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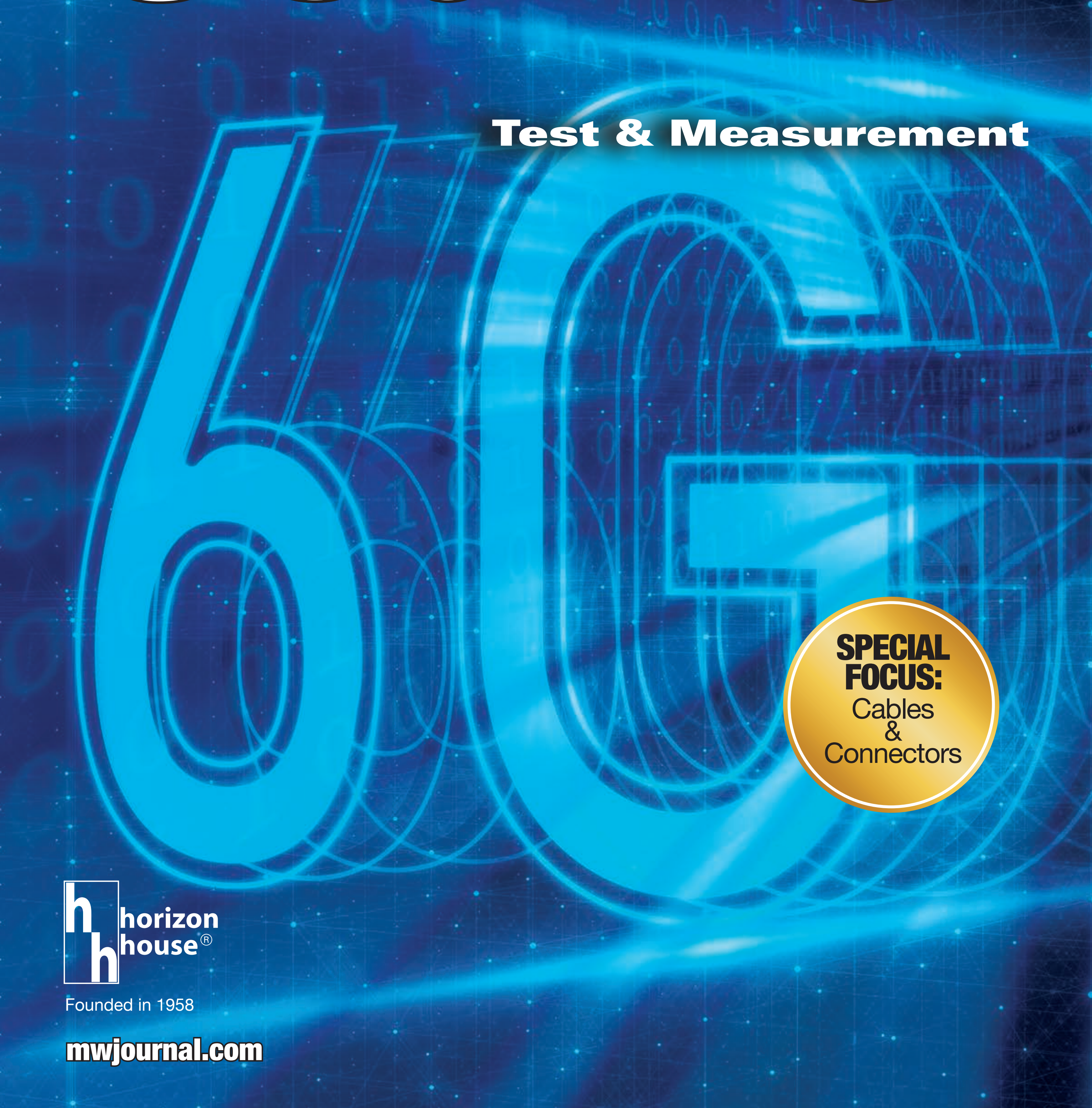

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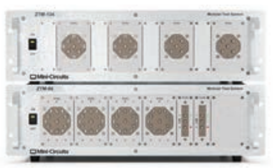

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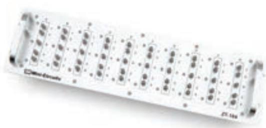

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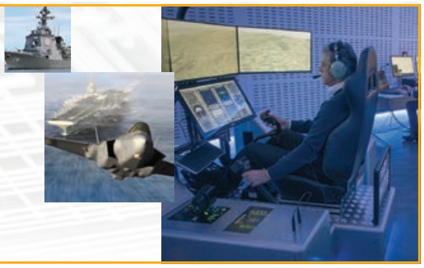

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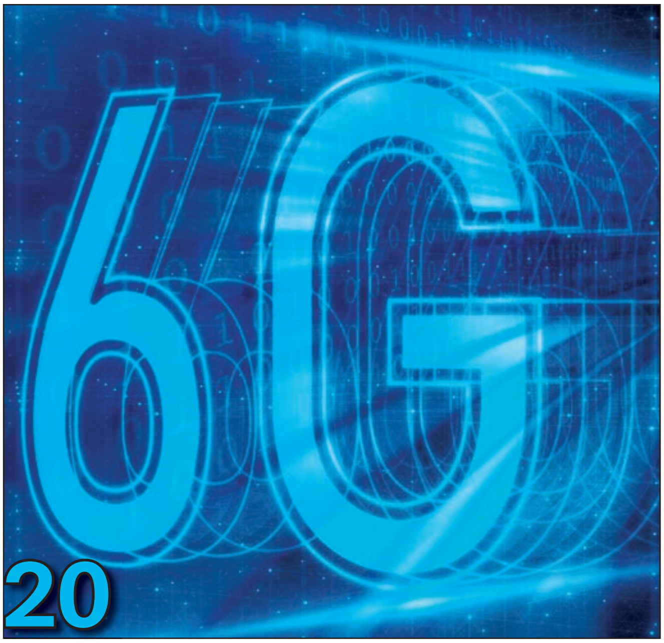

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A Quasioptic OTA Transmission at 285 GHz with 30 GHz Bandwidth

Greg Jue
Keysight Technologies, Santa Rosa, Calif.

6G aims to be the first generation of wireless technology to improve the quality of human life by bridging the physical, digital and mechanical worlds. Accomplishing this will mean adding artificial intelligence to networks to make them more efficient and building high fidelity digital twins. It will also require expanding spectrum use and building upon network architectures like non-terrestrial networks and highly virtualized disaggregated networks that began in 5G. For 6G to meet these goals, the spectrum allotted for wireless communications needs to be used more efficiently and new spectrum needs to be studied. Without expanding into new spectrum bands, it will be impossible to meet the high data throughput needs of applications like immersive telepresence, virtual reality and extended reality.

EXPLORING NEW SPECTRUM FOR 6G HIGH DATA THROUGHPUT RATES

The 220 to 330 GHz sub-THz frequency band can potentially use extremely wide swaths of contiguous spectrum. Although this spectrum could help increase data throughput, there will be significant RF and baseband challenges when using these extreme bandwidths. From an RF perspective, the achievable system performance is uncertain at such high frequencies and with such extreme bandwidths. As bandwidths increase with higher frequencies, the signal-to-noise ratio (SNR) decreases. Channel impairments, along with linear hardware amplitude and phase impairments, become significant compared with narrow bandwidth systems. Robust channel estimation and equalization become increasingly challenging in low SNR environments with significant channel impairments. Waveform quality decreases, limiting or precluding the use of higher-order modulation schemes. Overcoming free space path loss to maintain sufficient SNR for adequate link budget performance requires high gain, high directivity antennas such as phased array antennas or other techniques.

From a baseband perspective, channel estimation and equalization become increasingly complex for robust performance in low SNR scenarios. Receiver baseband algorithm implementations become challenging because of the higher sample rates needed to support extreme RF modulation bandwidths. Baseband resource parallelization increases to support high sample rates, quickly consuming baseband resources. At the same time, more robust and complex algorithms are necessary to perform channel estimation and equalization in low SNR scenarios over extreme bandwidths.

Sub-THz performance in the 220 to 330 GHz frequency band is relatively uncharted territory. There is limited availability of commercial off-the-shelf (COTS) hardware in this frequency band for early measurements. Relatively few publications show system-level RF performance, such as error vector magnitude (EVM) in this frequency band over wide or extreme modulation bandwidths.

This article presents two case studies to provide insight into system performance for the 220 to 330 GHz frequency band:

- **Conducted EVM** measurements provide insight into understanding what level of EVM performance is achievable over wide bandwidths with low SNR.

EVM measurements are performed with up to 30 GHz of occupied bandwidth, which corresponds to a bandwidth where data throughput approaches 100 Gbps for a single stream of data.[1] 6G applications will involve over-the-air (OTA) transmissions, but first performing conducted EVM measurements yields insights into best-case performance.

- **OTA EVM** measurements provide insight into understanding what level of OTA EVM performance is achievable over transmission distances. This article looks at a case study using quasioptic techniques for an OTA point-to-point transmission at 285 GHz with 30 GHz occupied bandwidth over a distance of 26.5 ft. (8 m) and discusses key findings.

GAIN INSIGHT WITH CONDUCTED EVM MEASUREMENTS

For this section, the Keysight sub-THz test bed shown in ***Figure 1*** was used to perform conducted EVM measurements with waveguide connected to waveguide.

Fig. 1 **Sub-THz test bed for 220 to 330 GHz.**

Test Bed Overview

The M8199A 128 GSa/s four-channel arbitrary waveform generator (AWG) generates wide bandwidth modulated IF signals. The M8199A AWG has an analog 3 dB bandwidth of 65 GHz. A Virginia Diodes Inc. (VDI) compact WR3.4 up-converter (N9029ACST-U03) converts the IF from the M8199A AWG to the desired sub-THz frequency. This up-converter uses a multiplication factor of either 6 or 12 for the local oscillator (LO) frequency (×12 version shown in this picture). An E8257D PSG analog signal generator with option UNY provides a low phase noise LO for the VDI up-converter and down-converter. A VDI-Erickson PM5B power meter with WR3.4 waveguide taper is used for power measurements.

On the receive side, a VDI compact WR3.4 down-converter (N9029ACST-D03) converts the sub-THz frequency to an intermediate frequency (IF), using a multiplication factor of either 6 or 12 for the LO frequency (×12 version shown in this picture). A high performance 110 GHz, four-channel UXR oscilloscope digitizes the IF signal. This UXR has a sample rate of 256 GSPS for each of the four channels.

This test setup uses either a VDI WR3.4 302 to 318 GHz waveguide bandpass filter or a VDI WR3.4 270 GHz high-pass filter for wider modulation bandwidth test cases.

Configure A 30 GHz Bandwidth Case For High Data Throughput

The symbol rate was set to 25 Gsps, which corresponds to a bandwidth where the theoretical raw calculated data rate approaches 100 Gbps without forward error correction (FEC) coding rate redundancy. This data rate arises from 25 G symbols per second multiplied by four bits per symbol for 16-QAM modulation, resulting in 100 Gbps for a single stream of data. The occupied bandwidth for this case is 25 Gsps × 1.22, with 0.22 root raised cosine alpha, resulting in 30.5 GHz. The actual data throughput was calculated to be 97 Gbps without FEC coding rate redundancy, using only the data payload symbols and excluding the symbols from the sync, SFD, CES, frame header and idle segments.

To improve the image suppression of the undesired lower image with the VDI 270 GHz high-pass filter, the M8199A IF was increased from 16 to 25 GHz. This higher IF improves the undesired lower image rejection by moving the undesired lower image spacing farther away from the desired upper image by 2 × IF or 50 GHz instead of 32 GHz using a 16 GHz IF. The undesired image occurs lower in frequency, where the high-pass filter skirt provides more rejection. The LO rejection also improved with a 260 GHz final LO with the 25 GHz

IF (25 GHz IF + 260 GHz LO = 285 GHz) instead of 269 GHz final LO (16 GHz IF + 269 GHz = 285 GHz). The LO feedthrough occurs lower in frequency, where the high-pass filter provides more rejection.

Figure 2 shows the VSA Flex Frame demodulation results, using a 25 GHz IF with the VDI compact WR3.4 up-converter and down-converter with an LO multiplication factor of 12. An external IF amplifier used on the VDI down-converter output increases the IF signal level into the UXR.

The conducted demodulation results using VSA Flex Frame show the measured 16-QAM constellation in trace A and the measured spectrum at 285 GHz in trace B. The blue-shaded region of trace B in the spectrum measures the occupied bandwidth of 30.5 GHz. Trace C shows the residual composite EVM measurement of 5.89 percent. Trace D, at the bottom, shows the Flex Frame summary for the sync, SFD, CES, frame header and data payload frame allocations.

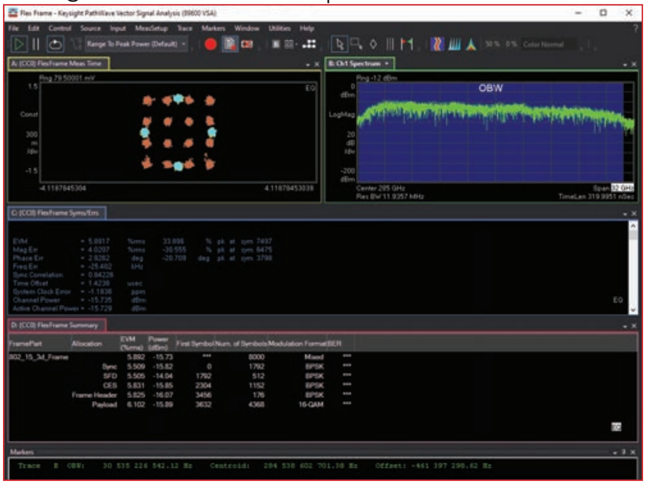

Fig. 2 VSA Flex Frame demodulation results at 285 GHz for 30 GHz bandwidth signal.

Gain Insight With OTA Measurements

The Keysight sub-THz test bed was used to investigate an OTA measurement at 285 GHz with 30 GHz bandwidth for a point-to-point transmission approaching 100 Gbps, transmitting over a distance of 26.5 ft. (8 m). High gain, high directivity antennas such as phased array antennas are necessary to overcome free space path loss. However, this was not possible because a 220 to 330 GHz phased array antenna was not available at the time of this experiment. Instead, quasioptic techniques were investigated using COTS lenses with performance specified to 220 GHz.

For this experiment, the test bed was split between a transmit section and a receive section. The transmit side of the test setup in ***Figure 3*** consists of the M8199A AWG to generate the 25 GHz IF signal.

An E8267D PSG signal generator with option UNY provides a low phase noise LO at 21.666 GHz for the VDI up-converter. A VDI compact WR3.4 up-converter converts the 25 GHz IF from the M8199A AWG to 285 GHz using a multiplication factor of 12 (21.666 GHz × 12 = 260 GHz). The VDI WR3.4 270 GHz high-pass filter rejects the lower undesired image (260 GHz LO - 25 GHz IF = 235 GHz) while passing the desired image (25 GHz IF + 260 GHz LO = 285 GHz). The 285 GHz signal passes through a VDI WR3.4 amplifier and is then transmitted OTA with a VDI WR3.4 diagonal horn antenna.

220 to 330 GHz lenses were not available at the time of this experiment, so 6-in. lenses were removed from a COTS G-Band Gaussian optics antenna assembly and 3D-printed fixtures were designed to mount the lenses to a track. A 3D-printed fixture was designed to mount the VDI converters, with careful consideration to align the center of the WR3.4 diagonal horn antenna with the center of the lens. Horizontal track mounts with hand brakes allow spacing adjustments between the diagonal horn antenna and the lens on the transmit and receive sides of the test setup.

Fig. 3 OTA quasioptic transmission at 285 GHz with 30 GHz bandwidth, transmit side.

QUASIOPTIC OTA TRANSMISSION

Figure 4 shows the concept of using lenses for quasioptic transmission. The radiating element of the transmitting source, a diagonal feed horn antenna sits at a distance Z_0 from the lens, the quasioptical focusing element. A beam waist, which is the minimum in the beam radius, occurs at distance Z_1 from the lens. The beam begins to diverge beyond the beam waist at Z_1. A more rigorous description of quasioptic systems can be found in Quasioptical Systems: Gaussian Beam Quasioptical Propagation and Applications.[2]

Quasioptic OTA Signal Analysis At 285 GHz With 30 GHz Bandwidth

The receive side of the test setup in ***Figure 5*** shows the receive lens, followed by a VDI WR3.4 diagonal horn antenna attached to the VDI compact WR3.4 down-converter. The final spacing between the transmit and receive lenses was 26.5 ft. (8 m) lens-to-lens spacing. Measurements for intermediate spacings from 3 to 13 ft. were also performed incrementally to achieve the final spacing. The E8257D PSG analog signal generator with option UNY provides a low phase noise LO at 21.666 GHz for the VDI down-converter. The E8257D PSG 10 MHz external reference is locked

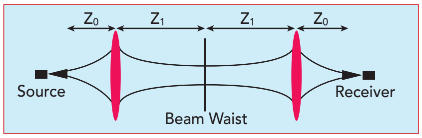

Fig. 4 Quasioptic transmission, assuming the same lenses and feed horns for the source and receiver.

Fig. 5 OTA quasioptic transmission at 285 GHz with 30 GHz bandwidth, receive side.

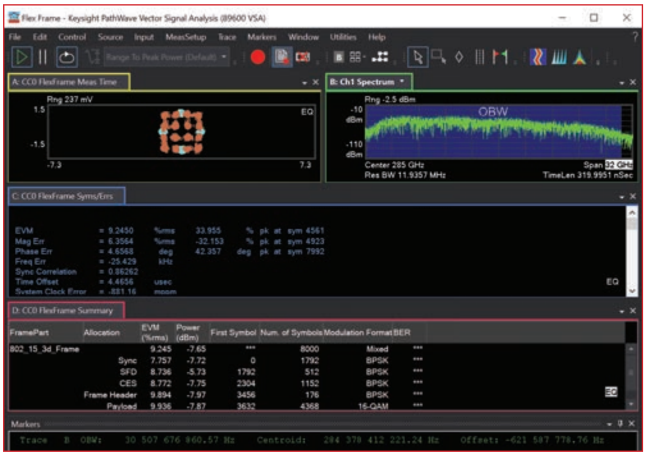

Fig. 6 VSA Flex Frame demodulation results for quasioptic transmission at 285 GHz with 30 GHz bandwidth.

to the E8267D PSG 10 MHz reference output on the transmit side. The 285 GHz signal is down-converted to a 25 GHz IF (285 GHz RF - 260 GHz LO = 25 GHz IF). The 25 GHz IF is amplified by an external IF amplifier, then digitized with a UXR four-channel high performance 110 GHz oscilloscope and demodulated using VSA Flex Frame software. The UXR 10 MHz external reference is locked to the two PSGs. A laser source mounted on the receive track performs the initial alignment of the receive lens with the transmit lens. Power measurements used an N1913PM5B VDI-Erickson power meter with the WR3.4 diagonal horn antenna connected to the sensor head and WR3.4 waveguide taper.

Figure 6 displays the OTA demodulation results us-

ing VSA Flex Frame, showing the measured 16-QAM constellation and measured spectrum at 285 GHz on the upper traces in trace A and trace B. For the OTA measurement, the Flex Frame normalized channel delay spread increased relative to the conducted case to address increased OTA channel delay. The blue-shaded region of the spectrum shown in trace B measures the occupied bandwidth of 30.5 GHz. Trace C shows the composite EVM measurement of 9.2 percent. The lower trace, trace D, shows the VSA Flex Frame summary for the sync, SFD, CES, frame header and data payload frame allocations.

The VSA Flex Frame software was enhanced to perform a two-pass channel estimation to address these challenging channel scenarios in low SNR environments. The first pass uses pilots and preamble to perform synchronization and initial channel estimation. The second pass adds data payload to perform channel estimation with pilots, preamble and data payload symbols, minimizing EVM over the specified number of symbols in the result length field.

Changing the number of data payload symbols included in the EVM measurement impacts composite EVM. The least mean square (LMS) equalizer attempts to minimize the EVM over the number of symbols specified, which is 8000 for this measurement. Symbols are noisy because of low SNR over the 30 GHz bandwidth, so the LMS equalizer algorithm has a more difficult estimation process as the number of symbols increases.

SUMMARY

The 220 to 330 GHz frequency band is relatively uncharted territory and there are many unknowns in understanding what level of system performance is achievable. Few publications show system-level RF performance, such as EVM in this band with 30 GHz bandwidth. The results shown here illustrate the achievable system-level performance and key challenges. This article presents two examples to increase insight into the achievable system performance in the 220 to 330 GHz frequency band:

- Conducted EVM measurements with up to 30 GHz of occupied bandwidth for the 220 to 330 GHz frequency band provide insight into the best-case achievable EVM performance.
- Quasioptic techniques for an OTA point-to-point transmission at 285 GHz with 30 GHz occupied bandwidth provide insight into the achievable OTA transmission distance. A distance of 26.5 ft. (8 m) was achieved, as shown in a video demo of this test setup.[3] ■

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To view the Keysight Test Setup Video Demo, please visit:
6G Testbed Over-the-Air Transmission using Sub-THz Quasi-Optic Techniques - YouTube at bit.ly/3JB1wWQ

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Cliff Drubin, Associate Technical Editor

Chilling Effect on Stacked Chips Could Ignite Computing at the Edge

As the future of microsystems technology converges around 3D heterogeneous integration (3HDI) microelectronics, the scientists, researchers and engineers working to advance the state-of-the-art, including at DARPA, are arriving at the same challenge: how can we pack the maximum computing into the smallest-possible space, and how can we manage the heat inherently generated by high-powered processing, especially in such a small space?

There's increasing recognition that 3DHI, which integrates different circuit types and materials in a 3D stack of tiers, promises tremendous performance advantages. However, thermal management technologies currently limit implementation. While stacking chips will be a critical part of the future of computing, challenges in dissipating the heat of internal processing components remains a barrier to significant progress.

"This is a key problem that we'll be trying to address, developing cooling technologies that will enable the 3DHI systems that are absolutely the key direction for continued growth in microelectronics," said Dr. Yogendra Joshi, program manager of DARPA's newly announced Miniature Integrated Thermal Management Systems for 3D Heterogeneous Integration (MiniTherms3D) program. "In any high-functional computing system, particularly as you make them more compact, there is heat you must get rid of. In a stack today, heat is transmitted to the top and/or bottom, transported away and ultimately rejected, typically to ambient air. High-powered 3D stacks are not currently possible because the interior temperatures would become unacceptably high and exterior heat rejection systems would be unacceptably large."

Dr. Joshi likened the stacks to high-rise buildings in which one floor is stacked on top of the other. The new cooling technology would enable cooling not just on the top and bottom floors, but throughout every floor of the "building."

IMSC Task Force Completes Maritime Exercise with Unmanned Systems, AI

The International Maritime Security Construct (IMSC) completed a three-day maritime exercise in the Arabian Gulf early this year, integrating unmanned systems and artificial intelligence (AI) during a naval drill for the second time in six months.

IMSC's operational task force, Coalition Task Force (CTF) Sentinel, completed exercise Sentinel Shield with U.S. Navy guided-missile destroyer USS Delbert D. Black (DDG 119) and two Saildrone Explorer unmanned surface vessels from U.S. 5th Fleet.

Saildrone (Source: U. S. Navy)

"We planned this exercise to demonstrate how AI and unmanned systems effectively increase CTF Sentinel's maritime domain awareness to maintain maritime security in Middle Eastern waters," said Royal Saudi Navy Capt. Alamri Assem, CTF Sentinel's director of plans.

During the exercise, unmanned and AI systems operated in conjunction with Delbert D. Black and CTF Sentinel's command center ashore in Bahrain. The systems were able to help locate and identify objects in nearby waters and relay visual depictions to watchstanders.

"Saildrones transmitted information on contacts of interest and our watch officers coordinated with the destroyer for further monitoring," said U.S. Navy Capt. Brian Granger, CTF Sentinel's deputy commander.

IMSC was formed in July 2019 in response to increased threats to freedom of navigation for merchant mariners transiting international waters in the Middle East. IMSC's operational arm, CTF Sentinel, was established four months later to deter state-sponsored malign activity and reassure the merchant shipping industry in the Bab al-Mandeb and Strait of Hormuz.

Airbus Launches European Defense Fund R&D Projects

Airbus has launched two defense research and development projects that it is coordinating as part of the 2021 European Defense Fund (EDF). In July 2022, the European Commission selected, among others, eight collaborative projects that Airbus is part of, covering different innovative technology areas. The EDF promotes cooperation among European companies and research institutes of different sizes and geographical origin in the EU, strengthening the resiliency and strategic autonomy of Europe.

Among the 61 collaborative defense R&T and R&D projects that were selected and funded with €1.2 billion, Airbus Defense and Space is coordinating the European Defense Operational Collaborative Cloud (EDOCC) project, while Airbus Helicopters is coordinating the EU Next Generation Rotorcraft Technologies Project (ENGRT). The contracts for these projects were signed in December 2022.

EDOCC will create a virtual platform to increase the interoperability, efficiency and resiliency of military operations, which will strengthen collaborative services on

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the battlefield. The project will study, design and conceptually validate the virtual platform and develop the first version of a services catalog while identifying appropriate standards and technologies for high performance and interoperability.

ENGRT will focus on analyzing and understanding the needs of European armed forces for rotorcraft operations beyond 2030. The project's partners will study military rotorcraft concept of operations and define key technologies needed for future military rotorcraft. Alternative rotorcraft concepts and architectures will be explored. This project will pave the way for the next generation of military rotorcraft in Europe.

Northrop Grumman Advances Scaled Electronic Attack Capability

Northrop Grumman Corporation has successfully demonstrated key components of the company's future Ultra-Lite Electronic Attack (EA) Prototype System. The demonstrations were conducted in collaboration with the U.S. Naval Research Laboratory (NRL) aboard a U.S. Navy Arleigh Burke class destroyer during the U.S. Navy's Rim of the Pacific (RIMPAC) exercise.

The Ultra-Lite EA System is a scaled-down, onboard EA system for anti-ship missile defense of smaller ships. Multiple EA capabilities that integrated the Northrop Grumman's transceiver technology with NRL's expeditionary EA antenna were successfully demonstrated over many RIMPAC exercise events.

"This at-sea demonstration proves Northrop Grumman's future low size, weight and power, scaled EA solution can effectively support U.S. Navy missions," said Monta Harrell, director, maritime electronic warfare advanced solutions, Northrop Grumman. "The lessons learned from the RIMPAC exercise provide real-world insights into our low-risk architectural solution for smaller ships that will revolutionize EA for the U.S. Navy."

Arleigh Burke (Source: U.S. Navy Photo)


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Cliff Drubin, Associate Technical Editor

Four Megatrends for 5G mmWave Technology in 2023 and Beyond

Continuous advances in artificial intelligence and machine learning, edge computing, robotics, IoT, Web3 and blockchain technologies, virtual reality (VR) and augmented reality (AR) and expanded 5G networks and services are among the promising highlights of a tumultuous year. 5G is gaining market traction that will accelerate in 2023 as wireless carriers expand deployments of networks at mid-band and increasingly mmWave frequencies. Here are the four megatrends Movandi believes will shape the future of 5G:

TREND #1: 5G has arrived and, when paired with mmWave technology, will begin to transform multiple industries in 2023.

Trials have consistently demonstrated that mmWave networks can deliver 5G performance, capacity and value to end users. Australia, Japan, India and other major new markets will come online in 2023. These markets present both economic challenges and huge opportunities to solve technical problems and unlock opportunities. 5G will not be a "one size fits all" market. Rather, 5G deployments will depend on unique areas of focus, such as fixed wireless access (FWA), network extensions and indoor/outdoor mobile use cases.

TREND #2: AR/VR and merged reality technologies will begin to emerge and bring a new focus on 5G networks for indoor applications.

According to a ConsumerLab report released by Ericsson, seven out of ten early adopters expect VR/AR technology to change everyday life fundamentally in six domains: media, education, work, social interaction, travel and retail. When it comes to mobile VR/AR platforms, size matters. We will see the rapid evolution of smaller, lighter and more cost-effective systems for merged reality applications. For the metaverse and merged reality to become mainstream, the tremendous bandwidth potential of 5G mmWave technology is essential to providing much-needed mobility, improving social experiences and addressing user comfort.

TREND #3: Smart repeater innovation will result in faster, more cost-effective 5G mmWave deployment.

Smart repeater technologies can dramatically reduce the complexity of mmWave network deployments while enhancing the end user experience and greatly reducing overall deployment costs. Repeaters will extend their utility beyond mmWave and begin to support mid-band frequencies. Propagation from outdoor to indoor environments is challenged in the mid-band, and widespread deployment of smart repeaters will help solve this challenge.

TREND #4: 5G FWA will make significant advances.

5G FWA platforms based on mmWave technology will gain traction in the U.S. market as multiple U.S. operators are looking to continue their growth in fixed wireless but have limited spectrum available to service their growth user base. At the same time, we will see growing enthusiasm for FWA as an effective means to deliver adequate broadband access to end users in countries where existing infrastructure is not capable of servicing cost effectively deployment. In countries like India, they have a huge untapped market of users who reside in densely populated areas, yet are lacking in the availability of more advanced services. 5G FWA holds great promise as a critical enabling technology that will help bridge the digital divide for people everywhere.

Distributed mMIMO, Radio Stripes, HBF Antennas and pCells Among the Revolutionary Technologies for Indoor Networks

With the majority of 5G networks being deployed using the 3.5 GHz bands, it is very likely to suffer indoor environments because outside-in does not provide adequate indoor coverage in the mid and high bands, 3.5 GHz and mmWave. In-building wireless solutions are critical for 5G's success in the consumer and enterprise markets. However, traditional solutions such as distributed antenna systems (DASs) do not support frequencies above 3 GHz and require major reconstructive engineering work to increase their capacity. The ever-growing need to increase network capacity and costly on-site infrastructure upgrades motivate infrastructure vendors to invest in other innovative technologies. According to a new report from ABI Research, some revolutionary technologies include distributed massive MIMO (mMIMO), radio stripes, holographic beamforming (HBF) antennas, pCell technology, open radio access network (RAN) DASs and reconfigurable intelligent surfaces (RISs).

Among the technologies, distributed mMIMO, HBF and pCell are already available and expected to be deployed on a larger scale in 2023. "Distributed mMIMO integrates mMIMO into indoor systems to enable gigabit connectivity and sustainable network capacity expansion. HBF antennas are tailored for mmWave and software-defined antennas to employ the lowest possible architecture in terms of SWaP-C. pCell technology exploits interference in wireless networks through large-scale coordination among distributed transceivers and synthesizes a cell for each user. It multiplies the spectrum capacity with uniform and high data rates in the entire coverage area," stated Fei Liu, 5G and mobile network infrastructure industry analyst at ABI Research.

"Moving toward 5.5G Open RAN DASs could be another technology where there are open interfaces between the radio units and virtualized RAN functions

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> In-building wireless solutions are critical for 5G's success.

operating on the cloud infrastructure, resulting in a reduction of the number of transmitter elements and, thus, the related power consumption, addressing one of the major issues that network operators face. In the longer term, RIS and radio stripes are viewed as promising for enhancing indoor coverage," Liu added. A RIS is nearly passive, does not have power amplifiers and does not transmit new waves. Hence, the power consumption is much lower. A radio stripe is another technology expected to improve network quality and performance while enabling easy network deployments.

Five-Year Open RAN Forecast Revised Upward

According to a recently published report by Dell'Oro Group, the Open RAN movement has come a long way in just a few years, propelling Open RAN revenues to accelerate at a faster pace than initially expected. These trends continued in 2022 and with this latest report, Open RAN expectations have been revised upward to reflect the higher baseline, supported by stronger than expected O-RAN progress in North America. Open RAN is now projected to account for 15 to 20 percent of global RAN by 2027.

Additional highlights from the January 2023 Open RAN Advanced Research Report include:

- The Asia Pacific and North America regions are projected to be the primary growth vehicles throughout the forecast period
- Since the last forecast, Open RAN projections have been revised upward in the North America region and downward in Middle East & Africa, Caribbean and Latin America and parts of the Asia Pacific
- Even with the slower start, European Open RAN revenues are expected to top $1 billion by 2027
- While the Open RAN movement is not confined to a specific technology, RF output power, spectrum band or deployment configuration, Open RAN macros are expected to drive the lion's share of the O-RAN capex, accounting for around 90 percent of the revenues throughout the forecast period
- Risks remain broadly balanced. On the one hand, the Open RAN movement continues to trend in the right direction. At the same time, preliminary data suggest Open RAN is having a minimal impact on the overall RAN supplier dynamics.

WR 3.4
220 - 330 GHz

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

MACOM has signed a definitive agreement to acquire assets and operations of **OMMIC SAS**. OMMIC SAS, located in Limeil-Brévannes, France, (20 km outside Paris) with approximately 100 employees, focuses in MOCVD epitaxial growth, expertise in wafer processing, fabrication and IC design; sub-100 nm GaAs and GaN processes in production; industry-leading mmWave products; and has 40+ years' experience in GaAs and GaN process development. MACOM's strategic rationale expands their technology portfolio with advanced semiconductor processes and products. It also increases wafer manufacturing with installed 6 in. capabilities, strengthens European footprint and access to customers and markets and has potential to expand SAM by approximately $100M.

Q-Tech Corp., a U.S.-based leading supplier of high-reliability crystal oscillators, announced the acquisition of **Axtal GmbH & Co. KG**, founded by Brigitte and Bernd Neubig 20 years ago—a German manufacturer offering frequency control products with world-class ultra-low phase noise capabilities. Both companies are technology leaders with an extensive selection of frequency and timing products specifically designed for aerospace, defense, avionics, high temperature, instrumentation and master clock applications and maintain a global sales presence throughout North America, Europe and Asia. The Q-Tech and Axtal product portfolios combined offer the full range of crystal oscillators: from basic clocks and temperature-compensated, to microprocessor-controlled and oven-controlled Quartz oscillators.

Infinite Electronics Inc., a global portfolio of leading in-stock connectivity solution brands, announced that it has completed the acquisition of **Cable Connectivity Group (CCG)** from Torqx Capital Partners and TKH Group NV. Headquartered in the Netherlands, CCG's brands operate across Europe, with offices and production and distribution facilities in the Netherlands, Germany, Italy, France, Belgium, Poland and China. Serving the global industrial and electronics markets, CCG's brands are leading suppliers of cables, ready-to-connect cable systems and accessories. They are comprised of the following brands: TKD, KC Industrie, Capable, Schrade Kabeltechnik, Jobarco, Pantaflex and ConCab.

NI confirmed that it has received a proposal from **Emerson** to acquire the company for $53 per share in cash, following a prior proposal from Emerson to acquire the company for $48 per share. As previously publicly announced by the company on January 13, NI's board of directors has initiated a review and evaluation of strategic options with the intent to unlock and maximize shareholder value. This strategic review process includes robust solicitation of interest from potential acquirors. NI's board of directors will evaluate Emerson's proposal within the context of the ongoing strategic review process, consistent with its fiduciary duties and in consultation with its financial and legal advisors.

Artemis, a Boston-based private equity firm focused exclusively on partnering with differentiated industrial tech manufacturers, has completed the sale of **KCB Solutions**, a manufacturer of specialty high-reliability RF and microwave technologies, to **Micross Components**, a provider of high-reliability microelectronic product and service solutions for aerospace, defense, space, medical, industrial and other applications. For 20 years, KCB has been applying its company culture of innovation, precision and quality proprietary technology to the manufacturing of highly engineered switches, amplifiers and attenuators. KCB's customers in defense and space rely on KCB's advanced microwave semiconductor technologies to serve mission-critical applications that require the highest levels of reliability, accuracy and ruggedness.

COLLABORATIONS

ipoque GmbH, a **Rohde & Schwarz** company, cooperates with **Chemnitz University of Technology** on a research project on cybersecurity and digital sovereignty. In doing so, ipoque is working on another technical innovation as a market leader in deep packet inspection. The project centers around protection from distributed denial of service and jamming attacks. Currently, there are only a few practical solutions for this problem. This gives ipoque the opportunity to be among the first with a fitting solution on the cybersecurity market.

Spark, New Zealand's largest telecommunications and digital services provider, together with **Ericsson** and **Red Hat** announced the successful completion of a 5G Standalone (SA) trial in New Zealand. The trial was delivered within an impressive three-month timeframe, demonstrating the ease with which standalone cloud-native solutions can be deployed. The 5G SA trial was underpinned by Ericsson's cloud-native 5G Core running on Red Hat OpenShift, integrated with Spark's 5G Fixed Wireless Access Network to test enhanced wireless broadband. The trial successfully confirmed and validated the technical capabilities of 5G SA technology on Spark's network.

Picocom, a 5G Open RAN baseband semiconductor and software specialist, has announced that **Antevia Networks** has selected Picocom's award-winning Si technology to empower its new innovative 5G in-building solutions. The partnership combines Antevia Networks' technology with Picocom's latest generation 5G system-on-chip Si to drive innovations to address the many challenges of deploying indoor 5G private networks. The all-new Antevia Networks 5G solution delivers a cost-effective 5G private network deployment that enables intelligent routing of coverage and capacity within buildings or campuses to accommodate variable demand or simply to provide highly reliable 5G connectivity.

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KBK-HP-1100	10 - 1000	10	0.5	1.2 / 1.4	17 / 15	5
KDK-HP-255	20 - 550	20	0.4	0.25 / 0.35	23 / 18	27.5
SDCHP-255	20 - 550	20	0.4	0.25 / 0.35	23 / 20	27.5
SDCHP-335	30 - 350	20.1	0.85	0.24 / 0.32	24 / 20	75
SDCHP-484	40 - 840	19.2	0.9	0.3 / 0.4	24 / 20	30
SCCHP-560	50 - 560	14.6	0.7	0.48 / 0.65	23 / 20	75
SCCHP-990	90 - 900	15.2	0.6	0.52 / 0.64	20 / 17	38.3
SBCHP-2080	200 - 800	12.3	0.7	0.64 / 0.80	24 / 18	48.3
SBCHP-2082	200 - 820	11.0	0.5	0.74 / 0.9	22 / 19	22.5
KDS-30-30-3	27 - 512	27.5	0.75	0.3 / 0.4	23 / 15	50
KDS-30-30	30 - 512	27.5	0.75	0.3 / 0.4	23 / 15	50
KBK-10-225	225 - 400	11	0.5	0.6 / 0.7	25 / 18	50
KBS-10-225	225 - 400	10.5	0.5	0.6 / 0.7	25 / 18	50
KDK-20-225	225 - 400	20	0.5	0.2 / 0.4	25 / 18	50
KDS-20-225	225 - 400	20	0.5	0.2 / 0.4	25 / 18	50
KEK-706H	500 - 2500	31.5	2.5	0.28 / 0.4	18 / 12	100
SCS-8012D	800 - 1200	20	0.6	0.22 / 0.25	22 / 18	100
KEK-704DH-2	850 - 1250	30	0.25	0.20 / 0.30	28 / 25	500
KEK-704H	850 - 960	30 5	0.25	0.08 / 0.20	38 / 30	500
SCS100800-10	1000 - 8000	10.5	2	1.2 / 1.8	8 / 5	25
SCS100800-16	1000 - 7800	16.8	2.8	0.7 / 1	14 / 5	25
SCS100800-20	1000 - 7800	20.5	2	0.4 / 0.75	12 / 5	25
SCS-1522B	1500 - 2200	10	--	0.65 / 0.75	23 / 18	100
SCS-1522D	1500 - 2200	20	--	0.32 / 0.38	23 / 20	100
SCS1701650-16	1500 - 15500	17	2.5	1 / 1.4	16 / 5	25
SCS1701650-20	1700 - 15000	21	2.5	0.9 / 1.3	10 / 7	25
SDC360440-10	3600 - 4400	8.6	0.25	0.7 / 1.4	18 / 10	10
SDC360440-20	3600 - 4400	19	0.25	0.7 / 1.2	16 / 10	10

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Around the **Circuit**

Nokia, NTT DOCOMO, INC. and **NTT** announced that they have achieved two key technological milestones on the path to 6G. The first is the implementation of artificial intelligence (AI) and machine learning (ML) into the radio air interface, effectively giving 6G radios the ability to learn. The second is the utilization of new sub-terahertz (sub-THz) spectrum to dramatically boost network capacity. The AI-native air interface and sub-THz spectrum are both critical research topics that Nokia, DOCOMO and NTT are exploring for future 6G networks. These technologies could pave the way for new immersive metaverse and extended reality (XR) experiences and a new generation of mobile applications.

ACHIEVEMENTS

CAES announced its recent award to perform on the Extremely Wideband Radio Frequency Spectrum Operations (EWO) System. The new award is an extension of an ongoing partnership with **MITRE** and the **U.S. Air Force**. Under the contract, CAES will deliver solutions for design and development of dual system-in-package circuit card assemblies and will continue to improve performance of the microelectronics-based wideband digital antenna array. CAES Missiles Advanced Technology and Engineering, based in Colorado Springs, Colo., develops cutting-edge RF, analog, digital hardware and software solutions for complex commercial and defense industries.

D-Link has selected **Airgain** embedded antennas to power the Wi-Fi 6 signal in its DWA-F18 VR Air Bridge. The VR Air Bridge was built exclusively for virtual reality (VR) headsets without the hassle of long cables or dependence on a Wi-Fi router. It was designed to provide a dedicated, ultra-low latency wireless connection between the PC and the VR headset in order to enhance the overall VR gaming experience. Airgain is a leader in embedded Wi-Fi antennas, powering many customer-premise equipment devices available in the market today. As wireless connectivity becomes more complex, Airgain's custom design, testing and optimization services simplify the ability to deliver maximum signal in any environment.

Altum RF announced an expanded scope to its recertification to ISO 9001:2015 for the quality management system. The renewed registration demonstrates Altum RF's commitment to excellence in the design and development of semiconductor products, along with areas of manufacturing and sales. This expanded scope also validates the company's unwavering dedication to regularly supplying high-quality and reliable semiconductor components to customers worldwide.

Maury Microwave announced that it has received International Organization for standardization (ISO)/IEC 17025:2017 accreditation from **Perry Johnson Laboratory Accreditation Inc**. Per the ISO, ISO/IEC 17025 enables laboratories to demonstrate that they operate competently and generate valid results, thereby promoting confidence in their work both nationally and around the world. ISO/IEC 17025 covers staff qualifications and skills, availability and use of equipment, calibration certificate content, measurement traceability and uncertainty analysis. Reporting on measurement uncertainty is an integral part of ISO/IEC 17025 and instills confidence in your measurements.

Liberty Defense Holdings Ltd., a technology provider of detection solutions for concealed weapons and threats, announced it has sold its first HEXWAVE™ system to **LINEV Systems US Inc.**, a provider of contraband detection security solutions to the corrections and other high-security markets. LINEV Systems plans to use the HEXWAVE unit for client demonstrations and act as a reseller for Liberty with a focus on the corrections and education verticals. LINEV Systems, which is part of the global LINEV Group, has been an industry-leading provider of X-ray imaging checkpoint security technology for over 15 years, including AI-driven X-ray security screening, benchtop scientific instruments and X-ray non-destructive testing systems.

Advanced Test Equipment Corporation (ATEC) has recently been recognized by local media outlet **NBC** as one of the top contributors to the ARTEMIS program by **NASA**. ATEC is one of a few San Diego companies that played a key role in supporting the NASA team in launching ARTEMIS. The key contribution from ATEC is supporting the EMC testing that happens on the Orion spacecraft at the Neil A. Armstrong Test Facility in Ohio. The project has been ongoing for five+ years in which ATEC has provided equipment, including advanced amplifiers, to accomplish multiple radiated immunity tests. NASA, and their subcontractor Lockheed Martin, have depended on the continued support from ATEC to meet testing deadlines and receive equipment quickly.

NEW STARTS

KYOCERA AVX has introduced a new circuit matching service designed to help customers quickly and confidently select suitable crystal timing devices. When oscillator circuits aren't optimized for customers' ICs or timing devices, it can result in abnormal oscillation or even prevent oscillation, which could lead to device failure. The new online circuit matching service identifies KYOCERA AVX crystal timing devices recommended by leading global IC manufacturers to ensure that customers choose compatible timing devices. This assurance delivers critical benefits including improved oscillation start-up times and stable oscillation with higher gain margins, which are especially valuable in automotive industry designs.

CONTRACTS

Epirus, a high-growth technology company, announced a $66.1 million contract award from the **U.S. Army's Rapid Capabilities and Critical Technologies Office (RCCTO)** in support of the Indirect Fire Protection Capability-High-Power Microwave Program. As part of the Other Transaction Authority, Epirus collaborates with the RCCTO to rapidly deliver several prototype systems of Leonidas for $66.1 million in 2023 with options to acquire additional support services. Epirus plans to deliver and support prototypes of integrated HPM capability

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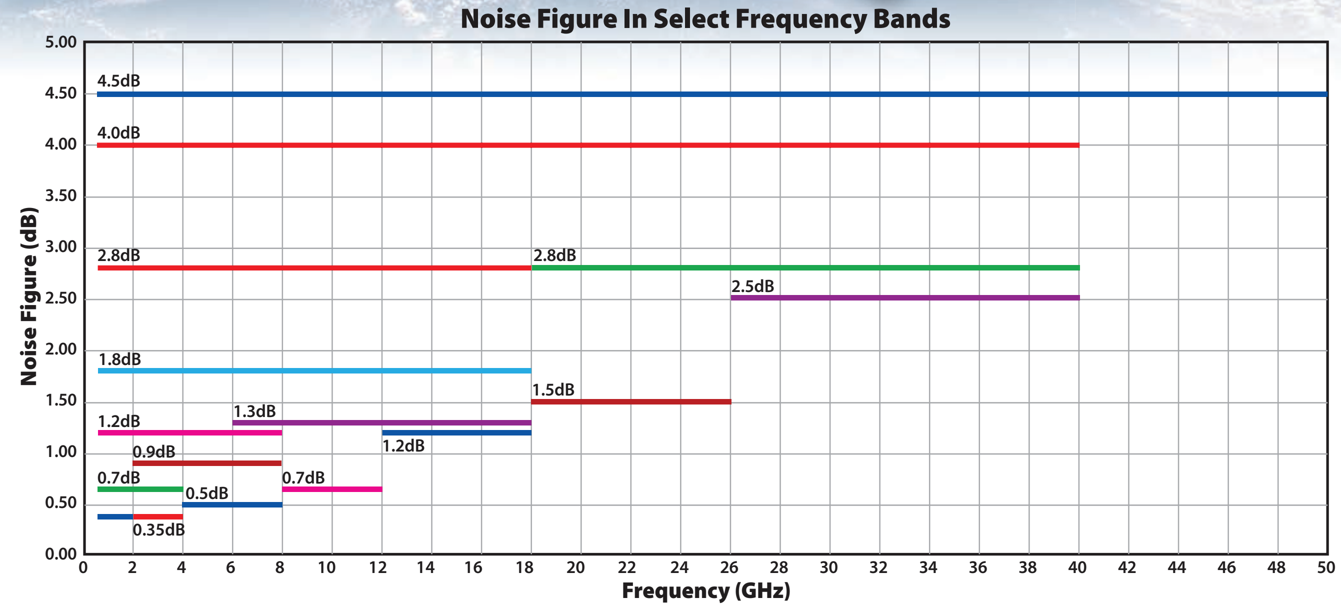

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Around the **Circuit**

and, as part of the contract's design, work with the RCCTO to transition Leonidas into a future program of record after successful demonstration of the prototypes.

Gilat Satellite Networks Ltd. announced that the company was awarded a multimillion-dollar contract for the expansion of satellite communications (satcom) capabilities on trains in Asia-Pacific. Gilat's ER7000 satcom on-the-move antennas were chosen by a leading integrator, for installation on trains to provide continuous internet access to passengers traveling across the Asia-Pacific region. Throughout the world, Gilat's field-proven ER7000 antennas have been deployed to empower satcom on-the-move applications. They provide reliable, high performance broadband connectivity for vehicles and rail travel, maximizing throughput with high efficiency in a low-profile system with minimal size and weight.

Airbus has signed a contract with the **Belgian Ministry of Defence** to provide tactical satellite communications services for a 15 year period. The armed forces will utilize channels of the Airbus ultra-high frequency (UHF) military communications hosted payload on-board a commercial telecommunications satellite manufactured by Airbus. As the UHF frequency band is a relatively scarce orbital resource, this offering will make up for the capacity shortage around the world. Airbus has already signed several firm orders for this capacity, well ahead of the satellite's scheduled launch. The UHF payload will be operated from Airbus's Network Operations Centre in Toulouse.

Viasat Inc. announced it was awarded a contract to provide end-to-end satcom support through a fully managed service to the **U.S. Marine Corps (USMC)**. The contract is an extension following a successful pilot and follow-on service program in the government's FY22 through which Viasat delivered a fully managed satcom as a managed service (SaaMS) solution to the USMC I Marine Expeditionary Force (I MEF), the Marine Corps' largest warfighting organization. This is the first commercially developed SaaMS implemented by a USMC command. Under this fully managed satcom service, Viasat has provided I MEF with a resilient beyond-line-of-sight communications capability that is both scalable and rapidly deployable to meet contract and operational requirements.

PEOPLE

▲ *Moran David*

GPR, provider of Ground Positioning Radar™ for precise vehicle localization, announced its next CEO is **Moran David**. David will lead the company through its next phase of growth and global product deployment and will join GPR's board of directors. Tarik Bolat, co-founder and former CEO will step away from day-to-day involvement but will remain

Around the **Circuit**

involved with the company as an advisor. David is a well-respected advanced driver assistance systems and autonomous vehicle leader, bringing over 25 years of marketing, sales and operations leadership experience, including nearly a decade of automotive experience, to his new role.

▲ *Chae Lee*

Tagore Technology Inc. announced the appointment of **Chae Lee** as CEO. Lee brings more than 35 years of experience to Tagore Technology. Prior to joining Tagore, Lee was president and CEO of Insyte Systems. Before that, Lee was senior vice president and general manager of NXP's Secure Interface and Power Solutions Business Unit where he grew the business unit's revenue to $1B.

▲ *Joseph Dominiak*

Stellant Systems Inc. announced the promotion of **Joseph Dominiak** to general manager of the Folsom, Calif., facility. In this role, Dominiak has responsibility for driving operational performance at the Folsom, Calif., site and reports to Steve Shpock, COO. Dominiak has over 30 years in program management and engineering leadership in the aerospace and defense industry. He started his career in the organization in 2009 as a program manager at Stellant's Torrance, Calif., facility. In 2016, he transferred to the Folsom, Calif., as senior director of programs.

▲ *David Horton*

mmTron Inc. has announced the appointment of **David Horton** as vice president of sales and business development. He oversees the semiconductor MMIC innovator's revenue pipeline as a leading fabless designer of mmWave broadband products for the satcom, 5G/6G, aerospace and defense markets. Horton brings more than two decades of experience in global strategy, sales and equipment manufacturing in the aerospace and satellite industries, working for industry leaders such as Panasonic, TECOM Industries, ORBIT Communication Systems and microwave/RF firm EMS Technologies, now part of Honeywell.

▲ *Stacy Smith*

Wolfspeed Inc. announced that **Stacy Smith** has been appointed to the company's board of directors, effective January 23, 2023. Smith is the executive chairman of Kioxia Corporation (formerly Toshiba Memory Corporation), a leading flash memory company, and non-executive chair of the board at Autodesk, Inc., a leader in design and make technology.

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CELEBRATING THE 80TH BIRTHDAY OF A LEGEND

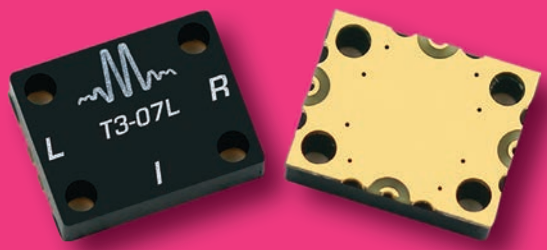
FERENC MARKI
The Godfather of Mixers

Ferenc Marki is not only the founder of Marki Microwave—he is also the Godfather of mixers. He recognized early on that the microwave industry had entered an era of specialization. Gone were the days of vertical integration where engineering design, manufacturing and testing could all be performed under one roof, or within a single company. For better or worse, the industry had become increasingly bifurcated, where engineering and manufacturing were seen as separate entities and outsourcing was all the rage.

> "As a designer in this industry, I was discouraged but the entrepreneur in me was thrilled. I saw an opportunity to build a better mousetrap, and that we did."

Ferenc is known to often tell this story to younger engineers because it teaches a valuable lesson: ***when you stop innovating, you go hungry***. In this case, all the major semiconductor manufacturers at the time assumed 1970s mixers could solve the problems of the 1990s and beyond. Once the commercial microwave business emerged in the mid-90s, and subsequently propelled Marki Microwave into prominence, it was clear that the mixer technology of the day was insufficient to solve modern problems.

"I had to invent new mixers to satisfy my new, expanding customer base. Because I was able to push the boundaries of microwave technology by building increasingly broadband, high-performance mixers, Marki Microwave thrived while my competitors and former employers began to disappear." Hence, the T3 mixers were born.



T3-07LCQG is considered by many as the preeminent T3 mixer.

GAME CHANGER

The T3 represents a true paradigm shift in mixer technology. Perhaps the greatest achievement of the T3 is the fact that much of the existing dogma surrounding mixers had been turned upside-down. Since the 1960s, mixer experts had promoted the following ideas:

1. *Mixers require specific LO drive over a range of approximately 3 dB.*
2. *Mixers compress 5-7 dB below the LO drive.*
3. *Mixer spurious performance does not always improve with increasing LO.*
4. *Mixer IIP3 is approximately 1-2 dB above the optimal LO drive.*
5. *Sine wave LO drive is acceptable, square-wave LO drive does not improve mixer performance significantly.*

Ferenc agreed with all the above statements, assuming the discussion was restricted to double balanced mixers. For the T3 mixer, new rules applied:

1. *T3 mixers can operate with any LO drive above about +13 dBm.*
2. *T3 mixer compression is approximately equal to the LO drive itself.*
3. *Increasing the LO drive always improves spurious performance in a T3.*
4. *Increasing the LO drive always improves the IIP3 of a T3. IIP3 is approximately 10-15 dB higher than the LO drive.*
5. *Square-wave LO drive is always better than sine wave drive for a T3.*

TECHNOLOGY TRAILBLAZER

A trailblazer in his own right, Ferenc's technology remains embedded in the fabric of Marki Microwave. The company continues to develop the T3 technology to reach an ever-increasing customer base. In time, it is conceivable that most of the legacy mixer technology available today will be superseded by the T3 and its offspring technology. For these reasons, the T3 is truly a mixer for the 21st century.

Chris Marki, Ferenc's son and current Marki Microwave CEO, sums things up the best: "There is no precursor to my father or his contributions to the microwave industry. Because of him, Marki Microwave is able offer products that would have been impossible years ago. Our generational continuity and historical perspective are key competitive advantages over our competition."

To view Marki Microwave's products visit www.markimicrowave.com.
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INVITED PAPER

Overcoming Planar Phased Array Circuit Design Challenges

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

This article details the design and layout challenges associated with the electronic design of planar phased arrays and focuses on an RF front-end containing power amplifiers (PAs), low noise amplifiers (LNAs) and beamformers. The printed circuit board (PCB) layout discussion highlights a single cell, consisting of a beamformer surrounded by four transmit/receive (Tx/Rx) modules. Thermal management challenges are discussed, including component side heat sinking and heat sink cavity design with RF absorbers to avoid oscillations.

Two-dimensional planar phased array systems, where the RF circuitry and the antennal elements are on the opposite sides of the same PCB as shown in ***Figure 1***, offer a significant size advantage over 3D blade-style structures. But that size advantage brings layout, power management and thermal challenges. This article will explore how some of these challenges can be dealt with using well-planned device functionality and interfacing, careful PCB layout that maximizes the usage of the limited available space and novel heat sinking techniques.

Phased array radar systems consist of many sections. These include the software and FPGA, ADCs and DACs, up-/down-converters, RF and beamforming circuitry and the phased array antenna elements. This article concentrates on the RF front-end and beamforming. In modern radars, the variable phase and amplitude blocks are consolidated into a beamformer integrated circuit (BFIC), with each BFIC containing several variable amplitude and phase blocks. Also, the PA, LNA and Tx/Rx switch can be integrated into a single Tx/Rx module and be optimally designed to work directly with the BFIC.

Fig. 1 The component side of a planar phased array front-end prototyping board.

PCB LAYOUT

Phased array radar systems can vary in element count and size, from a 2 × 2 prototyping subarray to arrays that have 256, 512 or even 1024 elements. The array layout can be simplified down to a unit cell, typically connected to four elements. The cell size primarily depends on the lattice spacing, usually one half-wavelength (λ/2) so that no grating lobes appear for beam steering to the aperture horizon. Sometimes lattice spacing slightly greater than λ/2 is chosen for larger antenna gain and thinner beamwidths, this reduces the beam steering range without grating lobes. The location of the BFIC and Tx/Rx modules is usually constrained within the lattice spacing.

Cell Layout

An example cell layout on an Analog Devices planar phased array system board

is shown in ***Figure 2***. It features a four-channel BFIC with four Tx/Rx modules surrounding the BFIC. The layout goals of the cell were to make the lattice spacing 15 mm (λ/2 at 10 GHz) and length-match the RF Tx and Rx lines going from the BFIC to the four TR modules. The 10 GHz frequency was chosen for λ/2 as it is at the center of X-Band, where many radar systems are operated, along with some satellite communications systems. Length matching of the Tx and Rx interconnect lines between the BFIC and the Tx/Rx module reduces the burden on calibration.

The glueless interface between the BFIC and the four Tx/Rx modules results in almost no external components on the Tx, Rx or coupler lines going to the power detectors. This makes the layout routing efficient, which is shown in Figure 2. The glueless interface, along with the Tx/Rx module chips orientated at 45 degrees off-axis relative to the BFIC, easily enables the length-matched routing of the Tx and Rx lines, while also maintaining the 15 mm lattice spacing. ***Figure 3*** shows the other side of the PCB, which contains RF connectors at 15 mm lattice spacing. In a real-world planar system, these connectors would be replaced with patch antennas.

Supply decoupling capacitors are kept at a minimum on this cell layout. The majority of the supply decoupling is for the BFIC. The Tx/Rx modules also have supply decoupling on the board, but most of these capacitors are technically not needed due to internal supply decoupling. Additional capacitors on the board were a conservative design decision and the 15 mm lattice spacing provided enough board space for these capacitors.

Another important goal of the cell layout was to keep the switching transients on the bias lines to a minimum so that switching times

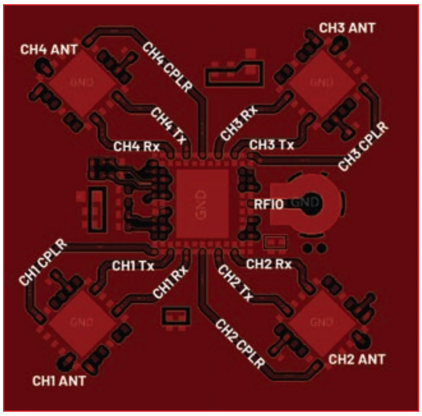


Fig. 2 A layout of one X-Band cell (top layer only).

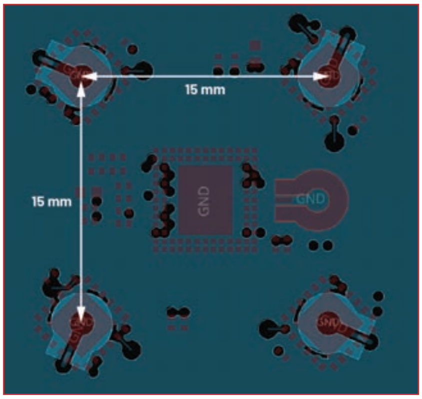
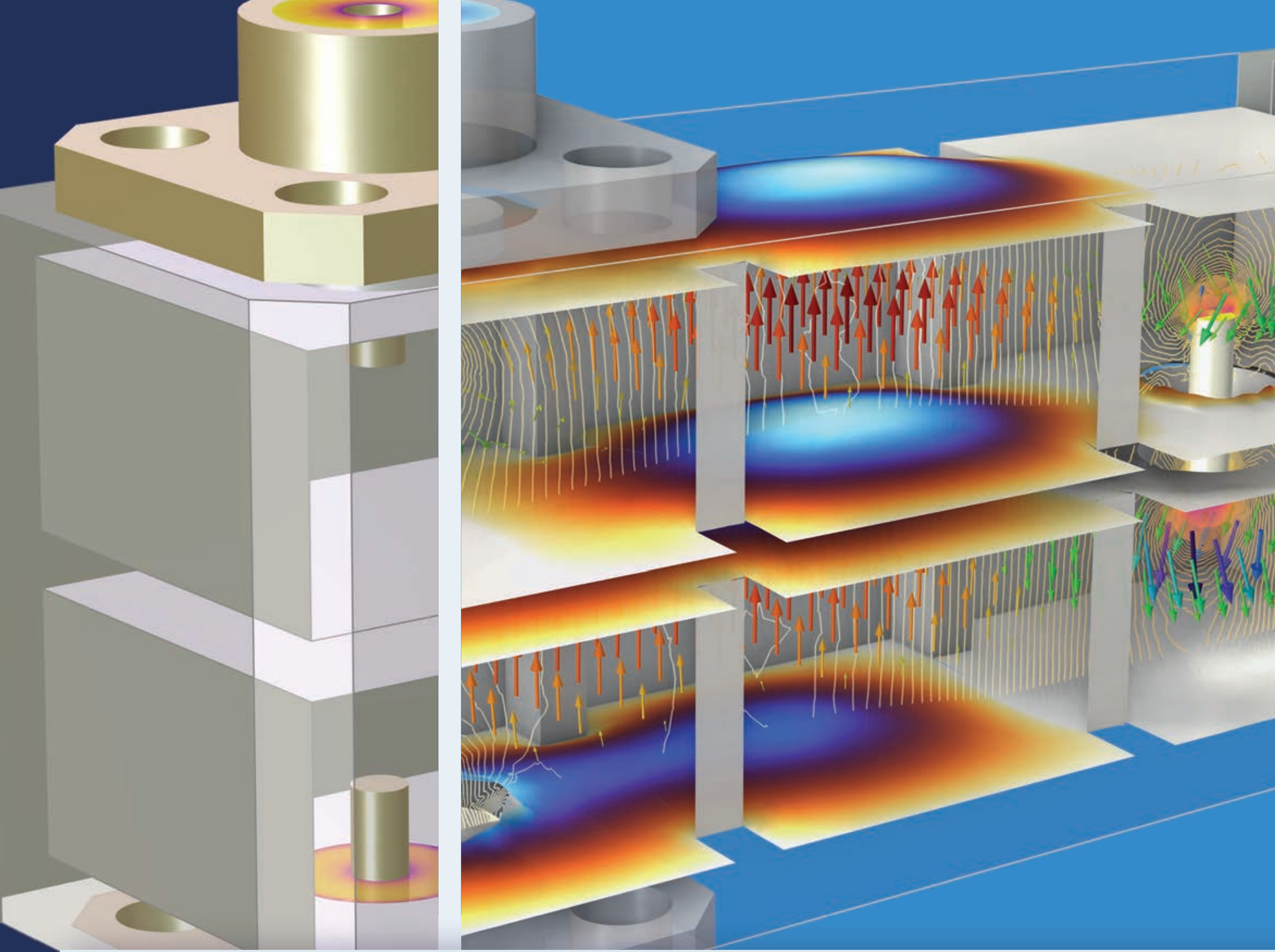


Fig. 3 Top and bottom layers showing locations of SMPM connectors (Layer 1 pins superimposed for reference).



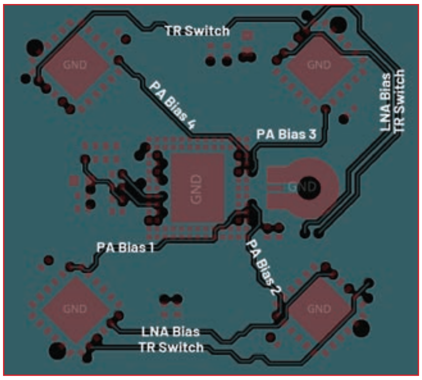


Fig. 4 Layer 4: PA bias, LNA bias and TR switch control routing (Layer 1 pins superimposed for reference).

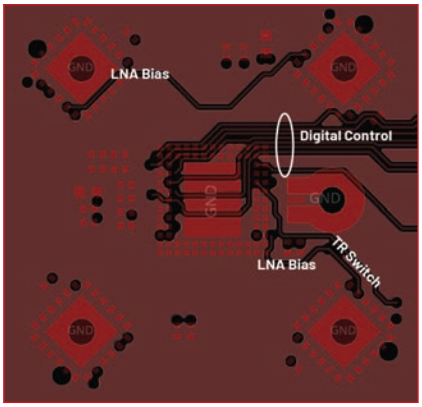


Fig. 5 Layer 5: LNA bias, TR switch control and digital routing (Layer 1 pins superimposed for reference).

could also be minimized. This was accomplished by keeping the length of these lines as short as possible to reduce line parasitics. With the RF lines and supply decoupling on the top layer, the PA bias and LNA bias lines from the BFIC to the Tx/Rx module had to be routed on the PCB inner layers 4 and 5. The various digital control lines to the BFIC from the microcontroller were routed on Layer 5, which is shown in ***Figure 4*** and ***Figure 5***. On larger arrays with necessarily longer trace runs between the controller and BFICs and/or higher clock speeds, signal integrity simulations must be done to account for all trace propagation delays and ensure all digital timing is correctly synchronized.

On the Analog Devices planar phased array system board, the RFIO trace is short and immediately goes to a connector; thus, its isolation to other ports is high. However, on a real-world planar phased array application board, care must be taken when routing the Tx/Rx module antenna ports and the RFIO port, particularly the Channel 2 antenna and Channel 3 antenna ports shown in Figure 2 as they are on the same side of the cell layout as the RFIO port. While in transmit mode, the paths have higher gain relative to Rx mode and the isolation requirement between the paths is higher to prevent instability and oscillations.

THERMAL MANAGEMENT

In a planar phased array system with the antenna array on one side of the board and components on the other side, the heat sink must be located on the component side of the board. This presents a challenge for generating a thermal management solution that will effectively remove a sufficient amount of heat from the various components, particularly the PAs, so that none of the components exceeds its maximum junction temperature.

Options for Heat Management in a Planar Phased Array Antenna

With the antenna array's location on the back side of the board, the thermal management solution cannot rely solely on the heat being pulled from a component's ground paddles through thermal vias to a back side-mounted heat sink. Instead, the heat must flow directly from the top side of the component or it must travel indirectly through the base of the component into the PCB, moving laterally before coming back out to a component side heat sink. This is shown in ***Figure 6a*** and ***Figure 6b***. There are two possible options for heat conduction away from the components:

- The heat sink contacts large amounts of area of the top (component) side ground layer
- The heat sink contacts the top side of the components.

The heat sink design largely depends on the power dissipation and thermal resistance values of the components. Most components have a low junction-to-case bottom thermal resistance ($\theta_{JC\text{-}BOTTOM}$) and relatively high junction-to-case top thermal resistance. So, the scheme shown in Figure 6a is generally more effective.

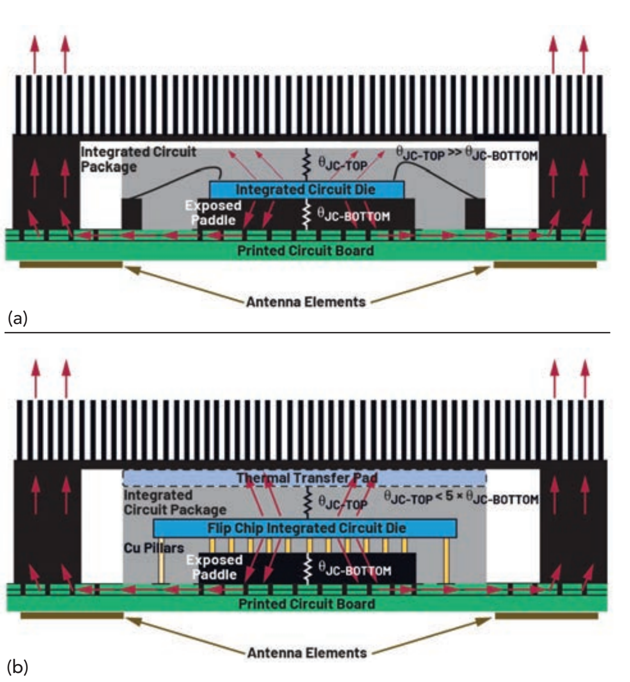


Fig. 6 Component side heat-sinking with an LFCSP package with heat flowing primarily through the bottom of the package (a). Component side heat sinking with a copper-pillar flip-chip LGA package with heat flowing through the top and bottom of the package (b).

Fig. 7 A planar phased array front-end with component side heat sink.

The question becomes whether to additionally contact the top side of the components or not. If the junction-to-case top thermal resistance ($\theta_{JC\text{-}TOP}$) is of the same order of magnitude as $\theta_{JC\text{-}BOTTOM}$ (for example, $\theta_{JC\text{-}TOP} < 5 \times \theta_{JC\text{-}BOTTOM}$) having the heat sink also contact the top side of the component packages would provide an additional useful parallel path for heat conduction. The metal of the heat sink should not contact the top of the package directly as this may cause mechanical stress. Instead, a piece of thermally conductive tape or a thermal transfer pad should be used as shown in Figure 6b.

A real-world example of component side heat sinking of a planar phased array is shown in ***Figure 7***. This is the same planar phased array front-end board shown in Figure 1, only with the heat sink attached. Thermal conducting compound can be seen at the interface between the heat sink and exposed ground metal on the board (the white material along the edge of the heat sink). Also, note the absence of fins in strategic areas to allow access to the RF input/output ports of the ADAR1000 BFICs.

HEAT SINK CAVITY DESIGN

Component side heat sinking forces each cell of the four Tx/Rx modules and one beamformer to be inside a metal cavity. Care should be taken in the sizing and design of the cavity. An electromagnetic simulation should be performed to ensure that the cavity does not interact with the circuitry and result in instability or oscillations. Analysis of metallic cavities whether for shielding purposes or thermal management cannot be overlooked at high frequencies. Resonant modes are generally supported when the larg-

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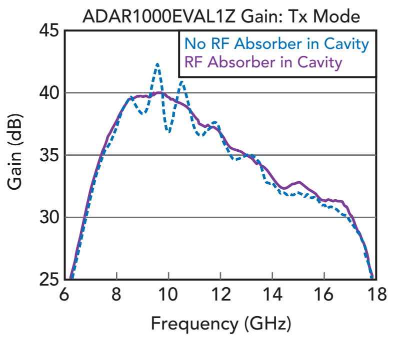

Fig. 8 Gain measurements before and after installing the RF absorber.

est cavity dimension is greater than or equal to λ/2 of the operating frequency in free space. Energy radiated from circuitry and PCB traces within the cavity have nowhere to propagate beyond the confines of the cavity, possibly resulting in instability and oscillatory behavior of active circuitry.

Various techniques can be employed to mitigate the undesired effects of cavity mode resonances. These techniques can be as complex as custom metallic structures within the cavity that only support resonances at frequencies outside the range of operation. A much simpler technique is the placement of an RF-absorbing material within the cavity to attenuate the energy of the resonant modes. The absorber is composed of materials that create a high permittivity and high permeability of the electric and magnetic fields, respectively, for a range of operational frequencies. This is analogous to an electrical bandstop filter.

The mechanical dimensions of the cavities in the Analog Devices planar phased array system board heat sink do support resonances at frequencies within its operational range. To mitigate the effects of the resonant modes, a die-cut RF absorber is installed within each cavity to dampen resonances without degrading the performance of the board. The RF absorber attenuation ranges from approximately 20 to 50 dB/cm over the frequency band of operation, effectively lowering the Q-factor of the cavity resonator.

An electromagnetic simulation of the heat sink cavity and RF absorber was performed using Keysight's EMPro simulation tool. A simple model was constructed to analyze a single cavity representing the mechanical design of the heat sink cavity, the PCB material and a bulk material to emulate the ICs attached to the PCB. Two simulations were performed using the finite element method simulation engine to calculate the eigenmode resonances within the cavity. The cavity material for the first simulation was defined as air and resulted in eigenmode resonances with high Q-factors. In the second simulation, RF absorber material was used as the cavity material instead of air and this resulted in no eigenmodes. The second simulation case concluded the selected absorber material lowered the Q-factor of the cavity suppressing the resonant energy within the cavity. To ensure accuracy, the two simulation cases were verified with measured data from the hardware. The frequencies that support resonant modes as well as the reduction of the Q-factor by the RF absorber can be observed in the two gain measurements shown in ***Figure 8***. These before and after measurements confirm the simulated predictions and highlight the importance of electromagnetic analysis.

CONCLUSION

In this article, we have looked at the challenges associated with designing the RF front-end of a planar phased array system. The size restrictions that stem from the required lattice spacing at high frequencies demand novel approaches to circuit design. These challenges can be significantly reduced through the use of BFICs and Tx/Rx modules, which easily interface together. This glueless interface has the additional benefit of shorter RF traces and fewer control lines, resulting in systems with fast responses that are easier to calibrate. Because one side of the PCB is reserved for the patch antenna array, compromises must be made to implement an effective heat sink. Proper heat sink cavity analysis and design are also vital to avoid oscillations. ■


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INVITED PAPER

Innovations in Pulse Fidelity for High-Power GaN Radar and EW Transmitters

Darren Miles and George Bollendorf
Empower RF Systems, Inglewood, Calif.
Bob Buxton
Boonton Electronics, Parsippany, N.J.

Radar and electronic warfare (EW) have been the primary applications for extremely high-power transmitters, driving the demand for specialized high-power traveling wave tubes (TWTs) and magnetrons. Diminishing sources of TWT supplies, coupled with their poor reliability, inefficiency, large size and high total lifetime cost of ownership are causing a migration away from tubes. While improved pulse fidelity accompanies the shift to solid-state transmitters, next-generation radar depends on further improvements in waveform fidelity and flexibility.

Next-generation radar systems utilize long pulse widths, which present specific challenges. In response, Empower RF Systems has developed technology to reduce pulse distortion as a development step towards pulse shape matching, allowing the reproduction of the input pulse without distortion. The pulse correction is performed within the amplifier in real-time. This is important because long pulse width radar is especially vulnerable to over/undershoot and droop, which can be eliminated to extend radar range and reduce receiver target acquisition time. The benefits from an EW perspective are the ability to accurately mimic adversarial pulses without pre-processing, allowing precise threat simulation and spoofing.

THE PRIMARY CAUSE OF DROOP IN SOLID-STATE POWER AMPLIFIERS (SSPAS)

This article discusses the correction of pulse droop and rising edge overshoot with data from Empower's 40 kW L-Band long duty cycle liquid-cooled pulsed amplifier, Model 2237, shown in ***Figure***

Fig. 1 Model 2237 L-Band 40 kW Pulsed Transmitter.

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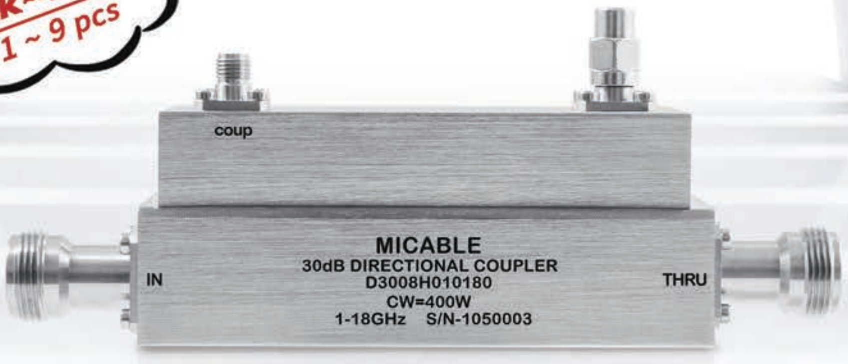
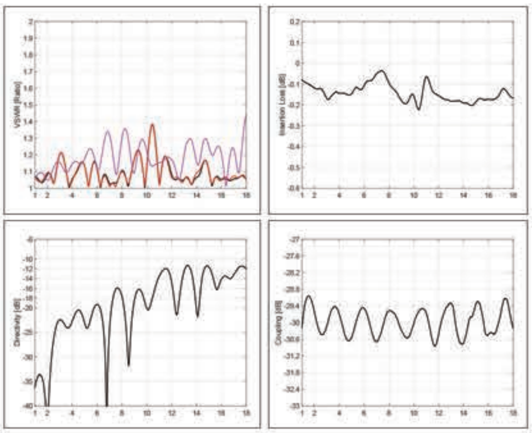


—— Test Curve of D3008H010180 ——



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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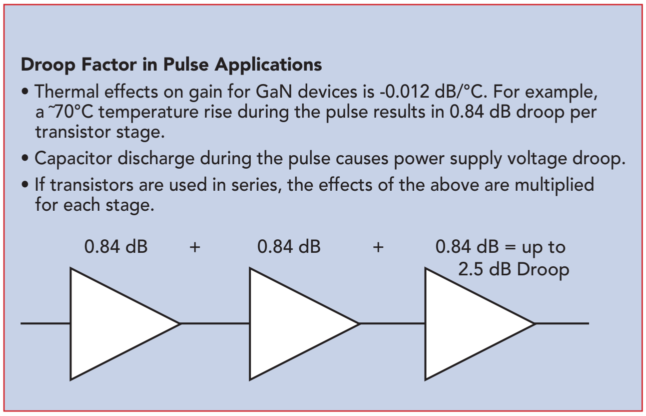

Fig. 2 The impact of cascading stages.

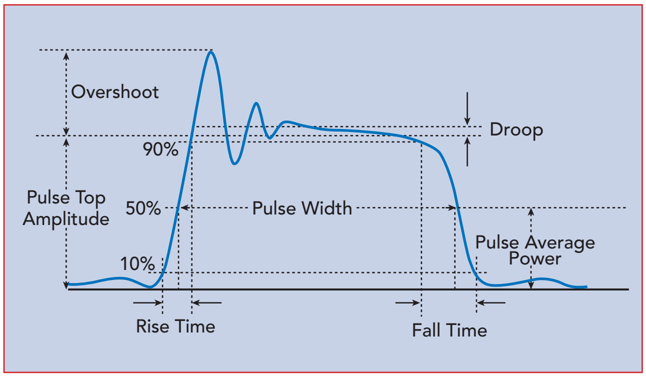

Fig. 3 Pulse parameters.

1. The primary cause of droop in a GaN power amplifier is the thermal response of the transistor. GaN has an inverse gain relationship with temperature. The thermal response of the transistors reduces the gain by 0.5 to 1.0 dB, depending on the temperature rise during the pulse. The droop is compounded with cascaded transistors resulting in a further reduction in output power. This is summarized in ***Figure 2***. The second contribution relates to a power supply's ability to source current at high frequencies. During the pulse, the capacitive energy across the drain of the transistor discharges. This starts at the leading edge of the pulse and as the pulse progresses to the trailing edge, the gain is increasingly reduced by the resulting drop in drain current and drain voltage. These two factors can account for up to 3 dB of droop. Fixing the droop using software allows a reduction in the size and complexity of the power supply and increases average transmit power. The result is improved size, weight and power (SWaP), cost and MTBF.

PULSE PARAMETERS AND IMPACT ON RADAR PERFORMANCE

Pulse droop is defined as the distortion of a flat-topped rectangular pulse, characterized by a decline of the pulse top. ***Figure 3*** describes the characteristics of a pulsed signal. Generally, each pulse includes an overshoot and ripple at the leading edge of the pulse and a pulse droop, which is the reduction in the amplitude between the beginning and end of the pulse.

THE IMPACT OF OVERSHOOT AND DROOP ON RADAR PERFORMANCE

A radar transmitter will have a limiter to protect the amplifier output stages from exceeding the peak power ratings. When overshoot is present, the gain must be set so the overshoot of the pulse does not activate the limiter. When overshoot is absent or minimized, the amplifier output can be set just shy of the limiter threshold. In the case of droop, the power during the pulse is dropping over time, further reducing the average power. By examining the radar range equation, the impact of reduced power can be seen in Equation (1).

$$R_{max} = \left[\frac{P_t G \sigma A_e}{(4\pi)^2 S_{min}}\right]^{1/4} \quad (1)$$

Where:
R_{max} = the maximum range
P_t = the transmitter power
G = the transmitter antenna gain
σ = the target's radar cross-section
A_e = the receive antenna effective aperture


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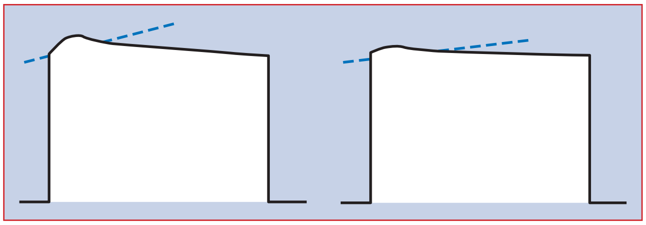

Fig. 4 Illustration of the pulse droop correction of RF output.

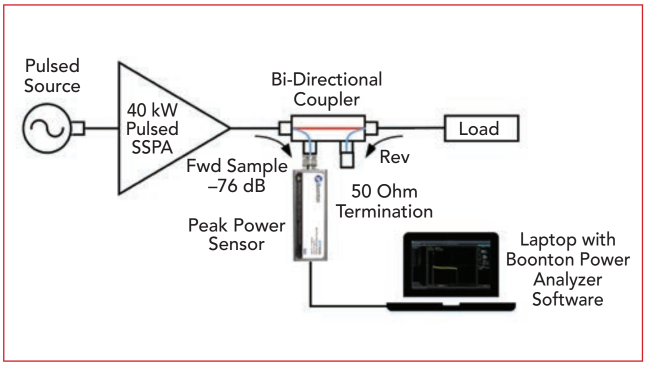

Fig. 5 Test setup.

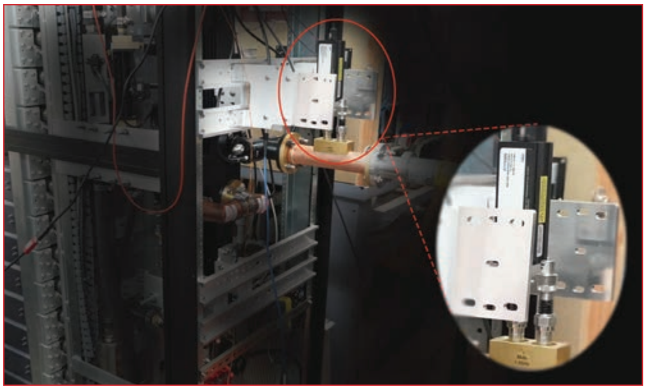

Fig. 6 Output power coupling.

S_{min} = the minimum detectable signal.

Assuming all other terms remain constant, the maximum range varies as the fourth root of the transmitter power. For example, a 1 dB improvement in average power increases the range by 6 percent.

PULSE CORRECTIONS

Each of the two main sources of droop has a repeatable response in time. These are typically marked from the leading edge of each pulse. With fast enough sample rates, an algorithmic solution exists that can change the amplifier gain throughout the pulse in real-time.

As an example, let's take the simplest form of the algorithm. Since the junction temperature rate of change is highest on the rising edge of the pulse when the transistor is turning on and conducting, the adjustment to the gain at the beginning of the pulse must be greater than during the remainder of the pulse. Implementing this will result in a significant reduction in overshoot. The expected result of this simple adjustment is shown in ***Figure 4***.

After the overshoot section, gain adjustment of the algorithm can be employed as a second element. The math is simple; the droop has a slope, so the gain adjustment simply adds in the inverse gain slope. The applied algorithm repeats itself with each pulse. This two-step algorithm can be further refined by adding more adjustment points, however, the results of a two-stage correction are very good and are shown later. The correction algorithm resides in the FPGA firmware and contains a finite-state machine described in HDL. The correction algorithm is configured with the appropriate parameters from a digital calibration process performed at the factory. The parameters include the slopes of the two-stage corrections and the initial power level at the leading edge of the pulse.

TEST SETUP (REFER TO SIDEBAR ON PAGE 68)

For demonstration, an Empower amplifier is driven with a 1.5 GHz, 500 µsec pulse, nominally at 0 dBm.

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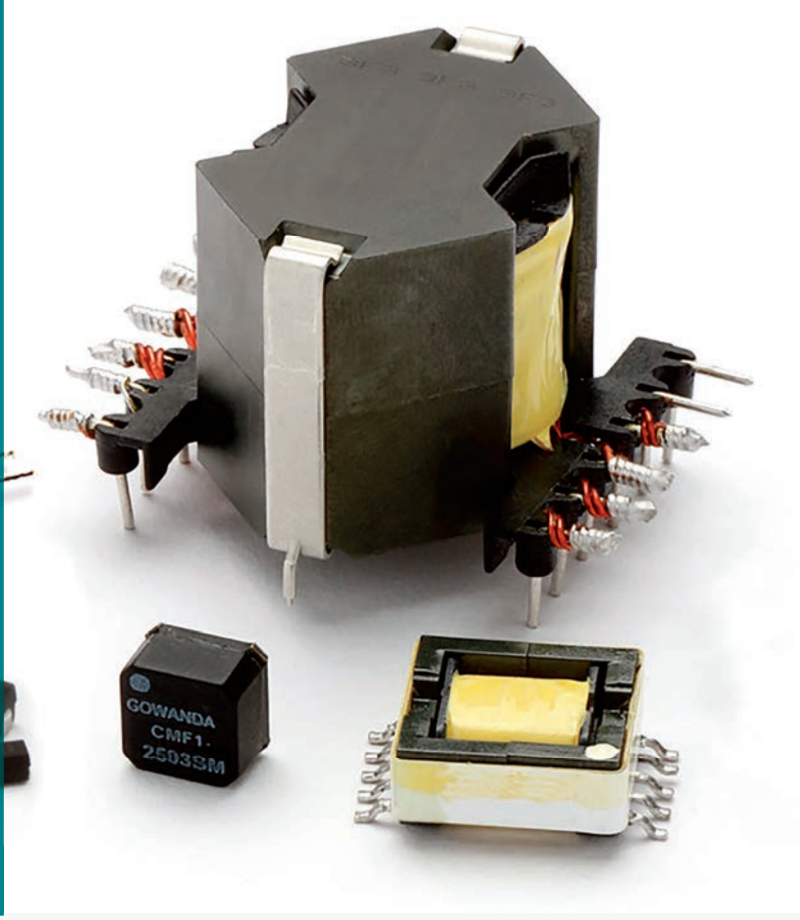

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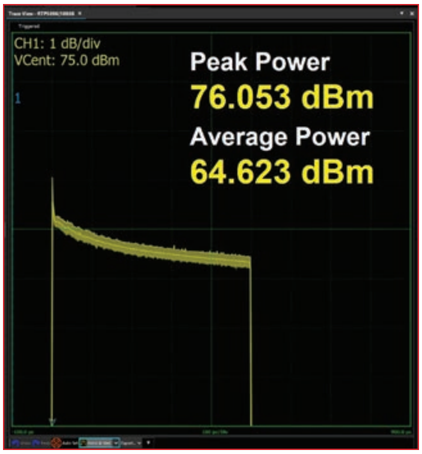

Fig. 7 Uncorrected 40 kW pulse.

A separate guard band input is used to frame the pulse for operating in true pulse mode. The amplifier is set to full gain, achieving 40 kW peak power at the output. The overall setup is shown in ***Figure 5***.

The amplifier has a bidirectional coupler at the output as seen in ***Figure 6***. The coupling factor is 76 dB. A Boonton RTP5006 USB real-time peak power sensor was used because this is the only sensor fast enough to capture the peak of the overshoot. The full power is terminated into a 50 Ω load.

RESULTS OF PRACTICAL IMPLEMENTATION

Figure 7 shows the measurement of the 40 kW SSPA output with the Boonton power sensor before applying the correction algorithm. This result was captured by the Boonton Power Analyzer Software. For a 500 µsec pulse width, the peak with overshoot measures 76.053 dBm. The end of the pulse top is measured at 74.36 dBm. The Boonton software captures the pulse envelope, which can be exported to a CSV table. From that table, the overshoot can be determined to settle around 75.2 dBm. The uncorrected pulse is then described as having an overshoot of approximately 0.9 dB (76.053 – 75.2 dBm) with a droop of approximately 0.8 dB (75.2 – 74.36 dBm).

Figure 8a shows the effect of the overshoot correction stage, which decreases the overshoot by approximately 0.6 dB from the uncorrected pulse. ***Figure 8b*** shows the effect of the droop correction stage, which decreases the overshoot again by nearly 0.6 dB. While these stages decrease the amplitude of the overshoot at the front edge of the pulse, the trailing edge of the pulse remains

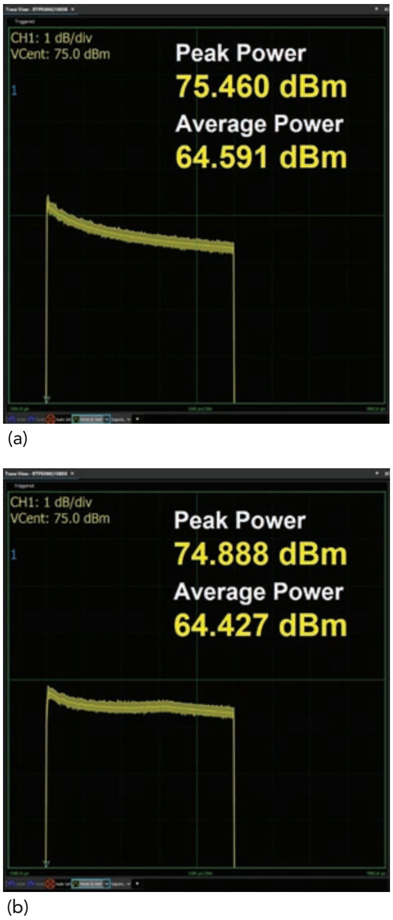

Fig. 8 Response with overshoot correction applied (a). Response with slope droop correction applied (b).

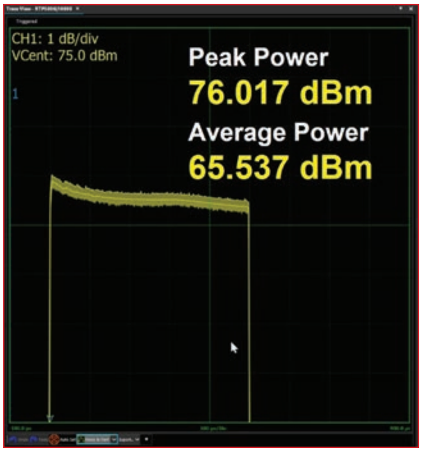

Fig. 9 Response of the optimized result.

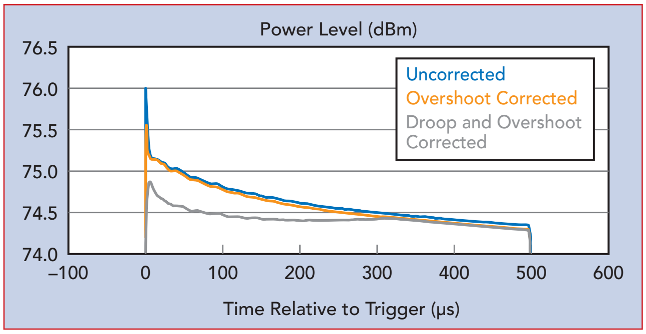

Fig. 10 Impact of overshoot and droop correction.

unchanged. The effect reduces the overall energy of the pulse, a poor tradeoff for the benefit of flattening the pulse. Once the pulse is flattened, however, the gain of the system can be increased since the reduced overshoot will no longer activate the amplifier peak limiter. This is shown in ***Figure 9***.

For the final result of Figure 9, the maximum peak power was adjusted by increasing the system gain. This results in a system gain higher than that of the uncorrected pulse example. For simplicity of illustrating the method, the gain adjustment has been described as the last step. In actual implementation, the correction factors are established ahead of time and stored, so setting the system to the optimized maximum gain is the first step. Next, the pulse rises and the overshoot is corrected with a final step of correcting the droop of the pulse.

SUMMARY

The power output measured over the duration of the 500 µsec pulse is shown in ***Figure 10***. This output demonstrates a flatter response with less overshoot that results from applying both droop and overshoot correction. In addition to providing more uniform power throughout the pulse, the amplifier can also generate higher average power. This is a result of higher system gain without fear of the overshoot activating the limiter and a pulse with less droop.

CONCLUSION

Using these techniques increased the average pulse power by 0.9 dB, which is close to the amount of pulse correction. This is as expected since the maximum transmitter output can be increased by the amount that the pulse variation is reduced. The result represents more than a 20 percent increase in average power, which also improves SWaP, cost and MTBF. The transmitter power density improves by 20 percent. The MTBF and cost improve since the component count in the RF chain would have been higher and the transmitter would have operated at a higher temperature to produce the 20 percent output power increase that would have been required without the pulse correction. In addition, the radar performance improves as roughly 1 dB of increased transmit power extends the range of the radar by 6 percent. ■

MEASUREMENT CONSIDERATIONS

Measuring pulsed radar signals requires a peak power sensor. For fast pulses, the rise time of the power sensor is important. The Boonton RTP5006 has a rise time of ≤ 3 ns. This means that a pulse rising edge of 5 ns can be comfortably measured. The rise time display of a representative pulse is shown in ***Figure S-1***.

Fast real-time and equivalent-time sampling provide fine resolution on narrow pulses. The RTP5000 real-time peak power sensors, with 100 MSa/s real-time and 10 GSa/s equivalent-time sampling, can make measurements on 10 nsec pulses with 100 psec resolution.

When measuring amplifier droop, automated measurements become important. Droop is one of the 16 automated pulse measurements available from the RTP5000 family. ***Figure S-2*** shows the effects of droop on a reference signal.

RTP5000 power sensors may be used with a PC running the Boonton Power Analyzer Software or with the PMX40 power meter for a benchtop instrument experience. Either way, they provide an ideal tool to characterize radar and EW signals.

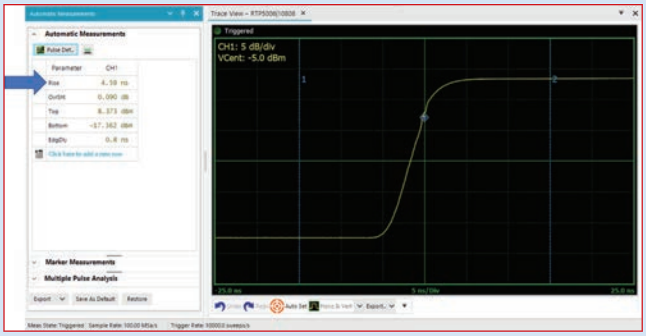

Fig. S-1 Pulse rising edge with automated 10/90% rise time measurement shown by the blue arrow.

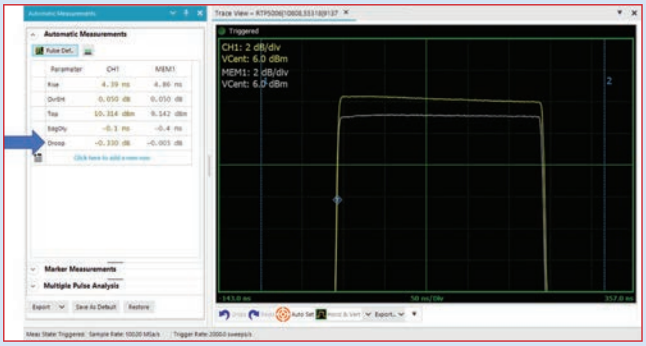

Fig. S-2 Comparison of live trace with memory to see the effect of signal changes on droop.

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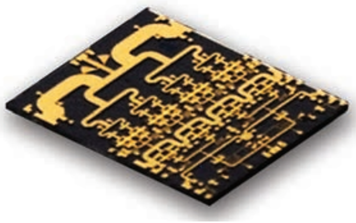

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INVITED PAPER

How to Reliably Align Compression Connectors for mmWave Applications

Jean-Jacques DeLisle
IXS, Theodore, Ala.

At frequencies below several GHz, the impact from solder process variations and other fabrication and assembly factors is typically benign when good design practice is used. At tens of GHz, the impact from fabrication and assembly variations becomes significant enough that minimizing tolerances in the signal path is essential for many applications. This is why compression-mount test connectors are becoming an increasingly popular solution for upper mmWave interconnects in test, prototyping and diagnostic applications. Another factor to consider is that compression connectors are also compact, which is advantageous as many upper mmWave applications are also now at far greater levels of interconnect density on boards with shrinking available board space.

However, these connectors are not without their challenges. The compact form factor and necessarily small size results in the potential for misalignment, as the tolerances for these connectors and landing pads are extremely tight. It is entirely possible to misalign coaxial compression connectors without knowing until the test setup is underway and unpredicted test results are observed. Fortunately, there is now a solution to this challenge that provides an easy-to-read visual indication of the proper alignment that speeds up the assembly and alignment of compression connectors.

WHY COMPRESSION CONNECTORS?

There is a growing demand for precision, high frequency test connectors that reach and exceed, 90 GHz bandwidth. This is a result of ever-climbing data rates, such as 224 gigabits per second (Gbps) pulse amplitude modulation 4-level (PAM4) and the increased interest in developing mmWave communication and sensing technologies operating in V-Band (40 to 75 GHz), W-Band (75 to 110 GHz) and beyond. The higher data rates used in backhaul and networking infrastructure necessitate the use of RF test equipment for development, verification and even troubleshooting. Hardware components of mmWave communication and sensing systems, even for devices that operate in the lower portion of V-Band, of-

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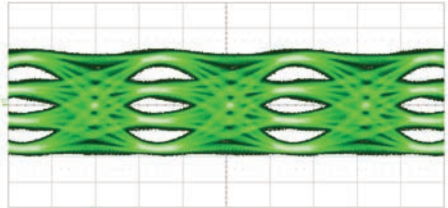

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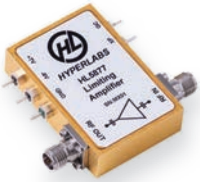

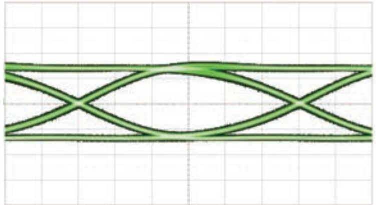

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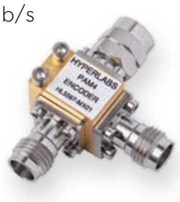

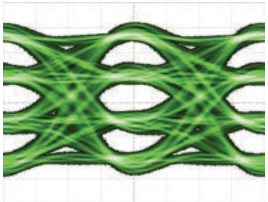

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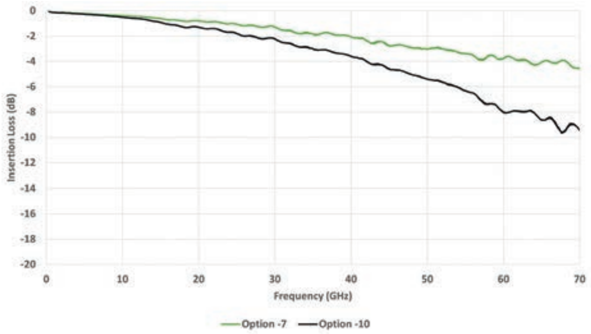

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The maximum frequency of a transmission line, be it planar or coaxial, is dictated by the dimensions of the conductors and the spacing between them. To realize higher-frequency transmission lines, the physical geometry of the planar traces and the coaxial conductors in a coaxial connector and cable are necessarily smaller than their lower-frequency counterparts. For some applications, this is advantageous, as it allows for higher levels of interconnect density. An example of this is the multitude of antenna feeds from advanced/active antenna systems operating in the upper mmWave range.

As the physical dimensions of the interconnect shrink, the tolerances associated with interconnect placement and fixturing also need to be tighter, meaning that many alignment strategies that are appropriate for larger interconnects are no longer viable with minute high frequency interconnects.

The Main PCB Surface Trace Interconnect Solution Parameters

- Bandwidth (Hz)
- Insertion loss (dB)
- Return loss (dB)
- VSWR
- Impedance (Ω) typically 50 or 100 Ω
- Power handling capability (dB) typically specified for continuous wave and/or peak
- Repeatability
- Ease of use and setup considerations
- Cost

PCB SURFACE TRACE INTERCONNECT SOLUTIONS

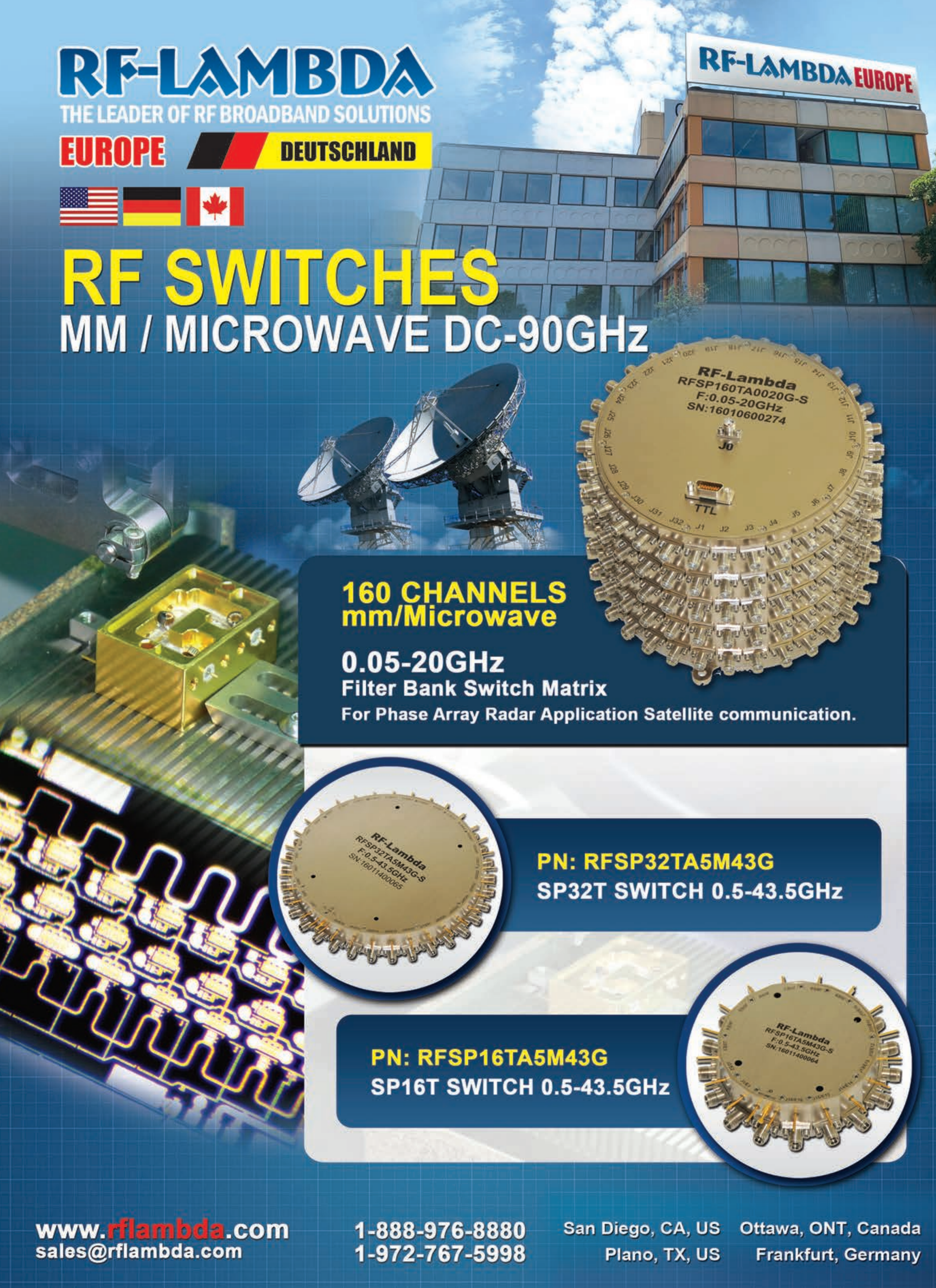
There are a variety of high frequency interconnect methods for attaching test and diagnostic equipment to surface traces or landing pads on a PCB, each with benefits and drawbacks. Given the desirability of broadband operation, coaxial interconnect and broadband planar transmission lines are common for these applications. Hence, the interconnect challenge is to ensure reliable, repeatable, high precision connections between minute landing pads of planar transmission lines to the test leads of high frequency test equipment.

The PCB Surface Trace Interconnect Solutions

- Coaxial cable directly soldered to surface planar transmission lines
- Coaxial connectors, either surface, through-hole or edge-mount soldered
- Pre-manufactured or custom single-use solder test leads
- Coaxial probe station
- Compression connectors, either surface or edge-mount

The traditional method is to directly solder a coaxial cable center conductor and outer conductor (shielding) to the landing pads on a board. This is often used to bridge two surface transmission lines or when using half of a coaxial cable assembly to connect surface transmission lines to external equipment. Though this method is functional, the poor tolerances achievable with hand-soldered and hand-prepared coaxial capable cutoff sections means this method is likely to have the lowest precision and repeatability. Depending on the technique used, this method likely will not be suitable for mmWave applications unless performed by a skilled technician with specialized equipment.

A more accessible and universal approach is to use surface, through-hole or edge-mount coaxial connectors that are attached to the landing pads with solder. If bonded properly, this method can provide a rugged connection that can be both reliable and compact. This method does require some effort to ensure alignment, but some connector types can be assembled automatically by pick and place technology. The main issue with this approach is the limitation of the tolerances of the solder bonds between the center and ground pins of the coaxial connectors and the landing pads. At 100 GHz, the free space wavelength is about 3 mm. A common rule of thumb is that geometric features that are on the order of one-tenth or even one-twentieth of a wavelength are significant. This means that achieving feature sizes for the solder connections that are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less than 300 µm and even 150 µm is required for high precision and repeatable interconnect applications. This is not readily done by hand without the tools and expertise of a skilled technician, but it is within the capability of machine assembly.

A solution to address the repeatability problem is to use premanufactured or custom solder test leads. However, the frequency limitations of this solution make it more suitable for use with oscilloscopes for probing time-domain signals to several GHz. These are used in place of hook or hand-probed interconnects. These connection types are only capable of reaching a maximum specified frequency range of 20 GHz. They are also costly to use and are often limited to single-use or several uses at most. Ultimately, these types of connectors are not suited to upper mmWave applications.

Another approach is to avoid attaching the test leads to the landing pads and instead press the precision contacts of transmission lines to the landing pads. A probe station can test these board-level test points and transmission lines while only minimally impacting the test board. Some precision probes reach 500 GHz of bandwidth using ground-signal-ground style probe tips with waveguide interconnect. Alternatively, precision probes can reach up to 145 GHz with a coaxial interconnect. Some probes have multiple signal lines on a single probe head, which could help test multiple high speed differential lines. However, using precision probes requires a probe station, which is typically a capital expense item and requires an experienced technician to operate.

COMPRESSION CONNECTOR BENEFITS

Another commonly available option for high precision mmWave interconnects is threaded, coaxial compression connectors. This type of connector is becoming more popular because of its ease of use, reusability, repeatability and performance. Compression connectors are much like soldered coaxial connectors, with the exception that the center conductor and ground connections are made through precision-designed compression contact surfaces, similar to a probe station and they do not require soldering for attachment. Instead, mounting screws are typically used to provide the fixturing and alignment.

Since soldering and through holes are not required, surface mount compression connectors can be used on traces anywhere on the board surface and not just the edge. End-launch compression connectors require a precision milled surface at the edge of the board that is precisely positioned with respect to a surface planar transmission line. This does not fit all testing applications, so a surface mount compression connector that can be attached to mounting holes anywhere on the surface prevents the need to route planar transmission lines to the edge of a board.

COMMON METHODS OF COMPRESSION CONNECTOR ALIGNMENT

mmWave compression connectors are compact in size. The overall footprint for 2.92 mm board connectors that will provide 40 GHz maximum mode-free frequency operation is typically around 10 x 6 mm with about 7 mm pitch between mounting screws. For 1.35 mm board connectors, these dimensions shrink to about 10 x 4 mm with a similar pitch. However, the center contact diameter for the 2.92 mm connector is around 508 µm and the center contact for the 1.35 mm connector is half of that, at 254 µm. The trace widths of the landing pads for these connectors are roughly the same dimensions as the center pin diameters. That means that the tolerances to achieve an optimal interconnect with the 1.35 mm connector is roughly half of that of a 2.92 mm connector, leaving little margin for error.

Methods are needed to ensure alignment with these connectors so that the connections are precise and repeatable. The most common method relies on the screws used to fixture the compression connector to the RF board. Another common method uses alignment pins

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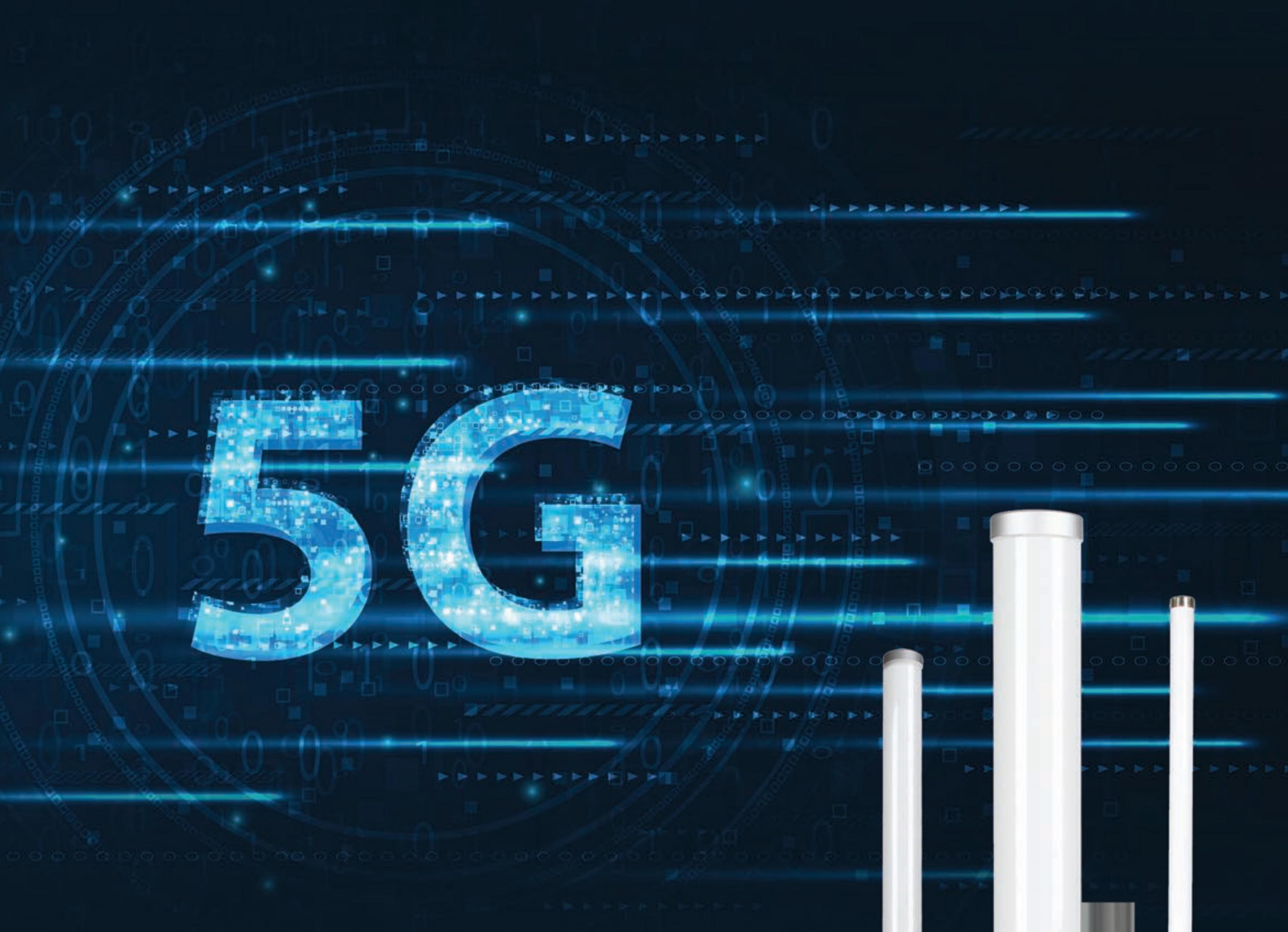

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Fig. 1 Potential tolerance issues arising from screw or pin alignment with machined holes in a PCB.

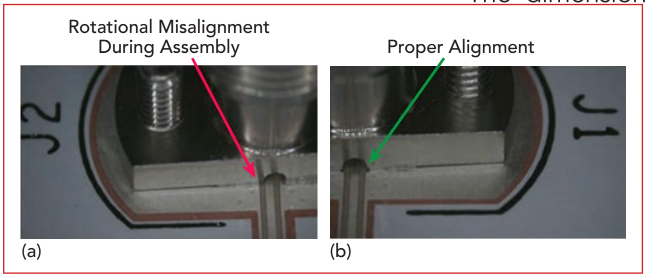

Fig. 2 Rotational misalignment (a) and proper alignment (b) of a compression connector on a PCB.

that are inserted through a feature on the compression connector body and the PCB.

There are a few challenges with these approaches. The PCB manufacturing process is done in several stages with large format boards that undergo etching, solder mask, silkscreening and milling in different machines. These boards are likely handled by different operators in a high-paced manufacturing environment, which means indexing the large format PCB at every stage for each job, often using mechanical and visual indicators.

This fixturing can be manufactured to reasonable tolerances, but it varies from board to board and the run-out of a board can be inconsistent between runs. The machining tolerances of a board can also vary depending on the tooling type, tool wear, operator skill and machine calibration. This leads to a tolerance stack-up between the etching and machining operations that can easily amount to hundreds of micrometers. Since this tolerance stack-up is the same order of magnitude as the contact area and trace widths used in upper mmWave interconnects, it can easily lead to misalignment issues based on screw or pin misalignment with the machined features of a PCB. This analysis does not include potential tolerance issues associated with manufacturing the screw or alignment pin along with the connector housing mounting holes, which would also contribute to the overall alignment accuracy of these methods. Some examples of these tolerance issues are shown in ***Figure 1***.

Alignment issues may also allow enough "play" between the two screws to permit undesirable rotation around the axis of the coaxial connector as shown in ***Figure 2***. The dimensions between the signal trace and the ground of the connector housing are critical for the electrical performance of the connection interface, so this type of misalignment can cause transmission line performance degradation, complicate testing and may invalidate test results. A slight misalignment caused by screw and pin alignment techniques may also be difficult for an assembler to detect. The operator may only become aware of the issue during electrical testing when the difficulty of troubleshooting the connection could be considerable.

It is desirable to use a visual alignment tool or indicator to get a clear indication of alignment. Typically, the perimeter of the outer housing is the only feature of these types of compression connectors that gives a useful visual indication of alignment. There are usually some flat surfaces on the outer housing of these connectors, but this is generally not considered a critical feature so these surfaces may not be machined to the same tolerance level as the internal features of the coaxial conductors.

Electrical testing has been the main method for ensuring the alignment of these connectors. This is often done by measuring the device under test or system under test performance and confirming that


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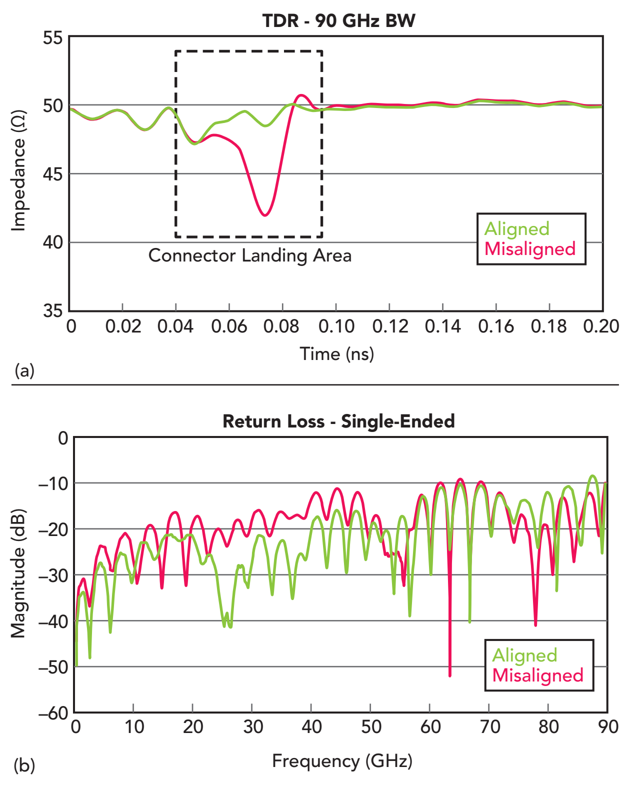

Fig. 3 TDR measurement of an aligned and misaligned 1.35 mm compression connector (a). Return loss of aligned and misaligned connectors at the landing area (b).

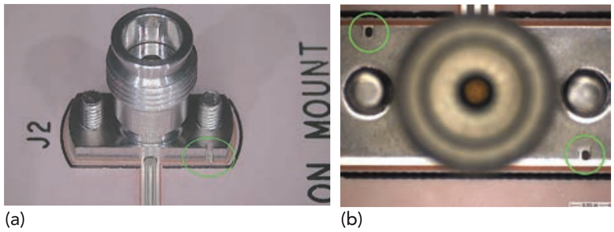

Fig. 4 Side view of visual alignment grooves on a 1.35 mm threaded compression-mount coaxial connector (a). Top view of visual alignment grooves on a 1.35 mm threaded compression-mount coaxial connector (b).

it meets electrical tolerances. Alternatively, the interconnect may be tested using a time-domain reflectometer (TDR) or a network analyzer. ***Figure 3a*** shows TDR results from an aligned and misaligned connector and ***Figure 3b*** shows return loss results from an aligned and misaligned connector. This type of testing can be time-consuming and potentially misleading if there are other interconnect issues with other RF hardware, defects in the transmission lines or issues with the interconnect between the board and RF hardware.

NEW VISUAL ALIGNMENT TECHNOLOGY FOR COMPRESSION CONNECTORS

To reliably achieve alignment with these small form factor mmWave connectors requires a positive visual indication alignment feature designed into the compression connector and the PCB. Using fiducials on a PCB is standard practice for automated component placement (pick and place machines). This technique is also used to align irregularly shaped or larger parts like inductors, capacitors and transistors. It has become good practice to use PCB surface metal fiducials near the landing pad of the surface traces to minimize alignment tolerance issues caused by the metal etching process.

Another possibility is to include precision features in the visible areas of the connector housing that are designed to align with the PCB fiducials. Visual guides in the coaxial area of the compression connector are not possible as this area is concealed by the coaxial housing during installation. These visual guides should be located as close to the connector body as possible while being readily visible during assembly. Also, these visual guides should

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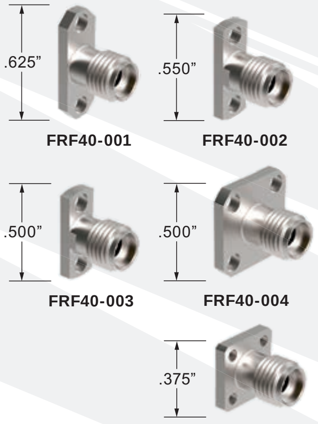

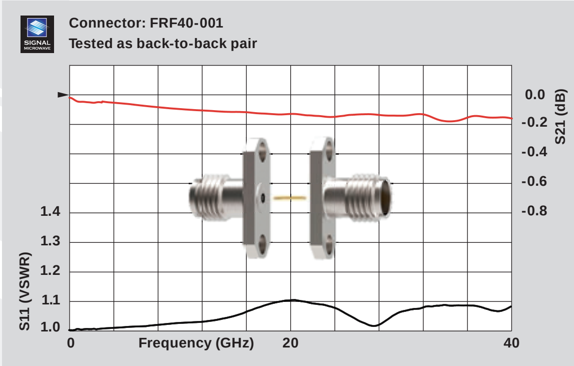

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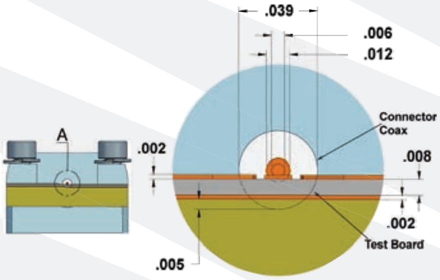
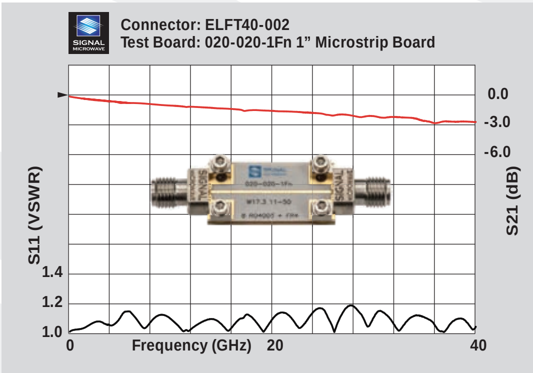


DETAIL A; 8 mil Test Boards and Connector Cross Section



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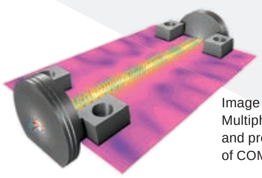

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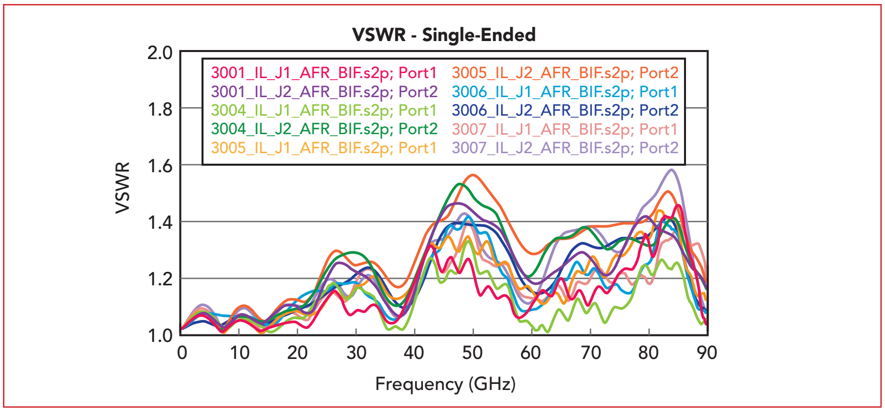

Fig. 5 **VSWR plot of 2-port tests of Samtec's 1.35 mm threaded compression-mount coaxial connectors.**

be close to the PCB surface to minimize any potential misalignment caused by perspective. As an example, precision machined alignment grooves on the opposite sides of the base of the compression-mount connector would provide the necessary visual guide.

Samtec's new threaded compression-mount connectors are an example of this approach, with visual alignment guides machined into the base of the connector housing as shown in ***Figure 4a*** and ***Figure 4b***. This approach enables visual indication of any x, y or rotational misalignment of the compression connector with reference to the surface metal layer of the PCB. If the PCB fiducials are specifically designed for the connector alignment guides, there is visual assurance that the connector center pin and recess for the planar transmission line trace will be aligned with the PCB landing pad.

Testing accuracy and repeatability are major concerns for devices operating in the upper mmWave frequency range. A suitable interconnect solution should be able to provide good performance and repeatability over several installation cycles. ***Figure 5*** plots measured VSWR for 10 samples (five tests using a two-port network analyzer), where 1.35 mm compression-mount coaxial connectors are assembled on either side of a planar transmission line. Using this method, the VSWR performance can be extracted from both the port 1 and port 2 connectors.

The results of the VSWR plot in Figure 5 show excellent performance, especially between 50 and 80 GHz. VSWR is lower than 1.2:1 at the connector's cutoff frequency. It is important to maintain alignment during installation since connecting the test cables to the compression-mount connector can create some rotation. Anti-rotation tools can be used to hold the connector in place while the test cable is connected and disconnected. This is typically done using a wrench or a pair of pliers to counteract the force of the torque wrench used to tighten the coaxial connector to specification.

CONCLUSION

Higher data rates for networking and backhaul communications, along with higher operating frequencies for communications and sensing technologies are leading to an increased need for high frequency, precision interconnect solutions. To allow these connectors to operate at higher frequencies and interconnect densities with a minimal board footprint, the entire interconnect solution needs to be very compact. Precision alignment of the center pin of these connectors to the landing pad at these high frequencies is both challenging and a critical requirement. The visual alignment technique described and implemented in Samtec's new threaded compression-mount connectors help address the alignment challenges associated with mmWave compression-mount connectors. ■


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RF SMP Board-to-Board Connectors Market Review

Earl Lum
EJL Wireless Research, Salem, N.H.

RF mezzanine board-to-board (BTB) connectors have been used extensively to allow for RF signal connections between the RF power amplifier printed circuit board (PCB) and the radio transceiver (PCB) within radio units (RUs) and remote radio units (RRUs) since the transition from UMTS to LTE technologies for wireless mobile radio access networks (RAN). These radio systems were low order MIMO systems ranging from 1T2R, 2T2R, 4T4R and 8T8R architectures. The quantity for these RF BTB connectors was one set for each RF channel, consisting of two male PCB connectors (either through hole or surface-mount) and one female-female bullet to connect the transmit (Tx) and receive (Rx) paths from the radio transceiver PCB to the power amplifier PCB and one set to connect the power amplifier PCB to the RF channel filters.

An Ericsson RRUS11 (code named Platform 4) 2T2R LTE RRU, shown in ***Figure 1***, is used as an example of this type of radio system architecture shipping in the 2010 to 2013 timeframe with ten sets of RF micro coaxial connector (MCX) BTB connectors between the radio TxRx PCB and the RF power amplifier PCB with quick lock SMA (QMA) cable connectors between the RF power amplifier PCB and the RF duplexer filters.

The Ericsson RRUS12 (code named Platform 5) 2T2R LTE RRU, shown in ***Figure 2***, is an example of the next generation radio system architecture shipping in the 2012 to 2015 timeframe. This radio system architecture had eight sets of subminiature push-on (SMP) BTB connectors and only one PCB (radio TxRx/RF power amplifiers) and the RF duplexer filter and replaced the QMA cable connectors with blind mate catcher's mitt SMP BTB connectors to reduce the manufacturing complexity compared with RF cable assemblies.

IMPACT OF MASSIVE MIMO RADIO SYSTEMS

The introduction of production 64T64R massive MIMO (mMIMO) radio systems (see ***Figure 3***), coupled with pre-5G mMIMO systems by the Chinese OEMs (Datang Telecom, Fiberhome Technologies, Huawei Technologies and ZTE Corporation) for China Mobile's TDD-LTE 4.5G

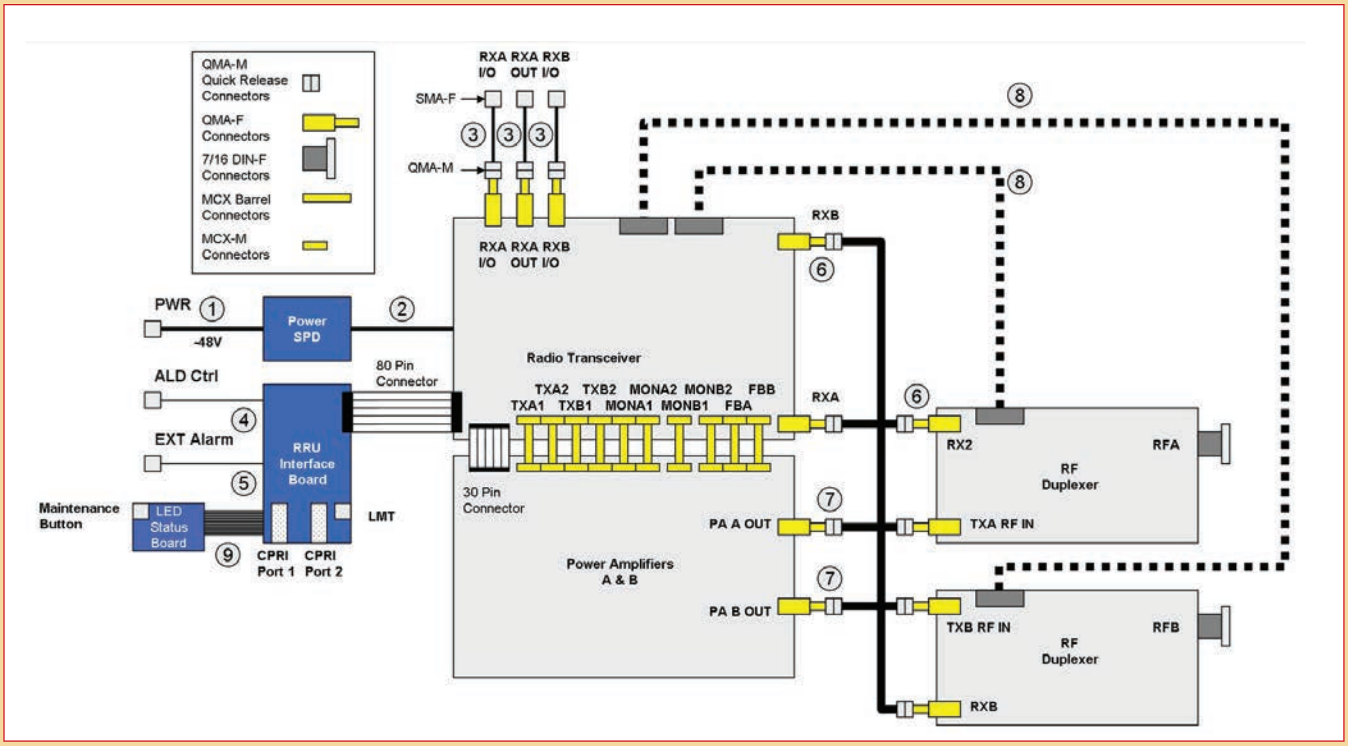

Fig. 1 Ericsson RRUS11 example (Source: EJL Wireless Research).

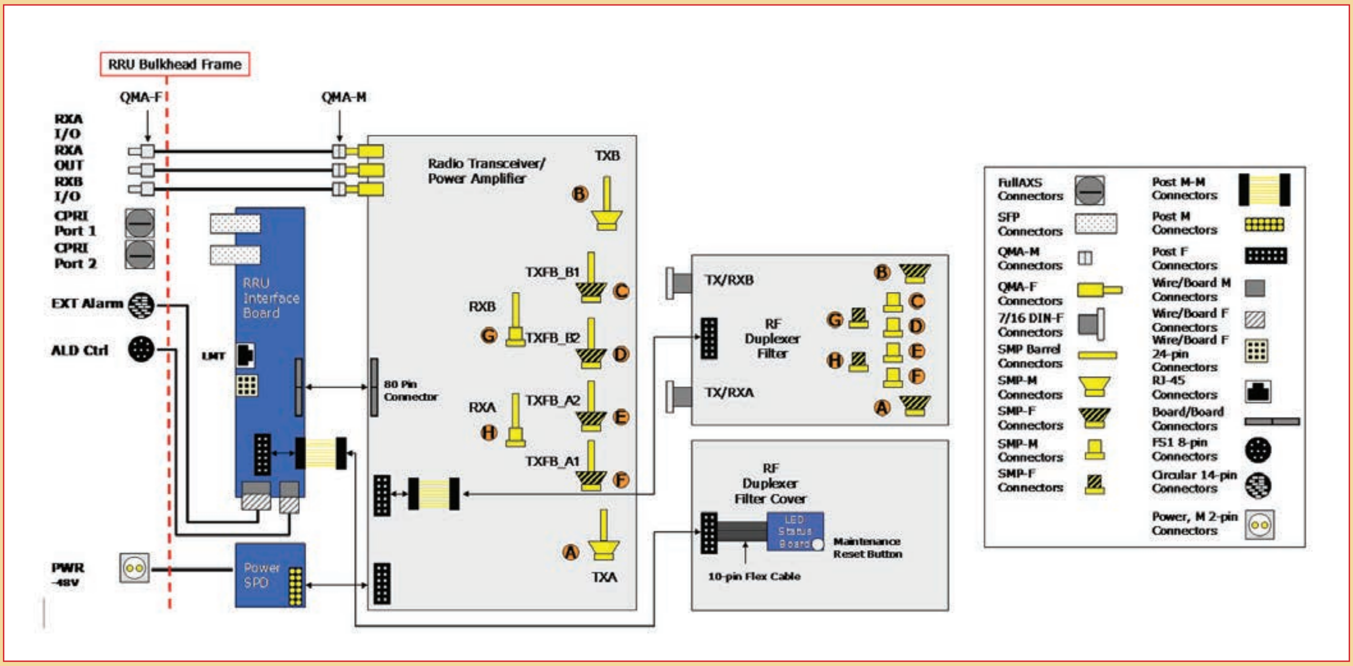

Fig. 2 Ericsson RRUS12 example. (Source: EJL Wireless Research).

mobile network in the 2015 to 2016 timeframe created a high volume requirement for high performance low-cost 5 to 20 W RF BTB connectors for first generation system architectures. The integration of the antenna array within the radio system architecture increased the requirement for the quantity of BTB connector "sets" for a 64T64R system from the radio TxRx/RF power amplifier PCB to the RF filter distribution PCBs to also include the RF signal paths between the RF filters to the mMIMO antenna array PCBs.

An example, shown in ***Figure 4***, of an early first-/second-generation 64T64R radio system architecture uses 66 sets of MMBX through hole male catcher's mitt and female-female bullets to connect the radio TxRx/power amplifier PCB to the RF filter subsystem. Each dual-channel RF filter has two MMBX male catcher's mitt connectors and two MMBX female connectors for a total of 128 RF connectors for each 32T antenna array. In this architecture example, a total of 326 RF connectors are needed to com-

Fig. 3 **MWC Barcelona 2015 ZTE 64T64R pre-5G mMIMO radio/antenna system (Source: EJL Wireless Research).**

plete the system. The length of the barrel/bullet connectors depends upon the clearance needed between the radio TxRx RF shield and the RF filter subsystem and/or the RF filter subsystem to the antenna/combiner PCB.

POGO PINS FOR RF BTB CONNECTORS

Pogo pins have been used extensively as probe contacts for semiconductor test equipment and can handle high levels of current, up to 30 A, but typically have been as a signal/electrical contact source where the entire body is metal as shown in the examples in ***Figure 5*** with an inner spring mechanism.

Before its export ban in May 2019, Huawei Technologies had already replaced the costly MMBX/SMP RF BTB connectors with low-cost pogo pins for all of its RF coaxial connectors for all of its 5G mMIMO radio antenna system platforms, substantially decreasing the global TAM for these types of RF connectors although the company continues to use RF coaxial connectors for its high-power 5G RRUs. The first generation pogo pins used are shown in ***Figure 6*** while the improved second-generation design is shown in ***Figure 7***.

What is different about the pogo pins used for RF signal paths as shown in Figures 6 and 7, is that the pogo pin itself acts as the center conductor for a coaxial connector with the insulative housing surrounding the pogo pin (see ***Figure 8***). The pogo pin and insulative jacket is then inserted into an RF shield system which acts as the outer conductor or ground plane for the coaxial pogo pin system.

SUPPLIERS

So, who are the main global suppliers of RF BTB traditional coaxial connectors? Here is a short list of known suppliers:

- Amphenol RF
- HUBER+SUHNER AG
- Molex LLC
- Radiall S.A.
- Suzhou Recodeal Interconnection System Co., Ltd./ Suzhou Ruida Connection System Co., Ltd.
- TE Connectivity Ltd.

For traditional pogo pins, a truncated list of known suppliers is shown here:

- CFE Corporation Co., Ltd. (China)
- MILL-MAX Mfg. Corp. (U.S.)
- Shenzhen Rtench Technology Co., Ltd. (China)
- Suzhou Shengyifurui Electronic Technology Co., Ltd. (China)
- Yokowa Co., Ltd. (Japan)

We are unable to provide the supplier for the RF pogo pin solutions shown in Figures 6, 7 and 8.

RF BTB CONNECTORS - ALPHABET SOUP

The designation of an RF SMP BTB connector is extremely broad as a family of products with numerous specific sub-types that are sometimes associated with the IP/design from a specific vendor. Size, cost, frequency of operation and misalignment tolerances typically dictate which type of RF SMP BTB connector solution is used within a radio system. ***Table 1*** illustrates just a few of the many different types of RF SMP BTB connectors available from one major vendor.

Adding to the alphabet soup of the RF SMP BTB connector solutions are the CSMP variant that is usable up to 65 GHz, similar to the SMPM solution from Radiall, the ASMP variant that is usable up to 26.5 GHz, and the PSMP/P-SMP which operates up to 10 GHz and can handle 200 W of power.

The letter that is very interesting is "R." The reachable SMP (RSMP) and RSMP+ variants have been developed by Suzhou Recodeal Interconnection System Co., Ltd. in China and awarded a patent and (to our knowledge) is only licensed to Changzhou Amphenol Fuyang Communication Equipment Co., Ltd. This deal excludes traditional European RF connector suppli-

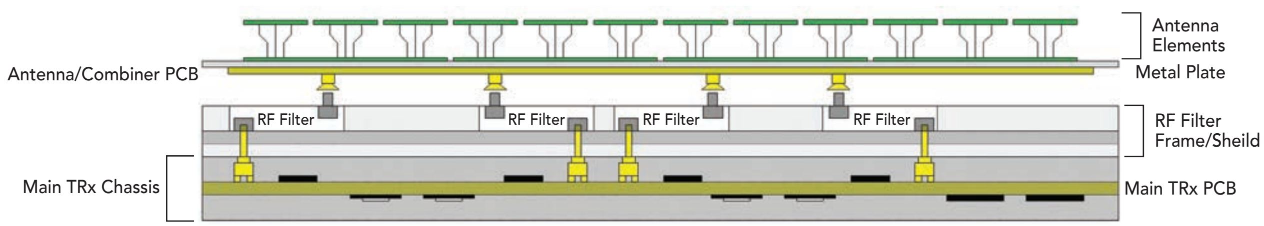

Fig. 4 **Sub-system PCB stack for 64T massive MIMO radio antenna system (Source: EJL Wireless Research).**

ers such as Rosenberger Hochfrequenztechnik GmbH & Co. KG, HUBER+SUHNER AG and Radiall S.A. (see ***Figures 9*** through ***11***).

MARKET OUTLOOK

While 5G deployments in the U.S. are expected to be mostly completed by the end of 2023 and continue to inch along in Europe, India has emerged as the next opportunity for 5G deployments. The first phase of the 5G networks for Bharti Airtel, Reliance Jio and Vodafone Idea will be supplied by RAN equipment vendors Ericsson, Nokia and Samsung Electronics as the Chinese OEMs, namely Huawei

Fig. 5 **Various examples of pogo pins from different manufacturers.**

Fig. 6 **First-generation pogo pin design for Huawei AAU (Source: EJL Wireless Research).**

Fig. 7 **Second-generation pogo pin design for Huawei AAU (Source: EJL Wireless Research).**

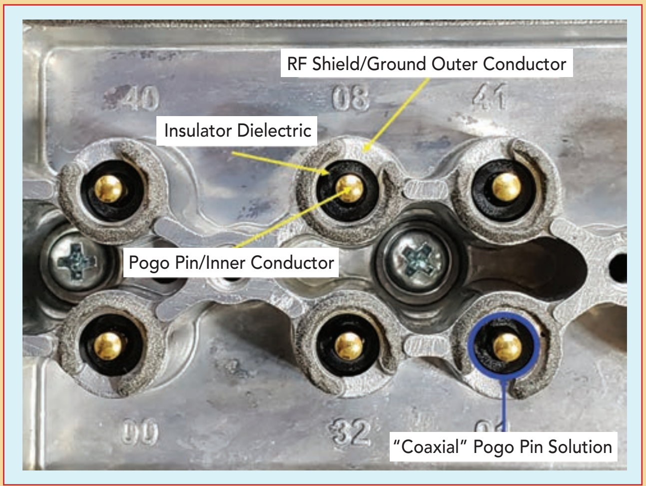

Fig. 8 **Second-generation coaxial pogo pin BTB example for mMIMO radio systems (Source: EJL Wireless Research).**

TABLE 1

RADIALL S.A. RF SMP BTB CONNECTORS

BTB Connector Types	*Operating Frequency (GHz)*
SMP	DC to 40
SMP-LOCK™	DC to 40
SMP-COM	DC to 12.4
SMPM	DC to 65
SMPM-LOCK™	DC to 65
SMPW[1]	DC to 100
SMP-MAX[2]	DC to 6
MMBX™ [3]	DC to 12.4

Source: Radiall S.A.
[1] Also known as WSMP
[2] Wider misalignment tolerance than SMP-COM
[3] For BTB distances < 7 mm

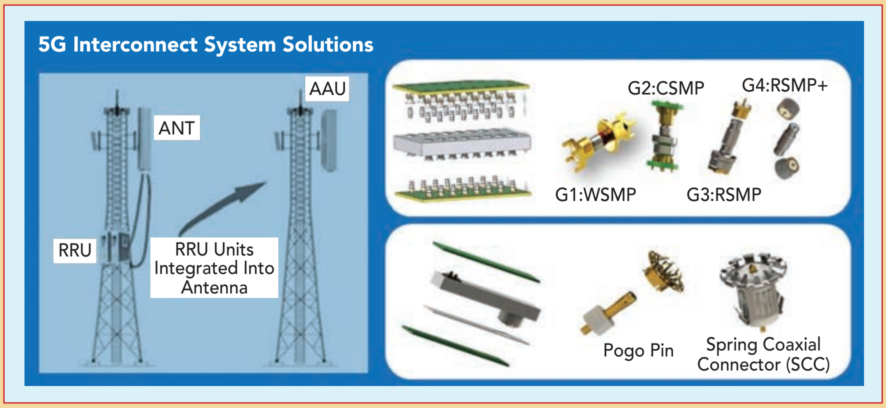

Fig. 9 **Suzhou Recodeal RF SMP BTB solutions for 5G (Source: Suzhou Recodeal Interconnection System Co., Ltd.).**

Technologies and ZTE, have been barred. While India, with its government and tech sector having high aspirations for a home-grown domestic Open RAN equipment ecosystem, has the potential vendors, their solutions remain unavailable until potentially the second phase of the 5G network deployments. The unique cost structure for RAN equipment in India will make it challenging for any Open RAN equipment vendor as well as RF connector and component suppliers to participate.

Regarding the 5G market in China, it has essentially been on hold for mMIMO antenna solutions since 2019 to 2020 when Huawei Technologies was put onto the Entity List by the U.S. Commerce Department's Bureau of Industry and Security and banned from purchasing advanced U.S. semiconductor chips and access to U.S. developed/manufactured advanced semiconductor wafer fab equipment and foundry services. While Huawei had stockpiled a sizable amount of semiconductor application-specific ICs (ASICs) in anticipation of such action from the U.S., we believe that it has consumed the majority of these critical semiconductor chips over the past several years, biding time, perhaps until it can port its TSMC ASICs over to SMIC's < 10 nm process nodes. We believe that such an event would trigger the ramp of 5G deployments again in China. Such a ramp would require 3 million+ 32 Tx and 64 Tx mMIMO radio antenna systems but with domestic Chinese/Taiwanese suppliers only and potentially with little to no BTB RF connector sockets available to non-Chinese/Taiwanese suppliers or at all if ZTE Corporation also converts to the use of RF pogo pin solutions. ■

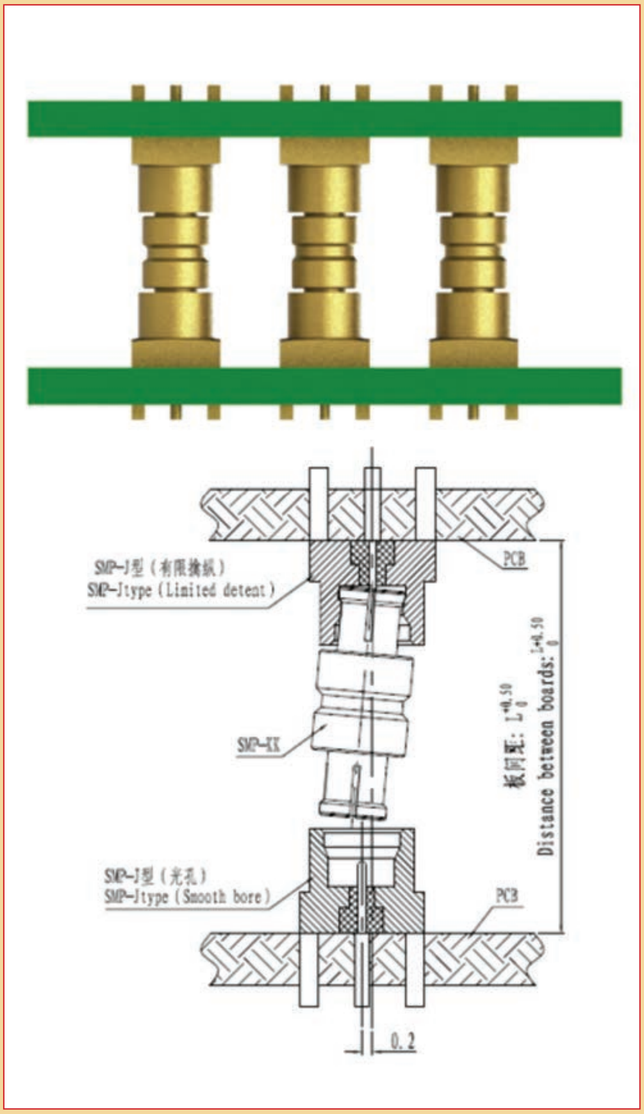

Fig. 10 **Suzhou Recodeal through hole RSMP RF BTB connector solution (Source: Suzhou Recodeal Interconnection System Co., Ltd.).**

Fig. 11 **Amphenol SMT RSMP RF BTB Connector Solution (Source: Amphenol Fuyang).**

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RF Interconnect Requirements for High Performance Quantum Computing Technologies

David Slack
Times Microwave Systems, Wallingford, Conn.

Quantum computing technology, the next frontier of computation, has been in development for several decades, but it is starting to heat up as technology continues to advance rapidly. Representing a significant shift in computing performance capabilities, quantum computing will save years of development time and a substantial amount of money in engineering design as it becomes more prevalent.

Leading manufacturers already utilize some form of quantum computing to tackle incredibly complicated operations. The primary use cases involve scenarios consisting of a complex problem with many thousands of inputs for applications including cybersecurity, financial and economic modeling, aerodynamic and thermodynamic modeling, cosmology simulation and more. To use aerodynamic and thermodynamic modeling as an example, certain developments in hypersonic aircraft are stretching the limits of the known aerodynamic and aerothermodynamic design principles. Computer simulations of these phenomena using the best supercomputers available can take weeks to perform. Speeds and velocities still need to be well known, so much physical testing is also being done today to understand these properties. A quantum computer running those models instead would be substantially faster and involve much less physical testing.

QUANTUM COMPUTING AND MICROWAVE ENGINEERING

The primary element for computations is called a quantum bit or qubit. However, unlike the bits that power a classical computing machine representing data as a one or a zero, quantum data can simultaneously be a one and a zero. This mechanism enables a quantum computer to process information significantly faster and more efficiently than a classical computer.

Qubits act similarly to a microwave resonant circuit; they can be driven from a zero state to one state by moving them with a microwave signal. Under this driven condition, the probability of being a one or a zero state varies sinusoidally with time. Like other signals, the qubits

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have a magnitude and a phase relationship. One of the limiting factors in quantum computing is that when the resonator is under this driven condition, it can only be predictable and controlled for a certain period. This is because, like with any resonator, there are effects that will cause it to lose energy and stop resonating.

The limiters are called the correlation of the qubit. When qubits become de-correlated, and they are no longer predictable and controlled; it is analogous to bit errors in data and creates computational issues. As a result, the correlation and control of qubits are one of the fundamental driving issues behind the technology development. It boils down to the fact that "noise" is introduced from thermal, magnetic and mechanical sources.

Microwave hardware can feed these resonators and minimize contaminations. One of the prime limitations is ultra-low noise driving signals for qubits, especially low phase noise, so a great deal of work is going on in the applications of ultra-low phase noise oscillators and similar technologies. When multiple bits are present, they can be coupled and controlled by driving a signal at a microwave frequency. It can be amplitude and phase modulated to give it specific properties. Aside from the low noise sources of these driving signals in precise modulation schemes, the hardware minimizes that contamination.

QUANTUM COMPUTING REQUIRES SPECIALIZED RF AND MICROWAVE CABLE ASSEMBLIES

The unique complexities of quantum computing require robust RF interconnects and cable assemblies to reliably transport qubit information to and from the quantum processor. This includes cables that can operate in extremely low temperatures, space-constricted environments and options that will not interfere with applied magnetic fields. One of the essential requirements to maintain low noise is to operate in very low temperatures. Quantum computers need to be exceptionally cold to be stable. These temperatures are typically colder than the vacuum of space with temperatures down to -459°F.

RF cables constructed using a silicon dioxide (SiO2) dielectric are used throughout the microelectronics industry for their excellent insulating properties and to offer semi-rigid cable solutions that are highly temperature and radiation resistant. These rugged, low loss and phase-stable coaxial assemblies were initially developed to support spaceflight missions, where the requirements of being vacuum sealed and able to withstand extremely low temperatures are essential. SiO2 cable assemblies represent a significant advancement in coaxial cable technology, providing exceptionally low hysteresis with phase and loss values returning to the same values at a particular temperature even after being in extreme environments. This type of cable works at temperatures ranging from just above absolute zero to 1000°C. ***Figure 1*** shows some examples of SiO2 cables.

Fig. 1 Examples of Times Microwave SiO2 cables.

The SiO2 coaxial cable construction begins with a solid oxygen-free copper center conductor, a SiO2 insulating dielectric and a stainless-steel jacket with copper cladding to act as the outer conductor. Using the development techniques for creating SiO2 cables and harsh environment aspects as a launch point, the next logical step is to apply materials that are more advantageous to quantum computing applications. Two material types fit into this space well and are applied at different temperature levels: Cu-Ni-based semi-rigid construction

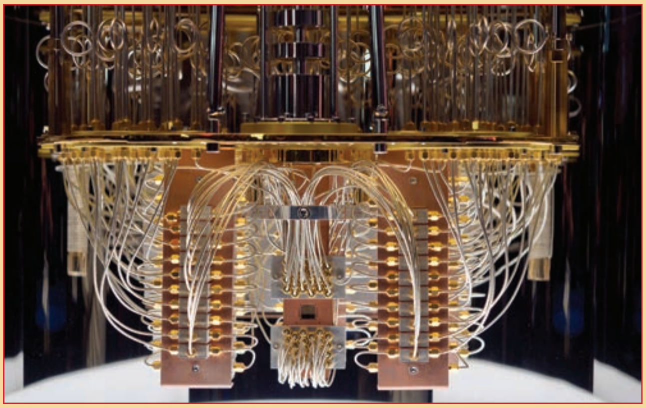

Fig. 2 Typical quantum computing system.

is used from room temperature to ~4K and NbTi construction from 4K down to 4mK. The NbTi is a superconducting cable that is designed to interface with the quantum processor directly.

Figure 2 shows a typical quantum computing system, where the quantum CPU (QCPU) is held at superconducting temperatures. RF cable assemblies are used throughout the entire system starting at the QCPU through the different temperature levels and out of the chamber to the control electronics. Room temperature cables play a vital role in this operation as well because phase stability is important. These cables generally have varying lengths associated with them and cannot introduce errors in the systems.

HIGHER FREQUENCIES, SMALLER SPACES

Technological advances across quantum computing are leading to more complicated requirements for RF systems that accommodate higher frequencies inside devices that are continually getting smaller.

For example, quantum computing requires signal access points close to processors. Cabling for these systems is a challenge because in tight space configurations, traditional semi-rigid solutions have limitations; in very small sizes, they become too fragile, making installation difficult as these assemblies are more prone to breakage. Using flexible cables specially designed to optimize space, bending around tight corners and connecting to various ports without wasted cable length is emerging as a preferred option. Durability and material selection are additional considerations as these cables are twisted around in tiny spaces in the challenging environments of quantum computers.

REDUCING MAGNETIC INTERFERENCE

Quantum computing also requires non-magnetic coaxial cables in critical areas of the signal path to eliminate potential interference with applied magnetic fields. Non-magnetic coaxial cables and connectors are primarily used in applications that transmit RF signals within a magnetic field, including quantum computers. The presence of any magnetic material in these components may interfere with the magnetic field, so a non-magnetic or non-metal coaxial cable or connector must be "invisible" to the magnetic field. This requires very low susceptibility and no field distortion. A class of hermetically sealed custom coaxial cabling assemblies addresses this by utilizing advanced manufacturing techniques that ensure zero electric field distortion.

CONCLUSION

Quantum computing is ushering in an era of significant computing performance improvements. The technology is both incredibly promising and extremely complex. To help ensure quantum computers perform to their highest potential, unique microwave technologies and RF cable assemblies will be required. As this technology is in its infancy and is rapidly developing, technologists should partner with an interconnect specialist that has a wealth of experience creating solutions that have powered the most innovative products to date, in the most extreme conditions possible, along with the ability to innovate as the technology evolves. ■

Software Encryption Enables Sharing of IP-Protected Models

Cadence Design Systems, Inc.
San Jose, Calif.

Today's high performance electronic systems require design teams to integrate high speed and/or high frequency components to meet aggressive timelines as well as stringent specifications. The traditional approach of "integrating in the lab" to build out systems is neither conducive to meeting aggressive time-to-market windows nor efficient from an engineering resource perspective. The more common practice is now to virtually integrate components from multiple suppliers into one complete system-level design to accelerate and ensure first-pass success. Component vendors are hesitant to share the level of detail required for complete system design and multiphysics analysis simulations within the design community ecosystem and this is a critical hurdle to overcome with this virtual integration methodology.

To address this situation, Cadence provides a software solution and workflow that allows vendors to supply 3D components, like connectors, to enable design teams to merge mechanical CAD component models with printed circuit board (PCB) designs. Everything can be simulated as a single, complex structure without revealing the underlying proprietary physical IP. This improves simulation accuracy since the PCB and the connector can be simulated as a complete/combined structure instead of as a cascade of S-parameter models. With Cadence encryption support within its multiphysics

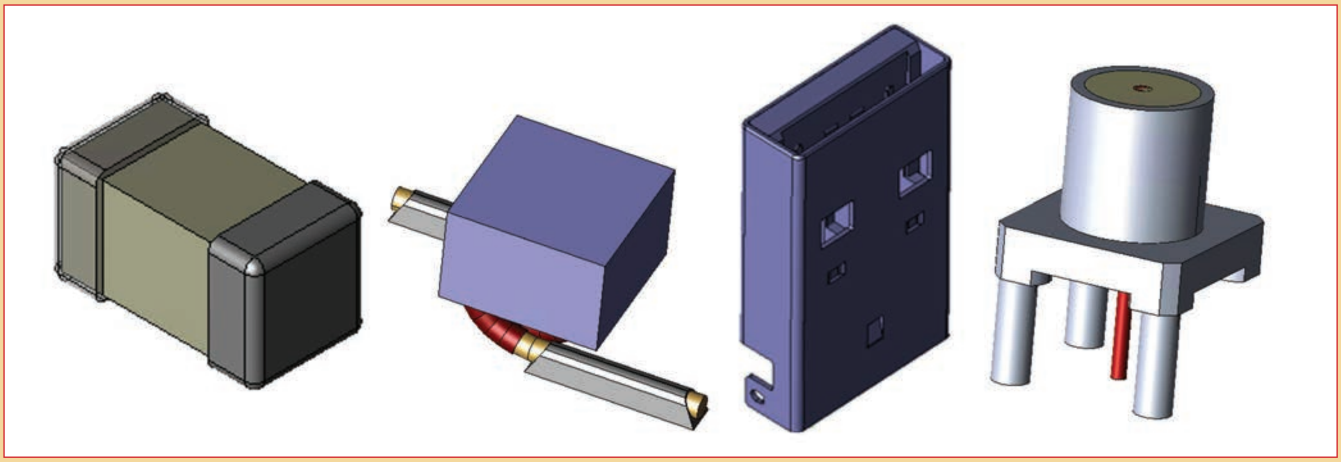

Fig. 1 **3D Components of typical models (capacitor, coil and connector).**

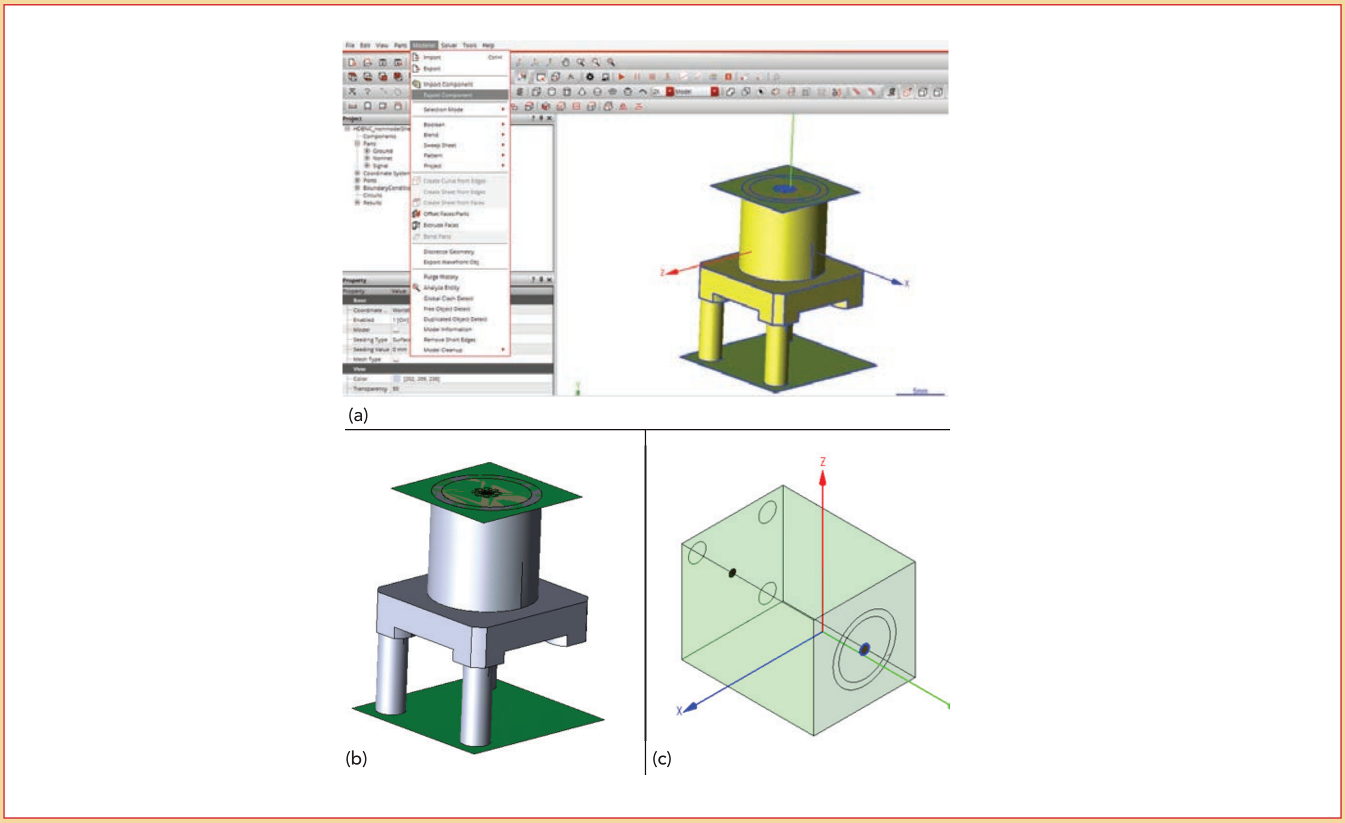

Fig. 2 **Menu to generate and export a 3D component (a), 3D connector component (b) and IP-protected equivalent model (c).**

systems analysis products, specifically Cadence® Clarity™ 3D Solver for electromagnetic (EM) analysis, designers can freely share their electronic component designs without the risk of revealing confidential IP.

CADENCE 3D COMPONENTS

A 3D component is an encapsulated model that includes a set of 3D objects, sheets, boundary conditions and ports/excitations from the Clarity 3D Solver and Clarity Transient Solver. Using the Clarity 3D Solver as an example, designers can easily import and export individual 3D component designs like those shown in ***Figure 1*** across Cadence platforms such as Allegro® PCB Design.

The 3D components solution enables designers to create an encrypted model and choose to show the user the outer portion of the design without revealing the underlying proprietary IP. ***Figure 2a*** highlights the menu to generate and export a 3D component. ***Figure 2b*** shows the 3D connector component in full detail, while ***Figure 2c*** shows the resultant IP-protected equivalent model displaying only the port location and rough footprint outline.

Cadence's 3D encryption of components enables designers to edit, share and work on high speed and high frequency electrical component designs with external customers and partners. It allows designers to protect the underlying IP of their designs when collaborating with others through password protection. It also hides the main portions of the design while showing only the necessary geometries.

Once a 3D component is encrypted, it can be shared. As Figure 1 shows, the recipient of the protected IP cannot see the inner workings of the components. The designer has successfully hidden the components' IP from view, guaranteeing IP protection while enabling customers and partners to use these components to carry out their respective multiphysics system-level simulations without any loss of accuracy.

VENDOR ADOPTION: JAPAN AVIATION ELECTRONICS (JAE)

JAE became the first 3D component vendor to take full advantage of Cadence's 3D component functionality within the Clarity 3D Solver, publicly announcing their use of the software in July 2022. Before encryption support, JAE provided their connector simulation model at a very high level of abstraction as an equivalent circuit or S-parameter. For connector manufacturers like JAE, 3D CAD data of high performance connectors is confidential and a highly-valued proprietary design asset not readily disclosed. Through collaboration, Cadence and JAE realized encrypted models capable of accurate EM field simulation while also hiding the internal structure of the connector.

CONCLUSION

Cadence encryption support within its multiphysics analysis products provides a solution for 3D components manufacturers who are concerned about sharing their valuable IP with partners. This solution enables vendors to safely merge their mechanical CAD models with PCB designs without revealing the underlying proprietary physical IP. Merging PCB designs and connector CAD models results in one combined structure that enables improved simulation accuracy.

As more vendors adopt the JAE approach, these encrypted component models will be made available for registered users to download from the vendor's website or through an online catalog. The protected nature of the models ensures that the component IP is protected while allowing the system-level design engineers access to the data they need. Cadence believes that this will enable designers to model what they make and make what they model, delivering high performing solutions on time and in spec to the market.

VENDORVIEW

Cadence Design Systems, Inc.
San Jose, Calif.
www.cadence.com

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Mini-Circuits

Exploring the Role of Innovative Cabling For 5G and Beyond

Junkosha
Irvine, Calif.

Test and measurement is a crucial application where cable assembly innovations like those introduced by Junkosha over the years are constantly required. As we move toward a 5G-enabled and in the coming years a 6G-enabled world, the cables and interconnects used in test and measurement processes must be of the highest standard and reliability.

5G represents the next major evolution of mobile communication technology and it is enabling next-generation applications such as the IoT, autonomous vehicles and virtual reality. The evolution to 5G brings significant hurdles that must be overcome. For example, frequency spectrum availability is limited and 5G operators are looking at even higher frequencies to deliver faster data speeds.

Advances in 5G have created interest in higher mmWave frequencies where cabling and interconnect solutions must be robust to withstand the rigor they are subjected to in many applications. These applications may be in the system development or device performance characterization phases where precision and repeatability are required, or in the stages of commissioning the overall system and monitoring performance in the production test environment.

Cabling assemblies deployed in a test environment are often utilized with vector network analyzers (VNAs). These analyzers are used to test and characterize individual components or a network composed of many components to ensure systems function properly together. At mmWave wavelengths, instances of flexure and mechanical stress have a significant impact on the accuracy of the results, which is accentuated as frequencies increase.

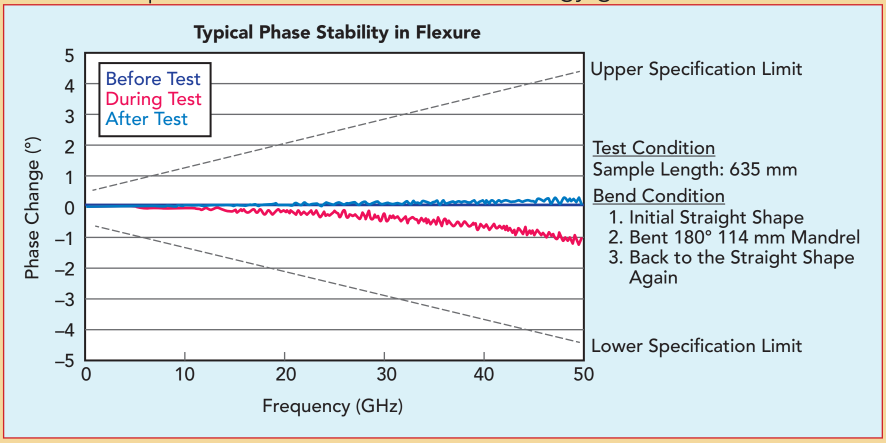

Fig. 1 **Phase stability versus frequency for flexure.**

Accuracy is crucial in any test setting, but particularly so for metrology-grade cabling. These applications demand the ultimate precision and the highest reliability for testing and calibration purposes. In response, Junkosha has been showcasing its 8 Series VNA Test Assembly over the last 12 months. The 8 Series is designed as a high-quality metrology-grade VNA test cable for users requiring optimum precision.

Utilizing Junkosha's precision-engineered expanded-PTFE tape-wrapping technology, a 25-in. long metrology-grade cable exhibits

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phase stability within ± 1.5 degrees at 50 GHz and amplitude stability within ± 0.08 dB at 50 GHz in flexure. ***Figure 1*** shows a graph of phase stability in flexure for this metrology-grade cable. The cable is flexible and can maintain this level of performance when bent 180 degrees on a 2.25-in. radius mandrel, with no spring back. Able to reach 50 GHz and available in a 2.4 mm connector, the assembly typically achieves 50,000 tick-tock cycles. The ruggedized port side NMD connector is also available to ensure reliable connections to the VNA.

A key application area for this metrology-grade microwave/mmWave VNA test cable assembly is in measuring the device under test when designing a high frequency component. This metrology-grade cable can also be used for coaxial cable, components and device development. Offering a calibration level standard bench test, target customers for this solution include national institutes, calibration laboratories and service providers who value repeatability.

Both 26.5 and 50 GHz versions of the 8 Series VNA Test Assembly are available with NMD-style ruggedized connectors for direct attachment to VNA test ports. Other iterations are available on demand. It can be shipped along with the VNA or as part of an aftersales package to replace an existing cable.

As 5G evolves, humans and devices will require more wireless connectivity to enable a connected world that will rely on innovation to create more efficient use of the available frequency spectrum. The demand for mmWave frequencies has gone from the domain of the few to the requirement of the many, thanks to varied new space and defense applications to emerging high volume commercial applications. To enable the required system performance at higher mmWave frequencies, "phase performance that endures" is a statement that the cable and interconnect ecosystem must live up to, especially in the test and measurement environment. Junkosha's latest solutions provide VNA manufacturers with the capability to test the high frequency networks that are at the heart of tomorrow's highly sophisticated systems.

In addition to the 8 Series, Junkosha has launched the MWX7 Series of cables within the past 12 months. This is another in the range of high-end mmWave cabling solutions. The ePTFE tape-wrapped, phase-stable MWX7 Series of cables deliver excellent phase and amplitude stability against temperature fluctuations for multiple applications. The cables offer reduced phase and amplitude drift due to mechanical fluctuations to support repeatable results. Junkosha's in-house manufactured dielectric ePTFE tape-wrapping technology promises consistent performance in both inter- and intra-batch quality to maintain peak performance.

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Irvine, Calif.
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Low Loss, High Performance Cable Assembly Operates to 70 GHz

HUBER + SUHNER is expanding its SUCOFLEX® 570 family with the introduction of the SUCOFLEX 570E phase stable, low loss cable assembly. These cable assemblies have a maximum frequency range of 70 GHz and they operate over a -40°C to +85°C temperature range. The SUCOFLEX 570E guarantees 14 dB return loss up to 67 GHz and the insertion loss is specified at a maximum of 6.05 dB/m at 70 GHz.

The SUCOFLEX 570E cable assemblies use silver-plated copper center and outer conductors with a PTFE dielectric to achieve a velocity of signal propagation value of 77 percent. The jacket material for the cable assemblies is polyurethane and these design features result in a minimum bend radius of 11 mm. The combination of materials and design features gives the SUCOFLEX 570E cable assemblies a high flex life and it makes them torque, crush and kick resistant. The cable assembly construction also makes it very light, weighing in at 0.02 kg/m.

The combination of high frequency operation, low loss and excellent flexibility make the SUCOFLEX 570E cable assemblies an ideal solution for precise measurements in critical laboratory applications. These cable assemblies target benchtop and RF production testing applications. They offer high performance solutions when mated with automated test equipment, vector network analyzers and scalar analyzers. These cable assemblies are also versatile enough to provide precise and repeatable solutions for portable test equipment, RF module and high speed digital testers. The SUCOFLEX 570E cable assemblies are in production now and available in customized lengths.

HUBER+SUHNER AG
Herisau, Switzerland
www.hubersuhner.com

CABLES & CONNECTORS

With nearly 500 custom cable designs and 5,000 custom and standard connectors, Frontgrade has the industry's broadest selection of cable systems for radar (airborne, ground, shipboard and missile), as well as electronic warfare, CNI, C4ISR, satellite communications and laboratory test equipment.
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The MIcable H09 series non-magnetic cable assembly is specially designed and developed for the application areas of magnetic resonance imaging, EMC laboratory, particle accelerator and high-power equipment connection. The product has the characteristics of non-magnetic, high shielding effectiveness, low loss, high-power and excellent VSWR performance. It is a good choice for the application areas above.
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LITTLEBEND SMP CABLES

The Littlebend Ultra Flexible RF Cable is designed for demanding microwave interconnect requirements. They are phase and amplitude stable. This cable is well suited for dense microwave packaging with a tight bend radius cable with stainless steel braid. HLB098 Littlebend flexible cables are terminated with high performance SMP connectors. Also available in 2.4 mm, 2.92 mm, SMA, SMPM and bulkhead connectors. Additional configurations available by special order.
HASCO
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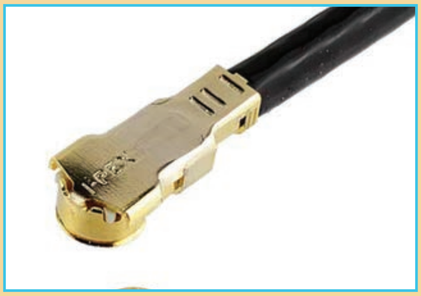
5G RF CONNECTOR FROM I-PEX



The I-PEX® MHF® 7S Connector is designed to solve EMI issues caused by 5G mmWave transmissions. The connector has unparalleled EMI performance in a small form factor (2.0 × 2.0 mm footprint). With a 1.50 VSWR maximum at 15 GHz, the MHF 7S solves 5G problems now. This connector is ideal for fixed wireless access, notebook PCs, small cell applications and any application where improved electrical performance is required.
I-PEX
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STABILITY WAFER™ ON-WAFER PROBING CABLE ASSEMBLIES

Stability Wafer™ on-wafer probing cable assemblies from Maury Microwave provide table and repeatable electrical performance, flexible to facilitate easy installation, small profile for tight spacing requirements straight, right-angle and extended 90-/83-degree connectors for optimized connections to probes and color-coded connectors to avoid damage caused by connector. Stability Wafer™ on-wafer probing cable assemblies are available with 3.5 mm connectors to 26.5 GHz, 2.92 mm connectors to 40 GHz, 2.4 mm connectors to 50 GHz and 1.85 mm connectors to 67 GHz.
Maury Microwave
www.maurymw.com

ULTRA-WIDEBAND COAXIAL AMPLIFIER

Mini-Circuits' model ZVA-5803X+ is an ultra-wideband coaxial amplifier with continuous frequency coverage of 0.5 to 80 GHz. It delivers 17 dB typical gain with ±3.0 dB gain flatness and +8.5 dBm or better output power at 1 dB compression. Ideal for communications, radar and test systems, the rugged amplifier includes reverse-and over-voltage DC protection and operates from a single supply of +10 to +15 VDC. It measures 1.85 × 0.90 × 0.84 in. (46.99 × 22.96 × 21.29 mm) with 1 mm female connectors.
Mini-Circuits
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IN-SERIES & BETWEEN-SERIES ADAPTORS

Samtec has released a family of 50 Ω, In-Series (PRFIA) and Between-Series (PRFBA) precision RF adaptors for SMPM, 1.85, 2.40 and 2.92 mm interconnects. PRFIA and PRFBA adaptors offer well-performing VSWR and insertion loss and are perfectly suited for high frequency test and measurement applications. SMPM-to-SMPM adaptors allow for axial and radial misalignment in high density blind-mate applications.

Samtec
www.samtec.com

VNA

The BN900-485 model is a USB-model VNA that performs as well as its benchtop model. It is the latest model we have launched to serve our customers who require test equipment with greater portability. Features include: frequency range: 300 kHz ~ 8.5 GHz, large dynamic range: > 125 dB at (IFBW = 10 Hz), typical 130 dB, low trace noise: 2 mdB rms at (IFBW = 3 kHz), measurement speed: 42 µs/point at (IFBW = 500 kHz) and high effective directivity: > 42 dB.

Sanko Technologies Sdn Bh
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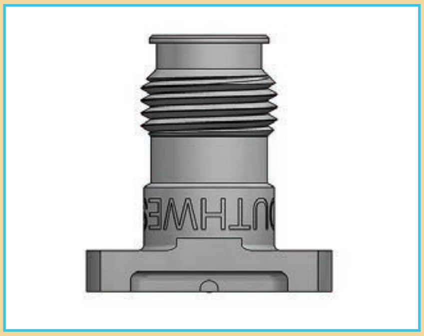
PCB VERTICAL LAUNCH COMPRESSION MOUNT CONNECTOR



Southwest Microwave Inc. (SMI) completes the vertical launch compression mount family, with the addition of a 1.35 mm model. SMI's solderless vertical launch connectors are designed for microstrip or grounded coplanar boards. They provide optimal signal integrity, are reusable and are installed without soldering. Suitable for various board materials and thicknesses, with operational frequency of 90 GHz. To learn more, please contact Southwest Microwave.

Southwest Microwave
www.southwestmicrowave.com

SNAP-ON CONNECTOR

VENDORVIEW

SPECIAL HERMETIC PRODUCTS INC.
Hi-Rel By Design
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The SMP snap-on connector has become a popular RF connector for use in high density RF system packaging. SHP has developed additional variants of these connectors, which improve their attachment characteristics. These include a robust aluminum compatible connector and a robust kovar compatible connector for solder applications. Contact SHP today for engineering guidance on these extensive SMP options to ensure maximum reliability of your product and minimize costs.

Special Hermetic Products Inc.
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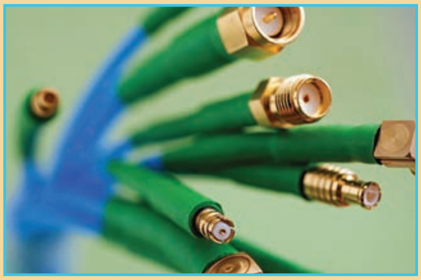
EXPRESSRF MATCHED PAIRS

VENDORVIEW



ExpressRF™ is Swift Bridge Technologies' most economical product line. These assemblies offer excellent overall performance to ensure accurate and repeatable measurements on the device under test. ExpressRF is now available in phase matched pairs, delay matched to within 1 ps, at operating frequencies of 40, 50 and 65 GHz. 2.92, 2.4 and 1.85 mm precision RF connectors in both male and female configurations are available. All assemblies are 100 percent tested to assure S-parameters meet/exceed their specified performance.

Swift Bridge Technologies
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SEMI-RIGID TEST CABLES

Clarity™ 110-SR semi-rigid test and measurement cable assemblies hold their shape even in tight places, with low loss and excellent phase stability through 110 GHz. These are ideal for reliable and accurate measurements of analog and digital circuits in automotive, 5G wireless communications and military and aerospace applications.

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Phase and Timing-Accurate Multi-Channel Radar Signal Generation

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

AnaPico launched its APVSG series of vector signal generators (VSG) in single- and multi-channel models two years ago. The main features of these models are:

- Wideband performance to 40 GHz and 500 MSa/s data processing capability supporting 400 MHz signal bandwidth
- 512 MSa internal memory with 32 bits per sample supporting sequential and waveform segment ID selective playbacks
- Fast frequency and amplitude switching ranges from less than a microsecond to a few microseconds depending on the frequency change range
- Phase coherence and phase-coherent switching
- Fast control port (FCP) for rapid modulation parameter setting and digital IQ data streaming up to 250 MSa/s.

The above feature combinations enable the flexible generation of versatile phase and timing-accurate, multi-channel radar signals. AnaPico has recently developed user-friendly and cost-efficient software to support the radar signal generation on the AnaPico multi-channel APVSGs.

PULSE DESCRIPTOR WORD

Engineers testing radar require the ability to generate multi-pulse streams with each pulse supporting dozens of parameters such as frequency, amplitude, phase, pulse width, time position and intrapulse modulation or chirping. ***Table 1*** summarizes the typical parameter set describing a single radar pulse, known as a pulse descriptor word (PDW). A list of PDWs will fully describe a radar pulse stream.

Multi-patch radar antenna arrays require additional parameters for full characterization. For these arrays, inter-channel phase coherence, which addresses relative phase stability becomes important. Phase-coherent switching, where the relative phase between channels is stored in memory and

Ultra Low Phase Noise

Phase Locked Clock Translators

Up to 27.5 GHz

Features

- [illegible]
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- [illegible]

Applications

- [illegible]
- [illegible]
- [illegible]
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- [illegible]

New!

Model	Frequency (Mhz)	Typical Phase Noise		Package
		@10 kHz	@100 kHz	
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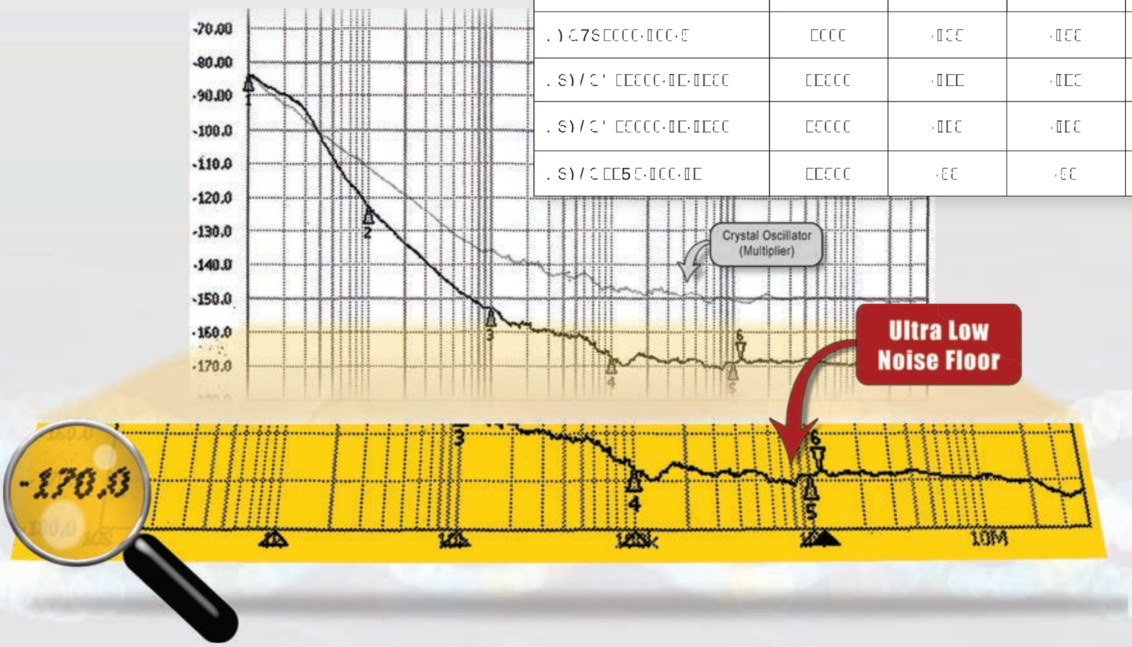

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TABLE 1
THE TYPICAL STRUCTURE OF A PDW

Parameter Name	*Parameter Group*
PDW Configuration	PDW Setting
PDW Start Time	
Fixed Carrier Frequency	Carrier & Output
Fixed Carrier Power	
Fixed Phase	
RF Output Control	
Segment ID	Waveform
Sequence ID	
Modulation State	
Frequency Offset	Offset
Amplitude Offset	
Phase Offset	
FM Frequency	FM/ΦM
FM Deviation	
ΦM Deviation	
AM Frequency	AM
AM Depth	
Chirp Rate	Chirp
Chirp Shape	
Pulse Delay	Pulse Mod.
Pulse Width	
Start Frequency	Sweep
Step Frequency	
Start Power	
Step Power	
Start Phase	
Step Phase	
Dwell Time	
Delay Time	
Number of Points	

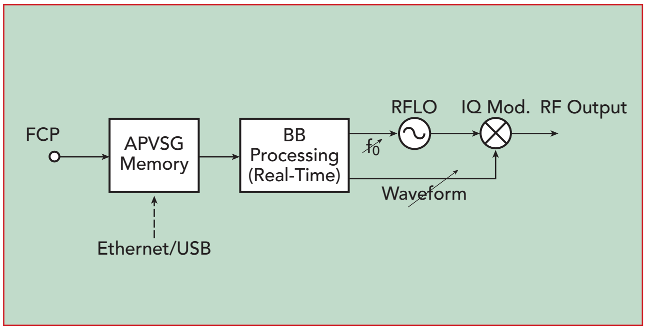


Fig. 1 Operation modes of the PDW list playback.

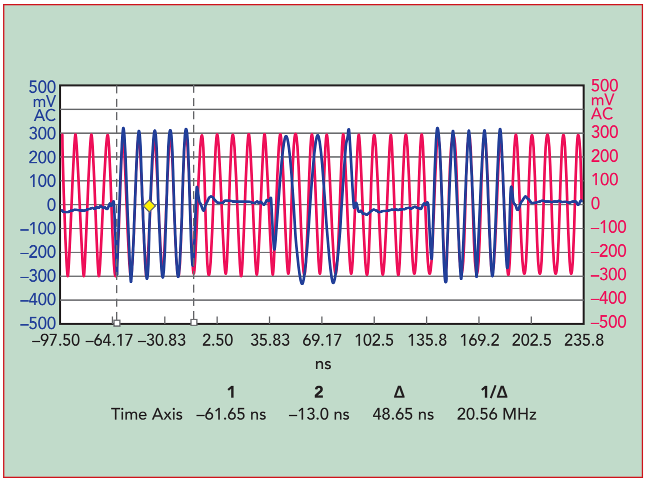


Fig. 2 Phase-coherent switching illustration.

inter-channel timing accuracy are also critical parameters.

SIGNAL GENERATION MODES

The AnaPico VSGs accommodate two different modes for generating the PDWs. These modes are implemented with circuitry within the VSG. ***Figure 1*** depicts the block diagram for the two PDW-related operation modes.

Mode 1: Sequential PDW Playback

In this mode, a list of PDWs, precompiled in a data format, can be uploaded into the APVSG internal memory through the Ethernet or USB communication port. During the playback, each PDW is translated to the corresponding modulation parameters, sequentially and in real-time. This generates a stream of modulated radar signals and accurately timed PDW sequences can be played back with the multi-channel APVSGs.

Mode 2: PDW Live-Streaming

In this mode, individual PDWs are fed into the APVSG internal memory sequentially and in real-time through the APVSG FCP for immediate playback as described in mode 1.

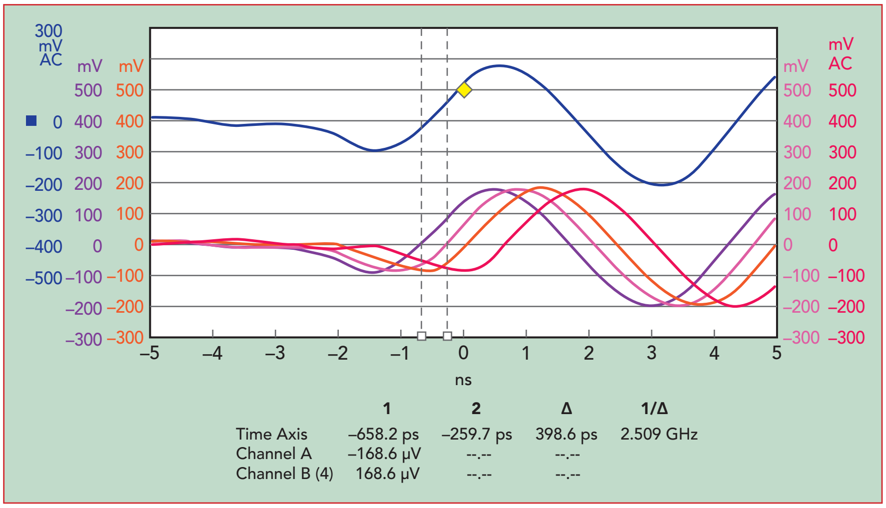
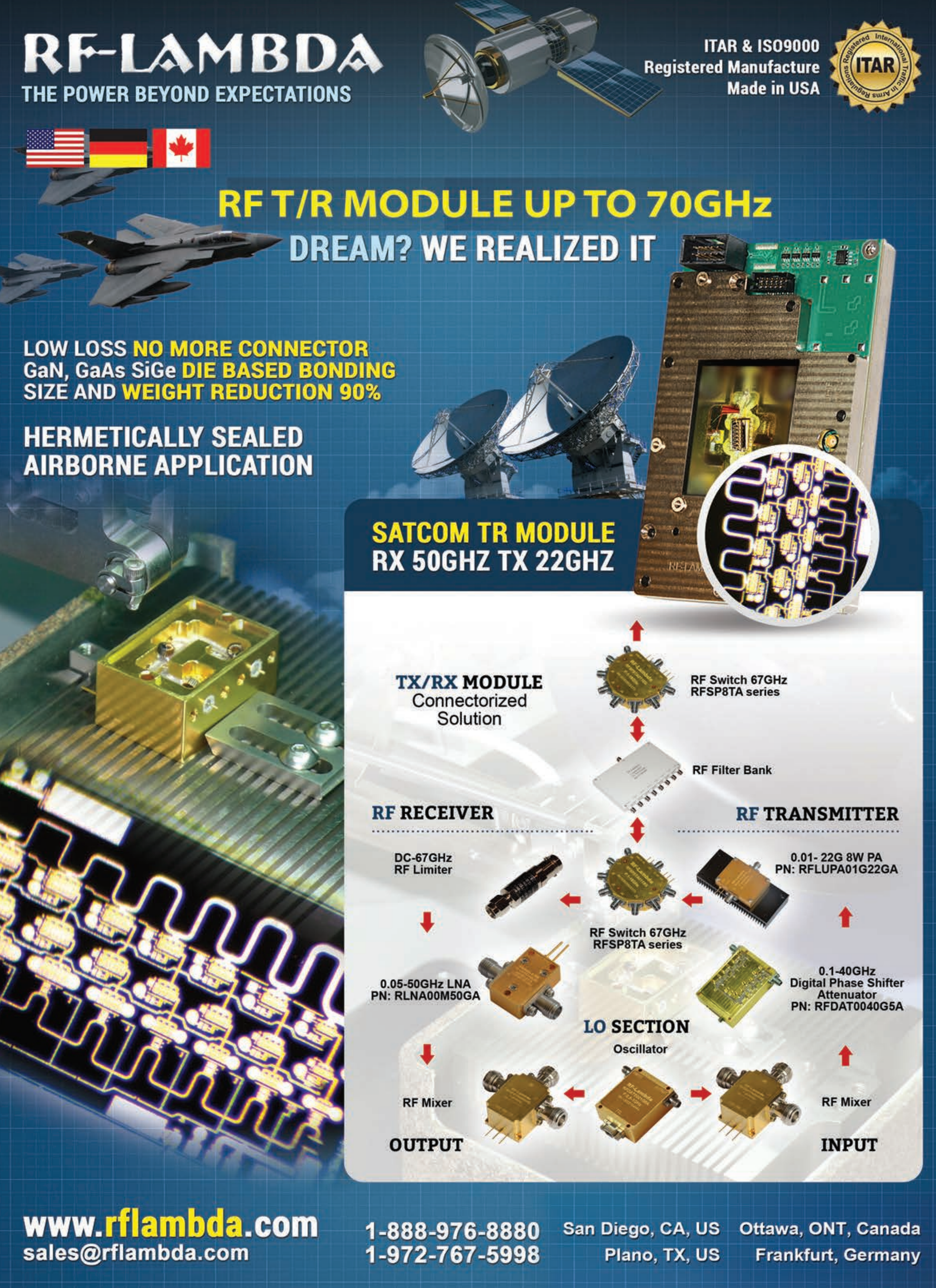


Fig. 3 Setting delays on identical chirping signals.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Frankfurt, Germany

KEY FEATURES AND PERFORMANCE POINTS

To generate radar pulse sequences that approximate real sequences, a number of features and aspects are important. Fast switching is a key parameter. The VSG must support a pulse width ranging from less than a microsecond to a few microseconds. The frequency chirp rate is limited by the modulation bandwidth of 400 MHz. At a 1 μs pulse width, chirp rates of close to 400 MHz/μs can be produced with excellent signal quality. Phase coherence is another important capability. For a multi-channel VSG to implement the correct radar beam angle specification, phase coherence becomes the most relevant feature. The phase difference variation of the multi-channel APVSGs over hours of operation is 0.3 degrees RMS between two channels generating 5 GHz signals.

Deterministic phase differences between the channels are essential for sustaining the angle information during radar operation. For a given frequency and power setting, the phase difference between channels does not change, even when the supply power switches on and off. This is called phase-coherent switching and it is illustrated in ***Figure 2***. The red sinusoidal signal is the reference channel. The blue signal switches to a different frequency and there is a phase offset, but the blue signal maintains the same relative phase to the red signal when both return to the same frequency setting.

Multi-channel APVSGs support fine delays to +/- 1 ps RMS precision over the entire operating frequency range. This allows multiple radar signal streams to be generated with accurate timing. The capability in a VSG is known as timing-accurate multi-channel triggering. A unique delay mechanism enables this fine trigger delay adjustment. The effective resolution is a very small fraction, typically less than 1/2000, of the sample time. This equates to less than 1 ps with a physical sample time of 2 nsec. ***Figure 3*** illustrates the fine delay setting capability.

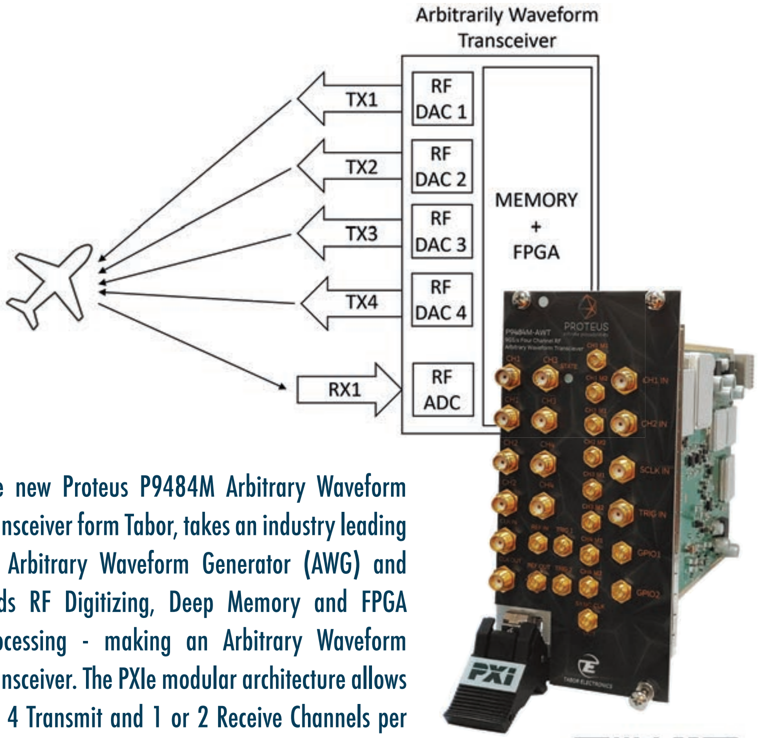
SUMMARY

AnaPico's multi-channel APVSG VSGs have a combination of features such as fast switching, phase coherence, phase-coherent switching and timing-accurate operation. These VSGs allow users to easily generate versatile and realistic pulse signals in radar and electronic warfare application scenarios. Multiple lists of PDWs can be replayed from the internal memories or live-streamed through the fast control ports.

VENDORVIEW

AnaPico AG
Zurich, Switzerland
www.anapico.com

Berkeley Nucleonics Corp.
San Rafael, Calif.
www.berkeleynucleonics.com/



Electromechanical Waveguide Switches Control Sub-THz Signals

Eravant, formerly Sage Millimeter Inc.
Torrance, Calif.

Electromechanical waveguide switches are widely used in radar, telecommunication and instrumentation systems. With the growth of applications operating above 100 GHz, there is increased demand for electromechanical switches designed for these higher frequencies. To fulfill this need, Eravant has developed full-band WR-08, WR-06 and WR-05 electromechanical transfer switches to cover sub-THz frequencies from 90 to 220 GHz. Typical insertion loss ranges from 1.2 dB for model SWJ-08-T1, which operates from 90 to 140 GHz and is shown in ***Figure 1*** to 2.5 dB for model SWJ-05-T1, which operates from 140 to 220 GHz. Measured insertion loss and isolation results for the WR-05 SWJ-05-T1 switch are shown in ***Figure 2***.

Fig. 1 **SWJ-08-T1 electromechanical transfer switch.**

Common to all SWJ models is a compact electromechanical actuator that provides a nominal switching speed of 125 ms. The actuator requires ±28 VDC at 250 mA and a TTL-level control signal to select the switch position. Power and control connections are provided through an MS3112E10-6P connector. Designed for operation from -25°C to +65°C, the switches measure 1.83 × 1.83 × 3.53 in. (46.4 x 46.4 × 89.8 mm) and weigh 7.0 oz. (200 g). They are rated for 100 W of CW signal power. Type UG-387/U-M anti-cocking waveguide flanges are symmetrically positioned 0.675 in. away from the central axis.

The entire SWJ-XX-T1 series of electromechanical DPDT switches cover full waveguide bands from WR-42 through WR-05 as shown in ***Table 1***. All models use a four-port E-plane waveguide junction as the stator. Using a symmetrical rotor inside the stator, each port is connected to one of its adjacent ports depending on the state of the control signal. Position 1 is selected when a high-level control signal is applied, resulting in a connection between ports 1 and 2 as well as a connection between ports 3 and 4. Position 2 is selected when a low-level control signal is applied, resulting in connections between ports 1 and 4 and between ports 2 and 3. These states are shown in the switching diagram in ***Figure 3***.

Applications for waveguide transfer switches include redundant and reconfigurable transmitters, agile antenna systems and various test and measurement appli-

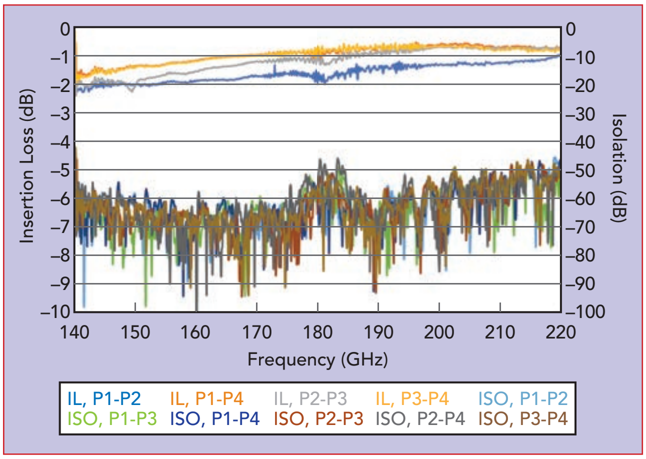


Fig. 2 Typical insertion loss and isolation for model SWJ-05-T1.

TABLE 1

PERFORMANCE PARAMETERS FOR THE SWJ FAMILY

Model	Frequency Range (GHz)	Insertion Loss (dB)	Isolation (dB)	Return Loss (dB)
SJW-05-T1	140 to 220	2.5	40	15
SJW-06-T1	110 to 175	1.5	45	20
SJW-08-T1	90 to 140	1.2	50	20
SJW-10-T1	75 to 110	0.6	55	20
SJW-12-T1	60 to 90	0.4	60	20
SJW-15-T1	50 to 75	0.4	60	20
SJW-19-T1	40 to 60	0.3	50	25
SJW-22-T1	33 to 50	0.2	60	25
SJW-28-T1	26.5 to 40	0.2	60	25
SJW-34-T1	22 to 33	0.2	50	23
SJW-42-T1	18 to 26.5	0.2	60	23

cations. A common application is to optionally select between the orthogonal feeds of a dual-polarized antenna. When used in an antenna test facility, such an arrangement enables the operator to change the polarization of the test signal without disturbing the physical setup. In communication systems with polarization diversity, the polarization of a receiver can be controlled to maintain higher fade margins than would be possible using fixed polarization under variable propagation conditions.

Another common application is in space communication transceivers. Transfer switches on a newly deployed satellite can be used to initially select a higher power amplifier (PA) and a lower gain antenna to establish a communication link with another satellite. After the satellite has established a stable position, a lower PA and a higher gain antenna may be used to conserve power.

Radar and electronic countermeasure systems often require high levels of reliability or periodic self-testing. In these applications, transfer switches can select between redundant components such as PAs or high-sensitivity amplifiers. While one of the redundant components is in service, the other component may be tested or replaced without incurring any loss of service.

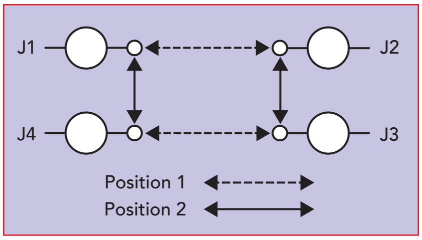


Fig. 3 SWJ-XX-T1 switching diagram.

In noise calibration systems, waveguide switches are often used to connect a noise power analyzer to either a reference noise source or a tested noise source. By rapidly alternating between two signals, the switch enables accurate comparisons of measured noise levels. This technique will also minimize the effects of temperature drift and other disturbances that could otherwise occur between measurements.

In most switching applications, low return loss, low insertion loss, high isolation and long operating life are desired. The SWJ family provides stable performance over more than 250,000 switching cycles. At frequencies above 100 GHz, innovative designs and advanced levels of mechanical precision are required to achieve these goals. The SWJ series of waveguide switches further demonstrate Eravant's continued progress into the sub-THz and THz realms with a variety of components used in radar, telecommunication and instrumentation systems.

VENDORVIEW

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

New PCIe Digitizers Offer 10 GSPS and High Resolution

Spectrum Instrumentation GmbH
Grosshansdorf, Germany

Two new PCIe Digitizer cards from Spectrum Instrumentation enable 10 GSPS sampling rate, 12-bit vertical resolution and 12.8 Gbps data streaming capabilities. The cards boast the highest sampling rate and bandwidth in company history, creating a powerful package for engineers and scientists working with today's most challenging GHz-range electronic signals. The one-channel M5i.3350-x16 and the two-channel M5i.3357-x16 feature front-end circuitry with over 3 GHz bandwidth and up to 16 Gb (eight GSamples) onboard memory. They also reach the fastest digitizer data transfer speeds over PCIe on the market. Using 16-lane, Gen 3 PCIe technology, data can be streamed over the bus at 12.8 Gbps. The data can be sent to PC memory for storage or directly to CPUs and CUDA-based GPUs for customized signal processing and analysis.

With 12-bit resolution, these digitizers offer a better dynamic range than most conventional test instruments. For example, they deliver 16× more resolution than many digital oscilloscopes, which typically use 8-bit analog-to-digital converters. The extra resolution allows measurements to be made with a better signal-to-noise ratio (SNR) and improved accuracy and precision.

The front-end circuitry offers programmable full-scale ranges from ±200 mV to ±2.5 V together with variable offset. Acquisitions can be made in single-shot or multiple-waveform recording modes. To help capture the most elusive signals, a host of trigger modes are available for use on the channels or external trigger inputs. The modes include conventional edge triggering, along with more sophisticated methods such as Window, Re-Arm, Or/And (logical), Software and Delay. Installing the cards into a suitable PCIe slot can turn almost any PC into a powerful measurement tool. This opens the door for anyone wishing to use the latest CPU and GPU hardware for signal processing and analysis.

The new cards come with a five-year product warranty and all the tools necessary to use them in a PC running either a Windows or Linux operating system. A software development kit is provided, so that the cards can be programmed with almost any popular language including C, C++, C#, Delphi, VB.NET, J#, Python, Julia, Java, LabVIEW and MATLAB. Alternatively, the company offers SBench 6 Professional. This powerful measurement software provides full card control, along with a host of data display, analysis, storage and documentation capabilities.

A low-cost option, M5i.33xx-spavg, is available for summation averaging using onboard FPGA technology. Averaging reduces unwanted signal noise while enhancing the dynamic range and SNR. The cards can average signals at a rate of up to 15 million events per second, making them one of the fastest signal-averaging solutions on the market.

The new M5i digitizers are suitable for many applications. One such example is testing high speed communications channels using quadrature modulation. ***Figure 1*** shows an example of the acquisition of a 1 GHz carrier modulated by a 40 Mbaud quadrature phase shift keyed (QPSK) signal displayed using Spectrum Instrumentation's SBench 6 measurement software.

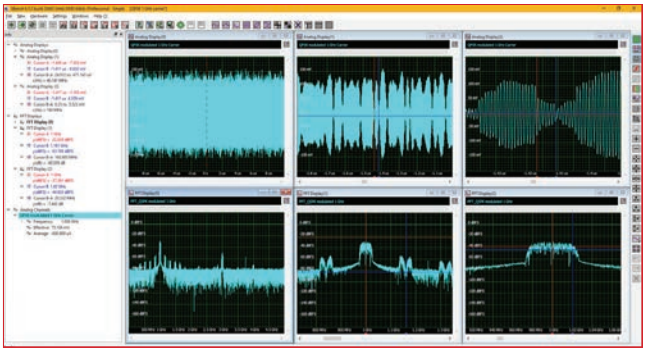


Fig. 1 Response of a 1 GHz QPSK-modulated signal sampled at 10 GSPS.

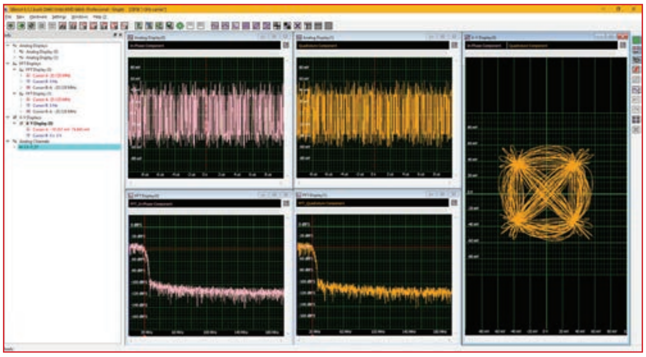


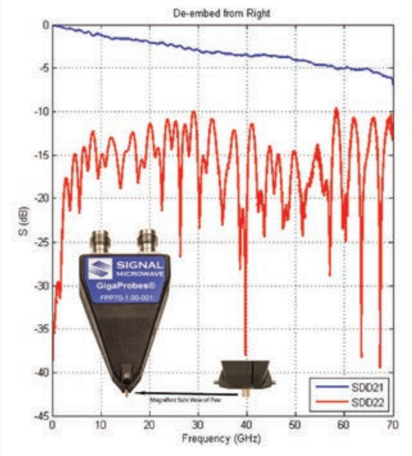
Fig. 2 I/Q, FFT and trajectory plot of 12.8 Gbps data stream.

Twenty microseconds of the QPSK signal were acquired at 10 GSPS. The FFT of the signal has a peak at the carrier frequency of 1 GHz. Modulation sidebands spaced at 160 MHz extend symmetrically from the carrier frequency. The signal components show significant energy out to 2 GHz and the harmonic of the carrier at 3 GHz. The bottom center trace shows the details of the sideband structure. The 160 MHz spacing of the modulation sidebands is due to the sampling in the transmitter. This is shown in the period between phase breaks in the time domain waveform in the upper right trace, as measured by the cursors. Cursor readouts and measurements of the signal frequency, amplitude and mean value appear in the info panel on the left of Figure 1. The narrowest burst in the top center trace highlights the 40 Mbaud data rate. The modulating signals are bandlimited to 20 MHz as seen in the expanded FFT in the lower right trace of Figure 1.

Transferring the data at up to 12.8 Gbps via the PCI Express x16 interface to a CPU or CUDA-GPU for custom processing creates the opportunity for further analysis, as shown in ***Figure 2***. The demodulated in-phase (I) and quadrature (Q) signals on the top and their FFTs on the bottom show the effects of 20 MHz raised root cosine low-pass filtering that has been applied to the signals. The cross plot of the I and Q components on the far right of the display in Figure 2 produces the trajectory diagram highlighting the transitions between digital states.

VENDORVIEW

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



40/50/70 GHz Wide Pitch True Differential TDR/VNA Probes

Signal Microwave, in partnership with DVT Solutions, is introducing a series of differential probes. The DVT-FPPXX family are 40, 50 and 70 GHz true differential probes. These probes are designed to support the industry's demand for higher data rates over differential traces. They are used to characterize transmission lines and devices such as 28 to 56 GHz Nyquist bandwidth S-parameters for standards such as PCIe5 and for current and future PAM4 and PAM5 encoding board and system designs.

To meet these needs, a newly patented differential probe design was developed. This differential probe replaces internal cable wires with a printed circuit board (PCB) with a high bandwidth differential transmission line that can be used with test equipment to measure differential S-parameters up to 70 GHz. The probe can also be used on packages and other devices that have differential inputs and outputs and wider spacing in the 1.0 mm range. The probes have two signal probe tips and no ground probe tips, which helps to reduce setup time. The probes have only two conductors at the probe tips with a characteristic impedance of 100 Ω. The two inputs from the 50 Ω connectors are converted to a differential pair and the ground plane is removed to create the true odd mode differential configuration at the probe tips. The new differential probe satisfies the need to probe PCB designs that have wide pitch test pads up to 70 GHz with a test pad pitch centering around 1 mm. These differential probes are used to make time and frequency domain measurements of final prototype PCB products to compare against design specifications and simulation results. There are also de-embedding methods and boards available that support the probes.

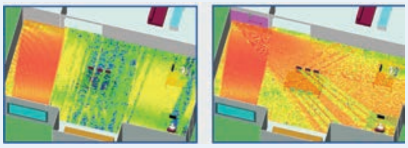
Signal Microwave, LLC
Tempe, Ariz.
https://signalmicrowave.com/

New Programmable Attenuators Operate from DC to 40 GHz

Pasternack, an Infinite Electronics brand and a leading provider of RF, microwave and mmWave products, has released a new series of programmable attenuators designed to meet the needs of test and measurement, electronic warfare and electronic countermeasures applications. Pasternack's new programmable attenuators offer flexibility and programmability by producing different values of RF signal attenuation on demand. These high performance attenuators provide +/- 0.7 dB attenuation accuracy and a switching speed of 0.35 microseconds. The comprehensive selection of programmable attenuators is available with TTL, USB or relay-controlled options and they feature SMA, N-Type and 2.92 mm female connector options. Pasternack's attenuators feature wide coverage with broadband RF, microwave and mmWave frequencies ranging from DC to 40 GHz as well as attenuation ranges from 31 to 95 dB with 0.5 and 1 dB step sizes. Additionally, these programmable attenuators are designed with compact and rugged military-grade coaxial packages and an operational temperature range from -40°C to +85°C. The comprehensive selection of attenuation ranges and step sizes, in addition to the broad frequency coverage, precise attenuation accuracy and high switching speeds make these attenuators ideal for test and measurement applications. Pasternack's new programmable attenuators are in-stock and ready for immediate shipment with no minimum order quantity. For inquiries, contact Pasternack.

VENDORVIEW

Pasternack
Irvine, Calif.
www.pasternack.com/t-programmable-attenuators.aspx
+1-949-261-1920



Propagation Analysis of EES Optimizes 6G Wireless Coverage

The new version of Remcom's Wireless InSite® includes propagation analysis for engineered electromagnetic surfaces (EES). EES are a class of passive metasurfaces that artificially enhance wireless coverage at microwave and mmWave frequencies via printed conductive patterns on substrates like plastic or glass. When placed on a wall, window or other structure, the scattering properties of these printed patterns redirect RF wave propagation in specific directions to augment wireless connectivity.

The ability to control the electromagnetic (EM) propagation environment is currently an important area of 6G research. Applications such as reconfigurable intelligent surfaces (RIS) rely on either metasurfaces or reflect arrays, an alternative technology, to optimize wireless channels.

Wireless InSite's X3D Model has been updated to incorporate the Ray-Optical EES Scattering Model developed by the Communications Research Centre Canada (CRC), part of Innovation, Science and Economic Development Canada. This integration enables the modeling of passive metasurfaces that are designed to optimize wireless communication coverage by manipulating how signals propagate through a scene.

The new EES capability provides a way to analyze improvements to coverage from either a static EES or a single configuration of a metasurface-based RIS. The integration of Remcom and CRC's models offers a novel way to simulate and analyze the channel characteristics of passive EM metasurfaces in any environment, including indoor, outdoor, outdoor-to-indoor and others.

VENDORVIEW

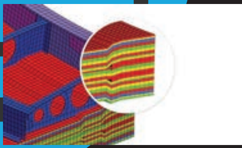
Remcom
State College, Penn.
www.remcom.com

MAKING WAVES

Altair Releases Simulation 2022.1 Software Update

Simulation 2022.1 allows users to launch leading tools like Altair HyperMesh, HyperView, SimLab and Inspire in browsers or on desktop/laptop.

Altair
http://bit.ly/3XCjCeK



VNA Extender Configuration Guide

In this blog post, learn about the STO series of VNA frequency extenders that increase the reach of coaxial VNAs to mmWave frequencies. Three different STO configurations are offered for waveguide bands from 50 to 330 GHz.

Eravant
www.eravant.com/vna-extender-configuration-guide

New Microwave Journal Website

Check out the new, redesigned microwavejournal.com website. The new design brings more interactive content to the home page and has a redesigned Buyer's Guide. The home page has been shortened so you don't have to scroll far to see everything. Visit the MWJ website today and let us know if you have any feedback.

Microwave Journal
www.microwavejournal.com

Six Premier Brands, One Website

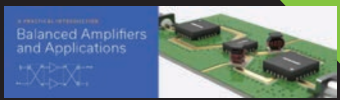
The new website from Microwave Products Group launches MPG Solutions as their flagship brand and combines all products, capabilities and heritage brands. Learn more in this video.

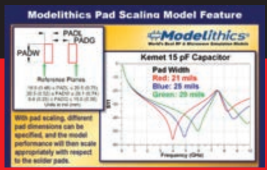
Microwave Products Group
https://bit.ly/3iZKg2v

A Practical Introduction to RF/Microwave Balanced Amplifiers and Their Applications

This Mini-Circuits blog post explores the theory, operation and common applications of a widely-used technique in RF system design: the balanced amplifier. See how quadrature-combined amplifier pairs improve a variety of system parameters.

Mini-Circuits
https://hubs.ly/Q01z_fxp0





Solder-Pad Scalability of Modelithics Microwave Global Models

Modelithics Microwave Global Models give users the flexibility to specify the desired solder-pad dimensions. The performance will then scale appropriately with respect to the values.

Modelithics
www.modelithics.com/model/PadScaling

Pasternack's 2023 Catalog

Check out over 65,000 unique RF products in the 2023 catalog from Pasternack.

Pasternack

http://bit.ly/3krsaae

Using Wireless InSite for Engineered Electromagnetic Surface Modeling

This short video clip demonstrates Wireless InSite's EES capability and compares coverage improvement with diffuser and grating EES placements on a glass window or a wall.

Remcom

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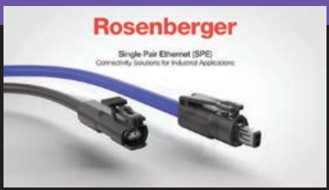
SPE - One Wire Pair - An Infinite Number of Applications

Single Pair Ethernet (SPE) sets new standards in intelligent communication architecture. Using power over data line (PoDL), parallel high performance data and power transmission is supported via just one Ethernet wire pair.

Rosenberger

www.rosenberger.com/markets/industry/iiot/



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Piconics
www.piconics.com

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Quantic PMI Model No. APD-4-218-LC-2 is a highly-reliable four-way power divider featuring excellent amplitude and phase balance, low insertion loss and high isolation electrically power divider that operates over the 2.0 to 18.0 GHz frequency range. It has a maximum insertion loss of 2.0 dB and a minimum isolation of 16 dB. This model is outfitted with SMA female connectors in a housing measuring 1.75" × 1.75" × 0.40".
Quantic PMI
www.pmi-rf.com

Variable Attenuators

RLC Electronics is manufacturing broadband 8 to 22 GHz variable attenuators, intended for panel mounting into customer systems. The frequency can be extended to approximately 24 GHz, as needed. These attenuators have 20 dB minimum attenuation range, exhibit low loss (< 0.5 dB) and are stable over MIL-STD-202 environment. RLC is also offering similar variable attenuators that cover the 4 to 18 GHz band and will support custom frequency requirements as well.
RLC Electronics
www.rlcelectronics.com

Phase Bridge Power Modules

Vishay Intertechnology Inc. introduced three new series of 130 to 300 A three-phase bridge power modules in the ultra-compact MTC package that deliver reliable operation for heavy-duty industrial applications. The 130 A VS-131MT…C, 160 A VS-161MT…C and 300 A VS-301MT…C series are optimized for line frequency input rectification in welding machines, switch mode power supplies, plasma cutting, battery chargers and motor control. The encapsulated devices offer a rugged design for these applications, while their highly conductive MTC package provides excellent thermal behavior.
Vishay Intertechnology Inc.
www.vishay.com

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SSG22645LX Smart wideband frequency synthesizer—new design covering 45 MHz to 22.6 GHz, with resolution as fine as 0.1 Hz. Unique features include dual frequency outputs with independent control, power attenuation from -20 to +7 dB, three frequency sweep modes (single, repeat, cycle), internal/external reference, all controlled through Bluetooth app or PC, LEDs for function status—ideal for lab, production and field testing. Available from stock through store.zcomm.com priced at $1,500.00.
Z-Communications
www.zcomm.com

AMPLIFIERS

Low Noise Amplifier
VENDORVIEW

Model SBL-2042242080-0505-E1 is a G-Band low noise amplifier (LNA) with typical small-signal gain of 20 dB across the frequency range of 195 to 220 GHz. With a nominal noise figure of 8.0 dB, the LNA requires a power source of +8 VDC at 50 mA. The 1 dB compression level is +8 dBm at the input. Rated for temperatures from 0°C to +50°C, the LNA measures 1.4 × 1.0 × 0.75 in. The input and output ports are WR-05 waveguide with in-line UG-387/U-M anti-cocking flanges.
Eravant
www.eravant.com

Wideband Low Noise Amplifier
VENDORVIEW

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Exodus Advanced Communications' AMP4022DBP-4KW pulse amplifier is designed for pulse/HIRF, EMC/EMI Mil-Std 461/464 and radar applications. Providing superb pulse fidelity and up to 100 μs pulse widths. Duty cycles to 6 percent with a minimum 66 dB gain. Available monitoring parameters for forward/reflected power in watts and dBm, VSWR, voltage, current, temperature sensing for outstanding reliability and ruggedness for compact integrations.
Exodus Advanced Communications
www.exoduscomm.com

High Gain Broadband Low Noise Amplifier

Model ABL1800-01-4525 is a high gain three stage MMIC based low noise amplifier module operating in the frequency range from 0.1 to 18.0 GHz. It offers 45 dB of linear gain and 2.5 dB typical noise figure with excellent gain flatness and input/output return loss. The unit has a built-in voltage regulator and operates with a single DC power supply voltage. The package size of the amplifier is 1.9 × 1.0 × 0.4 in.
Wenteq Microwave
www.wenteq.com

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- 5) DQGP LFURZDYHFLUFXLWVDQGV\VWHP V
- * * DQGP LOOLP HWHUZ DYH7+] ZLUHOHVVWHFKQRORJLHV
- : LUHOHVVWHFKQRORJLHVIRUELRP HGLFDO DSSOLFDWLRQV
- &RP SXWDWLRQDOHOHFWURP DJQHWLFV
- $ QWHQQDVDQGSURSDJDWLRQ
- 6SHFWUXP P DQDJHP HQWDQGFRH[LVWHQFH
- 5) DFWLYHDQGSDVVLYHGHYLFHV
- 0 LFURZDYHP HWURORJ\
- : LUHOHVVSRZ HUWUDQVIHU
- (OHFWURP DJQHWLFP DWHULDOVDQGP RGHOLQJ
- : LUHOHVVDQGRSWLFDOFRP P XQLFDWLRQV
- 3KRWRQLFV
- * HRSK\VLFDODQGVXEVXUIDFHP RGHOLQJ
- 5 DGDUDQGVHQVLQJ
- ,QWHUQHWRI7KLQJV
- (P HUJLQJ ZLUHOHVVWHFKQRORJLHV

6SHFLDO(YHQW

6WXGHQW5HVHDUFK3RVWHU&RP SHWLWLRQ SOHDVHVHHWKHZ HEVLWHIRUGHWDLOV

,P SRUWDQW' DWHV

3DSHU6XEP LVVLRQ' HDGOLQH) HE
$ XWKRU1RWLILFDWLRQ 0 DUFK
) LQDO0 DQXVFULSW' XH $ SULO
$ GYDQFHG5 HJLVWUDWLRQ' HDGOLQH $ SULO
7H[DV6\P SRVLXP $ SULO

NewProducts

SOURCES

High-Power Microwave Generator

With the KU SG 2.45 to 450 A, Kuhne electronic offers a high-power microwave generator for ISM band applications around 2.45 GHz with 0 to 450 W. This device can be used as power source in medical applications, for propagation tests of electromagnetic waves, plasma generation, for microwave heating applications and various others. The generator can be controlled via serial interface or analog voltage controls. The RF output signal can be adjusted in frequency and output power. Protection against mismatch and overtemperature are integrated.

Kuhne electronic GmbH
www.kuhne-electronic.de

Frequency Synthesizers

Micro Lambda, known for their MLMS-Series frequency synthesizers covering 250 MHz to 32 GHz, announced the production release of synthesizers that operate off a single + 5 Vdc supply. Standard frequency models are available covering 250 MHz to 6 GHz, 2 to 8 GHz, 4 to 10 GHz, 6 to 13 GHz, 8 to 20 GHz and 28 to 32 GHz. Applications include wideband receivers, automated test systems, telecom, satcom, UAVs and drones and a variety of military and commercial test applications.

Micro Lambda Wireless
www.microlambdawireless.com

MICRO-ADS

ANTENNAS

Portable 3D Antenna

VENDORVIEW

Compatible with any spectrum analyzer, the IsoLOG 3D Mobile PRO from Aaronia is the perfect antenna for 3D measurements on the go. Depending on the model, it offers a frequency range from 9 kH up to 8 GHz. Two integrated preamplifiers can be switched in lossless if required. Each of the three axes is equipped with two antennas, loop and dipole. The individual axes can be fixed or switched through with a frequency of 1 Hz to 50 kHz using the integrated “chopper” function.

Aaronia
www.aaronia.de

Waveguide Horn Antennas

VENDORVIEW

Fairview Microwave has released a new series of in-stock waveguide horn antennas for addressing a wide range of wireless applications. The new line of waveguide horn antennas features high gain from 10 to 20 dBi for transmitting greater power to receivers, as well as beam width options from 11 to 55.2.

Fairview Microwave
www.fairviewmicrowave.com

TEST & MEASUREMENT

Environmental Testing Lab

Gowanda is a market leader in high-reliability components for the electronics OEM marketplace. They offer an in-house environmental testing lab, allowing them to establish the consistent performance characteristics required to meet the most demanding designs.

Gowanda
www.gowanda.com

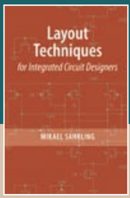
Negative-Slope Equalizers

VENDORVIEW

Pasternack, an Infinite Electronics brand and a leading provider of RF, microwave and millimeter-wave products, has just introduced an innovative series of in-stock, negative-slope equalizers for broadband applications, including electronic warfare, electronic countermeasures, microwave radio and more. Pasternack’s new negative-slope equalizers feature impressive performance with high reliability, low VSWR and excellent linearity. They provide low insertion loss ranging from 0.5 dB to 1.2 dB and wide coverage over octave bandwidths from 1 GHz to 26.5 GHz.

Pasternack
www.pasternack.com

Review by: Fred Schindler
Engineering Consulting Services



Bookend

Layout Techniques for Integrated Circuit Designers

by Mikael Sahrling

The title of this book is a good representation of what it is. It is a comprehensive guide to what you need to know to lay out and design Si ICs. It provides plenty of background information to understand the hows and whys of circuit layout. This includes not only circuit considerations but also the underlying process constraints that drive layout requirements. If you are a Si circuit designer, this is a good reference for you.

It is worth noting what this book is not. This is a Si design and layout book, so while there is information on GaN, GaAs and InP, this is not a useful guide for laying out designs in those technologies. The book's primary focus is on CMOS technologies and it includes plenty of content on BiCMOS and SiGe theory and layout. This also is not a manual for how to push polygons in your favorite layout tool. "Layout Techniques for Integrated Circuit Designers" goes much deeper than that.

In addition to providing underlying insights and practical guidance for the layout of Si designs, there are ample examples. The book has two parts; Part 1 focuses on how Si ICs are manufactured and how elements are laid out. Part 2 covers layout functions, including how the layout is done and structured, design verification, layout versus schematic and design rule checking. There are lots of Python examples in the book and even better, there are more available in a downloadable text file.

If you are an engineer that is about to embark on a Si design, "Layout Techniques for Integrated Circuit Designers" will give you plenty of understanding and guidance. Even if you are experienced in Si design techniques, Mikael Sahrling's book is a useful reference.

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ACT International
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floydc@actintl.com.hk

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FABS and LABS

WAFIOS: Engineered for What's Next

With the focus on ICs and the next wireless "G" in the electronics industry, WAFIOS may be a name not too well known beyond their sphere of influence. The seeds for the company were planted when Ernst Wagner started a mechanical workshop to weave thin wires in the town of Pfullingen, Germany, in 1893. By the mid-1900s, Wagner's wire fencing machines were winning awards and as the company grew, it moved to Reutlingen, Germany, in 1909 where it welcomed Hans Ficker as an active partner. The company, then known as Wagner & Ficker Maschinenfabrik, was competing with another fencing machine company run by Otto Schmid and these two companies merged in 1914 with the new company named "WAFIOS" in tribute to Wagner, Ficker and Otto Schmid.

From these beginnings at the onset of World War I, the company has grown to become a leading global supplier of precision machinery for wire, tube and formed parts. Along the way, WAFIOS counts many firsts and advancements in fencing, coiling, spring, bending and precision parts machines. What started with wires now extends to coaxial cables, tubes and metalworking. WAFIOS has facilities in the U.S., China, Mexico, Brazil and France, in addition to a big presence in Germany. The company maintains sales agencies on every continent except for Antarctica.

The company currently supports more than 120 active machine types. The WAFIOS machine types include spring coiling and forming, wire and tube bending and forming, wire straightening and cutting, along with machines producing spiral hose, nails, fasteners, chains, chain-link and other types of fencing. These machines produce a wide variety of products including cardiac catheters, surgical coils, springs, conductor rails and suspension springs, brake lines and heat exchangers. These products go into an equally impressive range of applications, with e-mobility, electric vehicle, electronic equipment and medical technology applications figuring prominently in production efforts. The company succinctly sums this up as "thousands of applications for almost all areas of life."

Befitting a company that has grown and evolved over the last 130 years, WAFIOS embraces innovation. The company claims about 200 active patents worldwide, with more than 120 employees worldwide (about 12 percent of the workforce) involved with research and development (R&D) activities. The company spends 18 percent of their revenue on R&D activities. The latest wave of innovation at WAFIOS aims at expanding and evolving the computerized and networking capabilities of their equipment. The company introduced its first computer numerical control (CNC) machine in 1978 and they are working toward the goal that "anyone on the shop floor can run a WAFIOS machine."

This goal acknowledges the current challenge of hiring skilled operators to manually operate the machines. The broader realization is that computer and software-controlled equipment can provide better, more cost-effective solutions. To support these goals and this evolution, WAFIOS has an extensive collection of iQ-functions that offer process optimizations for all WAFIOS machine groups.

The company is also developing a Smart Factory 4.0 concept as part of the Industry 4.0 transformation. To support this, WAFIOS has a standardized, open system to enable complete machine networking. This system includes an OPC-UA interface to connect the machine to the existing infrastructure. In their vision, this will include machine-machine communication, communication with a higher control level or the cloud. These and other activities are how WAFIOS, with 130 years of heritage, plans to address the next 130 years of product innovation.

The WAFIOS North American headquarters is in Branford, Conn., with spare parts stock, service resources and machines available for demonstration. The Chicago-area Midwest Technical Center located in Mokena, Ill., provides additional resources as a service center, with machines available for trials and demonstration. Both facilities are structured to support application development, as well as provide customers with hands-on training programs.

https://www.wafios.com/en/home/

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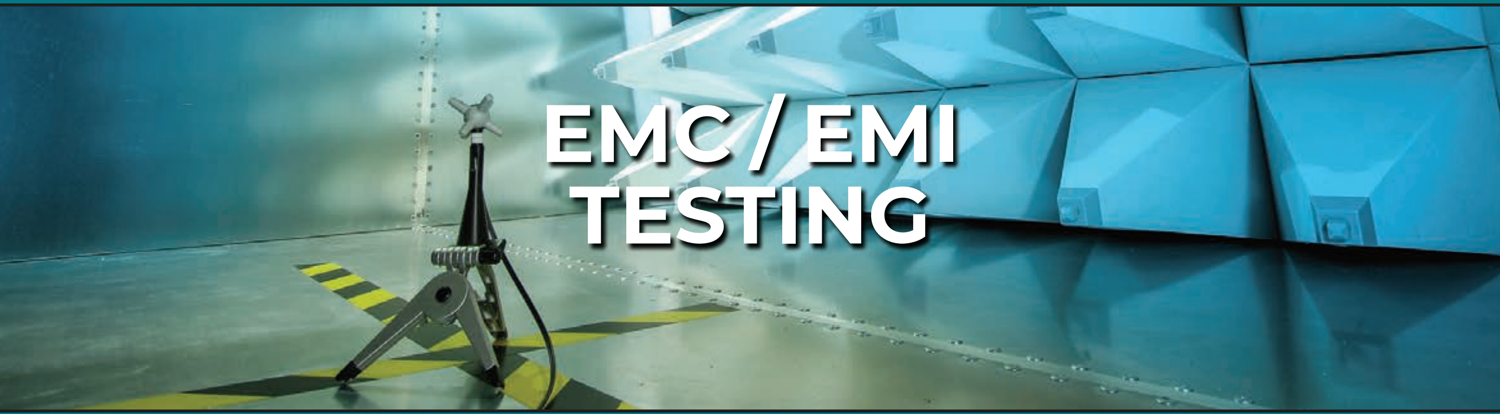

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C8730	Dual	0.009-250	500	40	0.40	N-Female	10.5 x 3.0 x 2.0
C8731	Dual	0.009-250	1000	40	0.40	N-Female	10.5 x 3.0 x 2.0
C11462	Dual	0.009-400	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
C8510	Dual	0.009-1000	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
C5047	Dual	0.01-100	4,000	50	0.15	7/16-Female	10.0 x 4.16 x 3.5
C1979	Dual	0.01-100	10,000	60	0.10	LC-Female	2.0 x 6.0 x 4.5
C5086	Dual	0.01-250	250	40	0.50	N-Female	5.2 x 2.67 x 1.69
C5100	Dual	0.01-250	500	40	0.40	N-Female	10.5 x 3.0 x 2.0
C5960	Dual	0.01-250	1,000	50	0.40	N-Female	10.5 x 3.0 x 2.0
C1460	Dual	0.01-250	2,000	50	0.15	N-Female	10.0 x 3.0 x 2.0
C4080	Dual	0.01-250	3,500	50	0.20	N-Female	10.0 x 4.6 x 3.5
C11026	Dual	0.01-220	5,000	60	0.10	LC-Female	12.0 x 6.0 x 4.5
C8390	Dual	0.01-250	10,000	60	0.10	LC-Female	12.0 x 6.0 x 4.5
C5339	Dual	0.01-400	200	40	0.50	N-Female	5.2 x 2.67 x 1.69
C6047	Dual	0.01-400	500	40	0.50	N-Female	5.2 x 2.67 x 1.69
C2630	Dual	0.01-1000	100	40	0.60	N-Female	5.0 x 2.0 x 1.51
C6021	Dual	0.01-1000	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
C6277	Dual	0.01-1000	500	50	0.45	N-Female	6.7 x 2.28 x 1.69
C11146	Dual	0.01-1000	500	43	0.45	SC-Female	6.7 x 2.63 x 2.20
C11047	Dual	0.01-1000	1,000	43	0.45	SC-Female	6.7 x 2.63 x 2.20
C11161	Dual	0.01-1000	1,000	50	0.45	SC-Female	6.7 x 2.63 x 2.20
C1795	Dual	0.1-1000	100	40	0.50	N-Female	5.0 x 2.0 x 1.51
C5725	Dual	0.1-1000	500	40	0.50	N-Female	5.2 x 2.28 x 1.69
C11077	Dual	0.1-1000	1,000	43	0.45	SC-Female	6.7 x 2.28 x 1.69
C3910	Dual	80-1000	200	40	0.20	N-Female	3.0 x 3.0 x 1.09
C5982	Dual	80-1000	500	40	0.20	N-Female	3.0 x 3.0 x 1.09
C3908	Dual	80-1000	1,500	50	0.10	7/16-Female	3.0 x 3.0 x 1.59
C6796	Dual	80-1000	5,000	60	0.20	1 5/8” EIA	6.0” Line Section
C8060	Bi	200-6000	200	20	0.40	SMA-Female	1.8 x 1.0 x 0.56
C8000	Bi	600-6000	100	30	1.10	SMA-Female	4.8 x 0.88 x 0.50
C10117	Dual	700-6000	250	40	0.20	N-Female	2.0 x 2.0 x 1.06
C10364	Dual	700-6000	500	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C10996	Dual	700-6000	700	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C11555	Dual	700-6000	1,000	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C10695	Dual	700-6500	500	50	0.20	7/16-Female	2.15 x 2.0 x 1.36

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