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March 2022

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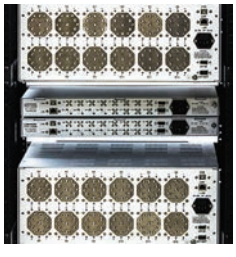

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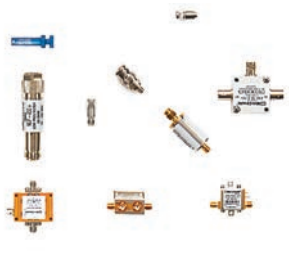

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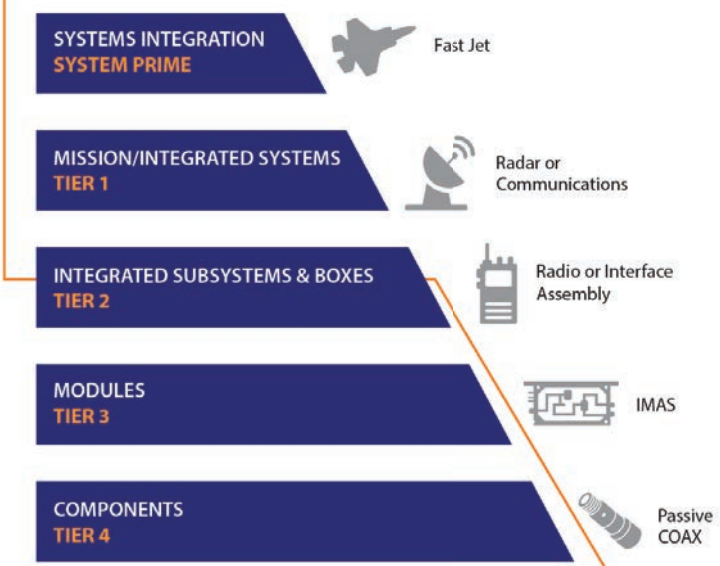

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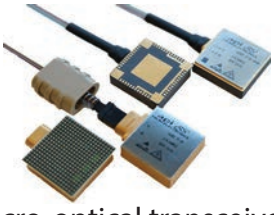

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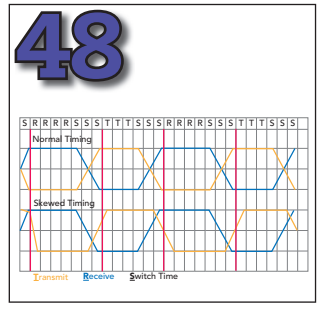

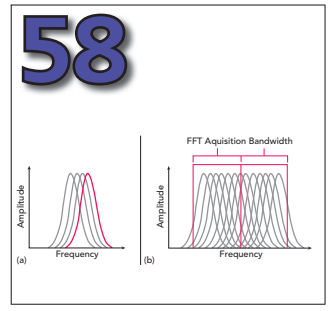

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Executive Interviews

Rob Russell, VP of **Satellite Business Unit** at **Vicor**, discusses the challenges for power in the LEO and MEO satellite market and how those issues are being addressed with new architectures.

David Young, senior VP and the chief technology officer of **CAES**, discusses trends in the aerospace and defense market, how CAES is responding to them and the challenges developing and maturing technology.

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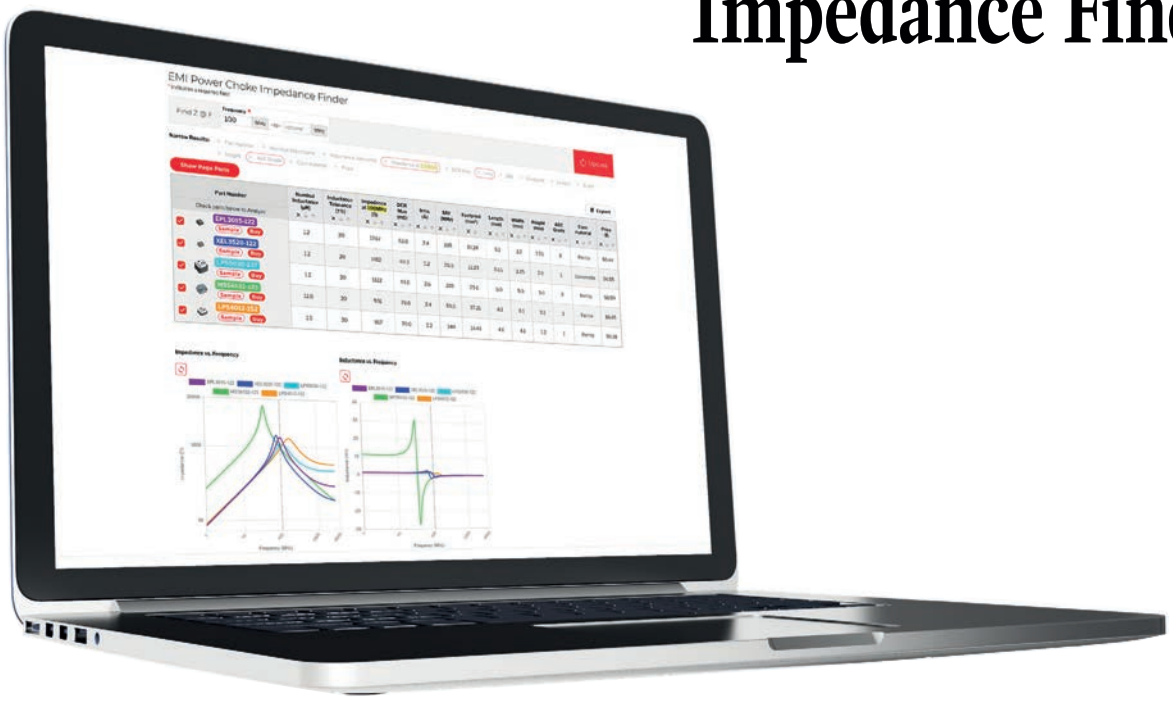

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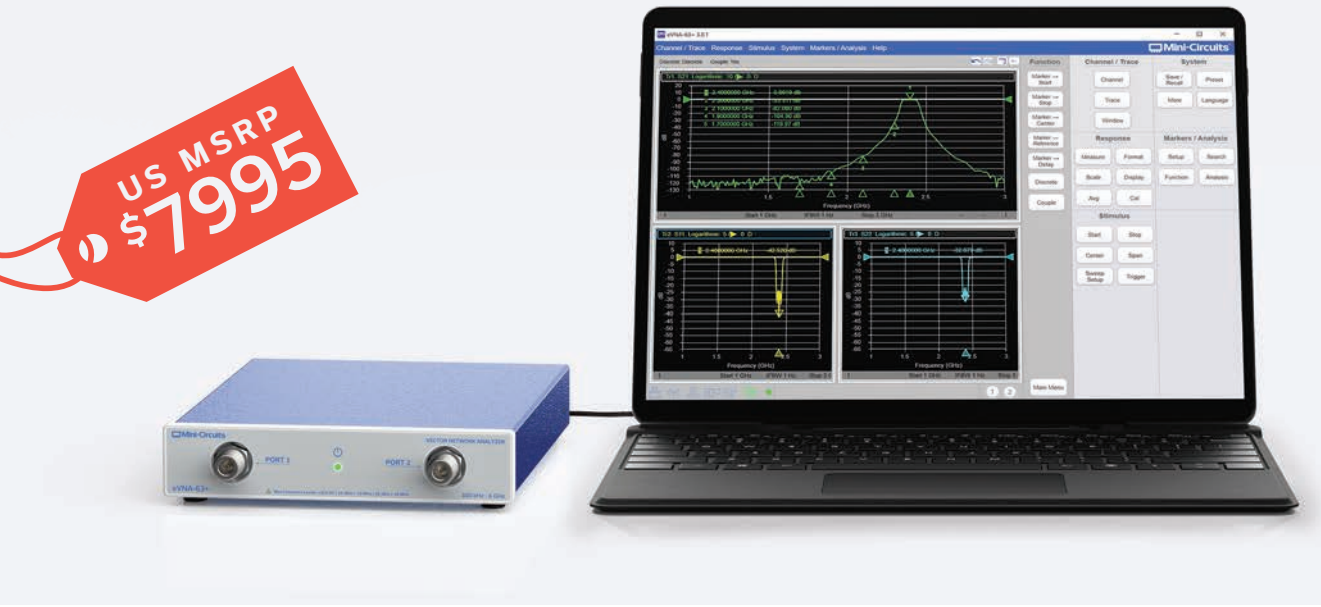

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COVER FEATURE
INVITED PAPER

Mobile Network Testing of 5G NR FR1 and FR2 Networks: Challenges and Solutions

Christoph Hausl, Julian Emmert, Manuel Mielke, Benjamin Mehlhorn and Corbett Rowell
Rohde & Schwarz, Munich, Germany

This article describes a mobile network testing approach for 5G new radio (NR) using a passive scanner, which measures synchronization signal (SS)/physical broadcast channel (PBCH) blocks, or SSBs, broadcast from 5G NR base stations. It starts with relevant background information about 5G NR and mobile network testing, followed by a description of a typical measurement methodology for the frequency ranges one (FR1) and two (FR2). Next, it addresses two typical challenges: 1) finding carrier frequencies with SSBs and 2) network synchronization. A solution is proposed for each.

5G wireless radio access technology, known as NR, contains more flexibility to address different usage scenarios.[1,2,3] The 5G NR specification allows optimization to reduce the latency and to significantly increase the data rate. These optimizations require many new technology components, including new frequency bands, beamforming support for synchronization and broadcast and multi-connectivity to enable the combination of 5G network elements with LTE. 5G NR supports operation in two frequency ranges: FR1 below 7,125 MHz[4] and mmWave bands (FR2) between 24.25 and 52.6 GHz.[5]

Throughout the entire chain of laboratory testing, field trials, network rollout, optimization and benchmarking, measurement tools for mobile network testing (MNT) are required to characterize the conditions of the wireless channel and network coverage in the field.[6,7] For example, measurements of received power enable verification of 5G NR cell beamforming and its impact on the coverage area. Measurements of the channel impulse response result in deeper knowledge about the propagation of wireless signals in different environments, i.e., reflection, absorption and scattering in urban versus rural areas. Measurements of arrival times enable verification of network synchronization aspects.[8]

5G and associated technologies such as beamforming and frequencies above 3 GHz have raised potential health concerns due to the human exposure to the electromagnetic field of base stations. Consequently, 5G base station deployment requires that the electrical field strength (V/m) is below the specific threshold for each country. Frequency selective measurement methods of exposure to 5G base stations have been described,[9,10] emphasizing the need for code selective measurement methods, especially in networks with several base stations and with data traffic.

A mobile network operator must evaluate the quality of the network to investigate network problems,

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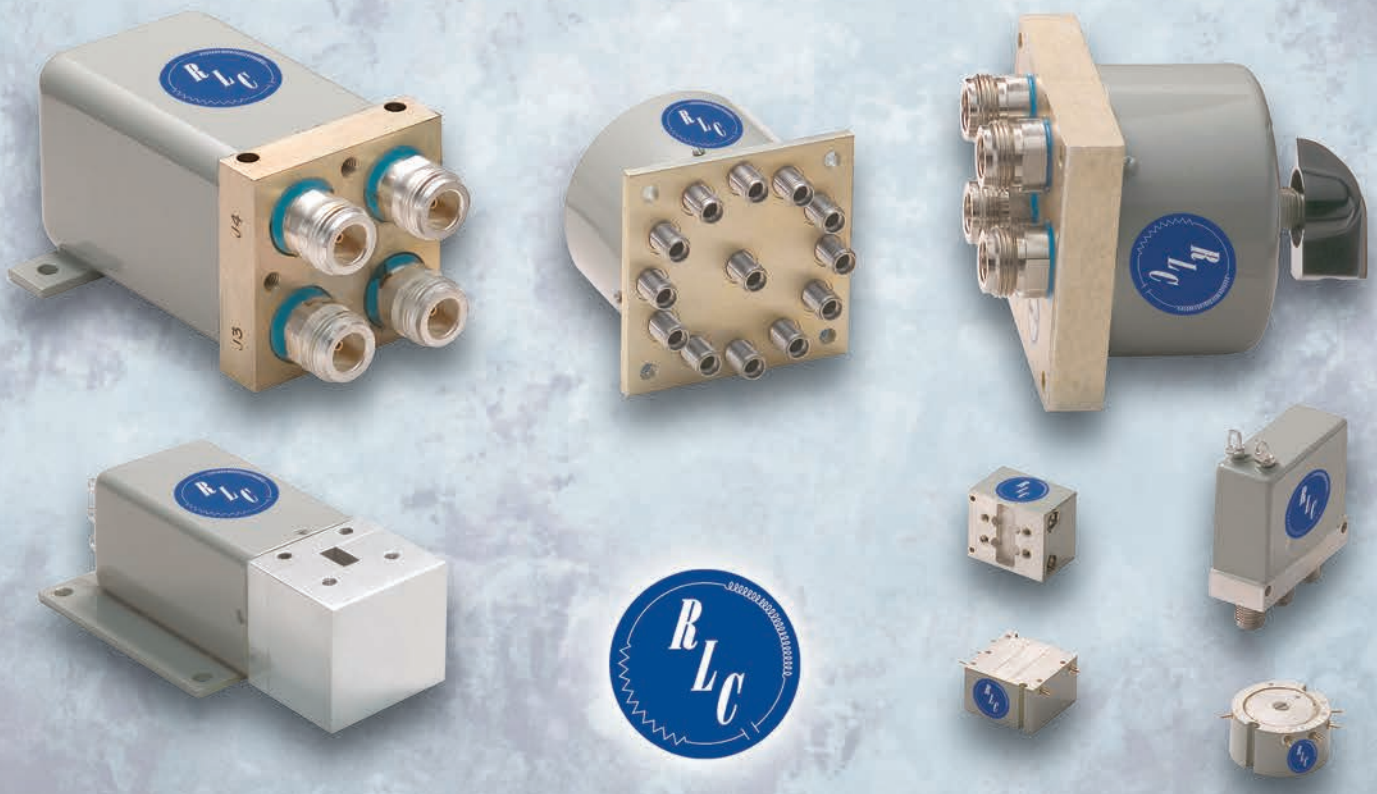

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unwanted interference or assessment of new base stations. While it is possible to evaluate the performance of the network using a mobile phone, the disadvantage is measurement variation, as results vary depending on the chip set or installed software. Therefore, a reference measurement device such as a receiver or scanner is required, which provides a common ground for comparison.

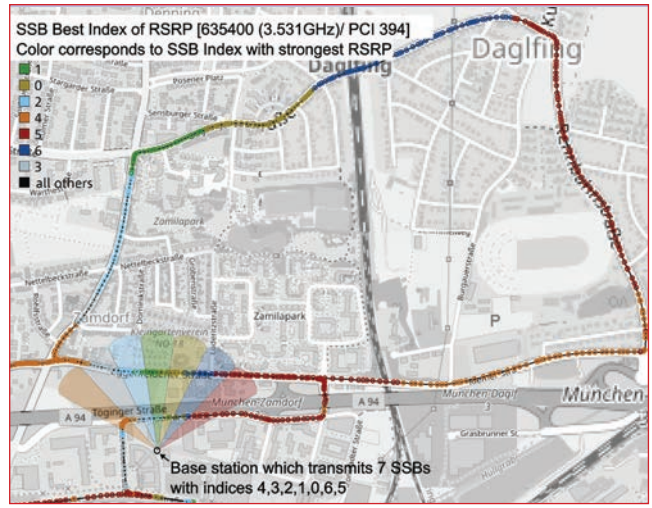

Fig. 1 Transmission direction of seven SSBs of one cell estimated by comparing the measured received power for all SSBs during a drive test. The color of the route corresponds to the SSB with the strongest receive power.[7]

With the use of non-standalone (NSA) and dynamic spectrum sharing, the 5G NR FR1 and corresponding LTE channel must be measured at the same time to ensure that both network links work as expected. Detection and measurement of these base station cells is challenging because the measurement must achieve a high sensitivity while avoiding false alarms that result in detecting non-existing cells (i.e., ghost codes).

Measurement of the carrier frequencies of a mobile network enables independent characterization of the network and, together with a wideband passive receiver, enables benchmarking of different networks—even networks that are completely unknown—removing the influence of the mobile phone. As this measurement approach is completely passive, all public and private networks, such as campus networks, can be detected and measured.

BACKGROUND

5G NR Synchronization Signal/ PBCH Blocks (SSBs)

5G NR technology uses orthogonal frequency division multiplexing (OFDM)[2] for downlink transmission. A band dependent table[4,5] defines whether time division duplexing (TDD) or frequency division duplexing is used to divide the downlink (DL) and uplink (UL). A 5G NR cell broadcasts SSBs to enable cell search and initial access. One SSB is mapped to four OFDM symbols and 240 subcarriers (SC).

The SSB consists of one PBCH block, a primary and a secondary synchronization signal (PSS and SSS). There are different SC spacings (SCS) defined: from 15 kHz for Case A in FR1 to 240 kHz for Case E in FR2.[11] Therefore, the bandwidth of one SSB is between 3.6 and 57.6 MHz. Correspondingly, the SSB duration is between 285 and 18 µs, enabling flexibility to use 5G NR in different frequency ranges and use cases.[1]

One cell transmits up to 64 SSBs within a 5 ms window (i.e., up to four or eight SSBs for SCS of 15/30 kHz). Each of these SSBs has a specific index, which is encoded beside the cell-specific physical cell identity (PCI) into the SSB-signal. The start time of a SSB within the 5 ms window depends on the index, as defined by the 3GPP technical specification.[11] The cells broadcast these 5 ms windows periodically, with the default period 20 ms.

Typically, a cell uses beamforming to transmit the SSBs in different directions (i.e., beam sweeping) and, consequently, the SSBs are also referred to as beams. These beams can be considered as micro sectors that further split the macro sector of the complete cell—typically 120-degree azimuth cover-

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age—into smaller angular portions.[6] ***Figure 1*** illustrates the main transmission direction of seven SSBs of one cell on a map. The use of beamforming for synchronization signals and PBCH provides better overall coverage. Note that the direction of the beams can be two-dimensional in the sense that each SSB transmits into a specific azimuth and tilt angle.

Mobile Network Testing

Figure 1 also shows the route of a drive test, a method often used for MNT. The aim of the drive test is to measure the reception quality of the base station cells and their SSBs to determine network quality and coverage. The drive tests are also used to find interference, either from other cells or unlicensed deployments. Variations of conventional drive tests are walk tests, bike tests and drone tests, the latter requiring small passive receivers with low power consumption because of limited battery capacity.

MEASUREMENT SETUP

Sub-6 GHz Measurement Setup

Figure 2 shows the proposed measurement setup with a passive receiver or scanner, such as the R&S TSME6 mobile network scanner. Fed by an external antenna, the scanner measures the wireless signal from 5G FR1 and LTE cells, converts this signal into a digital baseband signal of I/Q symbols and sends it to a connected laptop for demodulation, analysis and presentation. The scanner contains an internal global navigation satellite system (GNSS) receiver to measure its geographical position, as well as receiving date and time information. For security reasons, the scanner itself is a passive receiver with no transmission capability. It can measure a baseband signal with a bandwidth of 20 MHz between 350 MHz and 6 GHz, the frequency range controlled by the measurement software on the laptop. The measurement software can be based on R&S ViCom, an open application programming interface, which enables custom scanner applications. Alternatively, ready-to-use software such as R&S Romes can be used.

FR2 Measurement Setup

The carrier aggregation framework in 5G NR allows complementary operation in FR2 with an FR1 carrier to ensure good coverage,[1] requiring simultaneous SSB measurements in FR1 and FR2. ***Figure 3*** shows the measurement setup for FR2. It requires a down-converter which converts the mmWave signal to an intermediate frequency below 6 GHz, so a single scanner with dedicated antennas can support simultaneous measurements in FR1 and FR2. One single scanner with one down-converter supports SSB measurements in FR2, and it is possible to connect several scanners with one down-converter, extending the baseband bandwidth to 100

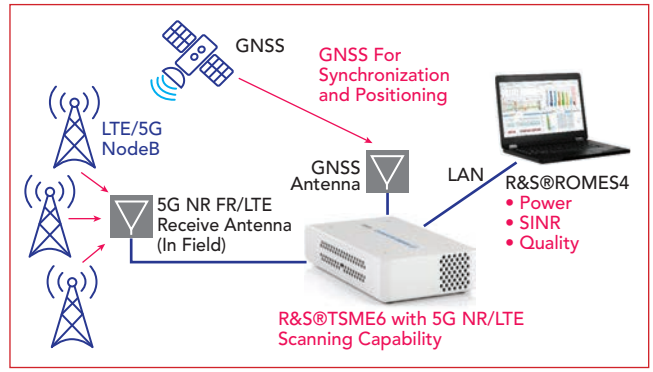

Fig. 2 Setup for sub-6 GHz measurements of 5G NR FR1 and LTE signals.

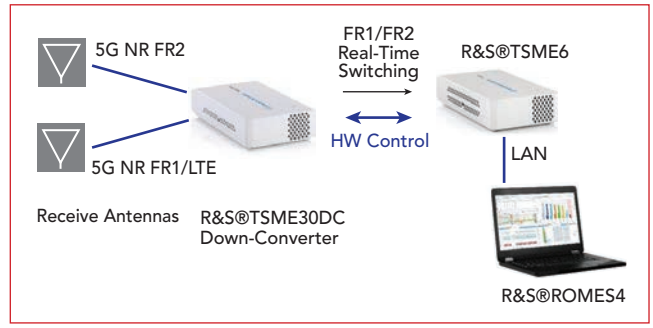

Fig. 3 Setup with mmWave antenna and down-converter for simultaneous 5G NR FR2 and sub-6 GHz measurements.

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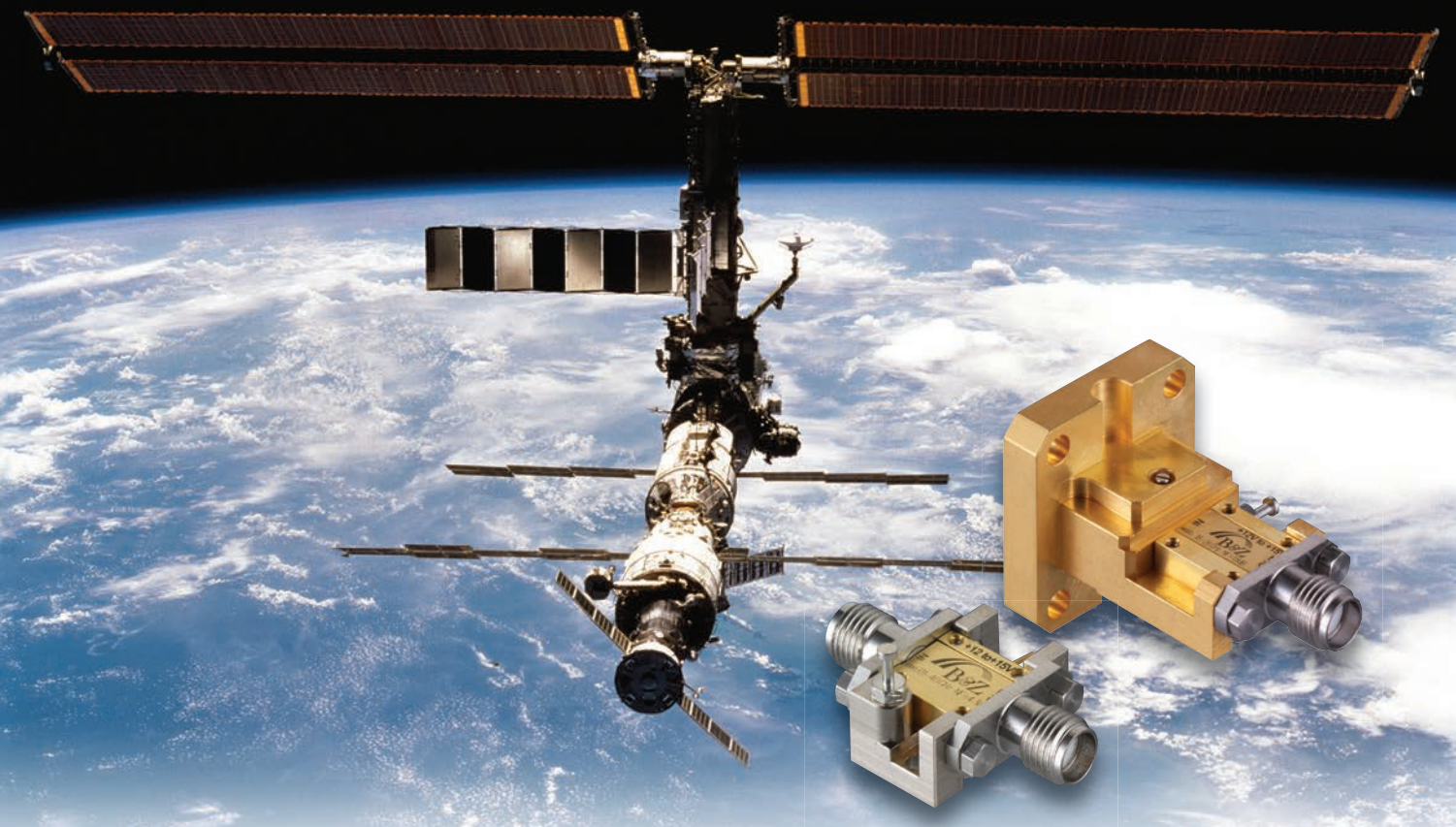

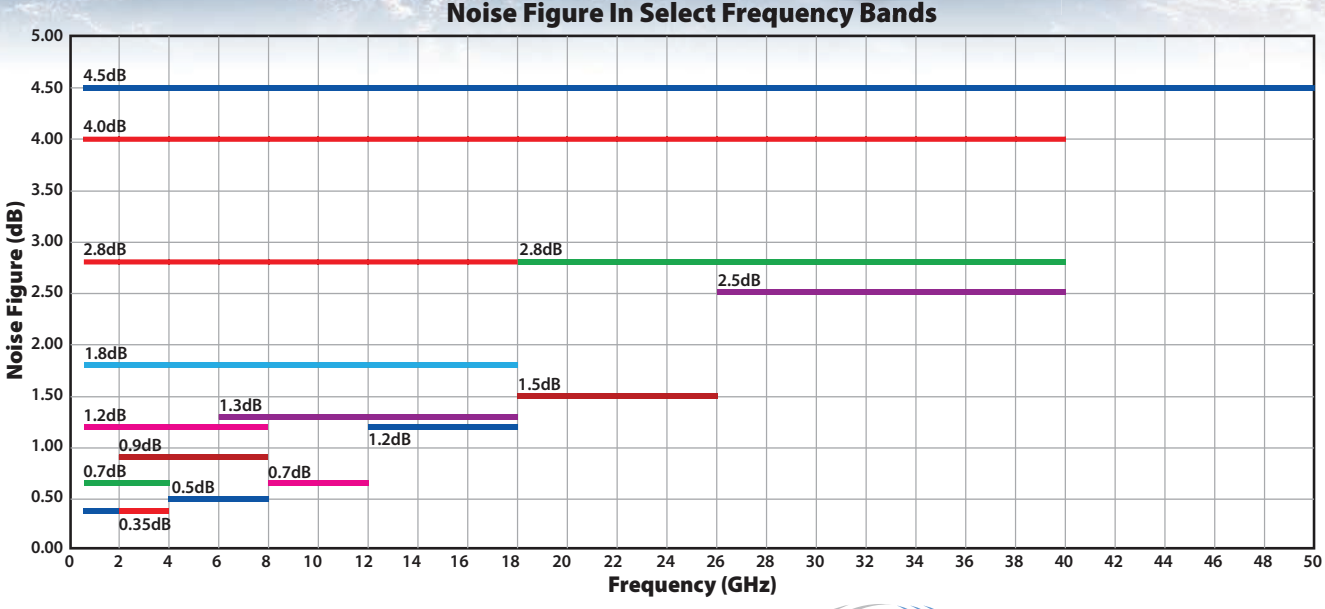

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MHz; however, this is not necessary for current applications.

CHALLENGE 1: HOW TO ANALYZE THE 5G NR SSBS?

Accessing or measuring a 5G NR carrier starts with discovering the center frequencies of the SSBs. In LTE, the PSS/SSS and PBCH signals are always transmitted around the center frequency of the carrier with fixed periodicity, making it possible to manually detect them in the power spectral density measured with a receiver. In 5G NR, however, the transmission characteristics of the SSBs are more flexible, creating new challenges to configuring a 5G NR receiver/scanner.

The most challenging problem is the flexibility regarding the SSB center frequency (SSRef). The 3GPP standard defines a frequency raster for the appearance of SSBs,[4,5] but the raster is narrow with hundreds of possibilities within a 5G NR carrier. Further, a single SSB only appears for a short time, so it is difficult to detect the SSB with a traditional swept-tuned spectrum analyzer; the SSB periodicity is flexible with the frame starting point and its corresponding period: 5, 10, 20, 40, 80 or 160 ms.[12]

To avoid time consuming spectrum scans, wrong scanner configuration or simply guessing the correct SSB center frequency, the proposed receiver/scanner solution is detecting the SSRef using an algorithm called Automatic Channel Detection (ACD). ACD can search quickly through large frequency ranges, where it runs an internal spectrum scan and searches for SSBs.[13] ACD delivers the correct SSRefs within seconds, enabling the scanner to analyze both in-band and out-of-band, i.e., competitor networks where the cellular network parameters are completely unknown.

The ACD algorithm first provides a list of the SSB center frequencies; then, the scanner starts the SSB measurement algorithm (SSBmeas) for these frequencies. ACD can run in the background of the baseband processing, continuously searching for new SSB center frequencies. As soon as the scanner receives the signal of a base station cell strong enough for ACD sensitivity during a measurement, the corresponding SSRef will be scanned with the more sensitive SSBmeas for the remaining portion of the measurement. The ACD algorithm expects a 3GPP compliant 5G NR SSB transmitted on frames with an increasing system frame number. Internally, it uses the 3GPP band table to select the SSB transmission case for the selected frequency bands. This accelerates the ACD algorithm and avoids checking for unnecessary cases (e.g., Case E for band n1).

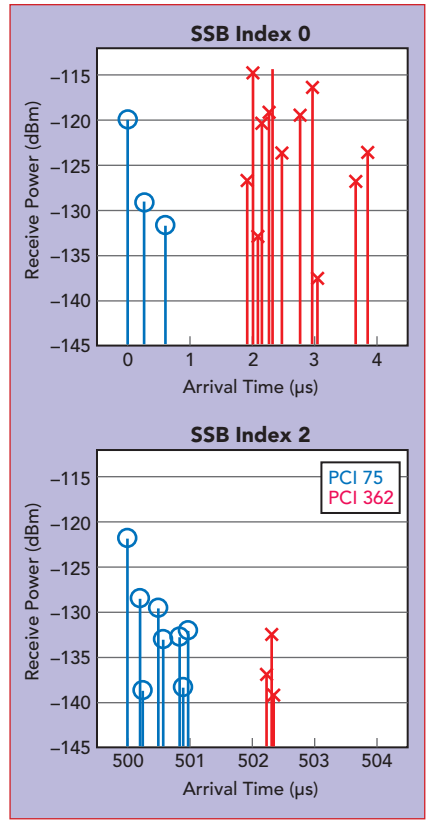

Fig. 4 Measured arrival times and channel impulse response of SSB indices 0 and 2 for two cells.

From the SSB measurement, many network features can be obtained to assess network quality, such as synchronization signal signal-to-interference-plus-noise ratio (SS-SINR) and synchronization signal reference signal received power (SS-RSRP).[14] It is also possible to extract the cell identity (PCI), the SSB index, the channel impulse response and the arrival time for all detected cells and beams. SSB detection includes a decoding of the PBCH, preventing ghost codes, as the PBCH payload contains a cyclic redundancy check for error detection.

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Figure 4 illustrates the measured arrival times of peaks of the channel impulse response for SSB-indices 0 and 2 of two cells (PCI 75 and PCI 362) at SSRef 3,574.56 MHz (Case C). The measurement is primarily interested in the arrival time difference to the first measured peak to measure the delay spread. The measurement confirms the expectation[11] that the SSB with index 2 is transmitted 500 µs later than SSB with index 0. From Figure 4, the distribution of the peaks indicates how much reflection and scattering occurred with higher delay spread for index 0. The signal of the cell with PCI 362 arrives approximately 2 µs later than the one from the other cell with PCI 75, which is mainly caused by the larger cell-to-receiver-distance for PCI 362.

CHALLENGE 2: NETWORK SYNCHRONIZATION MEASUREMENTS

Ensuring base station synchronization is a critical component for successful network deployment. If a base station is out of sync, the handover of active connections will fail, leading to dropped calls for the user and a poor user experience. For TDD, the synchronization requirement is particularly crucial, as a time offset can lead to an overlap of uplink and downlink time slots, impacting base station performance and interfering with correctly synchronized neighboring base stations (see *Figure 5*).

The allowed time alignment error is specified by the 3GPP (Release 15, Section 6.5.3). To ensure proper synchronization, the cells receive their reference time from the network or via a connected GNSS receiver.[8] Networks of different operators must be synchronized to avoid interference due to intermodulation products between networks on neighboring frequencies. This enables all operators to minimize interference.

Previously, these timing measurements were performed with a spectrum analyzer and special test ports on the base station, requiring cabled measurements. In 5G NR, the common deployment of remote radio heads and active antenna systems without special test ports makes conventional timing measurements difficult and requires over-the-air timing measurements.

To verify the time synchronization of a network, the proposed scanner uses two possible measurements of varying precision: 1) a time of arrival (ToA) measurement of the received SSBs and 2) a time alignment error (TAE) measurement of the received SSBs. The ToA measurement provides a time stamp for the received SSB. This provides a good indication whether a certain base station cell is out of sync compared to other base stations received. The ToA measurement provides a precision of about 400 ns. To achieve higher precision and fulfill the coordinated universal time (UTC) second synchronicity requirement, a TAE measurement is used.

For the TAE measurement, line-of-sight (LoS) to the cell is required where the distance between measurement antenna and cell antenna is known—which can be measured with a laser range finder—together with good GPS reception or an external time base as the time reference. The receiver/scanner can calculate the UTC transmission time of every received SSB as well as the frequency error of the cell (see *Figure 6*). Measurement precision is then dependent on the provided reference of the integrated GNSS receiver. Good GPS reception yields a time accuracy below 30 ns. From the known distance between mea-

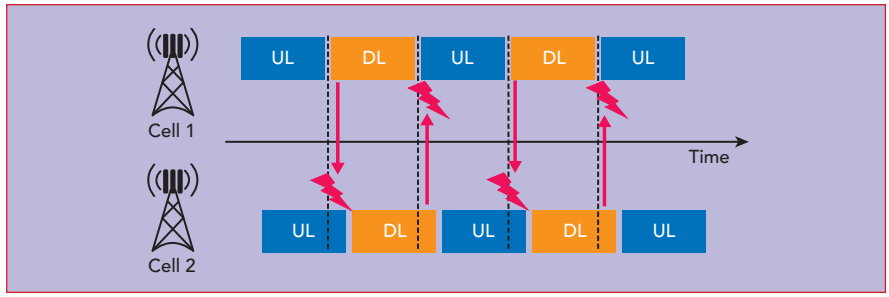

Fig. 5 Interference between two cells.

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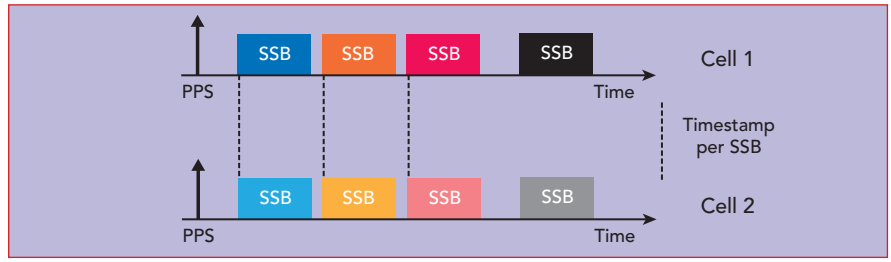

Fig. 6 **UTC synchronized base stations.**

surement position and base station, the transmit time can be calculated, identifying timing issues rooted in the setup of the base station. Experimentally, it has been verified that the following conditions need to be fulfilled to enable such a precise measurement:

- The signal from the measured base station must have a SINR above 15 dB
- The delay spread needs to be below 17 ns, which is used as indicator for LoS
- To obtain best performance with a GNSS receiver, movement faster than 30 kmph is recommended to remove reflections from the received signals.
- A high accuracy pulse per second (PPS) signal must be available, either from the GNSS receiver or an external connection
- The PPS signal needs to provide higher accuracy than the internal time base
- The GNSS receiver must report a valid UTC time synchronization.

CONCLUSION

This article demonstrated how to use a passive scanner for measurements in 5G NR networks, with special attention to network synchronization in both the FR1 and FR2 bands. Methods for the measurement of network coverage, network synchronization and channel impulse response were proposed and are straightforward to implement. An approach for ACD to find the relevant carrier frequencies for 5G MNT in networks with an unknown configuration was presented. Finally, the proposed methods were applied for deployed 5G networks to demonstrate effectiveness.

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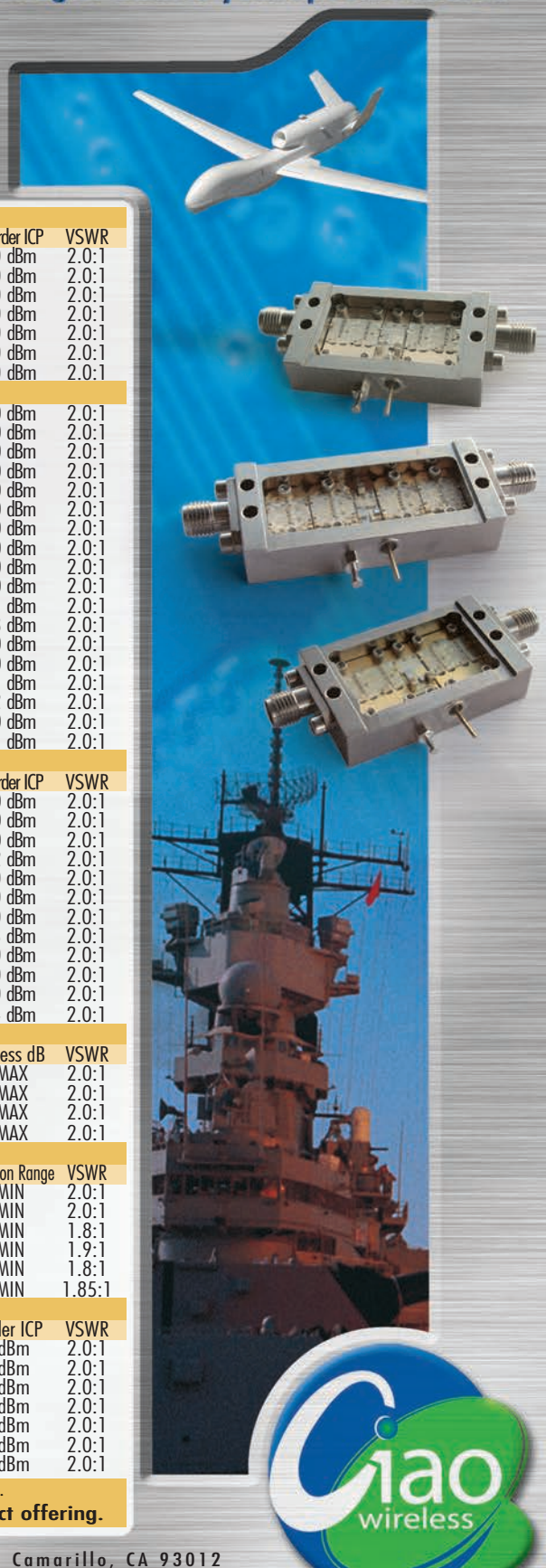

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CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

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CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
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CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

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CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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Navy Unveils Next-Generation DDG(X) Warship Concept

The U.S. Navy wants its next warship to fire hypersonic missiles and lasers that would be 10x more powerful than the service's existing laser weapons, according to the most detailed outlook to date of the DDG(X) next-generation warship issued by the service.

The warship, the largest the Navy's attempted in more than 20 years, is designed to provide the service with the power to drive a new generation of directed energy weapons and high-power sensors that will follow the Navy's current fleet of Arleigh Burke-class guided missile destroyers. The warship is estimated to start construction in 2028, the Navy told USNI News last year.

The Navy is developing the DDG(X) using the combat system developed from the Flight III Arleigh Burkes that incorporated the new SPY-6 air search radar and the Baseline 10 Aegis combat system.

The ship will trade the traditional gas-turbine propulsion system for one like the integrated power system found on the Zumwalt class of guided missile destroyers. On the three Zumwalt class DDGs, the ship's gas turbines drive a ship-wide electrical grid that generates more than 75 megawatts of power—enough to light a small town. The technology will be key for the DDG(X) to generate the power for directed energy and new sensors. Notionally, the new ship could power up to 600-kilowatt lasers that would be powerful enough to interdict hostile guided missiles.

Initially, the ship would feature a 32-cell Mk-41 Vertical Launch System forward of the superstructure that could be swapped for 12 larger missile cells capable of fielding the Pentagon's emerging hypersonic weapons being developed for the Navy, Army and the Air Force.

The Navy is also calling for a ship that can travel 50 percent farther and spend 120 percent longer time on station. The plan also calls for a 25 percent reduction in fuel usage compared to the DDG-51 and reduced requirement for the Navy combat logistics fleet. DDG(X) aims to have improved seakeeping and improved Arctic operations. Arleigh Burke destroyers were designed to operate primarily in the tropics.

The program office is working with the defense industry to refine the basic design after creating a draft Capability Development Document that will hone the operational requirements. Part of that work will be done by the shipbuilding industrial base.

DDG(X) (Source: U.S. Navy PEO Ships)

Light on Chip to Drive Next-Generation RF Platforms

In the last decade, major advances in RF oscillator performance have been realized using optical techniques to synthesize high fidelity microwave signals (i.e., frequencies from 1 to 100 GHz). Such RF oscillators typically employ optical frequency division to achieve low phase noise that can reach record-setting levels. Current solutions sacrifice other important attributes, however, in pursuit of spectral purity. Such tradeoffs are problematic because module size, cost, tunability and environmental sensitivity are also critical factors that determine the applicability of microwave sources to commercial and military systems.

The Generating RF with Photonic Oscillators for Low Noise (GRYPHON) program seeks to defy today's tradeoffs by leveraging recent advancements in the miniaturization, integration and volume production of precision optical components through lithographic microelectronic fabrication. "Nonlinear integrated photonics provides a path to achieve incredible oscillator performance while reducing system size by orders of magnitude," said Dr. Gordon Keeler, program manager in DARPA's Microsystem Technologies Office. "Beyond the cost and size advantages, integrated optical approaches could allow tuning over multiple frequency bands and environmental robustness. There is potential for very broad impact if our teams are successful."

The first technical area the GRYPHON program will pursue is to develop low noise, compact and frequency-agile prototypes with outputs spanning 1 to 40 GHz. The prototype target performance metrics are geared toward rapid adoption by military and commercial entities alike. Program success will also hinge on proving robustness to environmental effects and demonstrating a roadmap to high volume, low-cost domestic manufacturing. The research teams selected include: Honeywell, Nexus Photonics, BAE Systems, Caltech and hQphotonics.

GRYPHON's second technical area encourages performers to pursue advanced techniques that offer even lower phase noise or ultra-wide tunability to inform future oscillator architectures. Teams from Columbia University and University of Virginia have been selected to push the boundaries in materials and system integration to this end.

Hypersonic Weapons Meet Speed-of-Light Defenses

They are two of the biggest threats to U.S. and allied military power, and they could hardly be more different. One is the hypersonic missile, which travels at more than 5x the speed of sound and can strike targets at great distances. The

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other is the UAV, or unmanned aerial vehicle—particularly off-the-shelf drones modified into cheap weapons that are prohibitively expensive to defeat. Different as those threats are, there's one single emerging technology—the high-power microwave (HPM)—that could play a huge role in defending against both.

HPM systems, which use highly concentrated radio energy to damage their targets' electronics, are among the options that Raytheon Missiles & Defense is partnering with the U.S. Department of Defense to explore as part of a layered approach to air defense.

"Our adversaries are coming up with increasingly sophisticated and innovative ways to attack us," said Colin Whelan, vice president of Advanced Technology for Raytheon Missiles & Defense. "We need lower cost solutions to counter them."

The business is building a set of technologies that fall into three categories: small-scale systems for short-range air defense, larger systems for longer-range air defense and small airborne HPM payloads for maneuverable platforms like UAVs.

The advantage of HPMs and other directed energy weapons is that, once they're built, they're inexpensive to fire—and their ammunition is limited only by the availability of power. That makes them well-suited to take on drones that attack by the dozen.

"This technology makes it possible to knock out a whole swarm of electronic threats in a single shot," Whelan said.

HPM (Source: Raytheon Missiles and Defense)

Just as HPMs use concentrated radio energy, lasers project beams of light particles on to their targets. But while lasers burn into their targets, HPMs attack their electronics.

HPMs have an important edge over hypersonic weapons—they're much faster. While hypersonic weapons travel more than 5x the speed of sound—343 m/s or higher—HPMs travel at the speed of light—300 million m/s.

The innovation doesn't stop there. Advanced Technology is using digital engineering methods such as modeling and simulation to prove to the greatest degree possible that high-power microwave technologies work before costly prototyping. The modeling platforms allow the business to demonstrate the directed energy's effect on target is both predictable and measurable, offering the best defense for a mission.

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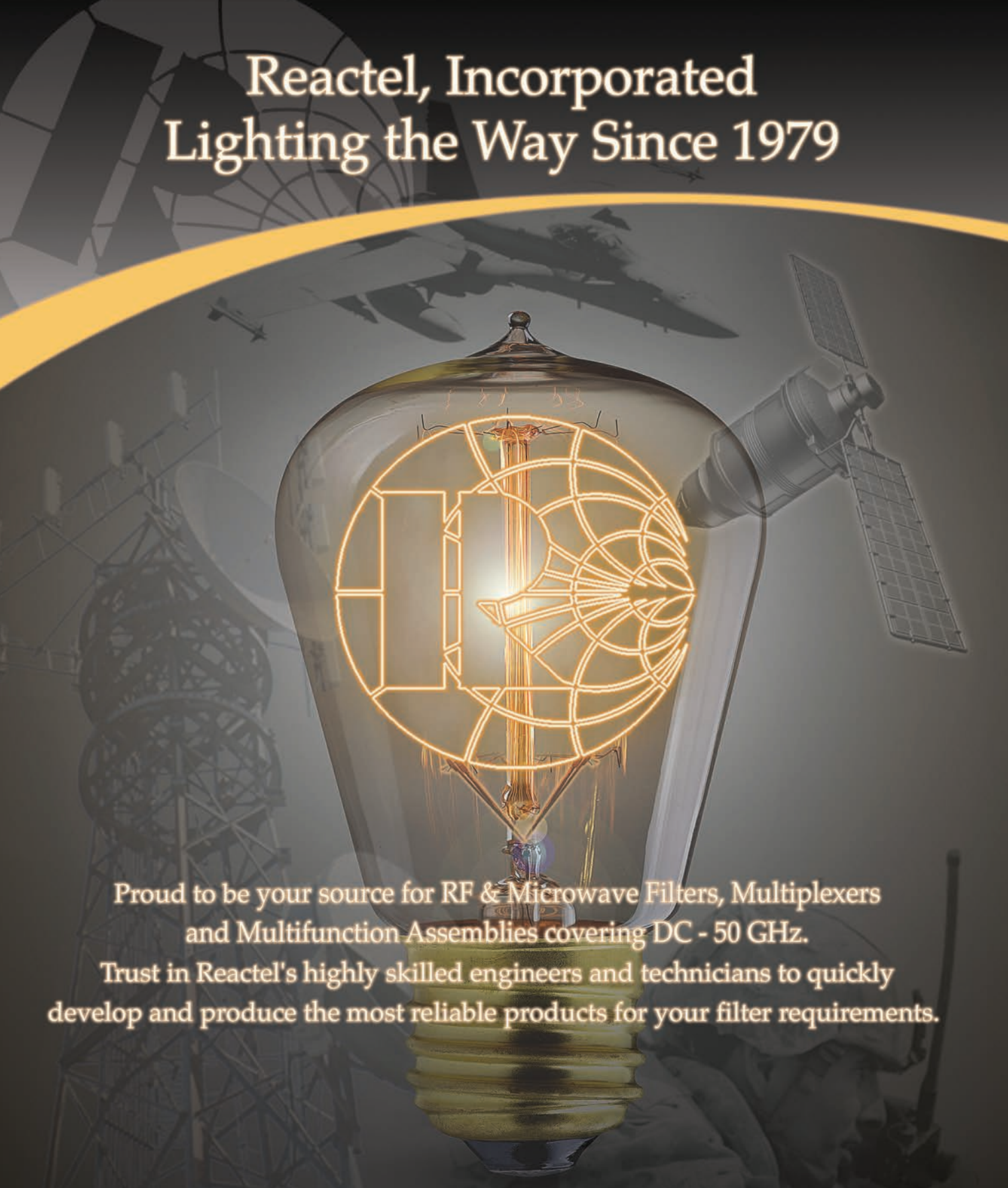

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Cliff Drubin, Associate Technical Editor

GSMA Sets Out 5G Roadmaps for Middle East & North Africa

The GSMA published an analysis showing how robust 5G growth in the Middle East and North Africa has followed ambitious 5G spectrum assignments. As governments worldwide strive toward realizing industry targets of 2 GHz of mid-band spectrum for 5G, the GSMA report details how the strong development of 5G in the Gulf has delivered some of the fastest 5G services in the world.

The GSMA's "Roadmaps for awarding 5G spectrum in the MENA region" provides a guide for 5G development in other countries in the Middle East and North Africa. It outlines the steps their governments and regulators should take to enable the most efficient and effective availability of spectrum.

The Gulf region was one of the first to assign key mid-band spectrum for 5G, and three regional giants—Etisalat, STC and Ooredoo—competed to be the first 5G operator in 2018. Since then, spectrum assignment has supported growth opportunities in the Gulf region. Today, mobile operators in the Kingdom of Saudi Arabia and UAE have access to more than 1 GHz of licensed spectrum to provide mobile broadband services in the low- and mid-bands. Alongside other Gulf markets, this places them among the leading 5G countries in Europe, the Americas and Asia Pacific.

In a roadmap focused on Tunisia, the report shares a forecast of a significant increase in 4G connections to 2025 with the expectation that 5G will be deployed in 2023. However, to meet that target, it will be essential to award the spectrum in the first half of 2022.

As the report notes, the operators in Algeria, Egypt, Morocco and Turkey have been undertaking testing and trials of 5G. In Lebanon, at least one operator has been planning their 5G network. In Egypt, the authorities are developing the legal framework for awarding 5G spectrum. Jordan's authorities are developing plans for 5G as well as identifying frequency bands.

The GSMA forecasts that all these countries will have commercial 5G services between 2022 and 2024. However, the report explains that widespread 5G adoption will take time. 4G will have a crucial role coexisting alongside 5G well into the 2030s. In some countries such as Palestine and Iraq, the report recommends that the focus should be on identifying and awarding 4G spectrum. 4G services were only launched in Iraq in 2020, while in Palestine there have been no awards for 4G spectrum. Therefore, it is premature to consider the requirements for 5G in these countries and more appropriate to roll out 4G and potentially stimulate the market for services not supported by 2G and 3G technologies.

Wi-Fi 6E Trial in Turkey Hailed a Success by Türk Telekom

Wireless Broadband Alliance (WBA) member, Türk Telekom, recently announced the successful completion of Wi-Fi 6E trials designed to demonstrate how the technology can be used to enhance speed and capacity in a variety of different end-user scenarios. Wi-Fi is vital to the success of Türk Telekom, which has the largest Wi-Fi footprint in the region spanning residential, enterprise and public space applications.

The trial, carried out in partnership with Broadcom and Intel under the auspices of the WBA trials program, clearly demonstrated Wi-Fi 6E real-world performance benefits for consumers, enterprises and municipalities. Such benefits include high bandwidth and low latency wireless applications in on-premise environments. The greenfield 6 GHz spectrum coupled with Wi-Fi 6 (Wi-Fi 6E) is a natural match with high speed fiber to the premises and accelerates deployment of 5G services. Regardless of the broadband service type to the premises, Wi-Fi 6E offers the opportunity to connect all endpoints at high speeds for a richer ecosystem and more opportunities for monetization of the 5G services.

The trial consisted of a series of scenarios with different tests in both a closed lab environment and over a live internet network to fully understand the potential of Wi-Fi 6 technology in the 6 GHz spectrum (Wi-Fi 6E). The tests were orchestrated using a router configured with Broadcom's Wi-Fi 6E evaluation platform, to which various clients were connected using Intel's AX210 160 MHz Wi-Fi 6E card to make the whole spectrum available and get the best out of the technology.

The trial made it clear that by opening the full 6 GHz spectrum, it is possible to future proof Turkey's wireless broadband capabilities in the short term with Wi-Fi 6E, and lay the groundwork for Wi-Fi 7 so that its citizens can use the digitally immersive services that will drive advancements in education, manufacturing, entertainment and more.

Türk Telekom CTO Yusuf Kıraç said, "As the first operator to trial the Wi-Fi 6E solution in Turkey, we were able to achieve a connection speed of 2 Gbps and above with low latency in the tests we conducted in the test laboratory established at Türk Telekom's Istanbul Acıbadem campus. These speeds we have achieved will enable many applications with the concept of smart office, health, entertainment, security and smart home to be used without any problems. Thanks to the Wi-Fi 6E solution, which we will combine with Türk Telekom's widespread and high capacity fiber power, we will ensure the widespread use of low latency high capacity services in homes and offices."

For More Information Visit mwjournal.com for more commercial market news.

RF SAMPO Project Strengthens Finland's Competitiveness in Radio Technologies

A consortium of major industrial and academic stakeholders led by Nokia and coordinated by the University of Oulu will start a massive project aiming to speed up the development of RF and antenna technologies and accelerate the transition from 5G to 6G. Through technological development, the project contributes to the creation of new jobs and new business opportunities.

RF Sampo is the lead ecosystem project for the theme Optimized Antenna Technology under Nokia Veturi program. Partners of this industrial co-creation project funded by Business Finland include at the moment nine companies and three research organizations: Nokia, Flex, Bittium, Optenni, Keysight Technologies, SAAB, Senfit, Okmetic, ExcellAnt, University of Oulu, Aalto University and VTT. Overall budget is 14 million euros.

In the 5G value chain, RF technology addresses infrastructure and devices and facilitates 5G ecosystem cycle growth. Radio technologies provide the access to the frequency spectrum which is the most valuable resource for wireless business. That access needs to be as efficient as possible in terms of resource and energy use but also to be commercially competitive and to support the rapid pace of new product introduction.

> Addresses ways of managing modern radio and network complexity in a comprehensive way.

The growth potential for RF technology companies arises from increasing need for wireless devices and from innovations linked to new disruptive technologies. New frequency bands (mmWave and Tera-Hz frequencies), massive MIMO and antenna array technologies and applying AI/machine learning have been identified as example of new disruptive technologies. In addition, new business opportunities arise from the fact that radio networks are sold directly to enterprise customers for example in the industrial segment. Industrial 5G is one of the fastest-growing markets in wireless communications.

The RF SAMPO project will enhance future radio platform design by introducing a modeling concept supporting the design of complex wireless solutions. The project will investigate new RF solutions for 5G and 6G including antenna structures, integrated circuits, RF related architectures and algorithms. The RF Sampo project develops new competences, which help the project partners to realize the business potential in various 5G application areas.

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

COLLABORATIONS

Kymeta and **Kratos Defense & Security Solutions Inc** announced a strategic partnership to jointly develop products and solutions that will enable modern, virtualized ground systems to better leverage the capabilities of next-generation mobile satellite antennas. Among the broader goals of the partnership are to advance the ability of ground systems to support, leverage, manage and control electronically-steered and multi-purpose antennas to better support the capabilities of software-defined and multi-beam satellites. This effort will initially focus on joint development of a software-defined remote terminal that will support a variety of dynamic satellite connectivity applications, including support for multi-orbit use cases where connectivity to LEO, MEO and GEO satellites through the same antenna are desirable.

In 2020, the University of Texas at Austin (UT Austin) published ground-breaking research results on a new RF switch technology based on hexagonal boron nitrite (hBN). The technology is energy efficient and allows higher bandwidths and speeds, making it ideal for 5G. In a recent follow-up project, **Rohde & Schwarz** and **FormFactor** have supported the academic institution in further research. Now, the RF switch technology was characterized at sub-THz frequency ranges, in particular at the D-Band (110 to 170 GHz), used for applications beyond 5G and future 6G.

CAES and **Lattice Semiconductor Corp**., a low-power programmable FPGA leader, announced an agreement whereby CAES will qualify and sell radiation-tolerant Lattice FPGAs for space and satellite applications. The collaboration will allow CAES to provide next-generation on-orbit reconfigurable processing systems for future satellite constellations. The Certus™-NX-RT and CertusPro™-NX-RT FPGAs are built on the award-winning Lattice Nexus™ platform delivering class-leading small form factor, system bandwidth and power efficiency—consuming up to 4x less power in comparison with similar devices. The 28 nm devices feature temperature-resistant tin-lead terminations using a radiation-tolerant, fully-depleted SOI manufacturing process.

Essence Group announced that it has joined the Qualcomm® Smart Cities Accelerator Program from **Qualcomm Technologies Inc.**, providing its suite of its security and safety products to help protect workers, buildings and assets. As part of the Qualcomm® Advantage Network, the Qualcomm Smart Cities Accelerator Program is designed to connect cities, municipalities, government agencies and enterprises with an ecosystem of providers to help deliver greater efficiencies, safety, cost savings and sustainability.

II-VI Incorporated and **Element Six** announced a strategic collaboration that will expand II-VI's diamond platform, accelerating the development of new disruptive applications by licensing Element Six's single-crystal diamond technology. In a world where size, weight and power consumption are strategic value drivers, the unique characteristics of diamond materials offer breakthrough solutions for designers of future generations of products. Applications of advanced power and RF electronics, including for 6G wireless components, as well as other emerging applications in life sciences, sensing, thermal management and quantum computing, are expected to drive the adoption of single-crystal diamond, a material extremely challenging to manufacture but well known for its outstanding optical, mechanical, thermal and electrical properties.

Nokia and **Nordic Semiconductor** announced a pioneering new approach to licensing the use of cellular IoT Standard Essential Patents. Companies purchasing IoT hardware from Nordic will now be allowed to acquire licenses to Nokia's industry-leading portfolio of cellular patents. This new agreement, which is the first of its kind, will simplify and speed up the Standard Essential Patent licensing process and provide greater transparency and predictability to companies delivering IoT products and services. Licenses will be available at the end device level and companies will continue to have the option to license directly with Nokia.

ACHIEVEMENTS

Energous Corp., a developer of RF-based charging for wireless power networks, has announced that its 1 W WattUp PowerBridge transmitter has received regulatory approval from the Innovation, Science and Economic Development Canada (ISED), the country's technology regulatory body, for RF-based power transfer at any distance. The approval in Canada follows similar recent 1 W WattUp PowerBridge approvals in the U.S., Europe and India and expands Energous' reach of its growing global ecosystem of wireless power transfer technology ideal for IoT deployments in markets such as retail, industrial and medical. Market analyst firm Statista forecasts the number of IoT devices to grow from approximately 9 billion this year to well over 25 billion by 2030.

MACOM Technology Solutions, a supplier of semiconductor solutions, announced that four of its manufacturing sites have achieved AS9100D certification. AS9100D is the internationally recognized quality management system (QMS) standard for aviation, space and defense organizations. MACOM's North Carolina, New Hampshire, Michigan and Massachusetts facilities achieved the AS9100D Aerospace certification. AS9100D builds on ISO 9001, adding industry-specific guidelines for the safe development and production of aerospace products.

Electronic Products Inc. has announced that the entire company has been granted ISO 9001:2015 certification

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SDCHP-140	10 - 400	18.75 - 1	1	0.5 - 0.85	27 - 22	25
KDK-HP-255	20 - 550	20 - 0.6	0.4	0.25 - 0.35	23 - 20	27.5
SDCHP-255	20 - 550	20 - 0.6	0.4	0.25 - 0.35	23 - 20	27.5
SDCHP-335	30 - 350	20.1 - 0.7	0.85	0.24 - 0.32	24 - 20	75
SDCHP-484	40 - 840	19.2 - 0.8	0.9	0.3 - 0.4	24 - 20	30
SCCHP-560	50 - 560	14.6 - 0.7	0.7	0.48 - 0.65	23 - 20	75
SBCHP-2082	200 - 820	11 - 0.46	0.5	0.74 - 0.9	22 - 19	22.5
KDS-30-30-3	27 - 512	27.5 - 0.8	0.75	--	23 - 15	50
KDS-30-30	30 - 512	27.5 - 0.8	0.75	--	23 - 15	50
KBK-10-225	225 - 400	11 - 1	0.5	0.6 - 0.7	25 - 18	50
KBS-10-225	225 - 400	10.5 - 1	0.5	0.6 - 0.7	25 - 18	50
KDK-20-225	225 - 400	20 - 1	0.5	0.2 - 0.4	25 - 18	50
KDS-20-225	225 - 400	20 - 1.0	0.5	0.2 - 0.4	25 - 18	50
KEK-706H	500 - 2500	31.5 - 2	2.5	--	--	100
SCS-8012D	800 - 1200	20 - 1	0.6	--	22 - 18	100
KEK-704DH-2	850 - 1250	30 - 1.5	0.25	--	--	500
KEK-704H	850 - 960	30 - 0.75	0.25	--	--	500
SCS100800-10	1000 - 8000	10.5 - 1.5	2	1.2 - 1.8	8 - 5	25
SCS100800-16	1000 - 7800	16.8 - 1.5	2.8	0.7 - 1	14 - 5	25
SCS100800-20	1000 - 7800	20.5 - 2.0	2	0.4 - 0.75	12 - 5	25
SCS-1522B	1500 - 2200	10 - 1.0	--	--	23 - 18	100
SCS-1522D	1500 - 2200	20 - 1	--	--	23 - 20	100
SCS1701650-16	1500 - 15500	17 - 1.5	2.5	1 - 1.4	16 - 5	25
SCS1701650-20	1700 - 15000	21 - 1.5	2.5	--	10 - 7	25
SDC360440-10	3600 - 4400	8.6 - 0.5	0.25	--	18 - 10	10
SDC360440-20	3600 - 4400	19 - 0.5	0.25	--	16 - 10	10

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as designated by TÜV SÜD America, Inc. After receiving certification for its Ceramics Division in 2018, the company has received this designation across its complete product line of RF/microwave, power semiconductor and optical packaging solutions, as well their custom multi-layer ceramic package development and manufacturing services. Electronic Products, Inc. was granted this up-to-date certification as a result of achieving outstanding implementation of a QMS throughout their entire facility in Newburyport, Mass.

Iridium recently awarded **Collins Aerospace** an Iridium Certus Developmental Over-the-Air License for Collins' new active low gain antenna (ALGA) and a high gain antenna (HGA). The license is the latest milestone in Collins' development of its new higher bandwidth Iridium Certus® airborne satcom solution—expected to be available in 2022. Collins is the first Iridium Certus Aviation Partner to have been awarded this license for both an ALGA and an HGA-based solution. Iridium awarded the licenses after Collins completed multiple tests in 2020 and 2021 where its ALGA and HGA successfully connected and transmitted data to an orbiting Iridium® satellite.

CRFS, a leader in RF spectrum monitoring and geolocation solutions, has been awarded Joint Supply Chain Accreditation Register (JOSCAR) accreditation, which gives aerospace and defense organizations confidence and assurance that CRFS meets stringent business criteria. JOSCAR is a collaborative tool used by the aerospace, defense and security industry to act as a single repository for pre-qualification and compliance information. Using JOSCAR can determine if a supplier is "fit for business." The accreditation process accessed CRFS on a range of criteria including financial and legal, anti-bribery and corruption, health and safety, environmental and sustainability, physical and IT security and quality.

Leader in inspection, verification, testing and certification, **SGS** has selected wireless connectivity testing specialist, **MVG**, to supply the first automotive over-the-air (OTA) test equipment compliant with the Vehicular Antenna Test Methodology (VATM) Standard for its service offering of automotive testing in the APAC region. SGS has purchased an MVG SG 3000, multi-probe antenna measurement and OTA test system for full-scale vehicle testing. This test system will be the first to support 5G FR1 SA and NSA and C-V2X OTA measurements for automobiles in compliance with the 5GAA VATM Standard, as well as the emerging UWB technology.

CONTRACTS

The **U.S. Marine Corps** has awarded **L3Harris Technologies** a competitive ten-year, $750 million single-award indefinite delivery, indefinite quantity (IDIQ) contract for multi-channel handheld and vehicular radio systems. The L3Harris Falcon IV® family of manpack

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Around the **Circuit**

and handheld radios selected by the USMC have been broadly adopted by the U.S. Army, U.S. Special Operations Command, U.S. Air Force and a growing number of key allies to provide secure, resilient and interoperable communications capabilities. The AN/PRC-163 is the most advanced hand radio available in the world today. They provide a wide range of secure communications waveforms—while simultaneously integrating voice and data communications, network routing and gateway functions.

AECOM announced that its joint venture with **Michael Baker International** has been awarded an IDIQ contract to provide architecture and engineering services in support of environmental compliance programs with the **U.S. Naval Facilities Engineering Systems Command (NAVFAC)**. Under the five-year contract with a $75 million ceiling, the Baker-AECOM Environmental Compliance joint venture will deliver comprehensive services, such as studies, plans, specifications, designs, reports and cost estimates, for the Navy, Marine Corps and DoD installations as well as federal agencies.

Mercury Systems Inc. announced it was awarded a $17 million contract to provide crucial RF microelectronics supporting missile capabilities of the U.S. and its allies in ensuring 21st century air dominance. These multi-channel digital RF assemblies will help provide real-time signals intelligence data, speeding information to the warfighter. The award was received in the company's fiscal 2022 first quarter and is expected to be shipped over the next several quarters. Mercury leverages more than 40 years of microelectronic manufacturing investments to support their customers from prototype to full-rate production, including automated manufacture and test, in-line quality assurance and on-site engineering support.

BAE Systems has been awarded a $14 million contract from the **Intelligence Advanced Research Projects Activity (IARPA)** to develop tools to decipher an ever-growing number of RF signals in order to quickly and accurately help secure mission-critical information. BAE Systems will advance ML and AI technology and techniques to identify signals in the RF spectrum under the terms of the contract, which is part of the Securing Compartmented Information with Smart Radio Systems (SCISRS) program. The technology will provide enhanced situational awareness, help to target threats and secure communications against malicious attacks.

Air Industries Group, an integrated Tier 1 manufacturer of precision assemblies and components for mission-critical aerospace and defense applications and a prime contractor to the **U.S. DoD**, announced that its Long Island-based subsidiary, **Air Industries Machining Corp.**, has been awarded a long-term agreement (LTA) to manufacture flight-critical products for the Blackhawk helicopter. The estimated value of the LTA is $2.4 million.

SIMULATION CASE STUDY

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Developing the 5G mobile network may not be the only step to a fully functioning Internet of Things, but it is an important one — and it comes with substantial performance requirements. Simulation ensures optimized designs of 5G-compatible technology, like this phased array antenna.

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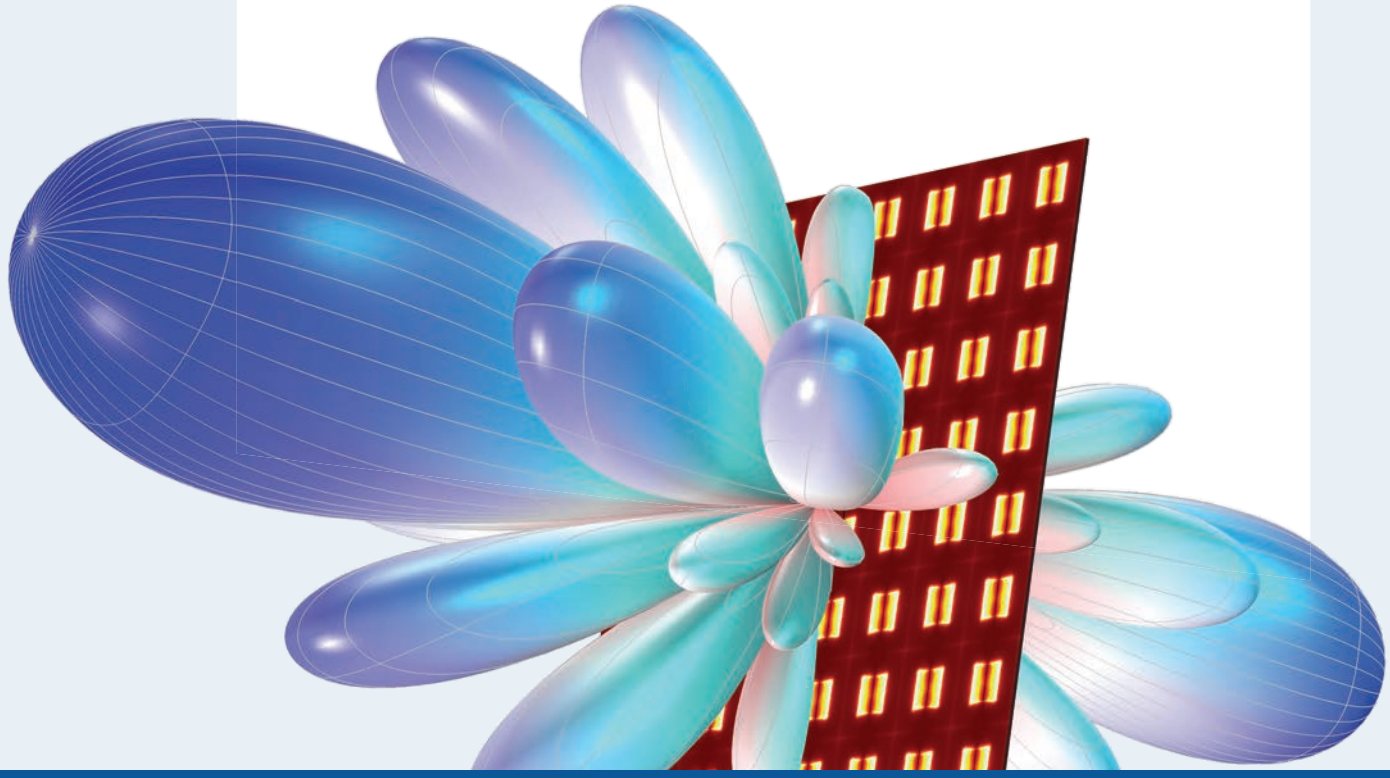

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Around the **Circuit**

Sypris Electronics announced that it has recently entered into a multi-year follow-on contract with a **U.S. DoD** prime contractor to produce and test electronic power supply modules for a large, mission-critical U.S. Navy program. The contract calls for a significant increase in production volume from existing levels beginning in 2022. Terms of the contract were not disclosed.

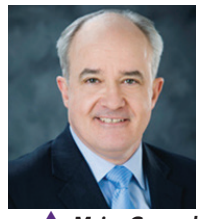
PEOPLE

Rash Sahota

Isotropic Systems, provider of transformational next-generation multi-link satellite terminals, announced that **Rash Sahota** has been appointed as general manager and chief operating officer. Sahota will be responsible for ensuring the company delivers its vision and strategy, while managing costs and driving revenue growth. Sahota brings over 30 years of experience in technology and telecoms, with senior leadership positions at Cirrus Logic, Motorola and Ericsson.

Stellant Systems Inc. announced that **Lieutenant General John F. Thompson**, U.S. Air Force (Ret.) and **Major General James O. Poss**, U.S. Air Force (Ret.) have been added to the Board of Directors. Lt. Gen. John F. Thompson most recently was the Commander at the Space and Missile Systems Center, Los Angeles Air Force Base, Calif. As the Department of the Air Force Program Executive Officer for Space, Previously, Lt. Gen. Thompson was Commander, Air Force Life Cycle Management Center, Wright-Patterson AFB, Ohio. Major General James O. Poss previously served as the Director of Intelligence at both Headquarter U.S. Air Forces in Europe and Air Combat Command. His final assignment was Assistant Deputy Chief of Staff for Intelligence, Surveillance and Reconnaissance, Headquarters U.S. Air Force.

Lieutenant General John F. Thompson



Major General James O. Poss

REP APPOINTMENT

RFMW has announced a global distribution agreement with **Menlo Microsystems**, known for reinventing the electronic switch with its Ideal Switch™ technology. Under the agreement, RFMW becomes a franchised distributor for worldwide marketing and sales of Menlo Micro products derived from their Ideal Switch™ technology, including RF and general-purpose switches, RF subsystems and power relays.

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

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INVITED PAPER

Key Sensor Capabilities for Precision Timing in 5G TDD Networks

Wireless Telecom Group

Time-division duplex (TDD) schemes enable 5G wireless systems to deliver next-generation performance. This article explores the essential capabilities for test instrumentation to characterize the performance of high speed switches in 5G TDD networks.

TDD is a type of duplex communication where uplink and downlink transmissions share a single frequency band, organized by rapidly interchanging time slots. For comparison, an alternate duplexing scheme known as frequency-division duplex (FDD) uses two separate channels for uplink and downlink transmissions. A sufficient frequency gap between the two is required to avoid interference between the transmitter and receiver.

While FDD is widely used, it demands more spectrum than TDD, contains a portion of unusable spectrum for adequate channel separation and must abide by predetermined allocations of uplink/downlink network resources. Due to these factors, TDD is becoming a more favorable option for 5G network applications, especially at high mmWave frequencies. TDD brings efficiency to spectrum management and can accommodate asymmetric traffic, enabling dynamic bandwidth allocation of high-band frequencies in dense 5G network deployments.

Successful TDD implementation requires superior synchronization and fast, efficient and precise switching components—typically operating in the microsecond or nanosecond range—to avoid latency and timing overlap. These timing requirements become more stringent as applications move up in frequency.

SWITCHING SPEED AT HIGH FREQUENCIES

In 5G TDD systems, each frame has a fixed 10 ms duration and is divided into subframes with fixed 1 ms durations. Subdividing even further, each subframe is broken into different slots that contain a cyclic prefix

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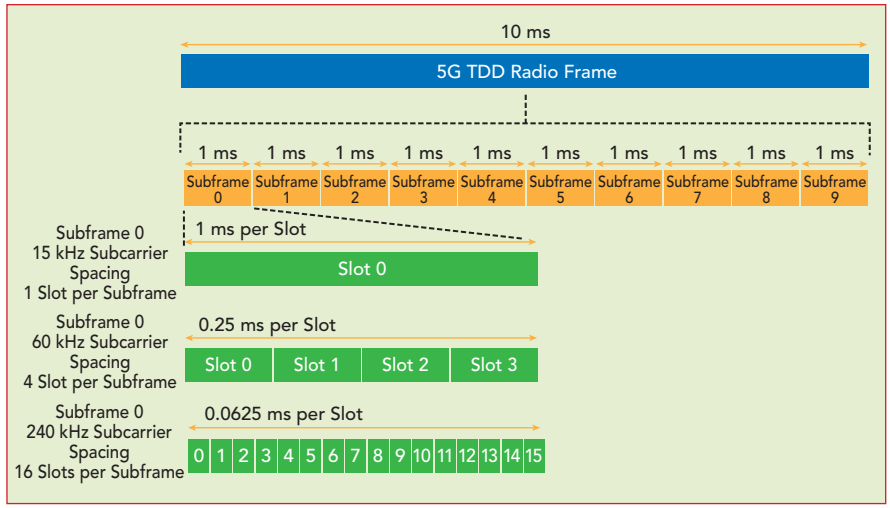

Fig. 1 10 ms 5G TDD radio frame showing 1 ms subframes and subframe 0 slot configurations at 15, 60 and 240 kHz subcarrier spacing.

and several orthogonal frequency-division multiplexing (OFDM) symbols. Classifications of TDD OFDM symbols include uplink, downlink and flexible symbols that can be assigned as either uplink or downlink. Special guard periods are used to prevent interference. Guard periods need a sufficient duration to accommodate receiving the downlink data and switching to the new uplink assignment.

Slot duration and the number of slots per frame are variable. Typically, when operating at higher mmWave frequencies, the subcarrier spacing widens as the slot length shortens. To illustrate this, ***Figure 1*** shows a 15 kHz subframe containing just one slot that takes up the full 1 ms allotment. Moving up to a 60 kHz subcarrier spacing reduces each slot's time to 0.25 ms, and even further to 0.0625 ms with a 240 kHz subcarrier spacing. For reference, FR1 frequencies use 15, 30 and 60 kHz subcarrier spacings, while higher FR2 frequencies use 60, 120 and 240 kHz subcarrier spacings. Consequently, shortening the slot length also compresses OFDM symbol length, which can dip into the sub-microsecond time range.

With uplink/downlink handover occurring at the symbol level, components tasked with switching between rapidly interchanging uplink and downlink assignments must operate at the proper speeds, especially in high frequency applications.

Switching speed is defined by the elapsed time interval between a switch's on/off state or off/on state, and key parameters for defining switching speed are rise time and fall time. As defined by IEEE, rise time is the time it takes a signal to change from 10 to 90 percent of the signal magnitude, i.e., the time interval from the first crossing of the proximal line to the first crossing of the distal line. Similarly, fall time is the time it takes a signal to change from about 90 to 10 percent of the signal magnitude, i.e., the time interval from the last crossing of the distal line to the last crossing of the proximal line.

Since rise time is a key metric in quantifying switching speed, TDD switches require test equipment with exceptional rise time capabilities for proper analysis. Diode-based peak power sensors use low-impedance loads across the smoothing capacitors so they can discharge rapidly when there is a drop in RF amplitude. Coupled with a small smoothing capacitance, an RF peak power sensor can attain a very fast rise time. Leading-edge power measurement instruments have 3 ns rise time capabilities, enabling the reliable capture of 5G TDD switching components. Interestingly, sensors with these fast rise times also have 195 MHz of video bandwidth, accommodating the 100 MHz bandwidth of an individual 5G channel.

In communications systems, the interval between 90 percent to the signal's steady state maximum level,

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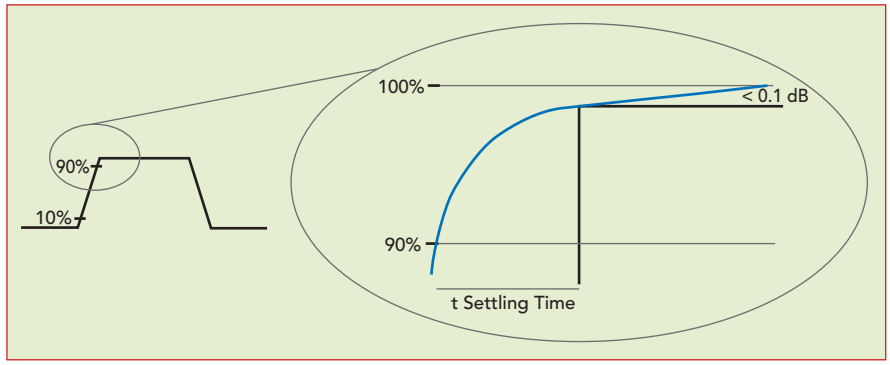

Fig. 2 Pulse settling time, defined as the time for the signal to reach < 0.1 dB of its maximum value from 90 percent of the maximum. The response time is the rise time + settling time.

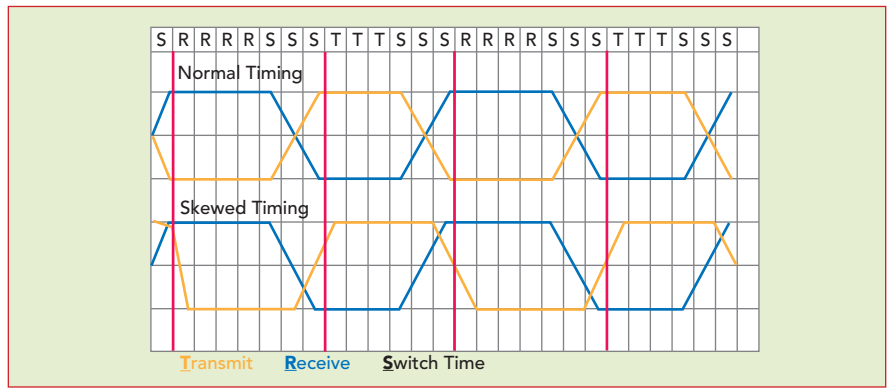

Fig. 3 Normal vs. skewed timing that overlaps the transmit (yellow) and receive (blue).

known as the settling time, is just as important in developing a proper understanding of a component's switching speed to minimize errors. The signal's peak performance can be 100 percent of the signal's magnitude, but some even consider a certain threshold, such as < 0.1 dB from a signal's maximum, as a sufficient indication that it has settled (see ***Figure 2***). This critical timeframe still denotes a region of unusable data and can add valuable microseconds to the rise time figures, which edges even closer to the precise TDD switching time specifications that these components must deliver.

Without taking note of a signal's settling time, interference can occur with the leading portion of data. Used as merit for quality control, block error rate (BLER) is the ratio between erroneous data blocks to the total blocks transmitted. Invalid data caused by settling time can lead to a high BLER, which often necessitates retransmissions and ultimately reduces network performance. Test instrumentation complemented by vendor-supplied or customer-developed power measurement software can help pinpoint the exact settling time of switching components. Software tools, for example, may enable users to place vertical and horizontal markers along the waveform. Engineers can then easily define the exact settling time window of a signal to maximize data transfer.

PROPAGATION DELAY AND WAVEFORM ANOMALIES

Ideally, TDD switches rapidly change between transmit/receive operations without a loss of data. However, some switches, especially those alternating from a power amplifier (PA) to a low noise amplifier (LNA), may experience propagation delay due to several factors, including excessive cable length, board runs, improper time adjustments or software commands.

Propagation delay is the round-trip time interval of a signal traveling from the sender, through all the necessary circuitry and networking infrastructure, to the receiving device.

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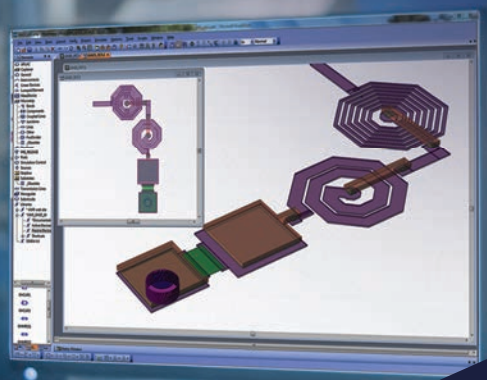

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Even the slightest discrepancy in TDD timing from factors like propagation delay can cause serious issues, such as downlink/uplink overlap, interference and a deterioration of network performance (see ***Figure 3***). Furthermore, the effects of propagation delay are compounded at higher mmWave frequencies with compressed switching time intervals. Any degradation in timing precision and switch performance becomes critical.

Delay can also create bleed through from the PA to the LNA, leading to unwanted signal phenomena such as overshoot, which occurs when a signal exceeds its top amplitude and is often followed by ringing artifacts until the signal reaches its steady, final value. While overshoot exceeds a signal's target, a similar effect known as undershoot occurs when a value dips below the set minimum. To maintain efficient network operation, designers must have the capability to capture and quantify the occurrence of any delay or unwanted signal phenomena in TDD circuitry.

Power sensors are key test and measurement tools to measure propagation delay and capture any signal distortion. While analyzing system performance in a test setup, measurement markers in accompanying software can pinpoint the delay window between input and output signals. Top-end sensor technology uses efficient and powerful digital signal processing techniques that eliminate gaps in acquisition and measurement latency to obtain lightning-fast performance. Fast measurement rates (e.g., 100,000 measurements per second) are made possible by capturing and processing waveform samples nearly simultaneously as opposed to serially, which avoids computational overhead, buffer size limitations and the need to stop signal acquisition.

For comparison, standard processing techniques capture waveform samples (typically during sub-1 second time intervals) and then halt acquisition for sequential data processing and transfer. Signal interference, distortion and other important events can occur during these acquisition gaps, heightening the importance of using sensors that reduce the total cycle time for acquiring and processing measurement samples. When coupled with compatible software applications, engineers can achieve real-time, gap-free acquisition of TDD signals to validate switching performance and reveal any anomalous events along the communications pathway.

SYNCHRONIZED MULTI-CHANNEL MEASUREMENTS

A situation with a single transmitter and receiver provides a simplistic TDD overview, but in more complex, practical situations there are various signals traveling at once emanating from multiple antennas, such as MIMO applications that increase radio link capacity. In

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this scenario, key questions arise: Are antennas switching at the same time? What is the time discrepancy between transmissions? One method to monitor more sophisticated systems is to use a vector network analyzer (VNA); however, this test instrument comes with a high price tag.

Sensors with the ability to synchronize in a test setup provide an economical alternative to a VNA, while still offering a means to monitor timing, integrity and accrued delay of numerous TDD signals. Time-aligned measurements can be achieved by using sensors that share a common time base on multiple synchronous or asynchronous channels. With this technique, the shared time base is distributed via a cable connection between the multi-function input-output ports of each sensor.

Since switching components may experience very small timing offsets, it is important to consider a test instrument's time resolution capabilities, especially when trying to resolve a 1 to 2 ns difference in timing between TDD switches. Conventional instrumentation with standard time resolution can easily miss vital nuances between TDD signals. Currently, the finest time resolution in power measurement instrumentation is 100 ps, which not only ensures the capture of meaningful TDD waveform data, but also increases trigger stability.

While leading-edge sensors that provide synchronized multi-channel TDD measurements minimize testing costs compared to VNAs, some also provide an additional advantage of using a client's actual signals during TDD transmission testing. Providing a simple methodology for signal optimization, clients can pinpoint delay and necessary corrections as their signals travel through TDD switches, many of which are embedded in the hardware of the RF cards. Software adjustments can then be used to fine-tune and optimize performance.

ADVANCED TEST SOLUTIONS FOR 5G TDD NETWORKS

Timing and switch performance are critical in 5G TDD network applications, especially at higher mmWave frequencies. Advanced test solutions can measure any delay experienced at various points along a 5G TDD communications path, catch signal phenomena like undershoot/overshoot, capture time between switch actuation and aid with multi-signal channel measurements. These testing solutions are enabled by key sensor capabilities such as fast rise times (3 nanoseconds), rapid measurement speed (100,000 measurements per second), wide video bandwidth (195 MHz), test setup synchronization and superior time resolution (100 ps). By choosing best-in-class test equipment, such as Boonton RTP5000 Real-Time RF Peak Power Sensors, engineers can fully capitalize on the capacity and coverage benefits of 5G TDD communications systems. ■

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INVITED PAPER

Faster EMC Compliance Testing with Accelerated Time Domain Scan

Paris Akhshi, PhD
Keysight Technologies, Santa Rosa, Calif.

Today's fast-paced business environment and development cycles make it imperative to provide electromagnetic compatibility (EMC) measurement facilities with rapid test turnaround, high throughput and accurate measurements. EMC tests must meet strict emission standards developed by EMC regulatory bodies such as the Comité International Spécial des Perturbations Radioélectriques (CISPR) and military standards such as MIL-STD-461.

EMC testing ensures that devices will perform as designed and not emit radiation that could degrade the performance of other equipment. EMC testing requires a detailed and exacting methodology to ensure the accurate measurement of all emissions. However, a long test time reduces the availability of the test facility, limiting the number of devices that can be certified and reducing the revenue a testing service can generate. Growing revenue without adding new test sites requires streamlining the EMC product testing cycle—setup, scanning, turntable rotation and antenna height adjustment time—to increase the capacity of the existing test facility.

TIME DOMAIN SCANNING REDUCES TEST TIME

To ensure impulsive signals are properly characterized, commercial and military testing standards require specific measurement or dwell times for each signal. When testing in the frequency domain, data must be collected in individual resolution bandwidths. Using the time domain scan (TDS) technique shortens the overall test cycle by reducing the receiver's scan time while meeting the required dwell time: With TDS, fast Fourier transforms (FFT) simultaneously analyze emissions over a range of frequencies, covering multiple resolution bandwidths to

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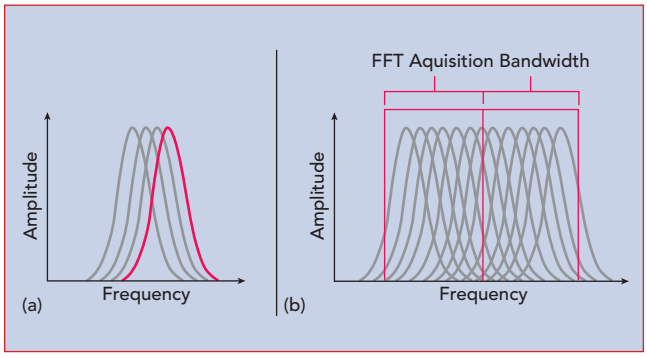

Fig. 1 **Frequency domain scanning sequentially measures individual resolution bandwidths (a), while TDS measures multiple resolution bandwidths within the FFT acquisition bandwidth (b).**

reduce the receiver's scan time (see ***Figure 1***). FFT acquisition bandwidths for TDS can range from 1 to > 10 MHz, far exceeding the resolution bandwidths required by CISPR and military standards. As soon as the receiver acquires the data, it processes it into the appropriate regulatory bandwidths to ensure measurements meet regulatory requirements.

Comparing the two techniques, frequency domain scanning requires that a receiver dwell on the resolution bandwidth required for each measurement. TDS saves measurement time by applying the regulatory dwell time once for all data in the FFT acquisition bandwidth. Using TDS saves time, since the wider acquisition bandwidth requires fewer frequency steps to cover the entire band of interest, unlike stepped frequency domain scanning. The local oscillator (LO) frequency changes with each frequency step: the fewer the number of steps, the lower the LO relock time.

Calculating FFTs often requires high overlap levels of more than 90 percent to achieve accurate amplitude measurements. Unlike the frequency domain scanner, a TDS receiver has amplitude accuracy fluctuations with frequency due to intermediate frequency (IF) effects, that must remain within regulator requirements. A high degree of FFT overlap in the time domain ensures accurate measurement of impulsive signals.

TDS acquisition bandwidths must account for microwave and RF preselector bandwidths. Preselector filters improve the dynamic range at the receiver's first mixer when measuring impulsive signals. TDS compensates for preselector edge-of-band response by adjusting the amplitude versus frequency response across the FFT acquisition bandwidth. Alternatively, the maximum FFT acquisition bandwidth can be reduced so the FFT amplitude versus frequency effect does not significantly alter the preselector's amplitude versus frequency response.

ACCELERATED TIME DOMAIN SCANNING FURTHER BOOSTS THROUGHPUT

Advances in high performance electromagnetic interference (EMI) receivers have enabled bandwidths in a single FFT acquisition up to 59 MHz for standard TDS and 350 MHz for accelerated TDS (see ***Figure 2***). The maximum bandwidth for each FFT acquisition can be determined based on the IF filters in the mixer output. For both standard and accelerated TDS, the IF can be implemented with selectable IF bandwidths up to 350 MHz. The high-performance analog-to-digital converter (ADC) enables wide bandwidth digitization for IF signals. The short time FFT (STFFT) engine can analyze up to 16,000 frequency points in a single acquisition to support wide FFT spans, which is much better than traditional EMI receivers.

Accelerated TDS accesses up to 350 MHz bandwidth in each FFT acquisition to significantly enhance

TABLE 1

TEST TIME COMPARISON

CISPR Band C/D	Stepped Scan	TDS	Accelerated TDS
30 MHz to 1 GHz Quasi-Peak Detector 1 s Dwell Time 120 kHz Resolution Bandwidth	9 hr	46 s	6 s
Four Antenna Positions (Left and Right, Vertical and Horizontal)	36 h	184 s	24 s

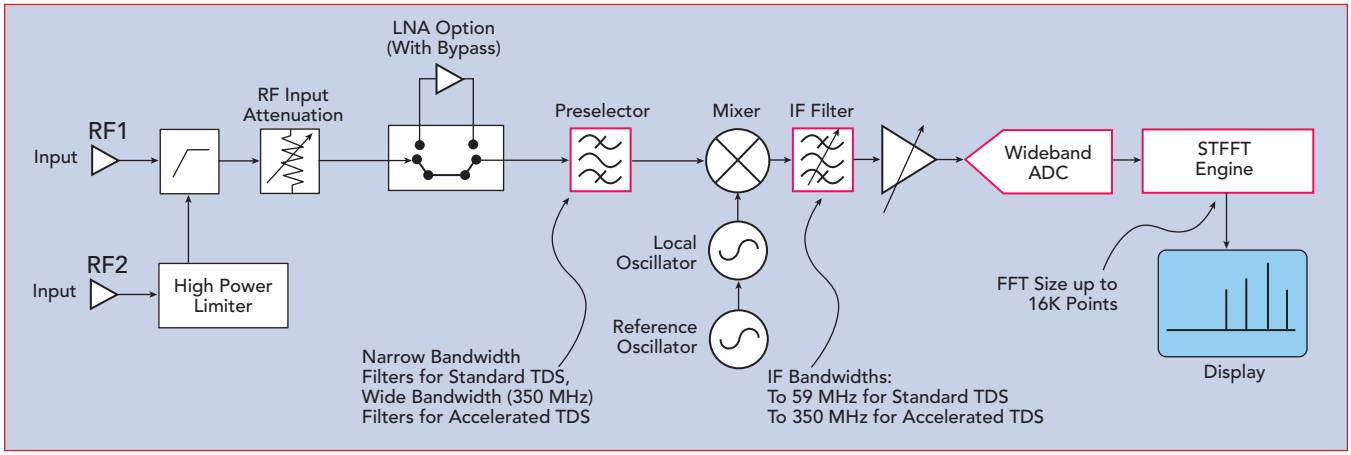

Fig. 2 **High performance EMI receiver.**

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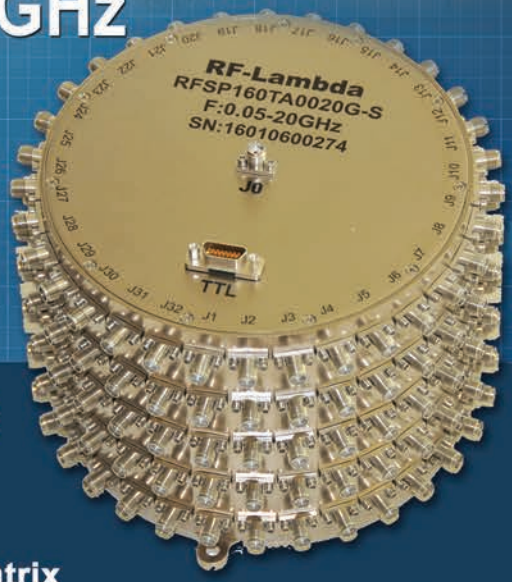

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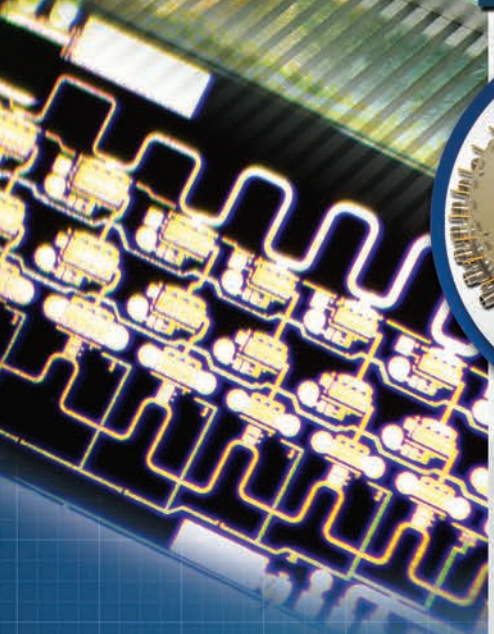

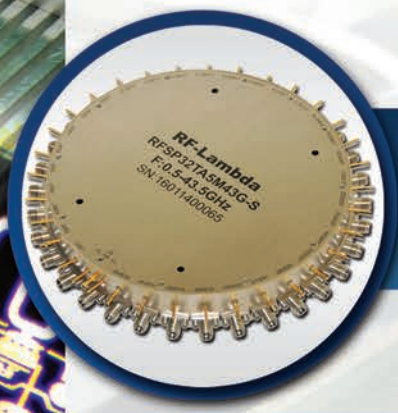

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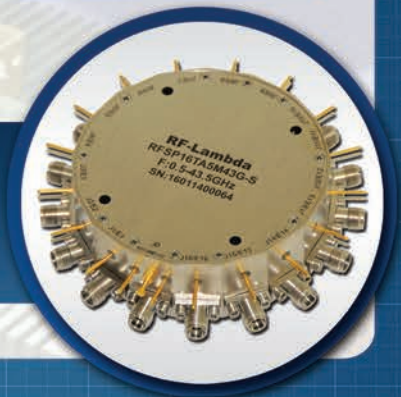
SP16T SWITCH 0.5-43.5GHz



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test throughput. To illustrate, non-accelerated TDS typically requires about 25 FFT acquisitions to scan the CISPR band C/D between 30 MHz and 1 GHz, which is significantly faster than conventional stepped scanning. Accelerated TDS typically requires no more than three acquisitions with the same frequency range, and allows to scan 8× faster than traditional TDS.

Pre-scanning the radiated emissions in an EMC test lab takes a considerable amount of time before final compliance measurements can be made. Accelerated TDS reduces this pre-scanning measurement time for each device under test (DUT). For example, an EMI receiver with accelerated TDS can reduce the scan time to less than 30 s, which is more than 5000× faster than stepped scan times (see ***Table 1***). Furthermore, accelerated TDS can increase the data capture bandwidth during real-time scan measurements more than conventional methods, analyzing the data spectrum up to 350 MHz in a single segment for accurate EMC diagnosis.

MAXIMIZING MEASUREMENT POTENTIAL

In capacity-constrained test facilities, TDS significantly improves the throughput by reducing the overall measurement test time, providing the opportunity to introduce new products and generate additional revenue. Accelerated TDS enables even faster measurements, further reducing EMC test time to certify more devices and speed new product time-to-market.

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Design Guidelines Using Theory of Characteristic Modes for a Broadband and Broad Beam SIW Cavity-Backed Microstrip Antenna

Ashutosh Kedar
Defence Research & Development Organization, Bangalore, India

The performance of a broadband broad beam substrate integrated waveguide (SIW) cavity-backed microstrip antenna (CBMSA) is studied using the theory of characteristic modes (TCM). TCM provides insight into characteristic mode (CM) propagation in the SIW CBMSA, which helps formulate design guidelines for broad bandwidth performance. These guidelines are validated with the design of a 64-element S-Band antenna array. The array is fabricated, and the measurements agree closely with simulation. It demonstrates gain greater than 8 dBi, beamwidth greater than 90 degrees, bandwidth greater than 18 percent, cross-polarization less than -20 dB and efficiency greater than 90 percent. This compares favorably with results reported in the literature.

TCM was first proposed by Garbacz.[1,2] Harrington[3] formulated it in a matrix form and applied it to scattering problems. It is shown that the CMs are orthogonal and usable as basis functions to represent the induced surface currents on any arbitrary perfect electric conductor (PEC) surface. An electric field integral equation was formulated, relating the surface currents to the tangential electric fields through a Green's function operator assuming a lossless dielectric.[3,4] Now, TCM is applied to numerous electromagnetic problems like antenna design,[5-10] antenna beam shaping,[5] RCS reduction,[11] antenna chassis design[12] and antenna-platform interaction.[5,13] Antenna bandwidth enhancement is also demonstrated successfully using TCM.[6,7,14,15] CMs depend solely upon the shape and the size of an object and are independent of excitation. The feed decides the coupling between the modal excitation coefficients (MEC) and the CMs.[5,6] Thus, TCM is useful in designing an antenna with desired characteristics.

Microstrip antennas (MSA) are desirable for the realization of phased array antennas for various applications such as 5G MIMO, phased array radar and direction of arrival (DoA) systems.[7,16-18] The U-slot MSA (UMSA) has a broadband capability utilizing multiple resonances,[14,15,19-21] and has demonstrated the broadest impedance bandwidth among the family of slotted MSAs.[20] In MSA arrays, there is strong mutual coupling (MC) between adjacent structures due to surface wave (SW) propagation.[17,22]

The CBMSA[22,23] has a metallic cavity beneath the MSA that prohibits SW propagation, isolates nearby elements and reduces MC. Thus, it supports the use of a thicker microwave laminate for bandwidth enhancement.[16,19] It also enables an overall size reduction: the radiating edge is less than $\lambda_g/2$, where λ_g is the guide wavelength.[22] This increases the -3 dB beamwidth

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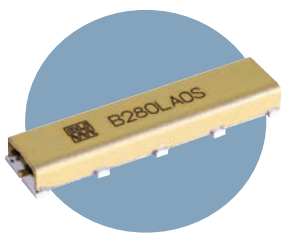

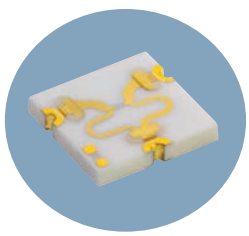

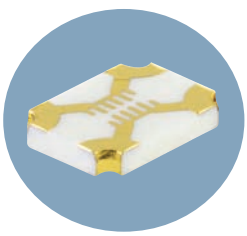

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(HPBW) and the separation between nearby elements, assuming λ/2 inter-element separation. This, in turn, reduces MC and avoids the onset of grating lobes (GL).[18] Thus, it helps to realize broadband and wide scanning phased array antennas.[17,23] The CBMSA, however, is a complicated assembly requiring precise machining of cavities, making it difficult to integrate with multilayer circuit assemblies. The problem is aggravated in larger phased array antennas.

Wu[24] introduced SIW technology, which emulates waveguide behavior in a printed form. SIW-based CBMSAs (SIW CBMSA) or slot antennas (SIW-CSA) have been demonstrated.[25-35] SIW mimics a metallic cavity with an array of plated through holes (PTH). Thus, it eliminates the need for bulky metallic cavities and exhibits minimal radiation leakage. A broadband SIW CBMSA was proposed for 5G applications.[25,43] A C-Band SIW-CSA with HPBW greater than 120 degrees and FBW of approximately 17.7 percent was demonstrated by Wen et al.[26] A C-Band CBMSA with a mushroom-like EBG structure by Vilenskiy et al.[27] demonstrated a FBW of approximately 12 percent and an 80-degree scan volume. Cai et al.[28] demonstrated a multilayer SIW-CBSA operating from 18 to 30 GHz. A wide scan, probe-fed, X-Band SIW CBMPA has also been proposed.[28,33] Chou et al.[29] describe a SIW-CBSA PAA for DoA estimation. Current literature contains a comprehensive review of SIW antennas.[30-35]

The design and optimization of SIW-CBMSAs, including probe location, is a time-consuming task using techniques like finite element method, finite difference time domain and method of moments.[16] TCM, however, does not require probe inclusion[7] and is computationally faster optimizing antenna performance, by providing information on various CMs propagating on the structure. This article describes a strategy for broadband and broad beam SIW CBMSA design using TCM. The CBMSA consists of a U-slot and an annular ring with a PTH array on a thick microwave laminate with low dielectric constant (ε_r) and dielectric loss (tanδ = td). The annular ring and UMSA have close resonances resulting in broad bandwidth.[36,37] The PTH array creates a SIW cavity mitigating SWs, reducing MC and producing a wide scan volume. The antenna's performance is evaluated in an active array environment. Simulations are compared with the measurements and prior literature.[25,27,33,42,43]

ANTENNA DESIGN

The TCM based strategy for SIW CBMSA design with a coaxial probe feed consists of the following design steps (see ***Figure 1***):

- Probe-fed MSA
- U-slot and integration with the MSA
- SIW CBMSA.

The design procedure uses analytical expressions[16] and the TCM module in Altair FEKO software.[38] The substrate is Rogers 5880 (ε_r =

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2.2, td = 10^{-3}) with h ~ 250 mils.

The design objective is an antenna element with broad bandwidth and broad beamwidth for wide scanning phased array applications, meeting the following specifications:

- Frequency of operation: S-Band
- FBW: 20 percent minimum with a center frequency = 3.3 GHz
- HPBW: greater than ±45 degrees
- Low MC and cross-polarization, i.e., less than -18 dB.

Revisiting TCM

CMs are the Eigenmodes forming a basis set for the induced surface currents scattered by PEC bodies.[5-7] Thus, the radiation pattern is the linear combination of the respective orthogonal modal currents. The current distribution can be decomposed into mutually orthogonal characteristic currents. The surface currents, J, and scattered electric field, E^s, are related through an operator, L, as[4]

$$L(J) + E^s = 0 \quad (1)$$

Equation 1 can be re-written for the tangential field component as

$$[L(J) + E^s]_{tan} = 0 \quad (2)$$

In equation 2, the operator part is expressible in terms of impedance

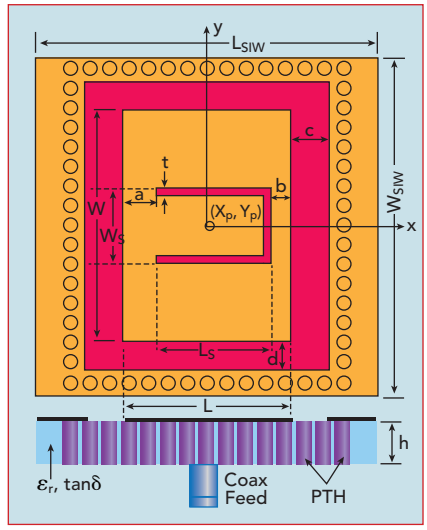

Fig. 1 Antenna structure.

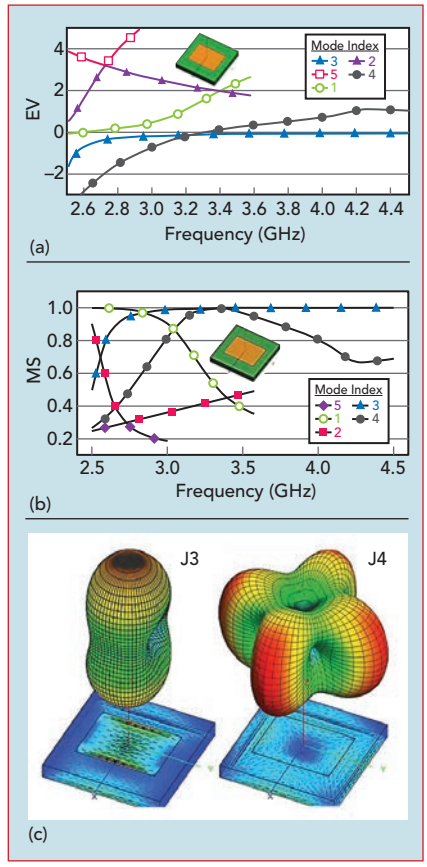

Fig. 2 Microstrip patch antenna EV (a) and MS (b) vs. frequency; radiation patterns and surface current distributions (c).

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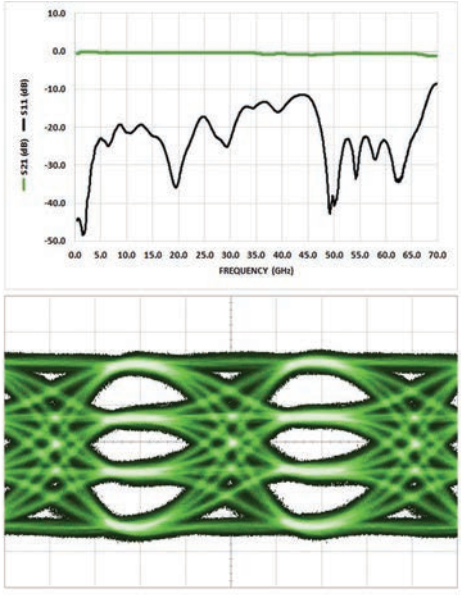

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as

$$Z=\left[L(J)\right]_{tan} \quad (3)$$

and

$$Z=-E^{s}_{tan} \quad (4)$$

where Z is a complex impedance:

$$Z=R+jX \quad (5)$$

In Equation 5, R and X represent the resistive and reactive portions of the impedance. An eigenvalue (EV) equation is given as:[4]

$$Z(J_n)=\mu_n R(J_n) \quad (6)$$

In Equation 6, μ_n are the EVs, and J_n are the eigenfunctions. Using Equations 5 and 6, 7 is obtained in a matrix form as:

$$X(J_n)=\lambda(J_n) \quad (7)$$

$$\mu_n=1+j\lambda_n \quad (8)$$

In Equation 8, λ_n is referred to as the EV. Thus, $\lambda_n = 0$ represents the resonance condition, while $\lambda_n < 0$ or $\lambda_n > 0$ represent storage in the form of electric or magnetic energy, respectively. Another characteristic parameter is Modal Significance (MS), which is defined as

$$MS_n=\left|\frac{1}{1+j\lambda_n}\right| \quad (9)$$

$MS_n \rightarrow 1$ represents resonance. Thus, the frequencies satisfying $MS_n > 0.707$, define the FBW of the structure. Another parameter, the characteristic angle (CA) α_n, defines the phase angle between the characteristic modal current and respective field and is given in Equation 10:

$$\alpha_n=1-\tan^{-1}(180-\lambda_n) \quad (10)$$

α_n = 180 degrees represents the point of resonance, and its slope gives the FBW. Thus, EV, MS and CA are the essential characteristic parameters that determine the radiation characteristics of the structure and the CMs contributing to ra-

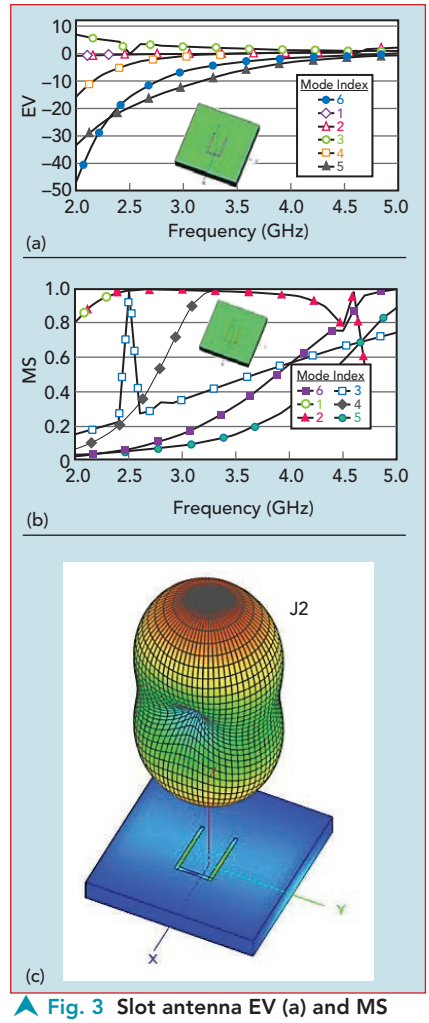

Fig. 3 Slot antenna EV (a) and MS (b) vs. frequency; radiation pattern and surface current distribution (c).

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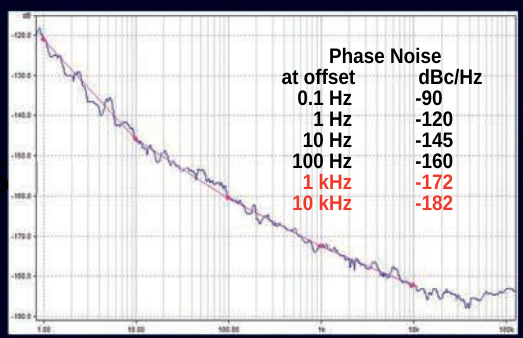

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diation. The Eigen currents and the fields are orthogonal; hence, CMs radiate independently of each other and can be used as basic functions to expand the total current (J):

$$j = \sum_n \frac{V_n^i J_n}{1 + j\lambda_n} \quad (11)$$

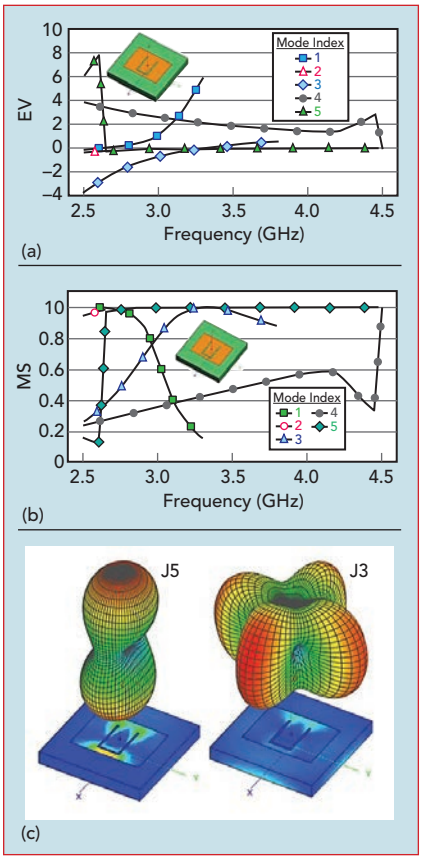

Fig. 4 UMSA EV (a) and MS (b) vs. frequency; radiation patterns and surface current distributions (c).

In Equation 11, V_n^i is the MEC, which assesses the effect of the applied excitations' position, phase and magnitude on a particular CM's contribution to the net radiation.

MSA Design

An MSA is modeled (see ***Figure 2***) using simple closed-form expressions[16] and analyzed using TCM. All possible mode excitations are determined over the range from 2.5 to 4.5 GHz. ***Figures 2a*** and ***b*** plot the EV and MS versus frequency. Five numbers of CMs are considered, J_1 to J_5 (mode indices from 1 to 5), chosen per the criterion in Equation 12:

$$NM = N_o \ (MS \geq 0.707) + p_o \quad (12)$$

In Equation 12, NM is the total number of stable CMs, N_o is the number of CMs achieving, MS ≥ 0.707 and p_o is the accuracy factor.

Figure 2 shows that two modes, J_3 and J_4, contribute over the complete band with resonances near 3.3 GHz (MS ~1). Figure 2b shows that J_3 covers 2.6 to 4.5 GHz (FBW = 53 percent) and J_4 covers 2.8 to 4.2 GHz (FBW = 40 percent). ***Figure 2c*** plots the respective 3D radiation pattern and surface current distributions. J_3 is the dominant mode giving the desired radiation pattern and J_4 is a higher-order mode.

U-Slot Design

A U-slot is modeled (see ***Figure 3***) using Babinet's principle of duality,[39] considering it as a metallic U-strip on a dielectric substrate. ***Figures 3a*** and ***b*** plot EV and MS versus frequency. Six modes are considered, i.e., J_1 to J_6 (mode indices from 1 to 6). Figure 3 shows that mode J_2 contributes from 2 to 4 GHz (FBW = 75 percent) and the other modes, except J_3, show capacitive behavior. ***Figure 3c*** shows the 3D radiation pattern and surface current distribution plots for J_2. The mode J_2 is dominant and gives a desirable radiation pattern.

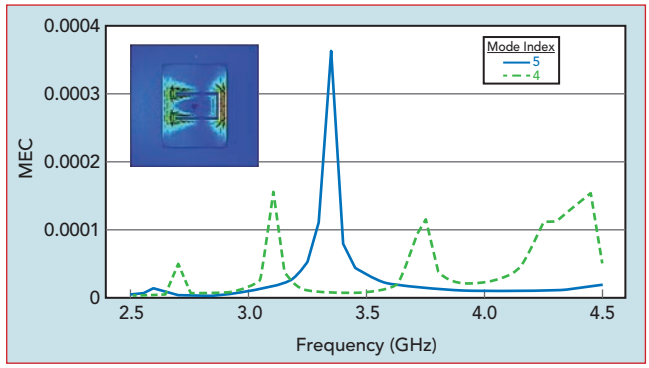

Fig. 5 UMSA MEC vs. frequency.

U-Slot MSA (UMSA) Design

The UMSA is designed, combining MSA and U-slot designs, and the overall structure is shown in ***Figure 4***. Figures 4a and b

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plot EV and MS versus frequency. Five modes are considered, i.e., J_1 to J_5 (mode indices varying from 1 to 5), and the figure shows that modes J_3 and J_5 contribute to the band of interest. Figure 4c plots the respective 3D radiation pattern and surface current distributions for modes J_3 and J_5 showing J_5 provides the desired current distribution.

A probe excitation with a diameter of 1.35 mm is modeled to see its effect on CM propagation. ***Figure 5*** plots the MECs versus frequency, confirming J_5 as the desired radiation mode with a higher value of MEC near the resonant frequency. The inset in Figure 5 shows the surface current distribution, illustrating the in-phase coupling between the U-slot and the dominant TM_{10} mode of the MSA.[14] The current distribution is maximum around the slot near the edges of the MSA.

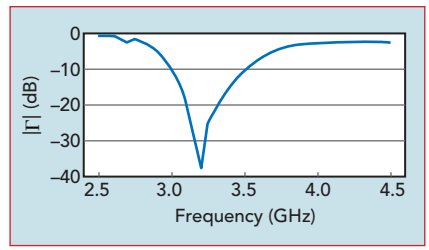

Fig. 6 UMSA reflection coefficient magnitude vs. frequency.

Figure 6 plots the magnitude of the reflection coefficient, $|\Gamma|$, versus frequency using the standard Method of Moments (MoM) simulation. It shows that the desired bandwidth is achieved with resonance at 3.3 GHz. Note that the resonance point differs slightly from that determined with TCM.

The next section validates the design with two of the most promising and proven techniques available in prior literature[40,41] to show TCM's accuracy and effectiveness.

UMSA Design Validation

The initial UMSA design is obtained from closed-form empirical expressions using the dimensional invariance (DI)[41] and three resonant frequency (TRF)[40] techniques. TRF defines the criterion of choosing ε_r and h depending upon the desired FBW = 100 $(f_{res2}-f_{res4})/ f_{res3}$, where f_{res2} and f_{res4} are the lower and upper bounds of the VSWR bandwidth (2:1) and f_{res3} is the center frequency. The substrate thickness, h, must satisfy the criterion in Equation 13. Initial design parameters of the UMSA are chosen using Equation 13 to Equation 20 depending upon desired VSWR bandwidth[40] (see Figure 1).

$$h \geq 0.06\frac{\lambda_{res3}}{\sqrt{\varepsilon_r}} \quad (13)$$

$$L + 2\Delta L \approx \frac{3.10^8}{2\sqrt{\varepsilon_r} f_{res3}} \quad (14)$$

$$W = 1.5L \quad (15)$$

$$\varepsilon_{r,eff} = 0.5(\varepsilon_r + 1) + 0.5(\varepsilon_r - 1)\left(1 + \frac{12h}{w}\right) \quad (16)$$

$$2\Delta L = 0.824h \frac{\left(\varepsilon_{r,eff} + 0.3\right)\left(\frac{W}{h} + 0.262\right)}{\left(\varepsilon_{r,eff} - 0.258\right)\left(\frac{W}{h} + 0.813\right)} \quad (17)$$

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$$t=\lambda_{res3(air)}/60 \quad (18)$$

$$W_s = \frac{3.10^8}{\sqrt{\varepsilon_{r,eff}}\, f_{res2}} - 2(L + 2\Delta L - t) \quad (19)$$

L_s is selected such that

$$\frac{L_s}{W} \geq 0.3 \text{ and } \frac{L_s}{W_s} \geq 0.75 \quad (20)$$

The DI method[41] predicts that the only parameter dependent on substrate choice is W/h, and all other-dimensional parameters (see Figure 1) follow a constant ratio, as given in ***Table 1***. A variation of W/h with frequency is studied and its empirical relationship is derived for the chosen substrate as

$$\frac{W}{h} = 0.145 f_{res3}^2 - 1.8 f_{res3} + 10 \quad (21)$$

The UMSA is designed using TRF and DI techniques and compared with TCM. ***Table 2*** summarizes the respective design variables with the achieved frequency band of operation. The three respective designs are simulated assuming the infinite substrate boundary conditions in MoM. Table 2 shows good agreement in terms of f_{res}; however, the TCM agrees more closely with DI and yields a much more compact geometry compared to the one achieved using the TRF technique. This is because the DI technique also derives its respective ratios from MoM simulations[41]; therefore, both DI and TCM consider the fringe fields and finite edge effects. Thus, the design procedure using TCM is validated.

TABLE 1

DIMENSIONAL INVARIANCE IN U-SLOT DESIGNS[41]

ε_r	W/h	L/L_S	W_S/L_S	L_S/b	t/W_S	W/W_S
1	8.168	1.515	0.835	4.237	0.13	3.203
2.33	5.624	1.444	0.777	4.5	0.143	2.571
4.0	3.87	1.443	0.776	4.51	0.144	2.573
9.8	2.87	1.442	0.777	4.48	0.144	2.574

TABLE 2

U-SLOT DESIGN DIMENSIONS

(DIMENSIONS IN MM AND FREQUENCY IN GHZ)

Case	W	L	W_S	L_S	t	b	a	h	f_{res2}	f_{res3}	f_{res4}
TRF[40]	45.9	30.6	21.1	19.7	1.5	5.88	5.88	6.35	2.8	3.48	3.59
DI[41]	33.8	24.4	15.0	18.8	1.8	2.78	2.78	6.35	1.95	3.3	3.65
TCM	34	25	11	17	1	2.5	11.5	6.35	2.0	3.4	3.8

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AMCOM's AM005MH2-BI-R is a part of the BI series ofGaAs HiFETs. The HiFET is a partially matched patented device configuration for high voltage, high power and broadband applications. This part has a total device periphery of 1mm. The AM005MH2-BI-R is designed for high power microwave applications, operating up to 6 Ghz. It is also an ideal driver for larger power devices. The flange at the bottom of the package serves simultaneously as DC ground, RF ground, and thermal path. This part is RoHS compliant.

AMCOM's AM032MH4-BI-R is part of the BI series of GaAs HiFETs. The HiFET is a partially matched patented device configuration for high voltage, high power and broadband applications. This part has a total device periphery of 12.8mm. The AM032MH4-BI-R is designed for high power microwave applications, operating up to 6GHz. The flange at the bottom of the package serves simultaneously as DC ground, RF ground and thermal path. This HiFET is RoHS compliant.

AMCOM's AM030WX-BI-R is a discrete GaAs pHEMT that has a total gate width of 3.0mm. It is in a ceramic BI package for operating up to 10 GHz.The BI package uses a specially designed ceramic package with bent (BI-G) or straight (BI) leads in a drop-in mounting style. The flange at the bottom of the package serves simultaneously as DC ground, RF ground, and thermal path. This part is RoHS compliant. For more information on this product or any other AMCOM product visit our website at www.amcomusa.com.

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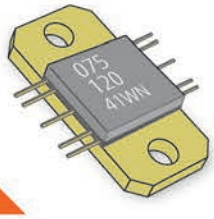

The AM07512041WN-SN-R is in a ceramic package with a flange and straight RF and DC leads for drop-in assembly. It has 27dB gain, and 41dBm output power over the 8.25 to 11.75 GHz band. Because of high DC power dissipation, good heat sinking is required.

Model	Freq(GHz)	Freq(GHz)	Gain(db)	Psat(dBm)	Eff(%)	Vd(V)	ECCN
AM003042WN-XX-R	0.05	3	23	42	33	40 / -2	EAR99
AM003042WN-00-R	0.05	3	24	42	35	40 / -2	EAR99
AM206041WN-SN-R	1.8	6.5	30	41	23	+28 / -1.8	EAR99
AM206041WN-00-R	1.8	6.5	32	42	27	+28 / -1.8	EAR99
AM408041WN-SN-R	3.75	8.25	31	41	23	+28 / -1.8	3A001.b.2.b
AM408041WN-00-R	3.75	8.25	33	42	27	+28 / -1.8	3A001.b.2.b
AM00010037WN-SN-R	DC	10	13	37	23	+28 / -1.8	EAR99
AM00010037WN-00-R	DC	10	13	37	25	+28 / -1.8	EAR99
AM00010037WN-QN6-R NEW	DC	10	13	36	25	+28 / -2.0	EAR99
AM08012041WN-SN-R	7.5	12	21	41	20	+28 / -1.9	3A001.b.2.b
AM08012041WN-00-R	7.5	12	22	42	20	+28 / -1.9	3A001.b.2.b
AM07512041WN-SN-R	7.75	12.25	27	41	22	+28 / -1.8	3A001.b.2.b
AM07512041WN-00-R	7.75	12.25	28	42	27	+28 / -1.8	3A001.b.2.b

MMIC in a Box

MC Analysis

MC behavior is described in 2 × 1 and 2 × 2 arrays. ***Figure 7*** shows a 2 x 1 array as an inset and plots the self and mutual scattering parameters (SP) versus frequency. Over the 3 to 3.5 GHz band, the coupling $|S_{21}|$ is less than -18 dB and $|\Gamma| = |S_{11}|$ is less than -10 dB. ***Figure 8a*** shows a 2 × 2 array model and its respective SPs. $|\Gamma|$ for all ports is less than -10 dB and MC is less than -18 dB over the 3 to 3.5 GHz band. A little variation in the resonance peaks of the four elements is observed due to the MC effect.[17] ***Figure 8b*** shows the uniformly fed array radiation pattern. The HPBW is ~54 degrees, G_e is ~ 6.9 dBi and the peak sidelobe level is less than -13 dB.

Annular Ring Design

An annular ring (see ***Figure 9***) is designed with dimensions based on the center frequency[36] using (22):

$$f_{res3} = \frac{v}{4\left(L_\alpha - W_\alpha\right) - \sqrt{\varepsilon_{r,eff}}} \quad (22)$$

In (22), $\upsilon = 3\times10^8$ m/s, $L_\alpha = L_{SIW}-(L+2c) = 42.21$ mm and $W_\alpha = W_{SIW}-(W+2\ d) = 39.21$ mm. TCM identifies two resonances, 2.2 and 3.4 GHz for modes J_1 and J_4 (see ***Figures 9a*** and ***b***), respectively. The dominant mode is the TM_{11} mode (J_1) in this structure.

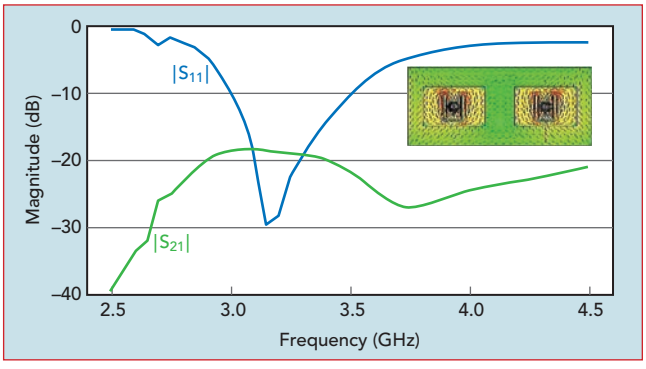

Fig. 7 **UMSA self and mutual SPs.**

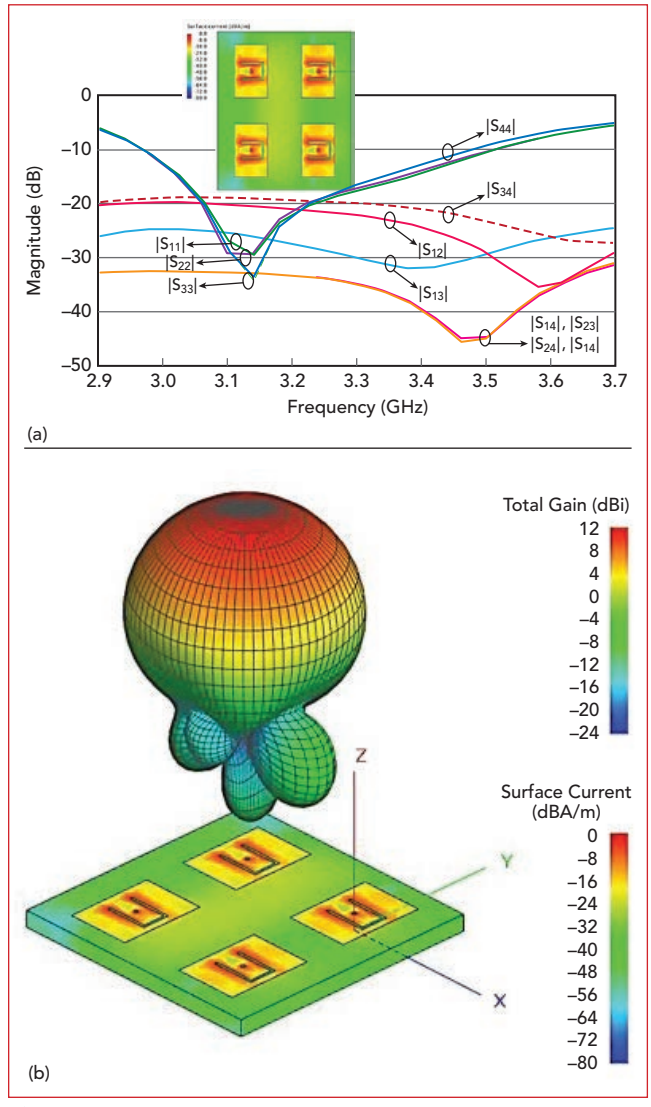

Fig. 8 **UMSA 2 × 2 array self and mutual SPs (a) and radiation pattern (b).**

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SIW Cavity-Backed UMSA (SIW CBMSA)

The annular ring with a PTH array adjoined to the UMSA (see Figure 1 and ***Figure 10***) forms the SIW CBMSA structure. The dimensions are L_{SIW} = 50.21, W_{SIW} = 50.21, c = 4 and d = 5.5 mm. The PTH diameter is 1 mm, with a spacing of 2.875 mm, optimized to minimize leakage loss based on MC estimation between two adjacent antenna elements.

Figures 10a and ***b*** show EV and MS versus frequency considering four CMs, from Equation 12. An

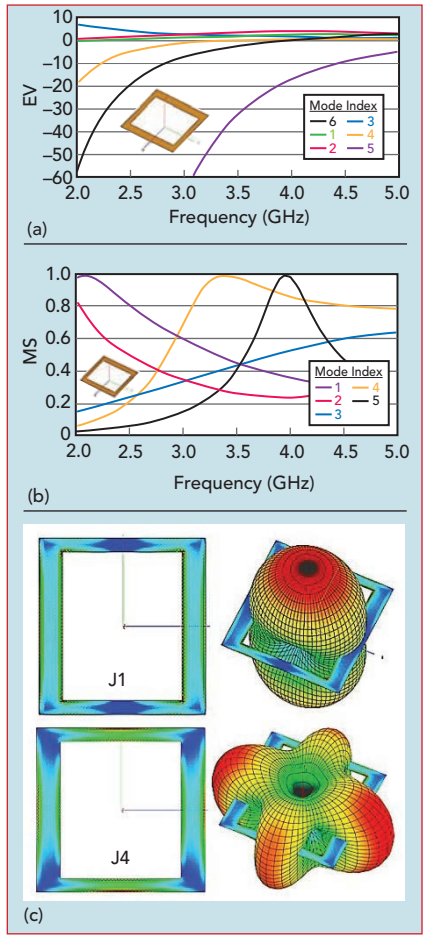

Fig. 9 **Annular ring EV (a) and MS (b) vs. frequency; surface current distribution and radiation pattern for modes J1 and J4 (c).**

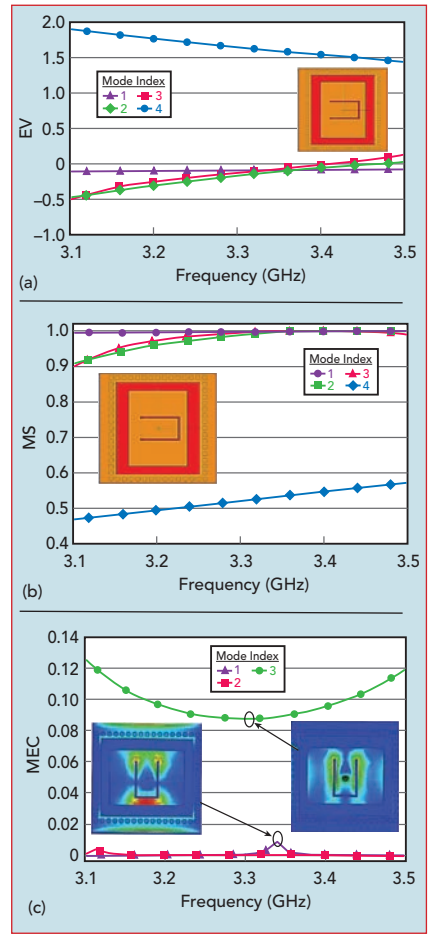

Fig. 10 **SIW CBMSA TCM EV (a), MS (b) and MEC (c) vs. frequency.**

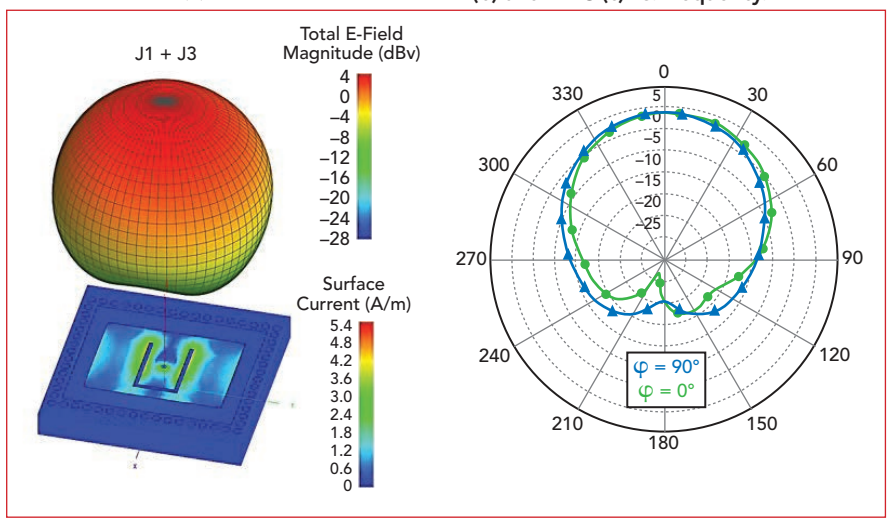

Fig. 11 **SIW CBMPA radiation pattern and surface current distribution.**

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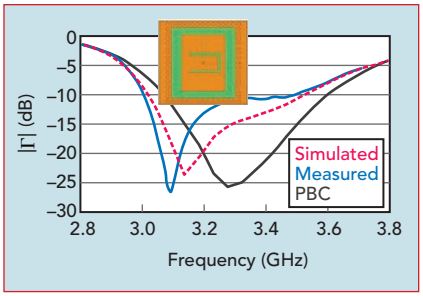

Fig. 12 Reflection coefficient magnitude vs. frequency.

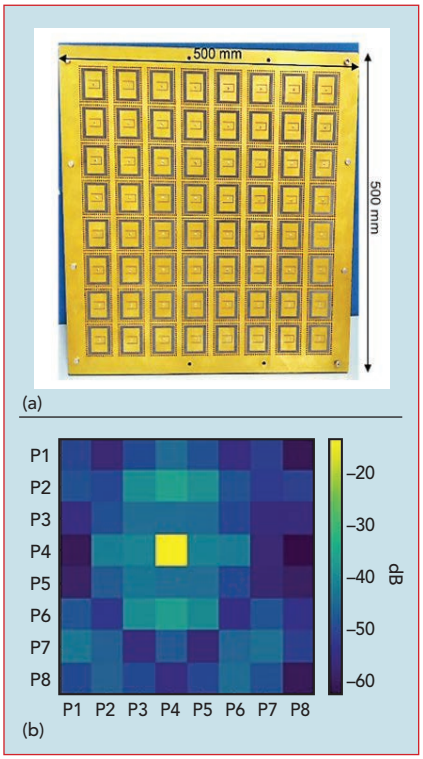

Fig. 13 SIW CBMA array (a) and mutual MC variation (b).

enhanced bandwidth is observed, contributed by modes J_1, J_2 and J_3. ***Figure 10c*** plots MECs considering probe excitation and shows that J_3 is the dominant mode while J_1 contributes to a lesser degree.

Figure 11 shows the combined surface current distribution, J_1+J_3, and associated 3D radiation pattern at 3.3 GHz; normalized phi-cut distributions are also shown. An in-phase coupling between U-slot and

TABLE 3
MEASURED ARRAY PARAMETERS

f (GHz)	HPBW ϕ = 0° (°)	X-Pol ϕ = 0° (dB)	Do (dBi)	HPBW ϕ = 90° (°)	X-Pol ϕ = 90° (dB)	G_e (dBi)	ηRE (%)
2.9	101.6	-18	8.7	116.1	-20	8.1	93.9
3.0	121.2	-22	8.4	110.2	-23	8.0	95.2
3.1	116.6	-25	8.6	114.1	-29	8.3	97.4
3.2	99.4	-30	8.4	100.0	-31	8.2	96.6
3.3	93.8	-33	8.6	90.1	-29	8.2	94.3
3.4	93.8	-33	9.1	97.1	-30	8.7	96.8
3.5	83.5	-33	9.0	90.2	-35	8.7	96.8
3.6	74.2	-27	8.8	85.2	-27	8.4	95.7

TABLE 4
PERFORMANCE COMPARISON
NM = NOT MENTIONED

Case	FBW (%)	Scan Volume (°)	MC (dB)	G_e (dBi)	X-Pol (dB)	ηRE (%)
Awida et al.[33]	12 (@10 GHz)	< ±60	NM	NM	< -20	> 80
Zhang et al.[42]	9 (3.34-3.37 GHz)	NM	NM	> 6.4	< -20	NM
Vilenskiy et al.[27]	12 (NM)	> ±51	< -20	> 5	< -20	> 80
Liu et al.[25]	19 (26.2-31.7 GHz)	<±40	NM	NM	NM	NM
Wen et al.[26]	17.7 (5.4-6.45 GHz)	-71° to 73°	NM	NM	< -13	NM
Tan et al.[43]	10.6 (27.8-30.9 GHZ)	NM	NM	> 8.4	< -25	NM
This Work	22.5 (2.9-3.7 GHz)	±50	-20	> 8.0	-20	> 93.9

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patch edges is observed with minimal leakage to the annular ring, thus ensuring isolation from nearby structures. G_e is ~6.9 dBi and HPBW is greater than 89 and 82 degrees in the respective planes.

A bandwidth of 670 MHz (FBW = ~20 percent) is shown by the dotted red curve in ***Figure 12***. Figure 12 compares the simulated $|\Gamma|$ obtained in an isolated environment with an infinite array environment generated using periodic boundary conditions (PBC).[17,18] It also compares these with the measured $|\Gamma|$ in an array environment. Generally good agreement is observed, with a slight difference between the PBC and measured results, due to neglecting the finite edges in the PBC environment.

MEASURED RESULTS AND DISCUSSION

A 64 (8 × 8) SIW CBMSA array 500 × 500 mm^2 in size is fabricated using standard photo-etching techniques. The inter-element spacing is $0.552\lambda_o$ along the x- and y-directions. It has a 5 mm-thick aluminum ground plane while ensuring that no air bubbles are formed in the structure (see ***Figure 13a***).

The central element performance and the MC variation is measured (see ***Figure 13b***). Coupling is measured between the central element and all other array elements. It is observed that the worst coupling is less than -20 dB, i.e., minimal leakage occurs from the SIW structure to its neighbors. Figure 12 shows the mea-

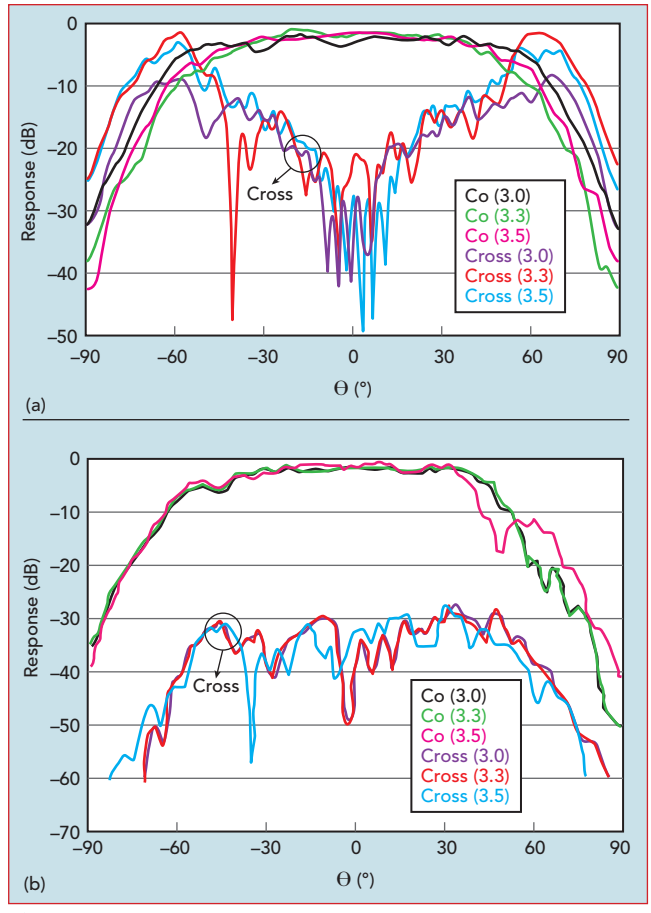

Fig. 14 Measured co- and cross-polarization radiation patterns vs. θ at 3.0, 3.3 and 3.5 GHz with φ = 0 (a) and 90 (b) degrees.

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*Theoretical 6dB Included

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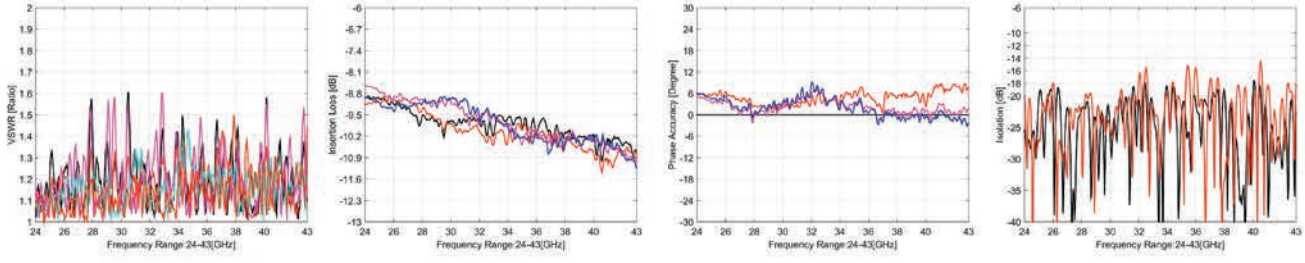

* *Corresponding Channels: A1B1, A1B2, A1B3, A1B4

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sured FBW is ~22.5 percent (~740 MHz), from 2.96 to 3.7 GHz for a VSWR less than 3:1, and 18 percent (~600 MHz), from 3 to 3.6 GHz for a VSWR less than 2:1.

Table 3 summarizes the radiation parameters in the array environment measured in a planar near-field test measurement facility. The variation observed between the measured and the simulated parameters are attributed to the variation in h, due to the bonding of two layers of the substrate using a Rogers 3001 bonding film to achieve the desired thickness. The set targets are met from 3.1 to 3.5 GHz, showing G_e is greater than 8.4 dBi, the efficiency η_{RE} is greater than 95.2 percent (see Equation 23), cross-polarization is less than -22 dB and the HPBW is greater than 90 degrees in both principal planes except near the upper edge of the frequency band.

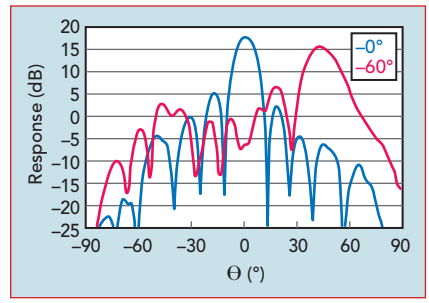
$$\eta_{RE} = 100.\ G_e / D_o \quad (D_o \text{ is the directivity}) \qquad (23)$$

Table 4 compares SIW CBMSA performance with the prior work.[33,42,27,25,43] Comparable performance with better efficiency, η_{RE} greater than 93.9 percent and FBW of ~22 is shown. ***Figure 14*** plots the measured co- and cross-polarized normalized radiation patterns in the array environment over the band, in the φ = 0- and 90-degree planes. A HPBW greater than 90 and 100 degrees in the two planes with cross-polarization less than -23 dB at boresight and better than -12 dB at extreme scan angles is demonstrated (see Table 3). The ripple level in the gain plots is less than ±0.5 dB.

Figure 15 shows the measured radiation pattern of a 64-element, uniformly fed array scanned to 0- and 45-degree angles. G_e decreases 1.15 dB from the peak value of ~17.6 dBi at 0 degrees with no visible GLs, validating wide scan performance.

CONCLUSION

A simple design strategy based on TCM to design a broadband, broad beamwidth SIW CBMSA is presented. TCM provides insight into propagating CMs and shows that the choice of CM propagation in the constituent parts of the antenna helps achieve broadband performance. The resultant antenna design is validated in a 64-element array environment. The fabricated antenna's measured performance agrees with the simulation and shows broad bandwidth and broad beamwidth. The results complement the existing literature and show promising applications to phased array antennas for various applications. ■



▲ **Fig. 15 Measured radiation pattern of the 64-element, uniformly fed array at center frequency.**

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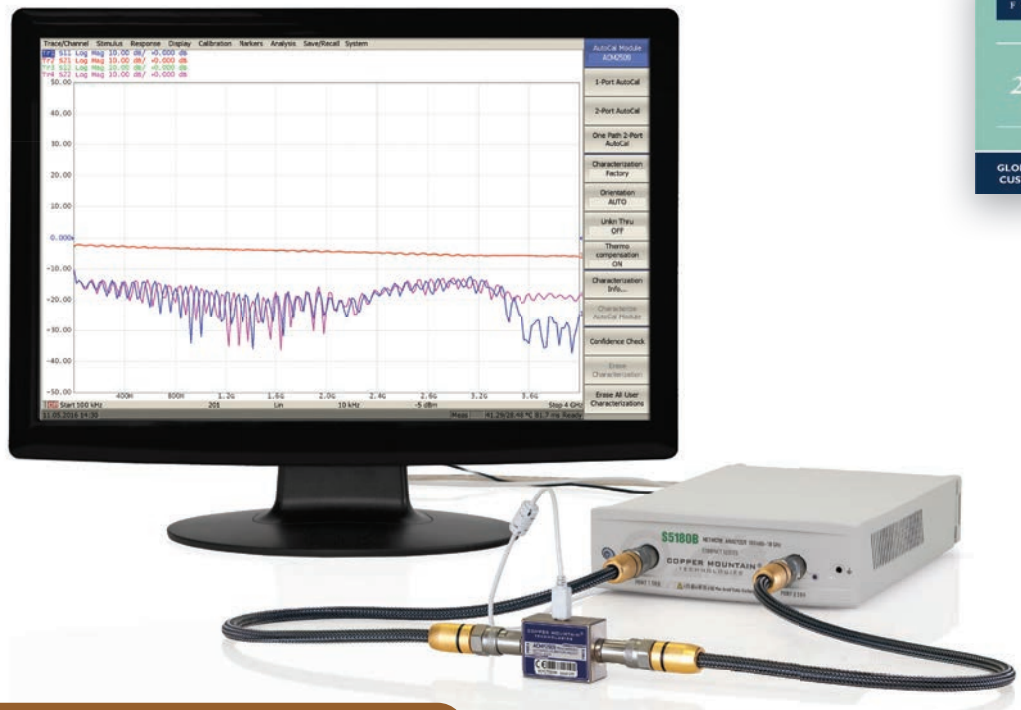

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PCIe Digitizer Cards Deliver Next-Generation Performance

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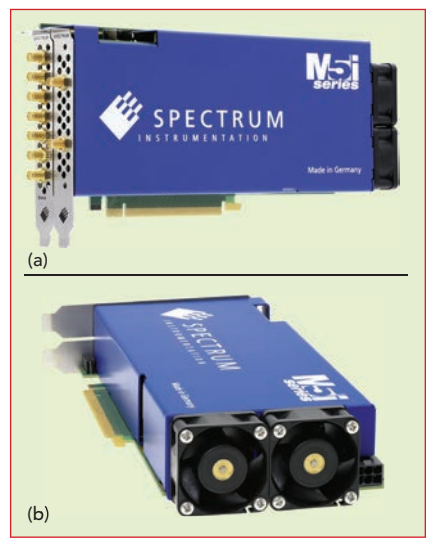
Grosshansdorf, Germany

Spectrum Instrumentation has released two digitizer cards that advance the performance standards in PC-based instrumentation. Using the latest 12-bit analog-to-digital converter (ADC) technology, the cards sample signals at rates up to an impressive 6.4 GSPS. Also differentiating them is the capability to transfer enormous amounts of data over the PCIe bus. Using 16-lane, Generation 3 technology, they stream acquired data at an astonishing rate of 12.8 Gbps. This speed, almost 2× greater than other PCIe digitizers on the market, means they can continuously run at the full 6.4 GSPS sampling rate and seamlessly send acquired data to the PC environment in real time. Once at the PC, the data can be stored or processed using the latest CPUs and CUDA-based GPUs.

The two new digitizer cards are a single-channel 6.4 GSPS card (M5i.3330-x16) and a dual-channel card (M5i.3337-x16). The dual-channel model, shown in ***Figure 1***, offers synchronous 3.2 GSPS sampling on both channels or the full 6.4 GSPS on a single-channel. Designed to handle a wide variety of signals, the digitizer designs use fully functional front-end electronics with > 2 GHz bandwidth, programmable full-scale ranges from ±200 mV to ±2.5 V and variable offset. 12-bit ADCs provide exceptional dynamic range, 16× greater than 8-bit digitizers and most digital oscilloscopes. This higher resolution improves the precision of voltage measurements and enables users to capture and characterize fine signal details often missed by lower resolution devices.

Large on-board memory enables capturing long and complex waveforms. A 4 Gb (2 GS) memory is standard, and it can be optionally expanded to 16 Gb (8 GS). A PLL-based internal clock, with better than 1 ppm accuracy, ensures precise timing measurements over long periods. Waveforms can be acquired in single-shot and multiple recording modes, together with trigger time stamping. Multiple recording divides the on-board memory into segments and supports the acquisition of numerous events,



▲ Fig. 1 **Front-side (a) and back (b) views of the dual-channel digitizer card (M5i.3337-x16), which performs synchronous 3.2 GSPS sampling on both channels or 6.4 GSPS on a single channel.**

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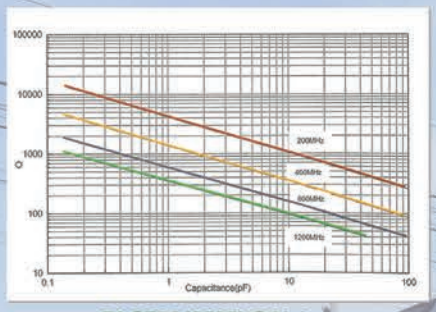
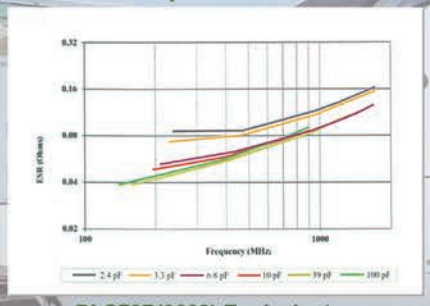


DLC70A(0505) Q Value and Capacitance Curve



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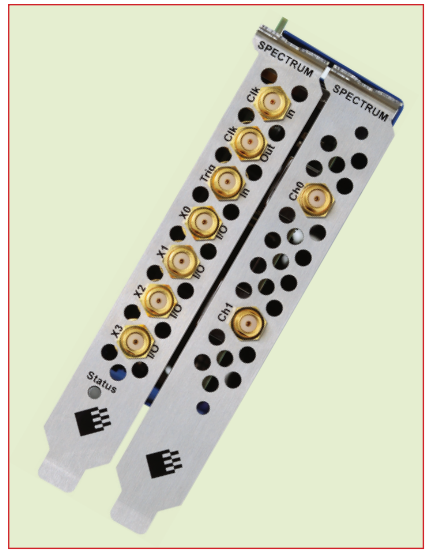
even at very high trigger rates. This is well-suited for situations found in systems using a stimulus-response process, such as radar and LiDAR, or when bursts of information must be acquired, such as testing a fast serial bus. For added flexibility, the on-board memory can be used as a FIFO buffer for continuous streaming of data to the PC environment or as a ring buffer, working much like a conventional oscilloscope.

Transfer speed tests made by Spectrum's design engineers with various PC platforms achieved the maximum speed using an AMD EPYC Model 7252 server processor. Spectrum also tested direct RDMA data transfers at full speed from the digitizer cards to a Nvidia model P2000 GPU. Streaming data directly to a CUDA GPU with up to 5000 processor cores is possible by using Spectrum's CUDA Access for Parallel Processing (SCAPP) package, available as a low-cost option. SCAPP comes with the necessary drivers for CUDA GPU support and lets users develop custom processing routines. Working examples are included for common functions like FFTs for spectral analysis and continuous averaging for noise reduction.

To make integration into a test system fast and simple, the front panel has SMA connectors for the channel inputs, clock and trigger inputs and outputs and four multi-functional digital I/O lines (see ***Figure 2***). The extra clock and trigger connections enable synchronizing the cards with other measurement devices. The cards can be installed in nearly any Windows or Linux PC using most popular programming languages: C, C++, C#, Delphi, VB.NET, J#, Python, Julia, Java, LabVIEW and MATLAB. Each card comes with a software development kit containing all the necessary driver libraries and programming examples. Alternatively, for users who don't want to write code, Spectrum offers SBench 6, a powerful graphical software with a host of capabilities for card control, data display, analysis, storage and documentation.



▲ **Fig. 2 Front panel RF, clock, trigger and digital I/O connections ease integration into a test system.**

The new cards, the first two products in Spectrum's new M5i high performance digitizer family, are the result of two years of research and development. The fast sampling rates with high-resolution and bandwidth make them well-suited for high frequency signal acquisition and analysis. They support applications in fields such as fiber optics, mass spectrometry, semiconductor testing, RF recording and quantum technology. The data transfer speeds enable continuous streaming of data in real time, which opens new applications requiring intense signal processing, such as astronomy and artificial intelligence. Faster data transfer yields improved measurement speed and better productivity, particularly for automated test systems.

The M5i.3330-x16 and M5i.3337-x16 digitizer cards are available now with delivery four to six weeks after receipt of an order. Like all Spectrum Instrumentation products, the cards have a five-year warranty and free software and firmware updates and customer support by the engineering team for the lifetime of the product.

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Compact Noise Sources Provide Flat, Wideband ENRs

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Torrance, Calif.

Noise sources are some of the most versatile devices used to measure and monitor the performance of microwave and mmWave components and systems. As external signal sources, they are commonly used with spectrum analyzers and other test equipment to determine the noise temperature, noise figure or frequency response of individual components and integrated receivers. Also, they are frequently teamed with built-in test equipment in radar, telemetry and communication systems where automatic calibration and system monitoring are required. In most applications, noise sources work best when they have flat and stable spectral characteristics. When they are integrated into mmWave subassemblies, small size is a major consideration.

Eravant's STZ noise sources cover wide portions of the microwave and mmWave spectrum, operating from 500 MHz to 170 GHz and with excess noise ratios (ENR) from 12 to 20 dB. The latest additions to this product family include the -02 and -0T2 series compact noise sources shown in ***Ta-***

TABLE 1

Eravant Compact Noise Sources
(For TTL and Toggle Switch Controls, Use Suffix -0T2)

Model Number	Frequency (GHz)	ENR (dB)	Flatness (dB)	Return Loss (dB)	Output Interface
STZ-05250318-2M-02	0.5–50	18	±2	15	2.4 mm
STZ-05240318-KM-02	0.5–40	18	±2	15	2.92 mm
STZ-05267313-VM-02	0.5–67	13–18	±3	15	1.85 mm
STZ-28-02	26.5–40	18	±1	15	WR-28
STZ-22-02	33–50	18	±2	15	WR-22
STZ-19-02	40–60	15	±3	12	WR-19

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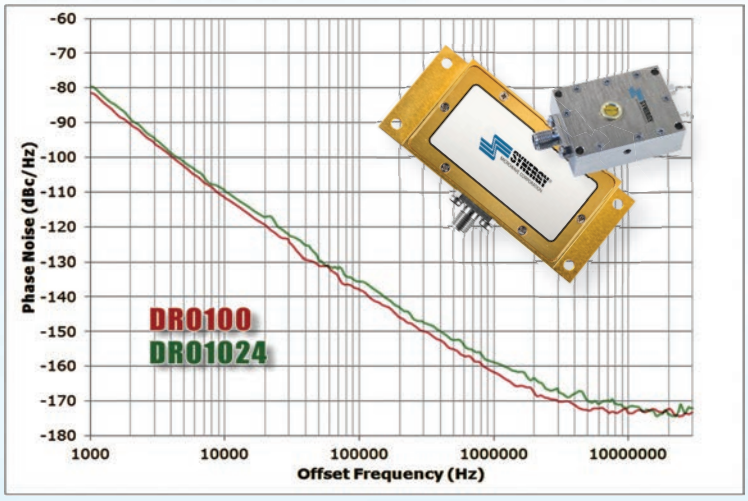

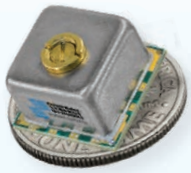

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Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @ 10 kHz (dBc/Hz)
Surface Mount Models				
SDRO800-8	8	1 - 10	+8 @ 25 mA	-110
SDRO800-8XT [1]	8	1 - 10	+8 @ 25 mA	-110
SDRO900-8	9	1 - 10	+8 @ 25 mA	-112
SDRO900-8XT [1]	9	1 - 10	+8 @ 25 mA	-112
SDRO1000-8	10	1 - 15	+8 @ 25 mA	-107
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-105
SDRO1118-7	11.18	1 - 12	+5.5 - 7.5 @ 25 mA	-104
SDRO1121-7	11.217	1 - 12	+5.5 - 7.5 @ 25 mA	-106
SDRO1130-7	11.303	1 - 12	+5.5 - 7.5 @ 25 mA	-106
SDRO1134-7	11.34	1 - 12	+5.5 - 7.5 @ 25 mA	-107
SDRO1140-8XT [1]	11.4	1 - 10	+8 @ 25 mA	-102
SDRO1250-8	12.5	1 - 15	+8 @ 25 mA	-104
SDRO1300-8	13	1 - 12	+8 @ 25 mA	-104
SDRO1400-8	14	1 - 12	+8 @ 25 mA	-102
SDRO1500-8	15	1 - 12	+8 @ 25 mA	-100
SDRO1800-8	18	1 - 12	+8 @ 25 mA	-100
SDRO2000-8	20	1 - 12	+8 @ 25 mA	-98
Connectorized Models				
DRO80	8	1 - 15	+7 - 10 @ 70 mA	-114
DRO8R95	8.95	1 - 10	+7 - 10 @ 38 mA	-109
DRO100	10	1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10.24	1 - 15	+7 - 10 @ 70 mA	-109
DRO1024H	10.24	1 - 15	+7 - 10 @ 70 mA	-115
KDRO145-15-411M	14.5	*	+7.5 @ 60 mA	-100

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Fig. 1 **Noise source STZ-05267313-VM-0T2 operates from 0.5 to 67 GHz and has a high speed TTL trigger input for automated test applications.**

ble 1. They provide flat ENR over wide bandwidths and are housed in small packages that facilitate their inclusion with portable test equipment or in compact hardware. With nominal ENRs of 15 to 18 dB, these noise sources provide calibrated noise power from 0.5 to 67 GHz. Typical ENR flatness is ±2 dB over the operating bandwidth and nominal output return loss is 15 dB for most models. For broadband system testing, ENR flatness is important because correcting or compensating for variations in the noise spectrum can be extremely

Fig. 2 **Noise source STZ-05267313-VM-02 operates from 40 to 60 GHz and has a UG-383/U-M anti-cocking flange.**

challenging. Each noise source includes an integrated attenuator that controls its output impedance and reduces measurement uncertainty from impedance mismatch. The attenuator eliminates the need for a costly external isolator. Each noise source is enclosed in a slim package that measures 4.0 × 1.2 × 0.8 in. and weighs 9.2 oz.

The models with coaxial output connectors cover extremely wide bandwidths: continuous frequency coverage from 0.5 to 40 GHz with a K connector (see ***Figure 1***), 0.5 to 50 GHz with a 2.4 mm connector and 0.5 to 67 GHz with a 1.85 mm connector. Current waveguide output options comprise WR28 (26.5 to 40 GHz), WR22 (33 to 50 GHz) and WR19 (40 to 60 GHz). The WR22 and WR19 versions have anti-cocking waveguide flanges (see ***Figure 2***).

The noise sources are biased with a supply voltage of +28 V and can be modulated by switching the DC power on and off, up to 1 kHz. Models with the -0T2 option have a high speed TTL control input and a toggle switch to support automated test setups, laboratory applications and equipment where the noise source is built in.

Their compact size makes the -02 and -0T2 series noise sources well-suited for the built-in test equipment used in radar, telemetry, radiometry and communication receivers. By including a noise source and a directional coupler in a receiver's front-end signal path, the receiver can perform self-calibration and monitor the health of various system components (see ***Figure 3***). The frequency responses of filters and gain blocks can be verified by injecting wideband noise into the receiver while performing a spectral analysis

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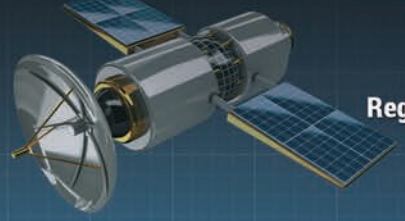

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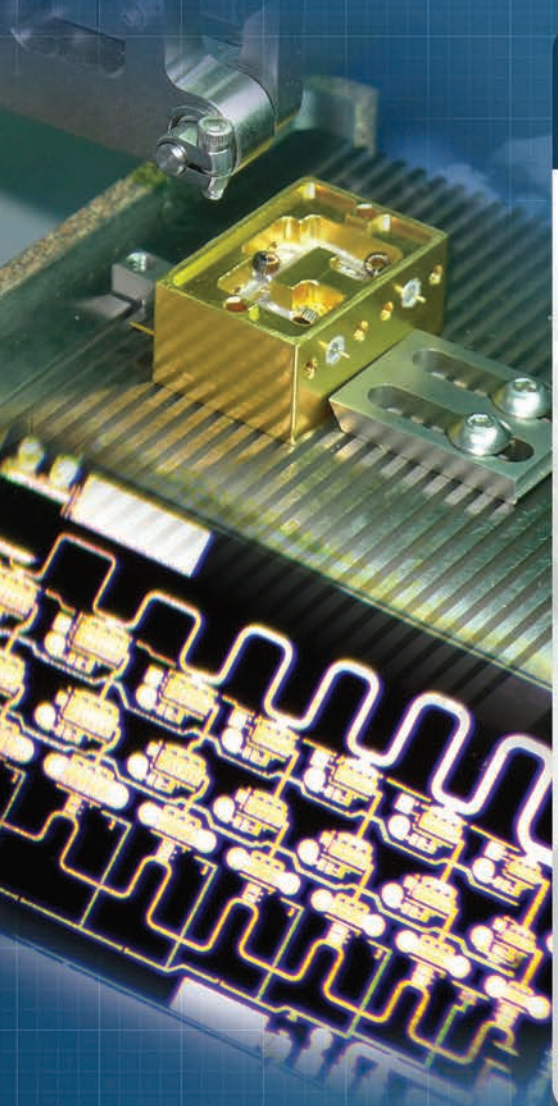

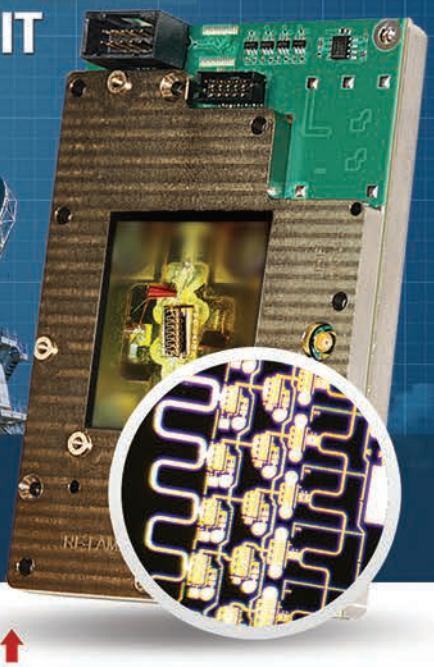

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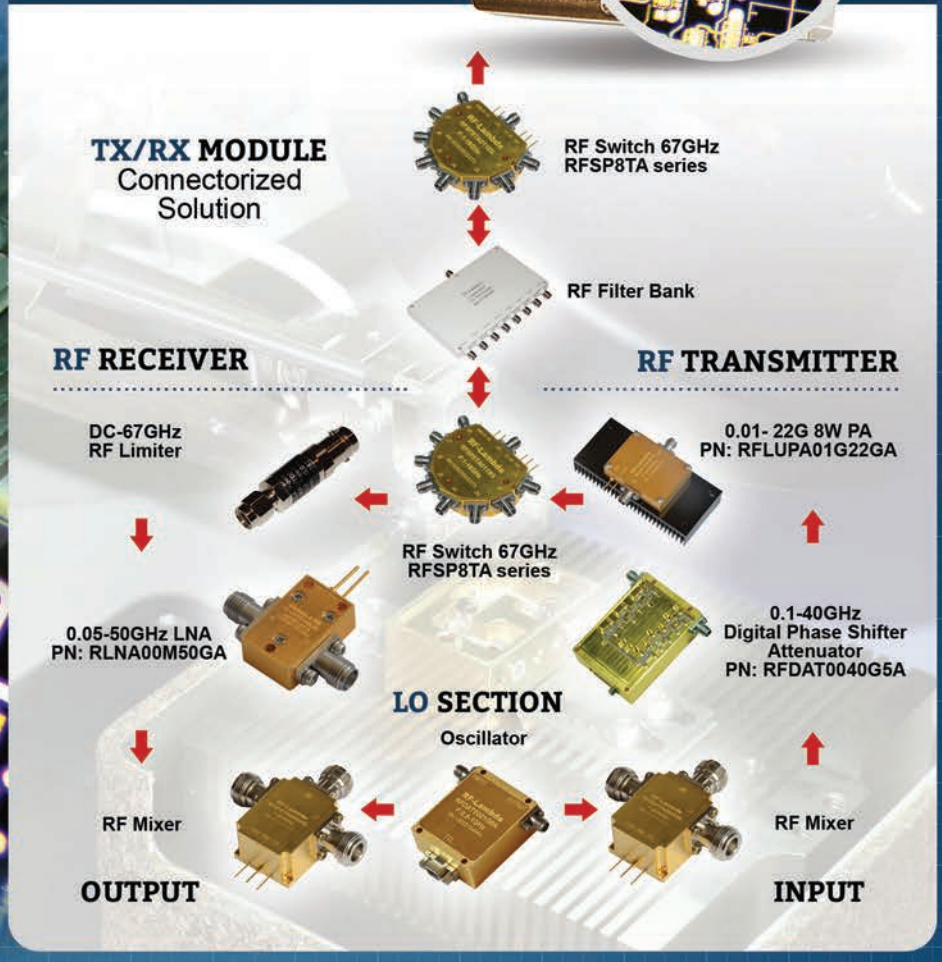

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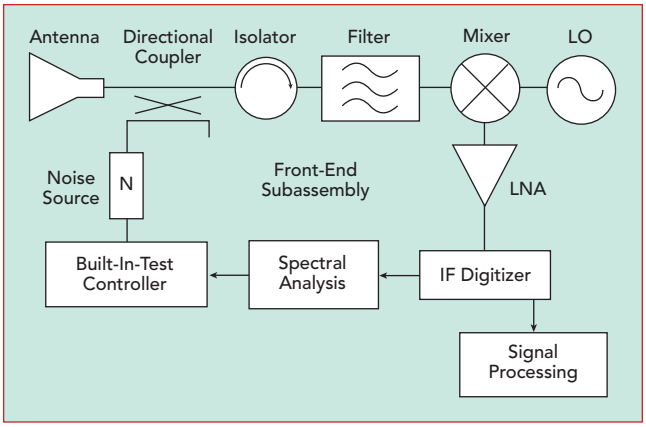
of the down-converted IF signal. Detected noise levels can also be used to reveal elevated local oscillator (LO) noise sidebands, spurious outputs in the LO signal or problems caused by a mixer's limited image or sideband signal suppression.

Noise sources have many other uses. They are frequently employed to measure the bit error rate of digital communication links. By independently varying the power levels of both the signal and noise, the effects of mixer saturation and amplifier compression can be quantified to establish a receiver's dynamic range or estimate its vulnerability to interference under various operating conditions. For measurements that do not require high dynamic range, an amplified noise source can be used with a spectrum analyzer to characterize the frequency response of amplifiers, attenuators, isolators and devices where low insertion loss and relatively flat frequency responses are common characteristics. Such a test system can be used with a pair of transmit and receive antennas to measure the reflectivity of surfaces or the attenuation of signals through materials without requiring a costly tracking signal generator or low loss mmWave transmission lines.



▲ Fig. 3 **Using a noise source for built-in test can calibrate a receiver's response and monitor the health of individual components.**

mmWave noise sources have many potential uses in systems, ranging from built-in test equipment in radar and communication receivers to laboratory instrumentation. By combining excellent ENR flatness with compact, flexible and cost-effective packaging, Eravant's -02 and -0T2 series of noise sources help mmWave system developers cover more spectrum using less equipment. Standard coaxial connectors and Uni-Guide™ waveguide connectors made the compact noise sources more cost-effective by sharing the same package designs to support component and system testing from 0.5 to 67 GHz.

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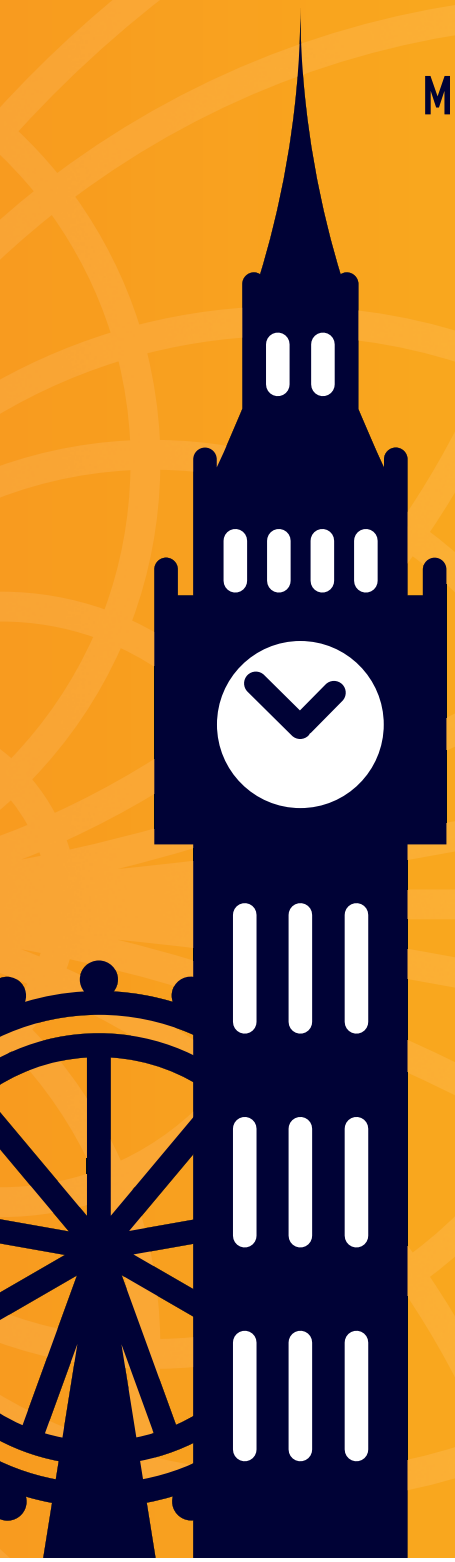

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Real-Time Spectrum Analyzer For Field Testing 4G and 5G FR1 and FR2 Signals

EXFO
Montreal, Canada

5G requires the installation and deployment of many new cell sites and small cells. All must be turned on quickly so operators can deliver 5G services and earn new revenue. As they move to 5G, operators need to support, maintain and test both the new and existing wireless technologies, e.g., 3G, 4G/LTE and 5G NR. At the same time, new bands, cell densification and 5G innovations—beamforming and massive MIMO, mmWave spectrum and CBRS and C-Band—make the RF environment complex to navigate for operators and field technicians. Unresolved, RF issues will impact network capacity, quality of service, the subscriber experience and revenue.

▲ Fig. 1 **The 5GPro Spectrum Analyzer measures the FR1 and FR2 bands and is field upgradeable.**

All this results in significant operational challenges and the need for new and innovative test capabilities. To get the most from their investment, operators need field-focused RF testing that scales and adapts as networks change. To address this requirement, EXFO applied its field-focused expertise to RF testing and created an innovative, modular solution that will adapt as networks transform.

5GPro Spectrum Analyzer

The 5GPro Spectrum Analyzer is the first field technology optimized, scalable RF spectrum analyzer (see ***Figure 1***). Balancing functionality and portability in a compact design for accurate over-the-air (OTA) measurements, it's the only modular, RF testing solution that provides accurate visibility into 4G/LTE and 5G NR environments. This single, field-upgradable solution has the capability to analyze both the FR1 (i.e., sub-6 GHz) and FR2 (mmWave) bands. Designed specifically for field technicians—with simplicity-of-use in mind—the 5GPro Spectrum Analyzer enables users to easily identify and resolve issues and close out jobs faster. The key features and benefits of the 5GPro Spectrum Analyzer are:

- First field-upgradable RF test system, meaning no downtime for factory upgrades
- The industry's only modular RF testing solution, with the option to start with FR1 and add FR2 as requirements change
- "Smart" graphical interface simplifies RF testing and saves time

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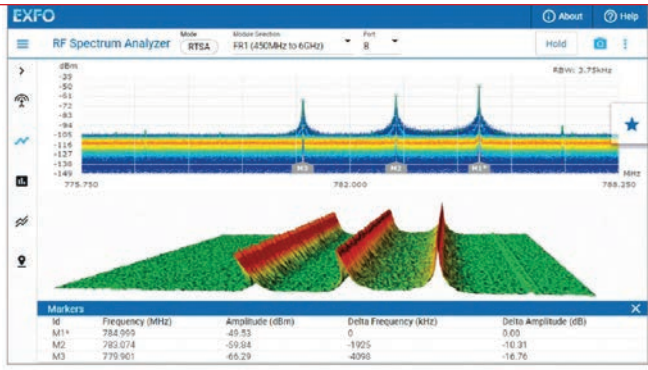

Fig. 2 3D spectrogram in the RTSA mode.

- Real-time spectrum analysis (RTSA) bandwidth to 100 MHz, with 5G NR demodulation and beamforming analysis, time-division duplexing (TDD) and LTE signal analysis
- Integrated with the cloud for centralized management of the workflow and sharing results.

CAPABILITIES

RTSA — The 5GPro Spectrum Analyzer provides RTSA, enabling continuous acquisition of RF signals with 100 MHz of analysis bandwidth. Quick characterization of wireless signals and detection of intermittent interference is possible with the combination of the RTSA persistence and spectrogram views (see ***Figure 2***).

The 5GPro Spectrum Analyzer brings innovation and intelligence to RF testing with a smart user interface featuring built-in expertise and patent-pending features like intelligent peak detection and Snap-to-Peak (see ***Figure 3***). With Snap-to-Peak, field technicians can use the touch screen to identify interferers through a moveable window, enabling them to search for the highest amplitude interferer and attach a marker.

5G NR Signal Analyzer — A 5G NR signal analyzer application demodulates 5G NR signals to validate the OTA performance of cell sites, helping ensure the communications link with user equipment (see ***Figure 4***). The application provides beamforming metrics, analyzing up to 64 beams and displaying the 12 strongest beams with their corresponding power measurements.

TDD Gated Sweep — TDD is a transmission technique where the uplink and downlink signals are transmitted on the same frequency and use independent, synchronized timed intervals. Both spectrum and interference analysis of TDD signals require a measurement technique called gated sweep. It facilitates visualization of the uplink and downlink spectrum by displaying data within a specified range of timeslots.

4G/LTE Analysis — The LTE signal analyzer demodulates 4G/LTE signals to validate the OTA performance of

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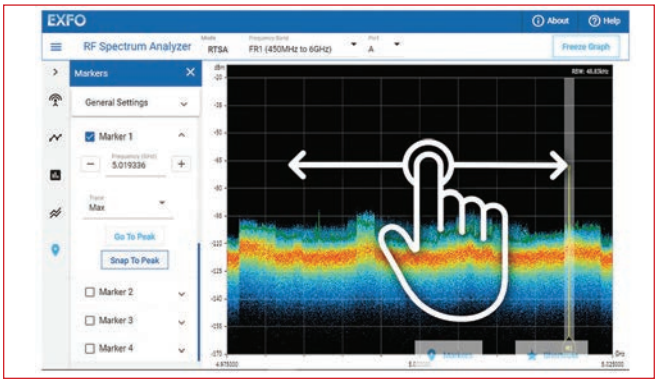

Fig. 3 **Snap-to-Peak feature.**

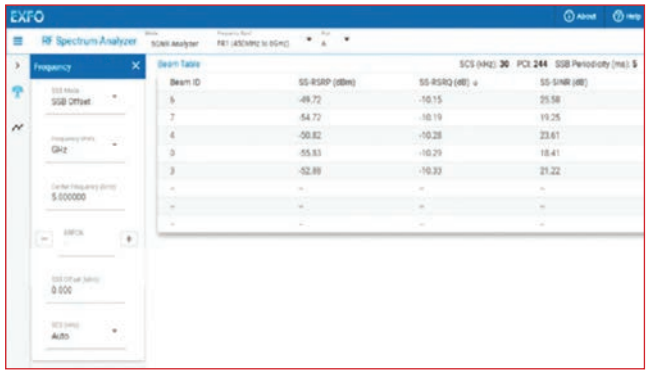

Fig. 4 **5G NR demodulation with beam and signal analysis.**

cell sites and provides key metrics: sector and group ID, physical cell ID (PCI), duplexing mode (frequency or time), RSRP (dBm), RSRQ (dB) and RSSI (dBm).

A SINGLE, COMPLETE TEST SOLUTION

EXFO's 5GPro Spectrum Analyzer is available on the FTB 5GPro Test Kit for a complete all-in-one solution to validate 4G and 5G networks. The FTB 5GPro also supports fiber inspection and characterization, CPRI/eCPRI/O-RAN, RF spectrum analysis over CPRI (iORF), Ethernet (up to 100G) and timing and synchronization with a high accuracy GNSS receiver, making it 90% faster to validate timing accuracy. EXFO's comprehensive solution reduces the number of devices field technicians must carry, speeding jobs and reducing the total cost of ownership for operators and contractors.

There is much more to 5G than increasing the speed of the network. 5G promises revolutionary uses cases that will change the way mobile networks are implemented and used by society. Understandably, this new world brings different challenges in installing, operating and maintaining networks. Operators will require innovative processes and tools to test existing and new technologies and be flexible and scalable to handle what comes next. They must be portable and easy to use, so field technicians and contractors can do more in less time and at a lower cost.

EXFO
Montreal, Canada
bit.ly/5GProSpectrumAnalyzer
1-800-663-3936

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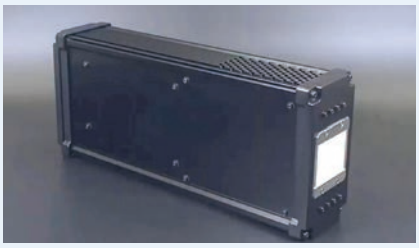

28 GHz Multi-Channel Up-/Down-Converter Module For 5G Prototyping

Tamagawa Electronics has developed a multi-channel mmWave up- and down-converter module for prototyping and testing 5G beamforming. The MMCX module covers 27.5 to 28.5 GHz with 1 GHz instantaneous bandwidth and an IF frequency of 3 GHz. It interfaces with up to 32 antennas. Both analog and digital beamforming are used to create the beams, and both can be used simultaneously. The analog beamforming module controls from four to 32 systems, and the digital beamforming module supports up to eight. The module requires an external 10 MHz sync signal and supports GPS synchronization.

With a nominal IF input to the MMCX of −20 dBm, the RF output power at the antenna port is +5 dBm with approximately −33 dB adjacent channel power ratio, which will support 256-QAM modulation. A multi-antenna array will generate approximately 2 W EIRP. Tamagawa minimized the heat dissipation of the module by integrating the circuitry to reduce the number of components, which also improves performance and reliability.

The antenna connectors are located on the front of the housing, and the outputs are co-located with the antenna connectors and selected via relay. The right side of the unit contains the connectors for controlling the transmit and receive signals and beamformer settings. Eight ports for the up- and down-converter IF signals are located on the back of the module.

Tamagawa Electronics plans to extend the digital beamforming capability to add a software-defined radio (SDR) for beamforming. The SDR will be programmed with predefined antenna patterns as well as supporting custom beams. The MMCX was designed to be customizable, so unique customer requirements can be accommodated.

Tamagawa Electronics' multi-channel mmWave up- and down-converter module provides a flexible and convenient system for prototyping and testing 28 GHz phased array antenna systems.

Tamagawa Electronics
Ayase, Japan
www.tmele.jp/en2020/

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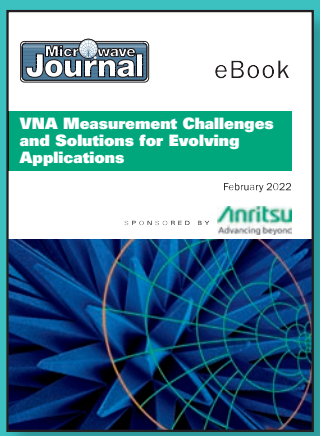

10 MHz OCXO Optimizes Temperature Stability, ADEV and Phase Noise

According to Morion, the MV336R oven controlled crystal oscillator (OCXO) is the only 10 MHz reference optimizing temperature stability, Allan deviation (ADEV) and phase noise. The temperature stability is 2 x 10^{-11} across the -20°C to +70°C range, ADEV is 7 x 10^{-14} over 1 s and phase noise is less than -124 dBc/Hz at 1 Hz offset. ADEV at 10 and 100 s can be specified at 2.5 x 10^{-13} and 4.5 x 10^{-13}, respectively.

Frequency stability over temperature influences ADEV measurements for longer than 3 s intervals. By minimizing the temperature influence on the oscillator, the MV336R enables precise and reliable measurements of ADEVs for 10 to 100 s. Frequency stability with temperature is caused by the temperature dependence of the individual components in the design: ovens, capacitors, inductances and transistors. With thermal modeling, Morion used various circuit and design approaches to significantly reduce the influence of these factors on frequency stability.

Studies of the surface state and optimum power dissipation in a crystal and their influence on close-in phase noise led to a special treatment of the crystal blank's surface. This enabled the OCXO's phase noise and ADEV performance, with significant improvement in the phase noise at 0.1 Hz offset. It is now specified at -94 dBc/Hz.

The MV336 R is free running with a sine wave output; PLL compatible units are available. The OCXO is biased with a 12 V supply and assembled in a 92 x 80 x 50 mm package.

Morion, based in Saint Petersburg, Russia, has developed quartz devices, from blanks to precision OCXOs, since 1930. Morion US is an independent California corporation serving the American market.

Morion US, LLC
San Jose, Calif.
www.morion-us.com
jmeyers@morion-us.com

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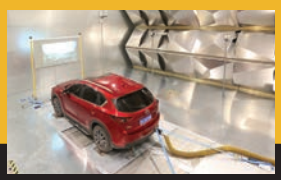
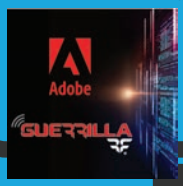


Guerrilla RF and Adobe Partner on Website Enhancements

Guerrilla RF announced it has collaborated with Adobe to deploy its award-winning web applications development platform, ColdFusion, within Guerrilla RF's web development workflow.



Guerrilla RF
www.guerrilla-rf.com

New Intelliconnect Website

Intelliconnect (Europe) Ltd. launched a new website offering visitors easier navigation, improved search facilities, a "Quote Basket," and a new chat facility to assist with sales and technical questions.

Intelliconnect
www.intelliconnect.co.uk

New Video: Learn About Low-Cost, Flexible mmWave Test Solutions

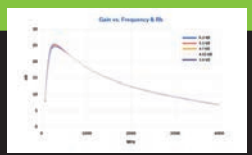
Creators and founders of Millibox, Jean-Marc Laurent and Chinh Doan, talk with *Microwave Journal* Editorial Director, Pat Hindle, about their low-cost, desktop mmWave test chamber with flexible software and 3D positioners.

Millibox
https://bit.ly/330LbeR

Choosing an LNA for your Receiver Front-End

Gain an understanding of why the low noise amplifier (LNA) is so important to the performance of your receiver chain and review the common tradeoffs designers make in choosing the right LNA for a given system.

Mini-Circuits
https://blog.minicircuits.com/choosing-an-lna-for-your-receiver-front-end/



Modelithics Releases COMPLETE Library Version v21.9 for Sonnet Suites

Modelithics announced the release of version 21.9 of the Modelithics COMPLETE Library for Sonnet Suites. This new release includes the addition of 23 new models as well as compatibility with the latest version of Sonnet (v18).

Modelithics
www.Modelithics.com/MVP/Sonnet

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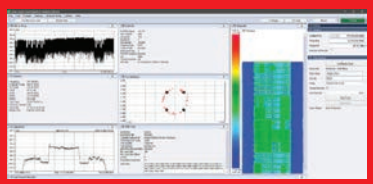
Signal Hound Introduces Free LTE Analysis Mode in Spike

Signal Hound recently updated its flagship Spike software to include LTE Analysis Mode. The addition of an LTE utility to the core spectrum analysis software package, Spike, aligns with Signal Hound's commitment to provide unrivaled value in the test equipment industry.

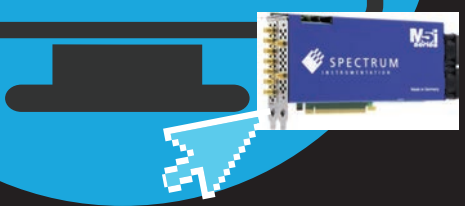
Signal Hound
https://signalhound.com



Web Update with New Digitizers

Spectrum Instrumentation's website has been updated with a new section for PCIe digitizers that deliver massive data streaming at 12.8 Gbps, enabling real-time processing at 6.4 GSPS with 12-bit resolution.

https://spectrum-instrumentation.com/products/digitizer/pf_pci.php



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SV Microwave offers fixed length RF cable assemblies using its most flexible ∅.047" cable yet. This super flexible coax cable is capable of extreme bends which allow it to fit in tight spaces and route for any application.

SV Microwave
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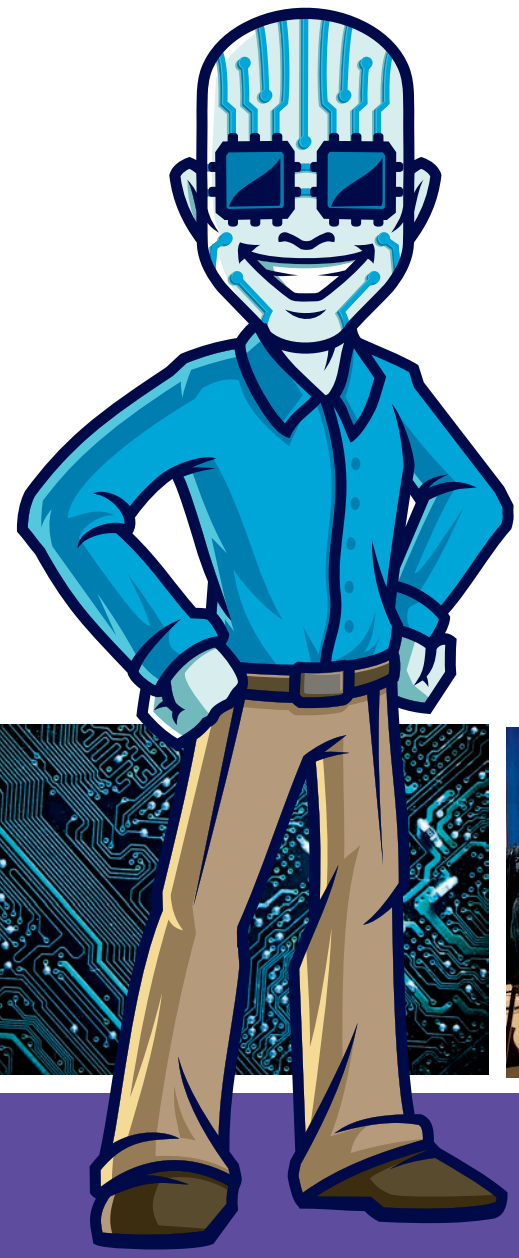

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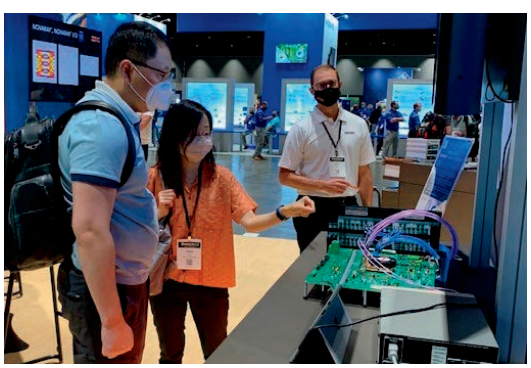

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Analog Devices
www.analog.com

Power Divider

VENDORVIEW

The FMDV1053 from Fairview Microwave is a two-way Wilkinson power divider that operates from 350 MHz to 6 GHz. The power divider has an insertion loss of 0.8 dB and provides over 20 dB of isolation. This divider is available in a module that measures 1.89 × 0.79 × 7.64 in. with SMA female connectors and is ideal for use in communication systems, amplifier systems, amplifier power dividing, aerospace/aviation and defense applications.

Fairview Microwave
www.fairviewmicrowave.com

Directional Coupler

VENDORVIEW

KRYTAR Inc., a leader in the design and production of ultra-broadband microwave components and test equipment, announces the expansion of its line of directional couplers with the addition of a new model offering 30 dB of nominal coupling over the frequency range of 26.5 to 40.0 GHz (Ka-Band), in a compact and lightweight package. The new directional coupler lends itself to wireless designs and many test and measurement applications within K-Band. Ka-Band is typically used for commercial and military satellite communications (satcom).

KRYTAR Inc.
www.krytar.com

High Performance Transformer

The MRFXF0835 is a new high performance 75 ohm 1.8 GHz BW balun with 20 dB RL with only 0.5 dB typical insertion loss. Most transformers performance drop at 1.2 or 1.5 GHz but MiniRF has hit the mark out to 1.8 GHz with its new MRFXF0835. Remarkedly, it is also designed to handle large RF signals to minimize any linearity concerns. All of this in the industry standard .150 x .150 S20 package.

MiniRF
www.minirf.com

Capacitors

Traditional high Q low ESR 0505 (0.055" × 0.055") MLCC's for UHF/microwave RF power amplifiers, mixers, oscillators, filter networks, low noise amplifiers and timing circuits and delay lines. These capacitors are available in two dielectrics (P90 or NP0); three different terminations: magnetic (100 percent Sn - sol-

ERRATUM

In the January 2022 issue, the following changes should be made to the article *Single Antenna Measurement Using Image Reflection:*

1. On Page 95, Equation (9): $\overline{\Gamma}_0=1.128e^{-4}\sqrt{f}-1$ Where f is in GHz.
2. On Page 98, change the two lines above Equation (22) to read as follows: "Ignoring edge diffraction, the forward S_{21} vector will add to the reflected S_{21} by a factor proportional to $L\frac{\lambda}{W}$ where W is the width or height of the reflector and L is the path length. The relationship can be expressed as"
3. On Page 100, Equation (23): $S_{21}= S'_{21} - kL\frac{\lambda}{W}$
4. On Page 100, Equation (24): $k=(S'_{21} - S_{21})\frac{W}{\lambda L}$
5. On Page 102, Reference 4: Change M. H. Hillbun to M. D. Hillbun.

der over nickel plating), non-magnetic (100 percent Sn - solder over copper plating) and tin/lead (90 percent Sn 10 percent Pb - solder over nickel plating); and are designed and manufactured to meet the requirements for MIL-PRF-55681 and MIL-PRF-123.
Passive Plus Inc.
www.passiveplus.com

Quarter-Wave Surge Protectors

VENDORVIEW

The PE73SP1070 is a quarter-wave surge protector that operates from 555 MHz to 4 GHz. The surge protector is designed using a quarter-wave stub design to provide repetitive strike protection for critical hardware while maintaining RF performance. The surge protector is ideal for CBRS networks, cellular, distributed antenna systems, emergency response systems and public safety systems applications.
Pasternack
www.pasternack.com

Absorptive Switch

VENDORVIEW

PMI model no. P2T-2G18G-60-T-SFF-PM-I is a single-pole, two throw, absorptive switch that operates over the 2 to 18 GHz frequency range with a maximum insertion loss of 3 dB; a minimum isolation of 60 dB; input power, +30 dBm maximum (survival) and +20 dBm maximum (operating), VSWR in/out 2.0:1 maximum, phase matching 5 degrees maximum and switching speed of 100 ns maximum. This model is outfitted with SMA female connectors in a housing measuring 1.00" × 1.00" × 0.40".
Planar Monolithics Industries
www.pmi-rf.com

High-Power 3 dB 90-Degree Hybrid Couplers

RLC Electronics has released its latest 500 W cW 3 dB, 90-degree hybrid coupler, which operates from 1 to 2 GHz. The device offers low loss (< 0.5 dB), return loss > 20 dB and high isolation, all while withstanding high average power requirements. Typical applications include power amplifiers, mixers and modulators. RLC can support hybrid coupler requirements up to 40 GHz. These devices are used either to equally split an input signal into two paths with a 90-degree phase shift between them or to combine two signals while maintaining high isolation between them.
RLC Electronics
www.rlcelectronics.com

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mmWave Cable Assemblies

VENDORVIEW

The 110 GHz mmWave cable assembly is built with 1.0 mm precision male connectors and phase stable low loss cable, its featured on low loss, low VSWR, high shielding effectiveness and excellent phase stability over both flexure and temperature, as well as mechanical and electrical stability and consistency, it's the ideal choice for the high frequency mmWave applications up to 110 GHz.
Fujian MIcable Electronic Technology Group Co., Ltd.
www.micable.cn

AMPLIFIERS

RF Amplifier

VENDORVIEW

The AMP2024A-1 from Exodus Advanced Communications is a RF amplifier with

frequency 80 to 1000 MHz, power gain 52 dB, gain flatness 3 dB, P1dB 50 to 51.76 dBm, P1dB 100 to 150 W. Tags: benchtop/rackmount, power amplifier.
Exodus Advanced Communications
www.exoduscomm.com

Solid-State Power Amplifiers

Kratos General Microwave's cutting-edge, field proven solid-state power amplifiers (SSPAs) are designed and built for the harshest environment conditions, including hostile temperatures, shock, vibration, moisture, altitudes and G-forces. The custom and off-the-shelf SSPAs in X-Band and Ku-Band, utilize the latest GaN and GaAs technologies and provide high power density in a compact footprint to meet critical space and weight requirements in high frequencies. All of our SSPAs can be supplied to meet the most stringent environmental requirements.
Kratos General Microwave
www.kratosmed.com

High-Gain Amplifier

VENDORVIEW

Mini-Circuits' model ZVE-453+ coaxial amplifier powers 18 to 45 GHz running on a single supply of +10 to +15 VDC. Typical gain is 32 dB from 18 to 30 GHz and 34 dB from 30 to 45 GHz, flat within ±2.5 dB. The RoHS-compliant 50 Ω amplifier handles as much as +7 dBm input power and provides at least +27 dBm output power at 1 dB compression. It measures 2.86 × 1.73 × 0.68 in. with female 2.4 mm connectors.
Mini-Circuits
www.minicircuits.com

Modular Amplifier

VENDORVIEW

RFMW announced design and sales support for a high power amplifier module from Elite RF. The MB1.08.0G404828 incorporates advanced, state-of-the-art, GaN on SiC technology to deliver 10 W of saturated power from 1 to 8 GHz with a P1dB of 4 W. Biased class AB, the amplifier provides 48 dB of gain and works in CW or pulsed mode to support applications including electronic warfare, commercial and military radar, jammers, satcom, mobile infrastructure, scientific, medical and laboratory use.
RFMW
www.rfmw.com

SYSTEMS/SUBSYSTEMS

mmWave Repeater

WilsonPro's Enterprise 1337R is the first repeater engineered to extend C-Band frequencies and amplify 5G in buildings. The Verizon and AT&T-compatible repeater operates at 3.7 to 3.8 GHz. With time division duplex technology, it automatically synchronizes to the carrier network ensuring reliable coverage. The ideal repeater for amplifying C-Band, the Enterprise 1337R requires no additional backhaul, data plan or recurring fees, and includes secure remote management.
Wilson Electronics
www.wilsonelectronics.com

SOURCES

Clock Oscillator

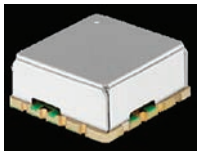
The Y1631 XO is available from 60 to 130 MHz and offers excellent phase noise performance of ± 120 dBc/Hz at a 100 Hz offset (frequency: 100 MHz) and frequency stability vs. temperature of ±15 ppm (-20°C to 70°C). The Y1631XO features a rugged, 17.3 mm square package, Sinewave output and ultra-low acceleration sensitivity of < 0.09 ppb/g. Power supply is 5.0 VDC. Environmentals: random vibration per MIL-STD-202, method 214 and shock per MIL-STD202, method 214.
Greenray Industries Inc.
www.greenrayindustries.com

Lucid RF Signal Generators

9 kHz to 12 GHz, 100 µs tuning times and up to four independent outputs. +15 dBm maximum power makes the LS1291D module great for driving mixers, chamber isolation measurements are easy with the

portable LS1291P, and the multi-channel LS1294B/R eliminate the need for finding multiple signal generators in the lab for mixer, ADC and intermodulation measurements. Plus, easy credit card purchasing and delivery starting at one day.
Tabor Electronics
www.taborelec.com

Frequency Source



The Z-COMM CRO5445X2-LF provides a crystal-clear signal source at 5445 MHz for demanding T&M applications. Phase noise of -105 dBc/Hz at 10 KHz provides the ideal low noise solution as a local oscillator. The tuning range of 5440-5455 MHz is covered by 0.5 to 4.5 VDC, with harmonic suppression of -30 dBc typical. Current consumption is just 24 mA from a 5 Vcc supply. Industry standard 0.5 × 0.5 in. SMT package, available on tape and reel, supports automated production lines.
Z-Communications
www.zcomm.com

ANTENNAS

W-Band Antenna

VENDORVIEW

Model SAY-9239634507-10-U5 is a Cassegrain antenna with nominal gain of 45 dBi and half-power beam width of 0.7 degrees from 92 to 96 GHz. The input port is WR-10 waveguide with a UG-387/U-M flange. The antenna supports linear polarization for indoor and outdoor applications. By removing the mode transition, the input port becomes a 0.094" diameter circular waveguide that supports both linear and circular polarizations.
Eravant
www.eravant.com

Omni Transparent Antenna

The omni transparent antenna is produced by a new nanomesh technique. This allows an operation frequency range from 617 MHz to 6 GHz with a transparency of 95 percent. No cover reduces also less carbon emission and the antenna can be used up to 1 W maximum power. The wide application area enables also integrated designs inside windows. Sensorview offers high-end RF and mmWave antennas that are ideally designed to increase overall efficiencies in 5G network infrastructure, wireless devices, as well as test and measurement.
Sensorview GmbH
www.sensor-view.com

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Arbitrary Function Generator

The SDG7000A is Siglent's next-generation arbitrary function generator. This feature-rich instrument can satisfy all basic needs but also allows to tackle special applications. 1 GHz bandwidth, 500 Mpts memory, high output voltage, differential outputs, optional 16 digital channels and optional 150 MHz IQ-Modulation bandwidth are just the highlights. It also features sequencing for playback of up to 1024 waveform segments and a maximum voltage of 48 Vpp. The well-thought-out and intuitive operating concept seamlessly increase lab efficiency.
SIGLENT Technologies Germany GmbH
www.siglenteu.com

Bookend

The Fiber-Optic Gyroscope, Third Edition

Hervé Lefèvre

This landmark work—considered by many in the field to be THE reference on fiber-optic gyroscopes (FOGs)—provides you with a complete and thorough system analysis of the FOG and remains unmatched by any other single source. Now in its third edition, this fully updated and authoritative book gives you access to all the details you need to know about optics, single-mode fiber optics and integrated optics to fully grasp the design rules of the FOG, helps you understand the concepts that have emerged as the preferred solutions to obtain a practical device, walks you through the advances that have occurred in the last five years since the previous edition was published and how they are implemented in the current FOGs. This third edition features new content on Allan variance, testing with optical coherence domain polarimetry, the Shupe effect and rare-Earth doped fiber ASE sources. This is a must-have reference for anyone working with FOGs, from students and academics learning about the device, to optoelectronics engineers and professionals needing to stay abreast of the current concepts and most recent advances.

Contents

Introduction; Principle of the Fiber-Optic Gyroscope; Reciprocity of a Fiber Ring Interferometer; Backreflection and Backscattering; Analysis of Polarization Non reciprocities with Broadband Source and High-Birefringence Polarization-Maintaining Fiber; Time Transience-Related Non reciprocal Effects; Truly Non reciprocal Effects; Scale Factor Linearity and Accuracy; Recapitulation of the Optimal Operating Conditions and Technologies of the I-FOG; Alternative Approaches for the I-FOG; Resonant Fiber-Optic Gyroscope (R-FOG); Conclusions.

About the Author

Hervé Lefèvre is chief scientific officer of iXBlue in France. He earned his doctorate in optics-photonics from the University of Paris-Orsay in 1979. His doctorate research was performed at Thales (formerly Thomson-CSF) Central Research Laboratory and his thesis subject was pioneering work on the fiber-optic gyroscope.

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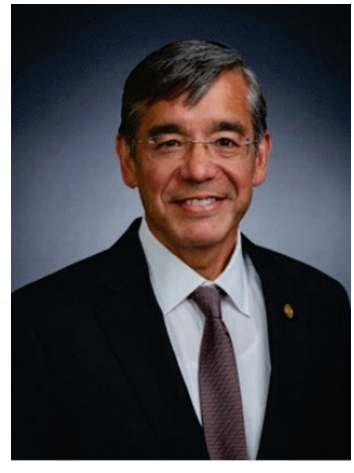

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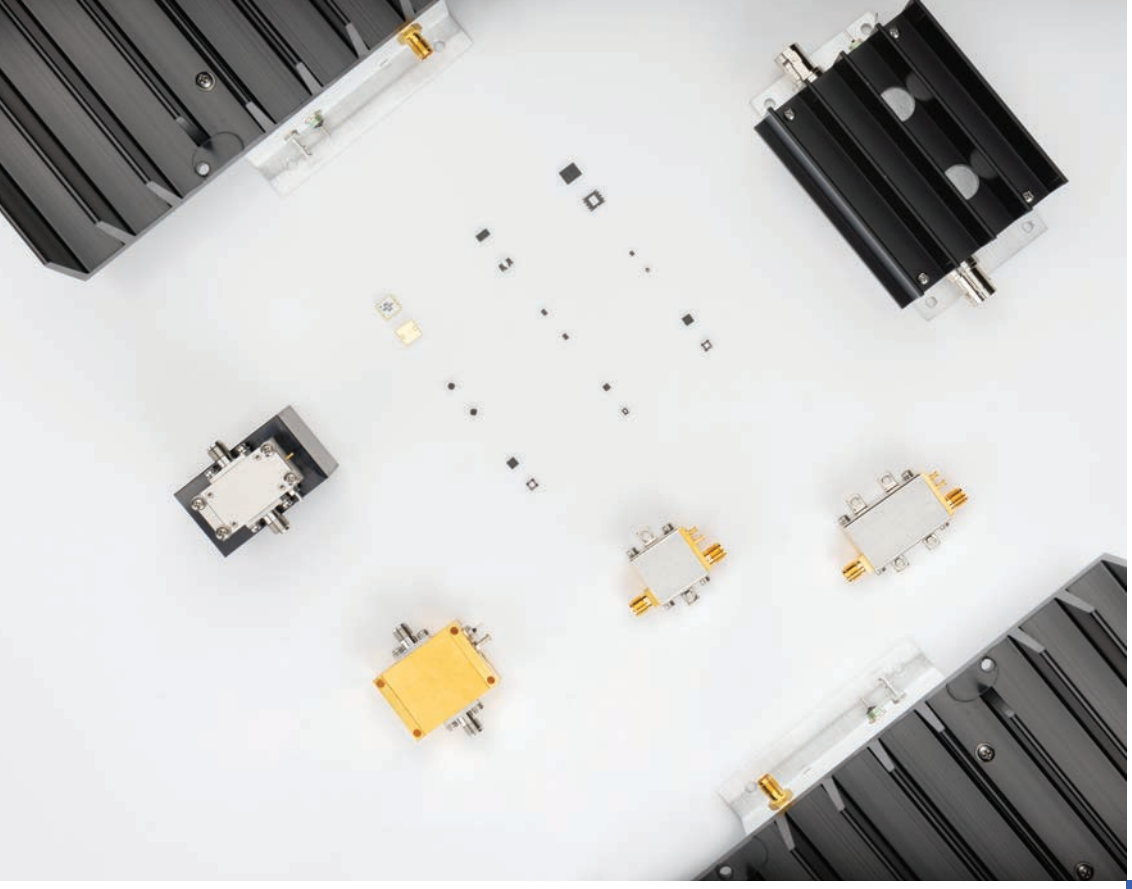

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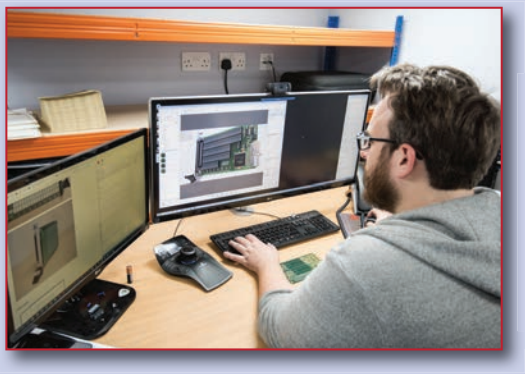
Pickering Interfaces: Leadership in Modular Switching Systems



Imagine a switch matrix containing some 4,000 RF switches. That's an example of the complexity of the switching systems developed by Pickering Interfaces, a leader in modular signal switching for electronic test.

The Pickering story starts in the U.K. in 1968, when John Moore formed Pickering Electronics to build high-quality reed relays for switching systems. Automatic test equipment (ATE) became a large market for its products and a source of significant growth. This led Keith Moore, John's son, to launch Pickering Interfaces in 1988. It was an intentional step up the supply chain to modular switching systems. The first product, System 10, was a 3U system controlled via the General Purpose Interface Bus (GPIB). Many more products followed, mirroring the evolving standards and form factors of modular test systems, from GPIB to VXI, then PXI, LXI and USB.

In 2003, Pickering's first RF instrument modules were released. Today, the company's RF/microwave matrices and multiplexers support the PXI, PCI and LXI standards, with upper frequency coverage to 67 GHz. RF multiplexers use reed relay, electromagnetic relay (EMR) and solid-state switches, depending on the frequency and application. All of Pickering's PXI RF products operating above 3 GHz are also available in the higher bandwidth PXIe format.

Pickering has an extensive catalog—more than 1,000 PXI modules and more than all the combined products from its competitors—which reflects its willingness to serve a customer's unique needs. Pickering says it fits the product to the customer rather than forcing the customer to fit the product. Custom designs are added to the catalog to be available to other customers or be the starting point for a new custom design. Pickering is largely vertically integrated, designing and manufacturing nearly all the components used in its test systems. This capability enables it to develop custom designs quickly.

Beyond the switching hardware, Pickering offers simulation hardware to simulate sensors used for temperature, altitude, strain and position. They also offer application software and simulation tools to support customers designing and implementing switching systems. Simulation tools enable programming and testing system software without the actual hardware. Drivers for LXI and PXI systems are offered in all popular programming languages. Applications cover test sequencing, switch path management, diagnostic testing and cable design. Pickering also offers a cable design and manufacturing service for companies wanting a turnkey solution.

Pickering stands behind its products, offering a three-year warranty and supporting its systems for 15 to 20 years. This is important because of the longevity of most ATE systems, particularly those used on military programs. Pickering is active in the industry organizations that define modular test standards, needed to ensure interoperability among all companies' products. Pickering joined the PXI Systems Alliance in 1998 and the LXI Consortium in 2005, chairing the LXI technical committee in 2007. Bob Stasonis of Pickering served as president of the PXI Systems Alliance twice, most recently from 2018 to 2021.

Pickering's headquarters is in Clacton-on-Sea in the U.K., where it also designs and manufactures hardware. A second manufacturing site is in Bystřice, in the Czech Republic, which is also the hub for software development. A global customer base and demand from multiple markets—automotive and transportation, aerospace and defense, semiconductor manufacturing and RF—are fueling the company's continued growth.

Pickering remains privately owned and singularly focused on its mission to provide high-quality modular signal switching systems. Its formula for success is to design, deploy and sustain the customer throughout the ATE life cycle. Whether high voltage, high current or high frequency—the toughest test challenges—Pickering aims to be the preferred partner for ATE.

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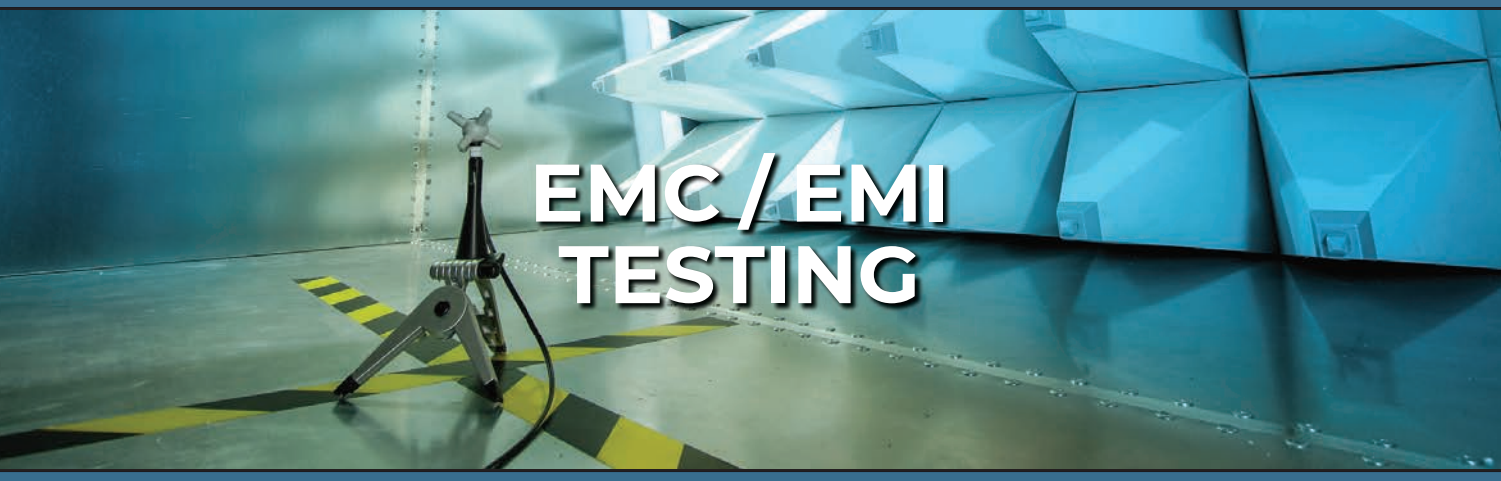

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C8731	Dual	0.009-250	1000	40	0.40	N-Female	10.5 x 3.0 x 2.0
C11462	Dual	0.009-400	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
C8510	Dual	0.009-1000	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
C5047	Dual	0.01-100	4,000	50	0.15	7/16-Female	10.0 x 4.16 x 3.5
C1979	Dual	0.01-100	10,000	60	0.10	LC-Female	2.0 x 6.0 x 4.5
C5086	Dual	0.01-250	250	40	0.50	N-Female	5.2 x 2.67 x 1.69
C5100	Dual	0.01-250	500	40	0.40	N-Female	10.5 x 3.0 x 2.0
C5960	Dual	0.01-250	1,000	50	0.40	N-Female	10.5 x 3.0 x 2.0
C1460	Dual	0.01-250	2,000	50	0.15	N-Female	10.0 x 3.0 x 2.0
C4080	Dual	0.01-250	3,500	50	0.20	N-Female	10.0 x 4.6 x 3.5
C11026	Dual	0.01-220	5,000	60	0.10	LC-Female	12.0 x 6.0 x 4.5
C8390	Dual	0.01-250	10,000	60	0.10	LC-Female	12.0 x 6.0 x 4.5
C5339	Dual	0.01-400	200	40	0.50	N-Female	5.2 x 2.67 x 1.69
C6047	Dual	0.01-400	500	40	0.50	N-Female	5.2 x 2.67 x 1.69
C2630	Dual	0.01-1000	100	40	0.60	N-Female	5.0 x 2.0 x 1.51
C6021	Dual	0.01-1000	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
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
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Cables & Connectors

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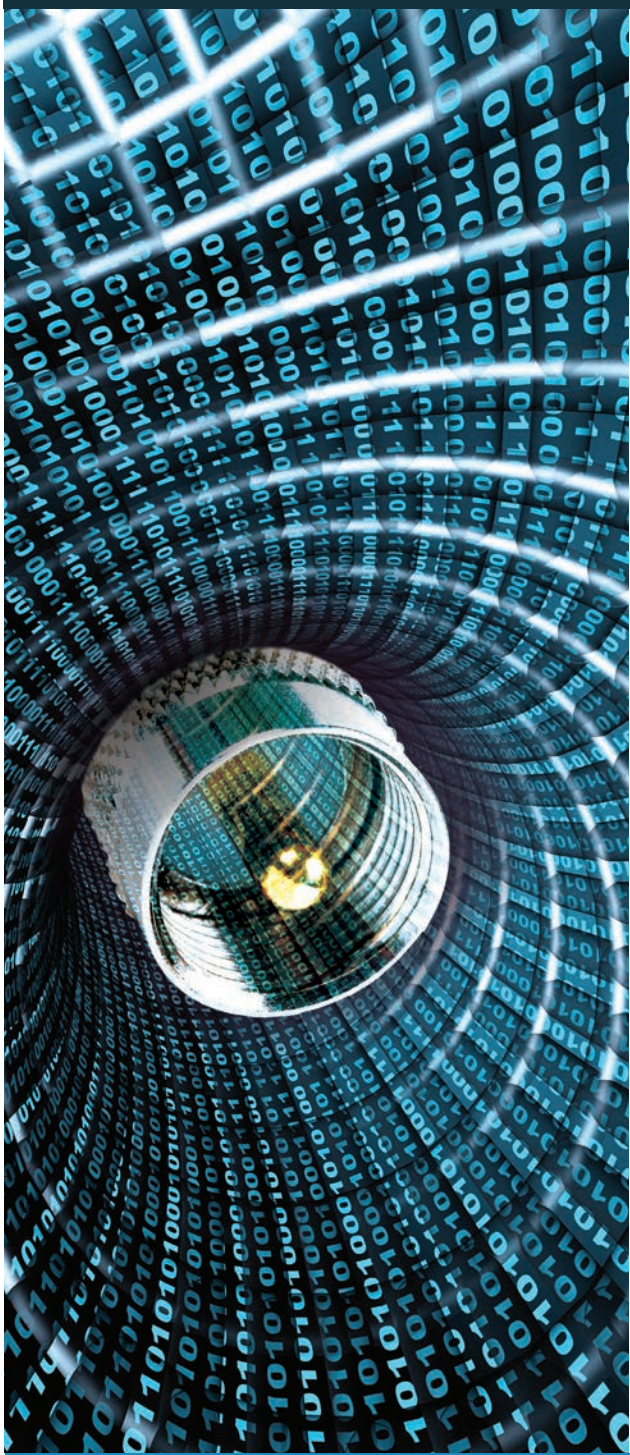

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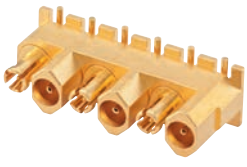

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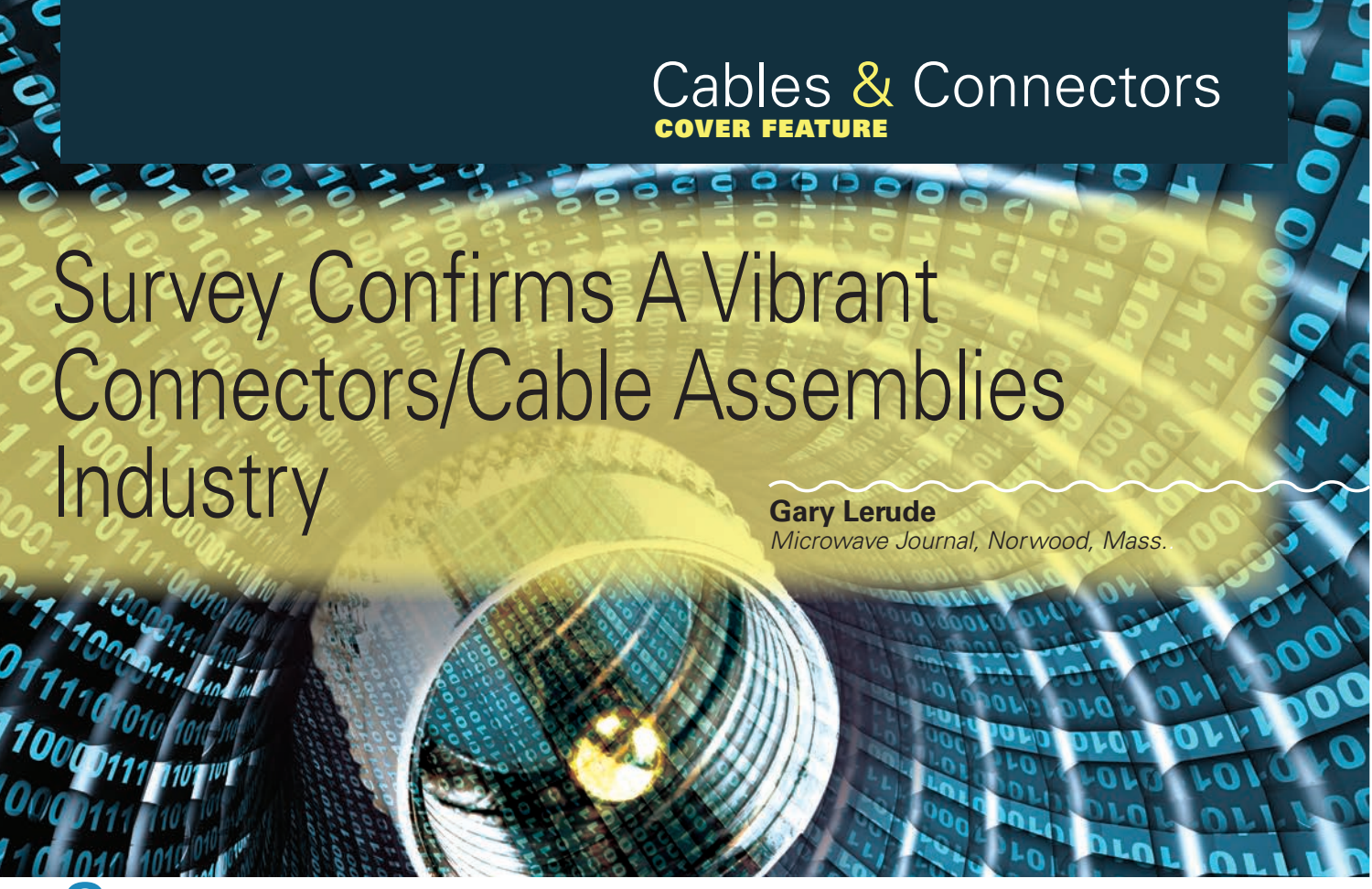
Survey Confirms A Vibrant Connectors/Cable Assemblies Industry



Gary Lerude
Microwave Journal, Norwood, Mass.

Other than waveguide, connectors and cable assemblies are probably the most mature category of RF, microwave and mmWave components. Yet connectors and cable assemblies do evolve, driven by performance requirements for higher frequency and higher power operation, low passive intermodulation (PIM) distortion, rugged environments and shrinking system size.

For this issue of *Microwave Journal's* longstanding Cables & Connectors (C&C) supplement, we thought readers would find a survey of manufacturers informative, to see how markets are shaping these RF interconnects and how the industry fared during the pandemic. We invited 17 companies in Europe and the U.S. to respond to our questions; 10 did so: CAES, Gore, HASCO, Maury Microwave, Mini-Circuits, Molex, Pasternack, Samtec, Southwest Microwave and SPINNER.

Our questions and company answers follow. We've edited and consolidated some of the responses to keep the article concise and summarize common themes.

HOW HAS DEMAND FARED DURING THE PANDEMIC?

While some markets suffered from lower demand because of the pandemic, most respondents reported either a temporary decline or overall growth in business.

Illustrating this, **CAES** saw demand from test and measurement (T&M) slow, attributed to less lab work as engineering teams began working from home during the early months of the pandemic. However, aerospace and defense cable assembly revenue grew 5 to 7 percent over the past two years, reflecting demand from aircraft and land-based ELINT and SIGINT systems.

Similarly, **Maury Microwave** reported the pandemic impacted customers differently, largely reflecting country and company policies. "Many companies reduced access to their labs, which in turn lowered the need to replace cable assemblies. Others went full-speed ahead and doubled or tripled their annual purchases as programs came online or new manufacturing sites opened." Overall, Maury's cable assembly business grew.

Echoing the same theme, **Molex** saw demand from the telecom and broadband segments increase, reflecting the abrupt shift to working from home and remote schooling. Automotive demand dipped during the second quarter of 2020, then ramped up the following quarter and has remained strong. Molex said it "shipped more coax cable assemblies at the end of 2020 and throughout 2021 than ever before," with 2022 demand from equipment manufacturers and harness tiers remaining "extremely strong."

Gore, **HASCO**, **Pasternack** and **Samtec** reported steady demand during the pandemic. Samtec has seen a strong reception for its new mmWave cable assemblies, which reach 50 and 67 GHz. **SPINNER** said it saw no effect on demand from the pandemic; its sales grew some 20 percent in 2020.

HAVE YOU BEEN AFFECTED BY SUPPLIER LEAD TIMES OR SHORTAGES?

While the pandemic didn't hurt demand, did it hurt the supply chain for connectors and cable assemblies? Yes. Most of the companies did see shortages or increased lead times on materials and were managing their supply chains to minimize disruptions to customers.

The exceptions: **Southwest Microwave** said it did not experience extended lead times or supply shortages, perhaps because of its manufacturing model and customer demand declined. **Pasternack** said it was not adversely affected because of its "availability model where we always have stock available for same-day shipping," including

GORE-FLIGHT microwave assemblies developed for airframes and low EMI applications.

finished assemblies and components to build assemblies. Similarly, **Mini-Circuits** said its operating model of stocking inventory helped it avoid supply chain delays hurting customers. "In our experience, interconnect products are often spur of the moment purchases. Customers get into the lab and realize they're missing the right cable or adapter for their test set-up, and they need it fast, so we've always maintained stock and availability of these parts to be prepared for those situations." **Maury Microwave** said its inventory strategy enabled it to offer "thousands of cable assemblies and tens of thousands of adapters from inventory or with short lead times."

As **Samtec** is vertically integrated, internally manufacturing its cable and many components, it has more control than many companies. While it experienced some lead time issues with external suppliers, they were not "major disruptors to our ability to service our customers." For **Molex**, its long-term supply agreements "have worked in our favor," although lead times on some resins increased, causing shortages and additional logistics costs. While some suppliers claimed force majeure, Molex avoided passing those on to its customers.

CAES said global shutdowns increased lead times for raw materials, delaying deliveries by one to two months and, for some specialty products, three to four months. **SPINNER** said it had difficulties with some suppliers, especially those in Asia. **HASCO** also said lead times for raw materials "have increased substantially over the past 18 months." Reframing the challenge to a positive outcome, HASCO said it "created new opportunities to develop new supplier relationships and introduce alternate product lines" to support customers.

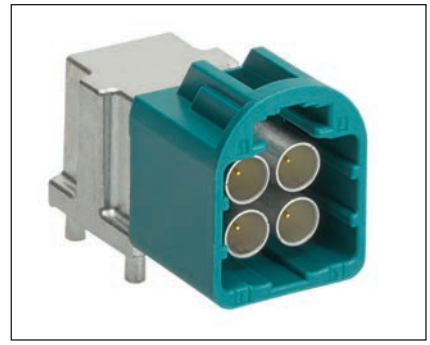
5G DEMAND

For several years, the hottest market has been 5G, adding bands to the sub-6 GHz spectrum and commercializing mmWave frequencies for mobile phones. We wondered how this has shaped RF/microwave cable assembly development. With many of the new 5G bands below 6 GHz, a spectrum well covered by RF/microwave components, the connector and cable assembly suppliers were already well positioned, as confirmed by our respondents. Yet sub-6 GHz 5G poses new challenges.

To achieve the higher data rates promised by 5G, base stations are adopting massive MIMO (mMIMO) architectures that multiply the number of transmit and receive channels compared to LTE MIMO base stations. This increase in channels leads to more volume for cable assemblies and connectors; however, operator demands to minimize the size and weight of base stations means smaller, multi-port interconnect systems, with lighter and smaller cable assemblies needed to fit in tight spaces. The connector interfaces must be able to handle many connect/disconnect cycles without degrading electrical performance.

Gore and **Molex** both cite the importance of the cable assembly in minimizing electromagnetic interference (EMI). Gore notes that 5G operates in bands very close to those used by aircraft survivability equipment, navigation and communication systems. Spectrum congestion can create interference with systems critical for the safe operation of aircraft—witness the concern over 5G use at C-Band and possible interference with aircraft altimeters. "It is even more crucial for airframe microwave/RF cable assemblies to be properly shielded from EMI. Maintaining signal integrity in these challenging environments is critical for the reliability of the aircraft's electronic systems," says Gore.

The allocation of mmWave bands for 5G has opened a new market for cable assemblies and connectors, although **Southwest Microwave** and **SPINNER** offered mmWave cable assemblies prior to the arrival of 5G. **Molex** and **Samtec** are starting to see interest in mmWave cable assemblies. Molex says although "mmWave deployments are fewer than anticipated," it has "many development projects with strong customer interest in this area."



Molex FAKRA mini interconnect, used to carry radar, camera and LiDAR data in a vehicle.

Samtec says it has "slowly seen some new mmWave applications" between 30 and 40 GHz. With 5G eyeing bands to 56 GHz, **CAES** sees the need to extend the frequency coverage of low loss, phase-matched cable assemblies for base stations and T&M systems.

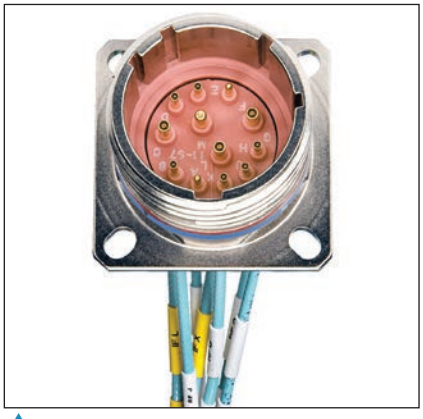
In addition to the electrical performance, **Gore** says customers need "extremely robust and rugged assemblies that can provide consistent performance and reliability over time." With all the attention on deploying systems in the field, we sometimes overlook that 5G systems must first be tested. **Maury Microwave** cautions that the testing requirements for 5G and the newest Wi-Fi standards "are so demanding that even the best cable assemblies can impact measurement results." Combining Maury's T&M cable assembly and test system expertise, it has focused on quantifying the uncertainties of 5G and Wi-Fi measurement systems. Using that insight, it can improve its own cable assemblies and help companies understand the error contributions from each system component on the measurement results to ensure accurate characterization of their products.

ABOVE 5G

5G is not the only market tapping the mmWave spectrum. Point-to-point radio links and automotive radar came before 5G, and 60 GHz has long been promoted for personal area networks and is being used in several locales for short-range fixed wireless access. Some researchers, already bored with 5G, have started working on 6G, eager to tap the unlimited bandwidths above 100 GHz. Will cable assemblies support these applications or will we see a resurgence of waveguide?

HASCO has extended its active and passive products to 110 GHz to support emerging applications such as synthet-

Samtec 1.35 mm cable assemblies and connectors support applications to 90 GHz.



Southwest Microwave custom multi-port cable assembly.

ic radar, communications and defense. Encouragingly, **SPINNER** notes a surge in demand for connectors, adapters and cable assemblies between 40 and 90 GHz. **Samtec** is also bullish on these new bands, developing products for the 40 to 90 GHz range, particularly 80 to 90 GHz. Samtec recently released a 1.35 mm family including compression-mount board connectors and flexible .047 cable assemblies offering 1.35 mm male or bulkhead female connector options. Looking higher, it is developing 1.00 mm cable assemblies to reach the 110 GHz benchmark.

Pasternack says it is betting on cable assemblies and waveguide, investing in test equipment and components to build both. Like Pasternack, **Mini-Circuits** sees the demand for mmWave and sub-THz applications "growing fast," particularly in T&M, which necessarily leads market development. Responding to these opportunities, the company says, "We've invested heavily in the design talent and facilities to expand our portfolio for cables, adapters and attenuators, as well as other connectorized products, including amplifiers up to 110 GHz." Mini-Circuits has launched its first waveguide to coax adapters and plans to build out its selection of waveguide products.

Molex has a strong position in automotive, particularly automotive antennas, and worked with Rosenberger to develop the High-Speed FAKRA Mini interconnect, which has 20 GHz bandwidth for relaying radar, camera, LiDAR and sensor data throughout the vehicle. Since the automotive market has not yet adopted mmWave for communications, Molex is working on mmWave sensing applications while developing the capability for mmWave communications, borrowing technology from its capabilities in base stations.

Both **CAES** and **Gore** are researching ways to serve market needs at these higher frequencies, CAES examining novel structures and new materials for designs above 60 GHz. Vertically integrated from R&D through manufacturing, Gore is exploring cable materials and connector options to extend frequency coverage, working with customers to ensure the new test assemblies will meet Gore's standards for accurate, reliable and repeatable measurements.

DEFENSE MARKET TRENDS

Microwave Journal asked about defense market trends and new requirements from military systems. **CAES** provided a list of emerging requirements for interconnects:

- Multi-function assemblies requiring multi-function interconnect mating: video, RF, microwave, mmWave and analog/DC cables packaged in multi-pack configurations
- Interconnects capable of hypersonic environments, i.e., able to withstand high shock and high temperature
- Smaller and lower weight interconnects for military and space systems, particularly low Earth orbit (LEO) applications.

Molex sees requirements for cable assemblies for surveillance systems and military communications. **Gore** cited upgrades to radar warning receiver, airborne electronic surveillance, countermeasure systems and other electronic warfare systems that include upgrades to the RF, microwave and mmWave components. Common themes from these upgrades are higher power, higher frequency and higher density coax assemblies for airframes.

Pasternack endorses the need for higher frequency coverage and size reduction to accommodate more compact footprints. Higher port count array antennas are driving custom compact interconnects, including edge-mount and spring probe connectors. Likewise, **Samtec** sees increasing need for higher frequency operation, to 110 GHz, and dense connector packaging, such as ganged SMPM board-to-board and cable-to-board products for phased array antennas. Samtec is also researching ways to make waveguide assemblies more flexible and cost effective.

COMMERCIAL SPACE

The commercial LEO satellite market is growing, enabled by lower cost rocket launches and less stringent requirements for lower orbit operation. We asked how this opportunity is changing the requirements for cable assemblies and influencing product development.

CAES noted requirements for higher frequency coaxial solutions with novel interfaces and very low RF susceptibility. These add to the standard requirements for ruggedness, small size, light weight, low insertion loss and, in some cases, phase-matched sets. Commenting on the need for higher frequencies, **Samtec** is seeing demand for cable assemblies for the 40 to 50 GHz band to complement the other satellite bands in use. The company is also developing cable assemblies to meet more stringent environmental requirements for future applications.

Southwest Microwave said it is seeing opportunities to support LEO satellites, as it is "well known in the

Pasternack low PIM cable assemblies.

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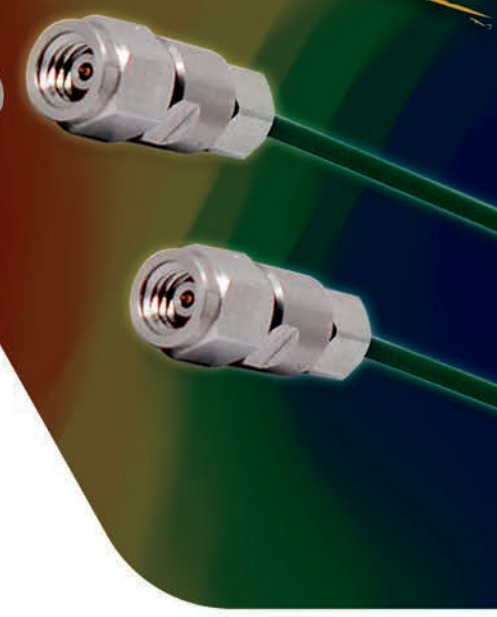
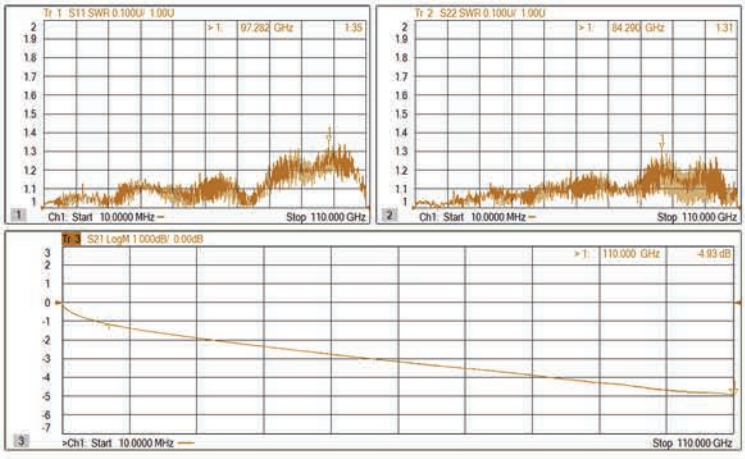


- **Cable Loss** <15dB/m@110GHz
- **VSWR** <1.50@110GHz
- **Shielding Effectiveness** <-90dB
- **Amplitude Stability vs. Flex.** <±0.1dB@110GHz
- **Phase Stability vs. Flex.** <±8°@110GHz
- **Phase Stablity vs.Temp.** 400ppm@-40°C~+70°C
- **Wire Diameter** 1.42mm w/o armor , 3.0mm w/ armor

Applications

- Connections of module to module or rack to rack
- Various test systems
- Temperature cycle test in chamber
- Military & commercial millimeter wave equipment

VSWR



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space industry for being able to supply great performance with very small footprint." **HASCO** noted that it has seen increasing demand for waveguide assemblies for satellite constellations such as Starlink. **Pasternack** added the need for cable assemblies for the RF/microwave components in the satellite ground stations, which link the LEO constellations to terrestrial communications networks.

THREAT OR OPPORTUNITY?

We asked whether so many systems becoming multi-beam phased arrays requiring over-the-air (OTA) testing was a threat to the C&C market. The companies that responded actually see OTA testing as an opportunity.

CAES said wireless testing increases cable demand, with multi-function chip sets requiring more complex testing and interconnects between the chip set and measurement system. **Gore** has a similar view, "It is an opportunity for high performance microwave/RF cable assemblies to reduce test scheme complexities and increase throughput." Gore offers the example of high volume OTA testing inside a test chamber, a set-up using long cable assemblies "that must be very stable and have very low VSWR to ensure repeatable and reproducible test results."

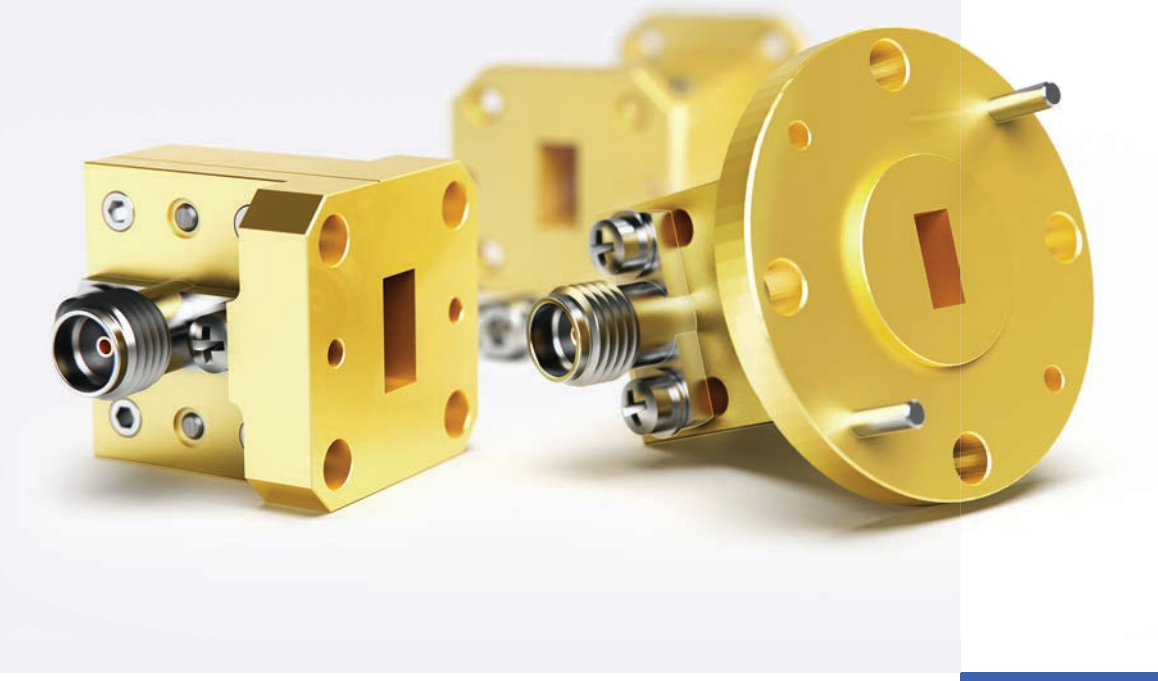
Molex looks behind wireless OTA testing to the backbone infrastructure, which must have high data rate coaxial connections. **Pasternack's** view is that OTA test systems still require interconnects, more than in the past because of high element phased array antennas and the test equipment ports to measure them. Given all these ports, **HASCO** sees the opportunity to develop more robust cable lines with shorter lengths and smaller diameters to reduce system and test space and weight. **SPINNER** reminds us that the test equipment for wireless systems must be pre-qualified and calibrated to eliminate linear errors and improve measurement accuracy.

▲ SPINNER waveguide to coax adapters cover V-, E-, W- and F-Bands.

THE FUTURE

We asked the companies to share the opportunities they see on the horizon, wondering if quantum computing is one of those.

CAES listed several opportunities: 1) Hypersonic airframes with the challenges of high temperature, high G and high shock. 2) mmWave active phased arrays for LEO constellations, with the need for novel interconnects.



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WR22-VFR+	2.4mm-F to WR22	33 to 50	1.19:1	0.25
WR28-KFR+	2.92mm-F to WR28	26.5 to 40	1.10:1	0.15

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3) ELINT and SIGINT systems pushing broader bandwidth and low loss. CAES is monitoring quantum computing, which requires low temperature and low loss interconnects, and has not yet decided whether to engage in this market.

Gore remains committed to its core mission, precision testing of mission-critical electronic systems, and will apply its capabilities to serve new markets as they develop.

HASCO sees the growth of 5G and IoT applications as a major opportunity for RF/microwave cable assembly suppliers. Wireless broadband, whether cellular or Wi-Fi, will require large numbers of micro base stations throughout municipalities, maintaining a steady demand for new cable components.

Maury Microwave noted the expanding opportunity for high accuracy measurements at higher frequencies. With the increasing complexity of measurements, T&M users must understand the impact of each component in the measurement system. Cable assemblies can be problematic and should not be treated as ideal components, particularly with extended use. The uncertainty caused by the cable assembly should be quantified and reduced where possible.

Molex sees significant growth opportunities in vehicles, including automobiles, commercial vehicles, recreational vehicles and e-bikes. All will need miniaturized coaxial interconnects to carry the data from an increasing number of high data rate sensors.

For **Pasternack**, IoT, commercial space and mmWave industrial applications offer growth, as well as the traditional aerospace and defense applications. Accessible and modular test equipment is also creating requirements for new test interconnects.

Samtec has long participated in standards committees, recently working on the new VNX+ standard to bring RF and fiber to the VNX form factor. Samtec sees this as a significant growth opportunity in addition to extending its product portfolio to 110 GHz. Samtec views quantum computing as a growth market that can be supported with minor modifications to its standard products. Entering this market will require a testing program to verify these modifications will perform as expected in the quantum environment.

Looking to its future growth, **Southwest Microwave** adds higher frequency phased arrays covering 20 to 70 GHz and multi-signal connectors handling RF, digital and power.

CONCLUSIONS

Although the C&C industry may seem mature, it is dynamic, reflecting the trends and needs of the many applications it serves. The future offers many opportunities, from connecting the front-end in a hypersonic missile seeker to a phased array on a satellite or a 5G mmWave base station. The overarching requirements driving the industry are higher frequencies, higher port density, smaller size, lower weight and consistency over time and the environment. Like other segments of the RF/microwave component industry, C&C suppliers are consolidating, yet a strong base remains. This is reflected in the responses from the 10 companies that participated in our survey. We appreciate their willingness to share their perspectives. ■

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1701	38	0.57 / 1.88
1571	40	0.64 / 2.09
1501	40	0.75 / 2.46
1401	50	1.02 / 3.34
1251	70	2.14 / 7.02
0471	110	4.95 / 16.23

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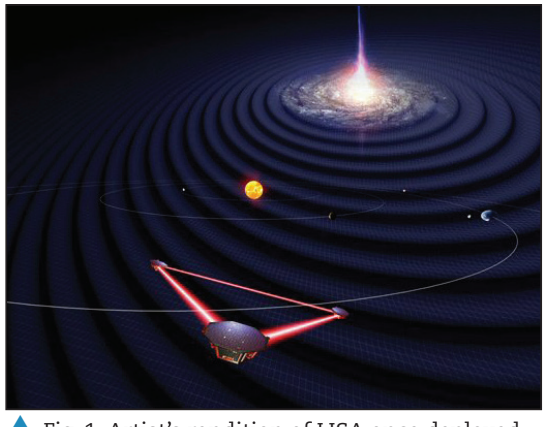
Coaxial Cables Support the LISA Gravitational Observatory in Space

Lina Schmidt
SSB-Electronic GmbH, Lippstadt, Germany

Simon Barke
University of Florida Precision Space Systems Laboratory, Gainsville, Fla.

The company SSB-Electronic GmbH from Lippstadt, Germany, specialized in high frequency solutions, is working with the University of Florida and supporting the team at the Precision Space Systems Laboratory (PSSL) on a new space project, the development of a special charge management device for the ESA and NASA Laser Interferometer Space Antenna (LISA) space mission. SSB-Electronic's coaxial cables are used to evaluate conformity with the strict timing requirements of the LISA project.



▲ Fig. 1 Artist's rendition of LISA once deployed in orbit. *Source:* University of Florida

LISA is the first gravitational wave observatory in space[1] and one of three large-class missions in ESA's "Cosmic Vision 2015-2025" program. The LISA mission, led by ESA, is a collaboration between ESA, NASA and an international consortium of scientists from 20 ESA member states, including the Max Planck Institute for Gravitational Physics in Hanover, DLR Institute of Space Systems in Bremen as well as numerous universities and institutes worldwide such as the University of Florida in Gainesville.[2]

LISA will consist of three identical spacecraft, separated by 2.5 million km, which will trail the Earth on their orbit around the sun in a triangular formation (see ***Figure 1***).[3] These three spacecraft will be connected by laser beams forming a

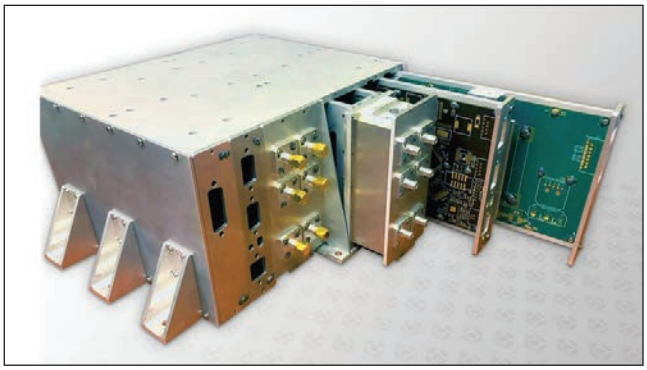


Fig. 2 LISA charge management device prototype. *Source:* University of Florida.

high-precision laser interferometer with millions of kilometer-long laser arms. Compared to the already existing ground-based gravitational waves observatories like Geo 600, LIGO or VIRGO,[4] LISA will address the much richer frequency range between 0.1 mHz and 1 Hz, which is inaccessible on Earth due to arm-length limitations and terrestrial gravity gradient noise arising from terrestrial gravity fluctuations. These fluctuations are caused by seismic activity, atmospheric disturbances (e.g. wind, rain, cloud movement) and anthropogenic activities (industry, busy roads or train routes).[4,5] From space, LISA can avoid the noise from Earth and access regions of the gravitational wave spectrum that are inaccessible from Earth due to its extremely long arms.[1]

The aim of the LISA mission is to complement terrestrial detectors in investigating new areas of the gravitational wave spectrum.[1] Like ground-based detectors, LISA is based on heterodyne laser interferometry. The three LISA spacecraft relay laser beams back and forth between them and the signals are combined to search for gravitational wave signatures that come from distortions of spacetime. The gravitational wave sources that LISA would discover include supermassive black hole mergers, neutron star mergers and other major astrophysical events such as the Big Bang.[3] Gravitational wave detection with LISA will complement our knowledge about the beginning, evolution and structure of our universe.[3]

The LISA mission is scheduled to be launched in 2034. From there, the LISA spacecraft will take approximately a year to reach and enter orbit around the sun and will then collect scientific data over a period of at least eight to 12 years.

The LISA mission needs many new key technologies to work including high-end optics and micro-thrusters.[2] Various systems and components are being developed for the mission in numerous projects around the world. For example, the scientists of the Cluster of Excellence Quantum Universe at the University of Hamburg are working on an electronic phase measurement system, a phase meter for ultra-precise laser-based length measurements at low frequencies, as well as optical components for the ground equipment.[3]

DEVELOPMENT OF THE CHARGE MANAGEMENT DEVICE AT THE UNIVERSITY OF FLORIDA

Another example is the project at the University of Florida. A team of researchers, professors and students at University of Florida led by John W. Conklin and Peter Wass (Department of Mechanical & Aerospace Engineering) in collaboration with Professor Dr. Guido Mueller (Department of Physics) has been awarded a $12.5 million NASA contract to build and test a prototype of a charge management device for the

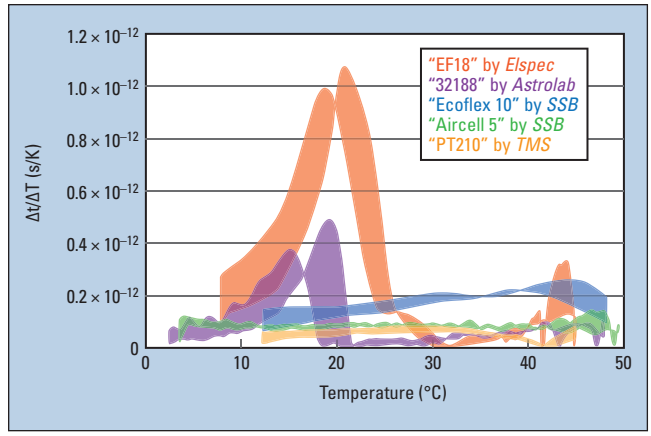


Fig. 3 Phase stability of five cables. *Source:* Simon Barke.[8]

space mission by July 31, 2025 (see ***Figure 2***).

This charge management system is a ultraviolet (UV) light device that can monitor electrical charges of the free falling test masses inside the three LISA spacecraft. These test masses are cubes made of a gold-platinum alloy, each with an edge length of 46 mm and a weight of 2 kg. The charge management device will shine the appropriate amount of UV light on the test masses to keep their charges at zero, preventing unwanted motion.[6] The job of the University of Florida team is to ensure nothing but gravitational waves move the particle masses and that the discharge of the test masses does not generate any undesirable side effects.[6]

Two internal test masses per spacecraft are used, each one dedicated to a single interferometry arm.[7] Every spacecraft uses high-precision heterodyne laser interferometry to measure extremely small distance variations (pm to nm) between the test masses caused by gravitational waves. All test masses inside the three spacecraft will be in free fall along the lines of sight between the spacecraft and serve as inertial sensors for estimating position.[4] The test masses are shielded by the containing spacecraft against external perturbations. Capacitive sensors surrounding each test mass will monitor their positions and orientations with respect to the spacecraft. To keep each satellite centered on the test masses the tiny orbital and attitude corrections will be determined by a drag-free attitude control system using the measurements of inertial sensors. This system of regulating the satellite position enables new missions which, for example, will also be used to measure the effects of climate change on the planet in the future. LISA will detect gravitational waves with three independent interferometric combinations of the light travel time measurements between the test masses along the sides of a triangular configuration.[7]

COAXIAL CABLES FROM SSB-ELECTRONIC EVALUATE COMPLIANCE WITH THE PROJECT REQUIREMENTS

The coaxial cables of SSB-Electronic are used at the PSSL of the University of Florida for test stands that will evaluate the LISA charge management system under the NASA contract. According to Simon Barke, one of the technical directors of the PSSL, the success of the PSSL team, but also of the entire LISA mission, depends on the phase stability of high frequency signals that help track changes in distance between the test masses. Gravitational waves are expected to affect this distance by just a few picometers. Changes in distance will be translated to slow (mHz) phase shifts on the order of microradians in a 20 MHz electrical detection

TABLE 1

TEST CABLE SPECIFICATIONS[8]

Cable Name (Manufacturer)	Dielectric Material	Operating Temperature (°C)	Maximum Frequency (GHz)	VoP (%)	Δt/ΔT (s/K)
EF18 (Elspec)	Low Density PTFE	-40 to 85	18	77	1.2×10^{-12}
32188 (Astrolab)	Low Density PTFE	-55 to 200	27	86	4.9×10^{-13}
Ecoflex 10 (SBB)	Low Density PE	-55 to 85	6	85	2.6×10^{-13}
Aircell (SBB)	Low Density PE	-55 to 85	10	82	1.4×10^{-13}
PhaseTrack 210 (TMS)	Proprietary TF4™	-55 to 85	29	83	8×10^{-14}

signal. The phase of a 20 MHz signal will be tracked with sub-picosecond precision over hours.

Spurious phase noise caused by any device in the measurement chain would spoil these delicate measurements. One limiting noise source is electrical cables. Temperature fluctuations can change the length and electrical properties of the cable, which results in a phase change of the signals. For the LISA project, cables must be used that will not change the phase of an electrical signal over temperature.

To evaluate the phase stability of different test cables, the change in signal arrival time (Δt) over temperature change (ΔT) per meter cable is measured.[8] A 2 GHz signal is split and passed through the cable under test and a reference cable of equal design and length. With a special device, a 28 cm section of the cable under test is heated and cooled in the range of 5°C to 50°C, which is the temperature range expected inside LISA spacecraft.[8] The phase of both signals is measured after mixing them down to a more convenient frequency of 1.6 GHz. Five candidate cables of three different types are used for the test, distinguished by different dielectric layers: polytetrafluoroethylene (PTFE), low density polyethylene (PE) or TF4™ (proprietary fluorocarbon dielectric material from the company TMS).

Figure 3 shows the results of measurements to evaluate the phase stability of the test cables. The width of each trace reflects the range of the calculated timing stability coefficients that are different for cooling and heating periods.

The results show that the cables with dielectrics based on PTFE exhibit an inherent, non-linear phase change when the material passes through the temperature range of 15°C to 25°C. These cables are therefore unsuitable for the LISA project.

The coaxial cables from SSB-Electronic using a PE dielectric, especially the cables of the Aircell 5 series, offer a flat temperature coefficient of maximum. $\Delta t/\Delta T = 1.4 \times 10e^{-13}$

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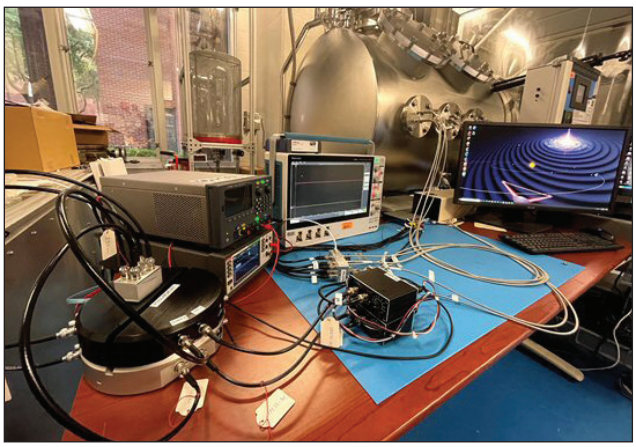

▲ Fig. 4 Test stand at PSSL. *Source:* University of Florida.

over a wide temperature range from 5°C to 50°C. These are among the most phase stable cables in the industry. Specifications of the cables under test, including the measured maximum timing stability coefficients per meter, are summarized in ***Table 1***.

Based on the measurement results, PSSL chose Aircell 5 cables for use in a test stand to evaluate the LISA charge management system under the NASA contract. Aircell 5 cables are used to carry electrical pulses from a frequency reference and photomultipliers tubes to Moku:Lab phasemeters. ***Figure 4*** shows the setup of the test stand at the PSSL, University of Florida. The cables enable confirmation that the light pulses emitted by the charge management system and detected by the photomultiplier tubes conform to the strict timing requirements of the LISA project.

CONCLUSION

Coaxial cables from SSB-Electronic are used in current basic research projects and are also suitable for space applications due to their phase stability. They are an attractive alternative to TF4 cables, especially for ground support equipment and test stands. ■

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David Kiesling
Times Microwave Systems, Wallingford, Conn.

Technology providers are creating advanced new wireless system designs within restricted space constraints in avionics, 5G, space and many other industries. These applications rely on high density RF interconnections capable of high signal integrity and reliability in ever more miniature housings. There are many challenges to providing practical RF interconnections in such dense housing environments. Fortunately, innovations in RF interconnections have led to reliable, high performance solutions that can fit the tightest spaces available, even at the most difficult interconnection angles.

AVIONICS

Avionics applications have limited space as they accommodate more application needs throughout the airframe. In the past, it may have been common to have 12 antennas on an aircraft, but there are now 50—even hundreds in some cases—antennas serving advanced avionics systems. More antennas in aircraft environments leads to more signal paths and the need for more RF interconnect solutions to accommodate them.

5G

As more users rely on 5G services, more antennas will be needed to provide coverage, both at lower FR1 frequencies (under 6 GHz) and at higher FR2 mmWave frequencies. Antenna densification is required to deliver increased peak data speeds, ultra-low latency, enhanced reliability, enormous network capacity and increased availability for 5G. Many 5G networks employ MIMO antennas, which are shrinking in size as higher frequency bands are used to accommodate larger bandwidth requirements. This translates into more antennas in smaller spaces and more RF interconnections within those smaller

Fig. 1 Example multiport connector assembly.

Fig. 2 Example mini-multiport connector assembly.

spaces.

5G small cells, such as micro, pico and femto cells, are examples of the electronic densification within 5G networks as they are spaced much closer than traditional wireless macrocell towers, often only 100 yards apart. Demand for high density cabling solutions to accommodate the necessary connections in smaller, more compact installations will continue to grow.

SPACE

Equipment used to support space technology must be lightweight, compact, reliable and capable of withstanding high levels of shock, vibration and radiation, as well as wide temperature ranges. RF coaxial cable assemblies must be designed to perform reliably in the smallest possible footprint. The high frequency cables required for space applications must support low loss communications, requiring a dense network of antennas.

HIGH DENSITY INNOVATIONS ABOUND

High density RF interconnection solutions have evolved from individual assemblies with multiple coaxial connectors to a single connection port. There are a wide variety of unique high density options suited to fit the specific needs of an industry/application, including multiport and mini-multiport connectors, bundled cable assemblies, locking miniature blind mate connectors and cable assemblies for densely packed in-the-box applications. Common requirements for these environments include ease of installation, high vibration (cannot come apart) and environmental seals.

MULTIPORT AND MINI-MULTIPORT CONNECTORS

Multiport and mini-multiport connector solutions are ideal for high density avionics environments, where space is at a premium, accessibility for maintenance is limited and performance is mission-critical. These connectors consist of multiple coaxial contacts of the same interface integrated into a single connector module or shell. There are numerous options for these types of connectors, including those with reduced size and weight that provide excellent electromagnetic shielding and phase stability with low VSWR and insertion loss to 20 GHz for multiport connectors and to 40 GHz for mini-multiport connectors. See ***Figure 1*** and ***2*** for examples.

BUNDLED CABLE SOLUTIONS

Densification creates numerous challenges related to installation, torquing, ensuring proper weather sealing and more. In addition, an increasing number of technologies such as 5G small cells have limited space for equipment, so minimizing size and weight are also key goals.

With so many components in such a small space, maintenance can be challenging. If an interconnect fails, it can be hard to troubleshoot the exact one. Moreover, installation can be a time-consuming, labor-intensive and logistical nightmare. Hooking up the right cables, ports and torquing can be difficult when working with multiple connections. Proper weather sealing is also necessary; it is imperative to ensure that the seal is secure but not over-torqued.

A bundled cable solution can help create the perfect flexible antenna jumper for applications requiring multiple runs, such as 5G. A spiral configuration of multiple flexible and ultra-flexible jumper cables can be created under a common polyurethane outer jacket to promote easy installation and improved operation. The individual coaxial cable runs are spun together in a way that easily flexes, essentially creating a bundle, which is then run through a large jacket extruder where a ripcord is placed.

This design enables four or five individual cables to be fed into the back of an industry standard MQ4/MQ5 bundled connector, incorporating multiple RF ports and significantly reducing the number of cables that have to be hooked up. MQ4/MQ5 bundled solutions also save a lot of labor and enable a more rugged solution. They also make the assembly more weatherproof and UV resistant.

Using the four- or five-conductor solution eliminates the need to create individual weather seals, resulting in tremendous labor savings. Furthermore, it reduces the need to worry about coupling torque, which is critical because all it takes is an error on just one weather seal to create a point of ingress for water that could create a multitude of problems and even potentially shut the system down. With a bundled solution, the connection between the male and female cluster connectors is sealed to IP-67, as are the connector bodies and the transition from the cluster connector to the bundled cable. Any potential system troubleshooting becomes much easier. Finally, the possibility of hooking up the wrong cable to the wrong port is eliminated. The solution is keyed, so the cables can only be hooked up a certain way—no torque wrenches, know-how or special technique required.

Bundled solutions are optimal for high density challenges as they permit installation in tight spaces; instead of connecting multiple threaded connectors, just one will do the job. They are faster and easier to install and maintain and provide one firm, reliable connection to support consistent high performance. Their design has many use cases, thus

▲ Fig. 3 Example industry standard MQ4 bundled connector.

becoming particularly popular in applications where cable installations and rising operating frequencies demand coaxial cables and connectors to deliver high signal integrity and reliability. An example of this type of solution is the TMQ4 and TMQ5 bundled cable assemblies from Times Microwave Systems shown in ***Figure 3***.

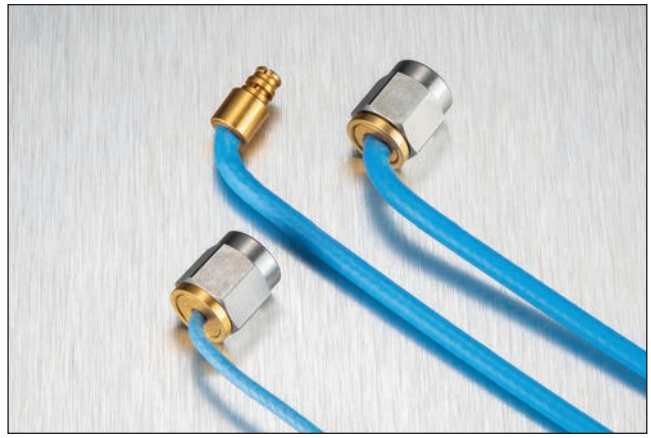
LOCKING MINIATURE BLIND MATES

A new generation of locking miniature blind mate connectors (TLMB) is specifically designed to overcome performance issues arising from typical SMP connectors' susceptibility to electromagnetic interference (EMI) and electromagnetic compatibility (EMC) interference, liquid and salt ingress. Their rugged, sealed design is more durable to withstand harsh conditions and operate in severe environments. TLMB connectors retain the small form factor of the SMP for highly dense environments but add improved environmental, shielding and power capabilities, with a frequency range from DC to 60 GHz.

While SMPs are still a valuable connector option for many designs, they pose problems as applications demand higher and higher frequencies. One of the critical issues is shielding and EMI. Similarly, the SMP's design reduces its ability to function without affecting other equipment in the same environment. The connector's signal leakage issues often result in failed EMC tests. In short, the SMP's lack of proper electrical bonding and shielding exposes the conductor's signal to external influence.

This signal leakage limits how closely the connectors can be placed in a single shell; without proper shielding, the contacts must be kept at a greater distance to prevent signal interference. With the improved shielding of a TLMB, more connectors and cables can be added in a much smaller footprint without interference issues.

Another major failure area in the SMP's design makes them susceptible to ingress from saltwater, fuel and other contaminants. The lack of an environmental seal due to their mechanical openings makes SMPs prone to corrosion and failure. Another problem arises with using SMPs in high vibration applications, where their easy connect/disconnect design makes them susceptible to unwanted de-mating in high vibration environments.



▲ Fig. 4 InstaBend cables for space constrained areas.

TLMBs were created for high-reliability, high vibration environments such as military and aerospace. Areas where EMI may be an issue, such as shipboard or aircraft, need an environmentally sealed and shielded connector. The standard SMP may also disconnect in high vibration environments such as a carrier landing, weapons launch or any powerful weapons platform, making a locking miniature blind mate connector the ideal choice.

CABLE ASSEMBLIES FOR DENSELY PACKED IN-THE-BOX APPLICATIONS

Additionally, it may be optimal in high density applications to reduce the footprint required behind the connector to help install numerous cables into a very small space. Minimizing space between the cables and connectors is also necessary for the interconnect system to survive the high vibration and other harsh environmental conditions found in applications such as space and avionics.

New cable assemblies can be bent around tight corners and very closely behind the connector to minimize footprint, save space and simplify cable routing in tight spaces while offering low loss and optimized performance. Originally designed for space flight applications, this type of high performance assembly uses a compact, phase stable, highly flexible, micro coaxial cable that can easily accommodate densely packed in-the-box applications. For example, Times Microwave System's new InstaBend™ high performance microwave assemblies provide a flexible preassembled design for interconnects between RF circuit cards, modules and enclosure panels. InstaBend is ideal for in-the-box applications with space constraints, including space flight, thermal vacuum, microwave test and other commercial and military applications. The cable can be bent very closely behind the connector, minimizing footprint, saving space and simplifying cable routing (see ***Figure 4***). This also eliminates the need to protect the back of the connector.

Additionally, InstaBend provides these benefits at a dramatically reduced lead time compared to competing solutions. The high performance microwave assemblies are available in standard configurations or customized to meet an application's specific needs. This new product's ability to bend from connector to connector provides maximum flexibility and minimum use of available volume in high density, inside-the-box applications.

SUMMARY

As advanced new mission-critical technologies are introduced, RF interconnect requirements are changing drastically, including the need for novel solutions to accommodate extremely restricted space constraints and rising operating frequencies. New innovations in high density RF interconnects are emerging to deliver high signal integrity and reliability in increasingly dense environments.

When selecting the right high density RF cables and connectors, it is best to work with a partner whose engineers can identify the application's unique needs and design an optimized, easier to use solution—creating better electrical, mechanical and environmental performance. Look for a supplier with a long history of building quality cable and connectors, along with the skill, processes, techniques and materials to bring custom solutions for specific application needs to life. ■

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Innovative Cabling for 5G and Beyond

Junkosha
Irvine, Calif.

Test and measurement (T&M) is a crucial application where cabling innovations are constantly required. As we move into a 5G-enabled world, the cables and interconnects used in T&M processes must be of the highest standards and reliability, pushing to ever higher frequencies. 5G represents the next evolution of mobile communications and promises to enable many new applications, such as autonomous vehicles and virtual reality.

With 5G, significant design and measurement hurdles must be overcome. As the frequency spectrum is limited, 5G must operate at higher frequencies to deliver faster data speeds. As 5G taps into these mmWave frequencies, cabling and interconnects must be robust to meet the rigorous performance requirements. Whether used in system development or device characterization, precision and repeatability are required, and this capability must be sustained within the production test environment after a system is commissioned.

Cable assemblies in a test environment are often used with vector network analyzers (VNAs), probably the core instrument for testing and characterizing components, then ensuring they function properly when integrated together. Accuracy is crucial in any test setting, particularly for metrology grade cabling, which offers the ultimate precision and demands the highest reliability for testing and calibration. With the smaller wavelengths at mmWave frequencies, flexure and movement can have a significant impact on the accuracy of measurements, and this is accentuated as the frequencies increase.

PHASE STABILITY

In response to these challenging requirements, global cabling and interconnect pioneer Junkosha launched the 8 Series VNA Test Assembly, designed to be a high-quality metrology-grade VNA test cable for users requiring high precision. Using Junkosha's precision expanded PTFE tape wrapping technology, the 8 Series metrology grade cable exhibits excellent phase and amplitude stability with flexure, within ±1.5 degrees and ±0.08 dB at 50 GHz, respectively, for a 25 in. long cable (see ***Figure 1***). The figure shows the

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phase performance of the cable assembly before, during and after being flexed around a 2.25 in. radius mandrel. The 8 Series is flexible and can maintain this level of performance when bent 180 degrees around a 2.25 in. radius mandrel, with no spring back. The assembly has impressive performance durability—50,000 tick-tock cycles typical—and has high phase stability over temperature. With a 2.4 mm connector, the cable assembly is specified to 50 GHz, and a ruggedized port-side NMD connector is available to ensure direct and reliable connection to the VNA. Other versions will follow during the coming months. The 8 Series can be shipped with a VNA or as part of an after-sale package to replace existing cables.

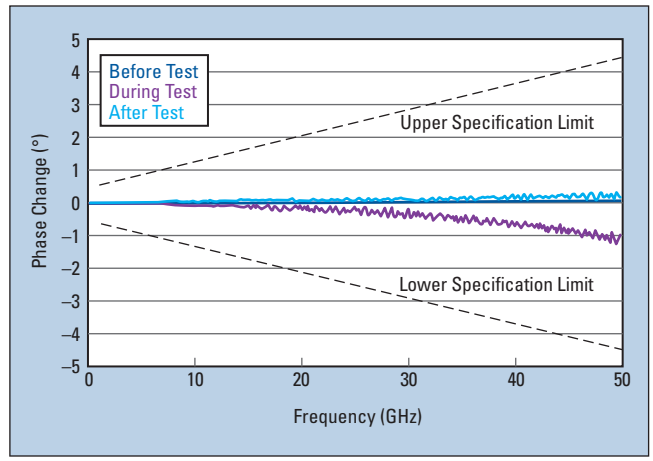

Fig. 1 Typical phase stability vs. frequency before, during and after flexing a strait 25 in. cable assembly 180° around a 2.25 in. mandrel.

Fig. 2 MWX004 cable assembly.

The key application area for the new metrology grade microwave/mmWave VNA test cable assembly is in measuring the device under test (DUT) when designing a high frequency component from scratch. In addition to devices and coaxial components, the metrology grade cable can be used to develop other coaxial cables. With a calibration level standard bench test, the cable assembly is well suited for national institutes, calibration laboratories, service providers or any application where repeatability is key.

PUSHING TO 145 GHz

Within the last 18 months, Junkosha has launched a range of high performance mmWave cabling solutions in addition to the 8 Series, such as the MWX004 (see ***Figure 2***). The MWX004 can uniquely operate up to 145 GHz and has the high phase stability associated with Junkosha, as well as the highest performing dielectric material and high flex life. The MWX004 was designed for applications operating above 100 GHz and systems such as LiDAR for connected and autonomous vehicles.

A world requiring constant wireless connectivity demands more efficient use of the available frequency spectrum, which requires innovative technologies. The use of mmWave frequencies has become a requirement for many new applications, whether commercial, space or defense. To enable systems to deliver the required performance at mmWave frequencies, phase performance that endures is a requirement that cable assemblies and interconnects must achieve, especially in the T&M environment. Junkosha's latest interconnect solutions provide VNA manufacturers with the capability to test these high frequency networks that will soon be at the heart of the next generation of highly sophisticated systems.

Both the 8 Series VNA Test Assembly and MWX004 will be featured at this year's European Microwave Week.

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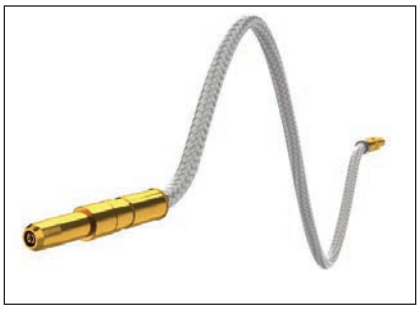

Flexible Cable Assembly Saves Space, Maximizes Performance

HUBER+SUHNER'S NANOBEND™ cable assembly bends immediately behind the connector without compromising performance. Designed for applications where space, weight and performance are equally important, NANOBEND enables connections where the footprint is extremely limited while meeting the stringent performance and reliability requirements of aerospace, defense and test and measurement: NANOBEND meets ESA, NASA and MIL standards as well as the new Sensor Open System Architecture standard.

The outer cable diameter of only 1.62 mm enables NANOBEND to be extremely flexible, bending where cable and connector meet without compromising RF performance or reliability. When configured for the highest frequency performance, NANOBEND will operate to 110 GHz with approximately 18.5 dB/m insertion loss. At 20 GHz, the loss is below 7.5 dB/m.

NANOBEND is triple shielded to minimize RF leakage. The cable comprises an inner CuAg conductor surrounded by an extruded PTFE dielectric, a CuAg flat wire outer conductor, an Al/polyimide tape barrier, stainless steel outer braid and FEP outer jacket. The cable can be assembled with one of several specially-designed connectors that are compatible with industry standards: SMA, SMP, SK, SMPM and SMPM-T. In standard lengths, NANOBEND is available for delivery from stock.

This new cable assembly from HUBER+SUHNER extends the MINIBEND® product line, which has the smallest bend radii in the industry.

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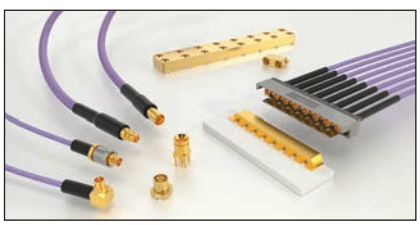

Family of RF SMPM Cable and Board Level Connectors

Samtec has expanded its portfolio of single- and multi-port SMPM interconnects, providing coverage to 65 GHz with a maximum VSWR of 1.4:1. SMPM micro-miniature connectors are well-suited for space-limited systems where push-on coupling is preferred or a blind-mate connection is required.

Single cable assemblies (RF23C series) have SMPM jack and plug connectors on a 23 AWG low loss flexible cable. The cable has three layers of shielding: SPC flat wire, copper foil and a 44 AWG outer braid.

Single-port cable-to-board SMPM interconnects are available using 0.047 in. (RF047-A series), 0.086 in. (RF086 series) or Samtec's low loss flexible cable (RF23C series) with optional End 2 connectors. SMPM board connector options include surface- or edge-mount and straight or right-angle through-hole terminations.

Multi-port ganged cable assemblies (the GC47 and GPPC series) also use 0.047 in. low loss flexible cable with an optimized latching system. Samtec has released eight- and 10-port configurations with 0.140 in. (3.56 mm) pitch, and more configurations are being developed.

The multi-port board-to-board system (GPPB series) offers three board heights: 0.210 in. (5.33 mm), 0.327 in. (8.31 mm) and 0.500 in. (12.70 mm). Full detent or smooth bore retention connection are available.

These SMPM interconnects add to Samtec's full line of off-the-shelf interconnects for microwave and mmWave applications. With upper frequency coverage from 18 to 110 GHz, the precision RF product family supports all major market applications: wireless communication, satellite communication, automotive, radar, aerospace, defense and test and measurement. Whether a quick-turn modification or new design, Samtec will customize a product to support a customer's unique requirements.

Samtec
New Albany, Ind.
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Cable Assemblies for Thermal Vacuum Testing

Thermal vacuum (TVAC) chambers are used by satellite manufacturers to test satellites and their subsystems and components in conditions mimicking space. In this environment, the test and measurement (T&M) components inside the chamber must perform reliably across the varying pressures and temperatures. Responding to this need, Maury Microwave developed StabilityTVAC™ cable assemblies, optimizing the mechanical and electrical design to provide accurate, reliable measurements, including stable phase.

Low outgassing is one of the requirements for T&M components inside the TVAC chamber. Outgassing occurs when the varying temperature and vacuum enable materials to release free volatiles that can deposit on other components and cause significant contamination. StabilityTVAC assemblies use low outgassing materials, meeting the requirements of ASTM E-595: a total mass loss under 1 percent and collected volatile condensable materials below 0.1 percent.

Changes in vacuum in the chamber force air in and out of the cable assemblies. Standard connectors require a slower change in pressure to avoid damage. StabilityTVAC cable assemblies use vented connectors, enabling the air to escape and the cable assembly to stabilize faster. This minimizes delays when testing with rapid pressurization/depressurization cycles.

Cable assemblies expand and contract over temperature, which changes the RF performance and can permanently degrade the cable assembly. StabilityTVAC assemblies are thermally conditioned to relieve mechanical stresses and ensure reliable performance over temperature.

Maury Microwave's StabilityTVAC RF/microwave cable assemblies are available in both standard and high power, low loss versions. Connector choices for the standard series are 2.92 mm performing to 40 GHz, SMA connectors to 26.5 GHz, TNCA connectors to 18 GHz and Type N to 12.4 GHz. The high power, low loss versions are available with Type N or SMA connectors performing to 18 GHz and TNC connectors, to 12.4 GHz. Low-profile, reduced size and weight options are also available.

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VENDORVIEW

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IW Microwave Cable Assemblies

IW Microwave Products is a manufacturer of low loss phase stable coaxial cable assemblies operating to 70 GHz. IW's unique dielectric lamination technique provides exceptional attenuation and phase performance over temperature, and with a range of diameters from 0.034" to 0.750". IW cables are suitable for inside enclosure through to system level applications. Various jacketing, armor and interconnect options are available including high power (EIA flanges, 7/16) to mmWave (SMP, SMPM, 2.4 mm, 1.85 mm), making its products suitable for a wide range of military RF/microwave systems—IW cables are in service on land, sea and airborne platforms worldwide.

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MegaPhase's patented HyperFlex™ Cable offers superior flexibility when compared to traditional solder-terminated connectors. HyperFlex™ Cables incorporate a solderless connector termination, making it easy to make very tight bends directly behind the connector. The design eliminates solder wicking and therefore cracking at the solder joint—typically the weakest point in a cable assembly. Ideally suited for inside-the-box applications in military airborne and space systems. HyperFlex™ is available in three sizes, with a maximum frequency range through 67 GHz.

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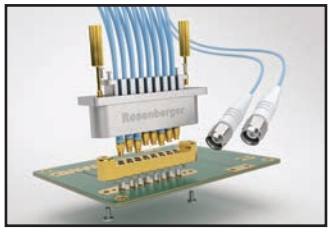


Multiport Mini-SMP for Solderless Mounting

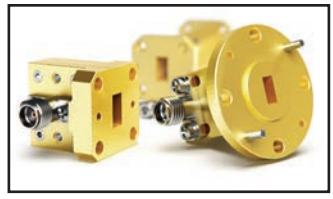
Rosenberger introduces Multiport Mini-SMP cable assemblies and printed circuit board (PCB) connectors which can be mounted solderless on PCBs. The PCB connectors offer superior signal integrity for all kinds of PCBs and can be connected with Mini-SMP – RPC-2.92 cable assemblies for frequencies DC to 40 GHz, or with Mini-SMP – RPC-1.85 cable assemblies for frequencies up to 65 GHz. The Multiport Mini-SMP system is very cost-effective—designed solderless, easy to assemble, reusable, low abrasion, damage-free connection and compatible with standard Mini-SMP interface.

Rosenberger
www.rosenberger.com

Insight Calibration and Measurement Software

Insight™ is the industry's first and only commercial software platform designed to increase confidence in your measurements by characterizing the uncertainty contribution of each component of your measurement setup and empowering you to measure your DUT with uncertainty boundaries (see image). Validate your VNA calibration using uncertainty, resolve measurement inconsistencies using uncertainty, get measurement traceability using uncertainty, improve the pass/fail production test process using uncertainty.

Maury Microwave
www.maurymw.com/Precision/Insight_Software.php



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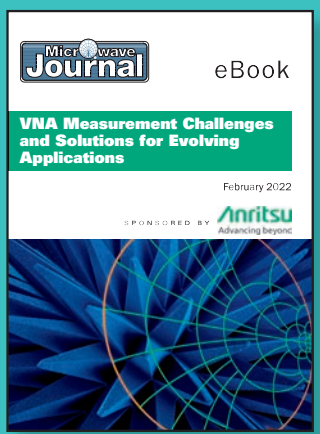

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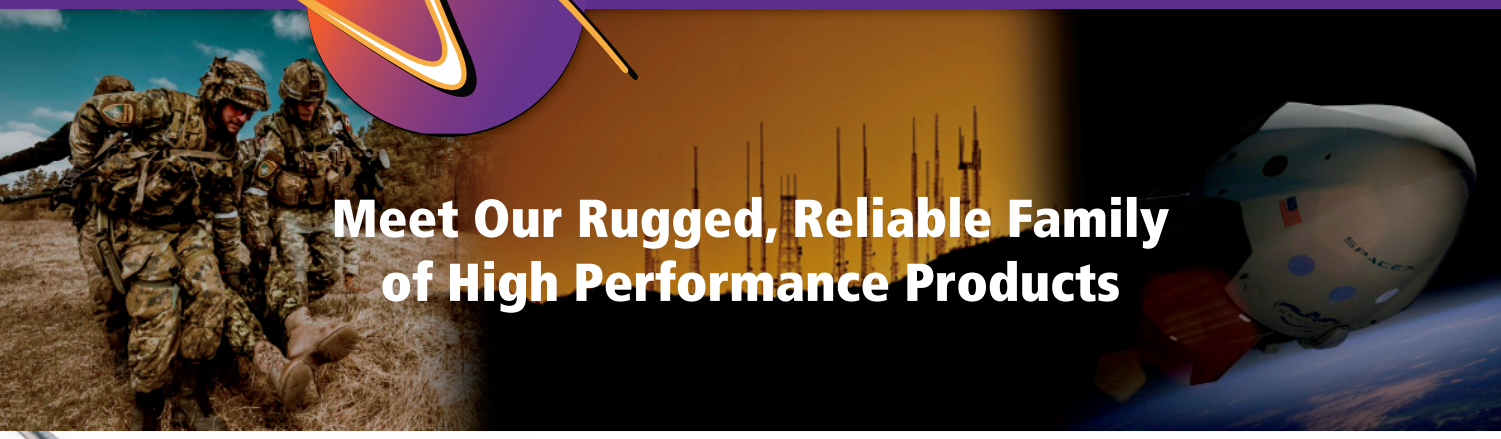

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