Vol. 66 • No. 10

October 2023

# Microwave Journal

## RECEIVER TESTING

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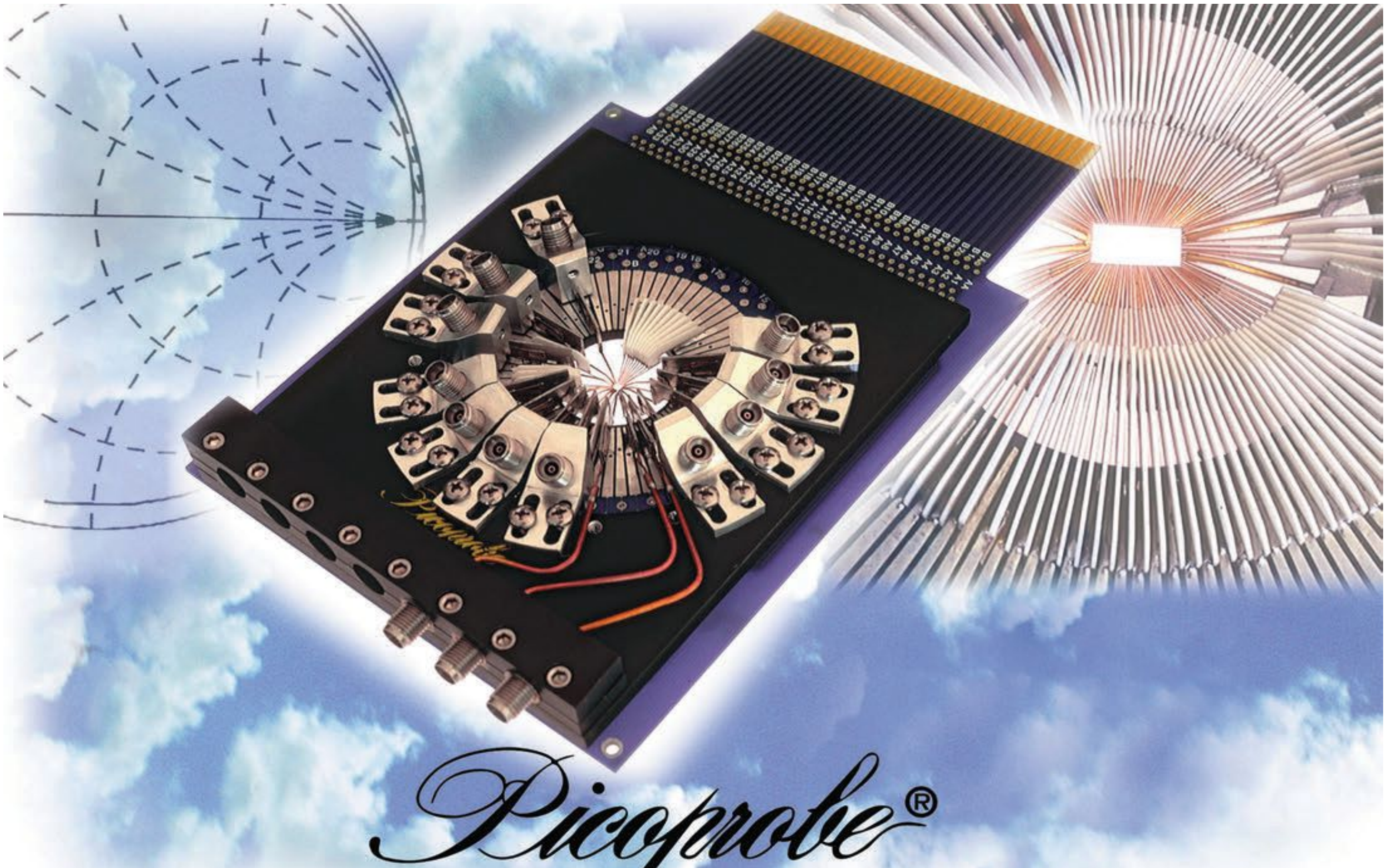


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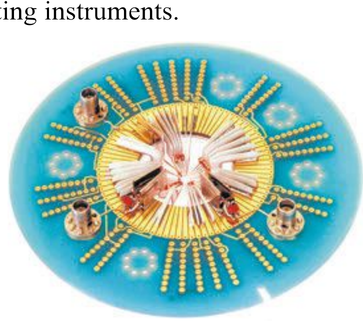

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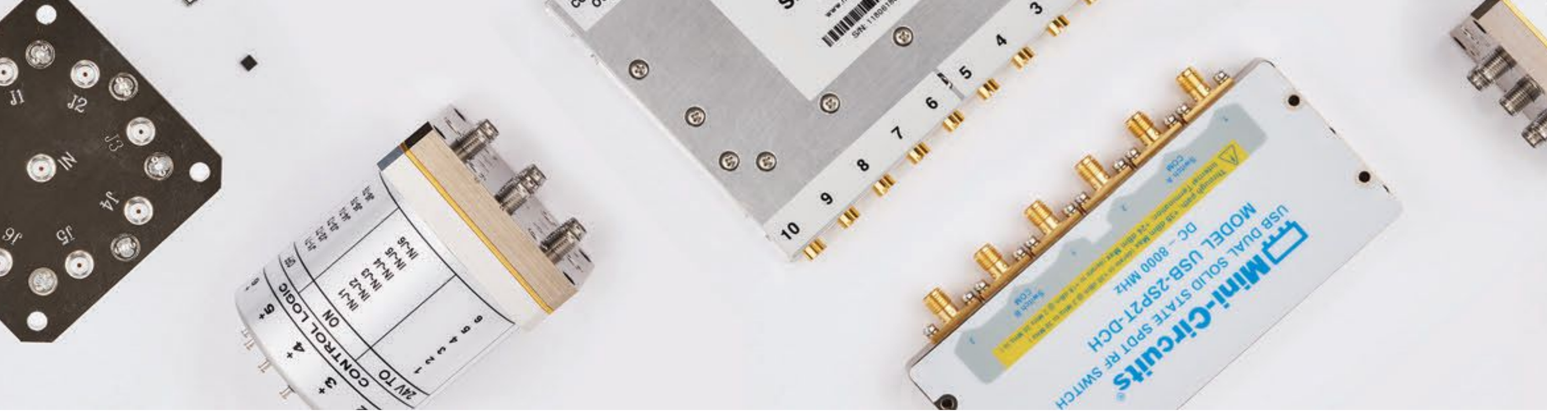


DC TO 67 GHz

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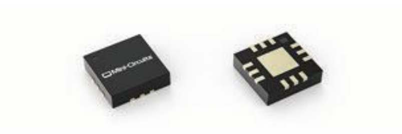

### MMIC

- DC to 6 GHz
- SPDT to SP6T

### Mechanical

- DC to 18 GHz
- SPDT to SP8T

### Coax. Solid State

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- SPDT & SP4T

## USB/Ethernet Modules

### Mechanical

- DC to 50 GHz
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### Solid State

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### Modular

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### Solid State

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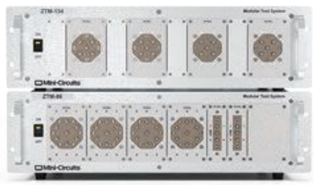
- Blocking & non-blocking



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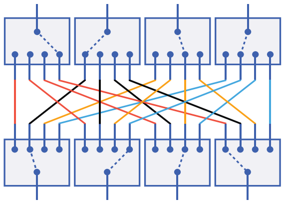

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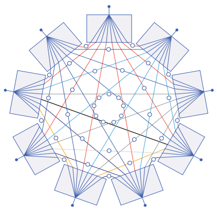

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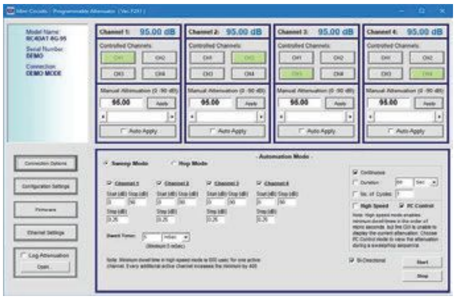

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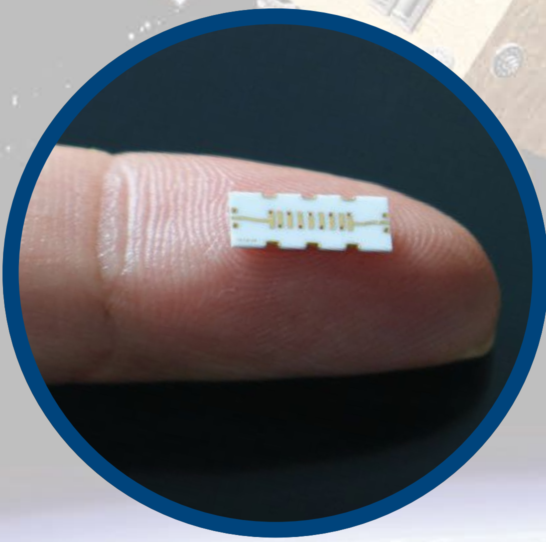

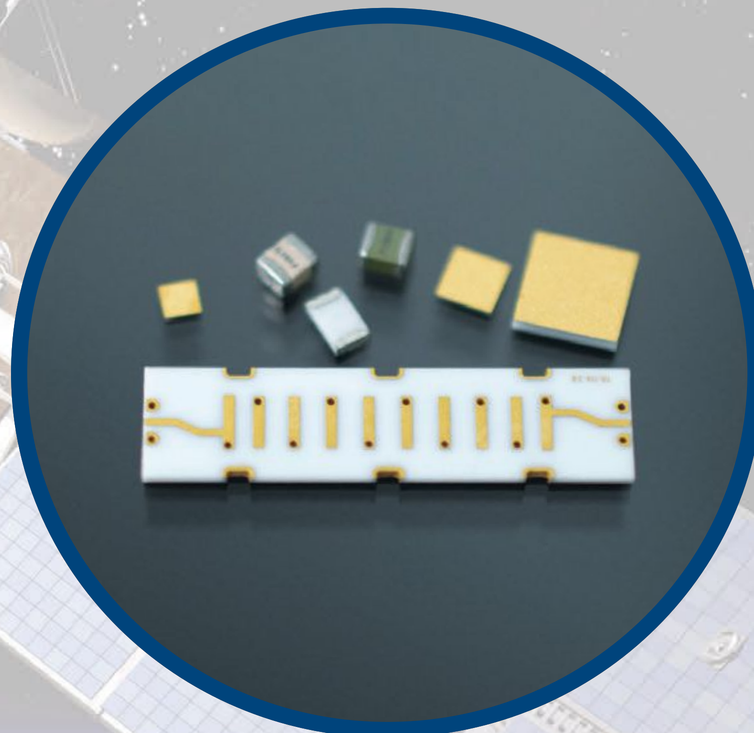

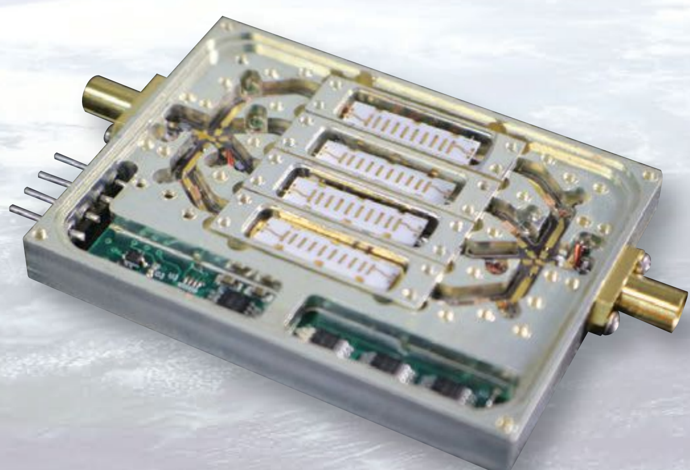

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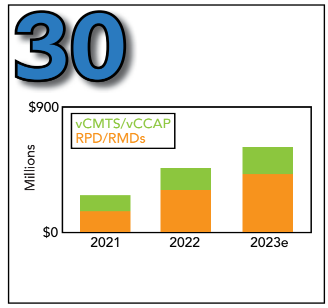


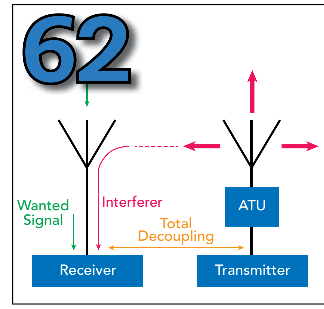


online spotlight

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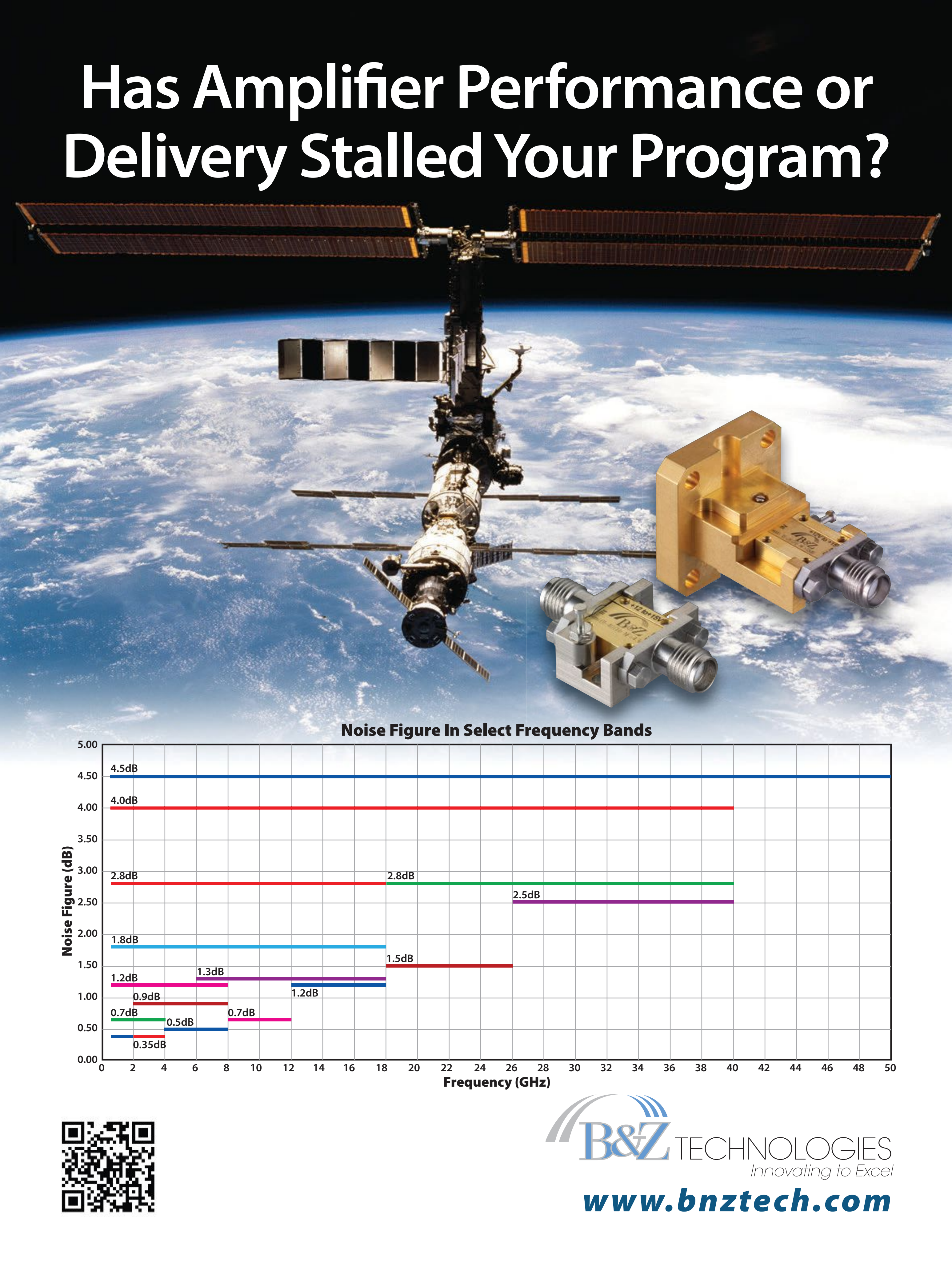
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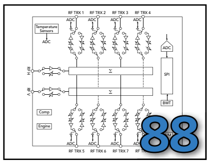


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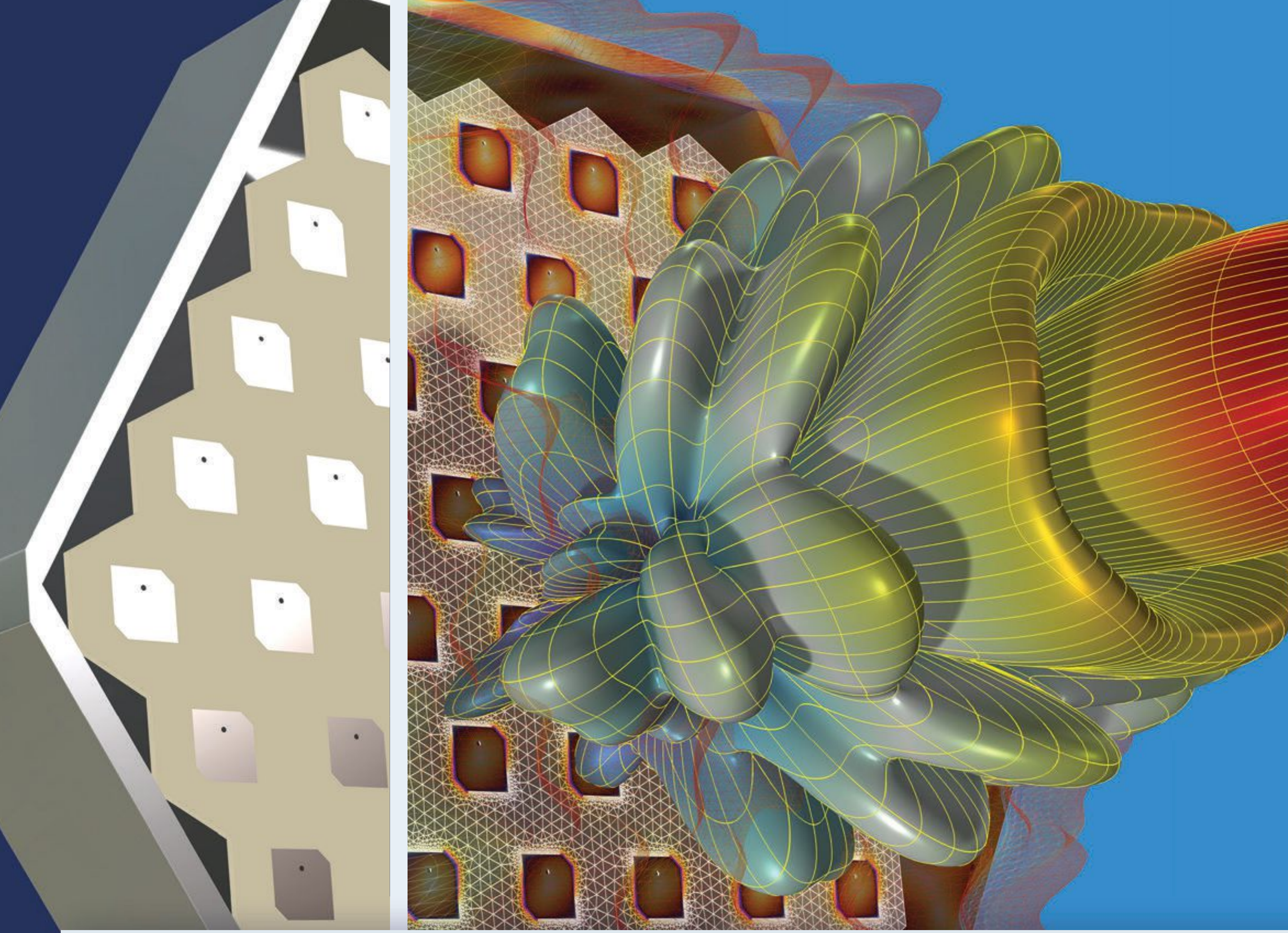

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## DECEMBER

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

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

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

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

**About Eravant**

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

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


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COVER FEATURE
INVITED PAPER

# Choosing the Right Programmable Attenuator for Receiver Sensitivity Tests

Bryan Walker
*JFW Industries, Inc., Indianapolis, Ind.*

With the explosion of connectivity technologies and the thirst for data communicated over wireless channels in virtually every application, from aerospace and defense to consumer handhelds, there is an increased need for testing systems capable of handling the growing numbers of wireless devices being manufactured. To increase the throughput of testing that is both more precise and more repeatable, the reliance on automated testing of RF hardware is greater than ever before. One crucial make-or-break test for many wireless communication and sensing devices is a receiver sensitivity test. This test is especially crucial for critical services such as public safety, fire rescue and military communications, as these services are becoming increasingly reliant on wireless connectivity and are often deployed in some of the harshest environments with the greatest risks.

A key element of modern receiver sensitivity testing is a variable, or programmable attenuator. This article will provide some background on receiver sensitivity testing and programmable attenuators. Additional guidance is also provided in this article to help readers select the most suitable attenuator for receiver sensitivity and related testing. A typical JFW Industries attenuator is shown in ***Figure 1***.

## RECEIVER SENSITIVITY TESTING PRIMER

Essentially, the sensitivity of a receiver is the lowest discernable signal a receiver can detect. This results in slightly different definitions for analog/linear receivers and digital receivers. In the case of analog/linear receivers, the signal, noise and distortion divided by the noise and distortion (SINAD) results in a signal level expressed in dB. For digital receivers, the key performance metric is the bit error rate (BER). The BER for a digital receiver is the number of bit errors in the receiver over a unit of time. This performance metric is related to the signal-to-noise (SNR) of the receiver, as well as the quality of the input signal. Typically, digital receiver specifications dictate a certain BER threshold that must not be exceeded for a receiver to be certified or deemed suitable. In some applications, this testing is done to determine the absolute lowest sensitivity of a receiver for operational purposes, as is the case with radar sensitivity being tied to the absolute range of the radar. For packet-based digital communications, the figure of merit is packet error rate instead of BER and is related to the error rate of packets instead of bits.


**Fig. 1 JFW benchtop programmable attenuator assembly with manual and Ethernet/RS-232 control.**

There are a variety of key receiver sensitivity tests for digital receivers that are a result of the various types of real-world interference. These tests are often baked into wireless standards, including Wi-Fi, Bluetooth, 4G/5G and satellite communications and they will continue to be critical in obtaining certification for wireless receivers. In many cases, the receiver sensitivity is set at a specific level, given a certain SNR, with the sensitivity dependent on the digital modulation type and the code rate. A high level, representa-

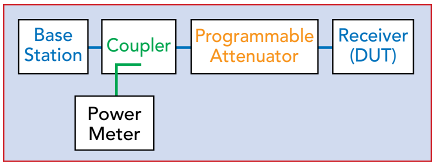


**Fig. 2** Representative test diagram for receiver sensitivity and dynamic range testing.

tive block diagram for receiver sensitivity and dynamic range testing is shown in ***Figure 2***.

Though related, receiver selectivity requires a slightly different set of tests that are used to measure the receiver performance in the presence of undesired adjacent channel interference and co-channel interference. These tests are also crucial to meet standard specifications and attain certification. They are often lumped into receiver sensitivity testing, as these tests can both be done in similar or even the same test setups. A representative block diagram of the test setup used to measure adjacent channel and co-channel interference is shown in ***Figure 3***.

A challenge with receiver sensitivity testing is that the receiver sensitivity level is necessarily very close to the desired test signal level. To inject interference signals that are precisely controlled, the distortion level needs to be as low as possible. If the distortion of the combination of interfering signals is too high, then nonlinearities in the system may produce spurious signals that are larger than the desired test signal. This could obfuscate the results of a test. This is another area where programmable attenuators are useful in receiver sensitivity testing.

## THE ROLE OF PROGRAMMABLE ATTENUATORS IN RECEIVER TESTING

Receiver sensitivity testing requires precise control of RF power levels. This high level of accuracy is a crucial requirement when controlling the stimulus power levels in production tests. These levels must be both precise and repeatable over several testing cycles. External variable/programmable attenuators with precise attenuation values enable input signal control to a device under test (DUT) or system under test (SUT). The ability to precisely control input power levels will reduce the frequency of test equipment calibration and increase the overall accuracy of the tests.

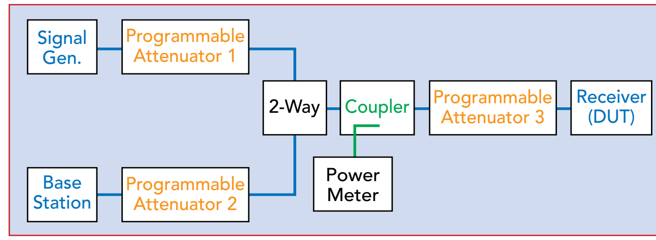


**Fig. 3** Block diagram for adjacent channel and co-channel interference measurements.

Accurate power measurement during receiver sensitivity testing is also crucial, as even relatively small errors in receiver sensitivity can impact performance in real-world deployments. An example of this requirement is cellular deployments, where the cell coverage is determined by the sensitivity of the base station receiver. This is true for large cellular base station deployments as well as advanced/active antenna system (AAS) base stations. However, in the case of AAS, the receiver sensitivity is also a function of MIMO performance and beamforming performance. With a cellular deployment, the coverage area is determined by the sensitivity of the receiver and any error in this measurement could result in far less actual coverage than was predicted during network deployment.

In addition to creating issues in the field, improper receiver sensitivity testing can create yield, quality and cost issues. In wireless standard compliance testing, an improperly designed and configured receiver sensitivity test may pass underperforming devices or only those with performance well above the specification requirements. Either scenario will directly impact yield and create inefficiencies in the automated testing process that must then be manually corrected at a high cost in terms of time and resources.

A precision programmable attenuator can help address power level

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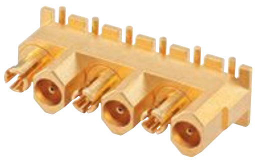

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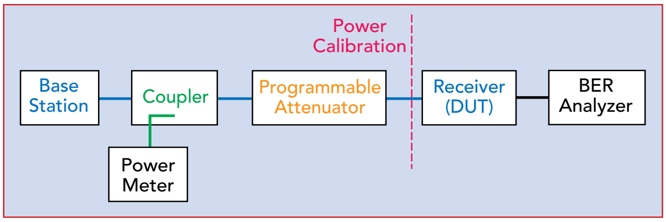


**Fig. 4** Test setup using external attenuators to enable efficient power calibration.

inaccuracies during receiver sensitivity testing. Systems like base stations, signal generators and base station emulators tend to be more accurate at higher power output levels and lose some level of accuracy at extremely low power levels. This is problematic for receiver sensitivity testing since the goal is to precisely measure the lowest possible power levels at which the DUT/SUT receiver functions.

***Figure 4*** shows a representative block diagram that addresses this issue. Using a programmable attenuator at the output of the directional coupler, before the DUT/SUT, allows the test setup to have a calibration plane at the output of the programmable attenuator. The purpose of this attenuator is to reduce the signal level from the output of the signal generator to a calibrated low level. In this setup, the coupled output to the power meter can be calibrated for the most accurate range of the signal generator. After calibration, the programmable attenuator can be adjusted for greater levels of attenuation to achieve precise lower power levels.

Using this technique with a programmable attenuator removes the need to calibrate the signal generator at every power level; the calibrated attenuator will precisely adjust the power level at the output of the calibration plane. This method also reduces the overall uncertainty in the measurement and allows for a calibrated output at extremely low power levels, provided a suitable attenuator with sufficient levels of attenuation is chosen. Any linearity or distortion issues that the signal generator may exhibit at various power levels are mitigated by this technique. This becomes especially important when minimizing the impact of nonlinearities in extremely deep modulation methods used in very high throughput digital data communications.

As mentioned earlier, this approach can reduce the number of calibrations that need to be performed in a specified period. In automated or high volume test environments, this can be extremely advantageous. Additionally, the calibration only needs to be performed at a single power level, rather than the several power level calibrations that would be required without a calibrated programmable attenuator.

Another factor to consider is that the signal generator, test base station or base station emulator will also have a noise floor. This impacts the dynamic range of the test signals. The instrument noise density at low power levels can contain a substantial amount of stimulus energy. Using external attenuators at the output of the signal generator reduces both the noise and signal power and does not introduce any significant added noise. Hence, using an external attenuator at the output of a signal generator can lower the signal level for receiver sensitivity testing, reduce the apparent noise floor of the RF instrument and extend the dynamic range of the test stimulus.

## PROGRAMMABLE ATTENUATOR KEY METRICS

Digital programmable attenuators are typically driven by TTL logic signals and exhibit a wide range of attenuation levels with discrete attenuation steps. This type of programmable attenuator generally comes with software tools. These tools may include a complete software suite, application programming interface (API) or some other method of controlling the attenuator. It is important to be able to differentiate between programmable attenuators to select the most appropriate attenuator for a given task. The following is a list of the key metrics of programmable attenuators and brief descriptions of the significance of these metrics or figures of merit.

**Key Digital Programmable Attenuator Metrics**

- Frequency range (Hz)
- Attenuation range (dB) maximum versus minimum attenuation
- Attenuation accuracy (+/- dB)
- Insertion loss (dB)
- VSWR
- Step size (dB)
- Switching speed (μsec)
- Port impedance (Ohm)
- Interconnect type (coaxial connector style or waveguide)
- RF input power (dB)
- Control method
- DC power supply.

***Figure 5*** shows an example of a JFW Industries programmable attenuator with USB control. A programmable attenuator is generally specified to perform within a given subset of these metrics and form factors over a specified frequency range. The interconnect type and internal architecture of the attenuator are selected to best meet the required performance and mechanical characteristics. For a programmable attenuator, one of the most important characteristics is the maximum and minimum attenuation. Programmable attenuators are generally an arrangement of various switched fixed attenuator sections internal to the module. The attenuation is always referenced to insertion loss. This means that the minimum loss of the attenuator is the lowest attenuation level setting plus the insertion loss of the attenuator. The maximum loss is the sum of all the fixed attenuators within the module and the insertion loss of the attenuator. It is important to note that for most RF devices the insertion loss is a function of frequency and increases at higher frequencies. A programmable attenuator may simply be specified for the "best possible" insertion loss, but a better approach is to specify the insertion loss of an attenuator at various frequency points.

The smallest attenuation step inside the module dictates the least significant bit or the smallest increment in which the attenuation can be adjusted. This is typically either 0.5 or 1 dB for most programmable attenuator models, though some allow much lower resolution steps. The other attenuation states are determined by summing the discrete

Fig. 5 **An example of a programmable attenuator with USB control.**

attenuation steps and the combinations, sequentially, from the smallest to the largest values. For instance, a 63 dB maximum attenuator with a 0.5 dB minimum step size will have attenuation steps of 0.5, 1, 2, 4, 8, 16 and 31.5 dB. This 7-bit attenuator will provide 0.5 dB attenuation increments above insertion loss for all attenuation values between 0.5 dB and 63 dB.

Attenuation accuracy is another critical specification for programmable attenuators used in test environments. The overall attenuation accuracy generally depends on what combination of attenuation steps is used to reach a given attenuation. The higher level attenuation steps are generally less accurate than the lower level attenuation steps, as smaller-value fixed attenuators are generally more accurate than larger-value fixed attenuators.

As the various fixed attenuators within a programmable attenuator are selected using a variety of switches, the speed of these switches dictates how fast an attenuator can shift between attenuation values. With electromechanical relays, this speed may be significantly slower than solid-state switches, which should switch within a matter of microseconds. For high throughput testing applications, such as automated testing of consumer wireless devices, this is a key metric, as it will often contribute significantly to the overall device test time.

The discussion to this point has assumed bidirectional attenuators. In these devices, the RF input power is symmetrical. There are also unidirectional programmable attenuators that are only specified with an RF input power for distinct input ports. When positioned properly, the techniques and characteristics

described apply to both types of programmable attenuators.

## SELECTING THE RIGHT PROGRAMMABLE ATTENUATOR FOR RECEIVER SENSITIVITY TESTING

The required attenuator performance for a given application depends on the type of receiver that is being tested. This can be very different depending on the receiver type, applicable wireless standards and available test and measurement equipment. For instance, a cellular base station receiver may only need to be tested down to -70 dBm, while a GPS signal may need to be tested down to -140 dBm. These two applications would require very different levels of attenuation depending on the capability of the signal generator/emulator used in the testing.

The noise figure of the receiver and the noise figure of the signal generator also play into the attenuation requirements that may be needed to adjust the apparent noise level of the test stimulus.

There is sometimes a tradeoff in programmable attenuators between attenuation range and attenuation step size. Programmable attenuators with higher attenuation ranges often have larger step sizes. Hence, it may not be advisable to go with the largest attenuation range if high resolution and high accuracy are required. This is not always the case, however, and the lowest step size may vary with the primary application of a given programmable attenuator model.

The frequency range of the programmable attenuator needs to match or exceed that of the receiver under test for receiver sensitivity testing. This is the case unless the receiver is only tested at given frequencies that are well within the receiver frequency range. The absolute attenuation accuracy of a programmable attenuator can generally be offset by calibration. In some rare applications, this absolute attenuation accuracy needs to be as high as possible.

For high throughput automated testing applications or when high-resolution testing of a receiver is needed, fast switching speeds may be desirable. Very fast switching may not be needed for all applications, but having a programmable attenuator that is faster than the requirement enhances the utility of the attenuator for a variety of use cases and test setups. In a laboratory setting with a limited budget, it may be desirable to select programmable attenuators that can serve multiple roles instead of the best fit for a single role.


**Fig. 6** **Programmable attenuator with TTL control.**

In some cases, a receiver sensitivity test may be performed in the same or only slightly modified test setup for various other wireless transceiver or system tests. There may be a need for a variable attenuator to accommodate different test techniques. For instance, programmable attenuators are also used in wireless testbeds for throughput testing, handover/fading testing and other test setups for wireless systems, such as multipath testing. A JFW Industries programmable attenuator with TTL control is shown in ***Figure 6***.

## CONCLUSION

Digital programmable attenuators are a key element in modern receiver sensitivity testing, as well as a wide range of other test applications. Knowledge of the receiver, RF stimulus and test bed strategy ultimately dictates the required attenuation range and frequency range of a programmable attenuator. Some signal chain analysis and understanding of the wireless standards and specifications is a prerequisite for precisely determining how best to employ a programmable attenuator to solve receiver sensitivity testing challenges. ■

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INVITED PAPER

# Cable Accelerates Its Efforts to Add Broadband Capacity and Speeds

Jeff Heynen
*Dell'Oro Group, Redwood City, Calif.*

Cable operators have historically taken a measured approach to improving their broadband networks by adding capacity incrementally through spectrum and modulation improvements. It is an approach that has served them incredibly well over the years, especially when it comes to balancing capital expenditures with the need to be market leaders when it comes to delivering the billboard speeds most subscribers care about. It is also a strategy they have been able to implement in the North American market because of their dominant share of broadband subscribers and homes passed.

However, this dominance is currently facing challenges on two fronts. At the low end of the market, the emergence of 5G fixed wireless services by industry players like T-Mobile, Verizon and AT&T is creating pressure. At the high end, fiber internet service providers (ISPs) expanding their own footprint while also overbuilding their DSL networks with an eye towards eventually decommissioning this aging copper infrastructure provides the challenge.

The net result is that cable operators, who have always had many tools at their disposal to expand broadband throughput and capacity, are accelerating their efforts to, at a minimum, keep pace with burgeoning fiber competition. These efforts involve tried and true methods of cost-effectively upgrading their hybrid fiber coax (HFC) networks through a combination of band splits and distributed access architectures (DAAs). These methods are complemented by greenfield fiber buildouts to new residential developments and via edge-out projects intended to deliver service to unserved and underserved markets.

For a large number of multi-system operators (MSOs) around the world, 2020 and 2021 were the years of node splitting, whereby service group sizes were reduced and available bandwidth increased by either logically or physically segmenting existing HFC optical nodes. These efforts were quick and cost-effective methods to relieve congestion that arose rapidly when the pandemic forced the closure of schools and businesses, pushing utilization rates per node beyond the 70 percent threshold that most MSOs set for themselves.

Those efforts, which are always ongoing, have been complemented by band splits, in

the form of either mid-split or high-split upgrades, which pushed upstream bandwidth from 5 to 42 MHz up to 85 to 200 MHz. These efforts, throughout 2022 and continuing today, enable MSOs to push upstream bandwidth from an average of 35 to 50 Mbps to 100 to 200 Mbps. This becomes a better complement to the 1 to 2 Gbps downstream services they were already offering.

The band-splitting work has frequently been done in conjunction with deployments of remote PHY devices (RPDs) and virtual CMTS (vCMTS) platforms. These are viewed as foundational steps toward either the full-duplex (FDD) or extended spectrum (ESD) versions of DOCSIS 4.0. Certainly, those operators moving forward with high-split projects will almost always do so using either RPDs or remote MACPHY devices (RMDs), both of which improve signal quality by taking advantage of digital optics in both the forward and return paths. Dell'Oro's latest thoughts on the actual DOCSIS equipment revenue for 2021 and 2022, along with the estimate for 2023 are shown in ***Figure 1***.

## DOCSIS 3.1 EXTENDED

The transition to DOCSIS 4.0 (D4.0) will be gradual, owing to the significant upgrades that need to be made to the outside plant to enable the speeds offered by both D4.0 variants. FDD D4.0 will require brand-new amplifiers, nodes and modems with DSP silicon that can handle echo cancellation. The integration of echo cancellation into those units will result in additional costs per unit, as well as added complexity. On the positive side, most current taps can remain in place.

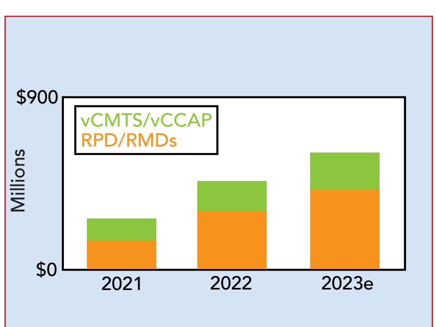


**Fig. 1** **Worldwide DOCSIS equipment revenue. *Source:* Dell'Oro Group.**

The same cannot be said for 1.8 GHz ESD upgrades, which will also require amplifier swaps along with taps and other passive elements. With ongoing labor shortages and costs still a critical consideration of any new buildout, not needing to touch any taps in neighborhoods is very attractive. Furthermore, replacing taps does require temporary service shutdown and this is always an important consideration for operators, especially when their competitors would likely exploit any service disruptions.

ESD, on the other hand, is what operators know. They have decades of experience adding spectrum and capacity through amplifiers, taps and passive swaps. There is no new spacing of the amplifiers to be done. Also, operators can go ahead and upgrade the amplifiers first and then tackle tap upgrades, as most taps in the field today support up to 1.2 GHz. That way, operators can derive some spectrum upgrades without having to do the heavy lifting of tap upgrades right away.

No matter the road operators choose to adopt D4.0, there is no question that there are a lot of moving parts. Taking into account existing supply chain problems and labor shortages, achieving the overall homes passed goals will vary significantly. Though nearly all operators committed to D4.0 concur that all systems are in agreement, it would be very unlike cable operators to have a contingency plan.

That contingency plan involves the deployment of D4.0 modems tied to DOCSIS 3.1 (D3.1) CMTS and vCMTS platforms in high-split configurations. Recent interoperability tests conducted at CableLabs demonstrated downstream speeds of over 8 Gbps and upstream speeds of 1.5 Gbps. This architecture has been dubbed D3.1 Extended (D3.1 E) and it has the attention of operators around the world, particularly those in Europe who have already said they are unlikely to deploy D4.0.

Way back in 2013, when the first D3.1 specifications were released, one of the goals was to deliver 10 Gbps of downstream speeds. Operators and equipment manufactur-

ers envisioned doing this by using a combination of orthogonal frequency division multiplexing (OFDM) channels and modulation orders ranging from 4096-QAM up to 8192-QAM and 16384-QAM over channel bandwidths ranging from 24 to 192 MHz. At the time, operators were universally offering far less than 1 Gbps of downstream speeds, so many of the CMTS platforms and modems only took advantage of the lower end of the standard's capability.

Today, with 1 Gbps speeds essentially table stakes for operators, MSOs and their vendor partners are working to take advantage of the available capacity through the combination of existing D3.1 CMTS and vCMTS platforms and D4.0 modems, which can support four OFDM channels' worth of bandwidth. The D4.0 modems, though expensive early on, are an essential purchase that will deliver multi-gigabit speeds even before the outside plant upgrades are complete. Plus, when the infrastructure upgrades are complete, subscribers will already have the modems in place to take full advantage of end-to-end D4.0 capabilities.

## D4.0 TO FIBER

While these DOCSIS-based architectures will serve as the backbone for the majority of their residential networks, it is clear that MSOs are aiming to provide more fiber to the home (FTTH) services than previously expected. By relying on a combination of remote PHY and vCMTS to re-architect existing DOCSIS networks and move to DAA, the MSOs can selectively deploy remote optical line terminal (R-OLT) modules alongside RPDs in existing node locations to peel off FTTH service groups of 32 to 64 homes. Traffic originating from those RPD and R-OLT modules can be transported back to the headend via Ethernet transport, with all subscriber endpoints, be they DOCSIS modems or passive optical network optical access point to terminals managed through the same vCMTS and/or virtualized broadband network gateway (vBNG) platforms. Dell'Oro's latest thoughts on the actual cable R-OLT revenue for 2021 and 2022, along with estimates for 2023 and 2024 are shown in ***Figure 2***.

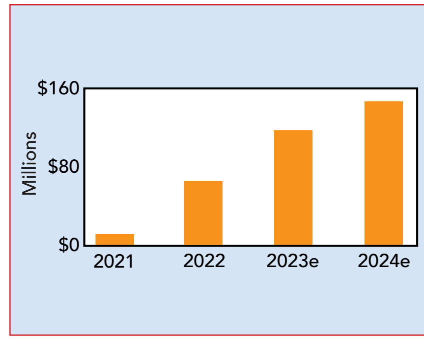


**Fig. 2** **Worldwide cable R-OLT revenue. *Source:* Dell'Oro Group.**

Another option for MSOs with this architecture is the mixed use of optical nodes for DOCSIS-based residential services and fiber-based business services using the R-OLT. There are many instances of optical nodes covering service groups that include both residential and business customers. Historically, MSOs have only been able to offer business-class DOCSIS services to these customers, with an upcharge for higher service level agreements (SLAs), static IP addresses and other features. MSOs have done extremely well over the last decade in stealing away small- and medium-business customers from telcos who had more inflexible pricing plans or relied on T1 or business-class DSL lines. But recently, telcos and other fiber ISPs have pushed hard to get these business customers back by pitching the higher reliability and technological advantage of fiber. Thus, the availability of R-OLTs, particularly those that can be added into existing node housings without significant upgrades, allows cable operators to offer a comparable fiber service to valuable business customers while evolving their access networks.

Other cable operators are bypassing this evolutionary progression and overbuilding with fiber today. Many of these operators either do not pass millions of homes or are located in countries where the cost to change the outside plant, due to labor, permitting or both, is simply too high for a step-by-step progression. Nevertheless, a clear roadmap for the transition from DOCSIS to fiber now exists and is being operationalized at a growing number of MSOs around the world. ■

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

### NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

### ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

### LIMITING AMPLIFIERS

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

### AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

### LOW FREQUENCY AMPLIFIERS

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

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## RTX to Deliver 5G Mobile Ad Hoc Networks to the Tactical Edge

RTX's BBN division will lead a team to create multi-hop mobile ad hoc networks (MANETs) for the Department of Defense. The technology will enable forward-deployed service members with 5G equipment to communicate directly without the need for a complex 5G infrastructure.

The Opportunistic eXtemporarY 5G Encrypted Network (OXYGEN) capability is being developed under a contract with the Office of the Undersecretary of Defense for Research and Engineering's FutureG and 5G Office with a potential value of $6.6 million over two years. It aims to connect a minimum of 20 pieces of user equipment by taking advantage of 5G's sidelink technology, while securely enabling the transmission of data at 100 Mbps.

"Our warfighters use existing infrastructure like roads and bridges when they are forward-deployed now," said Dr. Daniel Massey, program lead for the FutureG & 5G Office's Operate Through Team. "Why shouldn't we use existing communications infrastructure as well? Access to a 5G MANET allows us to move from single-digit megabit per second individual data sharing, for ground soldiers to 100x more throughput, which will enable sharing more high-resolution video and imagery."

Piggybacking sensitive information over commercial infrastructure requires additional layers of security and mesh networking on top of relay links. This allows for multicast traffic instead of simple peer-to-peer communication.

The Raytheon BBN-led team includes Kryptowire LLC, Novowi LLC and Curated Networks, Inc. Work on the program is being performed in Cambridge, Mass.; Brookline, Mass.; McLean, Va.; and Santa Cruz, Calif.


*OXYGEN (Source: RTX)*

## BAE to Develop Technology for Next-Generation Sensing, Imaging and Communications Systems

The Defense Advanced Research Projects Agency has awarded BAE Systems' FAST Labs™ research and development organization a $14 million contract for the Massive Cross Correlation (MAX) program. BAE Systems will develop technology aimed at enabling the deployment of advanced signal processing and computation on a new smaller category of military platforms.

Signal processing is at the heart of critical Department of Defense technology such as sensing, imaging and communications systems. Correlators are a vital tool in comparing, contrasting and ultimately processing signals. Current digital correlators are large, power-hungry systems that are the size of a briefcase. BAE Systems' approach to developing analog correlators will maintain or improve performance while reducing the system to the size of a hockey puck.

"Smaller and more efficient systems improve size, weight, power and costs to enable full-spectrum signal processing closer to the edge, or onto platforms operating in denied airspace," said Bryan Choi, technology development director at BAE Systems' FAST Labs. "This disruptive analog correlator technology can result in enhanced decision making, enabling mission-critical technology to be deployed on smaller platforms and create a new category of systems."

As part of the program, BAE Systems seeks to deliver a radically more power-efficient analog correlator with high dynamic range and wide bandwidth. It will enable new capabilities including synthetic aperture radar image classification and image formation, automatic target recognition, passive coherent location and jam-resistant communications in small form factor platforms.

Work on the program, which is part of BAE Systems' sensor technologies portfolio, includes collaboration with the University of Minnesota.

*MAX (Source: BAE Systems)*

## GA-ASI Advances Ecosystem for Autonomously Operational UCAV

General Atomics Aeronautical Systems (GA-ASI) advanced its ability to operationalize the unmanned combat air vehicle (UCAV) ecosystem by combining advanced autonomy and government-provided human-machine interface hardware. A GA-ASI-owned Avenger® unmanned aircraft system (UAS) was paired with a "digital twin" aircraft to autonomously conduct live, virtual and constructive (LVC) multi-objective collaborative combat missions.

The flights, which took place recently from GA-ASI's Desert Horizon Flight Operations Facility in El Mirage, Calif., show the company's commitment to matur-

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ing its UCAV ecosystem for autonomous collaborative platforms. The ecosystem's goal is to rapidly integrate best-of-breed capabilities in areas such as artificial intelligence, mission-relevant interfaces and other capabilities.

The team demonstrated manned-unmanned teaming (MUM-T) using the U.S. Air Force's Project FoX system with a touchscreen tablet for fighter cockpits. The tablet provided control and monitoring of advanced autonomy while it conducted a multi-objective combat mission consisting of LVC entities. Mission autonomy capabilities focused on optimized search and signature management. Search optimization autonomy behaviors were provided by Scientific Systems Company, Inc. (SSCI). These skills were integrated into and orchestrated by government-furnished equipment (GFE) autonomy core architecture enhanced by GA-ASI.

The flexibility of the GFE autonomy core software stack enabled rapid, seamless integration of one of SSCI's multi-UAS behaviors. Autonomous trajectories were calculated by SSCI algorithms and subsequently communicated to GA-ASI's autonomy core for translation to vehicle routes. SSCI provided an array of behaviors using its Collaborative Mission Autonomy suite where the software adapts to mission contingencies such as system failures, connectivity dropout and combat losses to ensure successful tactical execution.


*UCAV (Source: GA-ASI)*

The signature management skill, based on deep reinforcement learning (RL), was developed by GA-ASI. Skill development leveraged GA-ASI's RL architecture that was designed using agile software methodologies and industry-standard tools such as Docker and Kubernetes. Commanded using the FoX tablet, the RL agent navigated to an operator-identified target while minimizing the radar cross section. This MUM-T, facilitated via open mission system (OMS) messages and alignment to the newest government architectures, demonstrated real-time operator tasking and supervision of an autonomous platform as it conducted its mission.

The team used a government-furnished autonomy core engine and the government-standard OMS messaging protocol to enable communication between the RL agents and the LVC system. Using government standards such as OMS will make rapid integration of autonomy for UCAVs possible. In addition, GA-ASI used a General Dynamics EMC2 to run the autonomy architecture.

## Expanded Use Cases and Ecosystem Integration to Reignite Wearable Market

Wearable demand growth declined to 14.6 percent year-over-year (YoY) in 2022 from 27.7 percent YoY in 2021 due to the economic slowdown and reduced spending after the peak of the COVID pandemic. This trend persisted in the first half of 2023, as longer replacement cycles and a lack of compelling features suppressed consumer demand. However, ABI Research predicts that the overall wearables market will rebound, reaching 689.33 million shipments by the end of 2028, with a compound annual growth rate (CAGR) of 11.3 percent between 2023 and 2028. In 2023, the wearable market is projected to grow by approximately 10.2 percent YoY, with shipments expected to exceed 400 million units. The market is forecasted to recover in the latter half of 2023 and continue growing in the subsequent years, driven by expanded use cases and ecosystem integration.

"Advancements in areas such as connectivity and integrated sensors, followed by the availability of advanced features at low price points and user upgrades, will help drive consumer interest and result in the growth of the wearables sector in the coming years," said Sachin Mehta, senior analyst, consumer technologies at ABI Research.

Introducing 5G in wearables and accessories will be pivotal in this market's evolution.

In 1Q 2023, the smartwatch and activity fitness tracker sectors experienced YoY declines of 3 and 9 percent, respectively. These declines were primarily due to seasonal factors and an excess inventory buildup in the channel. Emerging countries, particularly India, offer significant growth potential, with India contributing one in four smartwatches shipped globally. Fire-Boltt, an Indian brand, has made a remarkable ascent, securing the second spot in the global smartwatch market with a 10.1 percent share, just behind Apple (21.6 percent) and ahead of Samsung (9.2 percent).

According to Mehta, "Activity and fitness trackers are facing a downward trend due to competition from smartwatches. However, the category is expected to persist as it caters to a dedicated user base seeking simplicity and affordability with basic functionalities." In 2022, Xiaomi (35.2 percent) led activity and fitness tracker shipments, followed by Huawei (23.7 percent) and Fitbit (15.8 percent).

Smart rings, a newly tracked category in wearables, have experienced a recent surge in demand, promising to drive future growth in the wearables market. In 2022, 17.2 million smart rings were shipped, and this is projected to grow by 10.0 percent YoY, reaching 18.9 million units in 2023 and exceeding 50 million units by the end of 2028, with a CAGR of 21.9 percent between 2023 and 2028.

Introducing 5G in wearables and accessories will be pivotal in this market's evolution. Real-time data transmission and processing capabilities will unlock a wide range of new functionalities and use cases for wearables. Health care will be at the forefront of this transformation, with exciting prospects for remote patient monitoring and advancements in fitness applications. As a result, high-end wearables sales are likely to experience a surge in the coming years due to increased demand for advanced use cases.

## Seaports to Deploy Over 370,000 AGVs by 2030 to Alleviate Congestion

The maritime industry has drastically surged its automation efforts in the wake of global seaport congestion. In addition to solutions such as gantries, automated port gates and stacking cranes, autonomous horizontal transport modes such as autonomous guided vehicles (AGVs) that transport containers and loads to and from ships have been the most productivity-augmenting solutions in seaports. According to ABI Research, AGV seaport deployments worldwide will have a CAGR of over 26 percent from 2022 to 2030 and exceed 370,000 global deployments by 2027.

Improves port operations' reliability, consistency and workplace security.

"Automation improves port operations' reliability, consistency and workplace security. Also, from an environmental perspective, automation can lead to efficient operations and faster services. Automated ports are also far safer than conventional ports. The number of human-related disruptions falls as performance becomes more predictable with automation and data capture solutions," explained Adhish Luitel, supply chain management and logistics senior analyst at ABI Research.

In addition to AGVs in seaports, adopting solutions in other modalities of the global supply chain, such as rail, air and road, has also seen growth. Automation solution providers, including VisionNav Robotics, Konecranes, HERE Technologies and VDL Automated Vehicles, have provided various automation and digital tools that enhance operational efficiency and visibility across different modalities.

Rail camera systems in rail infrastructure are a particularly growing sector. Over 29,000 inspection robots were deployed in rail infrastructure globally in 2022.

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This number is set to grow to over 43,000 by 2030 with a CAGR of around 5 percent, falling in line with the rising rail freight volume. Over 14 billion tons were transported in 2022 via rail freight. This number is set to grow to over 16 billion by 2030.

## E-Band Microwave Transmission Shipments Grew in 2Q 2023

According to a recently published report from Dell'Oro Group, shipments of E-Band (60 to 90 GHz) transmission equipment grew 77 percent year-over-year in 2Q 2023. The top two vendors, Huawei and Ericsson, held the vast majority of this market's share.

"Demand for E-Band equipment really picked up in the past three quarters," stated Jimmy Yu, vice president at Dell'Oro Group. "A lot of these systems are being installed in India as the operators in that country quickly ramp up on 5G. Network rollouts and upgrades to 5G are happening at a fast pace there. On top of this, the use of E-Band is steadily moving beyond shorter spans that are under a kilometer to longer spans that are over a couple kilometers. Longer reach is a benefit of the newer radios designed with higher transmit power and active antenna for site-to-site alignment," added Yu.

> E-Band equipment really picked up in the past three quarters.

Highlights from the 2Q 2023 Microwave Transmission & Mobile Backhaul Quarterly Report:

- The microwave transmission market grew 5 percent year-over-year in 2Q 2023, driven by both mobile backhaul and the vertical markets. The overall market forecast for 2023 is unchanged at an expected growth rate of 5 percent.
- The E/V-Band market segment reached a new record revenue amount in the quarter. For the trailing four quarter period, the revenue was approximately $600 million.
- Huawei and Ericsson captured most of the E/V-Band market in the quarter with a combined market share greater than 70 percent. Other major E/V-Band vendors include Nokia, Siklu and ZTE.

The Dell'Oro Group Microwave Transmission & Mobile Backhaul Quarterly Report provides coverage of the market with tables of manufacturers' revenue, ports/radio transceivers shipped and average selling prices by capacities (low, high and E/V-Band). It tracks point-to-point time-division multiplexing, packet and hybrid microwave as well as full indoor and full outdoor unit configurations.

# Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

## IN MEMORIAM

▲ *Bill Waskowitz*

**HyTech** has announced the passing of their founder and good friend **Bill Waskowitz**. Bill founded HyTech in 1980 selling microwave components and subsystems throughout southern California. In 2020 Bill stepped down from his managerial and sales activities but continued providing technical assistance to the HyTech Team through April of this year. Prior to starting HyTech, Bill was a part owner and sales representative for Scientific Devices, selling instrumentation and microwave components in southern California. Bill will be sorely missed by all those he worked with and the many customers he called on.

## MERGERS & ACQUISITIONS

**MACOM Technology Solutions Holdings Inc.** announced that it has entered into a definitive agreement to acquire the RF business of **Wolfspeed, Inc**. The RF business includes a portfolio of GaN on SiC products used in high performance RF and microwave applications. The business services a broad customer base of leading aerospace, defense, industrial and telecommunications customers and most recently generated annualized revenues of approximately $150 million. The acquisition is expected to be immediately accretive to MACOM's non-GAAP earnings. The acquisition includes a 100 mm GaN wafer fabrication facility in Research Triangle Park, N.C., (RTP Fab) with operations conveying to MACOM approximately two years following the closing and Wolfspeed's relocation of certain production equipment.

## COLLABORATIONS

**Modelithics**, a leading provider of RF/microwave simulation models, welcomed **Tagore Technology Inc.** into the Modelithics Vendor Partner (MVP) program at the Sponsoring level. Tagore Technology is a fabless semiconductor company providing GaN on Si and GaN on SiC solutions for RF and power-management applications. Modelithics and Tagore Technology are in collaboration to develop a new model for the TA9210D GaN power transistor. The TA9210D is a 15 W power transistor with an operating frequency range of 30 MHz to 4+ GHz. Typical performance in a 30 MHz to -1 GHz broadband application, the TA9210D achieves 18 dB of small signal gain at the same frequency, the device delivers +41.5 dBm of saturated output power and achieves greater than 70 percent PAE.

Sensor solution provider **HENSOLDT** and **ERA**, a pioneering company specializing in air traffic control and passive surveillance systems for air surveillance, air defense and electronic warfare, announced their strategic partnership to drive the advancement of air surveillance and defense capabilities. This collaboration is a response to the insights gained from recent conflicts in Europe, emphasizing the need for cutting-edge technologies to enhance national and European security. The primary objective of this partnership is to jointly offer the Passive Surveillance System VERA-NG to the German Luftwaffe. HENSOLDT and ERA will leverage their expertise to develop an integrated infrastructure solution that can be used in the state-of-the-art VERA-NG system and HENSOLDT Passive Radar Twinvis technology.

**ZTE Corporation** has successfully partnered with Thailand's leading telecommunications operator, **Advanced Info Service Public Company Limited (AIS)**, to accomplish the world's first dynamic reconfigurable intelligent surface (RIS) trial in an mmWave network at the AZ center in Bangkok. This collaboration explores new possibilities in the field of mmWave communication, offering a low-cost, low carbon solution for deploying mmWave networks at scale. RIS is an innovative multi-antenna technology that utilizes electromagnetic metamaterials. RIS enables the extension of base station coverage by intelligently reflecting or transmitting base station signals, resulting in improved coverage at a low-cost and with low carbon emissions.

## NEW STARTS

The **Passive Plus (PPI)** newly updated website presents the entire product line of PPI components, with datasheets that provide part numbering breakdown, mechanical and electrical specifications and customizable options. The EIA High-Q Capacitor (ultra-low ESR) line, N Series, also provides S-Parameter data, Modelithics modeling data and standard engineering design kits for the entire range of case sizes: 0201, 0402, 0603, 0805 and 1111. Custom capacitor kit options are available with the option to submit requests and specifications directly through the website. Also available on the website is the complete PPI RF & Microwave Components Catalog (and additional brochures for the other PPI product lines) and a High-Q Capacitor Cross Reference Chart.

## ACHIEVEMENTS

As **EM Solutions** prepares to celebrate its 25th anniversary, it also marks another significant achievement: the first stage completion of its factory expansion. The additional space, required to accommodate the design, manufacture and testing of its flagship Naval satcom systems, includes a new ISO7 (Class 10,000) clean room. This room spans 100 $m^2$ and features eight new workstation areas as well as three chip and bond machines. The expansion plan also incorporates a 125 $m^3$ environmentally-controlled chamber for military-standard certification of its 2 m King Cobra systems, as well as a 150 $m^2$ research and development laboratory, providing room for new innovations and designs.

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## Around the Circuit

**HUBER+SUHNER** was awarded the contract to manufacture and supply antennas for radar for autonomous driving to HL Klemove, a top Korean autonomous driving solution provider. By doing so, HUBER-SUHNER is successfully extending its customer landscape in this application to the Asian market after being nominated by various major European Tier 1 companies. HL Klemove has nominated HUBER+SUHNER as a partner for the development and production of antennas, which are used in radar sensors for advanced driver assistance systems and autonomous driving. The start of production is planned for 2024.

### CONTRACTS

**Hughes Network Systems LLC** announced that it has been awarded a five-year, indefinite delivery, indefinite quantity (IDIQ) contract by the **U.S. Space Force** for proliferated low earth orbit (LEO) satellite-based services. Under the IDIQ vehicle, valued at up to $900 million, U.S. Department of Defense (DOD), other federal agencies and international coalition partners can procure fully managed, low latency LEO services from Hughes leveraging capacity on two constellations: OneWeb and EchoStar Lyra™. Hughes previously announced a distribution agreement with OneWeb Technologies Inc., a wholly owned subsidiary of OneWeb, to deliver managed, wideband LEO services to the DOD; those services are now available under the IDIQ and the GSA Schedule.

**Peraton** was awarded a competitive subcontract to **NASA's Jet Propulsion Laboratory** with a total contract value of $513.5 million. The company has a history with deep space network dating back to 2004 — including helping the James Webb Space Telescope communicate across the cosmos, linking mankind and the moon and supporting the Perseverance rover on Mars. The work involves the highly technical sustainment of four antenna stations — each equipped with large parabolic dish antennas and ultra-sensitive receiving systems — capable of detecting incredibly faint radio signals from distant spacecraft. The project scope also entails base support functions, including operator to depot level maintenance of the antennas and infrastructure along with providing armed security for the complex.

**Sivers Semiconductors AB**, a subsidiary of **Sivers Wireless**, has received a $425,000 development contract from a leading satcom network provider to develop and prototype electronically steerable flat-panel phased arrays for ground terminals to communicate with their satellite network. The panels leverage Sivers' industry-leading Ka-Band beamformer ICs to achieve state-of-the-art performance at competitive cost points. The array panels are developed to be integrated in terminals by a terminal vendor partner for mass production. The development contract revenue will be recognized through 2H 2023 and Q1 2024. Ka-Band technology for satcom has over the last years opened the market to a new range of frequencies that are more cost-effective

than other bands providing higher quality, better performance and higher data rates.

**CAES** has won a $200 million follow-on, full-rate hardware production and sustainment award from **Raytheon**, an RTX business. Under the contract, CAES will provide fully tested radar module assemblies for the U.S. Navy's AN/SPY-6 family of radars. CAES has been a multi-year partner with Raytheon on the SPY-6 program, and has already begun delivering hardware. This follow-on, multi-year award demonstrates the continued strong partnership between CAES and Raytheon, and their demonstrated capacity to provide the SPY-6 radar with reliable components and meet the U.S. Navy fleet's needs for many years to come.

**Elbit Systems** announced that it was awarded a contract worth approximately $55 million to supply multi-layered ReDrone Counter Unmanned Aerial Systems (C-UAS) to the Netherlands. The contract will be performed over a period of four years. As part of the contract, Elbit Systems will supply several mobile, stationary and deployed configurations of the ReDrone integrated C-UAS solution along with a logistic support package and training. The ReDrone Solution is comprised of Elbit Systems' advanced DAiR Radar, signal intelligence sensors and COAPS-L electro-optical payload which provide an enhanced integrated aerial picture, along with high-end electronic attack capabilities, all fully controlled by a unified command and control system.

**Verus® Research** announced it has been awarded a two-year $15.6 million contract from the **Naval Research Laboratory (NRL)**, in conjunction with the Naval Air Warfare Center Aircraft Division. The company will develop an agile high-power microwave test capability suitable for multi-frequency output in the X-Band region of the RF spectrum. Through the contract, Verus Research will work on the Dual X-Band program and coordinate efforts to employ cutting-edge technologies developed by NRL to achieve high-power and agility from a solid-state source.

**Mercury Systems Inc.** announced it has completed delivery of the processing hardware for the **U.S. Army's** first six Lower Tier Air and Missile Defense Sensor (LTAMDS) radars, being built by Raytheon. LTAMDS is the Army's newest air and missile defense sensor that will operate on the Army's Integrated Air and Missile Defense network. LTAMDS is a 360-degree, active electronically scanned array radar that provides significantly more capacity and capability against the wide range of advanced lower-tier threats, including hypersonic missiles. Mercury has provided radar processing systems to Raytheon for Patriot® radars since 2009.

A team of industry and research partners led by the **TMD Technologies Division of Communications & Power Industries (CPI)** has been awarded more than £4 million by **Innovate UK's** SBRI Quantum-enabled


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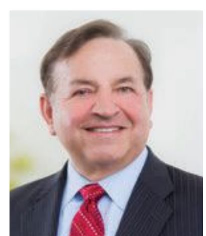
positioning, navigation and timing (PNT) systems competition, which issues contracts for pre-commercial procurement of innovative solutions, enabled by quantum technologies, to public sector challenges. Under this contract, CPI TMD Technologies and its partners will develop exceptionally high precision quantum-enabled PNT systems that can be used to identify an object's exact position in time and space without the use of satellite signals.

**Ericsson** is supplying the **German Federal Office for Information Security (BSI)** a full-scale 5G test network infrastructure for its 5G/6G Security Lab Test Environment for Mobile Infrastructure Security. The contract was awarded in June 2022 and the first stage of construction recently went into operation. In the test lab, the BSI conducts security tests on 5G components that are part of a 5G network. The aim is to promote the security of German telecommunications networks. Among other things, the BSI is concerned with the security of German telecommunications networks. The 5G Competence Centre at the BSI's Freital site is investigating in particular the security of 5G-based infrastructures and their further developments.

## PEOPLE



▲ *Dr. Bami Bastani*

**Sivers Semiconductors AB** announced that **Dr. Bami Bastani** has joined Sivers as a strategic advisor to the board and management to further strengthen the company's focus on the U.S. and global markets and provide guidance related to the semiconductor, Photonics, 5G and satcom ecosystems. Dr. Bami Bastani has over four decades of extensive experience in the industry, including a most recent role as senior vice president and general manager at GLOBALFOUNDRIES, where he led the high-growth mobile and wireless infrastructure business unit. He transitioned to senior vice president and senior advisor to CEO in August 2022 through March 2023.

▲ *Sven-Christer Nilsson*

**SweGaN AB**, a European semiconductor manufacturer that develops and produces custom-made GaN on SiC epitaxial wafers, welcomes a Swedish telecom executive, **Sven-Christer Nilsson**, to join the company as a senior advisor. Nilsson is former CEO of Ericsson and is today active in leading tech companies as an investor and board member. Nilsson is known for his strategic leadership abilities in high-tech industries. Nilsson is currently on several boards, including CEVA, Inc., a semiconductor industry leader in signal processing, sensor fusion and artificial intelligence processing. He has previously held long-term positions such as chairman of the board of the Swedish Defense Materiel Administration and other high-profile organizations.

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|---|---|---|---|---|---|---|---|
| SA-07-4B242275 | 24.2-27.5 | 1.9 | 10.8 | ±0.8 | ±0.8 | ±10 | 10 |
| SA-07-4B265295 | 26.5-29.5 | 1.9 | 11 | ±0.8 | ±0.8 | ±10 | 10 |
| SA-07-4B370400 | 37-40 | 2 | 12 | ±0.8 | ±0.8 | ±10 | 10 |

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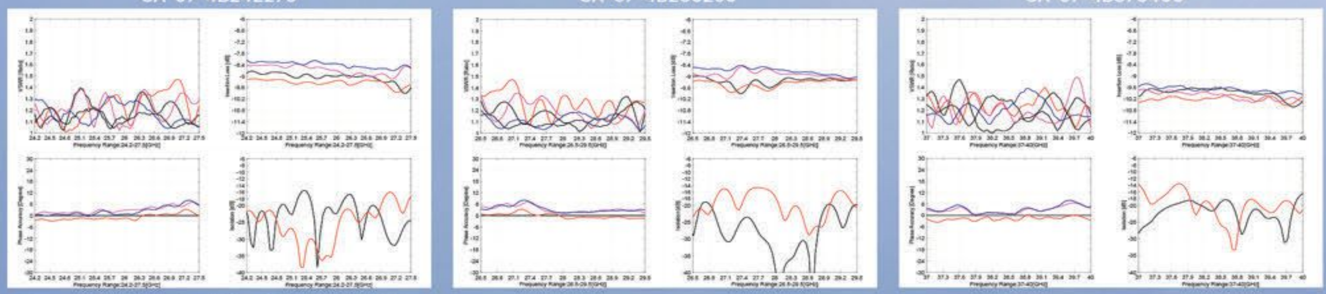

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INVITED PAPER

*Editor's Note: As additive manufacturing techniques evolve, these processes offer significant advantages and benefits to the electronics industry. Microwave Journal addresses aspects of this emerging area with a two-part article. This first part, published in the September Supplement of Microwave Journal, introduced dielectric measurement concepts and important challenges, along with a portion of a panel discussion with RF dielectric measurement experts from the industry. This second part continues the discussion with the panel of experts.*

# Estimating & Measuring the Dielectric Constant and Loss Tangent of Dielectric Lattice Structures for Additive Manufacturing (Part 2)

Phil Lambert
*Fortify, Boston, Mass.*

## Discussing Dielectric Measurements With The Experts (Continued)

**What methods are you currently using to determine the dielectric constant and/or the loss tangent of dielectric materials?**

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

Most common methods we use for determining complex permittivity are those which we also offer to our customers and which are known for their high accuracy. Those are split-post dielectric resonators (operating at single frequencies between 1 and 15 GHz) and Fabry-Perot open resonators (wideband single-device solution for a frequency band of 20 to 125 GHz) dedicated to laminar and other sheet dielectrics. Those two types of fixtures are excellent for dielectrics of Dk between 1 and 15 and loss tangent going down to 2 10^-5, with achievable accuracy of less than 0.5 percent and less than 2 percent, respectively. However, we also have and work on more specific designations, like ceramic resonators with losses going down to even 10^-7, low loss liquids and nonstandard materials like bituminous mixtures, foods, etc.

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

We ordinarily perform full-wave simulation of candidate unit cells because it is fast and accurate for complex unit cell designs. Simulations are validated using transmit/reflect measurements and the Nicholson-Ross-Weir (NRW) method in waveguides and free space.

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

If we are using a commercial material such as a Rogers laminate or resin for the first time, we will do an NRW measurement using a loaded rectangular waveguide. We have not had any issues with Rogers' materials, but we characterize every new material we use as a matter of due diligence. We have also done free-space measurements. This is a great way to measure the dielectric performance of a stack of materials and accurately characterize a stepped impedance transform in free space, which you cannot do in a rectangular waveguide due to the non-TEM propagation.

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

We use and develop a variety of dielectric test measurement technology. Free-space focus-beam, both microwave and mmWave, is one such. Another is an Epsilometer that we developed alongside Copper Mountain Technologies. What is unique about the Epsilometer is that the dielectric extraction is actually performed from an interpretation of the response of the sample in the Epsilometer referenced from a database of computational electromagnetic (CEM) codes using a CEM inversion method. This is as opposed to traditional parameter extraction methods which typically rely on physics-based approximations. Other examples of CEM inversion dielectric measurements we have developed include a slotted stripline waveguide for in-situ measurements of continuous sheet materials and square coaxial transmission lines that can be loaded with a cubic dielectric sample.

## What challenges are you having with these methods?

**Marzena Olszewska-Placha**

As for the challenges, material science and industry are continuously expanding towards new materials. Therefore, if they appear, the challenges typically come from our customers, either associated with using our fixtures for their new applications or while providing measurement services for our client's materials. These also stimulate further development on our side.

**Jonathan Chisum**

The downsides to these methods differ.

Waveguide:

- The method is limited to less than an octave of bandwidth.
- It is difficult to achieve a very accurate estimate of loss tangent in low loss materials. We have found that if great care is taken to maintain phase stability, including phase-stable cables, throughout a TRL waveguide calibration and the sample is manually placed in the waveguide cross-section several times and average values are computed. The method can achieve highly accurate results for both permittivity and loss tangents.[1] The TE10 waveguide mode is not the same as the operating mode. This is acceptable so long as the unit cell under investigation is much smaller than the waveguide cross-section, in which case, the field will be nearly uniform across the cell.

Free space:

- This is a wideband method limited only by the antennas.
- Spot-focus antennas are used. It is difficult to achieve a small spot size and therefore the material under test must present a large cross-section, typically several inches in diameter, to ensure the majority of the energy interacts with the material and the surrounding medium. This can be costly to fabricate to test structures.

**Nico Garcia**

Physical measurements are expensive and time consuming. Ideally, you would only do a single measurement run for a new type of composite structure/material. A typical flow is as follows: characterize a material/structure in electromagnetic simulation, fabricate some samples, measure the samples in NRW, then tune the simulation model to better reflect measurements and iterate as needed. This has been sufficient for our applications. I should emphasize that NRW does have weaknesses, such as difficulty measuring low loss tangents. Free-space measurements are difficult because you need spot-focusing antennas that are manufactured to metrology grade and you must use relatively large samples that occupy the full cross-section of the antenna beam.

**John Schultz**

Free-space measurements are good, in general, for wideband characterizations, as you can measure a wide range of frequencies with one measurement. Free-space methods, however, are not typically good for measuring loss tangents of low loss materials, such as high density polyethylene, Rexolite or other conventional low loss polymers, like Teflon. The reason is that by passing through the material once, in a free-space focus-beam method, for example, you cannot accurately capture the loss tangent. Also, with free-space focus-beam methods, the number one uncertainty for measurements of the real part of permittivity is the tolerance of the thickness of the sample. Any variation in thickness, flatness, camber or nonuniformity (inhomogeneity) within the sample results in uncertainty.

If you want to measure loss tangent accurately, you need to move to a resonant device. By definition, a resonant device is a narrowband and not a wideband measurement, which is a disadvantage of the Fabry-Perot method. Resonant methods have good sensitivity for low loss materials, as the stimulus energy basically sloshes back and forth multiple times through the material and effectively amplifies the significance of the loss in the material. That said, another drawback of the Fabry-Perot method is that the sample thickness must be less than half a wavelength. This has an impact on the types of metamaterials or patterned artificial dielectrics that you can measure, as a representative sample is needed and if that cannot be achieved in a limited thickness then the measurement results won't accurately capture the response of a larger metastructure. Another drawback of the Fabry-Perot is that the performance of this method starts to decline at E-Band frequencies and beyond. The reason is that the mirrors used in the system are not as conductive at higher frequen-

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cies where the skin depth starts to become electrically thick. This then reduces the Q of the measurement device and hence accuracy. The Epsilometer was designed to make measurements of microwave substrates. Therefore, it is good at measuring relatively thin sheets, 3 to 4 mm, of dielectric materials, but only at lower frequencies, say up to 6 GHz.

**What tolerances for effective Dk and Df are acceptable for your applications and do you have any guidance or rules of thumb that you would suggest to others testing these dielectrics?**

**Marzena Olszewska-Placha**

For the design activities that we run for microwave devices and systems, we focus on tolerances that are achievable with our test fixtures for materials characterization. For SPDR and FPOR, this is typically less than 0.5 percent for Dk and less than 2 percent for Df. For measurement methods like split-post dielectric resonators, Fabry-Perot open resonators or split-cylinder resonators, thickness variation or in other words, the uncertainty of thickness measurement translates almost one-to-one to Dk measurement uncertainty. For the Df, a crucial factor is the uncertainty of measuring quality factors with a vector network analyzer or other, like dedicated microwave Q-meters and this is of highest importance for low loss and high loss materials. If I were to choose one thing I would say, the quality of your material sample under test (SUT) is extremely crucial for the final uncertainty of your measurement in most of the commonly known and used material measurement methods. Therefore, much attention shall be put into preparing the SUT. Flatness and sample thickness variation across its surface are those factors, which are most pronounced in measurement uncertainty.

**Jonathan Chisum**

Variation in the effective permittivity of a unit cell degrades phase collimation and hence, antenna efficiency. For large-area GRIN lenses, for example, 10 to 20 across, it may be necessary to collimate as much as 15 to 20 radians of phase. A phase error of as little as 0.5 radians results in a gain reduction of several dB. Supposing a homogeneous effective medium, a 0.5 radian error upon 15 radians of collimated phase would result from a permittivity error of seven percent. Therefore, in order to achieve the expected phase collimation and hence maintain maximum gain, it is important to know the effective permittivity of a GRIN medium to within a small percentage error. Furthermore, to predict and anticipate losses through the thickness of the lens one must have an accurate measurement of the loss tangent.

**Nico Garcia**

I do not recommend using the rectangular waveguide NRW method with materials that have a dielectric constant above 10 because the samples either have to be extremely thin or the measurement data will exhibit resonances. I also do not recommend this method for use beyond 40 GHz because the samples will require very small cross-sections and measurements will be more sensitive to fabrication tolerance. You want the sample to fit snugly inside the waveguide and errors due to mechanical slop will scale with frequency. I recommend using WR-28 waveguides or larger, that is WR-62, WR-42 and WR-90. With bigger waveguides, it is easier to fabricate/handle the sample and the measurement is less sensitive to fabrication tolerance. However, the samples need to be thicker for lower-frequency characterization. My advice is to do your due diligence. Make sure you have a good basis for your effective media approximation and be sure to validate your simulation model with real measurements. It is worth taking the time to identify the real measurements' deviations from theory in order to generate a robust simulation model for future designs. Once you fabricate your structures, physically measure your samples' mechanical tolerances (looking under a microscope, counting image pixels, etc.) and determine if errors are systematic or individual. Identify and quantify any idiosyncrasies in your process. For high contrast GRIN lens antennas, which use a wide range of dielectric constants, it is essential that these process quirks are replicated in the full antenna simulation. Lastly, most GRIN materials are non-magnetic but it is possible that a GRIN structure/component may create a magnetic response. Specifically, if you use metal inclusions in metamaterial cells, you need to be mindful of rings and other inductor-like structures. In these cases, you will want to use a measurement paradigm that can also detect changes in effective permeability. If your measurement implicitly makes the simplifying assumption that your structure has no magnetic response when it actually does, then your measurement results will be inaccurate.

**John Schultz**

With free-space methods, the short answer is that it depends. You can make this method pretty precise, but there is a relation of uncertainty with loss. For low loss dielectric materials, this method can start to get more accurate toward E-Band frequencies. We have found ways of doing corrections with the focusing error and beam shift that have enabled high frequency loss tangent sensitivity down below ±0.002 to 40 GHz and ±0.0002 at E-Band frequencies. With the square, loaded transmission line method, it is possible to measure the cubic sample in three different orientations and get the three main directions of anisotropy. All of these measurement methods are just tools in a toolbox. Every good measurement laboratory will have a variety of techniques, as no technique is going to be a winner for all situations, they all have their tradeoffs. It is just like a screwdriver; it will not work for every fastener. That is why I always tell people to have multiple tools.

**Is dielectric isotropicity, homogeneity or linearity a concern for your applications? For anisotropic materials, which axis is important to you?**

**Marzena Olszewska-Placha**

In our research and development activities, we typically deal with isotropic materials. However, from our

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experience and discussions with project partners and customers, we know that the importance of being able to confirm isotropy or quantify anisotropy is continuously growing. With our solutions, we test in-plane complex permittivity and in fact, Fabry-Perot open resonator enables us to separate in-plane components evaluating a material's anisotropy.

**Jonathan Chisum**

In general, waves propagate from a feed to a lens with varying incident angles relative to the unit cell coordinate system. As such, the effective medium should be isotropic over a particular range of angles. Lens antennas are characterized by F/D where D is the lens diameter and F is the focal distance from the lens to the feed with typical ranges being 0.5 to 0.8. Waves propagate from the feed to the lens at angles ranging from broadside to $\tan^{-1}(0.5/(F/D))$ or from about 0 to 45 degrees (F/D=0.5); hence, permittivity should be relatively constant over this range of incident angles. We typically design unit cells for an isotropic response out to 45 degrees. In general, all-dielectric unit cells are more isotropic than metallo-dielectric unit cells and circular features on a hexagonal lattice are better than, for example, square features on a square lattice.[2]

In our typical application, we are exploiting inhomogeneity to realize a GRIN medium and hence we simply require that the host material be consistent and that our mixture of air to dielectric be predictable. The same print requirements that would maintain a homogeneous medium in another application also ensure our GRIN media is printed as designed.

Some of our lenses are intended to be operated in an interference-dominated environment where we rely upon the linear lens radiation pattern to provide angular filtering of interferers. Other of our lenses are intended for use in high-power, kW-level, applications. In both cases, we require highly linear dielectrics. We have performed high-power testing and determined that representative all-dielectric GRIN media is highly linear and this is a major advantage of lens antennas over, for example, a phased array with active components.

**Nico Garcia**

The rectangular waveguide NRW method exclusively examines the TE10 mode, so you only ever see one diagonal term of the permittivity tensor at a time. To measure other diagonal terms, you would need to make different samples with the structure rotated. Most structures tend to be fairly isotropic but if the simulations indicate high anisotropic character, then it's probably worth characterizing the other tensor values.

**John Schultz**

If you have a composite material that is a mixture of two different things, even old-school-type

stuff without purposeful patterning, like a fiberglass composite, you will have inhomogeneity and anisotropy. This is definitely another very large source of uncertainty with these material measurement techniques. The accuracy often is not limited by the device, because the material is not necessarily mixed well enough, or the fibers are not aligned properly, or there are voids. The limit to accuracy is often limited by the homogeneity of the material. That is the reality of these metamaterials and of complex, artificial dielectrics in general. Often the quality of these complex materials depends on how much money it will take to get them more homogenous. Another option is just to characterize the material over a larger area or take multiple samples and get a statistical average of performance. That may be what is needed for dealing with a given material, depending on the application requirements.

Anisotropy is very common, and it is critical as some may not realize that their materials are anisotropic. Say you are making a composite with fiberglass; the orientation of the fibers will induce some anisotropy. Often when manufacturing something with fibers, they will try to alternate layers with different fiber orientations to enhance the isotropy and create an approximately homogeneous material, though a composite will always be inhomogeneous to some extent. Even some homogeneous materials can be anisotropic. For example, stretched acrylic enables the polymer chains to align preferentially, which changes the in-plane versus out-of-plane properties of an RF window.

## CONCLUSION

The latest AM techniques have enabled the fabrication of new types of complex dielectric structures, including lattice dielectrics and dielectric metastructures. These new fabrication technologies have opened doors to creating innovative new solutions, at the cost of more complex testing and dielectric measurement requirements. Having a solid foundation in dielectric physics and dielectric measurement can enable a designer to more effectively harness these new AM technologies and realize new solutions leveraging AM. ■


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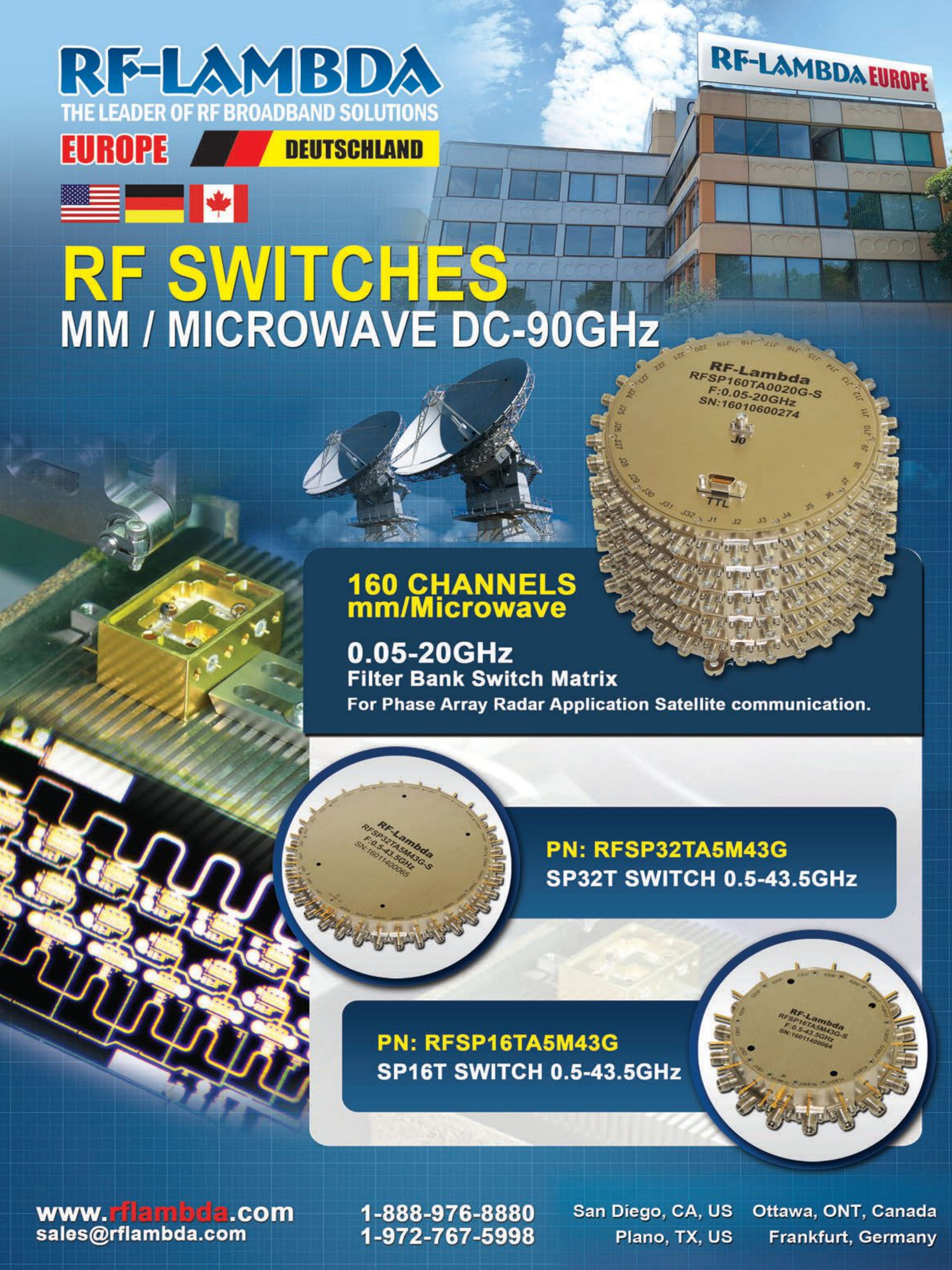
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INVITED PAPER

# A Modern HF/VHF/UHF Transceiver for All Applications – What Would it Look Like Today?

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*Modern RF transceivers represent more than just separated receiver and transmitter functionalities within the same box. In an operational scenario involving several transceivers, even a "perfect" receiver can demonstrate high-end performance only if the spectral purity of the transmit signals is sufficiently high. Therefore, a transceiver design must align major RF parameters and building blocks between transmit and receive paths to form a combined optimized transceiver architecture! In the following, a state-of-the-art "perfect" transceiver architecture is described.*

When a receiver and transmitter are operated at different locations and far away from each other, the only relevant receive parameter is sensitivity, while the only relevant transmit parameter is output power. The closer a transmitter is to the receiver, the more significant are additional performance characteristics for both. While the receiver must increase its robustness to withstand the strong transmit signal at its front-end, the transmitter must increase its spectral purity to ensure that no spectral component from the transmit signal falls into an adjacent receive channel.

Overall system performance is determined by the minimum usable frequency offset between a transmit channel and a receive channel with a given decoupling between a receiver and a transmitter operating a given output power.

This so-called co-site situation directly influences the specifications, for example, adjacent channel power ratio for the radio communication equipment. Within a particular frequency band and its typical applications, the operating parameters may lead to a different transceiver architecture when compared to different applications in other frequency bands. Consequently, a transceiver for a 5G mobile phone base station, for example, may look completely different than a mobile phone base station designed to operate in the high frequency (HF), very high frequency (VHF) or ultra-high frequency (UHF) band.

While the best architecture for communication equipment in a particular frequency band may vary slightly, for simplicity we focus only on systems below 600 MHz.

## DERIVATION OF KEY PARAMETERS FOR SPECIFICATIONS

The transceiver RF design is directly driven by some key parameters whose values and ranges strongly influence the required circuits and the concepts for major building blocks designed to meet system requirements. Therefore, it is highly recommended to define the worst-case system scenario concerning RF power levels and frequency offsets and derive the key parameters from this setup (see ***Figure 1***).

It is reasonable to assume that such a system is built up by using several transceivers of the same type that are operated either in a receive or transmit mode. This allows system performance to be enhanced by optimizing the receive and transmit paths as parts of a common transceiver RF architecture.

## SPECIFICATIONS FOR A HIGH-END TRANSCEIVER

The data in ***Tables 1*** and ***2*** is based on the use of very robust input stages necessary to enable operation in a highly contested environment. These input stages use filters and amplifiers in a cascaded configuration where some elements can be bypassed. Consequently, the total receiver noise figure (NF) with all filters active is on the order of 10 dB, typically 4 to 6 dB higher than usually expected. In situations where no strong interferers are present, some co-site filters can be bypassed and additional high gain amplifiers can be activated, which leads to noise factors on the order of 4 dB or less.[1]

## WHAT ABOUT RECEIVER INTERMODULATION?

The specifications in Tables 1 and 2 do not show values for receiver intermodulation because in a co-located environment, all interferers that may cause intermodulation products within receiver front-ends are those radiated from transmitters at the same station. These transmitted signals are present at any other transmitter antenna and create so-called backward intermodulation products, which are then reradiated into the station.

These spurious signals appear at the same frequencies where receiver intermodulation signals would appear as well. This means that even with no receiver intermodulation effects at all within a radio station, operation on a frequency affected by transmitter backward intermodulation is not possible.

The designer of a receiver front-end can set the intermodulation performance of the front-end to reasonable values by hiding the expected receiver intermodulation products behind those generated by the transmitters. Consequently, the operational system limit of the radio station is not limited anymore by the receiver intermodulation performance, but by cross-modulation.

Cross-modulation is a critical effect in communication systems with waveform amplitude changes or amplitude modulation (AM). This is the case, for example, in systems used for air traffic control because the communication waveform used is a double-sideband AM signal.

Cross-modulation occurs when a strong interferer drives the front-end into saturation. If an amplifier is saturated, its gain is reduced and any other low-level signal passing through the amplifier at the same time also sees some reduction of gain. As a result, the low-level signal is inversely modulated by those parts of the interferer's envelope that saturate the front-end.

An air traffic controller operating on a voice channel cross-modulated by another communication channel will not be able to communicate with pilots. Even a very high receive level will not help in this situation. It is therefore essential that all interferers are kept below the cross-modulation threshold of a receiver system to keep it within an area of linear operation. Below this limit, the quality of the reception is determined by key parameters of the re-

**TABLE 1**

**HIGH-END TRANSCEIVER SPECIFICATIONS FREQUENCY RANGE 1.5 TO 88 MHZ**

| | |
|---|---|
| Max. NF of Rx without Interferer with Pre-amp On – All Modes | 10 dB |
| Transmitter Output Power | 150 W peak envelope power |
| Tx Sideband Noise Below 30 MHz | -150 dBc/Hz at 10 kHz |
| Tx Sideband Noise Below 30 MHz | -180 dBc/Hz at 10 percent |
| Max. Interferer Level at Rx Below 30 MHz | +27 dBm at ≥ 100 kHz |
| Total Transmitter/Receiver Decoupling | 25 dB |
| Max. NF of Rx with Interferer with Pre-Amp Off, for Narrowband and Wideband Modes | 51 dB for Interferer with +27 dBm at ≥ 10 kHz<br>21 dB for Interferer with +27 dBm at ≥ 10 percent |

**TABLE 2**

**HIGH-END TRANSCEIVER SPECIFICATIONS FREQUENCY RANGE 118 TO 600 MHZ**

| | |
|---|---|
| Max. NF of Rx without Interferer with Pre-amp On<br>– All Modes Without Interferers<br>– All Modes With Interferers | 4 dB<br>10 dB |
| Transmitter Output Power | 200 W peak envelope power, 100 W CW |
| Tx Sideband Noise 225 to 400 MHz | -135 dBc/Hz at 100 kHz |
| Tx Sideband Noise 225 to 400 MHz | -180 dBc/Hz at 10 percent |
| Max. Interferer Level at Rx | +17 dBm at ≥ 10 percent |
| Total Transmitter/Receiver Decoupling | 36 dB |
| Max. NF of Rx with Interferer for All Modes | 13 dB for an Interferer with +17 dBm at ≥ 10 percent |

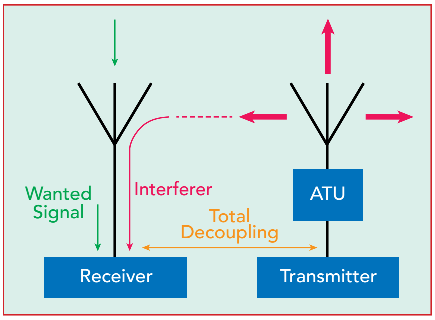


Fig. 1 **Co-location scenario for a transceiver.**

ceiver and those transmitters acting as interferers.

With additional frequency planning, operation on channels blocked by intermodulation products is avoided and the entire station can operate nearly free of self-created interference.

## STARTING WITH THE TRANSMITTER RF CHAIN

The transmitter RF design can be simply seen as an RF signal generator with some following amplifiers that increase the low signal level of the generator to the required high output power at the antenna.

A high-end transmitter is characterized by very low unwanted emissions outside the transmit channel. These unwanted emissions are either discrete signals or are represented by a noise floor. Discrete spurs can be caused by a variety of effects, such as the internal coupling of clock signals into the RF path. Other effects that can create discrete spurs may be based on nonlinearities in the transmit path, mainly within the final power amplifier (PA).

Before the minimization of discrete spurs, the basic transmitter design must first provide a low noise floor; otherwise, the radiated unwanted noise may already significantly interfere with adjacent channels.

The unwanted noise floor can be divided into two areas, which also represent two different noise-creating mechanisms. Close to the carrier noise is normally called phase noise and far from the carrier noise is called broadband noise. While phase noise is determined by the quality of the RF generator, the broadband noise floor is mainly determined by the design of the amplifier chain after the RF generator.

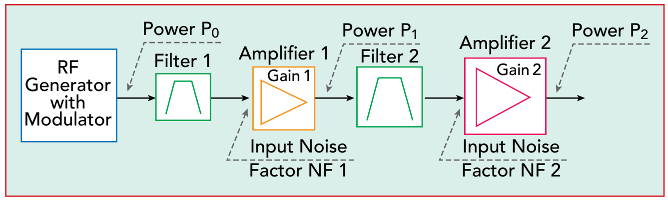


Fig. 2 **Improved transmitter RF path.**

For a high-end transmitter, the required broadband noise floor might be required to be so low that even with a "no noise RF generator," the resulting noise floor after the amplifiers may be too high. This means that a significant improvement can only be achieved by inserting filters in the RF path. The optimization of this filter-amplifier chain must then be done by going backward from the antenna through all stages and analyzing the gain of each amplifier stage.

***Figure 2*** shows a RF path improved by inserting two bandpass filters in front of each of the transmit amplifiers. The minimum broadband noise floor at the output of the transmitter is mainly the noise at the input of Amplifier 2 that is increased by its gain.

For a first optimization, the elements within the RF path can be seen as ideal, e.g. the filters have no insertion loss and the amplifiers only have a NF plus a flat frequency response with a given gain. It is also assumed that a filter in front of an amplifier completely suppresses all broadband noise coming from previous stages. With this simplification, it is clear that the broadband noise floor after the final amplifier is just the input noise floor represented by the amplifier's NF, which is then increased by its gain.

While the output power of the RF generator inside the filters' passbands is increased by the amplifiers, the broadband noise floor outside the filters' passbands is first suppressed by the filters; then, a following amplifier just increases its input noise floor by its gain. Consequently, the output noise floor always remains quite low while output power increases with the total gain of the transmitter's RF path.

In ***Figure 3***, the dotted purple line shows the suppression of broadband noise by the filters, which is then increased by the gain of the following amplifiers. The defining parameters of broadband noise performance are the maximum allowed gains for each amplifier stage, which also define the power levels appearing at all filters.

It may be that the filter in front of the final PA must handle a power level of some Watts due to the quite low allowed maximum gain of the amplifier following it. Such a high-power filter may be difficult to realize, especially because it must be tunable in frequency as well.

On the receiver side, a similar

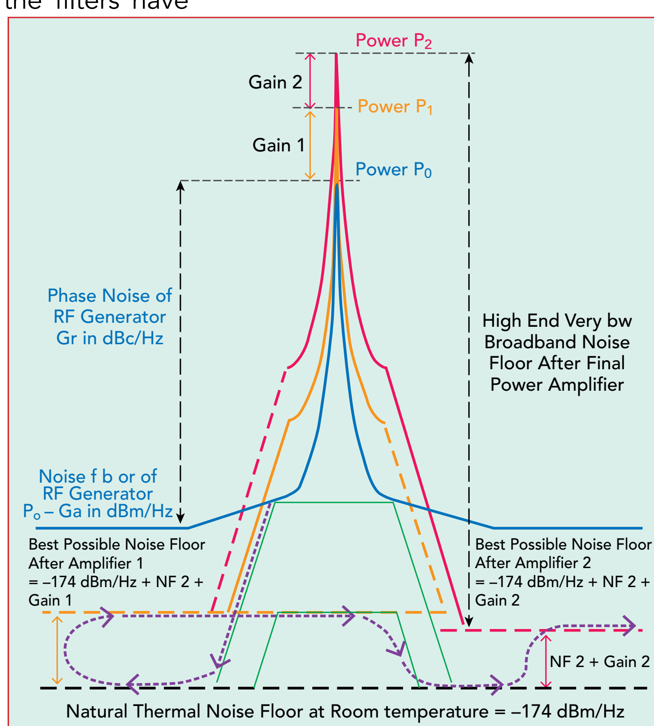


Fig. 3 **Spectrum of the improved transmitter RF path.**

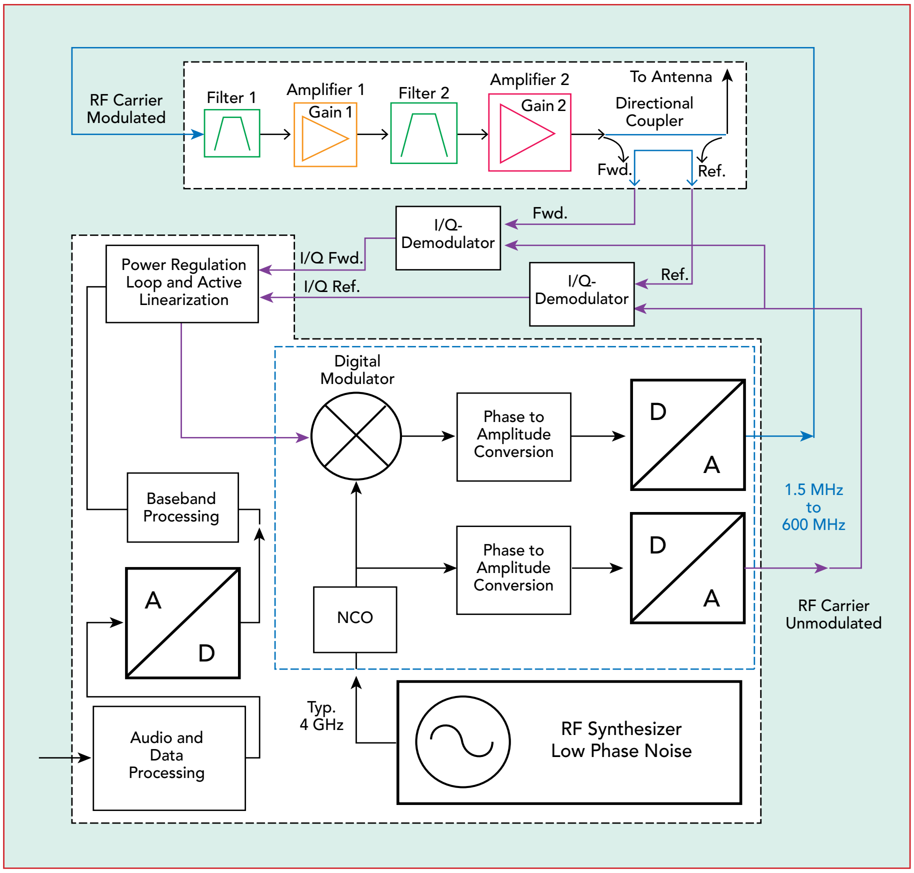


Fig. 4 Transceiver RF generator.

high-power filter may be required to ensure sufficient receiver performance in the presence of strong interferers. Therefore, the dual use of relevant resources like filters and other components for the receive and transmit paths should be considered during the process of optimizing the overall RF transceiver architecture.

## The RF Generator (Exciter) is the Heart of the Radio

The most important building block of a transceiver is the RF generator (see ***Figure 4***). It provides a low phase noise modulated RF signal that represents the complete transmit signal of the transceiver. It starts with a sufficiently high level, providing an already low broadband noise as a starting point to the following filter/amplifier chain of the transmit path. In receive, the unmodulated RF signal is either used as a local oscillator for superheterodyne receivers or is used as a clock signal for digital direct sampling receivers.[1]

Today it is technologically possible to realize the core part of the RF generator, represented by the box with the blue dotted lines in Figure 4, with a fully integrated solution. Even digital-to-analog converters (DACs) can be part of such a chip. Only some manufacturers currently provide fully integrated solutions, but with a split between purely RF functionality and the core direct digital synthesizer (DDS), a sufficiently higher number of components is available.

The information signal (e.g., voice or data) to be transmitted is filtered and adjusted in level and is then digitized. The digitized signal passes through a baseband processing stage that creates a digital I/Q signal stream representing the modulation, including filtering. This digital I/Q modulation information is complex multiplied with the digital unmodulated carrier signal from the numerically controlled oscillator (NCO). This fully I/Q modulated digital RF signal is then input to a DAC and appears at its output as an analog RF signal to be transmitted.

## Smart Power Control Loop

It is recommended to use a configuration for the RF generator where two parallel outputs are available, one with the modulated RF transmit signal, and one with the same, but still unmodulated, RF signal, derived from the same digital oscillator. This second unmodulated signal can be used to supply two feedback paths that provide phase-coherent demodulation of the RF signals present at the directional coupler after the final PA.

The signal from the forward output of the directional coupler can be used to set up a power regulation loop by monitoring the level of the transmit signal. This feedback signal can also be digitally compared with the transmitted signal to identify any signal distortions. A so-called active linearization loop is now able to pre-distort the transmit signal, compensating for all influences which happen on the way to the antenna through all stages.

The second feedback demodulator is connected to the reflected output of the same directional coupler and allows a highly capable analysis of all signals traveling from the antenna back to the final amplifier.

Due to the phase-coherent nature of the demodulation, it is now easy to distinguish between signals that are reflections of the transmit signal and those that have been radiated backward into the transmit antenna by other transmitters. Signals from other transmitters are characterized by a frequency offset when compared with the transmitted signal and can now be isolated. This enables an optimized strategy, keeping the transmit power constant or reducing it not any more than necessary, independent of the source of the reflected signals.[2]

## Always Design the PA for Good Linearity

The active linearization capability shown in Figure 4 is a regulation loop that can reduce the effects of nonlinearities from all elements between the RF generator and the antenna. It must be carefully designed with respect to its bandwidth; otherwise, it may increase the noise outside its bandwidth where broad-

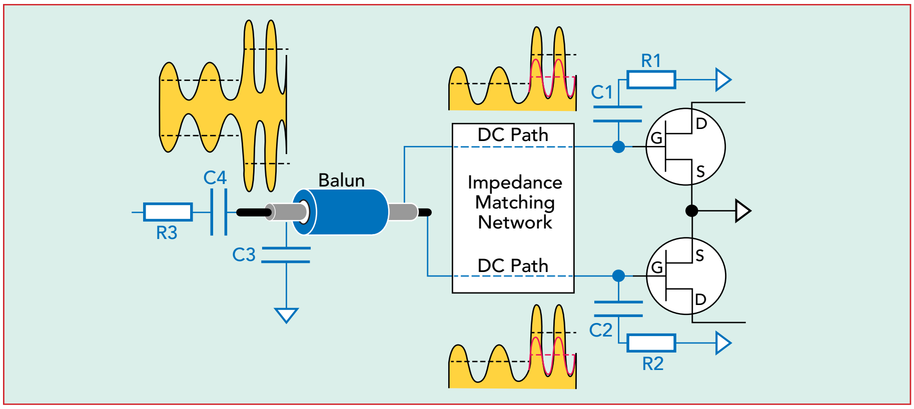


Fig. 5 **Input circuit limiting AM frequency response.**

band noise begins. Even with this capability in a transmit path, any amplifier should always be designed to provide good linearity.

Nonlinearities of amplifiers can be based on a variety of mechanisms and are often described with very complex formulas, but the practical view is much simpler. If, for example, a digitally modulated single carrier is used as a transmit signal, then linearity is just how fast and how accurately the output signal of an amplifier can follow the input signal in phase and amplitude.

The AM frequency response of an amplifier is a major parameter in the context of nonlinearities, and this AM frequency response is set and limited in most of the cases by the circuitry of the input stages, not by the transistor. For a Class AB amplifier, the gate voltage may increase with an increasing RF drive signal, which opens the transistor for a higher output power. This leads to a dynamic shift of bias voltage toward Class A. It is important that the average DC bias voltage at the gates follow the average level of the drive signal fast enough; otherwise, the output power of the transistor cannot follow amplitude changes at the input fast enough. ***Figure 5*** shows a simplified schematic of a push-pull amplifier, which may limit its AM frequency response.

The incoming RF signal is changed from unsymmetric to symmetric by the balanced-to-unbalanced (BALUN) circuit. Relative to GND, one transistor is driven with the positive half of the RF carrier sinewave, while the second transistor is driven with the negative half, and vice versa.

The envelope of the modulation signal represents the level of the RF carrier and should look identical on both gates. The average instantaneous level of the envelope is responsible for opening the gate to the required source gate voltage (shown as dotted lines in Figure 5).

The elements C1/C2 and R1/R2 set a lowpass characteristic. If the time constants are set too low, then the average DC voltage of fast modulation peaks cannot follow these fast changes in the envelope. Consequently, the gates are supplied with gate voltages that are too low (shown as red dotted lines) during fast modulation periods while the RF envelope is reaching full amplitude.

This leads to the suppression of fast amplitude signal changes, which looks like amplifier saturation. This mechanism creates almost the same intermodulation distortion as a saturated amplifier, but it is simply caused by a bandwidth limitation of the DC paths within the input circuits of the PA.

It is therefore recommended to first optimize the AM frequency response of a PA according to the required bandwidth of the transmitted signal and use the feedback loop only for further optimization of the remaining nonlinear behavior, if necessary.

It is a good choice to design an amplifier for an AM/FM frequency bandwidth response that is at least 2x or 3x higher than the highest modulation frequency of the signal to be transmitted. For an HF amplifier operating an SSB Voice signal, the AM frequency response shall be at least at 6 to 9 kHz. This method of improving amplifier linearity is easy to achieve and is easily validated because only an AM-modulated signal is required for testing.

In a push-pull configuration, it is also important that the gates of both transistors see identical circuits. Within Figure 5, a DC path through the matching network connects the gates to both capacitors C3 and C4. These capacitors likely have different values because they have been selected based on different goals. Additionally, C4 is connected to a series impedance, while C3 is directly connected to GND. As a result, AM frequency responses at the two gates may be different due to different capacitive loads, which leads to unequal transistor drives.

With a good design for the PA in combination with linearization, the following two-tone intermodulation values can be expected if the transmitter is driven with a two-tone signal level 6 dB below peak envelop power for each tone. The IM3 values represent the difference between the intermodulation products and the two tones:

- IM3 ≥ 30 dB – basic linearity
- IM3 ≥ 40 dB – enhanced linearity using digital predistortion
- IM3 ≥ 45 dB – superior linearity using digital active linearization.

On the receive side, an HF receiver (whether using direct sampling or intermediate frequency (IF) sampling) may be used as an IF receiver after a VHF/UHF down-converter as part of an overall superheterodyne concept.

Splitting into sub-bands makes sense for components close to the antenna. However, for an RF generator, it is possible today to create highly linear signals with low phase noise up to very high frequencies, where a split into sub-bands does not provide any advantage.

## CONCLUSION

A transceiver architecture comprises circuits for transmit and receive that can be completely independent of each other. An important step in optimization, however, is to harmonize key parameters of the transmit path with those of the receive path for best system performance where these functions are co-located with

Fig. 6 **High-end configurable V/UHF software-defined radio (SDR).**

low antenna decoupling.

It should be a goal for the designer that the robustness of the receiver is matched to the noise performance of the transmitter with a given antenna decoupling. The harmonization of the receive path with the transmit path within a transceiver architecture is then the basis for sharing valuable resources.

These shared resources may be high-quality filters that act as preselectors for the receive path or as co-site filters to reduce the noise of the transmit path. Another sharable resource is a low noise signal generator providing a clean signal in transmit that is also used as a clean sampling or mixing signal in receive for best desensitization performance.[1]

For high-end installations, such as military communication sites, radios can be adapted to the co-site situation (see ***Figure 6***). These radios can be equipped with special co-site options like hopping filters. Co-site filters are not only used as pre-selectors for enhanced receiver robustness, but they are also reused as bandpass filters within the transmit chain.

The co-site filters are active in all operational modes including fast frequency hopping modes, ensuring a highly robust communication link, even in the presence of intentional jamming. The RF specifications enable interference-free operation in complex antenna systems with antenna decoupling values as low as 25 dB.

Transmitters can additionally be equipped with optional circulators to reduce transmitter backward intermodulation effects and, in combination with a frequency planning, spurious-free operation can be achieved. ■

## ACKNOWLEDGMENT

We thank Ludger Korsmeier, Manfred Fleischmann, Robert Traeger and Harald Wickenhäuser DK1OP (all Rohde & Schwarz) for their support during the creation of this article.

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# Stacking Interdigital Filters Using Multi-Mix® Technology

James Logothetis and Kevin Spencer
*Crane Aerospace & Electronics, West Caldwell, N.J.*

Filters are routinely used in microwave frequency converter modules to channelize signals. Since most applications require multiple filters, size becomes a critical design parameter, particularly for filters in the L- and S-Band range where printed filters are desirable but can be large and can quickly use up the available area within a module. Interdigital filters are a good choice due to the topology's inherent size efficiency, but to significantly reduce filter area, a method of stacking filters is also needed. This article presents a strategy using Multi-Mix® technology for stacking filters in a common footprint, enabling optimal size reduction in converter modules. Multi-Mix® is a patented technology developed at the Merrimac Industries location of Crane Aerospace & Electronics.

## INTERDIGITAL FILTERS

The interdigital filter topology is compact, making it useful to reduce filter size at low microwave frequencies. Small size is the benefit, but there are significant tradeoffs with ease of implementation and sensitivity to resonator grounding. The typical implementation of a printed interdigital filter uses plated through via holes or plated through slots to ground the resonators. The associated reactance of the grounding geometry detunes the filter from the synthesized dimensions, but this can be overcome by using available analysis software to optimize performance and overdesign the bandwidth and selectivity for variations in dielectric constant ($\varepsilon_r$), substrate thickness and etching tolerance.

Using a filter synthesis tool, an initial model can be generated that includes the representative Q of materials. This is where the overdesign begins so that real-world variations can be absorbed into an approach that requires no tuning. A wider passband must be incorporated into the design to allow for a shift in center frequency and about 10 dB of additional close-in rejection should be built into the selectivity of the model by choosing a filter of sufficient order. A representative schematic is shown in ***Figure 1a*** for an optimized model of an interdigital filter.

Optimization of the initial synthesis model is always required due to the representative features of resonator grounding. The corresponding frequency response of the optimized model is shown in ***Figure 1b***. The layout generated by the model is used to build the physical 3D electromagnetic (EM) model of the interdigital filter.

***Figure 2a*** shows a typical HFSS model representation of an interdigital filter. In the illustration, multiple filters are shown in the multilayer, fusion-bonded stripline module, but the initial EM modeling should be isolated to a single filter to capture the variation with dielectric constant, ground plane

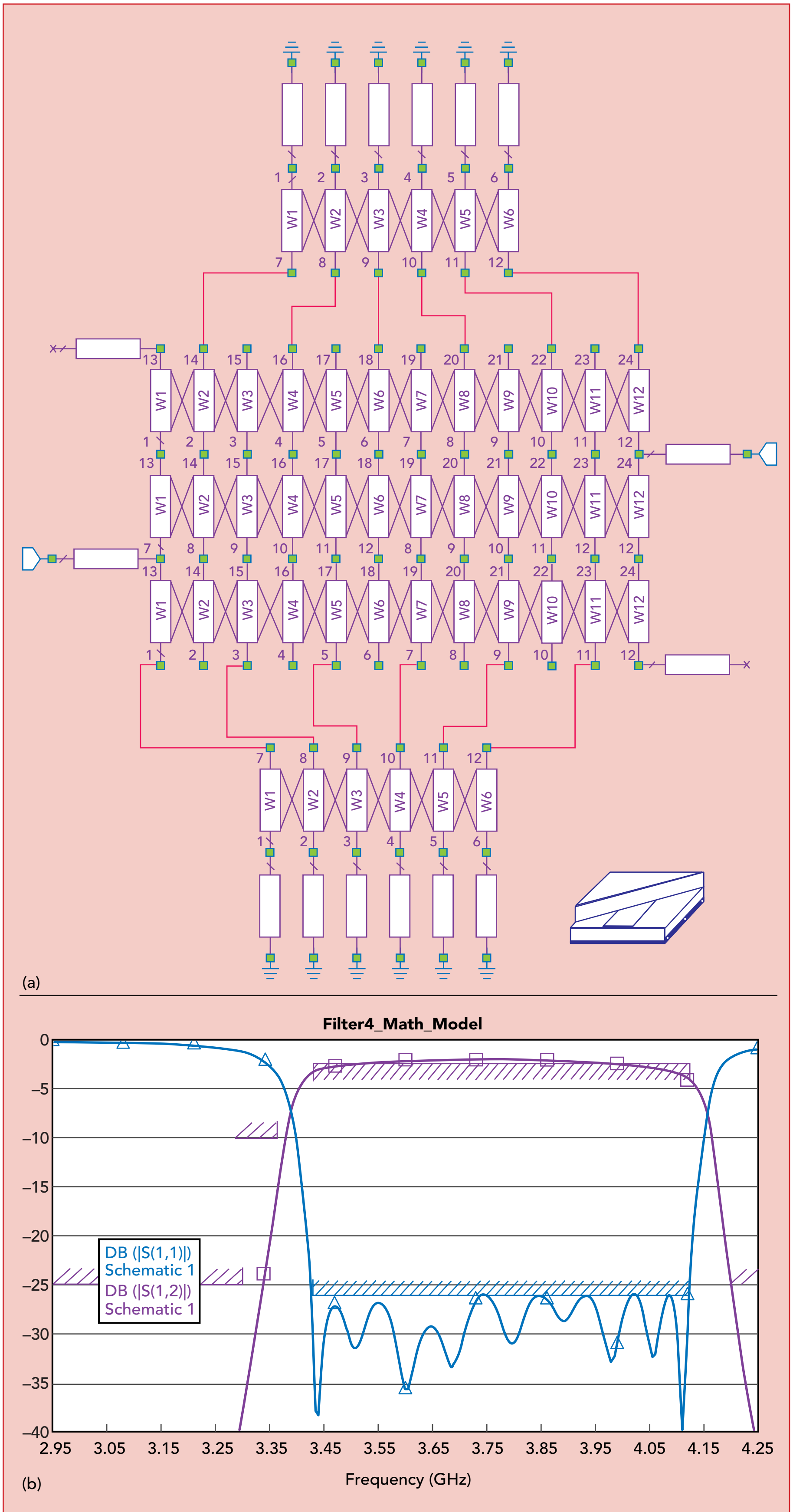


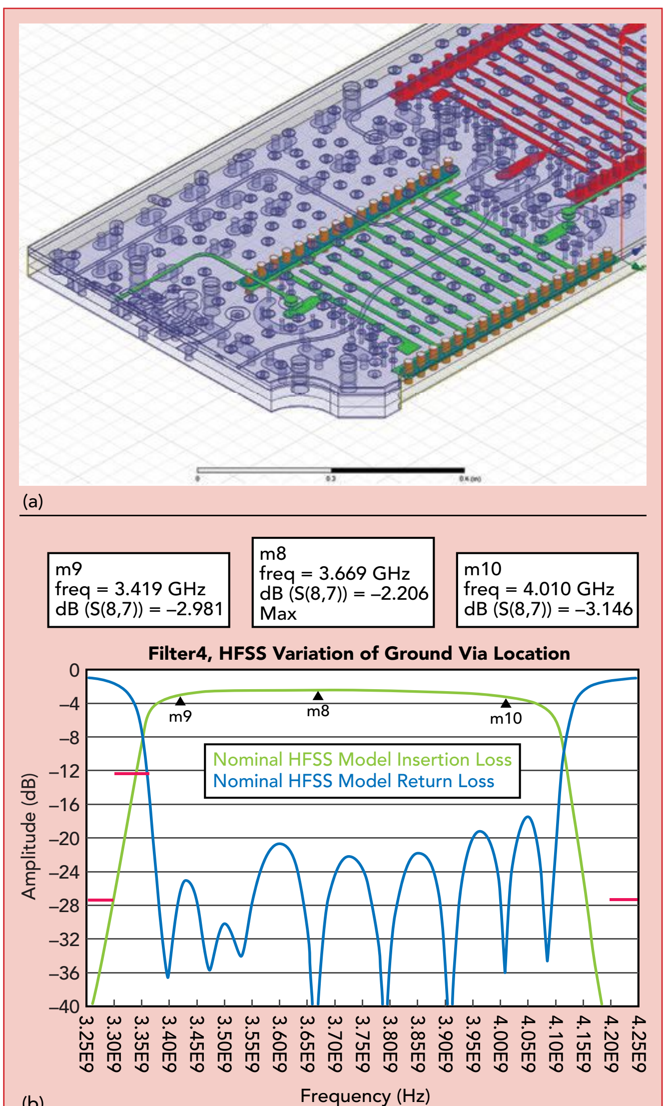

**Fig. 1** (a) Schematic of an optimized model for an interdigital filter. (b) Frequency response of an optimized model for an interdigital filter.

spacing and etching tolerance of resonator line widths and gaps. The corresponding nominal frequency response of the EM model is also shown in ***Figure 2b***.

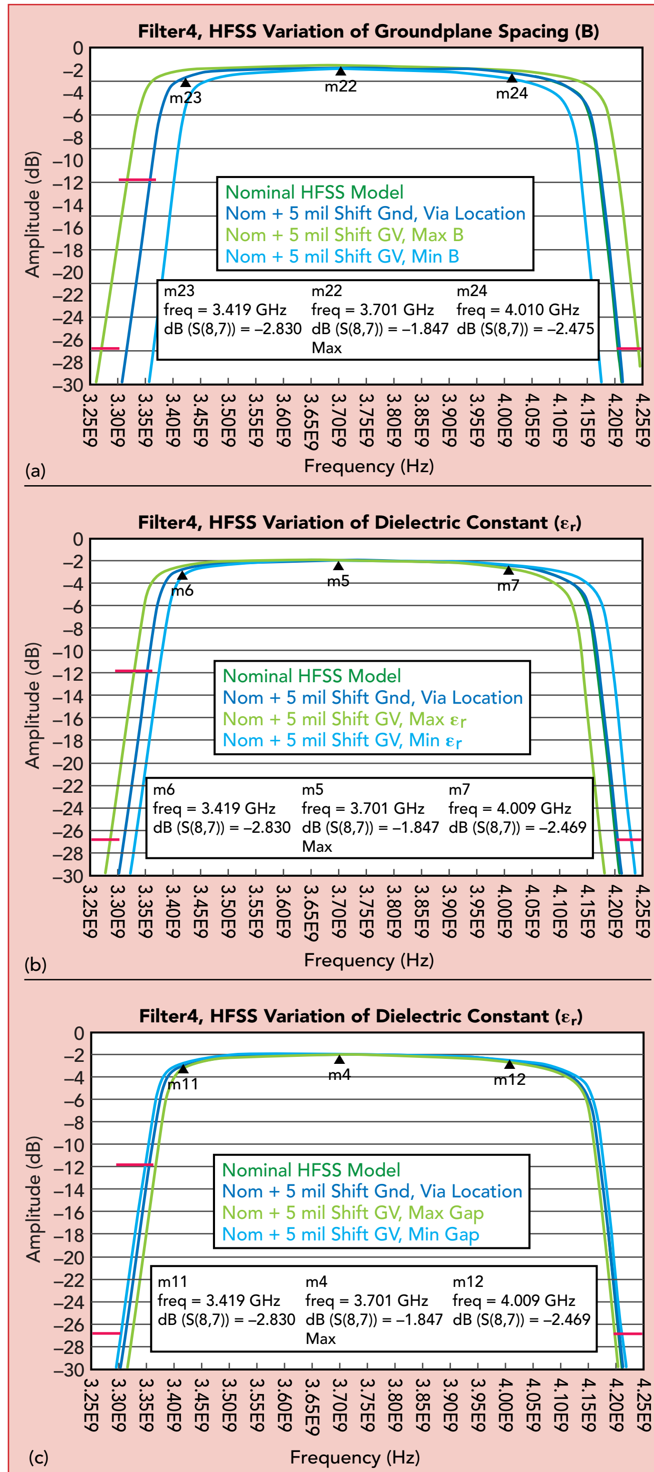
The EM model can be used to bracket the worst-case performance variation so that it can be determined if the effects of material and manufacturing tolerance can be absorbed, or if they need to be mitigated. ***Figure 3a*** shows the passband response of the 3D EM model with ground plane spacing due to the dielectric material thickness tolerance (B = 0.060 ± 0.003 in.) ***Figure 3b*** shows the effects of substrate material dielectric constant tolerance ($\varepsilon_r$ = 3 ± 0.04) and ***Figure 3c*** shows the etching tolerance of resonator line width and gap dimensions due to manufacturing processes (± 0.0005 in.). The performance variation due to dielectric material thickness affects the ground plane spacing and consequently, bandwidth. This variation is usually too extreme to be absorbed into a no-tune design. The dielectric thickness tolerance of laminate material ranges from ± 0.001 to ± 0.003 in. A typical tolerance of ± 0.0015 in. produces a substantial change in bandwidth as a thicker ground plane spacing widens the band and a thinner ground plane spacing narrows the band. Usually, the close-in rejection requirements cannot tolerate this variation, so the mitigation is accomplished by measuring and selecting layers by thickness within a tighter tolerance.

Several different circuits may be required to match the material availability, but the layer thickness should be specified and measured before fabrication. The performance variation, due to material dielectric constant, is usually absorbed into a design at lower microwave frequencies in L- and S-Bands. If this variational parameter requires mitigation for higher frequency designs or tighter frequency tolerances, there are two options. The dielectric constant for a given material lot is very consistent, so the baseline design for $\varepsilon_r$ = 3 can be run for each new material lot and if required, the circuit may be iterated to compensate for a particular lot. Alternately, several designs can be included on a panel array with resonators slightly longer and shorter to coincide with the increase or decrease in center frequency due to the variation in $\varepsilon_r$. This ensures there will always be some yield for this test panel. For that lot of material, this procedure will identify the best circuit to use for the balance of the filter production. The performance variation due to the etching tolerance of resonator line width and gap dimensions is small for a 0.0005 in. tolerance, so that variation is usually absorbed into the design.

The greatest challenge in fabricating a printed interdigital filter is in the drill-to-pattern registration. The typical manifestation of this variation is an axial shift of the via hole pattern that grounds the resonators. The shift is in one direction along the centerline of the resonators of the printed filter pattern. A visualization of this phenomenon can be seen in the HFSS model of Figure 2a, where the ground vias all shift in the minus X direction. In this case, the interdigital resonators get longer on one side of the filter and shorter on the other side. This shift, alternating between longer and shorter, causes a VSWR hump in the middle of the band. The effect of the axial via shift is shown in the amplitude versus frequency response of ***Figure 4a*** and the return loss versus frequency response of ***Figure 4b***. The effect is more sensitive than most analysis software will predict. For example, depending on the specific filter character-




▲ Fig. 2 (a) Physical 3D interdigital filter electromagnetic model. (b) Frequency response of the interdigital filter EM model.




▲ Fig. 3 (a) Passband response of the 3D EM model showing variation due to ground plane spacing. (b) Passband response of the 3D EM model showing variation due to dielectric constant. (c) Passband response of the 3D EM model showing variation due to etching tolerance.

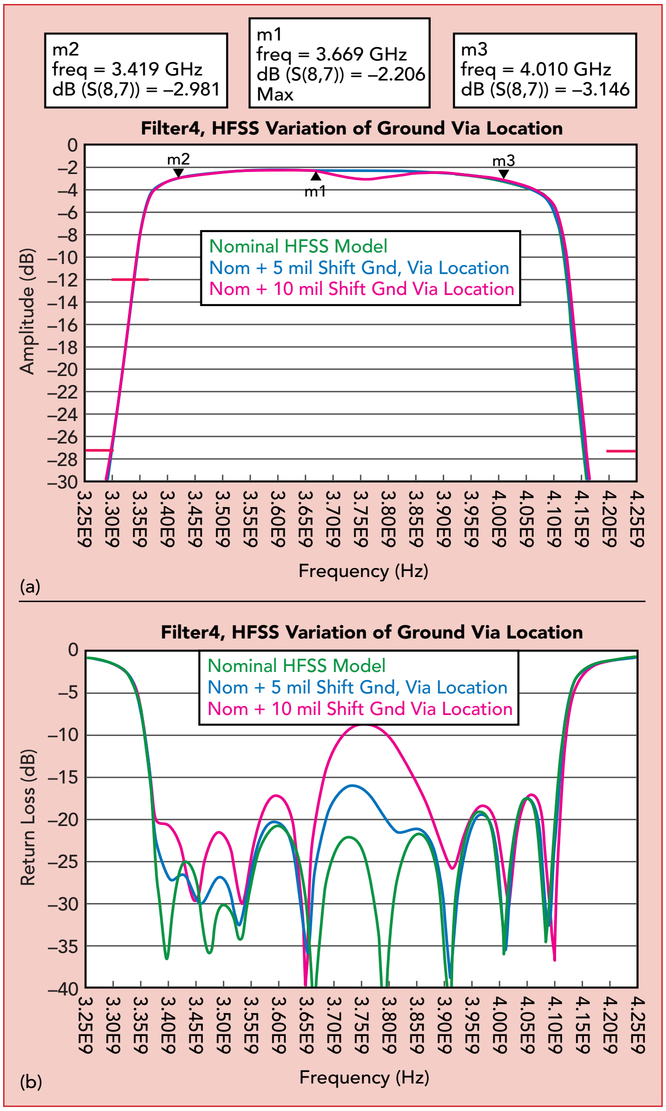



**Fig. 4** **(a) HFSS model showing the effect of axially shifted ground vias on amplitude. (b) HFSS model showing the effect of axially shifted ground vias on return loss.**

istics (order, frequency, bandwidth, etc.), the magnitude of the VSWR effect shown in Figure 4a for a 0.010 in. axial shift in ground vias will more likely occur at a much smaller value of axial shift. A good goal is to keep drill-to-pattern variation within 0.002 in. Fortunately, direct imaging technology can be used to register each filter image in the array to be aligned to the actual via pattern that is drilled and plated on the substrate panel.

## STACKED FILTERS

Stripline interdigital filters can be implemented as a fusion-bonded assembly of etched circuits with plated through holes, edge-plated (wrapped) grounding and surface-mount interface connections. The fusion bonding process for stacked filters begins with commercially available PTFE composite, copper-clad laminate material having inherently low dielectric loss and stable microwave properties. A low z-axis coefficient of thermal expansion (CTE), close to that of copper, ensures the reliability of plated through holes, along with blind and buried vias. Further, a low and uniform thermal coefficient of dielectric constant, coupled with the low CTE, results in consistent electrical performance over a wide operating temperature range. Stripline filter circuit patterns and transmission line geometries are chemically photo etched on the copper, maintaining dimensional tolerances of ± 0.0005. Layer-to-layer plated through holes (blind and buried vias) are realized with a minimum diameter of 0.005 in. Properly sized and spaced blind and buried vias are used throughout the layers to create matched impedance structures that connect between layers and through interstitial ground planes. These vias also isolate lines and filter structures within a ground plane. The ability to achieve a high degree of isolation within a given layer allows further size reduction and the elimination of unwanted resonances. Fusion bonding is accomplished by stacking the panels of the arrayed filter layers in a fixture. Carefully controlled, uniform pressure and temperature are applied to this fixture to meet the substrate fusion bonding requirements. After fusion bonding, the stacked filters are edge-plated with copper for EMI shielding and ground plane integrity and then finished with annealed matte tin, tin/lead or nickel/gold, depending on the application.

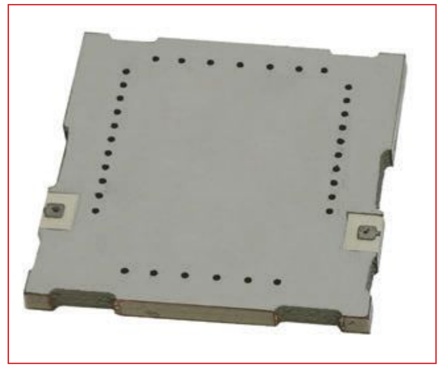
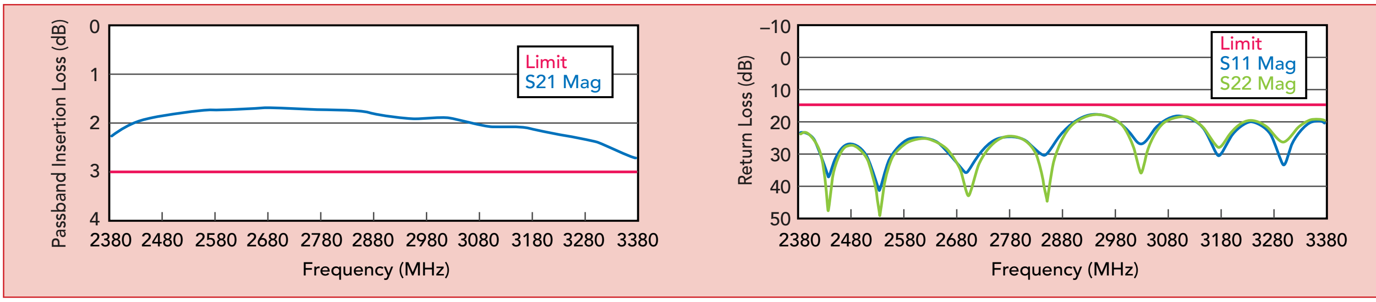


**Fig. 5** **2.9 GHz fusion-bonded, surface-mount filter.**

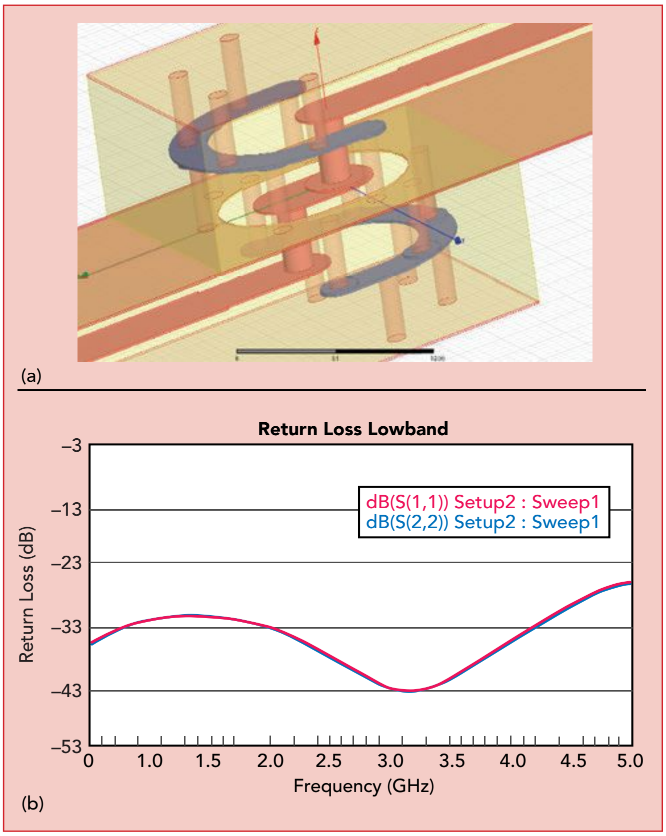
The operating frequency range of this stacking strategy has been demonstrated from Very High Frequency through Ka-Band, but an essential element of the strategy that allows for success is EM modeling. EM modeling of the full filter layout is important since there will be no opportunity to tune the bonded assembly. To accurately predict the expected performance, the full filter model should also be evaluated in its final form, mounted to a parent board as it would be in the integrated module assembly. A photo of an actual 2.9 GHz fusion-bonded filter is shown in ***Figure 5*** with outline dimensions of 0.75 × 0.75 × 0.07 in. Test data for this filter is plotted in ***Figure 6***, showing less than 3 dB of insertion loss and greater than 15 dB of return loss over a 1 GHz bandwidth.

Utilizing a fusion-bonded approach, a single-layer filter is easily extended to a stacked configuration using EM software to model the layer transitions and fusion bonding to implement the via-to-via interconnections. In this case, the port connections of the upper filter are required to transition through an interstitial ground plane to realize the surface-mount footprint. An HFSS model of this transition geometry is shown in ***Figure 7***, along with the return loss of this transition.

The full HFSS model of a stacked filter architecture in S-Band is shown in ***Figure 8***. For this model, the two stacked filters occupy the same surface area as the single filter. A photo of this stacked filter is shown in ***Figure***




▲ **Fig. 6** **Test data for the 2.9 GHz fusion-bonded, surface-mount filter.**

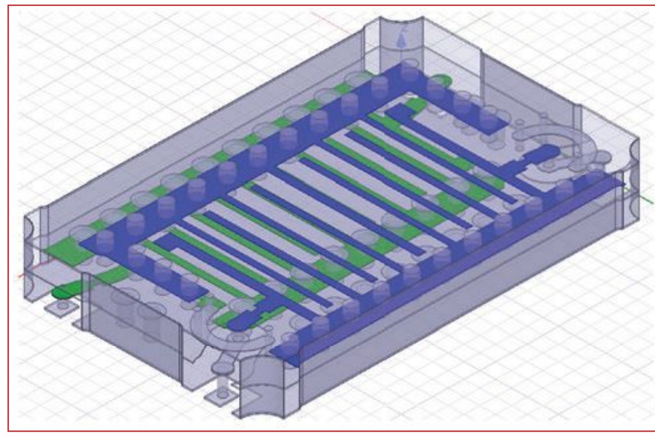



▲ **Fig. 7** **HFSS model of an internal via transition through an interstitial ground plane.**

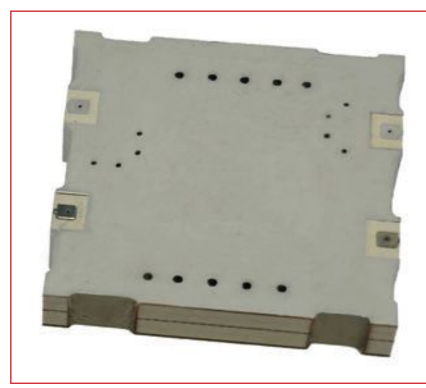
***9***. The outline dimensions of the filter are 0.75 × 0.75 × 0.13 in. Similarly, this approach can be used to stack up to four filters in the same surface area.

## STACKED, SWITCHED FILTERS

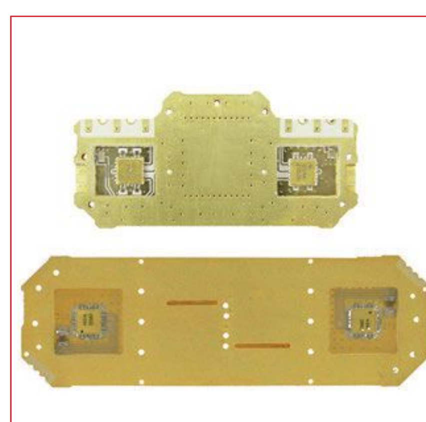
Stacked filters greatly reduce the area required for RF filtering in frequency converters and other integrated microwave modules. For applications requiring switched filters, the stacked filter component can be mounted to the parent board of the integrated microwave module to interface with the switches that are also contained within the module. An alternate approach is to integrate the switches within the stacked filters. In this case, the switches and associated circuitry are mounted inside or on top of the stacked filter component. Several fusion-bonded switched filter banks have been fabricated as six-layer and 12-layer designs in L-, S- and C-Bands. ***Figure 10*** shows two different switched filter banks using four filters. In these realizations, the input and output SP4T switches are mounted internally within the stacked filter component. The outline dimensions of the switched filter banks shown are 1.0 × 2.0 × 0.31 in. and 0.9 × 2.6 × 0.15 in. Another fabricated C-Band switched filter bank measured 0.8 × 1.1 × 0.15 in. Test data is shown for two different stacked switched filter banks in ***Figure 11***. This stacked switched filter approach has been extended to banks of as many as eight filters as shown in the 3D EM model of ***Figure 12a*** with the measured results shown in ***Figure 12b***. This approach has been used in multiplexers with as many as 12 channels.



▲ **Fig. 8** **HFSS model showing the internal structure of a stacked fusion-bonded surface-mount filter.**



▲ **Fig. 9** **Stacked fusion-bonded surface-mount filter.**



▲ **Fig. 10** **Stacked fusion-bonded switched filter banks with four filters.**

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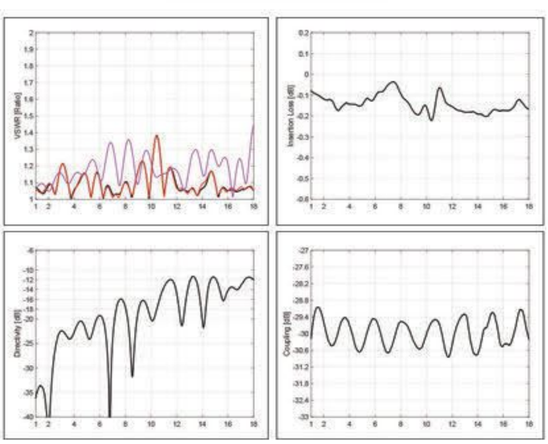

| Freq. Range (GHz) | P/N | Coupling Max.(dB) | Main Line VSWR Max.(:1) | Coupling VSWR Max.(:1) | Insertion Loss* Max.(dB) | Flatness Max.(dB) | Directivity Min.(dB) | Power Max.(W) | Unit Price** (USD) |
|---|---|---|---|---|---|---|---|---|---|
| 0.3-6 | D3012H003060 | 30±0.9 | 1.4 | 1.4 | 0.6 | ±1.2 | 15 | 600 | 1,678 |
| | D4012H003060 | 40±1.0 | 1.4 | 1.4 | 0.6 | ±1.3 | 15 | 600 | 1,678 |
| 0.5-6 | D3012H005060 | 30±0.7 | 1.3 | 1.3 | 0.4 | ±1.0 | 15 | 600 | 1,175 |
| | D4012H005060 | 40±0.8 | 1.3 | 1.3 | 0.4 | ±1.1 | 15 | 600 | 1,175 |
| 0.5-18 | D3008H005180 | 30±1.2 | 1.5 | 1.6 | 1.0 | ±1.2 | 10 | 400 | 3,362 |
| | D4008H005180 | 40±1.2 | 1.5 | 1.6 | 1.0 | ±1.4 | 10 | 400 | 3,362 |
| 0.7-8 | D3012H007080 | 30±0.8 | 1.4 | 1.4 | 0.5 | ±1.0 | 14 | 600 | 1,265 |
| | D4012H007080 | 40±0.8 | 1.4 | 1.4 | 0.5 | ±1.0 | 14 | 600 | 1,265 |
| 1-8 | D3012H010080 | 30±0.8 | 1.4 | 1.4 | 0.4 | ±0.9 | 14 | 600 | 1,076 |
| | D4012H010080 | 40±0.8 | 1.4 | 1.4 | 0.4 | ±0.9 | 14 | 600 | 1,076 |
| 1-18 | D3008H010180 | 30±1.2 | 1.5 | 1.6 | 0.6 | ±1.0 | 10 | 400 | 2,475 |
| | D4008H010180 | 40±1.2 | 1.5 | 1.6 | 0.6 | ±1.0 | 10 | 400 | 2,475 |
| 2-18 | D3008H020180 | 30±1.0 | 1.5 | 1.6 | 0.6 | ±0.8 | 10 | 400 | 2,178 |
| | D4008H020180 | 40±1.0 | 1.5 | 1.6 | 0.6 | ±0.8 | 10 | 400 | 2,178 |
| 6-18 | D3008H060180 | 30±1.0 | 1.5 | 1.6 | 0.5 | ±0.7 | 10 | 400 | 928 |
| | D4008H060180 | 40±1.0 | 1.5 | 1.6 | 0.5 | ±0.7 | 10 | 400 | 928 |

* Theoretical I.L. Included
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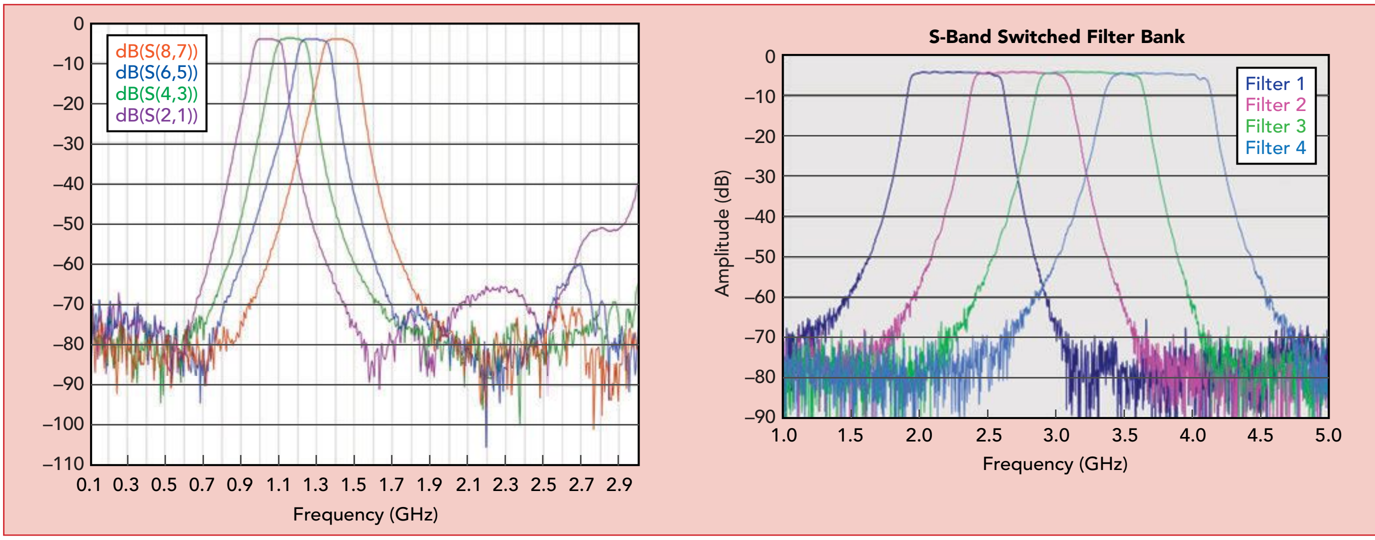
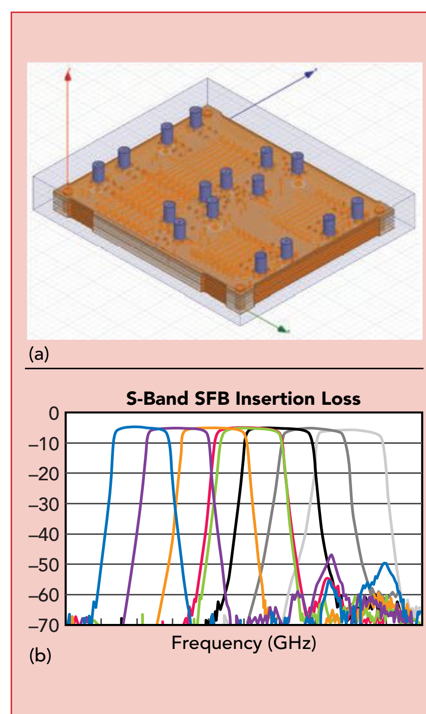



▲ Fig. 11 Four filter stacked fusion-bonded switched filter banks data.

## CONCLUSION

This article has demonstrated a stacking strategy for interdigital filters using a fusion bonding approach that enables size reduction in a common footprint. The examples show how fusion bonding facilitates the interconnections of the inner structure, providing a homogeneous component. Since temperature-stable materials are used in this process, the performance of the resulting components is also stable over temperature extremes and able to withstand the rigors of MIL-STD screening. Several of the filter examples have been qualified for both airborne and space applications. Multi-Mix® is being used in many applications to integrate filters along with various functional components within multilayer microwave assemblies. Multi-Mix® technology has proven attractive because of size and weight reduction, power handling and superior electrical and reliability performance and devices using this technology have been space-qualified on multiple programs. The examples in this article demonstrate the ability of Multi-Mix® technology to be used as a differentiator allowing designers greater flexibility for integration. ■






▲ Fig. 12 (a) 3D EM model of stacked fusion-bonded switched filter bank with eight filters. (b) Measured results of stacked fusion-bonded switched filter bank with eight filters.

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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.

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5 December 2023 (Tuesday)
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**PAPER DISPOSITION**

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**IMS2024 will feature a variety of important thematic areas that highlight the symposium's focus on "capitalizing across the spectrum." In addition to showcasing a broad spectrum of engaging technical topics, IMS2024 will celebrate the diversity of contributions, talents, and accomplishments across our society's "human spectrum" throughout the week. Moreover, the major technical themes of the conference will emphasize the role our host city of Washington D.C. has played in supporting the use and management of the RF-to-THz spectrum, including:**

## Systems & Applications

The development of RF, microwave, mm-wave and THz systems continues to expand in several areas, with many application examples. This broad theme encompasses design from device and module through to the overall system and applications. Particular areas of focus of IMS2024 will be:

- Radar Systems and Phased Arrays,
- Communications, including 6-and Future-G developments,
- RF and microwave system-on-chip integration,
- Applications of High-Power Microwave Systems

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This theme includes use of the electromagnetic spectrum for defense and security as well as air and space-based applications, including secure communications, navigation, remote sensing, design for reliability, radiation hardness, LEO Sat systems, and CubeSats.

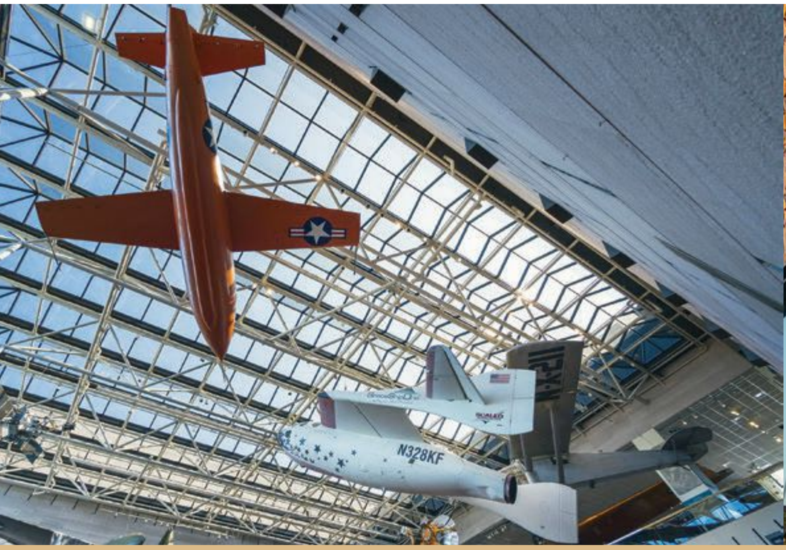
## Spectrum CubeSats Coexistence and Sustainability

Access to the RF-to-THz spectrum has become paramount with the rapid advance of wireless technology and applications. Topics in this area include techniques and technologies for spectrum sharing and coexistence between active and passive users, interference mitigation, spectrum monitoring and metrology, energy efficiency and sustainability.

## Emerging Technologies and Directions

Innovative and new contributions in AI/ML, quantum technologies, materials, terahertz systems and technologies that enhance security and enable spectrum access across our society.

**These technical themes will be aligned with different days of the conference, and will comprise special Focused Technical Paper Sessions, Panel Sessions, Invited Speakers, and Workshops.**

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TBD, *TMTT Special Issue Co-Editor*

*To view the full IMS2024 Steering Committee list visit ims-ieee.org.*

# Technical Paper Submission

**Authors are invited to submit technical papers describing original work and/or advanced practices on MHz through THz theory and technology. A double-blind review process will be used ensuring anonymity for both authors and reviewers. The Symposium proceedings will be archived electronically and submitted to IEEE Xplore.**

## Submission Instructions

- All submissions must be in English.
- Submissions must be a maximum of 3 pages plus one additional page for references, be compliant with the IEEE conference template, which can be downloaded from the IMS2024 website, and be compliant with double-blind requirements.
- The submission must be in PDF format and cannot exceed 4 MB in size.
- Authors must upload their paper submission by midnight Hawaii time on 6 December 2023. Late submissions will not be considered.

## Paper Selection Criteria

All papers are reviewed by subject-matter expert sub-committees of the IMS2024 Technical Program Review Committee (TPRC). The selection ciriteria will be:

- **Originality:** Is the contribution unique and significant? Does it advance the state of the art of the technology and / or practices? Are proper references to previous work by the authors and others provided?
- **Quantitative content:** Does the paper give a comprehensive description of the work with adequate independent verification (measurements, if applicable, or otherwise independent simulated data) ?
- **Clarity:** Is the paper contribution and technical content presented clearly and in a logical manner? Are the English writing and accompanying figures clear and understandable?
- **Interest to MTT-S membership:** Will this paper interest the IMS audience and encourage discussion?

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

**Presentation Format:** IMS offers three types of presentation formats. The authors' preference will be honored where possible, but the final decision on the presentation format is with the IMS2024 TPRC

1. Full-length papers report significant contributions, advancements, or applications in a formal (20 minute) presentation format with questions and answers (Q&A) at the end.
2. Short papers typically report specific refinements or improvements in the state of the art in a formal (10 minute) presentation format with Q&A at the end.
3. Interactive forum papers provide an opportunity for authors to present their theoretical and/or experimental developments and results in greater detail and in a more informal and conversational setting. An IMS2024 template will be provided.

## Notification

Authors will be notified of the decision by 1 February 2024. For accepted papers, an electronic version of the final 3-4 page manuscript along with copyright assignment to the IEEE must be submitted by 6 March 2024.

The submission instructions will also be provided through emails and can be accessed through the IMS2024 website.

## Clearances

It is the responsibility of the authors to acquire all required company and government clearances, prior to submission of their manuscript


## IMS Paper Competitions

**Competitions for the best Industry Paper, Advanced Practices Paper, Student Paper, and Early Career Paper will be held at the conference.**

**Student Paper Competition:** Eligible students are encouraged to submit papers for the Student Paper Competition. These papers will be reviewed in the same manner as all other contributed papers. First, second, and third prizes will be awarded based on content and presentation. To be considered for an award, the student must be a full-time student during the time the work was performed and still be a student on the submission deadline, be the lead author, and personally present the paper at IMS. Eligibility details can be found on the IMS2024 webpage.

**Industry Paper Competition:** Authors from industry are encouraged to submit papers for the Industry Paper Competition. Papers will be evaluated using the same standards as all contributed papers, the work should highlight technical innovation or state-of-the-art performance. The prize will be awarded based on content. and the prize includes a free advertisement in Microwave Journal or IEEE Microwave Magazine, for the author's company.

**Advanced Practice Paper:** Any author who submits a paper on advanced practices may be entered into the Advanced Practice Paper Competition. A paper on advanced practices describes an innovative RF/microwave design integration technique, process enhancement, and/or combination thereof that results in significant improvements in performance and/or in time to production for RF/microwave components, subsystems, or systems. The prize will be awarded based on content.

**Early Career Paper Competition:** This novel competition is open to authors from industry, government agencies/laboratories as well post doctoral scholars with less than 10 years of professional experience, and who are not full-time students. These papers will be reviewed in the same manner as all other contributed papers, and the prize will be awarded based on content and presentation.

## IEEE Transactions MTT Special Issue

Authors of all papers presented at IMS2024 can submit an expanded version of their paper to a special symposium issue of the *IEEE Transactions on Microwave Theory and Techniques*.

## IEEE Microwave and Wireless Technology Letters

Up to 50 of the best papers at the Symposium will be published in a special issue of *IEEE Microwave and Wireless Technology Letters*, at the authors' discretion.

## Details at www.ims-ieee.org

# Technical Areas

## EM Field, Design and Measurement Techniques

1 **Field analysis, guided waves, and computational EM —** Novel guiding, radiating, and electromagnetic structures; new analytical techniques and numerical methods for such structures, and new computational EM methods, incl. EM-coupled multiphysics modeling

2 **Circuit and system CAD —** Linear/nonlinear simulation and design optimization techniques; behavioral modeling; statistical approaches; surrogate modeling; space mapping; model order reduction; uncertainty quantification in simulations; stability analysis; non-EM related multiphysics simulations, design automation

3 **Instrumentation and measurement techniques —** Measurement techniques from microwave to THz for materials, linear and nonlinear devices, circuits, and systems; calibration and de-embedding techniques, measurement uncertainty, and over-the-air measurement methods and novel instrumentation

## Passive Components and Packaging

4 **Planar passive components and circuits, excl. filters —** Novel planar transmission-line components; artificial transmission lines, metamaterial structures, and high-impedance surfaces; planar couplers, dividers/ combiners, multiplexers, resonators, and lumped-element approaches

5 **Planar passive filters —** Planar passive filters, including lumped elements, theoretical filter and multiplexer synthesis methods

6 **Integrated passive circuits and filters —** Design and characterization of silicon integrated, III-V integrated passive components and filters, including IPDs

7 **Non-planar passive components, filters, and other circuits —** Transmission line components, resonators, filters and multiplexers based on dielectric, waveguide, coaxial, or other non-planar structures

8 **Tunable passive circuits and active filters —** Tunable and active filters, tunable phase shifters and couplers

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

10 **Packaging, MCMs, and 3D manufacturing technologies —** Component and subsystem packaging, assembly methods, multi-chip modules, wafer stacking, 3Dcinterconnect, and integrated cooling; package characterization; novel processes related to inkjet printing, 3D printing, or other additive manufacturing techniques

## Active Devices and Circuits

11 **Semiconductor device technologies and modeling —** RF to THz devices on III-V, silicon, and other emerging technologies, incl. 2D devices); MMIC and Si RFIC manufacturing, reliability, failure analysis, yield, and cost; linear and nonlinear device modeling (CAD, compact, physics-based, empirical) including characterization, parameter extraction, and validation

12 **HF/VHF/UHF circuits, technologies, and applications —** Advances in passive and active circuits (incl. PAs), components, and systems that operate in the HF, VHF, and UHF frequency ranges ranges (<1 GHz)

13 **Signal generation, modulators, frequency conversion —**CW and pulsed oscillators in silicon and III-V processes including VCOs, DROs, YTOs, PLOs, and frequency synthesizers, frequency conversion ICs in silicon and III-V processes, such as IQ modulators, mixers, frequency multipliers/ dividers

14 **Microwave and millimeter-wave low-noise amplifiers, variable-gain amplifiers, and receivers —** LNAs, VGAs, receivers, detectors, integrated radiometers, and low-noise circuit characterization, including cryogenic circuits

15 **Low-power (<10 W) amplifiers, below 30 GHz —** Advances in discrete and IC power amplifier devices and design techniques based on Si and III-V devices, demonstrating improved power, efficiency, and linearity for the microwave band (1-30 GHz)

16 **High-power (>=10 W) RF and microwave amplifiers, below 30 GHz —**Advances in discrete and IC power amplifier devices and design techniques based on III-V and LD-MOS devices, demonstrating improved power, efficiency, and linearity for the microwave band (1-30 GHz); power-combining techniques for SSPA and vacuum electronics

17 **Millimeter-wave and THz power amplifiers —** Advances in IC power amplifier circuits, design techniques, and power combining based on Si and III-V compound semiconductor devices demonstrating improved power, efficiency, and linearity for millimeter-wave and THz bands; vacuum electronics for millimeter-wave

18 **Linearization and transmitter techniques for power amplifiers —** Power amplifier behavioral modeling; linearization and pre-distortion techniques; envelope-tracking, out phasing, and Doherty transmitters for III-V and silicon technologies

## Systems and Applications

19 **Mixed-signal, wireline, and signal shaping circuits —** High-speed mixed-signal components and subsystems, including: PLLs, TDCs, ADCs, DACs, DDSs, and supporting circuits to interface these to the analog world

20 **Integrated transceivers and phased-arrays —** Design and characterization of complex III-V ICs, silicon ICs, heterogenous systems in the RF to mm-wave band including narrowband and wideband designs; innovative circuits and sub-systems for communications, radar, imaging, and sensing applications; Integrated on-chip antennas and on-package antennas

21 **Microwave and Terahertz Photonics —** Photonic techniques for the generation, processing, control, and distribution of microwave, mm-wave, and THz signals, Radio-over-fiber links; Design and characterization of microwave photonic and THz circuits; Interaction between microwaves, THz waves, and optical waves; THz circuits for communications, radar, imaging, and sensing applications; Nanophotonics, nanoplasmonics, and nano-optomechanics.

22 **Wireless power transmission —** Energy harvesting systems and applications, rectifiers, self-biased systems, combined data and power transfer systems

23 **Sensing and RFID systems —** Short range wireless and RFID sensors, gas and fluidic sensors; passive and active tags from HF to millimeter-wave frequencies; RFID systems including wearables and ultra-low-power

24 **Microwave and millimeter-wave wireless subsystems and systems —** Technology advances combining theory and hardware implementation in microwave/millimeter- wave subsystems such as beamformers; microwave and millimeter-wave (<300 GHz) communication systems, incl. 5G – 6G, with hardware implementation for terrestrial, vehicular, and indoor applications, point-to-point links, cognitive and software-defined radios, MIMO, full-duplex technologies, shared and novel spectrum use, novel modulation schemes, and channel modeling

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

26 **Airborne and space systems —** Technologies and systems for remote sensing for earth observation; positioning, navigation, and timing; space exploration, human spaceflight and space transportation; satellite communications including 5G, 6G applications involving aerospace platforms; communication and sensor system for UAVs, high altitude platforms, airplanes, and satellites

27 **MHz-to-THz devices, circuits, and systems for biological and healthcare applications —** Electromagnetic field interaction at molecular, cellular, tissue and living systems levels; devices, circuits, and systems for characterizations of biological samples; microwave-enhanced chemistry; instrumentation and systems for biomedical diagnostic and therapeutic applications, incl. MRI and microwave imaging; wireless, wearable, and implantable devices for health monitoring

## Emerging Technologies

28 **AI/ML for RF to mmWave —** AI/ML, algorithms implementations, and demonstrations for: spectrum sensing; mobile edge networking; MIMO and array beam operations and management; design and optimization; in-situ sensing, diagnostics, control, reconfiguration of MHz to THz communication and sensing circuits and systems

29 **Quantum devices, circuits, and systems —** Quantum devices and circuits (incl. cryogenic RF circuits); algorithms, interfaces, and systems for quantum computing and quantum sensing applications

30 **SubTHz and THz circuits and systems —** SubTHz and THz systems (300GHz to 1 THz+), incl. sub-THz architectures and implementations for passive and active sensing, 6G and Future-G communication systems.

31 **Microwave field-matter interaction, material sensing and high-power applications —** Industrial and scientific applications of microwave energy (e.g., chemistry, metallurgy, ceramic sintering, plasma generation, waste treatment, "green" materials, energy converters); MHz-to-THz sensing (from microwave microscopy to large surface/volume imaging) of materials for electronics and energy applications; multiphysics modeling of materials processing and characterization.

32 **Other innovative MHz-to-THz systems and applications —** Submissions that describe innovative contributions in new and emerging areas of interest to the MTT community not falling under the above categories are encouraged.

# Microwave Signal Source Replaces and Upgrades QuickSyn

AnaPico AG
*Zurich, Switzerland*
Berkeley Nucleonics Corporation
*San Rafael, Calif.*

In the relentless pursuit of compact, high performance signal sources and frequency synthesizers, AnaPico has raised the bar once again with the launch of the APMQS20, a microwave signal source delivered in the form of a flange-mount module. This module is intentionally designed to seamlessly replace the QuickSyn FSW-0020 frequency synthesizer, which was phased out by NI a few years ago. AnaPico's APMQS20 serves as a drop-in replacement, providing an uncomplicated transition for QuickSyn users and ensuring uninterrupted performance.

## ELEVATED PERFORMANCE

The APMQS20 preserves the best attributes of the FSW-0020 while implementing a host of enhanced capabilities. The APMQS20 is an instrument-grade signal source that achieves performance that is on par with or surpasses the performance of the FSW-0020. The heart of the APMQS20's exceptional performance lies in the integration of a high-quality oven-controlled crystal oscillator (OCXO) as an internal reference. The OCXO delivers low close-to-carrier phase noise, establishing excellent long-term frequency stability. Capitalizing on AnaPico's proprietary signal synthesis techniques, the APMQS20 integrates a low noise VCO with phase detectors, frequency dividers and multipliers. This architecture results in a signal source with what we believe is the lowest phase noise among all compact frequency synthesizers currently available. The measured single sideband (SSB) phase noise of the APMQS20 signal source at 10 GHz is shown in ***Figure 1***.

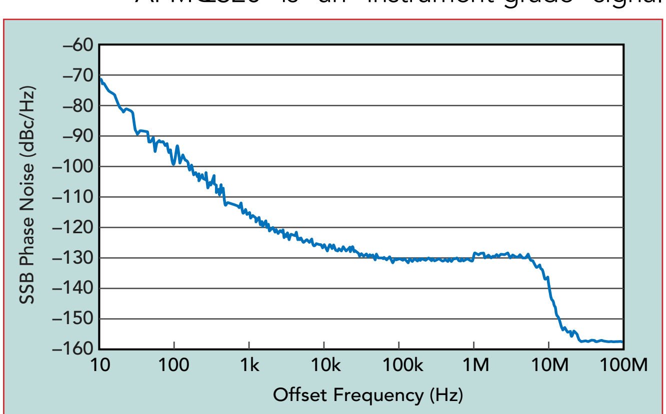



**Fig. 1** **SSB phase noise of APMQS20 at 10 GHz.**

To minimize non-harmonic signal components, AnaPico has implemented a two-stage frequency synthesis scheme. In the initial stage, a finely tuned reference frequency is generated that deliberately avoids an integer multiple of the OCXO. The second stage employs this reference frequency for octave frequency range synthesis, bolstered by level conditioning and filtering. This architecture results in a -70 dBc level of non-harmonic frequency components across the spectrum from 0.1 to 20 GHz. This is complemented by direct digital synthesis technology, offering frequency resolution down to 1 MHz.

The APMQS20 contains a whole host of other features that improve performance and

**TABLE 1**

**TECHNICAL COMPARISON OF NI FSW-0020 AND ANAPICO APMQS20/BNC MODEL 805-M**

| *Parameter* | *NI FSW-0020* | *AnaPico APMQS20 BNC Model 805-M* |
|---|---|---|
| Frequency Range | 0.2 to 20 GHz | 8 kHz to 20 GHz |
| Switching Speed | 100 µs (list sweep)<br>200 µs (over SPI) | 20 µs (list sweep)<br>200 µs (over SPI) |
| Power Range | -10 to +13 dBm at > 0.5 GHz | -25 to +16 dBm at > 1 GHz |
| Level Accuracy | ±2.0 dB | ±0.3 dB |
| Phase Noise at 100 Hz / 10 kHz / 1 MHz from 10 GHz | -83 / -122 / -126 dBc/Hz | -95 / -126 / -130 dBc/Hz |
| Harmonics / Non-harmonics | -35 / -70 dBc at > 0.5 GHz | -50 / -70 dBc at > 0.1 GHz |
| Modulations | Pulse, AM/FM | Pulse, AM/FM |
| Reference In/Out | 10 MHz | 10 MHz, 100 MHz, 1 GHz |
| Communication Ports | SPI, USB | SPI, USB, Ethernet |
| Power Supply and Consumption | 12 VDC / 20 W | 12 to 30 VDC / 24 W |

user experience. It has an automatic level control mechanism that delivers power level setting accuracy of ± 0.3 dB, surpassing the QuickSyn capabilities. The APMQS20 harnesses multiple switched VCOs within the base frequency octave to provide a fast frequency switching capability, with switching typically occurring within 20 µs. This approach significantly improves frequency tuning times, ensuring responsiveness that matches the demands of multiple applications. The APMQS20 also boasts the ability to support analog modulations, further enhancing its versatility in a diverse set of applications

AnaPico maintains a commitment to a holistic user experience. The module's energy-efficient design enables passive cooling when correctly mounted on heat-dissipating surfaces. The device is provisioned with comprehensive GUI control software, facilitating seamless control. Communication capabilities are enriched through USB, LAN and SPI ports, catering to diverse user preferences.

## BENCHMARKING EXCELLENCE: A COMPARATIVE OVERVIEW

A concise comparison between the APMQS20, the co-branded 805-M model from Berkeley Nucleonics Corporation and NI's FSW-0020 is presented in ***Table 1***. This table succinctly highlights the APMQS20's performance enhancements and reinforces its position as an innovative replacement for the FSW-0020.

## UNLEASHING POSSIBILITIES

The APMQS20's versatility extends to a wide spectrum of applications. It serves as a precision system clock, a high purity local oscillator for analog mixers and digital modulators and a reliable microwave source for spectroscopic systems. Its fast switching prowess makes it a solution that is well-suited for fast frequency hopping, radar signal generation and mission-critical electronic warfare applications. Notably, former NI QuickSyn frequency synthesizer users now have an exceptional replacement that ensures product availability and continuity without the burden of costly redesigns.

The APMQS20 is positioned as a top choice for RF and microwave engineers and scientists. It encapsulates the trifecta of high signal purity, precise setting capabilities and fast switching capabilities. As the industry continues its quest for excellence, the APMQS20 stands at the forefront, ushering in a new era of microwave signal sources that empower innovation.

VENDORVIEW

**AnaPico AG**
**Zurich, Switzerland**
**www.anapico.com**

**Berkeley Nucleonics Corporation**
**San Rafael, Calif.**
**www.berkeleynucleonics.com**

# 8-Channel, Dual Polarization Beamforming IC Operates in 5G FR2

iCana
*New Taipei City, Taiwan*

5G cellular networks promise massive connectivity, ultra-low latency and higher data rates. The first 5G deployments have been focused on the sub-6 GHz spectrums of frequency range 1 (FR1). To deliver this promised performance, these networks will eventually require mmWave frequency deployments.

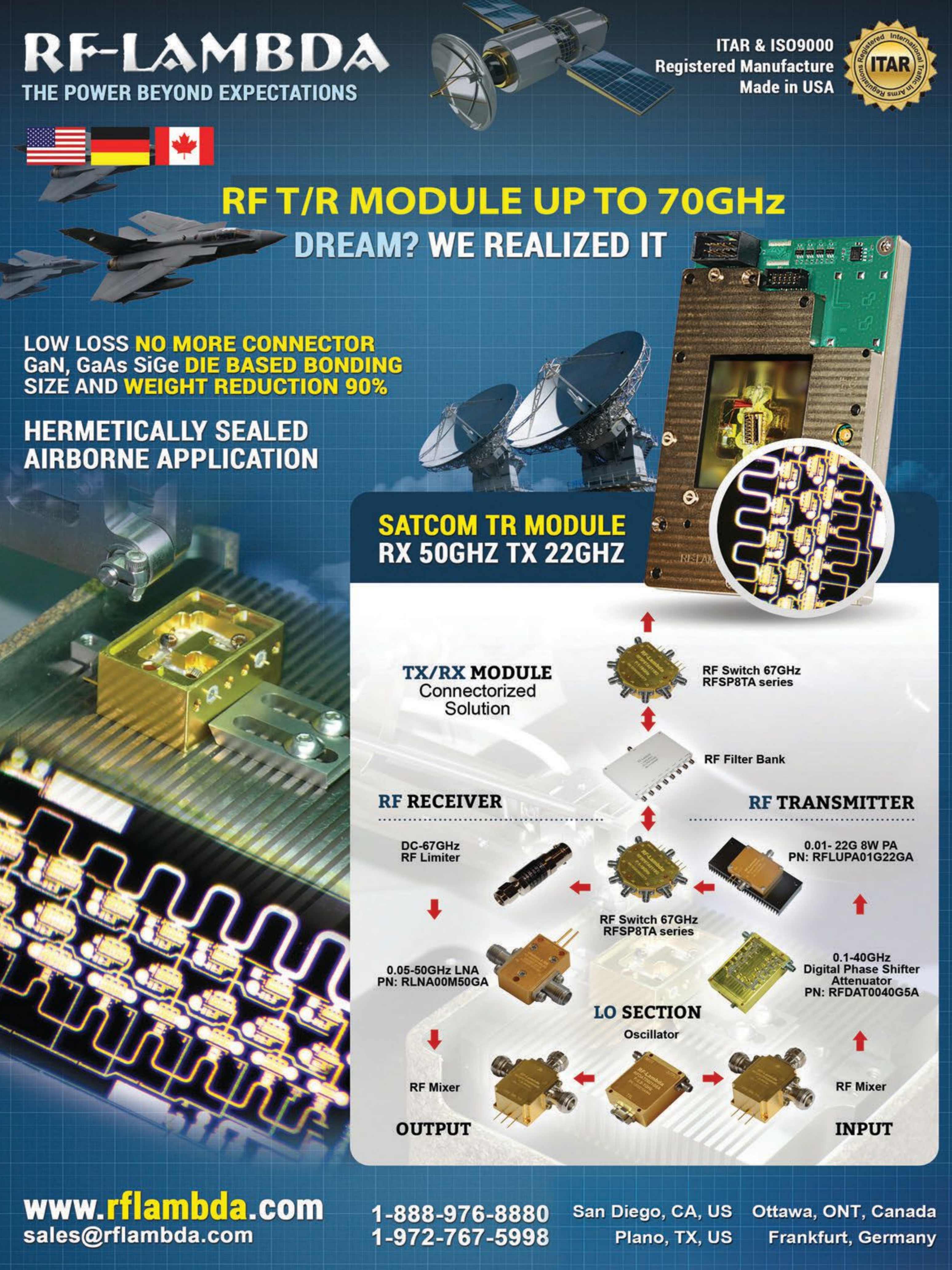
Such a deployment brings many challenges as moving to higher frequencies increases the path losses and reduces the range of the signal to the end user. To overcome these challenges, mmWave 5G deployments demand densification of the small cell network and the introduction of beamforming to increase the range of the signal. This network densification requires a huge investment from mobile network operators, which slows down the current roll-out at mmWave frequencies.


Fig. 1 **ICAMB2629-A BGA package.**

To help with these challenges in the mmWave infrastructure market, iCana is launching the ICAMB2629-A, a highly integrated cost-effective beamforming IC with eight channels supporting dual polarization. It targets n257 and n261 5G New Radio (NR) frequency range 2 (FR2) wireless infrastructure applications. iCana plans to disrupt the market with this device by delivering a low-cost, high performance solution that will enable mobile network providers to deploy 5G mmWave networks more cost-effectively. The ICAMB2629-A comes in a 90-pin, 4.6 × 5.1 mm BGA-based package, as shown in ***Figure 1***. The functional block diagram is shown in ***Figure 2***.

## FEATURES AND BENEFITS

To enable high data rates, the ICAMB2629-A provides 800 MHz of signal bandwidth across the 26.5 to 29.5 GHz frequency range. The ICAMB2629-A can operate in two polarizations simultaneously across this band. This allows operators to offer an improved and more stable commu-



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ITAR & ISO9000
Registered Manufacture
Made in USA
ITAR
RF T/R MODULE UP TO 70GHz
DREAM? WE REALIZED IT
LOW LOSS NO MORE CONNECTOR
GaN, GaAs SiGe DIE BASED BONDING
SIZE AND WEIGHT REDUCTION 90%
HERMETICALLY SEALED
AIRBORNE APPLICATION
SATCOM TR MODULE
RX 50GHZ TX 22GHZ
TX/RX MODULE
Connectorized
Solution
RF Switch 67GHz
RFSP8TA series
RF Filter Bank
RF RECEIVER
RF TRANSMITTER
DC-67GHz
RF Limiter
0.01- 22G 8W PA
PN: RFLUPA01G22GA
RF Switch 67GHz
RFSP8TA series
0.05-50GHz LNA
PN: RLNA00M50GA
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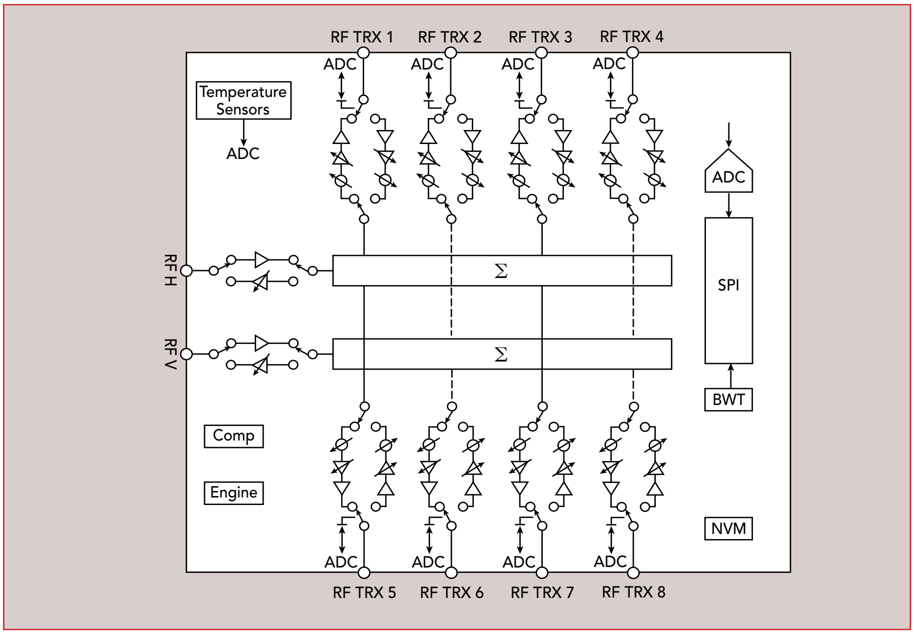


Fig. 2 **Functional block diagram.**

nication link compared to a single polarized beamforming solution. In transmit mode (Tx), the IC provides an average output power of more than 10 dBm per channel at three percent error vector magnitude, 100 MHz 5G NR, 64 QAM with a gain of 27 dB. In receive mode (Rx), it provides a gain of 27 dB with a noise figure of less than 4.5 dB while only consuming 0.7 W of power. With these features, the ICAMB2629-A improves the link stability, link quality, overall link capacity and coverage; all benefits 5G users are desperately awaiting.

## GOOD AMPLITUDE AND PHASE ACCURACY

Beamforming is a combination of beam steering and beam shaping. To steer the beam in the de-

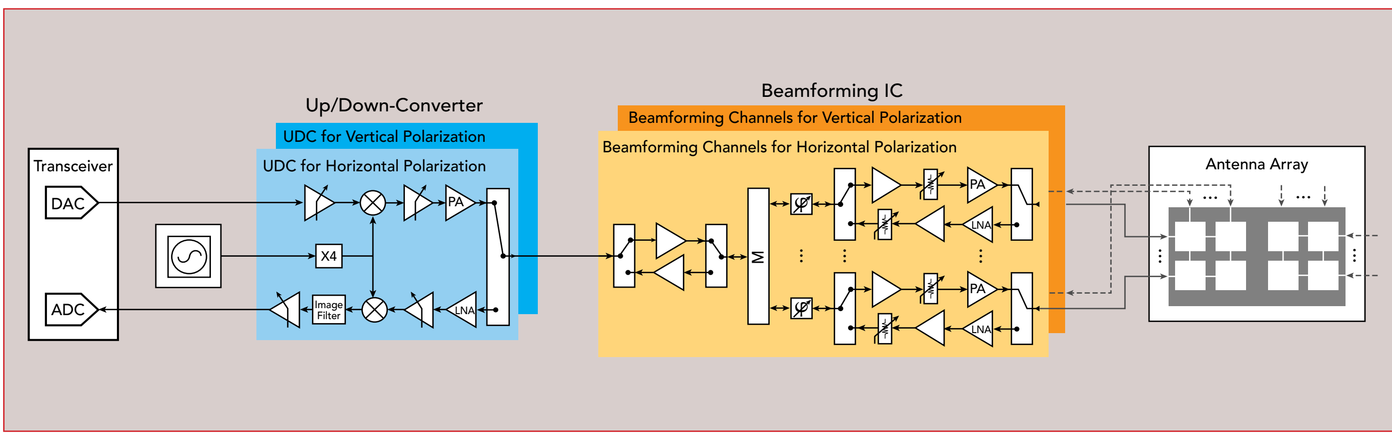


Fig. 3 **Block diagram for iCana phased array solutions.**

sired direction, each antenna element in an antenna array is fed with the same, but phase-shifted or time-delayed signal. This phase shifting is one of the most important functions provided by beamforming ICs. With many beamforming ICs in each mmWave small cell, the cost of each IC becomes a crucial factor in enabling a dense network roll-out.

Besides beam steering, the ICAMB2629-A can also shape the beam by tapering or nulling certain signals to further reduce the undesired interference between different users. This sidelobe suppression allows the operator to optimize the communication link and maximize the throughput to each user. This requires highly accurate gain and phase control with high linearity across a wide frequency range. These parameters must remain under tight control across temperature and this is exactly what iCana's beamforming IC offers.

To enable beamforming with this level of accuracy, the ICAMB2629-A offers a channel gain range of 7 dB in 0.5 dB steps and 6-bit phase resolution with a 5.6-degree phase step. The beamformer IC offers gain accuracy with less than 0.15 dB RMS gain error and less than 2 degrees RMS phase error at 28 GHz. This performance enables both beam steering and shaping functionality and delivers excellent tapering and nulling performance.

## CONTROL CIRCUITRY GUARANTEES PERFORMANCE

The ICAMB2629-A performance is guaranteed for every beamforming IC across various operating conditions, thanks to the built-in digital control circuitry and sensor platform. This sensor platform monitors temperature, RF power and power consumption. With this input, smart control is enabled to guarantee gain and phase accuracy and maximum orthogonality to get the best beamforming performance. The IC achieves fast beam switching between 2048 pre-stored different transmit and receive beams. Automatic control loops based on the built-in sensors guarantee this performance across different operating temperature conditions.

## CALIBRATION

A pre-configured set of correction settings stored in non-volatile memory in the ICAMB2629-A allows the device to fully calibrate itself at boot-up. This ensures the best performance for every channel with limited variation from channel to channel. In addition, the ICAMB2629-A requires minimal effort to calibrate the IC performance, maximizing the overall performance of the active phased array that will contain multiple beamforming ICs.

The above features come at what iCana believes to be a competitive cost. This makes the ICAMB2629-A an attractive beamforming IC solution to deliver on the 5G promises of massive connectivity, ultra-low latency and greater bandwidth. This IC will provide benefits for wireless communications infrastructure, customer premises equipment, repeaters and fixed wireless access applications.

## EXPANDING ICANA'S 5G MMWAVE PRODUCT LINEUP

In addition to the beamforming IC, iCana will launch an up/down-converter (UDC) in 2024 to complete the total mmWave beamforming lineup, as shown in ***Figure 3***. For incoming intermediate frequencies in the 3 to 7 GHz range, the UDC will up-convert to an mmWave frequency as part of a dual-channel solution that provides both horizontal and vertical polarization. This signal feeds multiple beamforming ICs connected in the antenna array to enable beamforming of the RF signal.

iCana is a fabless semiconductor component supplier specializing in the design and manufacturing of RF components for wireless communication. iCana's primary markets are 5G NR FR1 and FR2 infrastructure, together with automotive connectivity. By managing the end-to-end process from IC design through qualification and mass production, iCana is committed to providing unrivaled performance, quality and reliability. Headquartered in Taiwan, iCana has additional research and development centers located in Belgium and the U.S.

**iCana**
**New Taipei City, Taiwan**
**www.icana-rf.com**


# Connectorized Bias Tees Offer Ultra-Broadband Control Solutions

The new KRYTAR line of bias tees offers broadband control solutions with coverage within multiple frequencies from 0.5 to 40 GHz. These bias tees target applications like powering remote control of preamplifiers or LNAs in antennas, controlling remote DC signals and testing of many RF applications. A key application for a bias tee is to inject DC currents or voltages into RF and microwave circuits without affecting the RF signal passing through the main transmission line. Bias tees are also used to provide DC power to power amplifiers and other devices mounted at the top of a communications tower near the antenna.

The new KRYTAR family of 12 coaxial connectorized bias tees are rugged, compact designs offering the following performance:

Insertion loss (dB maximum): less than 1.4 dB to less than 6.0 dB; isolation (dB minimum): 10 to 18 dB; VSWR (maximum): 1.5:1 to 1.9:1; power (W maximum): 20 DC voltage (V maximum): 36 to 60; DC current (A maximum): 1.0 to 2.0.

The bias tees are available with standard SMA female or 2.4 mm female connectors, for higher frequencies. KRYTAR also offers complete engineering services for custom designs that meet or exceed critical performance and/or packaging specifications.

For nearly 50 years, KRYTAR, Inc. has specialized in the design and manufacture of broadband mmWave, microwave and RF components and test equipment for both commercial and military applications. The KRYTAR product line covers DC to 110 GHz and it includes directional couplers, directional detectors, 3 dB hybrids, MLDD power dividers, detectors, terminations, coaxial adapters and Butler matrices. KRYTAR microwave components are manufactured in full compliance with the EU RoHS-6 environmental requirements.

VENDORVIEW

**KRYTAR, Inc.**
**Sunnyvale, Calif.**
**krytar.com/products/detectors/bias-tees/**


# Digitizers Offer 10 GSPS Sampling Rate and Continuous Streaming

Spectrum Instrumentation has announced new data streaming capabilities for their flagship M5i.33xx series digitizers, allowing them to acquire and stream data at rates up to 10 GSPS using COTS PC technology. The digitizers, which include seven different models, offer sampling rates from 3.2 to 10 GSPS with 12-bit resolution and bandwidths from 1 to 4.7 GHz. All variants can transfer data over the PCIe bus at up to 12.8 GBps. The transfer rate can be combined with a special 8-bit mode, enabling data acquired at 10 GSPS to be continuously streamed to the PC environment without any loss of information.

For endless streaming and processing, the company offers SCAPP. SCAPP sends data directly from the digitizers to CUDA-based GPUs. Users can utilize the multiple processing cores and large memory of the GPUs for on-the-fly processing. SCAPP includes working examples for advanced processing functions like digital down-conversion, FFTs and signal averaging.

The company also offers streaming and data storage systems based on a Supermicro server with an AMD EPYC processor and RAID storage using U.2 SSDs. With up to 240 TB of storage, these COTS systems can record 6+ hours of data at the maximum sampling rate.

The digitizers come with a five-year warranty and an SDK for programming with popular languages such as C, C++, C#, Delphi, VB.NET, J#, Python, Julia, Java, LabVIEW and MATLAB. The SDK contains both driver libraries and programming examples. The company has its measurement software, SBench 6 Professional, which provides full card control, along with display, analysis, storage and documentation capabilities.

VENDORVIEW

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

## The Sky's the Limit

Check out Analog Devices' new web pages featuring their avionics products and solutions.

**Analog Devices, Inc.**
**https://bit.ly/45irjeh**

## USB Controlled Frequency Synthesizers

Dive into the world of USB controlled frequency synthesizers in Fairview's blog post.

**Fairview Microwave**
**https://bit.ly/47XsUrW**


## Auto Tech Talks Ep. 2

The latest episode of Auto Tech Talks is available now! Join us for "The Key to Long-Range EVs: Understanding Battery Test Parameters," as we delve into testing at the different levels of the battery development process.

**Keysight Technologies**
**https://bit.ly/3L1hKs8**


## Mini-Circuits Passes ISO 9001 Recertification

Mini-Circuit's global locations are unique in the capabilities they bring to the enterprise, but high standards and industry-leading quality are universal. Mini-Circuits' team in Surrey, U.K., passed their ISO 9001 recertification audit with flying colors.

**Mini-Circuits**
**www.minicircuits.com**


## Video Tour: WaveFarer Radar Simulation Software Highlights

Watch this short overview of WaveFarer's innovative features for automotive and indoor radar applications, including diffuse scattering from rough surfaces such as roads and the ability to transmit through walls, windows and more.

**Remcom**
**www.remcom.com/wavefarer-radar-analysis-video-overview**


## Millimeter Wave Measurement Brochure


SPINNER millimeter wave testing components give you unprecedented flexibility in creating millimeter wave testing environments. Their solutions are mechanically extremely flexible and uncompromisingly good in technical terms. See this brochure for more details.

**SPINNER**
**https://bit.ly/44CH3YF**

# NEW PRODUCTS

FOR MORE NEW PRODUCTS, VISIT
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## DEVICES/ COMPONENTS/MODULES

### High Sensitivity Radar Sensor

A new version of radar receiver detecting signals 2.5x the distance of any product available on the market, SDLAC21802B covering 2 to 18 GHz with sensitivity of -78 dBm (TSS), a dynamic range of 77dB and a pulse response of 12/20 nSec. (rise/fall time). This product is thin film construction designed for air, land and sea applications with rugged construction and compact size (0.82 in.$^3$).

**Advanced Microwave, Inc.**
**www.advmic.com**

### RF Filter

American Microwave Corp. offers its Model Number: SM-8T-818 OPTION A8429468-1, an 8.2 to 10.34 GHz bandpass RF filter. The RF filter has a frequency range of 8.2 to 10.34 GHz with an insertion loss of 2.0 dB maximum. This module has a VSWR of 1.5:1 maximum, minimum power rating of 200 mW CW, RF input connector type SMA female, RF output connector type SMA male, and operating temperature range of -54°C to +70°C. The size is 4.0 x 1.5 x 0.75 in.

**American Microwave Corp.**
**www.americanmic.com**

### Up/Down-Converter IC

VENDORVIEW


The AWMF-0210 is a highly integrated silicon frequency-conversion IC intended for 5G phased array applications. When used together with Anokiwave's beamformer IC products, this device enables low-cost, high performance and feature-rich 5G phased array systems. The half-duplex IC integrates Tx single-sideband up-conversion and Rx image-reject down-conversion functionality. An on-chip frequency multiplier simplifies board-level integration with external PLLs. The IF up/down-converter ICs are fully compatible with the respective Anokiwave beamformer ICs, sharing common mechanical and electrical interfaces.

**Anokiwave**
**www.anokiwave.com**

### Double-Ridge Waveguide Couplers

VENDORVIEW

Fairview Microwave has announced its double-ridge waveguide couplers designed with integrated coaxial connectors. They are available in various sizes, including WRD-650, WRD-750 and WRD-180. Fairview's new waveguide couplers are not only meticulously crafted but provide a remarkable power rating of up to 400 W (CW) maximum. In addition, they offer diverse coupling levels from 10, 30, 40 and 50 dB, providing clients with an expanded range of options to perfectly match their specific requirements.

**Fairview Microwave**
**www.fairviewmicrowave.com**

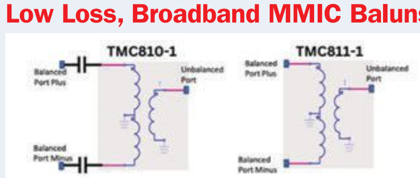
### Relay Programmable Attenuators

VENDORVIEW

JFW's online 50 Ω relay programmable attenuator models are now available. JFW offers relay attenuators with either TTL or direct voltage control. For direct voltage control the DC voltages are typically +12, +15, +24 or +28 Vdc. These DC voltages are applied to the control feedthrough pins to activate an attenuation step. With no control applied the relay is failsafe to the through path setting (i.e. 0 dB). Users can activate multiple attenuation steps simultaneously to set combination attenuation values.

**JFW Industries**
**www.jfwindustries.com**

### Low Loss, Broadband MMIC Baluns




Fabless mmWave semiconductor startup mmTron Inc. announced the first four products in a family of broadband, low loss, 50 Ω baluns, covering 3 to 18, 11 to 65 and 27 to 100 GHz. Baluns are components that transform balanced to unbalanced signals and vice versa. The TMC810-1 and TMC811-1 cover 3 to 18 GHz and have 2 dB midband insertion loss. The balanced ports have 0.4 dB amplitude and 1 degree phase matching, with a common-mode rejection of 35 dB. Return loss is 10 dB.

**mmTron Inc.**
**www.mmtron.com**





# New**Products**

## 8-Bit Digital Phase Shifter

VENDORVIEW


Quantic PMI Model PS-2G6G-8B-SFF is a 8-Bit digital phase shifter that operates over the 2.0 to 6.0 GHz frequency range. This model offers 360 degrees of phase shift having a LSB of 1.4 degrees. The insertion loss is 10.5 dB typically with a phase accuracy of ±0.5 degrees. It is supplied in a housing measuring 3.25 × 3.25 × 0.94 in.

**Quantic PMI**
**www.quanticpmi.com**

## Discrete Component Filters

VENDORVIEW


Reactel discrete component filters can satisfy a variety of filter requirements. These versatile units cover the broad frequency range of 2 kHz to 5 GHz and are available in either tubular or rectangular packages, connectorized or surface-mount and standard or high-power versions. All standard discrete component filters utilize a low ripple Chebyshev design which offers the best compromise of low loss, low VSWR and high selectivity. Should a different design become necessary to meet your requirements, Reactel can provide these units with Bessel, Butterworth, elliptic, Gaussian or linear phase responses.

**Reactel Inc.**
**www.reactel.com**

## Ultra-Broadband Capacitors

VENDORVIEW


Richardson RFPD Inc. announced the in-stock availability and full design support capabilities for a series of RF and microwave multilayer capacitors from KYOCERA AVX. The 550-560 Series of ultra-broadband capacitors features rugged ceramic construction to provide reliable and repeatable performance from 7 kHz through 110 GHz. The UBCs exhibit ultra-low insertion loss, flat frequency response and excellent return loss. They are ideal for DC blocking, coupling, bypassing and feedback applications requiring ultra-broadband performance.

**Richardson RFPD Inc.**
**www.richardsonrfpd.com**

## Gold-Plated OFHC Copper Bandpass Filters

RLC Electronics Inc. has successfully built and delivered gold-plated OFHC copper bandpass filters for quantum computing applications (copper has the best electrical conductivity of any metal, except silver). This filter is a C-Band filter centered at 5350 MHz. Despite the 11 sections response, insertion loss at the band edges is 0.27 dB and 0.35 dB. The filter achieves > 100 dB attenuation carrying up to 15 GHz (minimum) spurious free and handles 50 W cW.

**RLC Electronics Inc.**
**www.rlcelectronics.com**

# CABLES & CONNECTORS

## Cable Assembly Series

Amphenol RF announced the expansion of their between-series cable assembly series with N-Type plug to SMA plug assemblies on flexible RG-142 cable. The combination of the more ruggedized N-Type connector with the lightweight, compact SMA connectors provides a versatile solution for applications such as connecting to antennas within a device, radar, satellite systems and broadcast equipment. This new

# New**Products**

cable assembly configuration is designed on RG-142 cable which offers a low loss solution with a bend radius of 1 in.
**Amphenol RF**
**www.amphenolrf.com**

## Hermetically Sealed RF Connectors and Adapters

VENDORVIEW

Pasternack has announced a new series of hermetically sealed RF connectors and adapters designed to meet the stringent requirements of military and defense applications. The hermetically sealed terminal connectors and bulkhead-mount adapters in the series are developed with a variety of BNC, Type N, TNC, SMA, 2.92 mm and 2.4 mm options. This provides users with a vast range of options tailored to various specifications and needs.
**Pasternack**
**www.pasternack.com**

## 1.35 mm End Launch Connectors

Southwest Microwave, Inc. introduces the 1.35 mm Series as the latest addition to its end launch connector product line. Features include compatibility with both microstrip and coplanar waveguide transmission, robust, reusable, repairable and solderless, unique bottom clamp design for effective grounding, HFSS and .stp files available, low VSWR, low insertion loss and are rugged and durable.
**Southwest Microwave**
**www.southwestmicrowave.com**

# AMPLIFIERS

## C-Band Pulsed Power Amplifier for Radar

VENDORVIEW

Combining an array of 12 amplifiers, the liquid cooled Model 2247 is a 30 kW peak


pulsed transmitter capable of long and short pulses between 5.4 and 5.9 GHz. Designed for mission critical applications, the 2247 continues to stay on air with maximum available power in the event of component, power supply or amplifier drawer failure. Featuring a modular and distributed architecture, there is no single point of power supply or RF failure and availability is maximized. With no cabling to disconnect, the transmitter allows fast field replacement of any drawer in less than 15 minutes.
**Empower RF**
**www.EmpowerRF.com**

## 50 W SSPA, AMP2145C-LC

VENDORVIEW


Exodus Advanced Communications' 18.0 to 40.0 GHz, 50 W solid-state amplifier (SSPA) is another industry first from Exodus. Designed for broadband EMC and lab testing, MIL-STD 461(RS103) standards as well as other high-power applications. Exodus Model AMP2145C-LC is a compact, 5U design providing outstanding power/gain flatness, forward/reflected power monitoring in both dBm and watts, VSWR, voltage/current and temperature sensing for superb reliability and ruggedness. Unprecedented reliability compared to TWT's, 47 dB gain including gain control and -20 dBc harmonics.
**Exodus Advanced Communications**
**www.exoduscomm.com**

## Low Noise Amplifier

VENDORVIEW

Mini-Circuits' model WVA-71863LNX+ is a low noise amplifier (LNA) with 39 dB typical gain from 71 to 86 GHz. It maintains gain within ±1.5 dB across its bandwidth and holds noise figure to typically 5 dB or less. Well suited for aerospace/defense systems, radar and test applications, the LNA delivers +14.5 dBm typical output power at 1 dB compression and runs from supply voltages from +10 to +15 VDC. It incorporates over-voltage and reverse-voltage protection and is equipped with WR12 interfaces.
**Mini-Circuits**
**www.minicircuits.com**

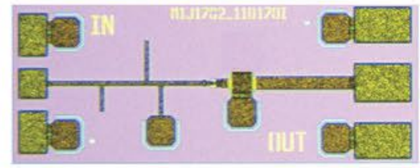
# ANTENNAS

## Broadband Horn Antennas

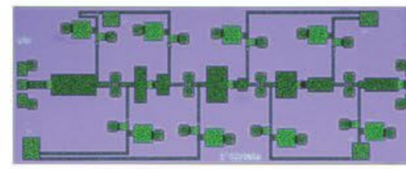
VENDORVIEW

NSI-MI Technologies' broadband horn antennas (ANT-BHA) are suitable for a wide variety of applications that require stable antenna performance over extremely broad frequency bandwidths. The best-in-class radiation patterns remain consistent across the operating frequency band for applications that require broadband performance. Each model is also designed to maintain VSWR across the complete frequency bandwidth.
**Ametek NSI-MI Technologies**
**www.nsi-mi.com**

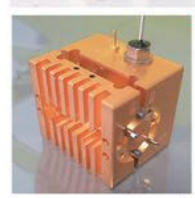
















# NewProducts

## TEST & MEASUREMENT

### Signal Source Analyzer

VENDORVIEW

The APPH is a fully contained signal source analyzer with a frequency range of 1 MHz to 7, 26 and 40 GHz. It offers an indispensable set of measurement functions for evaluating signal sources ranging from VHF to microwave frequencies but also active and passive non-self-oscillating devices like amplifiers or frequency dividers. A mixed-signal system architecture with an FPGA cross-spectrum engine enables very fast signal processing and ultra-low phase noise sensitivity.

**AnaPico AG**
**www.anapico.com**

### Frequency Extender

VENDORVIEW

Compatible with many industry-standard coaxial vector network analyzers (VNAs), model STO-0620300-CM-E1 is a transmit/receive frequency extender that measures transmitted and received signals through its WR-06 test port. Dynamic range is 100 dB from 110 to 170 GHz. One Tx/Rx extender can measure S11 or S22 while two extenders can measure S11, S12, S21 and S22 simultaneously. For direct connections without additional hardware, the VNA must have dual signal generators with independent frequency and amplitude control and provide access to its measurement receiver channels.

**Eravant**
**www.eravant.com**

### 0.6 ~ 5 GHz 8 × 8 Butler Matrix

VENDORVIEW

MIcable SA-07-8B006050 is a 0.6~5 GHz 8 × 8 butler matrix which can transfer the signal reciprocally from any of eight ports to any of other eight ports. It covers 5G NR band (FR1) and has high versatility in 5G test applications. Because the high performance passive components and cables are used inside, the system has super phase accuracy (±14 degrees maximum), amplitude balance (±1.3 dB maximum), stability and repeatability.

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

### emSCOPE™

A Microsanj/eV Technologies partnership has resulted in a holistic approach for over-the-air testing and evaluation of microwave and mmWave components. With emSCOPE™, designers will be able to quickly assess the performance of AiPs, AoCs and AoPCBs. A proprietary coating based on quantum spin-crossover technology, exhibits functional properties that are responsive to external stimuli. Using this coating as an overlay or interface for the circuit under test in conjunction with infrared or thermo-reflectance-based imaging enables observation of the electromagnetic field.

**Microsanj**
**www.microsanj.com**
**eV Technologies**
**www.ev-technologies.com.**

# New**Products**

## Microwave Switching Family

Pickering Interfaces announced its new 40/42-890 family of modular, flexible PXI/PXIe microwave switches, bringing highly configurable RF switching solutions up to 110 GHz to the PXI platform. This new range will support the latest and most demanding RF and communications test requirements as operating frequencies continue to evolve to ever higher levels. Ideal for test environments requiring high frequency microwave switching, from radar, satellite and short-range land-based secure communications to consumer electronics and 5G infrastructure.

**Pickering Interfaces**
**www.pickeringtest.com**

## GPS Timing Antenna

PolyPhaser, an Infinite Electronics brand and an industry-leading provider of RF and data surge protection, filtering and grounding solutions, has just rolled out a new active GPS timing antenna. With high gain and low noise, this new timing antenna filters and amplifies GNSS L1, GLONASS G1 and BeiDou B1 global positioning signals received from satellite constellations. Precise timing and positioning data and phase synchronization is essential in applications such as agriculture, mining, construction, military and security and law enforcement and public safety.

**PolyPhaser**
**www.polyphaser.com**

## Digital Oscilloscope

The Siglent SDS1202X-E 200 MHz digital oscilloscope offers a premium test instrument at a remarkably affordable price. With a real-time sampling rate of 1 GSa/s, this 200 MHz scope features waveform capture rates of up to 100,000 wfms/s in normal mode and 400,000 wfms/s in sequence mode. The SDS1202X-E has a huge waveform record memory of up to 14 million points, a 256-level color and intensity grading and color temperature display. Together, these technologies are described by Siglent as super phosphor oscilloscope technology.

**Saelig Company Inc.**
**www.saelig.com**

# MICRO-ADS

Review by:
Katerina Galitskaya


## Antenna and Array Technologies for Future Wireless Ecosystems

**By Dr. Yingjie Jay Guo and Dr. Richard W. Ziolkowski**

The book "Antenna and Array Technologies for Future Wireless Ecosystems" authored by Dr. Yingjie Jay Guo and Dr. Richard W. Ziolkowski is an enlightening book that shares the latest research findings and perspectives from world-class antenna researchers, exploring the exciting possibilities that lie ahead. The book begins with an exploration of one of the hottest antenna research topics of the last two decades, metamaterials. The editors and the contributors provide a comprehensive understanding of thin metamaterials and their ability to manipulate electromagnetic properties.

Addressing the demands of 5G and beyond, the book covers Luneburg lens antennas, electrically small antennas, reconfigurable antennas and antenna-in-package, featuring the latest advances in the areas. An innovative application of leaky wave antennas as low-cost smart antennas for wireless networks is presented.

The book pays a lot of attention to beamforming, a crucial technology for 5G, 6G and future communications networks. A novel photonic approach that employs radio-over-fiber transmission and integrated photodiodes with array antenna elements is presented in the book. This innovative method overcomes power losses in RF cables and phase shifters, offering cost-effective and power-efficient beamforming solutions.

The book explores the challenges and opportunities of THz antennas for the upcoming sixth generation of wireless communications networks. The readers get valuable insights into THz lens antennas, with a focus on material losses and fabrication tolerances.

The book concludes with an intriguing exploration of quantum antenna arrays, co-authored by Dr. Inigo Liberal and Professor Richard W. Ziolkowski. The book introduces quantum technologies, paving the way for potential quantum antenna array applications in the future. Overall, "Advances in Antenna Technologies for Future Wireless Communications" is a remarkable compilation of cutting-edge research and breakthroughs in antenna engineering. It serves as a valuable resource for antenna researchers and engineers looking to shape the future of wireless communications.

**ISBN 13:** 978-1-119-81388-0
**Pages:** 512
**To order this book, contact:**
**Wiley-IEEE Press (August 2022)**
**www.wiley.co**

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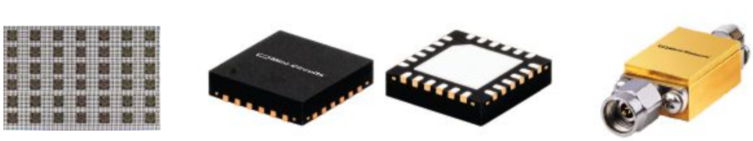

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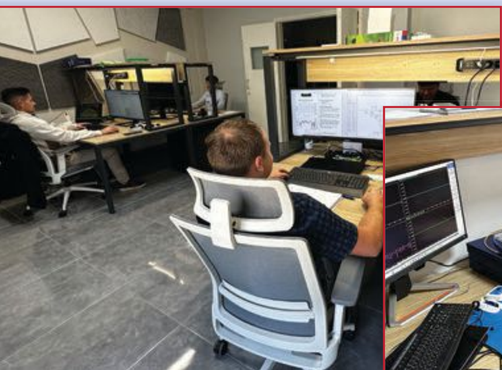
# FABS and LABS

## Copper Mountain Technologies: Founded by VNA Users for VNA Users




In 2011, Copper Mountain Technologies (CMT) launched the industry's first metrology-grade USB VNA, offering a 21st-century alternative to vector network analyzers (VNAs) that have been used for S-parameter measurements since the 1960s. CMT identified that the bulky size, quickly aging built-in computers with outdated operating systems and the high cost of these instruments limited their accessibility for engineers as well as their use in many types of newly emerging applications outside of the traditional lab. Helping engineers solve problems with portable, affordable and very precise and metrologically supported VNA solutions was a much-needed and very attractive opportunity. Assisting engineers in solving their problems remains central to the CMT business model, and the company has changed the VNA industry by creating a new category of metrology-grade VNAs: USB VNAs with product and applications support that goes "beyond the box."

Today CMT offers more than 30 VNA models and various applicable test accessories. The company is headquartered in Indianapolis, where it manufactures many of its products. As a member of the Conexus Indiana Advanced Industries Council, CMT collaborates with the state of Indiana and other council members in advanced manufacturing initiatives. They have an R&D office and service center in Cyprus along with regional sales offices in Singapore, London and Miami. From these locations, CMT has provided cost-effective metrology-grade, portable USB VNAs to thousands of engineers in close to 100 countries around the world.

CMT differentiates with solutions that maximize engineering productivity. VNA software includes advanced features at no additional cost and a dedicated and highly engaged support team staffed with RF engineers helps customers identify optimized solutions. These solutions involve recommendations on measurement methodology, automation scripts and custom software development, in addition to measurement hardware to solve customer-specific challenges. CMT also collaborates with customers in creating custom VNA modules for applications where a standard VNA does not meet the need. As its customer base grows, CMT continues to expand its technical team in R&D and Service, where it has seen 100 percent growth since 2020 in the calibration team with two ANAB-accredited labs in the U.S. and Europe. The company is expanding its manufacturing capabilities to respond to specialized customer needs. CMT has more than doubled its facility square footage since 2020 with expansion in Indianapolis and the addition of the Cyprus office.

As equipment and testing needs become more sophisticated, testing is shifting away from traditional stationary testing to solutions that provide better SWaP-C. CMT's innovative USB VNAs enable RF engineers to benefit from this trend and expand VNA usage to a broader range of applications. CMT application-specific VNAs serve secured, IoT, smart device, connected transportation, automotive, medical device and diagnostic, 5G and other applications. The VNAs from CMT are easily embedded and integrated into whole test solutions, enabling innovative technology beyond traditional VNA uses.

The CMT product portfolio is diverse. The company offers 50 Ω VNAs in various port and frequency combinations up to 44 GHz. Their 6- to 16-port 9 GHz Multiport VNAs are one of the newest product offerings. CMT also has mmWave frequency extension systems. CMT 2- and 4-port VNAs can be utilized with CMT frequency extender modules for coaxial measurements from 18 to 54 GHz, waveguide systems in the WR15 to WR6 bands or other brands of frequency extenders up to 330 GHz. CMT also offers a range of 75 Ω analyzers and a host of 50 Ω and 75 Ω accessories.

The company's engineers use their own products every day and understand what engineers need. The traditional values of respect for customers and helping them achieve their objectives remain foundational elements of CMT's corporate mission.

**www.coppermountaintech.com**

WERLATONE
ENGINEERING EVOLVED

# DIGITAL RF POWER METERS

**Optimal Accuracy ✦ 40 dB Dynamic Range ✦ No Calibration Required**

## Simultaneously Monitor: Forward Power, Reverse Power, Load VSWR, & Temperature

## ACCURACY

- Multi-Octave Solutions provide accuracy within ± 5% of a Customer Lab Standard (± 2% Typical).

## CALIBRATION

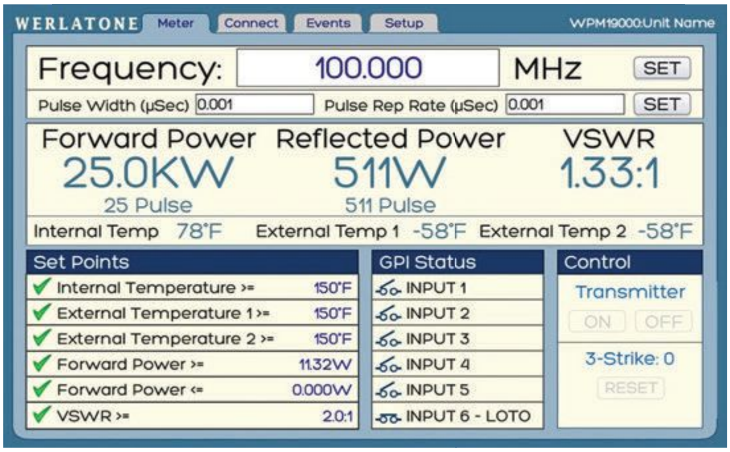
- No On-Site Calibration Required.
- Calibration Routine completed internally to each Power Sensor.
- Traceable to National Institute of Standards & Technology (NIST).

## ALARMS & RELAYS

- Alarm Thresholds of Forward & Reverse Power.
- Full VSWR Monitoring/Alarm Capability.
- Full Temperature Monitoring/Alarm Capability.
- Six General Purpose Inputs & 2 Form-C Relays to External Devices

## FIRMWARE

- Windows Application includes an ergonomic tab-based access system for easy setup and operation of the Power Meter.
- Multi-Window Display for access to up to five Meters on screen.
- VSWR Indication & Reflected Power on main Power Sensor display.
- MIB File available for use with SNMP software.
- LabVIEW Driver Available.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