energy efficiency though they pose significant challenges in terms of development costs, yield rates and manufacturing complexity. The industry is, therefore, actively exploring innovative solutions through More than Moore approaches. NAND memory is headed full steam into 3D stacking, while advanced packaging has become vital for all leading players. Many innovation trends are driving the semiconductor industry; wide bandgap compound semiconductors, photonic integration, quantum computing and neuromorphics will play roles in expanding the industry.

Toward 90 Percent of Cars Connected in 2028: What are the Driving Forces?

he connectivity module market is projected to grow from US\$2.9 billion in 2023 to US\$6.1 billion in 2028 with a compound annual growth rate (CAGR) of 16 percent. Nevertheless, according to Yole Intelligence, the landscape is evolving rapidly, with compelling use cases like teleoperated autonomous vehicles and automated valet parking expected to be implemented by the end of the decade. New car assessment programs (NCAPs), especially China NCAP and EuroNCAP, are also driving vehicle-to-everything (V2X) adoption as soon as 2025.

Yole Intelligence has combined its long expertise in semiconductors and its deep knowledge of automotive connectivity technologies and markets to deliver this first edition of the RF for connected vehicles report. This study provides market metrics and forecasts for automotive connectivity. It analyzes the drivers and challenges for automotive connectivity adoption and presents the main technological trends and ongoing developments in automotive connectivity with a focus on 5G RedCap and Global Navigation Satellite System (GNSS) correction services. This report also discusses the main players across the automotive connectivity supply chain and analyzes how the business models and supply chains are evolving.

Regarding V2X, NXP initially led with its DSRC chipset, but due to regulatory challenges and the introduction of cellular-V2X, Autotalks and Qualcomm gained prominence. Qualcomm's advantage lies in its scale and the integration of V2X in the cellular baseband, aligning with non-safety applications. However, for safety-related V2X applications in the future, Autotalks is expected

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Commercial Market

to excel as a standalone V2X is necessary for Automotive Safety Integrity Level (ASIL)-B certification.

Qualcomm's integration of GNSS capabilities in its cellular baseband impacted U-Blox's position in the telematics control unit business. However, with safety becoming a requirement for future applications, GNSS players like u-blox are seeing renewed interest.

Consolidation has occurred among sub-system companies, such as the merger of Telit and Thales' module business and the equity acquisition of Rolling Wireless by Fibocom. At the Tier 1 level, consolidation has already occurred, with Valeo acquiring Peiker and Samsung purchasing Harman. However, there are still numerous small-scale companies in the supply chain that may be acquired as the market continues to grow.

Vehicular Child Presence Detection to Drive 3.5M 60 GHz Automotive Radar Shipments in 2030

river and occupant monitoring systems will be the fastest-growing active safety system over the decade, growing at a CAGR of 25 percent between 2023 and 2030, according to a new report by ABI Research. Regulation and the standardized testing of fatigue detection, attention assistance and child presence detection (CPD) in safety rating agencies, such as the National Highway Traffic Safety Administration's NCAP, drive this growth.

mmWave radar is the ideal technology for CPD. This safety application detects if children have either been left behind or have gained access to a vehicle and become trapped inside. CPD detects signs of life in the rear of a locked car, alerting the owner or emergency services and activating the heating, ventilation, and air conditioning system, where possible. mmWave radar can penetrate through occlusions such as the driver/front passenger, front seats and child blankets to detect forgotten children in areas that camera sensors cannot see. mmWave sensors can also catch the subtle movements associated with breathing and heartbeat, resulting in more robust detection of a forgotten child, as opposed to an empty child seat.

Volvo has pioneered the first radar-based CPD system, set for its introduction on the EX90 SUV, which will leverage three 60 GHz radar sensors. This wavelength benefits from broad regulatory approval for in-cabin sensing in key automotive markets and a broad range of application-specific solutions from vendors such as TI, Infineon and Socionext. In the long term, ultra-wideband sensors equipped to vehicles to power the smart access use-case could also be repurposed to deliver the CPD use-case without needing an additional 60 GHz radar — an approach pioneered by NXP.



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IN MEMORIAM

In May of 2023, the microwave industry lost one of its pioneers, when Fred P. Storke Jr. passed in Palo Alto, Calif. Fred earned a B.S.E.E. at the University of Colorado along the way, then a National Science Foundation fellowship and an M.S.E.E. at Stanford University. After stints at the National Bureau of Standards, NASA, Magnavox, Fairchild and Philco, Fred changed avenues. In partnership with Fred Kruse, he formed a new company called Kruse-Storke, which conceived the Kruse-Storke sweeper. After years of working independently, Fred returned to mainstream engineering, with posts at Ford Aerospace and California Microwave before co-founding Storke Industries and then Syntonic Microwave. Even in retirement, Fred continued engineering from his home garage. To multiple generations of people inhabiting the RF and microwave space, Fred was a leader, a visionary, a teacher, an inspiration and shining example of how to fearlessly and unhesitatingly turn ideas into reality.

MERGERS & ACQUISITIONS

Maury Microwave Inc., backed by Artemis Capital Partners, announced that it has completed its previously announced acquisition of Wireless Telecom Group Inc. Since its founding in 1985, Wireless Telecom Group's test and measurement businesses — comprising of Boonton, Holzworth and Noisecom — have served as trusted technology solutions partners to many leading manufacturers in the wireless technology chain. Across aerospace, defense, satellite communications, semiconductor, quantum and directed energy applications, the group's technology portfolio enables its customers to push the boundary of RF and microwave technology.

Frontgrade Technologies, a portfolio company of Veritas Capital and a leading independent supplier of high-reliability, advanced electronic solutions for space and national security missions, announced the completion of its acquisition of Aethercomm, a designer and manufacturer of high-power RF solid-state power amplifiers as well as transmit/receive and high-power RF switches. Since its inception over 60 years ago, Frontgrade and its products have had a presence on major historical U.S. space platforms. The combined company will now offer complete, integrated and turnkey solutions for aerospace and defense customers by joining Aethercomm's active RF amplifiers, switches and hardware with Frontgrade's existing antenna solutions.

Trexon, a portfolio company of Audax Private Equity and provider of connectivity solutions for missioncritical applications, announced that it has completed the acquisition of **603 Manufacturing**, a value-added manufacturer of high performance wire and cable assemblies, RF/microwave coaxial cable assemblies.

Avanos Medical has announced that it has entered into a definitive agreement to acquire Diros Technology, a leading manufacturer of innovative RF products used to treat chronic pain conditions. Based in Toronto, Canada, Diros Technology has been at the forefront of radiofrequency ablation (RFA) technology since its founding. In the global market, over one million RFA procedures are performed annually in the treatment of chronic musculoskeletal pain. For chronic pain management, Diros Technology's products deliver RF energy through precisely placed, minimally invasive probes that heat nervous tissue near the probe's tip, deactivating the nerve's ability to transmit pain signals.

Versar Inc., a global engineering, environmental and security services platform backed by Kingswood Capital Management, announced that it has completed its acquisition of Louis Berger Services (LBS) from WSP Global Inc. LBS specializes in operations and maintenance services for complex infrastructure assets at mission-essential defense and civilian facilities worldwide and currently employs approximately 1,400 people. Versar, Inc. delivers high value solutions to vital programs in the natural, built and digital environments. Versar is headquartered in Washington, D.C., and has three operating segments including environment and sustainability, national security and installation management and support services.

Sentar Inc., a women-owned business specializing in advanced cyber intelligence solutions and technology, announced that they have acquired Waterfront Technical Services, a Huntsville-based company. Waterfront's portfolio includes flight and ground operations, data center operations, information technology, software development and test supporting NASA's spaceflight missions. As a key member of Teledyne Brown Engineering's MOSSI team, Waterfront is currently providing mission-critical support to NASA's ISS, Artemis, Gateway and Human Lander projects. Sentar is a leading cyber intelligence solutions provider focused on the national security sector. Its cyber domain solutions blend expertise in cybersecurity, systems engineering, intelligence and analytics into holistic solutions that combine these disciplines to deliver superior results to mission partners.

COLLABORATIONS

Rohde & Schwarz, in collaboration with Qualcomm Technologies, conducted a broad range of NB-IoT over NTN tests that address the many challenges inherent to satellite-based non-terrestrial networks that use geosynchronous orbit (GSO) and geostationary orbit (GEO) constellations. The test set covers time and frequency synchronization from prolonged delays and the Doppler effect, low signal-to-interference-plus-noise ratio, power saving mechanisms, satellite ephemerides,

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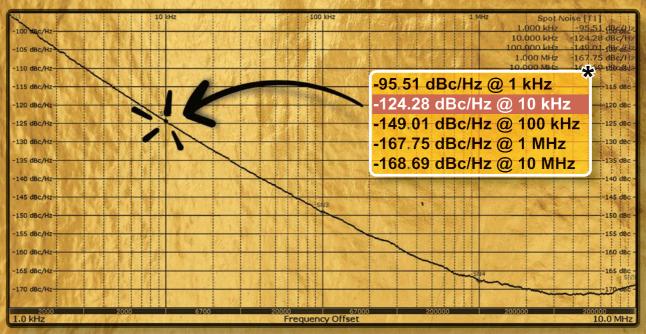
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Around the Circuit

GNSS acquisition and more.

Aitech Systems has collaborated with FlySight Srl to bring improved situation awareness into size, weight and power (SWaP)-constrained military applications. In this innovative partnership, FlySight's artificial intelligence-based, real-time augmented reality (AR) engine OPENSIGHT-mc has been integrated into Aitech's A172, a small form factor mission computer for applications requiring high performance data and video processing in harsh environments. Designed to assist in critical aircraft missions, this robust, data-driven system seeks to provide military and defense operations with improved autonomous tasks, situation control, intelligence and decision-making assurance. The combined mission computer and AR engine solution eases integration issues and facilitates better model recognition, event reasoning and adaptive learning using available data.

ACHIEVEMENTS

Ulrich L. Rohde has been awarded the 2023 IEEE Antennas and Propagation Society Distinguished Industry Leader award. It was awarded for his contribution and leadership to the field of antennas and related communication systems leading to development of state-of-the-art antennas products for industrial, military and aerospace applications.

Quantic Wenzel announced that it has received recognition from the State of Texas for outstanding service in the space electronics engineering and manufacturing industry. Senator Sarah Eckhardt sponsored the ceremonial resolution honoring the company's 30th year delivering crystal oscillators, frequency sources and integrated microwave assemblies for space applications. Additionally, a flag was flown over the state capitol in the company's honor. The flag and ceremonial resolution are on display at the company's facility in Austin, Texas.

Hughes Network Systems announced its JUPITERTM 3 ultra-high density satellite has successfully launched on a SpaceX Falcon Heavy rocket from historic Kennedy Space Center Launch Pad 39A in Florida. Also known as EchoStar XXIV, JUPITER 3 was built by Maxar Technologies in Palo Alto, Calif., and is engineered to deliver gigabytes of connectivity to customers across North and South America. On July 29 at 2:32 a.m. EDT, three hours and 28 minutes after lift-off, JUPITER 3 successfully deployed from the launch vehicle. The satellite began sending and receiving its first signals, and engineers deployed the JUPITER 3 solar arrays, which unfolded in space to their full ten-story span.

CableLabs, an innovation and research and development lab for the cable industry, and Telecom Infra Project (TIP) OpenWiFi, an open-source-based Wi-Fi architecture that enables part multi-vendor, managed Wi-Fi networks, have announced the successful validation of

new interoperable hardware and software, version 2.9, and the commissioning of a refreshed OpenWiFi Community Lab to serve as a testing ground and demonstration stage for global cable operators. This new initiative is part of CableLabs' ongoing collaboration with the TIP. OpenWiFi is a community-developed open-source platform designed to lower the cost of developing and operating Wi-Fi networks.

Ericsson announced that **Spark**, one of New Zealand's largest telecommunications and digital services providers, has appointed Ericsson to supply its 5G Core solution to power Spark's 5G Standalone (SA) network in New Zealand. This marks a major milestone in the partnership to create the potential for new monetization opportunities from the network slicing, network automation and edge computing capabilities of Ericsson's dual-mode 5G Core. The appointment follows the successful completion of a three-month 5G SA trial in 2022, demonstrating the ease with which cloud-native core network solutions — to support 5G SA — can be deployed.

CONTRACTS

Amentum was awarded an \$818 million contract for adversary aircraft sustainment and modernization of the U.S. Navy F-16 fleet. Amentum will manage all aspects of the Viper Maintenance Group Aircraft Maintenance and Contractor Logistics Support contract by providing technical, sustainment and logistics solutions for the Navy F-16 aircraft based at Naval Air Station in Fallon, Nev. Under this contract, Amentum maintains F-16/A/B/C/D aircraft and provides full system maintenance and supply chain support to aid continuous flight operations, along with many detachments executed simultaneously with home station operations. During the contract period, Amentum will support the Navy in growing their F-16 Adversary fleet across all sites.

DRS Global Enterprise Solutions, acquired and now part of SES's wholly-owned subsidiary SES Space & **Defense**, has been awarded a five-year X-Band blanket purchase agreement (BPA) with an estimated value of \$134 million in support of the U.S. Department of Defense (DOD). The single award BPA was awarded through Defense Information Systems Agency's Defense Information Technology Contracting Organization by the U.S. Space Force. To deliver a near-global solution, SES Space & Defense has partnered with several industry-leading players, including integrators, satcom and teleport operators. Together, the contracted satellite operators will deliver global X-Band satellite capacity, teleport and network services over a highly secure global terrestrial network and other ancillary services to meet enduring and emerging DOD requirements.

Viasat Inc., a global communications company, announced it has received awards totaling over \$80 million to develop active electronically scanned array (AESA) systems for ground, maritime and space applications. AESA, a type of phased array antenna that offers greater flexibility and resilience to support military



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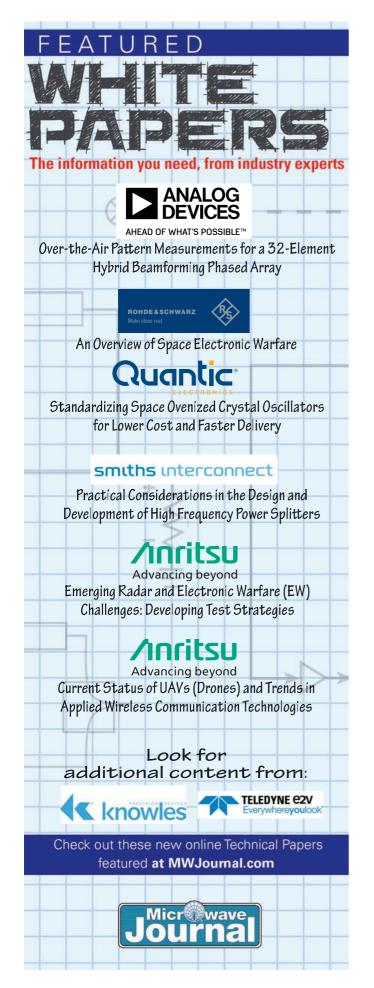


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Around the Circuit

platforms, is often employed when multiple beams, low probability of intercept and jamming resistance are required. Viasat is leveraging commercial AESA phased array antenna technology and products to meet these demanding defense requirements. The developments will enable Viasat's existing phased array technology to be extended and adapted to support defense operational environments and mission needs, enabling scalable and highly flexible capabilities to be achieved at previously unattainable recurring cost.

The Commonwealth's Capability Acquisition and Sustainment Group has selected EM Solutions to upgrade the Royal Australian Navy's satcom systems across its existing fleet of vessels. This is by far the largest contract ever signed by EM Solutions and demonstrates how support for the Sovereign Defence Industry, particularly small to medium enterprises, can deliver world leading capability and enhance sovereign capability. EM Solutions enters this contract as the prime contractor which will initially result in around 30 new positions, some of which have already been filled, at the company's head office in Brisbane.

PEOPLE



Mini-Circuits President, **Ted Heil** and Board Chair, **Alicia Kaylie Yacoby** announced that **Jin Bains** joined Mini-Circuits as CEO. Heil, who plans to step down as president, will continue in his current role through the remainder of 2023, supporting Bains during the transition. He will re-

main engaged on special projects and in governance and oversight indefinitely. Bains will serve as the third chief executive in Mini-Circuits' nearly 55-year history, following founder Harvey Kaylie and Ted Heil in leading the company, which is privately held.

REP APPOINTMENTS

Narda-MITEQ, a supplier of the high-quality RF/microwave components, subsystems, space-borne and satcom products and integrated microwave assemblies for military and commercial applications, has announced that it has expanded its distribution agreement with RFMW, a top-tier distributor for RF and microwave components with global reach and high technical capability. Under this agreement, Narda-MITEQ will be offering its broad portfolio of active and passive products through RFMW. Initially, the emphasis will be on high performance, low noise amplifiers, as well as broadband directional couplers and power dividers. RFMW's distribution services for Narda-MITEQ will include opportunity identification and development, technical sales support and distribution. A selection of Narda-MITEQ standard components will also be available through the RFMW online store.





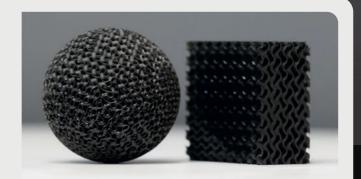
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Characterization of a MoS₂ Film Frequency Doubler with Direct Current Bias

Jianhao Ma, Yong Fang, Qingsong Zhang, Huijun Wang, Ziwei Xie and Qi Zhang Chengdu University of Technology, Chengdu, China

The strong nonlinearity of molybdenum disulfide (MoS_2) provides a basis for microwave and mmWave devices. Under natural conditions, MoS_2 exhibits a strong third-order nonlinearity, and it demonstrates a second-order nonlinearity with applied voltage. Based on this unique electrical property, a voltage-controlled MoS_2 frequency doubler is designed. With an input power of 20 dBm at 1 GHz, the output power is -27 dBm at 2 GHz. Experimental results are consistent with simulation demonstrating an excellent frequency doubling effect. Although this work was conducted at 1 GHz, MoS_2 has unique advantages for higher frequency applications as well. This offers new possibilities for controlling the electrical properties of two-dimensional (2D) semiconductor materials.

tudies have shown that 2D materials such as transition metal dihalides play an important role in optoelectronics due to their strong nonlinearities. MoS₂ is a new type of 2D semiconductor material with an ultra-thin, layer-like structure. It not only has a controllable bandgap and a special hexagonal crystal structure but also possesses a strong electrical nonlinearity. In 2017, Säynätjoki et al.¹ investigated the nonlinear properties of monolayer and multilayer MoS₂. It was shown that monolayer MoS₂ has a strong optical nonlinearity; the third harmonic is 30x stronger than the second harmonic.

The nonlinear property of ${\rm MoS}_2$ can be used to make devices such as microwave frequency multipliers and mixers that have unique advantages in microwave and mmWave

device applications. In 2019, Fang et al.² used the nonlinearity of MoS₂ to fabricate a microwave triplexer. The MoS₂-based triplexer, with an input power of 14 dBm and an input frequency of 0.75 to 1.1 GHz yielded an output power at the third harmonic of -27.1 dBm with a conversion loss of 41.1 dB, but the second harmonic effect was poor.

The nonlinear behavior of MoS₂ changes with applied DC bias. Based on this property, the design described is of a frequency doubler using a stable 2H MoS₂ semiconductor crystal.^{3,4}

Modeling of MoS₂ is important for the simulation of nonlinear devices based on it. In this work, MoS₂ is equated to a reverse parallel diode pair. Simulation shows that the model matches well with measured results and that the frequency dou-

bling effect can be adjusted by changing bias voltage.

By applying bias voltage to both sides of the MoS_2 crystal, the second harmonic output power is increased and the third harmonic output power is reduced. The proposed doubler has a compact structure with a simple fabrication process, making it suitable for the development of micro and nanodevices.

DESIGN AND MODELING

\mathbf{MoS}_2 Frequency Doubler Design Overview

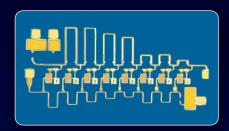
The design takes advantage of the strong nonlinear microwave properties of MoS₂, which are suitable for nonlinear devices such as a frequency multiplier.⁵ The structure comprises a bandpass filter, a bias circuit and a microstrip gap of



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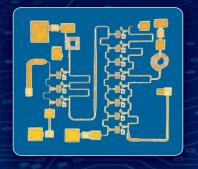




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- Gain, 23.5 dB
- Input & output matched to 50 Ohms

AMCOM's AM02018026WM-00-R is a broadband GaAs MMIC Distributed Power Amplifier die which operates between 2 and 18 GHz. This amplifier has 23.5 dB gain, and 26 dBm output power. The chip input and output are internally matched to 50 Ohms.

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Bandpass Filter

 MoS_2 (see **Figure 1**). The circuit is designed on an FR-4 substrate with thickness H = 0.8 mm and relative

Bias V_{bias}

GND

dielectric constant $\varepsilon_r = 4.41$. The microstrip line thickness is T = 0.35 μ m and its loss tangent TanD = 0.02. The

 $50\,\Omega$ microstrip line width is 1.41 mm with a gap length of 0.35 mm. The MoS $_2$ crystal is in the form of a tape sticker from Shenzhen Six Carbon Technology Company.

The bandpass filter eliminates clutter with a passband of 400 to 1200 MHz covering the operating band of 800 to 1100 MHz. DC is provided on both sides of the microstrip gap by bias networks to enhance second harmonic emission from the MoS_2 and improve the frequency doubling efficiency.

Modeling

When metal is in contact with a semiconductor material (Schottky contact), a potential barrier, called a Schottky barrier, is formed at the metal-semiconductor junction.^{6,7} The Schottky barrier controls the current and capacitance characteristics at the contact surface, which in turn affects the electrical properties of the Schottky semiconductor.⁸⁻¹⁰

Based on the electrical conductivity of MoS₂¹¹⁻¹⁴ and the relationship between multilayer MoS₂ and monolayer MoS₂, ¹⁵ MoS₂ can be equated to a nonlinear resistance and capacitance in parallel. The equivalent circuit based on the resistor-capacitor model tends to ignore the parasitic capacitance, resulting in a slight difference between simulated and measured results.

Schottky diodes are designed based on the physical properties of metal-semiconductor Schottky contacts, for which a diode model is proposed that can effectively describe the frequency doubling characteristics of MoS₂ films. According to the theory of MoS₂ Schottky contacts, ¹⁶⁻¹⁸ the MoS₂ Schottky junction is equivalent to a combination of a resistor and an anti-parallel diode pair. The Cu-MoS₂ and MoS₂-Cu interfaces in the circuit form the reverse-connected Schottky diodes.

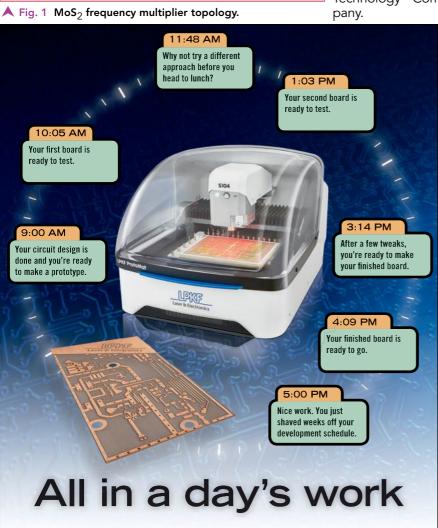
The I-V characteristic of a non-linear device can be represented by: 19,20

$$I = f(u) \tag{1}$$

Where \mathbf{u} is the voltage $\mathbf{u} = V_0 + \mathbf{u}_0$ applied to the nonlinear device. Equation (2) is a series expansion of Equation (1):

$$I = \alpha_0 + \alpha_1 u_1 + \alpha_2 u_1^2 + \dots + \alpha_n u_1^n + \dots = \alpha \sum_{n=0}^{\infty} n u_1^n$$
 (2)

Where α_n (n = 0, 1, 2...) is deter-



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mined by Equation (3).

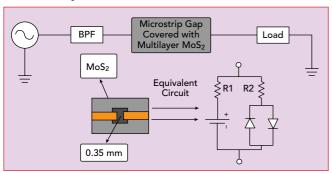
$$\alpha_{n} = \left(1/n!\right)\left(d^{n}f\left(u\right)/du^{n}\right)\left|u = V_{o} = \left(1/n!\right)f^{(n)}\left(V_{o}\right)$$
(3)

and V_0 is the bias voltage.

MoS₂ has a strong nonlinearity, with its odd-order harmonic signal output being greater than the value of its even-order signal output when $V_0 = 0.^{21,22}$ Consequently, the nonlinear characteristic of multilayer MoS₂ without bias is represented by Equation (4).

$$I \approx \alpha_1 u_1 + \alpha 3 u_1^3 + \dots + \alpha_{2n+1} u_1^{2n+1} + \dots + \alpha_{n=0}^{\infty} 2n + 1 u_1^{2n+1}$$
 (4)

When $V_0 \neq 0$, the value of the



▲ Fig. 2 MoS₂ resistor-diode model.

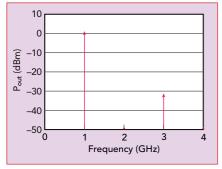
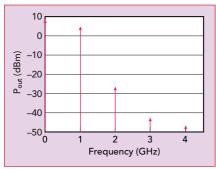


Fig. 3 Simulated output spectrum without bias voltage.



▲ Fig. 4 Simulated output spectrum with bias voltage applied.

even-order signal is increased and the value of the odd-order signal is attenuated. Therefore, the nonlincharacteristic of the MoS₂ film described by Equation (2) when a bias voltage is added, and the values are different with different bias voltages.

In summary, carrier conductivity is adjusted to obtain the greatest fre-

quency doubling effect.²³ The seriesconnected resistance represents the finite conductivity of the MoS₂ crys-

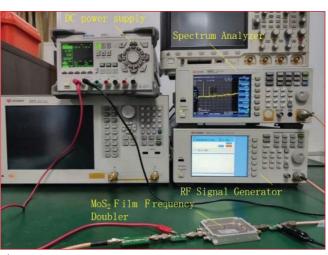
tals. A current path is formed between the semiconductor and the external circuit when a voltage is applied. The MoS₂ circuit model can be equated to a resistor-diode model; the diode equivalent model simulates its nonlinear characteristics.



The simulation circuit is shown in Figure 2. The simulation is carried out without and with bias voltage applied. Without bias, the simulation results are shown in Figure 3. The third harmonic output power is about -35 dBm, while the second harmonic output power is barely -50 dBm. When the bias voltage is 21 V, the simulation results are shown in Figure 4. The second harmonic output power is about -32 dBm, while the third harmonic output power is about -45 dBm. The simulation results of the MoS₂ equivalent diode model show that by applying a bias voltage to its terminals, the third harmonic decreases and the second harmonic increases.

TESTING

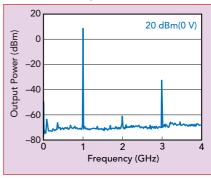
To verify the accuracy of the diode equivalent model, a prototype MoS₂-based frequency multiplier is



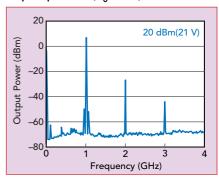
🖊 Fig. 5 Test setup.

fabricated and tested by connecting it to an RF signal source and spectrum analyzer. The RF signal source provides a fixed input frequency of 1 GHz at 20 dBm (see *Figure 5*).

After measuring the output without bias voltage, input DC bias is gradually increased to 30 V in 0.5 V steps. As a function of voltage, the second and third harmonic is observed on the spectrum analyzer. *Figure 6* shows the spectrum at 0 V where the second harmonic output power is below -60 dBm. *Figure 7* shows the spectrum at 21 V (determined to be optimum for this MoS₂



ightharpoonup Fig. 6 MoS₂ frequency doubler output spectrum (V₀ = 0 V).



Arr Fig. 7 MoS₂ frequency doubler output spectrum (V₀ = 21 V).



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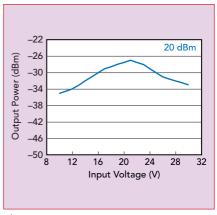
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sample). Optimum bias is dependent upon the MoS_2 film thickness and crystal structure. At 21 V bias, the output power at the second harmonic is -27 dBm. The trend with bias voltage is shown in **Figure 8**.

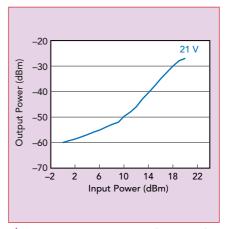
With a fixed bias voltage of 21 V, *Figure 9* shows output power of the second harmonic as a function of input power. The output power gradually increases when the frequency and bias voltage are fixed.

CONCLUSION

A voltage-controllable microwave frequency doubler is based on a 2D MoS₂ film. MoS₂ film possesses strong nonlinear characteristics, and its nonlinear efficiency is further improved with applied DC bias. In this work, a frequency doubler is developed leveraging these characteristics. With an input power of 20 dBm at 1 GHz, the output power of the second harmonic is below -60



A Fig. 8 Output power at the second harmonic as a function of bias voltage at a fixed input power of 20 dBm.

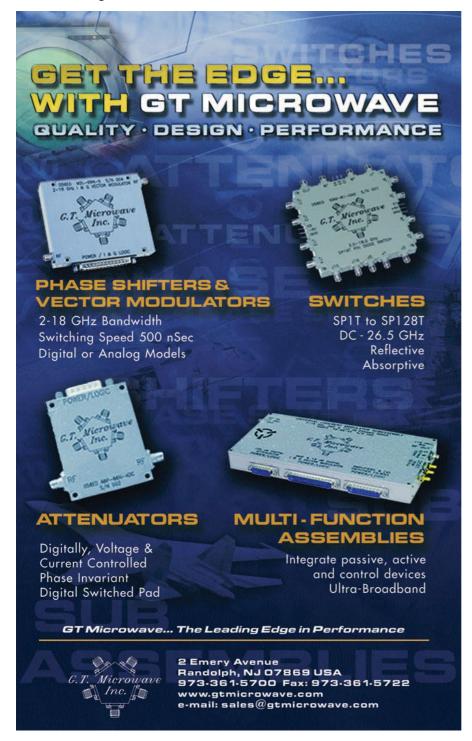


▲ Fig. 9 Output power at the second harmonic as a function of input power at a fixed bias of 21 V.

dBm without bias voltage applied. With 21 V bias applied, the output power of the second harmonic is -27 dBm, an improvement of 33 dB. Simulation using a theoretical model equating the MoS₂ film to a reverse parallel diode pair agrees well with measurements. ■

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Power Handling Capability in Waveguide Longitudinal Shunt Slot Arrays

Yong Liao Institute of Applied Electronics, China Academy of Engineering Physics, Mianyang, China

An essential performance metric for a high-power microwave (HPW) array antenna's power handling capability is mainly determined by the magnitude of the electric field at the slots of the array. The power handling capability of an L-Band waveguide longitudinal shunt slot array with different slot widths is determined through simulation and measurement. Analysis shows that there is an optimum slot width resulting in maximum power handling capability. Different slot shapes are examined, including rectangular, end-rounded rectangular and elliptical. The results indicate that a longitudinal shunt elliptical slot array provides the highest power handling capability.

ith the development of HPM, more attention is given to the array antenna for its high gain and high efficiency. 1-3 Recently, some traveling wave arrays have been used as HPM antennas.4-6 A traveling wave array has the advantage that its power handling capability is more than that of a standing wave array; however, its radiation efficiency is lower. Also, the longitudinal shunt slots of the rectangular waveguide array are standing wave antennas.7 For radiating gigawatt HPM, the longitudinal shunt slot array is faced with the problem of significant electrical breakdown at the slots.8-10

A slotted waveguide HPM antenna array consists of a slotted waveguide with dielectric windows. A 100 megawatt (MW) high power handling capability can be realized by maintaining a vacuum in the waveguide. The thickness of the slot wall is only approximately 1 to 3 mm and the maximum electric field of the waveguide is near the slot, so the power handling capability of the array is determined mainly by the

electrical field near the slots.^{8,9}

Some researchers have verified that an elliptical slot can increase the power handling capability of the waveguide array. 9-11 As is reported by Bemal et al.,8 when an elliptical slot is used, the maximum electric field encountered at the slot decreases by approximately 10 percent with respect to the fields associated with the rectangular slot. Baum⁹ guessed that an elliptical slot might be a good starting point. These references, however, do not provide the detailed structure of the elliptical slot as well as a comprehensive analysis of the power handling capability.

The goal of this work is to determine the best longitudinal shunt slot configuration for the highest power handling capability. The power handling capability of an L-Band waveguide longitudinal shunt slot array with different slot widths is determined. There is an optimum width and slot length for maximum power handling capability. Longitudinal shunt slot arrays with rectangular, end-rounded rectangular and elliptical slots are considered.

The longitudinal shunt elliptical slot array provides the highest power handling capability. The optimum slot length is 0.51 free-space wavelength (λ_0), which is the longest of the three configurations. This is supported by simulation and measurement. In addition, the array antenna can work in a vacuum (~10-2 Pa) for higher power handling.

SLOT CONFIGURATION

Schematics of the considered slot waveguide array antennas are shown in *Figure 1*. The slot lengths are almost half a wavelength in free space. Slot conductance can be adjusted by its length and offset from the central axis of the waveguide wide edge. Although the slot is not fed at the waveguide center, the transverse electric mode (TE₁₀) passes underneath it.

The field distribution of the slot is approximately equiphase half-cosinusoidal. 12-16 The length of the waveguide's wide inner wall is 120 mm, the length of the narrow inner wall is 40 mm and the thickness of the waveguide wall is 3 mm. The working frequency is 1.575 GHz.

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Each waveguide has nine wide edge longitudinal shunt slot elements and the slots are staggered on both sides of the waveguide's center line.

SIMULATION

When the waveguide structure is fixed, the slotted array power handling capability is mainly determined by the width of the slot.^{1,11} According to Elliott,¹⁴ the electric field distribution in a longitudinal slot array is:

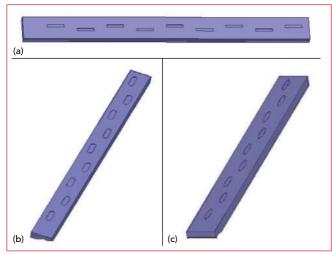
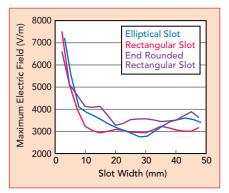


Fig. 1 Waveguide slotted arrays: rectangular slots (a), rounded rectangular slots (b) and elliptical slots (c).



♠ Fig. 2 Maximum electric field for the three slot geometries as a function of slot width.

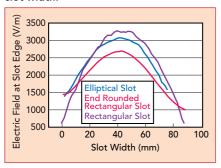


Fig. 3 Electric field as a function of slot length.

$$E_{X}\left(x',z'\right) = \frac{V_{S}}{w}\cos\frac{\pi z'}{2l} \tag{1}$$

where 2l is the slot length, w is the slot width, V_s is the slot voltage measured across the slot at its center, x' is the slot width and z' is the slot length. The width of the slot is optimized to yield the maximum handling power capability.

Arrays with different slots are analyzed using Ansys' High Frequency Structure Simulator (HFSS) software.

Power handling capability is determined by the maximum electric field in the array slots. Because the thickness of the slot wall is only 3 mm, to maintain simulation accuracy the mesh is no greater than 1 mm. The simulation results show that when the mesh is smaller than 1 mm the simulation results tend toward stability.

Figure 1 shows three waveguide slot arrays with nine elements each.

When the slot width changes, the slot offset from the central axis of the waveguide wide edge and the slot length must also be adapted to meet the resonant condition of the array. Power handling can be increased by increasing the slot width.¹¹

Figure 2 shows the maximum electric field in the slot for the three arrays when the input power is 1 W. When the width of the slot is larger than 10 mm (0.05 λ_0), the maximum electric fields drop rapidly in agreement with Equation (1). The minimum value for the maximum electric field of the rectangle slot is 3260 V/m, which occurs at a slot width of 20 mm (0.1 λ_0). The minimum value for the maximum electric field of the end-rounded rectangle slot is 3064 V/m, which occurs at a slot width of 15 mm (0.08 λ_0). The minimum value for the maximum electric field of the elliptical slot is 2667 V/m, which occurs at a slot width of 27.5 mm (0.14 λ_0). The power handling capability of the rounded-end rectangular slot array is almost 1.1x that of the rectangular slot array and the power handling capability of the elliptical slot array is almost 1.5x that of the rectangular slot array.

From Figure 2, when the rectangular slot width increases from 15 mm, the maximum electric field in the array varies around 3500 V/m. When the rounded-end rectangle slot width increases from 10 mm, the maximum electric field in the array varies around 3000 V/m. In the elliptical slot array, when the slot width increases from 17.5 mm, the maximum electric field in the elliptical slot array varies around 3250 V/m.

Figure 3 plots the electric field near the edges of the slot near the center of the waveguide. The field distribution across the slot is approximately equiphase half-cosinusoidal. Figure 4 shows the resonant lengths of the three types of array antenna slots. The lengths of the optimized rectangular, end-rounded and elliptical slots that provide maximum power handling are 87.5, 92.5 and 96.8 mm, respectively (0.46, 0.49 and 0.51 $λ_0$). The elliptical slot's resonant length is the largest.

Figure 5 shows that the offsets of the three types of slots are almost the same when the slot width is not

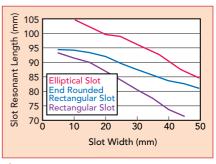
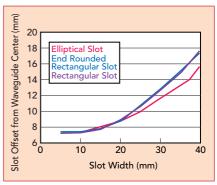


Fig. 4 Optimized resonant slot length as a function of slot width.



♠ Fig. 5 Optimized slot offset from the waveguide central axis as a function of slot width.



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After optimization, the areas of the rectangular, end-rounded and elliptical slots are 1554, 1018 and 2206 mm², respectively. The optimized elliptical slot has the largest aperture area (1.4x that of the rectangular slot). Because the radiated power of each slot is equal, a larger area results in a lower power density and therefore a higher power handling capability.

MEASUREMENT

A four-element array is connected to a high-power source (see *Figure 6*). There are three arrays, designed with either rectangular, end-rounded rectangular or elliptical slots. The widths of the rectangular, end-rounded rectangular and elliptical slots are 15, 20 and 27.5 mm, respectively. The waveguide is vacuum sealed to maximize its microwave power handling capability.

With a microwave source power of about 100 MW, the maximum electric field produced within the rectangular, end-rounded rectangular and elliptical slots is 46, 43 and 38 MV/m, respectively. According to Kilpatrick,¹⁷ the following relationship exists in a vacuum:

$$f = 1.643E^2e^{-8.5/E}$$
 (2)

where f is the frequency in MHz and E is the breakdown electric field in MV/m.

According to Equation (2), E is ~35 MV/m at 1.575 GHz. When the electric field in the waveguide exceeds the breakdown electric field, there is evidence of tail erosion (pulse shortening). Figure 7 compares the envelopes of a pulsed radiated waveform at the output of each of the slotted arrays. Tail erosion is the most serious in the rectangular slot array and least pronounced in the elliptical slot array. This shows that the elliptically shaped slot array has the largest handling power capability.



An L-Band waveguide array is designed with longitudinal shunt slots to investigate the power handling capability of longitudinal shunt slot waveguide arrays with various slot geometries and slot widths. Three



Fig. 6 Four-element antenna array with rounded rectangular slots.

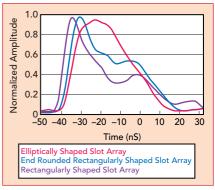


Fig. 7 Array radiated waveform.



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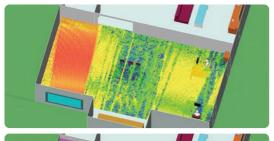
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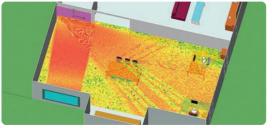
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different types of array slots are considered: rectangle, end-rounded rectangle and elliptical. Simulation shows that the power handling capability of the rounded-end rectangle slot is almost 1.1x that of the rectangle slot and the power handling capability of the elliptical slot array is almost 1.5x that of the rectangular slot. This is supported by experimental measurements of tail erosion in slotted array radiation measurements. ■

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| 10-1000 MHz | 25 | 0.5 | 1000 | 1.20:1 | BT-20 |
| 800-1000 MHz | 30 | 0.5 | 5000 | 1.50:1 | BT-21 |
| 1700-2000 MHz | 30 | 0.5 | 5000 | 1.50:1 | BT-22 |
| 500-2500 MHz | 25 | 1.0 | 200 | 1.20:1 | BT-02 |
| 10-3000 MHz | 25 | 1.8 | 3000 | 1.50:1 | BT-06-411 |
| 500-3000 MHz | 25 | 1.0 | 500 | 1.20:1 | BT-05 |
| 500-3000 MHz | 30 | 1.8 | 2000 | 1.50:1 | BT-23 |
| 10-4200 MHz | 25 | 1.2 | 200 | 1.20:1 | BT-03 |
| 1000-5000 MHz | 35 | 1.0 | 1000 | 1.50:1 | BT-04 |
| 100-6000 MHz | 30 | 1.5 | 500 | 1.50:1 | BT-07 |
| 0.5-10 GHz | 30 | 1.0 | 200 | 1.50:1 | BT-26 |
| 100 KHz - 12.4 GHz | 40 | 1.5 | 700 | 1.60:1 | BT-52-400D |
| 100 KHz - 18.0 GHz | 40 | 2.0 | 700 | 1.60:1 | BT-53-400D |
| 0.3-18.0 GHz | 25 | 1.5 | 500 | 1.60:1 | BT-29 |
| 30 KHz - 27.0 GHz | 40 | 2.2 | 500 | 1.80:1 | BT-51 |
| 30 KHz - 40.0 GHz | 40 | 3.0 | 500 | 1.80:1 | BT-50 |
| 30 KHz - 70.0 GHz | 30 | 3.5 | 500 | 2:00:1 | BT-54-401 |
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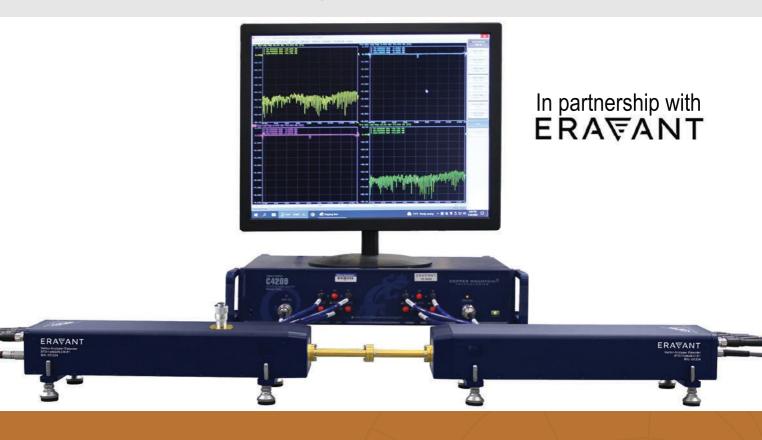
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Designing a 30 to 1000 MHz 10 W GaN HEMT Power Amplifier Using a Novel Coaxial Impedance Transformer With Ferrite Beads

Ivan Boshnakov Ametek Compliance Test Solutions, Reinach, Switzerland Larry Dunleavy and Chris DeMartino Modelithics Inc., Tampa, Fla.

hen designing multi-octave high-power amplifiers, it is a challenge to achieve both broadband gain and power matching using a combination of lumped and distributed techniques. One approach to overcoming this challenge is to design the power amplifier (PA) using load line methods combined with a novel coaxial impedance transformer with ferrite beads. This approach relies on accurate, linear and non-

| TABLE 1 POWER AMPLIFIER DESIGN GOALS | | | | | |
|---------------------------------------|-----------------|--|--|--|--|
| Parameter | Specification | | | | |
| Frequency | 30 MHz to 1 GHz | | | | |
| Output Power (Pout) | 10 W | | | | |
| Power Gain (Gp) | ≥ 12.5 dB | | | | |
| Gain Flatness | ± 0.5 dB max | | | | |
| Input Return Loss | ≥ 15 dB | | | | |

linear models as the basis for all components. This article focuses on the design of a single-stage, 10 W PA with broadband performance from 30 MHz to 1 GHz. This design utilizes the Qorvo QPD1010 GaN high electron mobility transistor (HEMT).

The PA design used several software tools and models. The design software employed was Microwave Office for RF and microwave circuit design and Analyst[™] for 3D EM finite-element method (FEM) analysis. Both of these programs are contained within the Cadence® AWR Design Environment® software tools. In addition, Modelithics models were used for the QPD1010 transistor and all surface-mount passive components.

This design requires a coaxial line combined with ferrite beads/cores impedance transformer to achieve the desired performance at the specified frequency range with the selected transistor. Although many amplifiers have been designed with these types of transformers, only those with downward impedance transformations have typically been documented. The transformer is designed using the Analyst 3D EM analysis tool.

DESIGN GOALS

As stated, the goal is to design a PA that operates from 30 MHz to 1 GHz. The PA must deliver at least 9 W of output power (Pout) over this operating frequency range with a Class AB bias condition. The power gain (Gp), defined as the gain at saturated output power, must be at least 12.5 dB. Finally, the gain flatness must be no more than ± 0.5 dB and the input return loss must be at least 15 dB. These design goals are listed in **Table 1**.

DESIGN PROCESS

The following section describes

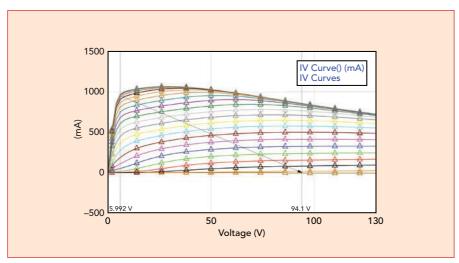


Fig. 1 Approximate load line for maximum power.

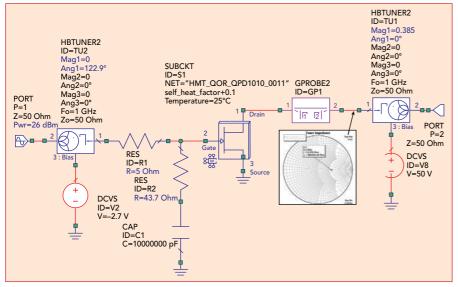


Fig. 2 This schematic diagram for the load lines across the required bandwidth.

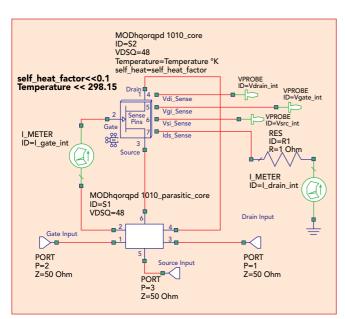


Fig. 3 The Modelithics transistor model.

the PA design process in more de-

The Intrinsic Load Line Design Approach

The transistor's I-V curves reveal that the intrinsic impedance (the fundamental frequency load line) needed for maximum power must be approximately $100~\Omega$ or more. Figure 1 shows the transistor I-V curves and it defines the optimum load line graphically.

The schematic shown in *Figure 2* is used to determine the load lines that correspond to an impedance transformation of 2.25x greater than 50 Ω at the output of the transistor across the operating frequency range. The simulation is only performed with the fundamental tone, which can be selected from Options within the schematic.

The load line (the intrinsic drain dynamic impedance) can be observed because the Modelithics model for the QPD1010 GaN transistor allows the designer to analyze the voltages and currents inside the model, specifically across the intrinsic generator. The Modelithics transistor model with access to intrinsic voltages and currents is shown in *Figure 3*.

Figure 4 shows the I-V curves and the initial load line results obtained after simulating the schematic of Figure 2. The fundamental frequency load lines across the bandwidth fall into the appropriate

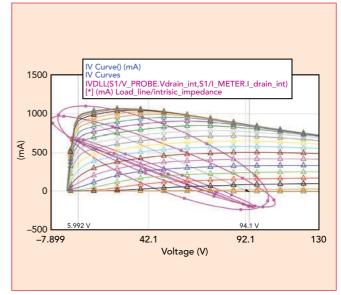


Fig. 4 The simulated fundamental frequency load lines.

Tutorial

region for good performance. Additional matching networks can be implemented to make the dispersion of the load lines appear even tighter.

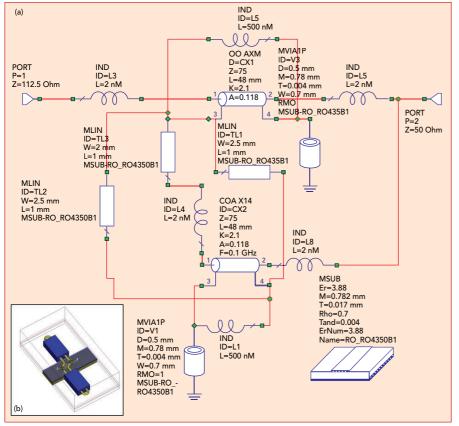
The Coaxial Transformer

As discussed above, the relatively new 10 W, 50 V GaN HEMT re-

quires an upward impedance transformation to achieve the optimal fundamental frequency load line. In this case, the transformer must have an impedance transformation ratio of 1:2.25.2 Employing a coaxial line with a ferrite core impedance transformer allows for better performance in terms of gain flatness

and power over multi-octave bandwidths for applications below 1 GHz compared with matching networks that consist of reactive components.

The Microwave Office schematic of a simple model of the coaxial line transformer used here is shown in *Figure 5a*. This model shows that the appropriate circuit



← Fig. 5 (a) Coaxial line transformer model. (b) 3D model of the coaxial line transformer.

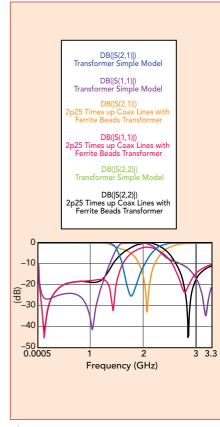


Fig. 6 Simulated performance results of the coaxial transformer.

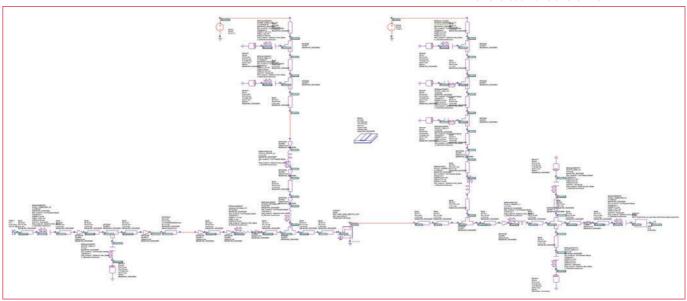


Fig. 7 Complete PA schematic.



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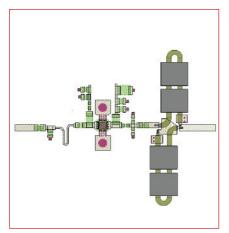


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A Fig. 8 RF layout of the PA.

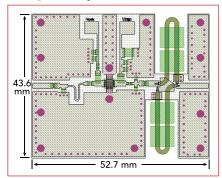
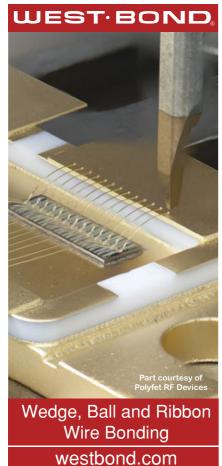


Fig. 9 PCB assembly of the PA.



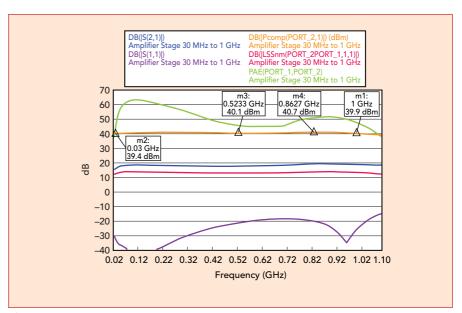


Fig. 10 Simulated RF performance of the PA.

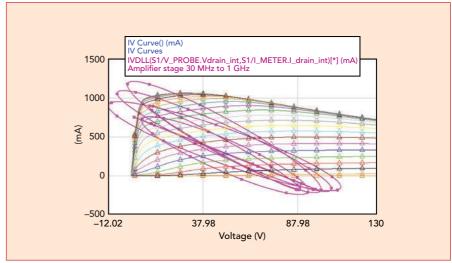
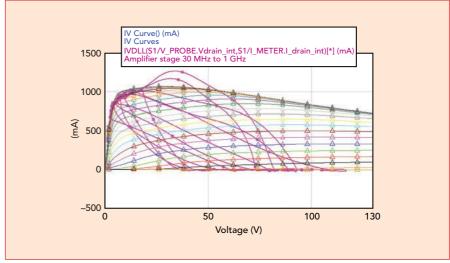


Fig. 11 Fundamental tone intrinsic load lines.



▲ Fig. 12 A depiction of the complex intrinsic load lines.







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Suitable for Compact Space Installation



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Low Loss Low VSWR High Shielding



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Cable Loss: 4.92dB/m@40GHz Typ.

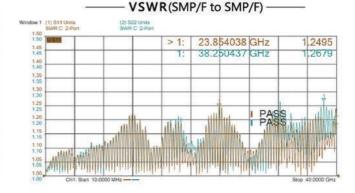
VSWR: 1.35:1@40GHz

Shielding Effectiveness: <-90dB

Amplitude Stability over Flex.: <±0.1dB@40GHz

Phase Stability over Flex.: <±3°@40GHz

Phase Stability over Temp.: 500PPM@-40~ +70°C





Tutorial

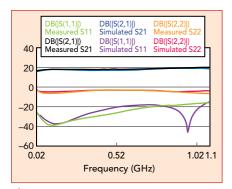


Fig. 13 Simulated and measured small signal S-parameters.

elements are incorporated into the schematic. *Figure 5b* shows the full 3D model of the transformer with the Analyst simulator included within the Cadence AWR Design Environment. *Figure 6* shows the simulated performance results of the schematic simulation and the full 3D analysis.

Complete PA Design

Pulling everything together, *Figure 7* shows the complete schematic of the PA. *Figure 8* illustrates

the corresponding RF layout. *Figure 9* shows the full printed circuit board (PCB) layout.

For this PA, typical design techniques were used for the matching/ stabilizing bias-decoupling networks. **Figure** 10 shows the simulated RF S-parampower and added efficiency (PAE) performance at 60°C. Note that temperature is defined with respect to the bottom soldering plate of the transistor package.

Figure 11 shows the I-V curves along with load lines at a few frequencies across the bandwidth at the intrinsic generator. In this case, only the fundamental tone is selected for simula-

tion. *Figure 12* shows these same I-V curves and load lines after simulating with 17 harmonics. Figure 12 shows the typical characteristics of a Class AB-biased transistor.

TEST RESULTS

Figure 13 shows the simulated and measured small signal S-parameters. The results show that the simulated and measured S-parameters are in good agreement with each other. **Figure 14** shows the simulat-

ed and measured saturated output power (Psat). The measured Psat is about 1 dB less than the simulated results, demonstrating a good overall result. Finally, *Figure 15* presents the simulated and measured gain at Psat.

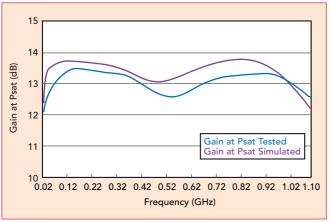
Note that while it was not possible to accurately test PAE with the available test setup, it was estimated to be just above 40 percent. *Figure 16* shows the prototype board and assembly that was used to test the PA.

CONCLUSION

The successful design of a multioctave bandwidth PA, operating from 30 MHz to 1 GHz, using a 10 W, 50 V GaN HEMT from Qorvo, is demonstrated in this paper. The design used Modelithics models for all components. Good performance across this bandwidth can only be achieved by employing a coaxial line transformer with ferrite beads. This transformer must allow for an upward impedance transformation. To the authors' knowledge, the use of such a transformer is presented for the first time in this paper. The transformer is simulated with the Analyst 3D FEM EM analysis tool within the Cadence AWR Design Environment. The design approach is based on the simulation of the load lines at the intrinsic generator. This simulation is possible because Modelithics GaN transistor model lets the designer analyze the intrinsic voltages and currents. The full design is realized using Microwave Office software within the Cadence AWR Design Environment. The test results confirm that the design approach produces a first-pass success.

42 40 6 38 36 34 32 0.02 0.12 0.22 0.32 0.42 0.52 0.62 0.72 0.82 0.92 1.02 1.10 Frequency (GHz)

Fig. 14 Simulated and measured Psat.



A Fig. 15 Simulated and measured gain at Psat.

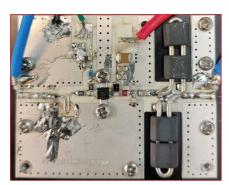


Fig. 16 Prototype test circuit for the PA design.

References

- I. Boshnakov, "A Simulation-Based Design Flow for Broadband GaN Power Amplifier Design," High Frequency Electronics, March 2016, pp. 22–32.
- A. Grebennikov, "Power Combiners, Impedance Transformers and Directional Couplers," High Frequency Electronics, December 2007, pp. 20–38.

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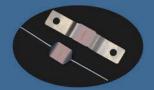
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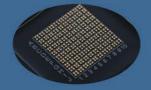
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Electromagnetic Simulation Platform Unleashes the Potential of Metasurfaces

CEMWorks Winnipeg, Canada

> In the rapidly evolving world of wireless communications, improving signal quality and coverage across the electromagnetic (EM) spectrum has become increasingly vital. The ability to steer beams in real-time to concentrate power and conserve bandwidth by controlling exactly where power is directed at a unit cell level has gained significant importance. As a result, metasurfaces and more specifically, reconfigurable intelligent surfaces (RIS), have emerged as a promising solution that can fulfill these new requirements without any required mechanical componentry and thus greatly enhance wireless communication systems.

> RIS designs are comprised of an array of unit cells distributed over a surface that is thin relative to the wavelength. These unit cells

♠ Fig. 1 An RIS array and unit cell design from Emerald's visualization tool.

can be controlled individually and the entire array grants the ability for spatial and/or temporal control of EM radiation. One ability that this type of design creates is reconfigurable beam steering. However, with this ability comes a new challenge of complexity in the simulation since a single far-field simulation is insufficient to characterize the complete behavior of these surfaces.

Emerald by CEMWorks is a comprehensive solution for simulating and analyzing metasurfaces and RIS. This solution has the potential to expedite research and development in this exciting domain. Emerald is well-equipped to handle these challenges due to its powerful set of features:

CUSTOMIZABLE MATERIAL PROPERTIES

Metasurfaces and RIS often rely on specialized materials with precise electromagnetic properties. The solver provides a rich library of material models, enabling users to define custom dielectric and metallic properties. With the ability to tailor these properties, researchers can explore novel metasurface designs and optimize their performance for specific applications, such as beam steering, pattern synthesis and polarization control.

VERSATILE GEOMETRICAL CONFIGURATIONS

Metasurfaces and RIS come in a wide range of geometries, including planar ar-

ProductFeature

rays, nanoparticle arrays or surfaces with repeated patterns. Emerald accommodates these diverse configurations, allowing users to model and simulate surfaces of varying complexity. From unit cell arrays to arbitrary structures, researchers can accurately capture the EM response and study the impact of geometrical parameters on RIS functionality.

BROAD FREQUENCY RANGE

Understanding the behavior of metasurfaces and RIS across a wide frequency range is crucial for comprehensive analysis and design optimization. Emerald supports simulations from DC to optical frequencies and it offers a seamless transition between different frequency domains. This capability empowers researchers to investigate metasurfaces spanning from DC to high frequency analysis, unlocking a plethora of applications in telecommunications, sensing, imaging and more.

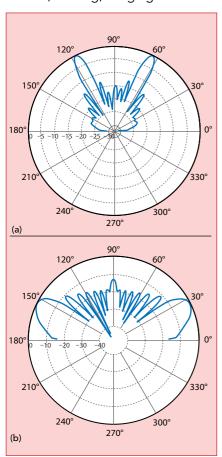


Fig. 2 (a) Reflected far-field pattern (in dB) with the main lobe 27 degrees off broadside. (b) Reflected far-field pattern (in dB) with the main lobe at 66 degrees off broadside.

ADVANCED POST-PROCESSING AND VISUALIZATION

Analyzing and interpreting simulation results play a vital role in the design and optimization of metasurfaces and RIS. Emerald provides an array of post-processing tools to extract key parameters. Additionally, advanced visualization options, such as 3D models of far-field patterns facilitate an intuitive understanding of RIS behavior.

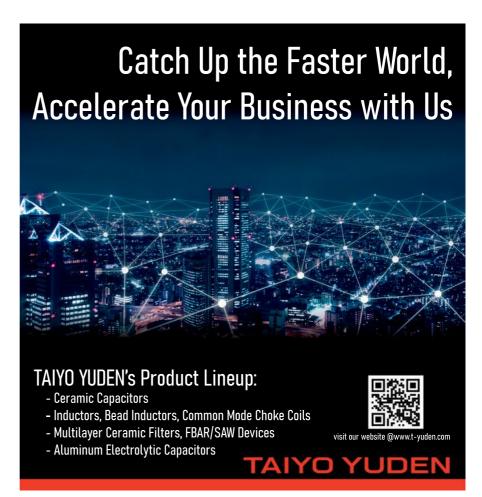
To demonstrate some of these features, a reflective RIS design consisting of 160 resonant patch unit cells controlled by simulated diodes has been implemented. These diodes control whether current can flow to a parasitic patch, causing the reflected fields to have a relative phase shift of 180 degrees at resonant frequencies. This design is shown in *Figure 1*.

Since the relative phase for each individual cell that can be reconfigured can be controlled, the total field can be configured by controlling the interference between cells.

The cumulative effect opens the possibility to synthesize and reconfigure radiation patterns. As an example, the plots of *Figure 2a* and *Figure 2b* display the two resulting far-field reflection patterns of the same surface in two different main lobe configurations.

The arrival of RIS has opened exciting possibilities for controlling and manipulating EM waves. The Emerald EM solver allows researchers to delve into the intricacies of RIS structures, accurately model their behavior and optimize their performance. By combining powerful simulation capabilities with customizable material properties, versatile geometrical configurations advanced post-processing tools, Emerald paves the way for ground-breaking advancements in metasurface and RIS research and applications.

CEMWorks Winnipeg, Canada www.cemworks.com



Solid-State GaN Power Amplifiers for Weather Radar Systems

Pulse Systems, Inc. South Easton, Mass.



▲ Fig. 1 Front panel of TR-3600 Solid-State Weather Radar Transmitter.

ulse Systems (PSI) has taken advantage of recent advances in solidstate GaN high-power RF transistor technology to develop the TR-3600 solidstate power amplifier (SSPA) that targets the high-power requirements of weather radar applications. The total amplifier assembly, known as the TR-3600 Solid-State Weather Radar Transmitter and shown in Figure 1, provides a peak output power of 6 kW over a frequency range of 5400 to 5700 MHz. The transmitter can supply this output power at pulse lengths up to 100 µs with the caveat that pulses longer than 6 µs generally require a pulse compression signal processor.

The Pulse Systems TR-3600 Solid-State Weather Radar Transmitter is packaged to be compatible in form and fit with the PSI line of magnetron transmitters. This new product offers an easy upgrade or replacement option for any radar using a PSI C-Band magnetron transmitter. The TR-3600 accepts the same input power connection and trigger connection as the magnetron transmitter. It uses the same ethernet or discrete I/O DB-37 connection for remote control and status monitoring and the waveguide output is in the same physical position as the magnetron transmitter. The TR-3600 SSPA provides the specified output power from an input RF pulse of 0 dBm nominal power. The receiver used in a magnetron transmitter would need to be modified to add an exciter channel to generate this RF pulse, which is easily done. If the TR-3600 replaces a klystron-based transmitter, the receiver would already be equipped with this

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|---------------------|-----------|---------------------|----------|------------|
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| VFCTS100-10 | 100 | -156 | -165 | |
| VFCTS105-10 | 105 | -156 | -165 | 1 |
| VFCTS120-10 | 120 | -156 | -165 | |
| VFCTS125-10 | 125 | -156 | -165 | |
| VFCTS128-10 | 128 | -155 | -160 | 1 |
| FCTS800-10-5 | 800 | -144 | -158 | (*) |
| FCTS1000-10-5 | 1000 | -141 | -158 | (*) |
| FCTS1000-100-5 | 1000 | -141 | -158 | (*) |
| FSA1000-100 | 1000 | -145 | -160 | 0 |
| FXLNS-1000 | 1000 | -149 | -154 | 0 |
| KFCTS1000-10-5 | 1000 | -141 | -158 | 17.1 |
| KFCTS1000-100-5 | 1000 | -141 | -158 | 17.1 |
| KFSA1000-100 | 1000 | -145 | -160 | 111 |
| KFXLNS-1000 | 1000 | -149 | -154 | 1 |
| FCTS2000-10-5 | 2000 | -135 | -158 | * |
| FCTS2000-100-5 | 2000 | -135 | -158 | (*) |
| KFCTS2000-100-5 | 2000 | -135 | -158 | TIES . |
| KSFLOD12800-12-1280 | 12800 | -122 | -123 | - |
| KSFLOD25600-12-1280 | 25600 | -118 | -118 | |
| KSFLO27R5-100-12 | 27500 | -88 | -98 | 1 |



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type of exciter. The first TR-3600 has been successfully installed in a local weather radar site operated by a TV station and the solid-state-based radar is exceeding expectations.

There are several advantages to using a solid-state radar over a conventional magnetron. Some of the main advantages are:

- The maximum voltage used in the SSPA system is 50 VDC. With no high voltages in the SSPA transmitter, there is much less radar maintenance.
- The output peak power is much lower than a magnetron or klystron-based transmitter, so there is no requirement for waveguide pressurization. A pressurizer can still be used to keep the waveguide clean and dry if desired.
- SSPA transmitters can continue to operate with reduced power output when a module fails, while a magnetron failure is catastrophic.
- SSPA transmitters power up instantly, eliminating the warmup time required by magnetrons and klystrons.
- The estimated MTBF for an SSPA transmitter is 250,000 hours versus 3000 hours for a typical magnetron-based transmitter.
- SSPA transmitters provide greater phase stability as compared to magnetron transmitters for better clutter rejection and improved data quality.
- The SSPA transmitter pulse lengths are adjustable up to 200 µs whereas a magnetron transmitter is usually limited to just a few pulse lengths.

KEY SPECIFICATIONS

- 6 kW peak output power, either combined into a single output, or possibly two separate outputs of 3 kW each if used in a non-power-split dual polarization configuration.
- Operating frequency is tunable in the range of 5400 to 5700 MHz.
- Pulse lengths up to 100 µs. Pulses longer than 6 µs generally require a pulse compression signal processor. Pulses up to 6 µs do not require pulse compression and offer sensitivity on par with a 1 µs pulse from a 250 kW magnetron or klystron transmitter.
- 10 percent maximum duty cycle,

- which allows for a 100 µs pulse at 1000 Hz PRF.
- 230 VAC input with 10 Amps maximum current draw, accommodating the same power connector used in the PSI magnetron transmitter.
- The RF input pulse is nominally 0 dBm peak power.
- The same 5 V into the 50 Ω trigger input and the same control/status I/O connection as the PSI magnetron transmitter.
- Touch screen PLC for local control and status monitoring.
- Form-fit compatible with PSI magnetron transmitter for 19 in. rack mount.
- WR-187 waveguide output is in the same physical position as the PSI magnetron transmitter in single polarization or split-power dual polarization. Separate WR-187 outputs are available if used as non-split-power dual polarization (3 kW for each output).
- Forced air cooling. No oil or other liquids are used in cooling or insulating.
- Internal voltages are limited to 50 VDC.
- Graceful output power degradation in the event of failure of an SSPA module.
- Control inputs (local or remote) power on/off, radiate on/off, fault reset.
- Internal fault protection for airflow, over duty, temperature, amplifier fault and VSWR fault. Any fault immediately stops the SSPA output and is latched requiring a local or remote reset to return to operation. Faults and output



OCAI Fig. 2 Back view of TR-3600 Solid-State Weather Radar and Transmitter.

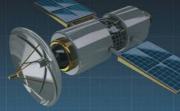
power can be monitored on a remote interface.

The functional components and architecture of the TR-3600 Solid-State Weather Radar Transmitter assembly that goes into the rack are shown in *Figure 2*.

PSI has nearly 55 years of technical and manufacturing experience in the fields of magnetic components, weather radar subsystems and RF sources. PSI's flexible and efficient design and manufacturing processes allow them to respond to customer needs and implement new technologies quickly. In addition, extensive production efforts and improvements by Pulse Systems allow these new transmitter systems to be competitively priced with magnetron products, especially considering the dramatically improved lifetime of the solid-state solution. PSI prides itself on proven product durability, quality and performance.

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o provide OEMs with automotive-qualified 10BASE-T1S Ethernet solutions, Microchip Technology announced its first automotive-qualified Ethernet PHYs. This family of devices with AEC-Q100 Grade 1 qualification includes the LAN8670, LAN8671 and LAN8672.

The LAN8670/1/2 10BASE-T1S Ethernet PHYs are functional safety-ready and designed for use in ISO 26262 applications. These PHYs allow low speed devices to connect to a standard automotive Ethernet system without a separate communication system. Connecting multiple Ethernet PHYs to a common bus line makes it simpler to implement automotive applications on a single, well-known architecture, reducing cabling and switch

Automotive-Qualified 10BASE-T1S Ethernet Devices Simplify Architecture

ports and saving implementation costs. The LAN8670/1/2 enables the network edges to use Ethernet and Internet Protocol to easily communicate with the rest of the network infrastructure. These devices include advanced PHY diagnostics to provide troubleshooting capabilities. In addition, sleep/wake functionality allows for low-power modes. The family of Ethernet PHYs are available for purchase now and they are supported by the EVB-LAN8670-RMII, EVB-LAN8670-USB and MPLAB® Harmony v3.

The 10BASE-T1S device specifications include 10 Mbps, half-duplex mode, flexible topology with a multidrop bus line and point-to-point on

a single balanced pair of conductors. These devices also feature enhanced EMC/EMI performance. Time-Sensitive Networking support allows for synchronized timing across far-reaching Ethernet networks.

Microchip was a key contributor in the development of the standards with IEEE for the automotive-qualified 10BASE-T1S technology. This technology simplifies system design by expanding the reach of Ethernet to the devices that are typically at the very edge of the network.

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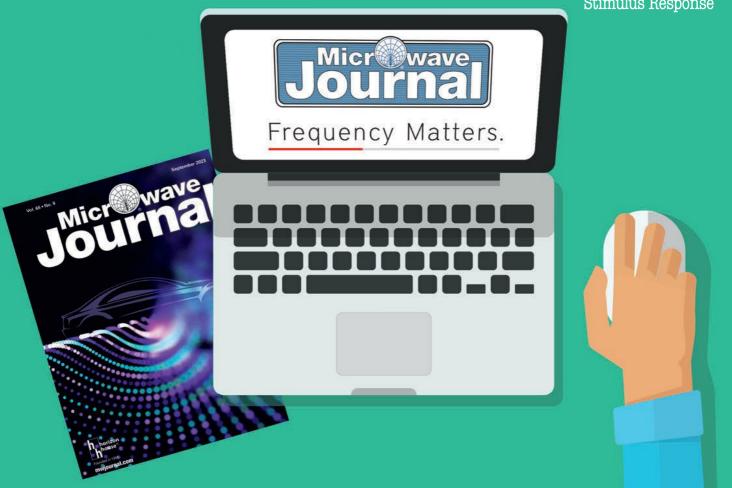
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Designing a 30 to 1000 MHz 10 W GaN HEMT Power Amplifier Using a Novel Coaxial Impedance Transformer With Ferrite Beads

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In a rush to complete a series of measurements, it's tempting to take test gear off the shelf, plug it in and begin the process. Resist the urge! This app note looks at how a VNA measurement can change from initial power-up to thermal equilibrium.



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RFMW Supplier Showcase at IMS2023

In case you missed the RFMW Supplier Showcase at IMS2023, here is the full summary of what was shown.

RFMW https://bit.ly/47t7SRM





400G Transport Testing Solutions

Watch this video to learn more about the 400 GbE testing capabilities and advantages of Anritsu's Network Master Pro MT1040A.

Anritsu Company https://bit.ly/3dEJXqI



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Mini-Circuits' business centers around the manufacturing, design and shipping of their products, but it all starts in one crucial place: their Brooklyn-based receiving and kit room departments.

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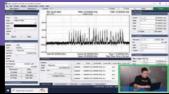
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and tracking generators. Providing full device control, a configurable spectrogram display and user interface, with a variety of analysis modes, Spike is the perfect application for powerful RF analysis.

Signal Hound

www.youtube.com/watch?v=Zw5JJ_iU9Mw













2024 IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM

16-21 JUNE 2024

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IMS2024 is the centerpiece of Microwave Week 2024, which includes the RFIC Symposium (www.rfic-ieee.org) and the ARFTG Microwave Measurement Conference (www.arftg.org).

IMS2024 will feature a far-reaching Technical Program focused on **Capitalizing Across the Spectrum** — the electromagnetic spectrum from RF-to-optical, the application spectrum from commercial wireless to scientific sensing, and the human spectrum encompassing diversity, equity, and inclusion.

The location of IMS2024 is our nation's capital, Washington D.C. The Walter E. Washington Convention Center is located in downtown Washington D.C., near Chinatown and the city's hip Shaw neighborhood which is known for its lively social and restaurant scene. Washington D.C. is home to many famous landmarks and historical sites such as the White House, the National Mall with its famous monuments and memorials, the Smithsonian Institution — the world's largest museum complex, the National Zoo, and the Kennedy Center for the Performing Arts.

Washington D.C. is also home to many agencies and institutions that oversee use of the electromagnetic spectrum. One of our conference themes is to highlight advances in spectrum access and use, including coexistence, sustainability and emerging Future-G systems. Other themes will feature the critical role of the RF-to-THz spectrum for aerospace and transportation, national security, and radar. The central role that equity, inclusion and diversity play across the spectrum of our community will be highlighted throughout the week.

For more information: ims-ieee.org





NEW PRODUCTS

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DEVICES/ COMPONENTS/MODULES

UWB 3-Way Power Divider/ Combiner



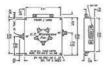


MIcable's 6 to 67 GHz ultra-wideband (UWB) 3-way power divider/ combiner can accept a 6 to 67 GHz signal and deliver three output signals with equal amplitude and

phase. Due to extremely wide bandwidth, excellent VSWR, insertion loss and isolation, it can be widely applied in 5G, testing, instrumentation and other fields.

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

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Model POP-84A-5 is a digitally controlled PIN Diode 360-degree phase shifter operating from 18 to 26 GHz in 0.35

monotonic dB steps. Across the entire band, phase accuracy is ± 10 degrees and amplitude balance is ± 2 dB. The unit's insertion loss is less than 14 dB and VSWR of less than 1.8:1 in 50 Ω . It can accommodate a handling power of +15 dBm CW or 1 W maximum. The operating temperature range is -10°C to +60°C with 10 BITs of TTL compatible binary logic.

G.T. Microwave www.gtmicrowave.com

5GCAN Tx/Rx Module



The innovative 5GCAN Tx/Rx module, designed and manufactured by IMST, is a front-end module covering the 5G Ka-Band from 24.25 to 29.5 GHz. The 24 beamformer ICs feed 2 \times 96 antenna elements, all dual linear polarized. The module generates in standard configuration 48 beams with flexible polarization (LHCP, RHCP, dual linear, etc.) Four beams can be generated simultaneously. Scanning performance is 360 degrees in azimuth and ± 30 degrees in elevation. The dual polarized antenna elements are based on a combined metal and dielectric waveguide design.

IMST www.imst.com

Coaxial Detector VENDORVIEW



Mini-Circuits' model ZV47-E673RMS+ is a coaxial power detector with 35 dB dynamic range from 0.1 to 67 GHz. Ideal for testing mmWave

signal levels, it measures power from -35 to 0 dBm with ± 1 dB accuracy, providing output voltages from 0 to ± 1.2 VDC in a ± 29 mV/dB logarithmic relationship. It features 12 dB typical return loss, 2.9 μs pulse rise time and 8.1 μs pulse fall time. The power detector operates on a typical ± 3.3 VDC supply and is equipped with 1.85 mm female connectors.

Mini-Circuits www.minicircuits.com

10-Bit Programmable AttenuatorVENDOR**VIEW**



Quantic PMI Model DTA-26R5G40G-30-CD-1 is a 10-bit programmable attenuator with a frequency range of 26.5 to 40 GHz. It has an insertion loss

of 6 dB, an attenuation range of 30 dB and an accuracy of attenuation of 0.09 dB. It also has a VSWR of 2.0:1, an input power of +24 dBm and an input 1 dB compression point of +10 dBm. It has 2.92 mm female connectors and the size is $2.00\times1.80\times0.50$ in.

Quantic PMI www.quanticpmi.com

Band Reject (Notch) Filters



RLC Electronics has introduced higher power band reject (notch) filters, designed to operate

over the frequency range of .01 to 40 GHz. The filters are available in compact sizes and are constructed to operate over the most severe military environmental conditions. This particular notch filter is centered at 1300 MHz, with a 200 MHz wide notch having 50 dB min attenuation. The units are phase-matched in pairs and can handle 250 W cW.

RLC Electronics www.rlcelectronics.com

8-Channel Programmable Attenuator



Spectrum Control introduced the high value 4801-8-127 solid-state 8-channel programmable attenuator that delivers high performance in a compact package to

enable Wi-Fi and 5G test systems. The Spectrum Control 4801-8-127 meets the needs of automated high-channel count RF systems operating in challenging environments. The 8-channel programmable attenuator covers a frequency range of DC to 8 GHz, has a dynamic range of 127 dB, and high linearity to limit signal amplitude while maintaining signal integrity. Its combination of cost efficiency and repeatability is unmatched in the market.

Spectrum Control www.spectrumcontrol.com

Reflective MEMS Switch Modules





Withwave's MEMS switch modules are reflective type RF switches such as

SP4T, SP10T, 4-port matrix switch according to switching applications and frequency range. They deliver 25 W power handling, low insertion loss and high linearity, making these devices ideal for RF signal routing in wireless infrastructure and applications from DC to 20 GHz. External connectors included are 2.92 mm vertical launch connectors for all RF port. They are powered and controlled through USB type-C connector.

Withwave www.with-wave.com

AMPLIFIERS

Solid-State Power Amplifier Module



COMTECH PST introduced its latest addition to its GaN solid-state power amplifier product line. Comtech's latest

development continues to expand on its integrated RF GaN power amplifier designs by offering a small form factor module. Consistent with its planned technology development roadmap, Comtech proudly introduces the latest in GaN-based 6 to 18 GHz RF amplifier for TWT/MPM replacement. This highly integrated design is ideal for use in communication, electronic warfare and radar transmitter systems where space, cooling and power are limited.

Comtech PST www.comtech.com

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NewProducts

AMP2115-LC VENDORVIEW



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nominal. Excellent band flatness with a minimum power gain of 61 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.

Exodus Advanced Communications

RF Power Amplifier SolutionsVENDOR**VIEW**



Richardson RFPD, Inc. announced the availability and full design support capabilities for a featured lineup of RF power amplifier

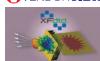
solutions from leading manufacturers. A variety of devices is available to meet a range of applications and system requirements, from discrete transistors to full RF front-end boards. The lineup includes power amplifier solutions from Analog Devices, Empower RF Systems, ERZIA, Guerrilla RF, MACOM, Microchip, NXP, Skyworks, Tagore Technology, TT Electronics, United Monolithic Semiconductors and Wolfspeed.

Richardson RFPD www.richardsonrfpd.com

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Remcom www.remcom.com

Software Package VENDORVIEW



Rohde & Schwarz has introduced a new software package for its proven BBA300 RF amplifiers, designed

for various test environments. The new software and intuitive operation enable users to accurately set the operating parameters of the amplifier and manage test sequences. The BBA300 provides stable, robust and precise test signals, across a continuous frequency range from 380 MHz to 6 GHz at up to 300 W output power. It supports amplitude, frequency, phase, pulse and complex OFDM modulation, making it ideal for laboratory and validation test environments, where precisely reproduced test signals are required.

Rohde & Schwarz www.rohde-schwarz.com

ANTENNAS

Embedded Antennas



Amphenol RF introduces embedded antennas into their antennas portfolio. These surface-mounted chip antennas

offer excellent electrical performance up to 8.5 GHz. They support cellular 4G/5G-FR1 frequencies along with Wi-Fi and Bluetooth/ Bluetooth Low Energy and LoRa, ultra-wideband and GNSS. Embedded RF antennas are ideal for loT and smart devices due to their compact size and durable construction. By surface-mounting the chip antenna directly on the printed circuit board, with SMT solution, the need for external antennas is eliminated. These embedded antennas are manufactured out of ceramic or FR-4 materials.

Amphenol RF www.amphenolrf.com

Dual Polarized Scalar Feed Horn Antenna





Model SAF-1141741525-082-S1-065-DP is a dual polarized, WR-06 scalar feed horn antenna assembly that covers the frequency range of 110 to 170 GHz. Nominal boresight gain is +15 dBi with excellent beam symmetry. The antenna includes an orthomode transducer (OMT) that separates incoming signals into horizontal and vertical components. Alternatively, any polarization may be transmitted by controlling the relative amplitude and phase of signals applied to the OMT ports. Sidelobe levels are -25 dB or lower and typical return loss is 15 dB.

Eravant www.eravant.com

Microwave Wi-Fi 6E Antennas VENDORVIEW



Fairview Microwave announced its new line of Wi-Fi 6E antennas set to deliver flawless network communications across various applications. The

newly introduced antennas also offer access to the latest Wi-Fi 6E frequency bands, ensuring high compatibility and ultra-fast gigabit transmissions. This technology handles demanding networking requirements with ease and is key for businesses aiming to stay at the forefront of their respective industries.

Fairview Microwave www.fairviewmicrowave.com

RET Sector and Omnidirectional Antennas



L-com has introduced a line of remote-electrical-tilt (RET) sector and omnidirectional antennas. The antenna beams in these products can be adjusted remotely and continually to react to changing traffic patterns and

environmental conditions. Such a capability benefits communication networks that require continuous wireless signal optimization. These include mobile, WISP, Wi-Fi, GSM, UMTS, LTE, 5G, public safety, smart cities and industrial networks.

L-com www.l-com.com

Marine-Grade Ship/Boat RF Antennas





Pasternack has launched its premier line of commercial marine-grade ship/ boat RF antennas, specifically designed for the harshest

marine environments. Offering high performance for sea-bound communications, the product range is a beacon for ship-to-ship correspondence, distress signal transmission and harbor chatter. Pasternack's cutting-edge marine antennas operate within the vital marine frequency band of 156 to 163 MHz and CB to 27 MHz, 10m-HAM, offering clear, continuous connectivity on the open sea.

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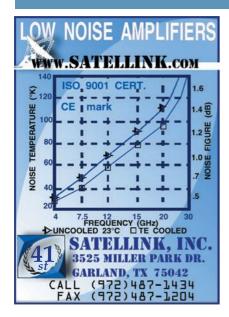
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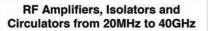
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FieldFox Handheld Analyzer **VENDORVIEW**



Keysight Technologies Inc. expanded its FieldFox portfolio with the new N9912C FieldFox handheld analyzer, a softwaredefined RF testing platform offering field

engineers more than 20 vector network analyzer, cable and antenna tester and spectrum analyzer options for upgrade and download. Field engineers conduct routine maintenance on and troubleshoot RF. microwave and mmWave systems. During their work, they need to accurately measure a variety of devices or signals, including cables, antennas and over-the-air signals, to ensure robust signal quality and uninterrupted service.

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Review by: Brian Rautio, Sonnet Software



Bookend

Microwave Plasma Sources and Methods in Processing Technology

By: Ladislav Bárdoš & Hana Baránková

s someone involved in various professional outreach efforts, I always light up when people ask me a certain type of question. It takes various forms, but all point to the same answer and do so in such a way that may as well be an infomercial setting me up for a sales pitch. The question? "What do you like about science/engineering/in your job/your field?" The answer? "All the really cool stuff."

Plasmas, emphatically and in a way that is beyond reproach, are really cool stuff. They are another state of matter. They are on an on-demand conductor path between, well, most any two points. They may be the key to the holy grail of energy: fusion power. And they are the source of infinite infinitely complex math problems. No, that sentence is not a typo. It's a byproduct of how cool plasmas are.

So, it's no surprise this is a fun book to read. I haven't had the pleasure of doing much work with plasmas professionally, but it took me back to graduate school in a nostalgic way and continued a train of thought I had put a pin in on a topic I cared to know more about simply because it is fun to know about. The book is relatively short, frank and to the point. This is what plasmas are, that is what plasmas do, these are some citations if you want to know more.

The flow is logical. It starts with basic principles as either a useful primer or refresher and then moves to interactions of plasmas with other matter. It discusses the systems at reduced pressures, the systems at higher pressures and finishes with some applications. There are also appendices and an index to use the book as a reference, but it is not remiss to read Bárdoš and Baránková's book in a linear fashion.

It is unfortunately not a perfect book. At 196 pages, I found it a bit short. I would have loved to read about more applications or to dive into further detail on the ones there. Keen readers can also pick up on certain parts of the book contrasting writing styles, presumably between authors. I'd like to see a second edition at some point, perhaps updated with some new trends and additional editing.

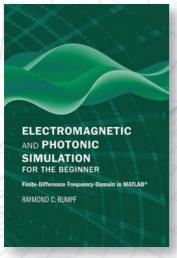
Overall, though, I'm certainly happy to have spent time with microwave plasma sources and given how interesting the subject matter is, don't feel a need to qualify the intended audience beyond "STEM." If the word plasma makes you curious or excited, you will be able to find something that interests you here.

ISBN: 978-1-119-82687-3

196 Pages

To order this book contact:

Wiley-IEEE Press (10 February 2022) www.wiley.com



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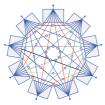
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Samtec: Defined by Sudden Service®





Design Center.

amtec opened its doors on January 2, 1976, in the back of an insurance agency with two employees. Samtec established itself as a service-oriented connector company that could provide products and services to little guys needing small quantities and big guys needing products fast in production "line down" situations. From these beginnings, Samtec now serves customers in approximately 125 countries with revenues exceeding \$1 billion. The company has 24 sales offices, 13 design centers and 14 operations/ inventory locations across the globe. The service concept first implemented has evolved into Samtec's Sudden Service philosophy.

Samtec's Sudden Service encompasses design, sales and delivery. In the design stage, customers can visit the Samtec website to access product specifications, characterization/test reports, detailed white papers and application notes, interactive web design tools and 3D models. Specialized technical support is also readily available directly from engineers in the Samtec Signal Integrity Group, Interconnect Processing Group and Application Support Group.

Samtec prides itself on being much more than just another connector company. They put their people first, along with a commitment to exceptional service, quality products and innovative technologies that take the industry further faster. Samtec believes that their service culture makes them unique. That culture is driven by four major characteristics that they call the "Samtec DNA." These characteristics are SPEED (make things happen, recover quickly), FLEXIBILITY (embrace change, create solutions that fit the situation), INNOVATION (learn, grow, have fun, think creatively) and WIN/WIN (be responsible, take ownership).

They have followed these principles to develop a portfolio that ranges from standard catalog products to unique high performance designs. These "solution blocks" support any interconnectivity need, regardless of application, performance requirements or environment. Samtec provides products in industrial, 5G networking, computer/semiconductor, datacom, medical, instrumentation, aerospace and defense, automotive/transportation/telematic, arti-

ficial intelligence/machine learning and consumer markets. In 2023, Samtec continues to expand its operations. A new 24,000 ft.² cable manufacturing facility has just been built in Pennsylvania, expansions of the Vietnam and Costa Rica manufacturing facilities are underway with expected completion this year and a Singapore Distribution Hub has been completed and is fully operational. Later in 2023, Samtec plans a grand opening of their Taiwan

Samtec's new Pennsylvania facility uses some of the most advanced machinery for extruding, wrapping, braiding and winding, all critical processes for manufacturing high performance microwave cable. The facility can validate the electrical, mechanical and environmental capabilities to ensure the performance and durability of those solutions. The facility is focused on developing next-generation products by harnessing the latest advances in material science and signal integrity.

Over the years, Samtec has developed an extensive RF product catalog and roadmap that includes cable assemblies, cable connectors and board-level interconnects that go to 110 GHz. The company is using its system-level signal integrity expertise to focus on high-quality, differentiated RF products that push the performance boundaries of existing and emerging high bandwidth applications. The Samtec Wilsonville, Ore., design center and cable plant has been instrumental in the development of unique RF cable products that are key enablers for test systems.

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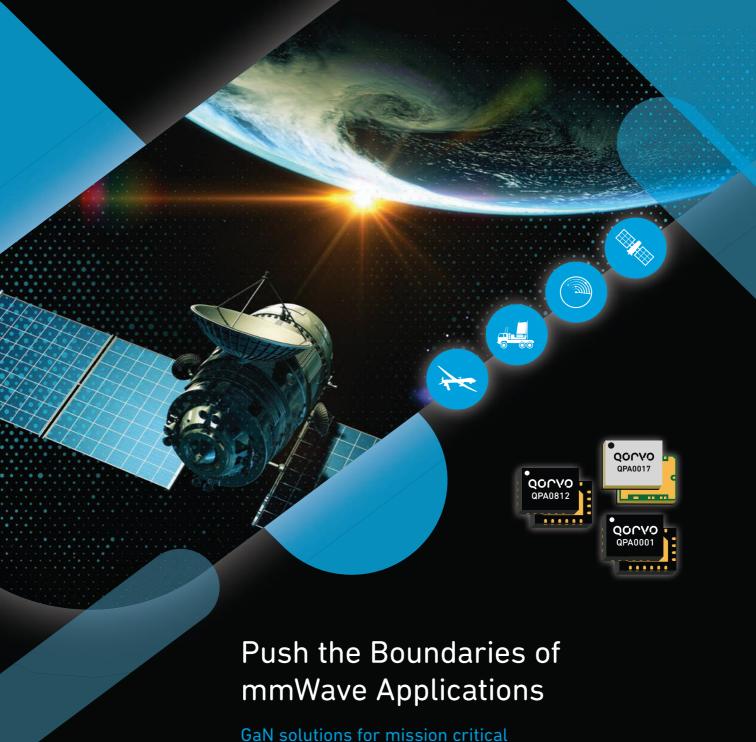
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| C8731 | Dual | 0.009-250 | 1000 | 40 | 0.40 | N-Female | 10.5 x 3.0 x 2.0 |
| C11462 | Dual | 0.009-400 | 500 | 40 | 0.45 | N-Female | 6.7 x 2.28 x 1.69 |
| C8510 | Dual | 0.009-1000 | 500 | 40 | 0.45 | N-Female | 6.7 x 2.28 x 1.69 |
| C5047 | Dual | 0.01-100 | 4,000 | 50 | 0.15 | 7/16-Female | 10.0 x 4.16 x 3.5 |
| C1979 | Dual | 0.01-100 | 10,000 | 60 | 0.10 | LC-Female | 2.0 x 6.0 x 4.5 |
| C5086 | Dual | 0.01-250 | 250 | 40 | 0.50 | N-Female | 5.2 x 2.67 x 1.69 |
| C5100 | Dual | 0.01-250 | 500 | 40 | 0.40 | N-Female | 10.5 x 3.0 x 2.0 |
| C5960 | Dual | 0.01-250 | 1,000 | 50 | 0.40 | N-Female | 10.5 x 3.0 x 2.0 |
| C1460 | Dual | 0.01-250 | 2,000 | 50 | 0.15 | N-Female | 10.0 x 3.0 x 2.0 |
| C4080 | Dual | 0.01-250 | 3,500 | 50 | 0.20 | N-Female | 10.0 x 4.6 x 3.5 |
| C11026 | Dual | 0.01-220 | 5,000 | 60 | 0.10 | LC-Female | 12.0 x 6.0 x 4.5 |
| C8390 | Dual | 0.01-250 | 10,000 | 60 | 0.10 | LC-Female | 12.0 x 6.0 x 4.5 |
| C5339 | Dual | 0.01-400 | 200 | 40 | 0.50 | N-Female | 5.2 x 2.67 x 1.69 |
| C6047 | Dual | 0.01-400 | 500 | 40 | 0.50 | N-Female | 5.2 x 2.67 x 1.69 |
| C2630 | Dual | 0.01-1000 | 100 | 40 | 0.60 | N-Female | 5.0 x 2.0 x 1.51 |
| C6021 | Dual | 0.01-1000 | 500 | 40 | 0.45 | N-Female | 6.7 x 2.28 x 1.69 |
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| C11077 | Dual | 0.1-1000 | 1,000 | 43 | 0.45 | SC-Female | 6.7 x 2.28 x 1.69 |
| C3910 | Dual | 80-1000 | 200 | 40 | 0.20 | N-Female | 3.0 x 3.0 x 1.09 |
| C5982 | Dual | 80-1000 | 500 | 40 | 0.20 | N-Female | 3.0 x 3.0 x 1.09 |
| C3908 | Dual | 80-1000 | 1,500 | 50 | 0.10 | 7/16-Female | 3.0 x 3.0 x 1.59 |
| C6796 | Dual | 80-1000 | 5,000 | 60 | 0.20 | 15/8" EIA | 6.0" Line Section |
| C8060 | Ві | 200-6000 | 200 | 20 | 0.40 | SMA-Female | 1.8 x 1.0 x 0.56 |
| C8000 | Ві | 600-6000 | 100 | 30 | 1.10 | SMA-Female | 4.8 x 0.88 x 0.50 |
| C10117 | Dual | 700-6000 | 250 | 40 | 0.20 | N-Female | 2.0 x 2.0 x 1.06 |
| C10364 | Dual | 700-6000 | 500 | 50 | 0.20 | 7/16-Female | 2.15 x 2.0 x 1.36 |
| C10996 | Dual | 700-6000 | 700 | 50 | 0.20 | 7/16-Female | 2.15 x 2.0 x 1.36 |
| C11555 | Dual | 700-6000 | 1,000 | 50 | 0.20 | 7/16-Female | 2.15 x 2.0 x 1.36 |
| C10695 | Dual | 700-6500 | 500 | 50 | 0.20 | 7/16-Female | 2.15 x 2.0 x 1.36 |







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FPGAs in SDRs for Radar, EW and MilCom Applications

Brandon Malatest

Per Vices, Toronto, Canada

oftware-defined radios (SDRs) are becoming increasingly popular across various applications, including electronic warfare (EW), radar and military communications (MilCom). The flexibility and versatility of SDRs enable them to adapt to changing requirements and challenges, making them an ideal choice for these applications. For instance, in EW applications, SDRs can detect and identify signals from various sources and jam them to disrupt communication, providing a significant tactical advantage on the battlefield. In the same way, SDRs can be used for radar applications to detect and track targets in real-time, making them an ideal choice for military applications. In MilCom, SDRs offer interoperability between different types of radios, allowing different forces to communicate seamlessly, regardless of the radio system used



▲ Fig. 1 Air defense radar. Source: Shutterstock.

all while being able to adapt to changing requirements, making them ideal for dynamic battlefield conditions. This flexibility enables troops to communicate effectively, make critical decisions in real-time and improve overall battlefield situational awareness. All these features and applications are enabled by SDRs and the underlying use of field-programmable gate arrays (FPGAs).

FPGAs are semiconductor devices based on a reconfigurable matrix of logic blocks. Unlike traditional processors that are hard-wired to perform specific functions, FPGAs can be programmed and reprogrammed to perform different functions, making them extremely versatile. FPGAs typically consist of configurable logic blocks, digital signal processing blocks, input/output blocks and random-access memory (RAM).

This article discusses how the integration of FPGAs into SDRs enables key performance benefits across EW, radar and MilCom applications. The use of FPGAs as the digital logic in SDRs provides several advantages. These include waveform storage, external triggering, channelizing capabilities, processing (filters, decimation, interpolation, etc.) and the implementation of modulation and demodulation on board. *Figure 1* shows a typical air defense radar that might benefit from SDRs with FPGAs. *Figure 2* shows a typical air traffic control/air traffic management radar display.

FPGAs have been an integral part of many modern systems because of their superior performance and flexibility. Unlike an application-specific IC, which is designed for a specific application and cannot be reprogrammed, FPGAs can be programmed and reprogrammed to perform a

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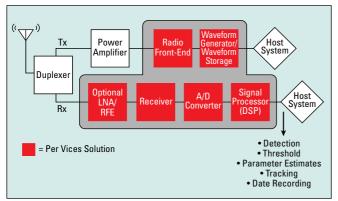
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▲ Fig. 2 Typical ATC/ATM radar display. Source: bbc.co.uk.



▲ Fig. 3 Representative radar system block diagram showing the Per Vices solution.

wide range of tasks. In recent years, FP-GAs have gained increasing popularity in SDRs for EW, radar and MilCom applications due to their unique advantages. When integrated into SDRs, FPGAs are incredibly powerful and can sustain high data throughput, providing both the I/O bandwidth and processing capabilities needed for these applications. FPGAs can be programmed to perform real-time signal processing tasks, such as demodulation, filtering, modulation and encoding, enabling SDRs to handle the high data rates required for all these applications.

Why Use FPGAs in an SDRs?

FPGAs are increasingly being used in SDRs due to their ability to handle high speed data processing and provide a high degree of flexibility and reconfigurability. Their ability to support high data throughput enables SDRs to process in real-time, the enormous amounts of data collected during a mission or exercise. FPGAs can be used to implement high speed digital signal processing algorithms and to perform parallel processing, which allows for the efficient processing of the data

captured or sent by SDRs.

2222

FPGAs can be programmed and reprogrammed to implement various signal processing algorithms, modulation demodulation and schemes and other signal processing functions. This makes FPGAs ideal for implementing the complex signal processing functions required in SDRs, such as frequency-hopping, adaptive filtering and channel equalization. One of the main benefits of using FPGAs in SDRs is the ability to store waveforms, enabling faster and more efficient signal Waveprocessing. form storage allows SDRs to record and store large amounts of data, which can be processed and analyzed later.

The use of external triggering is another benefit of

using FPGAs in SDRs. External triggering enables SDRs to synchronize with other devices, such as radars, enabling more accurate signal processing and reducing system complexity. This capability is essential in radar applications, where accurate synchronization is required for precise target tracking.

Overall, the combination of high speed data processing, flexibility, storage and triggering and reconfigurability make FPGAs an ideal choice for SDRs. By using FPGAs, SDRs can provide a high level of performance and flexibility. This makes them suitable for a wide range of military applications.

Benefits of FPGAs in SDRs for Radar Applications

As mentioned above, one of the most significant benefits of FPGAs is their ability to handle high data throughput rates. Radar systems generate large amounts of data that need to be processed in real-time, and FPGAs are capable of processing this data efficiently. FPGAs can be used to implement advanced digital signal processing algorithms, such as fast Fourier transforms, that are required to extract useful infor-

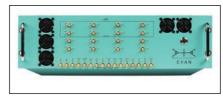
mation from radar signals.

Another benefit of using FPGAs in SDRs for radar systems is their ability to perform real-time signal processing. FPGAs can be used to implement realtime filtering, decimation and interpolation, which are essential processes for removing noise from the radar signals and improving the accuracy of the system. FPGAs can also be used to implement adaptive filtering algorithms, which can automatically adjust the filter parameters based on the incoming signal and enable signal processing tasks such as Doppler processing, pulse compression and target detection, providing high-resolution images of the radar environment.

In addition to these benefits, FPGAs can also be used to implement advanced modulation and demodulation schemes that are required in radar systems. For example, FPGAs can be used to implement pulse compression techniques that are used to increase the range resolution of the radar system. FPGAs can also be used to implement frequency-hopping techniques that are used to reduce interference and improve the reliability of the system.

Finally, FPGAs incorporated into SDRs, enable both waveform storage and triggering. This enables these products to store predefined radar waveforms for different types of radar techniques and activate the transmission of these waveforms using external triggers connected to the FPGA within the SDR. This simplifies the overall architecture of a radar system and enables greater performance in a smaller footprint than alternative architectures.

Figure 3 shows a representative functional block diagram for a radar system along with where Per Vices SDR platform solutions can add value. Figure 4 shows the Per Vices Cyan SDR that can be used in radar, EW or military communications applications. This platform provides simultaneous support for up to 16 fully independent transmit or receive radio channels. Each of these channels has 1 GHz of RF bandwidth with support for up to 3 GHz of bandwidth and up to 16-bit converters. The Cyan platform can tune from near DC to 18 GHz. The digital throughput includes four 40GBASE-R



▲ Fig. 4 Cyan commercial off-theshelf (COTS) SDR and FPGA solution.



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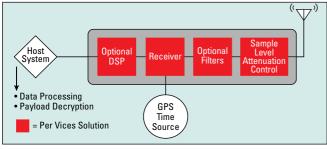
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▲ Fig. 5 Representative EW system receiver block diagram showing the Per Vices solution.

qSFP ports to receive and transmit radio data and this capability can be upgraded to four 100GBASE-R. The complexity and functionality of this platform hint at the benefits that SDR, coupled with FPGAs add to active electronically scanned array radars with many

antenna elements.

Benefits of FPGAs in SDRs for EW

Flexibility is critical in EW. FPGAs can be programmed to perform a wide range of signal processing tasks and can be reprogrammed on the fly to adapt to changing requirements to meet these flexibility needs. This means that SDRs with FPGAs can easily accommodate new signal processing algorithms and modulation schemes, making them suitable for a broad range of EW applications.

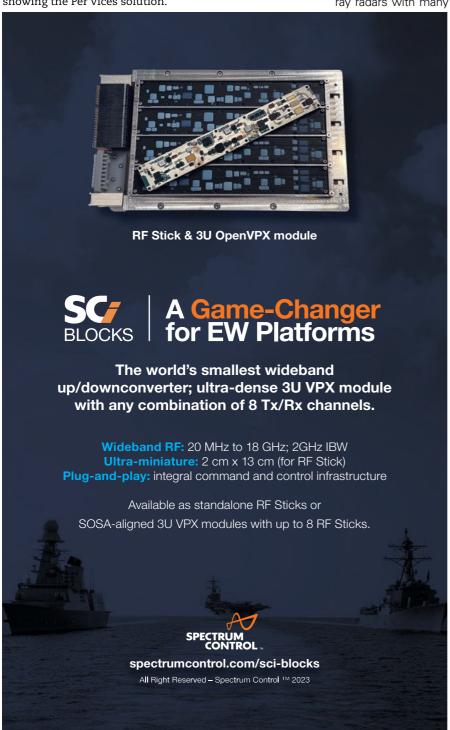
FPGAs can process large amounts of data quickly. This is critical in EW applications, as this capability enables rapid detection, analysis and response to threats in the electromagnetic spectrum. The high speed processing capabilities of FPGAs make them an ideal choice for complex signal processing tasks inherent in EW applications. The ability to support real-time signal processing of vast amounts of data at high speeds makes this architecture invaluable in EW applications.

The ability to process large amounts of data is not the only benefit of FPGAs for EW systems. There is a need to acquire and process the data quickly, so low latency is another important characteristic of FPGAs. Latency refers to the time delay between the input signal and the output response. In EW applications, low latency enables the system to respond quickly to threats in the electromagnetic spectrum. With FPGAs, SDRs can achieve extremely low latency in signal processing, making them an ideal choice for high speed applications in electronic attack, protection and support.

FPGAs offer high performance computing capabilities, including filters, decimation and interpolation. This makes FPGAs an ideal choice for the complex algorithms and computations required in EW applications. With their parallel processing capabilities, FPGAs can perform multiple operations simultaneously, enabling them to handle complex computations quickly and efficiently. This allows this architecture to be used for all elements of EW, including electronic attack, electronic protection and electronic support, where real-time



▲ Fig. 6 Chestnut SDR and FPGA solution.





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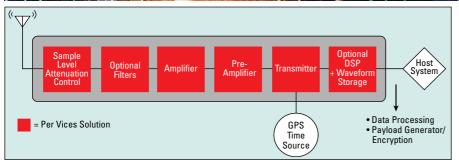
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▲ Fig. 7 Representative EW system transmitter block diagram showing the Per Vices solution.



processing of complex algorithms is required for rapid detection and response to threats. Implemented properly, the FPGA and SDR combination can create significant tactical advantages on the battlefield.

All the above benefits are amplified by the fact that FPGAs can significantly reduce power consumption in SDRs for EW applications. Unlike traditional processors, FPGAs consume power only when they are performing computations. This means that they consume less power than traditional processors, making them a good choice for battery-powered warfighter applications. This is particularly important in EW applications, where the ability to operate for extended periods on battery power is a critical differentiator.

Figure 5 shows a representative functional block diagram for the receive chain of an EW system. Figure 6 shows the Per Vices Chestnut SDR that can also be used in EW, radar or military communications applications. The Chestnut SDR offers four receive and four transmit radio chains that may each be independently controlled. Each chain of the platform has up to 500 MHz of bandwidth. The architecture allows for either a common LO or separately tuned LOs to be used to improve the coherency and stability for the applications requiring this architecture. The tuning range of Chestnut is from near DC to 9 GHz with 16-bit converters and dual 100GBASE-R digital throughput for up to 200 Gbps of data transfer. While the DC to 18 GHz frequency coverage of the Cyan SDR may be better suited to the most demanding EW applications, the Chestnut platform addresses applications, like EW, with fewer transceiver channels. The benefits of SDR, coupled with FPGAs turn the advantages described into real differentiators.

Benefits of FPGAs in SDRs for Military Communications

FPGAs offer several benefits for military communication systems when integrated into SDRs. Similar to the other applications discussed, one of the primary benefits is the ability of FPGAs to handle high speed data processing. Military communication systems require high data throughput rates to transmit and receive large amounts of data in real-time and FPGAs are capable of easily handling the required levels of data processing. FPGAs can be used to implement advanced digital signal processing algorithms, such as error correction and encryption, which are essential for en-



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▲ Fig. 8 Crimson TNG SDR and FPGA solution.

suring the reliability and security of the communication system.

In military communications applications, SDRs with

FPGAs utilize their ability to perform real-time signal processing to implement real-time filtering, modulation and demodulation. These capabilities are essential for improving the quality of the transmitted signal and reducing interference. FPGAs can also be used to implement adaptive filtering algorithms, which can automatically adjust the filter parameters based on the incoming signal.

In addition to these benefits, FPGAs can also be used to implement advanced modulation and demodulation schemes that are required in military communication systems. For example, FPGAs can be used to implement frequency-hopping techniques that are used to reduce interference and improve the reliability of the communication system. FPGAs can also be used to implement spread-spectrum techniques that are used to increase the security of the system. FPGAs also enable channelization in SDRs. This allows for the simultaneous processing of multiple channels. Channelizing becomes particularly useful in MilCom systems, where the ability to handle multiple channels simultaneously is essential for effective communication. The low latency signal processing in FPGAs is an essential differentiator in MilCom systems. Low latency in the signal chain means less time delay and this enables troops to communicate and make critical decisions faster and more efficiently, improving overall battlefield situational awareness.

Figure 7 shows a representative functional block diagram for a transmitter chain for a wireless receiver, whether that is for an EW system or a communications terminal. **Figure 8** shows the Per Vices Crimson TNG SDR platform that can also provide value in radar and EW applications, in addition to communications applications. The Crimson TNG platform offers a radio architecture with four receive and four transmit chains. Each radio chain can be controlled independently, or it may share a common LO for better phase coherency and stability performance. Each radio chain has 325 MHz of bandwidth with 16-bit converters and a tuning range from near DC to 6 GHz. The digital interface for controlling the system is a standard 1G Ethernet port and the data transfer is done over dual 10GBASE-R interfaces, providing users with up to 20 Gbps of data transfer.

Summary

In conclusion, incorporating FPGAs into SDRs offer several benefits for radar, EW and military communication applications. The flexibility offered while accommodating real-time signal processing at high data rates allows this architecture to offer differentiated benefits and high performance in these applications. The additional benefits of low latency, reduced power consumption, the ability to modulate and demodulate data and being able to trigger the FPGAs externally increase the utility of these systems. For EW applications, these FP-GA-based SDRs increase the ability of systems to detect, identify and counteract threats in the electromagnetic spectrum. In radar systems, the FPGA/SDR architecture improves system-level performance and accuracy, while simplifying the overall system complexity. In military communications applications, FPGAs coupled with an SDR can increase the performance and security of these systems.



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Military Radar: Surveying Beyond Battle Grounds

Aparna M.A

Kings Research, Dubai, UAE

he military radar segment covered in this article includes radar technology used for applications like monitoring aircraft and missiles, managing air-to-air missiles and guns along with detecting potential threats such as hypersonic missiles and drones. Military radar technology has advanced significantly over time. These systems have become crucial components of broader detection and tracking networks for military operations due to improvements in radar resolution, range and detection capabilities.

There are several different kinds of military radars, including air defense radars, early warning radars and ground surveillance radars. These systems have become an indispensable part of top-level defense strategies. The strategic objective and eventual success of these military applications are supported by the rapid evolution of radar systems, typically driven by technological and digitization breakthroughs. A typical military radar antenna is shown in *Figure 1*.

Decoding the Future of Military Radar

Radar is an umbrella term used to refer to a wide spectrum of techniques and devices for detecting and surveying objects using radio waves. Radar systems cover a wide range of applications, including ground-penetrating radar, weather radar and air traffic control radar, in addition



▲ Fig. 1 Military radar. Source: Alarmy.com.

to more defense-related applications like search, fire control and surveillance radar. The ability to identify objects using radio waves makes radar a general name for a variety of remote sensing technologies.

Extrapolate says that the military radar market size is likely to reach \$25.75 billion by 2030, recording a healthy CAGR of 4.5 percent during the 2021 to 2030 forecast period. These numbers are clear indications that the market is poised for robust growth in the near future. As a result of the breakthroughs and trends sweeping the industry, military radar is anticipated to advance quickly, transforming defense forces along the way. The forecast graphic associated with the Extrapolate report is shown in *Figure 2*.

Radar is used in defense applications to locate missiles, ships, airplanes and spacecraft that represent a threat from the air, land, water or space. Radar devices are also crucial to the task of locating explosives and landmines that are concealed from view. One of the most popular products in the military radar sector that has significant demand on a global scale is lightweight radar. High demand for these radars will create a large market opportunity for these systems. The global military radar sector is being driven by increased national spending to strengthen home defense and border defense forces.

What Is Driving the Military Radar Market?

Military radar is gaining immense popularity as border disputes increase. These disputes point out the need for improved defense capabilities. The Middle East has a long history of conflict due to disagreements over borders and hostilities in areas like Saudi Arabia, Iraq and Syria. In light of regional power uncertainties and local conflicts, the region has experienced an increase in the appetite for weapons and defensive systems. Regional markets are growing in response to increasing border disputes and political upheaval in neighboring countries and this uncertainty influences the procurement of cutting-edge weapons.

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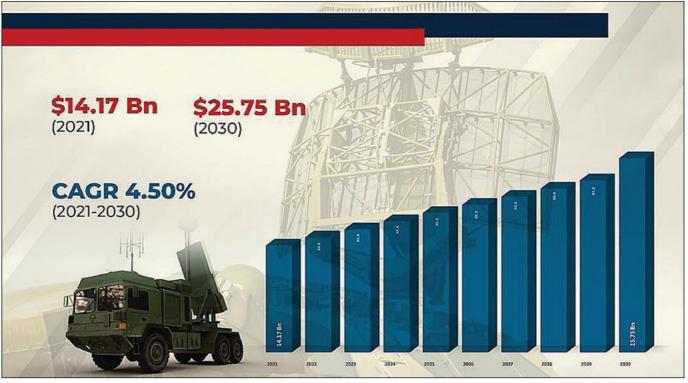
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▲ Fig. 2 Military radar market forecast. Source: Extrapolate.

These factors are fueling increased defense expenditures and the acquisition of military radars to address potential threats. According to "The Economic Times," the world's military spending has surpassed \$2 trillion for the first time.² The U.S., the world's largest economy, remains the biggest spender, according to a report released by the Stockholm International Peace Research Institute (SIPRI), a Swedish defense think tank. In its 2021 report.3 SIPRI stated that overall global military expenditure increased by 0.7 percent in real terms to \$2,113 billion in 2021. The U.S., China, India, the U.K. and Russia were the top five spenders in 2021, collectively accounting for 62 percent of expenditures. Military budgets are also anticipated to benefit from the shift from traditional combat to electronic and cyber warfare.

Another defense budget driver is the pressing demand to track global terrorist activities. These and other activities are increasing geopolitical tensions, which also contribute to increasing defense expenditures in developing countries, especially in the Middle East and Asia-Pacific regions. These demands have pushed various countries to develop radar systems that are suited to specific needs and criteria. In April 2021, as an example, China launched a portable and adaptable radar that can detect stealth aircraft, cruise missiles and drones.

Increasing investment in military radar is driven by the need to improve air defense capabilities by incorporating new technological developments and an increase in combat aircraft acguisition. Market growth is constrained by the size of early-stage investments, the inability to detect small targets, like drones and strict cross-border trading regulations. The escalation of geopolitical tensions and the expansion of military radar research and development for airborne platforms are anticipated to create profitable business opportunities for manufacturers of military radar equipment in the market.

Military Radar Trends

As military radars evolve, regional defense agencies are increasingly integrating technology and innovative features as differentiators against other countries. An emerging radar trend is the introduction of MIMO phased array radars. An array of antennas with digital receivers that can transmit any waveform is a mainstay of the architecture of these MIMO radars.

MIMO radars are the evolution of active electronically scanned array (AESA) radars. AESA radars are still widely used, providing substantial advantages over mechanically or passively scanned radars, but they are potentially heavier and more expensive than the next-generation MIMO radars. These radars can

use a 3D range because of the number of elements and transceivers. The new MIMO technology is anticipated to outperform the current AESA systems for ground radar applications. MIMO radars also offer greater jamming resilience capacity when compared to AESA radars and this also contributes to its growing demand.

The Drone Challenge

As shown in Figure 3, most drones are comparatively small, making their identification by radar systems difficult. On the radar screen, there is presently no way to block such a small object. The expanding use of commercial or personal drones exacerbates the problem, making it difficult for radar systems to manage such a large number of simultaneous targets. Built-in display filters only show the most critical targets and filter out the remainder to prevent system overload. The inability to identify drones and the rising use of small drones for monitoring are expected to limit market growth.

The Threat and Opportunity of HAPS

Recent innovations and trends are high altitude platform systems (HAPS). These high altitude platforms are being envisioned as tools in the broadband connectivity portfolio, but they are also in use in surveillance applications. One



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▲ Fig. 3 Conceptual drawing of a drone.

recent example of this use that caught everyone's attention was the incursion of high altitude balloons into U.S. territory. Even if the three balloons that have subsequently been blown up by fighter aircraft were allegedly benign, U.S. intelligence officials are still persuaded that the first suspected Chinese spy balloon that was shot down was meant for surveillance over key military locations. 4 A photo of the Chinese spy balloon is shown in Figure 4. According to reports, the balloons were used as a part of China's military spy program to get information about the U.S. It was thought that the balloons in-



▲ Fig. 4 Spy balloon. Source: Setav.org.

cluded sophisticated sensors and cameras that could record video and collect data at a great height.

This is not the first time China has used spy balloons. Since 2017, at least four balloons have reportedly breached U.S. airspace, according to sources. According to American officials, the balloons may have violated international law and presented a risk to national security. Despite previous incidents, this was the first time that the U.S. military intervened to shoot down the balloons. To combat this issue, the U.S. military intends to deploy an over-the-horizon radar in Palau by 2026. This installation

will enhance the early warning capabilities in the western Pacific as China's military power rises.

The Shift Toward Military Radar

Military radars are experiencing tremendous growth and demand due to the various advantages they offer. Some of the advantages of evolving radar systems:

- Robustness in all weather conditions: Radars are built to function and gather data in challenging weather, such as snow, rain and fog, which can impair the effectiveness of other sensors.
- Long-range surveillance and early warning capabilities: Radar systems are capable of detecting objects hundreds of kilometers away.
- Detecting the location and speed of objects: Military radars can identify the location and speed of objects, such as aircraft, missiles, ships and ground vehicles by evaluating the Doppler shift in the return signal.
- Providing situational awareness: On the battlefield, military radars can assist commanders in making choices by providing real-time data on the location and movement of both friendly and opposing forces.
- Real-time detection and monitoring: Military radars can be used in air traffic control to increase both the safety and effectiveness of air transport.

Regional Defense Expenditures

The challenges to incorporate the latest innovative, cutting-edge technology advancements in military radar are driving military budgets and competition in the industry. Since the United States spends the most on defense and has purchased the latest military radars, the North American region is predicted to maintain a significant share of the market. As a result of ini-

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tiatives and programs such as the Air and Missile Defense Radar and the Three-Dimensional Expeditionary Long-Range Radar, the regional market is anticipated to see good growth. The rising demand for military radars is also aided by significant OEMs such as Boeing, Lockheed Martin and Northrop Grumman, among others.

Three transmit/receive sites are required by the operational DARC program, positioned at mid-latitudes all around the world, to detect and track satellites. The U.S. Space Force's Space Systems Command awarded Northrop Grumman a \$341 million contract in February 2022 to start construction on the global system, with the initial installation in Australia planned for the year 2025. The locations of the next two sites have yet to be determined, but they will be in Europe and the U.S.

A growing number of military modernization projects are expected to propel Europe to become a significant region in the industry. Demands will be made by Spain, Germany and other nations whose military spending has increased year-over-year. In July 2020, German defense electronics and sensor company, Hensoldt and Airbus Defence and Space received a \$1.7 billion contract for the delivery of AESA radars for the Eurofighter fleets of Germany and Spain. At contract completion, 130 aircraft will be outfitted with radar components, such as digital multi-channel receivers, antennas and transmitter modules.

According to the Norwegian Government Security and Service Organisation, on November 17, 2022, the Norwegian Defence Material Agency and Lockheed Martin signed a contract for the shipment of eight military air surveillance radars, with the potential for three more radars. By the end of 2025, the first radar will be installed atop Gyrihaugen in Ringerike, where arrangements are already underway. By 2030, all the radars will be delivered.

This does not mean Asia-Pacific is lagging. This region will experience the largest growth during the forecast period. Growing cross-border issues and geopolitical tensions between countries such as China, India and Pakistan are driving an increase in the need for advanced threat detection systems. This region imports a substantial portion of its systems. The percentage of foreign purchases for defense products and equipment from 2017 to 2021 ranged from 34 percent to almost 42 percent.

A Practical Example

There are various novel innovations in the military radar industry. The Indian Army recently purchased six Swathi Mark II Weapon Locating Radar (WLR) from Bharat Electronics (BEL). The Defence Research and Development Organisation and BEL collaborated to develop the Swathi WLR, a mobile artillery-locating phased array radar. The radar system has a variant created for use in mountainous terrain. Its purpose is to identify the source of the counter-battery fire by detecting and tracking incoming artillery, mortar and rocket fire. The WLR is set up on a wheeled Tatra 8×8 truck frame and has a C-Band frequency range with a configured range of 50 km. According to various reports, the radar system is more user-friendly than the AN/TPQ-37 radar but is identical in performance and design.

Conclusion

In times of conflict, military radar is a vital tool for tracking aircraft, seeing potential threats and providing early missile detection. Radar technology has been used in a wide range of applications in recent years due to developments in digital signal processing and machine learning. These include guided missile target locating systems, self-driving cars, ground-penetrating radar for geological observations, air and terrestrial traffic control, radar astronomy, air defense systems, anti-missile systems, marine radars, aircraft anticollision systems, ocean surveillance systems and space surveillance and rendezvous systems. ■

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Editor's Note: As additive manufacturing techniques evolve, these processes offer significant advantages and benefits to the electronics industry. Microwave Journal investigates some of the aspects of this emerging area with a two-part article. This first part introduces the dielectric measurement concepts and some of the challenges. It also includes a portion of a panel discussion where RF dielectric measurement experts from the industry examine some of the most important topics in that area. The second part of this feature will continue the discussion with the panel of experts.

Estimating & Measuring the Dielectric Constant and Loss Tangent of Dielectric Lattice Structures for Additive Manufacturing (Part 1)

Phil Lambert

Fortify, Boston, Mass.

ecent advances in low dielectric constant (Dk) and low loss (Df) resins capable of being used in additive manufacturing (AM) applications have opened the door to creating dielectric lattice structures with tunable dielectric parameters. The ratio of the volume of air to the volume of dielectric lattice can be used to design complex dielectric properties. This technique can be an enabling factor in the realization of metamaterials, complex dielectric lattice structures and artificial dielectrics with performance that, historically, has not been viable with traditionally-fabricated dielectric materials. Increasing the design degrees of freedom brings the challenge of accurately determining the dielectric properties of the material early in the calculation, simulation and measurement process.

This article discusses this challenge and presents a variety of methods used to test dielectric performance, with many only suited to a narrow range of applications. The article also summarizes excerpts from interviews with some of the leading experts in the field. Their insights help frame the applications and benefits of these materials, along with some of the manufacturing challenges.

There have been extensive studies into dielectric materials and methods of characterization, measurement and prediction/simulation, with additional studies of more complex materials over

the past 40 to 50 years. 1-10 Methods for measuring simple materials, those with non-magnetic, linear, homogeneous and isotropic dielectric properties, are very well established. The emergence of new methods of dielectric fabrication over the past several years has warranted the exploration of new methods for characterizing, measuring and predicting the behavior of more complex dielectric structures. AM adds a new level of complexity to the design and testing of complex dielectrics since this process can also change the properties of the material. This means that the 2D and 3D structures may exhibit dielectric behavior that cannot readily be predicted or modeled using as-labeled dielectric material properties.

Considerations for Dielectric Structure/Media Testing

This article explores the concepts of measuring and modeling AM dielectric structures. There are a variety of methods for measuring dielectrics. The suitability of a given measurement method is determined by the properties, structure and state of the dielectric material, as well as the testing goals of the dielectric material. With modern, complex AM dielectric structures, there are additional considerations that compound the process of determining the most appropriate test method.

Historically, the type of dielectric material was categorized as either bulk or thin. This described the structure of

the dielectric material as either a bulk dielectric that could be measured as a single monolithic structure or a thin dielectric sheet or coating, which requires a different set of testing considerations. In addition to these two categories, a lattice structure or complex dielectric structure must be added. These structures create additional measurement considerations beyond simple bulk dielectric material testing.

Other measurement considerations include the frequency range, the measurement accuracy and the permittivity/ permeability range. The intended use of a dielectric generally determines the frequency range. However, in the case of complex dielectric structures, the structure may dictate the operational frequency range and this may deviate from the typical frequency range for the dielectric materials. Measurement accuracy relies on using the best test method, but it may also establish boundaries for the properties and geometry of a given sample. This may be a limiting factor for complex dielectric structures as these structures often have frequency-dependent design features that require certain geometries for optimal performance. Lastly, the permittivity/permeability range of a complex dielectric structure may be difficult to assess initially. Using a dielectric measurement method that is not well-suited to the actual permittivity/permeability range of the dielectric may result in unforeseen errors that are difficult to detect.

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Brief on Linearity, Isotropy and Homogeneity of Dielectric Structures/ Media

A material that is linear, isotropic and homogeneous will present the same response to a stimulating field regardless of the applied field strength, orientation or how the material's constitutive parameters are positioned. However, a material may be nonlinear, anisotropic and/or inhomogeneous. These terms mean that the response of a material to a stimulus may depend on the field strength or the orientation of the stimulating field and it may have different profiles based on the constitutive parameter configurations. These factors must be taken into consideration when characterizing, designing or measuring dielectric media or structures. This is because small variations in the material makeup, manufacturing process or assembly can change the material properties, which may then impact the dielectric material features.

To some degree, all materials present some non-idealities that contribute to the overall uncertainty of a given measurement. It can often be difficult to determine the extent of this uncer-

tainty and the appropriateness of various measurement techniques that may be sensitive to these non-idealities. In some cases, it may be appropriate to ignore these non-idealities to some degree and simply use a measurement method that best represents the real-world use of a dielectric structure/media. In other cases, it may be necessary to characterize the dielectric structure or media as completely as possible for the sake of modeling and simulation accuracy.

Common Methods of Dielectric Constant and Loss Tangent Measurement

A wide variety of dielectric measurement methods have been developed to account for the diversity of dielectric materials. The advent of AM and more complex dielectric structures has driven the need to develop measurement processes that best account for capturing the nuances of lattice structures. Due to the relative size and dimensions of lattice structures at various frequencies, there are only a few measurement methods that can be functionally used to make dielectric measurements on dielectric lattices.

Common Dielectric Measurement Methods

- Impedance analyzers/LCR meters
- Parallel plate capacitor or three terminal method (ASTM D150)
- Open-ended coaxial probe
- Dielectric loaded waveguide (filled waveguide)
- Coaxial transmission line (filled transmission line)
- Planar transmission lines
- Focused microwave or mmWave beam (free space)
- Resonant cavity or resonant surface structure
- Split cylinder resonator
- Split post dielectric resonator
- Fabry-Perot open resonator
- Cavity perturbation (ASTM D2520)
- Inductance measurement method.

Most of the common dielectric test methods are not suitable for measuring lattice structures because many of these structures are likely to be based on unit cells. This means that a number of these cells must be arranged to faithfully represent the lattice structure and replicate the desired dielectric performance. In addition, these structures likely will not exhibit the same dielectric behavior if they are improperly arranged into a flat disc or another sample shape that does not recreate the behavior of the dielectric structure. Given that the "bulk" performance of the dielectric lattice is likely what is being tested, this factor alone rules out most dielectric test methods. A unique case of this guideline can occur if the dielectric lattice structure is used as a planar substrate. In this case, the dielectric lattice is likely designed specifically for that purpose and testing using planar transmission line, parallel plate capacitor, split post dielectric resonator, Fabry-Perot open resonator or other methods that can leverage a planar/laminar sample may be appropriate.

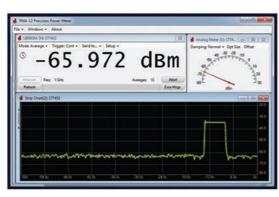
For 3D bulk dielectric lattices, loaded wavequide/transmission line, freespace methods like focused mmWave/ microwave beam and in some cases, the open-ended coaxial probe method are likely the only applicable test methods. For the open-ended coaxial probe, there may be some limitations in using this method for dielectric lattice structures that do not present a flat, uniform face because air gaps will lead to errors. Issues also arise if there are structural elements significant to the desired dielectric performance that cannot be adequately captured within the fringe fields of the coaxial probe.

For loaded transmission line and waveguide approaches, the physical size of the transmission line/waveguide

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will impose limitations on the measurement frequency range. Here, the tolerances scale inversely with the frequency to ensure adequate measurement accuracy. Free-space methods have limitations on the sample size and the orientation and isotropicity of the sample must be considered when performing free-space methods like loaded transmission line techniques. Free-space measurements are possible at very high frequencies with relatively small samples, but since the sample size of this method scales with the wavelength, this imposes a constraint on lower frequency measurements.

Expert Discussion on Dielectric Measurements

To gauge the prevailing trends and applications the industry is addressing for dielectric structures, the authors interviewed some of the leading experts in the field. The following are excerpts from interviews conducted with these industry experts on complex dielectric structures and dielectric measurement methods.

What are the applications for these dielectric structures?

Marzena Olszewska-Placha, Ph.D., Vice President for Research & Development, QWED Sp. z o.o.:

Most common materials that are tested with test fixtures, which we develop and offer, are sheet dielectrics, semiconductors and conductive composites. Dielectrics typically include electronic laminates, polymers and ceramic substrates such as LTCC and ULTCC materials. Conductive composite materials cover a wide spectrum of applications from EMC/EMI to energy materials, including anodes for battery cells.

Jonathan Chisum, Ph.D., Associate Professor for Electrical Engineering, University of Notre Dame:

Our research focuses on low-cost and wideband beam scanning lens antennas for applications in 5G/6G mmWave wireless communications, satcom and sensing. Emerging commercial and low-SWaP defense applications demand extremely low-cost and low-power beam scanning antennas. Gradient-index (GRIN) lenses support extremely wideband operation (e.g., 8 to 60 GHz in a single aperture) and provide sufficient degrees of freedom that they can be optimized for wide angle beam scanning with high aperture efficiency. ^{1,2} However, they are difficult and expensive to fabricate. Due to recent developments in low loss tangent 3D-printed dielectrics, GRIN lens antennas offer a passive beam scanning alternative to the PAA and, when 3D-printed, are low-cost.

Nico Garcia, Ph.D., CEO & Founder, Cheshir Industries:

We are designing and building GRIN lens antennas, a disruptive technology platform with various applications in microwave and mmWave communications and sensing. Our GRIN lens antenna products are low-cost, power-efficient, ultra-wideband alternatives to conventional beamforming antenna solutions.

John Schultz, Ph.D., Chief Scientist, Compass Technologies Group LLC:

At Compass Tech, we are experts in electromagnetic (EM) measurements, especially dielectric measurements and measurement test systems. We also design specialized antennas and probes. For instance, we recently developed a low frequency antenna technology designed to replace bulky low frequency



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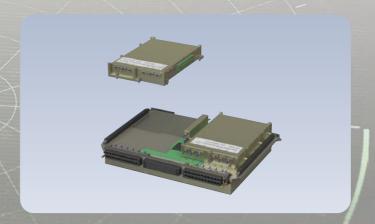


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horns, a metamaterial flat lens antenna. Instead of being 30 to 40 in. wide, like the low frequency horns, it is only 2 in. wide. Another example that we are developing is a flexible, slip-on lens for enhancing probe directivity that we manufacture using a fused filament fabricated (FFF) AM technology. We also manufacture a laboratory focus-beam system that we have available at various frequencies with different lens types and technologies.

How and why are precise dielectric constant and loss tangent figures for a dielectric critical for your application? Do these parameters need to be precisely measured or can they be estimated?

Marzena Olszewska-Placha, Ph.D.:

In the case of QWED, I can answer this question from two perspectives, which are related to company activities. Firstly, from the perspective of a vendor of test fixtures for the precise measurements of dielectric properties. And secondly, from the perspective of a company running various research and development activities related to our expertise in designing a wide spectrum of microwave devices. In the design of

microwave devices, where interactions between EM fields and materials are involved, e.g., a microwave applicator for bituminous surface treatment, precise knowledge about materials' parameters, mainly dielectric properties, often as a function of temperature, is required. The more precise this knowledge is, the higher the effectiveness of a design and final real-life device. This experience is our driving force in our second branch of activities, for developing fixtures for microwave characterization of dielectric properties of materials of various kinds.

Jonathan Chisum, Ph.D.:

To realize these benefits, a GRIN lens requires a continuously varying dielectric constant throughout the lens volume. And, to maintain high radiation efficiency, the dielectric should exhibit very low insertion loss. Since there are no methods by which one can realize an ordinary material with arbitrary dielectric constant, GRIN lenses are realized as artificial dielectrics comprising unit cells with varying volume ratios of air and a background or host dielectric to achieve an effective dielectric constant. A curve that illustrates the effects of the volume fill factor on effective permittivity is shown in Figure 1(a).

Figure 1(b) shows that the optical path length is constant over an order-of-magnitude change in dielectric loss tangent, indicating that phase collimation is insensitive to dielectric loss, but the insertion loss is linear, in dB, with loss tangent. Therefore, it is essential that low loss dielectrics be used and quantified to determine gain from directivity.

Nico Garcia, Ph.D.:

Accurate measurement of the dielectric constants of GRIN materials is crucial. The dielectric constant relates directly to the propagation constant and wave impedance of a GRIN substructure; accurate characterization of these parameters is essential to the overall GRIN lens design. Accurate measurement of the loss tangent is less critical assuming that the loss tangent is sufficiently low, ideally around or below 0.002. This is generally easier with alumina and other ceramics, but modern RF composites and laminates are now consistently around this threshold. GRIN lenses generally comprise composite dielectric structures and it is often necessary to take real measurements of these structures' EM properties before proceeding with design or fabrication. Modern simulation



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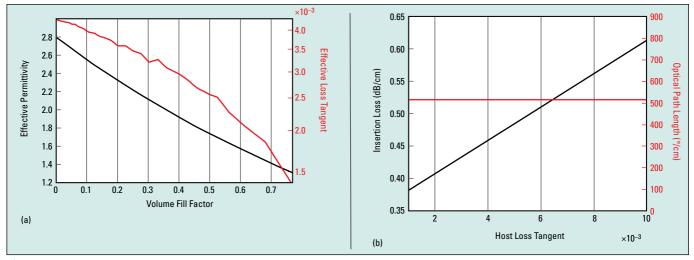
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🔺 Fig. 1 (a) Effective permittivity vs. volume fill factor at 28 GHz. (b) S21/cm vs. host loss tangent at 28 GHz.

tools are extremely accurate but the simulation model needs to account for manufacturing non-idealities and tolerances; this is only possible if you have real sample measurements on hand with which to compare/tune the simulation model. This step is crucial because GRIN lenses tend to be sensitive to fabrication tolerance. Of course, once you are comfortable with a fabrication paradigm and associated non-idealities,

it is sufficient to rely on well-honed simulations. For example, if you are using a relatively simple composite structure like drilled laminates and your manufacturer has excellent tolerances, you may be able to get away without doing any measurements beyond the first round of characterizations. However, if you are working with complicated or unproven structures then high accuracy measurements are essential. The degree of dielectric precision needed depends on the operating frequency. This is largely because the propagation constant scales with frequency; characterization error of the propagation constant, as a result of characterization error of the dielectric constant, will be exacerbated at higher frequencies. If you design for W-Band or terahertz, you'll want very precise and accurate EM characterizations only because the





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"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."

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propagation constant is so high. Of course, at these frequencies, your mechanical tolerances need to be tighter too because the wavefront will be increasingly sensitive to physical kinks and discontinuities in the structure.

John Schultz, Ph.D.:

For lenses, you don't want a high permittivity lens, you will get too much reflection. Hence, you need to reduce the permittivity of the lens to enhance overall performance. For practical dielectric applications, such as metamaterial or dielectric lattice structures, you need a pattern with features that are less than a wavelength in order to stay away from resonance. This results in a wide bandwidth structure, which then means you also need to be able to characterize or make measurements of the structure precisely over a wide bandwidth. An approach we have used in the past for dielectric lens development is to make samples with various fill fractions and use the focus-beam

metamatructures,
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system to precisely characterize the
complex permittivity of the samples.
In this way, we can then take what we
know and design a lens with the desired performance.

Conclusion

Additive manufacturing technologies are allowing for even greater degrees of freedom in the design and fabrication of 2D and 3D dielectric structures. Capturing the performance of these structures and being able to predict the dielectric response reliably and accurately is crucial in developing technologies with this new technology. This first part introduced concepts of performing measurements on these new classes of dielectrics. The second part of this article, to be published in an upcoming issue of Microwave Journal dives deeper into these concepts with more from a panel with extensive expertise in dielectric measurement.





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Overcoming the Limitations of 3D EM Simulation of Electrically Large Devices

Jean-Jacques DeLisle EMRFS. Theodore. Ala.

Dr. Daniel Faircloth

Nullspace, Inc., Irvine, Calif.

D electromagnetic (EM) simulation technology has been steadily advancing over the past 30 years. Integration of multi-core and multi-GPU capabilities, extension to cloud and high performance computing resources and development of novel solution techniques have reduced the simulation time of complex and large simulations. However, many of these features are not native to commercial software suites, require additional software modules or are paywalled.

Traditionally, there have been limitations to design optimizations that legacy EM simulation codes could perform. This comes about because

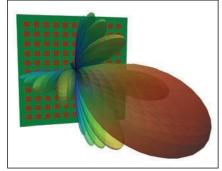
most well-known, commercially-distributed EM codes originated three to four decades ago.² Embracing new EM simulation software tools, designed from the ground up with modern computing technology and advanced algorithms in mind, can revolutionize the practical utility of EM simulation for complex RF applications.

This article discusses EM simulation challenges for modern RF technologies. It also provides updates on recently released ad-

vances in EM simulation technology. The article also discusses the potential benefits of having access to faster and more accurate EM simulation software that has been purposefully built to efficiently simulate electrically large bodies.

Current Challenges in EM Simulation

Trends in RF technology are creating greater challenges for legacy EM solvers. First, there are historical challenges, such as performing accurate simulations of electrically large bodies. Most current EM solvers originated some decades ago, often in academic settings. The original software suites to support these solvers were developed to leverage the technology of that time. These software suites have advanced somewhat over the years to include new simulation techniques and add-ons or support for multicore and GPU processing, but these accelerating technologies are not typically innate functions of the core solvers. As complex phased array antenna systems with multiple antenna elements have evolved for commercial and defense applications, simulations of these electrically large and complex objects have gotten time and computing resource intensive. Figure 1 shows the output from a simulation of an electrically large and complex active electronically steered array



▲ Fig. 1 Output of an AESA radar simulation.



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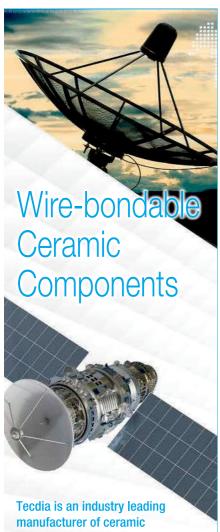
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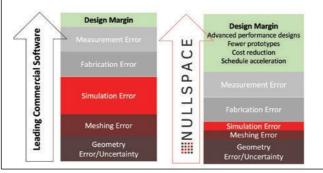
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 \blacktriangle Fig. 2 Comparing Nullspace solver performance versus a leading competitor.

(AESA). For these types of structures, radar cross-section analysis and co-site interference assessment are typically prohibitively expensive from a computational standpoint.

As is often the case with common EM software suites, much of the capability of the software tools are optional upgrade modules that require additional licensing for GPU acceleration or other accelerating methods. The most common licensing methods fix the simulation capability to a single computer, with this method called node-locked licensing, though floating licenses are sometimes available for an additional cost. Some EM software suites are extensible or allow for scripting functions to perform some type of automation or organization of complex/parametric simulations. This is not universal functionality, however.

In the past, there may not have been adequate standardization between CPU and GPU processing technologies. This did not readily allow for software designs that natively took advantage of the scalability and processing benefits of using multi-core CPUs and multi-GPU technology. Many of the legacy EM solvers are also only well-suited to a narrow range of models and problems and the most widely known commercial EM solvers require large amounts of computational resources to accurately simulate electrically large bodies.

Benefits of High Efficiency EM Simulation Technology

EM simulation of electrically large bodies and/or complex structures has been a trade-off between available computational resources, time and accuracy. The further a simulation model is away from physical reality, the harder it becomes to verify the simulation tool and process with real experimentation. Inadequate accuracy in an EM simulation can also result in the loss of many

man-hours chasing artifacts of poor-quality simulation.

These artifacts can be caused either by limitations of the modeling technique along with omission or addition of aberrant model data. This aberrant data may include CAD or material information or approximations in the model's excitations or postprocessed data. Ex-

amples of this include simulations with inadequate low-order meshing leading to geometry-approximation errors or low-order physics approximations.

With a flexible and efficient EM simulation tool, users can perform more early-stage virtual prototyping and integrate these models into larger model-based systems engineering environments. Capturing system concepts and performance early, with confidence in the accuracy of the models, provides tremendous potential for improved customer satisfaction, cost savings and reduced project schedule risk. To illustrate this, Figure 2 shows the same EM simulation, run on the same hardware with legacy commercial EM simulation software and the Nullspace solver technology. This figure shows how errors accumulate during a typical design process and how the reduction of simulation and meshing errors provides the benefits of innovation, cost reduction and shorter time to market.³

Advances in EM Simulation Technology Optimized for Electrically Large Bodies

To efficiently handle realistic simulations of electrically large bodies requires extensive optimizations throughout the simulation process, as well as a small geometry error. Reducing the initial modeling error can have dramatic impacts on the overall accuracy of an EM simulation, as geometry errors tend to compound with simulation complexity. This presents a hard limit on the simulation accuracy of EM solvers not built to reduce geometry error.

In most cases, EM software consumes large amounts of system memory, often prohibitively so, while attempting to run compute-intensive simulations. Highly efficient compression algorithms can help reduce the amount of data that needs to be stored,





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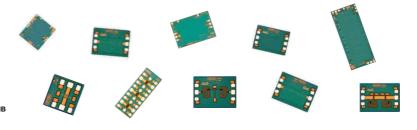
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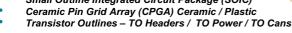


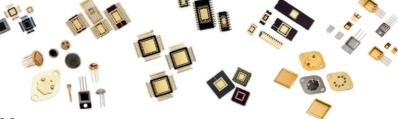
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reduce the time that the data is stored and reduce the time needed to process and redeploy the data generated by EM simulation. A more advanced version of this concept is adaptive and on-the-fly compression, which intelligently handles data in a way that optimizes the use of memory and storage space. This approach enables an EM simulation tool to handle much larger problems more rapidly with the same computational resources.

The last major efficiency hurdle that

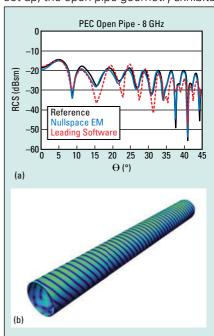
needs to be addressed with EM simulation tools is the handling of multicore, multi-CPU and multi-GPU acceleration. Most established EM software tools were designed when multi-core CPUs were still evolving and multi-CPU platforms were often proprietary. Multi-GPU acceleration is a more recent feature in some EM simulation software suites and this technique can be a crucial factor in reducing overall simulation times. However, many EM software suites put multi-CPU and multi-GPU

acceleration behind paywalls that require the purchase of additional modules. This results in the same trade-off between cost and computational resources. As the cost of these hardware resources has dropped enormously in recent years, it would be a benefit for many EM simulation users to have access to full support of the computational hardware they have available.

Why EM Simulation Efficiency & Accuracy Matter

With more efficient EM simulation, the same computing hardware requires less EM simulation time. If the efficiency and speed of the simulation are substantially better, that time can be used in other areas, like additional optimizations, uncertainty analysis or faster product introductions. This concept is illustrated in *Figure 3a* and *Figure 3b*.

Simulating the radar cross-section (RCS) of electrically large bodies is generally a very demanding simulation. Figure 3a shows a perfect electrical conductor (PEC) hollow cylindrical tube at 8 GHz. The RCS analysis requires a model that is relatively simple to set up in most EM simulation software tools. This reference solution analysis provides a useful comparison between the tools because it allows for simultaneous analysis of the accuracy and speed. This reference case can also be useful for tuning and calibration of a simulation setup. While the model is easy to set up, the open pipe geometry exhibits



▲ Fig. 3 (a) Surface current depiction for a PEC at a particular radar lookangle. (b) PEC open pipe RCS simulation for varying angles of attack.

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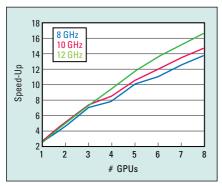
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▲ Fig. 4 Comparing simulation process times for an electrically large PEC hollow cylindrical tube in free space.



▲ Fig. 5 Speed-up factor versus number of GPUs to simulate PEC hollow cylindrical tube RCS.

complex scattering physics, which are generally challenging simulations for most EM codes.

Figure 3b compares the RCS in dBsm to the angle of attack in degrees for a PEC open pipe at 8 GHz. The plot shows that the Nullspace EM simulation software matches the reference very closely. The reduced geometric error and the high-order physics of the Nullspace solution results in a much more accurate simulation when compared to a leading commercial EM simulation software.

In addition to benefits in accuracy, the Nullspace solution is much faster. A greater level of optimization, built-in compression algorithm and intrinsic integration of multi-CPU and multi-GPU acceleration leads to an enormous reduction in the simulation time with only a marginal increase in the CAD/meshing time. *Figure 4* shows a side-by-side

comparison of the simulation process times for a leading commercial EM simulation software tool and Nullspace EM on identical hardware simulating an electrically large PEC hollow cylindrical tube in free space.

2222

To illustrate the value of intrinsic multi-GPU support,

the plot in *Figure 5* shows a roughly linear benefit in increased simulation speed with additional GPUs. In addition, the simulation speed factor increased with frequency. Of the three frequencies tested, the greatest benefit came at the highest frequency, 12 GHz. This is not a surprising result because the simulations become more resource intensive as the frequency increases.

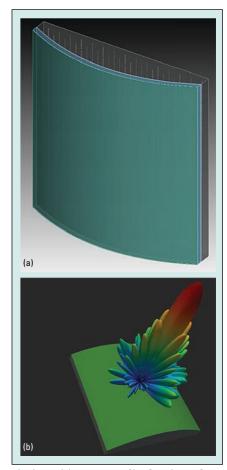
EM Simulation Software Efficiency Demonstrations

Radomes impact the performance of the antennas that they protect. This is especially true of AESA antennas. There is a trade-off between providing protection from the environment to the elements and enhancing the performance of the overall system. It is often challenging or impossible to perform a detailed analysis before fabricating such a complex system.

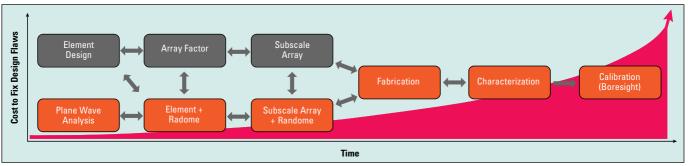
In many cases, the design tools used to design the radome and antenna structure are entirely different and this disaggregated approach can lead to additional costs and schedule risk. Without the ability to fully assess the combined performance of the antenna and radome in a simulation, there is the chance that design issues may not be apparent until later in the fabrication, assembly and qualification process. The further through the process that any issues are identified; the higher costs of mitigation.

Figure 6 illustrates this concept. A key stage in the entire process of devel-

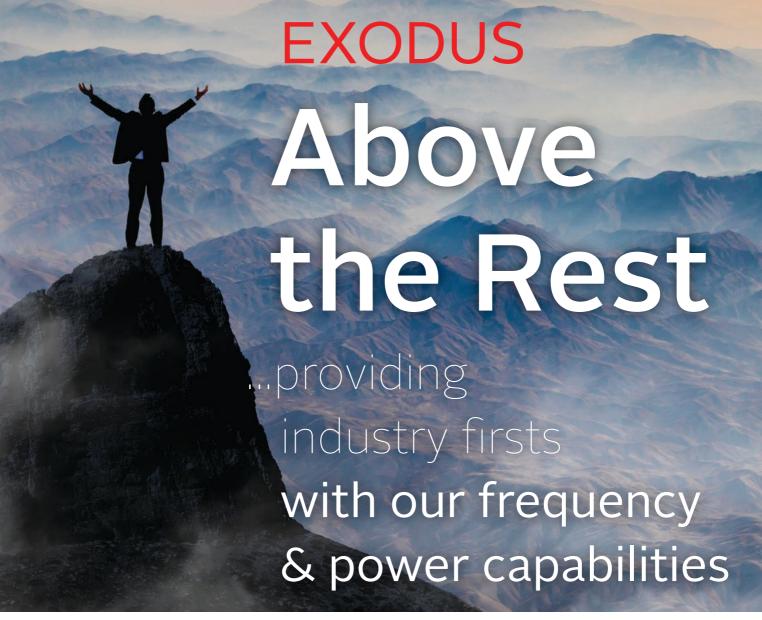
oping an active antenna system is the calibration of the boresight stage. This is generally the final stage in the process once the radome and antenna system are fully assembled and characterized. Traditional EM simulation tools make it challenging, if not impossible, to analyze the antenna and radome as a system. With appropriate EM simulation resources, the entire antenna system and radome could be fully analyzed with weights optimization, uncertainty analysis and perhaps even simulation-based calibration, which would be a benefit.



▲ Fig. 7 (a) A 30 x 15 dipole triangular lattice/radome model. (b) The 30 x 15 dipole triangular lattice 3D antenna pattern simulated in Nullspace EM.



▲ Fig. 6 Cost increase of design flaws at various stages of the production cycle.





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Radome & Antenna Array Example

Figure 7a shows a 30 \times 15 dipole triangular lattice array with a curved quartz-cyanate ester (QCE)/foam/QCE multilayer radome material. **Figure 7b** shows an example of the 3D antenna pattern from this antenna when it is simulated in Nullspace EM. Beam steering error analysis is a critical tool to minimize this error in the final design. This type of analysis is generally done with a drastically simplified version of a simulation or after fabrication.

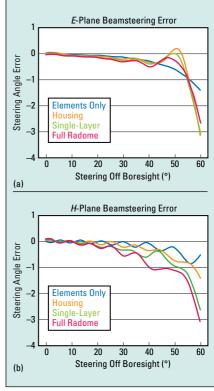
The Nullspace EM solver changes this process. In this example, the Nullspace EM software simulated all the beam steering angles for the entire antenna system and radome combination and this simulation ran roughly 7× faster than a leading commercial EM simulation tool that considered only one beam steering angle. A direct comparison of all scan angles was unrealizable between the EM software packages, given the time and computational resources required by the leading EM simulation tool.

Figure 8a shows the EM simulation results in the E-plane and **Figure 8b** shows the H-plane plot. It is possible to perform a parametric analysis and de-

termine the contributing factors to the beam steering error. A sensitivity analysis can be performed to varying tolerances to understand the stack-up of the beam steering error. This is only possible with the detail allowed by more efficient and modern EM simulation software. The design resource headroom afforded by using more efficient EM simulation software can be instrumental in predicting practical performance or driving the requirements for the various stages of fabrication to ensure that production devices meet the desired performance and quality standards.

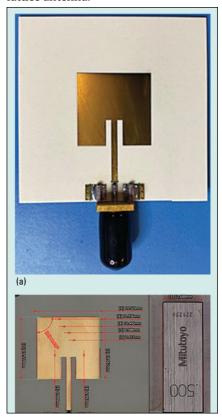
Patch Antenna Simulation Accuracy Experiment

To analyze the potential accuracy discrepancies with legacy EM simulation software more fully, an experiment involving patch antennas was devised. *Figure 9a* shows an example of a relatively small patch antenna designed to operate in the GHz range. To remove fabrication variability considerations, 12 patch antennas were fabricated in two batches, with six each from two different vendors. The patches were also physically measured using a profilometer to ensure the fabrication accuracy



▲ Fig. 8 (a) E-plane steering angle error for the 30 x 15 dipole triangular lattice antenna. (b) H-plane steering angle error for the 30 x 15 dipole triangular lattice antenna.



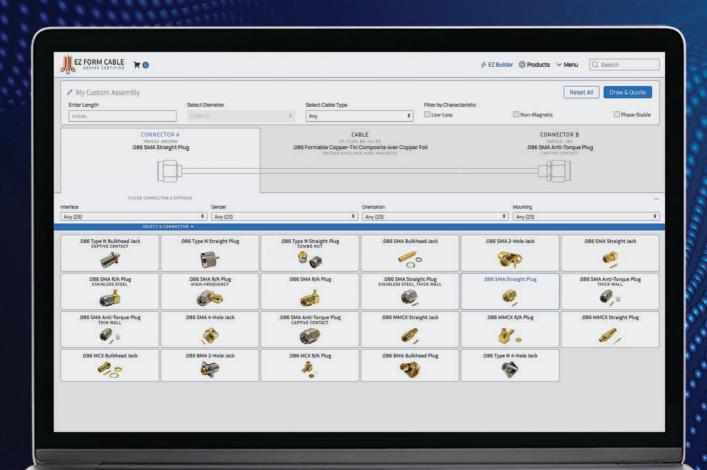


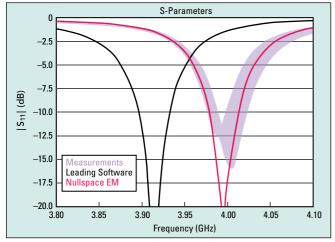
▲ Fig. 9 (a) Sample patch antenna. (b) Profilometer results for the patch antenna.

Introducing the New EZF Cable Builder Tool From EZ Form Cable

EZ Form Cable, A Trexon Company is proud to announce a new website and the EZF Cable Builder tool for building custom RF assemblies. EZF builder offers hundreds of configurations including semi-rigid, formable, flexible, as well as standard delay line options.

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ightharpoonup Fig. 10 S_{11} versus frequency simulated and measured results for the patch antenna samples.

of the patches. The patch design is indicative of the type of patch antenna commonly used in antenna array technologies. *Figure 9b* shows the profilometer results for the patch antenna to ensure the fabrication tolerances compared to the 3D model used in the simulation.

The patch designs were also simulated with a leading commercially available EM simulation software, as well as Nullspace EM. The plot in **Figure 10** shows the minimum and maximum S_{11} response of all 12 patch antennas predicted by the leading software, along with Nullspace EM's results. The results show that Nullspace's EM simulation

software is more accurate out of the box than the other commercially available EM software suite. Typically, the solution in these cases is to tune the EM simulation software to yield better agreement with the given design and fabrication process. While this will improve the accuracy, it also creates an iterative loop to achieve the necessary levels of accuracy and trust in the simulation software when modeling new designs. The Nullspace EM software avoids this iterative step.

Conclusion

EM simulation has become an essential tool for RF product design and technology development and many stages of the design cycle depend largely on the accuracy and efficiency of the EM simulation software. Greater levels of EM simulation accuracy and efficiency can have significant impacts on the overall design cycle time and the number of iterations a design team must go through to meet with success. Recent advances in EM simulation technology optimized for complex and electrically large simulations can now deliver many times the speed of legacy EM simulation codes while maintaining high accuracy.

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Digitally Enabled RF Building **Blocks Address Emerging EW System Needs**

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Fairview, Pa.

lectronic warfare (EW) applications are growing more complex due to near-peer threats and the explosion of commercial products that clog the spectrum and can be adapted to make adversarial systems. Our future is a vast array of autonomous and semi-autonomous machines tethered wirelessly to people, businesses and governments. They will implement and realize some of the most complex wireless systems-of-systems ever built, operat-

TABLE 1

| SCI BLOCK UP-/DOWN-CONVERTER SPECIFICATIONS | | | | | | | | |
|---|------------|----------------------------|--------------|----------------------------|--|--|--|--|
| | Down-c | onverter | Up-converter | | | | | |
| RF Input (GHz) | .020 to 18 | | .020 to 18 | | | | | |
| Instantaneous Bandwidth (GHz) | 2 | IF output centered at 4 | 2 | IF output centered at 4 | | | | |
| Noise Figure (dB) | < 14 | 12 (typical) | < 20 | 18 (typical) | | | | |
| Gain (dB) | 25 | | 20 | | | | | |
| OP1 (dBm) | 15 | 18 (typical) | 14 | 16 (typical) | | | | |
| OP3 (dBm) | 25 | 28 (typical) | 24 | 26 (typical) | | | | |
| Single-Tone Spur-Free Dynamic Range (dBc) | > 60 | | > 55 | | | | | |

ing in the electromagnetic spectrum and largely controlled in software. EW systems must operate in this congested spectrum with the ability to analyze and respond to signal data in ever-increasing frequencies and shorter reaction times.

To address this reality, Spectrum Control developed the SCi Blocks family of RF components, modules and subsystems to deliver RF signal fidelity in small modular building blocks with plug-and-play architectures. Built around the company's new digital gateway, a hierarchical, modular and open approach to controlling RF components, modules and subsystems dubbed the SCi Block Controller, these building blocks can be used to realize more agile EW subsystems, systems and systems-of-systems.

The first SCi Block release is a dense, modular, open architecture, 3U OpenVPX wideband down-converter and up-converter. Among its

- 1. All surface-mount technology, a significant departure from historical modules of this type and an important step in shortening the design/delivery cycle
- 2. Digitally enabled for no mechanical tuning and online monitoring and rapid integration into higher-level systems
- 3. Modular, allowing multiple configurations of











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Washington D.C. is also home to many agencies and institutions that oversee use of the electromagnetic spectrum. One of our conference themes is to highlight advances in spectrum access and use, including coexistence, sustainability and emerging Future-G systems. Other themes will feature the critical role of the RF-to-THz spectrum for aerospace and transportation, national security, and radar. The central role that equity, inclusion and diversity play across the spectrum of our community will be highlighted throughout the week.

For more information: ims-ieee.org





EW, Radar & MilCom



▲ Fig. 1 RF Stick module.

up to eight transmit/receive channels

4. Open and aligned with SOSATM.

The wideband down-converter and up-converter are miniaturized into a 13 x 2 cm printed circuit board. **Table 1** outlines the specifications for the SCi Block wideband up-/down-converter. The RF Stick module is shown in **Figure 1**

The long march of Moore's Law continues to enable miniaturization in digital functionality. Spectrum Control

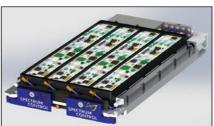
leverages this capability with integrated digital control in every SCi Blocks device, which reduces product development and bring-up activities by 50 percent. This plug-and-play functionality translates into significant integration, qualification and low-rate initial production savings.

A 2 to 18 GHz electronic support (ES) mission can be implemented as eight RF down-converter sticks in one 3U Open VPX slot, providing 16 GHz of instantaneous bandwidth and greater than 60 dBc of spur-free dynamic range. Traditional ES receivers in a 3U VPX module cover around 4 GHz. The SCi Block 3U module provides a tremendous reduction in size, weight and power (SWaP) for the RF elements.

The SCi Blocks can be used in an EW transceiver with four up-converters and four down-converters. Each block covers 2 GHz, for a total of 8 GHz of bidirectional frequency coverage. Two SCi Blocks modules can produce 16 GHz of receive and transmit capabilities in a wideband digital RF memory (DRFM) EW system.

Another module advantage is the ability to easily integrate various RF functions into a system. The SOSAaligned hardware and software of the SCi Blocks module make them extensible, flexible and highly adaptive. The digital gateway on the 3U OpenVPX module is implemented in the SCi Block Manager system on chip (SoC) device that commands and controls the 3U Open VPX modules. This device is an Intel Arria 10 SoC field programmable gate array (FPGA) with embedded dual-core Arm Cortex-A9 MPCore processors (SX270). The FPGA interfaces to the P1 Open VPX connector per the Payload Slot Profile SLT3-PAY-1F1U1S-1S1U1U2F1H-14.6.11-5. The SoC is responsible for the data and control plane physical interfaces like Ethernet and PCI Express. Various SOSA software protocols, such as MORA Low Latency Bus and VICTORY Data Bus messaging, are implemented via the SoC device. A representative device is shown in *Figure 2*.

Spectrum Control also implements



▲ Fig. 2 SOSA-aligned OpenVPX

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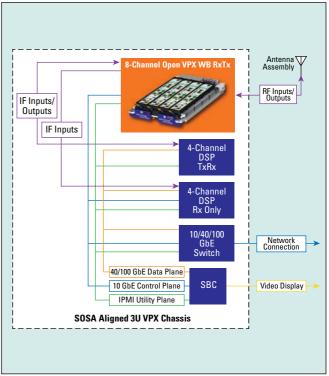
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▲ Fig. 3 SCi Blocks small form factor EW system.

a scalable physical architecture for the GbE, 10 GbE and 40 GbE interfaces to enable retrofit into currently deployed systems without changing existing system software. The SoC may also be used to implement Vita 49.2 messaging and data path protocols for future products. The SCi Blocks Manager allows system integrators a common command and control infrastructure for various RF circuitry, lending itself to much faster system integration.

The SWaP and ease of system integration of the RF Sticks are realized without compromising performance in the RF chain while creating other benefits. The reduction in SWaP into one slot in a 3U VPX chassis for an ES receiver opens the ability to add a general-purpose GPU (GPGPU) to a system, enabling cognitive or adaptive scanning of unknown threats or signals of interest. Unique small form factor EW systems are enabled by the RF Sticks. An example of this is shown in *Figure 3*.

The SCi Blocks module utilizes four down-converters for an ES receiver to provide situational awareness. Two up-converters and two down-converters are paired to produce the RF front-end for a wideband DRFM. The common command and control architecture for the SCi Blocks module along with the SOSA-aligned interfaces allows for quick and easy integration with the various digital signal processing elements and single-board computers. The combination can add new EW capabilities to small platforms such as unmanned aircraft systems previously unavailable due to SWaP constraints.

Spectrum Control's new SCi Blocks family is ideally suited for military and commercial Open Systems Architecture and SWaP-conscious platforms. Flexibility and adaptability without compromising RF performance bring a new level of creativity to system designers.

Spectrum Control Fairview, Pa. spectrumcontrol.com/sci-blocks







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High Temperature RF and Microwave Adapters

asternack, an Infinite Electronics brand and a leading provider of RF, microwave and mmWave products, has launched a new series of high temperature-rated RF adapters to address a wide range of industrial and military connectivity applications. Engineered with precision for extraordinary temperature resilience and longevity, these adapters stand up to the most demanding environments found within military and

defense landscapes. Meeting the MIL-STD-348B interface standard, these adapters encapsulate quality and consistency, keeping pace with the most exacting needs of military and defense applications. These new high temperature adapters are offered with in-series and between series interfaces and support frequencies up to 67 GHz. Connector options include 1.85 mm, 2.4 mm, 2.92 mm and 3.5 mm types which stand up to over 500 mating cycles while maintaining the highest levels of performance. These adapters

boast extended temperature ranges from -50°C to +170°C and comply with the MIL-STD-202 standard for shock and vibration. Pasternack's new high temperature-rated RF and microwave adapters are in-stock and available for same-day shipping.

VENDORVIEW

Pasternack Irvine, Calif. www.pasternack.com

8 KW Solid-State Pulse Amplifier Operates from 1 to 2.5 GHz



xodus Advanced Communications has developed a high-power solid-state amplifier (HPA) system for L- and S-Band pulse radar testing applications as well as general radiated susceptibility requirements such as EMI-Lab/RS103 and electronic warfare applications. The AMP2074P-LC-8KW Pulse Amplifier covers frequencies from 1 to 2.5 GHz, providing outstanding RF pulse fidelity. The amplifier satisfies radar requirements with narrow or wide RF pulses and duty cycles up to 10 percent. The AMP2074P-LC-8KW produces 8 KW pulse power, minimum, with a nominal value of 10 KW across the band with 3 dB peakto-peak power gain flatness. The HPA uses a class AB design, achieving less

than -20 dBc harmonics at rated output, -60 dBc spurious and an 80 dB on/off ratio.

The HPA has extensive control and monitoring, including optional calibrated power monitoring. Monitoring is done via a large color display or remote control. The color touchscreen shows forward and reflected power, real-time VSWR, system voltages and currents, along with operating temperatures of the PA module(s) heat sinks and internal system temperature. Gain control of > 20 dB is accessible using the screen or the remote interface.

The AMP2074P-LC-8KW is rackintegrated with open panel space for additional test equipment. The HPA has type N-female connectors for the RF input and optional RF sampling ports. To handle the high power, the RF output connector can be SC or a 7/16 female connector.

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

VENDORVIEW

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



Measuring the Dynamic Range of VNA Frequency Extenders

requency extenders are external modules enabling vector network analyzers (VNAs) to operate at mmWave frequencies. Dynamic range is a key figure of merit for VNAs and VNA frequency extenders with the system dynamic range definition commonly applied to both. This definition refers to S21 or S12 measurements at the nominal test signal power level. Eravant's STO-series of VNA frequency extenders can increase the VNA frequency range to 330 GHz.

System dynamic range is the ratio between the nominal test signal power available at the VNA test ports and the minimum input power that the system can detect. This sensitivity level is set by the receiver's noise floor and is a function of the IF bandwidth. For a VNA equipped with frequency extenders, the dynamic range is measured after a twoport calibration. The frequency extenders are separated and the test ports are terminated to prevent signal leakage. The VNA's IF bandwidth is set to a low value, usually 10 Hz and either S21 or S12 is displayed. The average level indicates the system dynamic range.

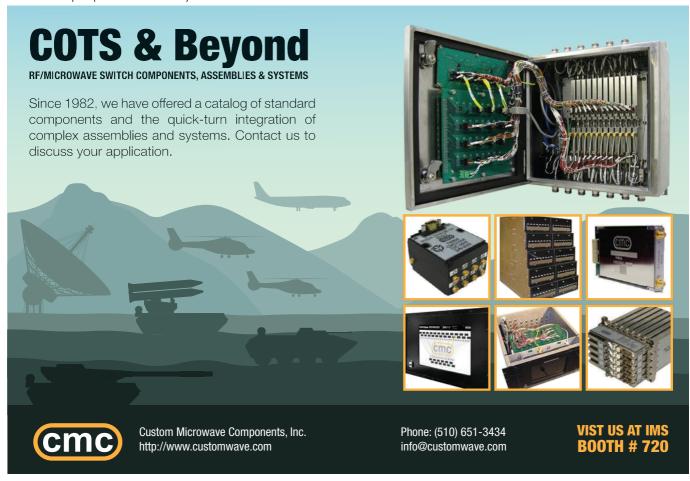
An IF bandwidth of 10 Hz is typical when specifying or measuring the dynamic range of VNA frequency extenders. This bandwidth limits the VNA sweep rate to about one measurement per second when moderate averaging is applied. Although the sensitivity

achieved at this measurement speed is rarely required, 10 Hz is the most common IF bandwidth used for dynamic range specifications.

Antenna testing is one of a few applications requiring more than 100 dB dynamic range. Test systems with greater dynamic range can accommodate a wider variety of antenna types and measurement conditions without configuration changes. Even at mmWave frequencies, 100 dB of dynamic range is usually sufficient.



Eravant, formerly Sage Millimeter Inc. Torrance, Calif. www.eravant.com





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40 MHz streaming bandwidth and -160 dBm displayed noise average. An included internal GPS adds the dimension of spectrum analysis when out in the field. It is USB-C powered for fast and accurate RF data acquisition in a continuously changing environment.

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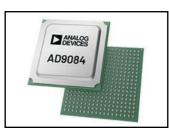


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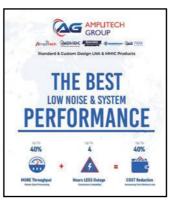
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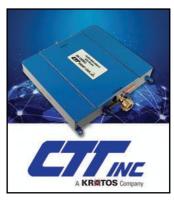
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including mmWave and 5G. Nominal coupling is 16 dB, ±2.0 dB, frequency sensitivity of ±1.2 dB (1 to 32 GHz) and ±1.5 dB (32 to 65 GHz), insertion loss of less than 2.8 dB and includes 1.85 mm female connectors. KRYTAR couplers offer solutions for ultra-broadband applications including electronic warfare, commercial wireless including mmWave, 5G, satcom, radar, signal monitoring and measurement, antenna beamforming and EMC testing environments.

www.krvtar.com



The Ways MMIC Filters Enable the **Development of Next-Gen Systems**

Traditionally. MMIC hasn't been considered a viable technology for filter development. Next-generation systems are reconsidering the specification trade-off space to ease loss and rejection requirements in exchange for size

reduction. Due to the precision of MMIC lithography, MMIC is uniquely positioned to emerge as the ideal solution to shifting trends. This white paper discusses what Marki Microwave contends to be the key metrics of a modern competitive filter and the capabilities of GaAs MMIC filters demonstrated thus far.

Marki Microwave/RFMW

www.markimicrowave.com/assets/appnotes/WP_ MMIC Filters NextGenSystems.pdf



V Series Dielectric Varactor for mmWave **Applications**

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. Typical passband insertion loss is 3 dB and the passband range is 20 to 42 GHz.

Micro Lambda Wireless www.microlambdawireless.com

EW, Radar & MilCom

COMPANY SHOWCASE



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



See Norden's VPX **Transceiver Specs**

VENDORVIEW

wideband VPX Norden's 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. Contact Norden with your specific requirements and discuss custom configurations to meet your specification needs

Norden Millimeter

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



PLATH Signal Products of PLATH Group

PLATH Signal Products is a sensor division company within the PLATH Group. They formed in 2021 with the mission of taking their COMINT subsystems to market via system integrators, resellers and agents. Their antenna, monitoring receivers, direction finders and advanced Interception Automation subsystems are available as integrable elements of System Integrator's own SIGINT or COMINT platform. PLATH draws upon seven decades of signals experience to support partners in the development of operationally superior and effective systems.

PLATH Signal Products

www.plath-signalproducts.com



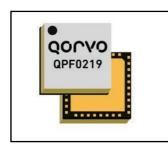
RF Subsystems & **Integrated Filter Products by Q Microwave**

 \bigcirc Microwave supplies customers with high performance switch filter subsystems, down-converters,

up-converters and more. Discover its range of integrated products trusted for 25 years by leading providers of applications like frequency conversion, electronic warfare systems and radar systems.

Q Microwave

www.qmicrowave.com/rf-subsystems



Smallest 2-18 GHz 10 W FEM for **Defense and** Communications **Applications**

VENDORVIEW

Qorvo's QPF0219 is a 10 W multi-chip FEM that integrates a transmit/receive switch, a limiter, a low noise

amplifier and a power amplifier, making it ideal for electronic warfare, multifunction wideband arrays, radar and communications applications. Available in an 8x8 mm air cavity QFN package, the multi-die QPF0219 offers the optimal semiconductor technology for each functional block to maximize performance in challenging radar applications.

Qorvo

www.gorvo.com/products/p/QPF0219



Golden VHF Bootstrap Oscillator

Available from 80 to 130 MHz, the Golden Bootstrap oscillator provides ultra-low phase noise performance and low-g sensitivity of better than 5e-11/g below 300

Hz offsets, and 5e-12/g sensitivity above 300 Hz when vibration isolation is included. Quantic Wenzel's bootstrap oscillator technology consists of two rugged OCXOs of the same frequency phase locked together. Special compensation techniques minimize vibration induced phase noise by mechanically aligning the two oscillators and summing a compensation voltage with the electrical tuning to the oscillators.

Quantic Wenzel

www.quanticwenzel.com

EW, Radar & MilCom COMPANY SHOWCASE



RF and Microwave Filters and Integrated Assemblies

VENDORVIEW

Reactel manufactures a line of filters, multiplexers and multifunction assemblies covering up to 67 GHz. From small, lightweight units suit-

able for flight or portable systems to high-power units capable of handling up to 25 kW, connectorized or surface-mount — their talented engineers can design a unit specifically for your application.

Reactel

www.reactel.com



The mRO-50 Ruggedized

The mRO-50 Ruggedized is a breakthrough microwave optical double resonance low SWaP-C oscillator uniquely tailored for situations where stability and power consumption are critical in a GNSS-denied

environment with extreme conditions (wide operating temperatures, shock and vibration). It features a one-day hold-over below 1 µs and a retrace below 1E-10 in a form factor that takes up less than 52 cc and consumes less than 0.45 W. Applications include military communications, radars, low earth orbit, electronic warfare, airborne and avionics (UAV/UGV/USV/UUV).

Safran

https://safran-navigation-timing.com/product/mro-50-ruggedized



Signal Hound

Meet Signal Hound's latest analyzer, the USB-C powered SP145. A high performance, 14.5 GHz real-time spectrum analyzer and monitoring receiver, the SP145 features sweep speeds up to 200 GHz/sec, 40 MHz

streaming bandwidth, -160 dBm displayed noise average and an internal GPS for enhanced field measurements. Offering real-time analysis up to 14.5 GHz with ultra-fast sweep speeds in a portable form factor, the SP145 is your ideal RF analysis companion in the field and at the lab.

Signal Hound

www.signalhound.com/sp145



Excellence in T&M Solutions

VENDORVIEW

Rohde & Schwarz offers an extensive product range for testing radar, electronic warfare, satellite, navigation, guidance, military radio communications and radio monitoring systems in all

relevant frequency bands. Outstanding performance and application-tailored measurement functions address the specific needs of the aerospace and defense sector in research and development, validation, production and in the field. This includes RF and microwave test and measurement (T&M) instruments for lab and field measurements, turn-key systems, a full range of EMC measuring equipment as well as antennas and RF accessories.

Rohde & Schwarz

www.rohde-schwarz.com/aerospace-defense-testing



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 printed circuit board footprint, it be-

comes 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/alignment



SCi Blocks

Spectrum Control introduces SCi Blocks, a family of next-generation, digitally enabled, plug-and-play RF solutions that addresses the size, weight, performance modularity requirements

of emerging aerospace and defense systems. Today's SCi Blocks architecture has three levels; RF system in package chips, integrated boards and SOSA-aligned VPX modules that slide into a standard chassis/backplane. The lower levels of the architecture are designed to be used standalone and to readily integrate into the higher levels.

Spectrum Control

. www.spectrumcontrol.com

COMPANY SHOWCASE



The SPINNER Plugand-Play Slip Ring System

SPINNER has now developed a special maintenance approach for rotary joints that use slip rings. It elimi-

nates the need to remove the entire coupling for servicing or replacement. Instead, the data transmission unit is designed so that it is quick and easy to remove in just a few simple steps: a "plug-and-play" slip ring system. These plug-and-play slip rings have revolutionized rotary joints, delivering a number of advantages over conventional models. In addition to being designed for easy installation, use and maintenance, they save time and costs.

SPINNER Group www.spinner-group.com



Tecdia Announces High Q SMT Varactor with 2 W Power Handling

VENDORVIEW

Tecdia's Dielectric Varactor has a high Q factor, improved tunability and fast switching speeds for phase

shifting in mmWave applications. The unique tunable dielectric technology boasts low ESR at mmWave frequencies, enabling up to 2 W of RF power to be passed per device. These SMT-compatible 0201 form factor devices are available with a with a lineup of nominal capacitance values from 0.1 pF and up to suit most applications. Contact sales@tecdia.com for more information and samples.

Tecdia

https://us.tecdia.com



Ruggedized NI® SDR and Small Form Factor Enclosures

For ruggedized NI (Ettus Research™ brand) softwaredefined radios (SDRs), Pixus has a solution for you. From the powerful RX410 with an UltraScale+ field-programmable gate array to

the compact, man-wearable RB210, the SDRs come in IP67 weatherproof and full military ruggedized versions. Pixus also offers semi-rugged air cooled versions with superior cooling. Models include the RX310, RN310, RX410, RB210 and custom solutions are available upon demand. Contact Pixus today for your hardened enclosure requirements.

Pixus Technologies

https://pixustechnologies.com



Microwave Power Modules from Stellant Systems

Stellant Systems' M-1270 microwave power module (MPM) is a state-of-the-art amplifier used in threat simulators and search radar systems onboard common unmanned aerial vehicles and

other high profile aircraft. Its' extremely high-power output of 1 kW at 5 percent duty cycle from 9 to 10 GHz distinguishes it from the field. The MPM includes Stellant's L6134-54 mini-helix traveling wave tube driven by a low-power solid-state power amplifier contained within Stellant's proprietary power control unit.

Stellant Systems

www.StellantSystems.com



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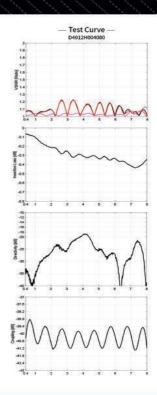
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- High power handling: up to 6000
- Low VSWR & insertion loss
- Excellent coupling, flatness and directivity which will significantly improve the signal acquisition accuracy
- Environment conditions meet MIL-STD-202F

| P/N CW Power | Nominal Coupling | Main Line VSWR | Coupling VSWR | Insertion Loss* | Coupling | Flatness | Directivity | |
|---------------|------------------|-------------------|------------------|-----------------|------------|----------|-------------|------------|
| | MOX(W) | (dB) | Max.(:1) | | Max.(dB) | | | IVIII.(GB) |
| | | 0. | 4-8GHz Di | rectional | 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 |
| | | 0.4-8 | GHz Dual | -Direction | al 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

