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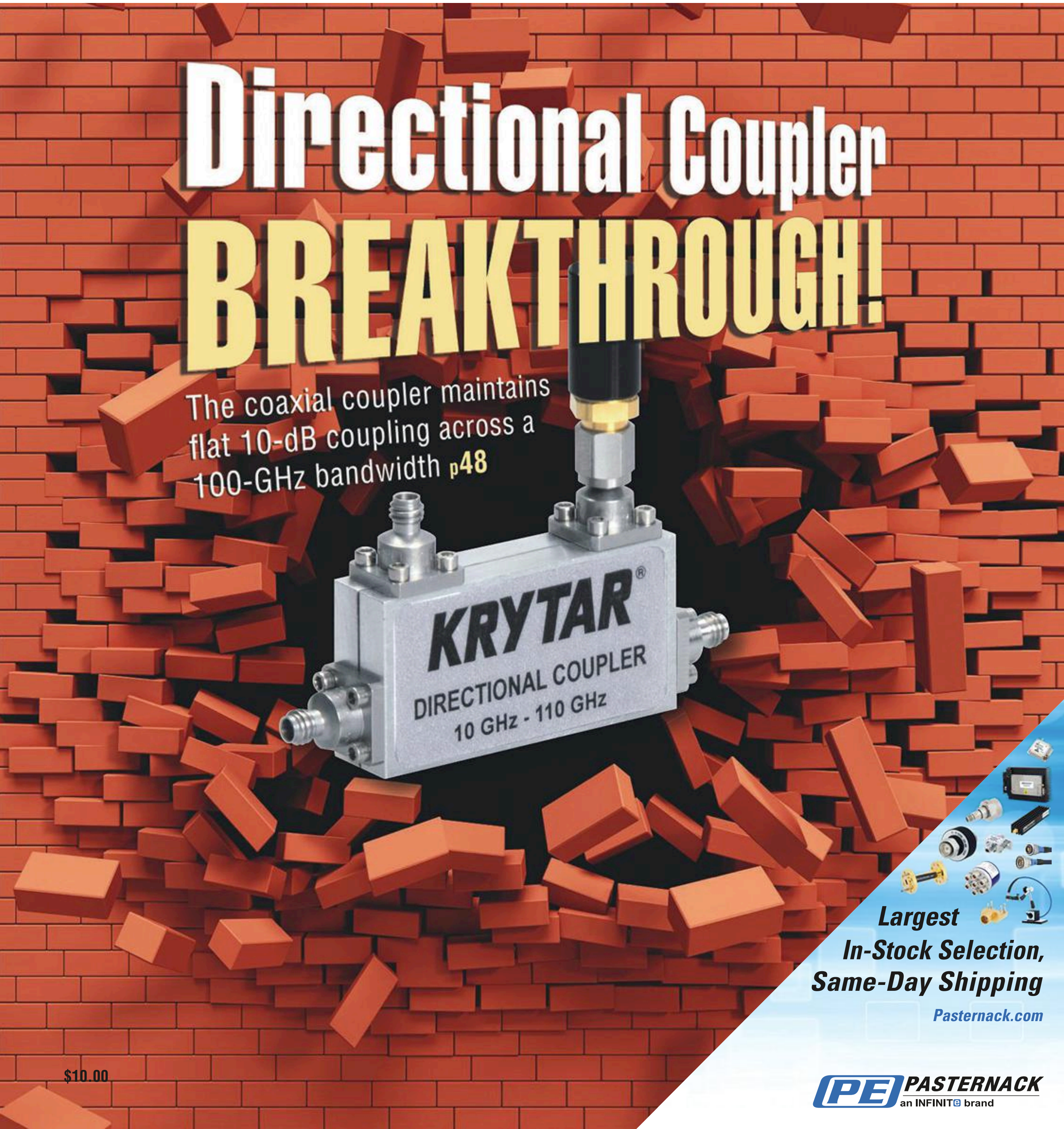

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LM-10M9G-100CW-1KWP-SFF https://www.pmi-rf.com/product-details/lm-10m9g-100w-1kwp-sff	0.01 - 9	2	2.0:1	100 W CW Max	20	60 ns	1.86" x 0.38" x 0.65" SMA (F)
LM-10M14G-100W-1KWP-SFF https://www.pmi-rf.com/product-details/lm-10m14g-100w-1kwp-sff	0.01 - 14	2	2.0:1	100 W CW Max @ 1 KW Peak	15	17 ns	0.90" x 0.38" x 0.38" SMA (M/F)
LM-20M15G-100W-15DBM https://www.pmi-rf.com/product-details/lm-20m15g-100w-15dbm	0.02 - 15	1.6	2.0:1	100 W CW Max @ 1 KW Peak	15	91 ns	0.90" x 0.38" x 0.38" SMA (M/F)
LM-10M18G-16-20W-AL https://www.pmi-rf.com/product-details/lm-10m18g-16-20w-al	0.01 - 18	2	2.0:1	20 W CW Max @ 1 KW Peak	17	225 ns	0.90" x 0.38" x 0.38" SMA (M/F)
LM-20M18G-80W-15DBM https://www.pmi-rf.com/product-details/lm-20m18g-80w-15dbm	0.02 - 18	2.6	2.0:1	100 W CW Max @ 1 KW Peak	15	91 ns	0.90" x 0.38" x 0.38" SMA (M/F)
LM-20M18G-100W-15DBM https://www.pmi-rf.com/product-details/lm-20m18g-100w-15dbm	0.02 - 18	2.6	2.0:1	100 W CW Max @ 1 KW Peak	17	24 ns	0.90" x 0.38" x 0.38" SMA (M/F)
LM-1G18G-16-4W-SMF https://www.pmi-rf.com/product-details/lm-1g18g-16-4w-smf	1 - 18	2.3	2.0:1	4 W CW	16	24 ns	0.90" x 0.38" x 0.38" SMA (M/F)
LM-1G18G-15-3W-500WP-SFF https://www.pmi-rf.com/product-details/lm-1g18g-15-3w-500wp-sff	1 - 18	2.5	2.0:1	3 W CW 500 W Peak	17	33 ns	1.00" x 1.00" x 0.40" SMA M/F)


LM-20M15G-100W-15DBM


LM-10M18G-16-20W-AL


LM-20M18G-80W-15DBM


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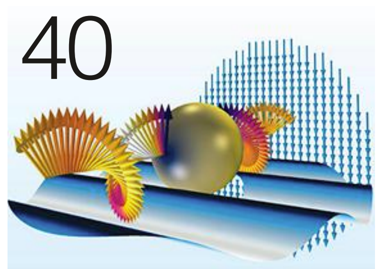

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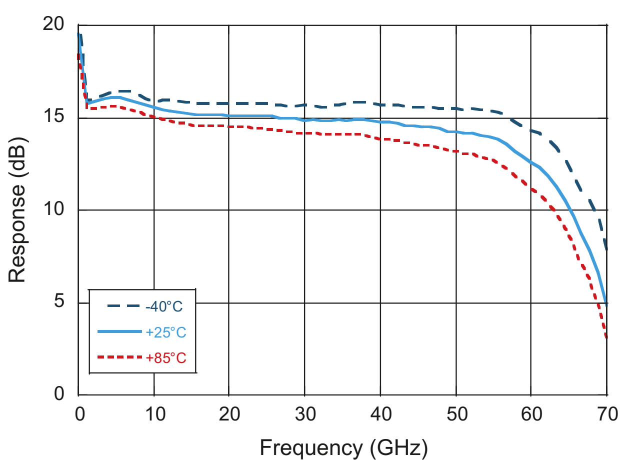

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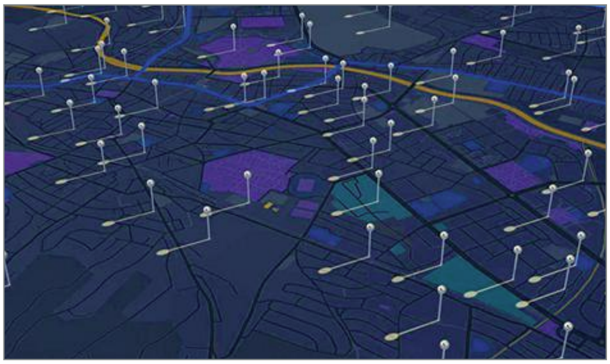
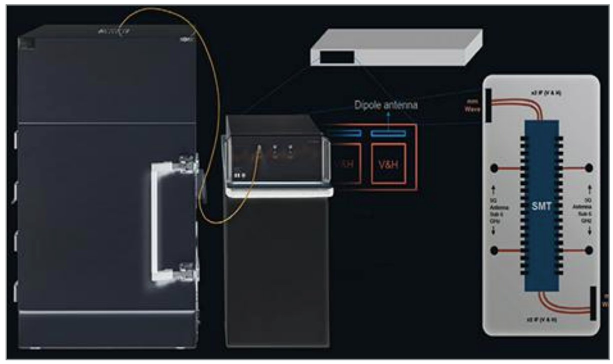


Algorithms to Antenna: Where Should I Locate My Radar?

This latest blog from MathWorks focuses on radar system planning. The goal here is to select the three best locations to place low-power radars out of five candidate locations in a hypothetical radar network.

https://www.mwrf.com/systems/algorithms-antenna-where-should-i-locate-my-radar



Over-the-Air Testing for 5G mmWave Devices: DFF or CATR?

This article investigates OTA test methods, such as direct far field and compact antenna test range, examining the tradeoffs in cost and path-loss performance.

https://www.mwrf.com/test-measurement/over-air-testing-5g-mmwave-devices-dff-or-catr

Overcome mmWave Automotive Radar Testing Challenges

With automotive radar moving to higher frequencies, the need exists for the right test solutions such as high-bandwidth oscilloscopes and versatile arbitrary waveform generators.

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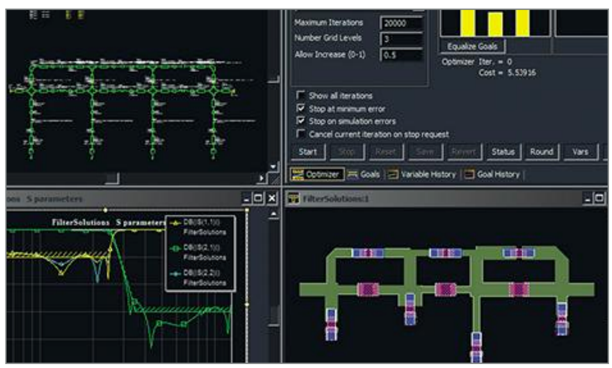

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Editorial
LOU FRENZEL | Contributing Editor
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New Applications Bring Renewed Life to UWB Wireless

ULTRA-WIDEBAND (UWB) wireless has been around for many years in multiple forms. Though it's found numerous niches, UWB has never caught on like Bluetooth, Wi-Fi, and others. It seems to come and go as the technology develops and new applications are found.

Well, here it comes again. Semiconductor company Decawave recently introduced a UWB product to address a new IEEE wireless standard.

UWB BACKGROUND

According to the FCC, a wireless signal is said to be UWB if it occupies a minimum of 500 MHz of spectrum or a bandwidth of at least 20% of its center operating frequency. The allocated spectrum is for unlicensed applications in the 3.1- to 10.6-GHz range. The power level is restricted to −41.3 dBm/MHz or 75 nW. Many other wireless services exist in that spectrum, but because of the very low operating power and the extremely wide bandwidth, the UWB signal looks more like noise than an interfering signal.

That broad definition has resulted in several forms of UWB. The original form is an impulse scheme where the serial data to be transmitted is converted into short pulses modulated by pulse-position modulation or binary phase-shift keying. Direct sequence spread spectrum (DSSS) is also used. The pulse width determines the center frequency and is approximately equal to the reciprocal. Another form of UWB developed by the WiMedia Alliance leverages orthogonal frequency-division multiplexing. The UWB spectrum is divided into 528-MHz-wide bands or channels; the format was able to achieve a data rate of 480 Mb/s.

A NEW IEEE STANDARD

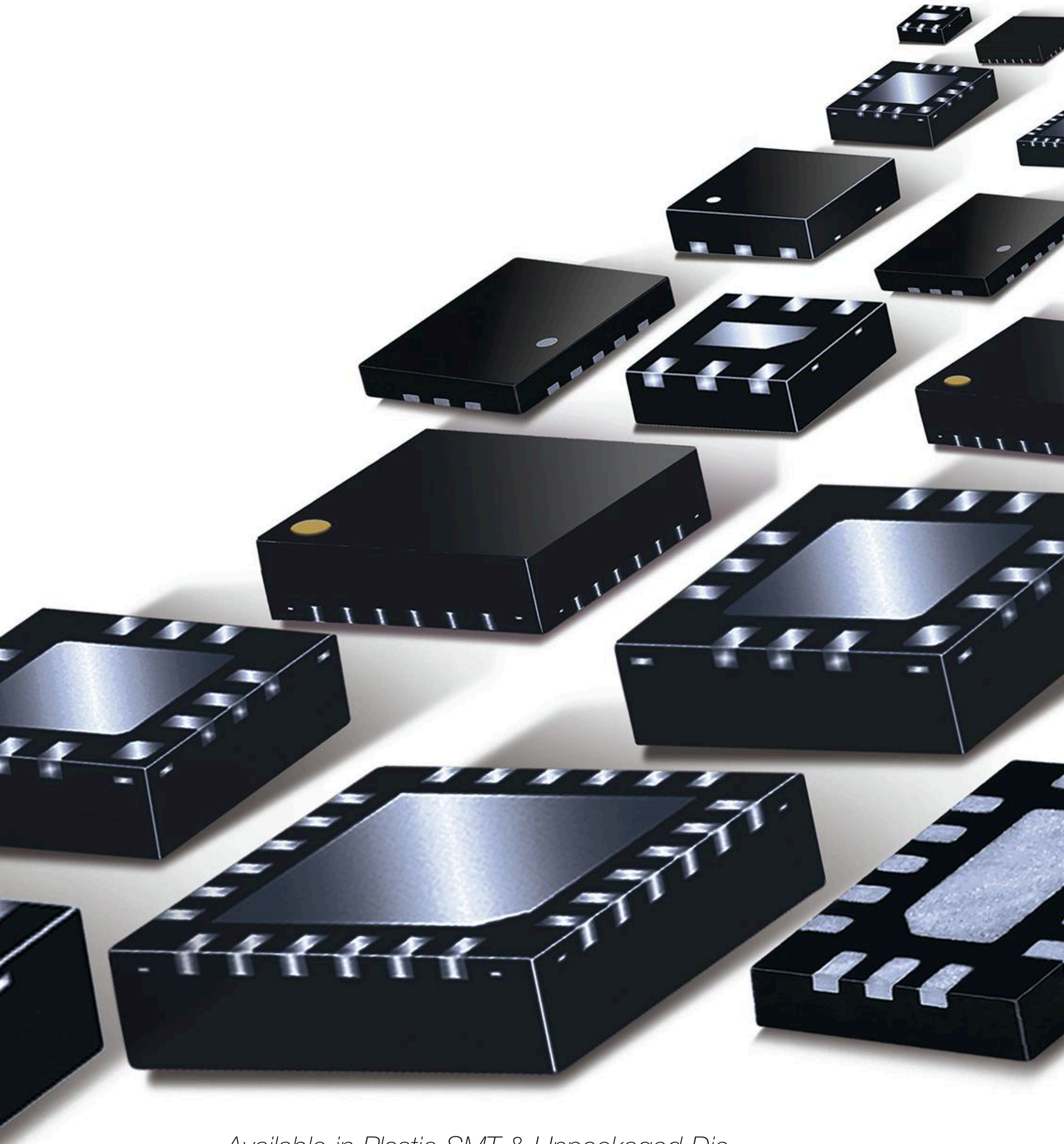
One of the many objectives of the IEEE is to develop standards for a wide range of components and systems. It's established a variety of wireless standards, the most well-known being Wi-Fi (IEEE 802.11). The newest Wi-Fi versions are 802.11ac and 802.11ax, both featuring data rates well above 1 GHz. Its main application is wireless local-area networks for internet access. The IEEE also established a UWB standard called 802.15.4a.

A new UWB standard under development is 802.15.4z. It expands and improves upon the 802.15.4a version. Final ratification of the standard is expected sometime during 2019.

The emerging application for this UWB version is real-time location services (RTLS). This technology locates and tracks assets. It uses impulse UWB to locate a mobile node with respect to an application point. Each has the appropriate UWB transceiver that uses the time-of-flight or time-of-arrival algorithm called trilateration. It determines the distance between the two devices by measuring the time of signal transmission to locate the intersection of three circles. Accuracy is in the 2-10 cm range.

RTLS ability makes possible a new UWB application: wireless payment. It would compete with NFC for smartphone space, but offers the benefit of highly increased mobile transaction security. The standard creates a "digital twin" and the user's location is utilized for authentication.

Back to Decawave, its UWB product is the 802.15.4a-compliant DW1000 transceiver. The 4z standard isn't backward-compatible with 4a, but future Decawave chips will support both 4a and 4z. mw



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News

NEW SOLUTION MANIPULATES mmWave Signals

By amplifying and moving signals around, this solution is able to conquer the challenges associated with millimeter-wave 5G.

One company with a clear focus on 5G communications is Movandi (*www.movandi.com*), which recently announced its BeamXR solution (*see figure*). The firm asserts that BeamXR is intended to solve today's real-world 5G deployment challenges, as it addresses factors like non-line-of-sight, high path loss, and self-installation. According to the company, utilizing BeamXR can result in extended indoor and outdoor coverage, while maintaining very low latency. Movandi had already developed its RF front-end solution, known as BeamX.

The BeamXR solution makes it possible to boost or bend millimeter-wave signals so that they can either penetrate or go around buildings.

The BeamXR solution is intended to overcome the obstacles associated with millimeter-wave (mmWave) frequencies and accelerate large-scale 5G commercialization. "We're trying to be impactful beyond trying to make a device that's powerful," says Maryam Rofougaran, Movandi's co-CEO/COO. "Your base stations can have the highest output power and your devices can have the highest output power and highest performance, but this won't solve the issues surrounding coverage and the challenges generally associated with mmWave frequencies. It can be very challenging if you have a building in front of the base station, if you have trees, or if you have windows that have more loss.

"Some of these challenges have been experienced during trials and initial deployments. And while operators are now convinced that mmWave 5G is possible, there are still things that have to be improved."

To address the mmWave challenges mentioned, Movandi developed the BeamXR solution. "The BeamXR system is an affordable way of trying to address the challenges associated with line-of-sight and penetration," says Rofougaran. "For example, let's say a base station is trying to connect with a device inside a building and you're trying to get through a window that's more lossy or a wall. With BeamXR, you basically can enable that.

"Or if you have buildings that are blocking the base-station signals, BeamXR can be sitting on a pole outside and ensure that the signals go around the building. You're basically maximizing the coverage of the cell in an affordable way. You don't need to spend a lot of money to be able to get the coverage within a cell. When you want to come inside the building, you can actually use this device."

Rofougaran adds, "BeamXR is utilizing the front end we have developed—but it's more than that. It's a system that can take a signal, amplify it, and at the same time, move the signal around or make the beam wide enough to be able to get the coverage within the building. Or you can actually have multiple devices and reach different rooms and cover the whole building."

Rofougaran sums it up with these words, "The main concept is to make 5G more possible and get it everywhere." ■

KEEPING WATCH Over the IoT World

STAYING CURRENT WITH the latest and greatest in the Internet of Things (IoT) space—and the different wireless technologies associated with it—can be quite a challenge. Right in the thick of it all is Silicon Labs *(www.silabs.com).* The company offers a wide range of wireless solutions, supporting technologies like Wi-Fi, Bluetooth, Zigbee, and others.

Sid Sundar, senior product manager at Silicon Labs, recently weighed in on some of the emerging trends and technologies that he's seeing in the IoT world. "For a long time, I think people were waiting to see whether there would be one wireless technology to rule them all," said Sundar. "There were discussions about whether it would be Wi-Fi, Zigbee, Thread, Bluetooth, Z-Wave, or other proprietary standards. I think people are acknowledging that there's a place under the sun for all these wireless technologies, and they're each carving out a niche."

Sundar pointed out that the emergence of ecosytems is a major development in the IoT. "We're seeing a lot of decision-making by customers and product manufacturers now being driven on the ecosystem side," he explained. "There's no longer this idea of just trying to support every technology or service for every single device. Manufacturers are targeting the ecosystems they want to be a part of. We're seeing the choices that the ecosystem vendors are making, whether it's Comcast and Amazon going with Zigbee or security infrastructure teams going with Z-Wave.

"These choices that infrastructure teams and ecosystem leaders are making are driving decision-making on the end-node side. People still want to be able to utilize multiple protocols and talk to multiple devices, but they're recognizing much more that the technology choice depends heavily on the use case and application as well as the ecosystem they're targeting."

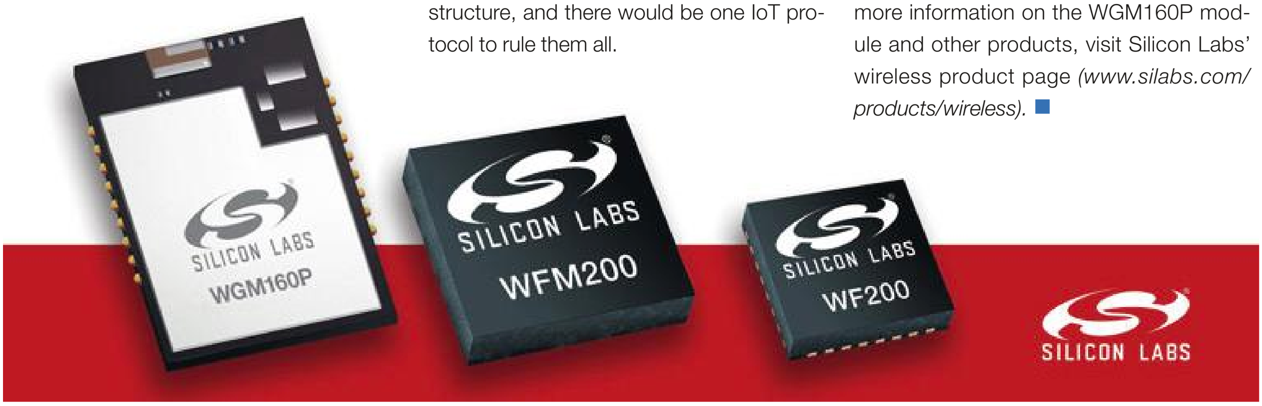
WI-FI'S RESURGENCE

Also gaining traction in the IoT, according to Sundar, is the reemergence of Wi-Fi. "The other trend I've noticed is the resurgence of Wi-Fi in IoT-type applications. I think part of it is this understanding that there is a divergence in all the standards that are being supported for IoT today. That isn't likely to be resolved anytime soon. I think a couple years ago there was a mentality that you would use Wi-Fi for streaming content, you would have low-power wide-area-network (LPWAN) consolidation for cellular infrastructure, and there would be one IoT protocol to rule them all.

"Given that's not happening, I think there's a resurgence of Wi-Fi in terms of it becoming more and more relevant for IoT end nodes. I think that's being driven by a couple of factors. One, we're seeing end nodes that actually need direct cloud connection capability and have reasonable throughput requirements. Security cameras are a great example of that. Also, I think there's a renewed emphasis by wireless vendors to try to drive Wi-Fi to get to a price point and a power point that makes it more and more acceptable for our end customers as a wireless solution of choice for IoT deployments."

Silicon Labs recently made an announcement concerning its new Wi-Fi solutions. They include the WF200 transceiver integrated circuit (IC), the WFM200 transceiver module, and the WGM160P standalone module *(see figure).*

The WGM160P Wi-Fi module is a standalone Wi-Fi solution optimized for IoT systems. It has a built-in host processor capable of running the full Wi-Fi stack and customer applications. The WGM160P supports IEEE 802.11 b/g/n Wi-Fi with low transmit and receive current. In addition, its blocking performance ensures robust operation in crowded network conditions. For more information on the WGM160P module and other products, visit Silicon Labs' wireless product page *(www.silabs.com/products/wireless).* ■



The WGM160P is a standalone module. The WF200 comes in a 4- × 4-mm QFN32 package, while the WFM200 is a 6.5- × 6.5-mm system-in-package (SiP) device.

MOVING MORE MMICs to Market

A supplier of monolithic microwave integrated circuits continues its product push in 2019, proven by recent introductions that include low-noise amplifiers, driver amplifiers, etc.

CUSTOM MMIC (WWW.CUSTOMMMIC.COM) has picked up the pace even further in delivering new monolithic microwave integrated circuits (MMICs) to the industry.

Following the company's large number of product releases in 2018, Custom MMIC has already introduced various MMICs in the early part of this year. Customers can also be assured that more new products are on the way.

One of this year's early arrivals is the CMD283 low-noise amplifier (LNA), which is the die version of the CMD283C3 LNA released last year. The CMD283 covers a frequency range of 2 to 6 GHz, delivering 27 dB of gain at 4 GHz and achieving a noise figure of 0.6 dB at the same frequency. It's well-suited for electronic warfare (EW) and communications systems that require small size and low power consumption.

Continuing the same theme, Custom MMIC also introduced two other LNAs: the CMD298 and CMD299. The CMD298 spans a frequency range of 17 to 25 GHz. At 21 GHz, it provides about 27 dB of gain and attains a noise figure of 1.4 dB.

The CMD299 is an extremely broadband LNA—it covers a frequency range of 18 to 40 GHz. At 30 GHz, the CMD299 delivers around 17 dB of gain and achieves a noise figure of 3.5 dB.

Another new release of note is the CMD295 driver amplifier. Covering a frequency range of 2 to 20 GHz, this amplifier provides approximately 26.5 dB of gain at 10 GHz. The CMD295 also achieves an output 1-dB compression (P1dB) of +16 dBm at 10 GHz.

Sparking interest on this front is the CMD293 driver amplifier *(see figure)*. Operating from 20 to 45 GHz, the CMD293 serves as a replacement part for the Avago AMMC-6345. At 30 GHz, the amplifier delivers 20 dB of gain and achieves a P1dB of +26 dBm.

Not to be outdone, the new CMD275 is the die version of the CMD275P4 low-phase-noise amplifier (LPNA). The

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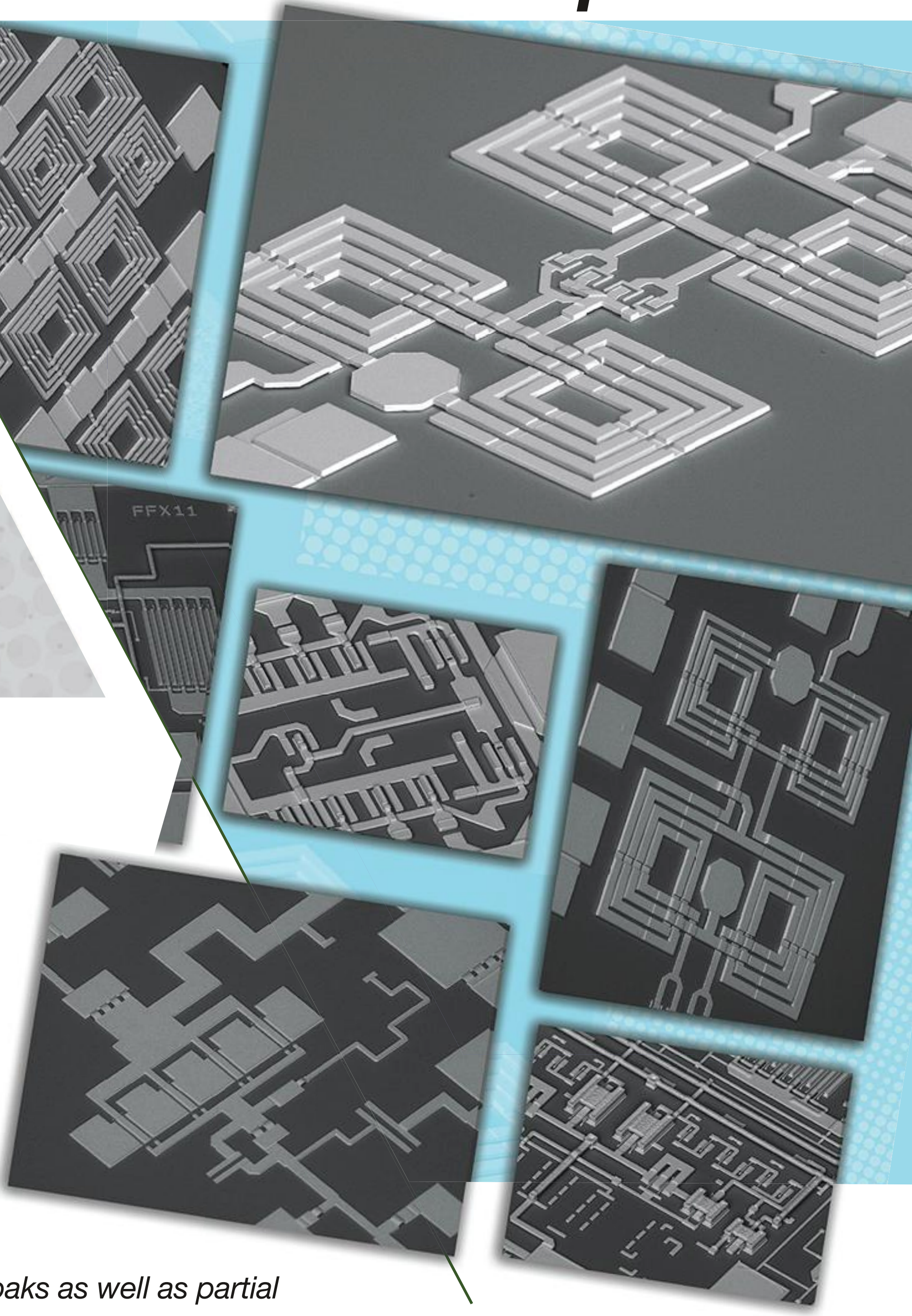

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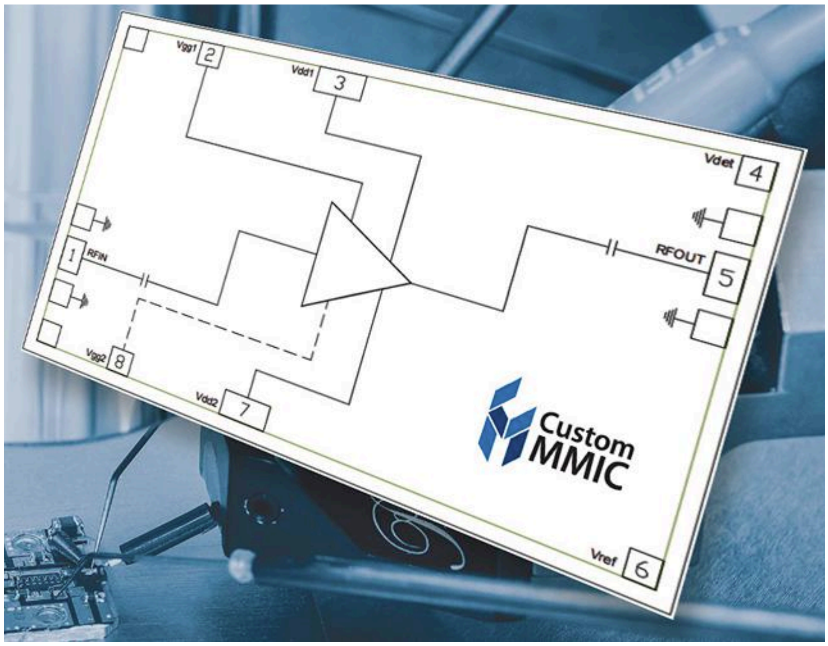
CMD275 operates from dc to 26.5 GHz, and will find homes in military, space, and communication systems. At 10 GHz, the device offers 16 dB of gain and achieves a noise figure of 5.5 dB. Furthermore, at 10 GHz, the CMD275 achieves a saturated output power level of +20.5 dBm. And with a 10-GHz input signal, the amplifier's phase-noise performance is −165 dBc/Hz at 10-kHz offset.

Lastly, the CMD297 is an analog phase shifter that operates from 5 to 18 GHz. It features a control voltage that ranges from 0 to 10 V, allowing the phase shift to be controlled over a 550-degree range at 7 GHz and a 240-degree range at 12 GHz. ■



The CMD293 driver amplifier covers a frequency range of 20 to 45 GHz.

LANSDALE PROMOTES McNaughton to QA Manager

LANSDALE SEMICONDUCTOR, a leading manufacturer of semiconductors for commercial, industrial, and military applications, promoted Michael "Mac" McNaughton to Quality Assurance (QA) Manager. McNaughton has been employed for more than 30 years at Lansdale/Motorola and has been involved in the company's high-reliability (hi-rel) activities. According to R. Dale Lillard, President of Lansdale, "McNaughton will be responsible for all the company's quality assurance and control functions, including Lansdale's ISO9001/2015 Certification and the Qualified Military Line to MIL-PRF-38535 requirements."

For many specifiers, Lansdale represents a source of long-available and earlier integrated-circuit (IC) designs as well as modern, state-of-the-art semiconductor technology. The company continues to produce over 3000 ICs, many from earlier developers such as Motorola, National Semiconductor, Fairchild, Harris, and Intel Corp. The firm follows an exclusive lifecycle management program to ensure customers of the availability of their devices. In his latest role, NcNaughton will ensure not only availability but the highest quality and reliability. ■

PLANNING FOR DEVICES Beyond mmWaves

MUCH HAS BEEN written recently about the growing need for components, devices, and circuits at millimeter-wave (mmWave) frequencies from 30 to 300 GHz. The need is fueled by applications such as advanced driver-assistance systems (ADAS) and 5G cellular communications systems that are taking advantage of the wide bandwidths available at those frequencies, especially when compared to the very occupied bandwidths at lower RF and microwave frequencies.

But what happens when the mmWave range also becomes congested? Researchers from the Department of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology (Cambridge, Mass.) are looking ahead to when even higher-frequency devices will be in demand, in the terahertz (THz) frequency range, and whether available semiconductor technologies can provide such devices to serve THz applications.

Because of the need to generate and detect THz-range frequencies (300 to 3000 GHz), transistors fabricated on silicon (Si) or silicon-germanium (SiGe) materials cannot simply be scaled or miniaturized to achieve sufficiently high maximum frequency of oscillation (f_{max}) to generate those frequencies. Silicon-based devices have been used for amplifier designs at frequencies of about 0.2 to 0.3 THz, but signal generation at frequencies above that range—when using silicon-based devices—requires harmonic generation.

Despite the limitations of silicon-based substrate materials, the researchers point to several innovative device designs on SiGe to hint at the possibilities of silicon for THz applications. This includes a 1-THz radiation source based on 130-nm SiGe heterojunction-bipolar-transistor (HBT) technology. The device integrates 91 coherent radiators within a 0.1-mm^2 chip area, with a multifunctional slot resonator that has a fundamental oscillation frequency (f_0) of 250 GHz. Radiation is used at multiples of the fundamental frequency to produce the 1-THz output frequency.

The high density of such coherent radiation arrays, when fabricated on relatively small chip sizes of about 10 mm^2, yield devices with relatively narrow bandwidths at 1 THz. Material parameters such as consistency of thickness and dielectric constant are critical to achieving performance consistency at 1 THz. But a THz laser chip of this type could provide the signal generation and sensing functions needed for practical short-range communications (within tens of meters) at extremely high data rates for wireless communications systems beyond the mmWave frequency range.

See "Filling the Gap," *IEEE Microwave Magazine*, April 2019, pp. 80-93.

SUPERCONDUCTING CIRCULATORS Channel Quantum Computers

CIRCULATORS ARE ESSENTIAL components in many high-frequency systems, providing signal flow and protection, such as from transmitters to receivers. Traditional coaxial circulators are being developed for the rise in millimeter-wave (mmWave) system applications through 110 GHz, but even higher-frequency requirements await them; for example, circulators for quantum-computing systems.

Rather than use conventional ferrite Y-junction circulators for such applications, researchers from Raytheon BBN Technologies (Cambridge, Mass.) and the National Institute of Standards and Technology (NIST) in Boulder, Colo., report on several nonreciprocal devices that function as more compact, quantum-limited superconducting circulators at cryogenic temperatures.

On-chip, semiconductor-based circulators and isolators can be designed as very small components and are able to provide the high isolation needed for many high-frequency applications. However, they don't always function well at the cryogenic temperatures of quantum-computing systems.

For that reason, several other superconducting circuit approaches, typically based on multiple Josephson junctions (JJs) with almost no resistance or loss at cryogenic temperatures or on superconducting quantum interference devices (SQUIDs), have been developed for possible integration into compact quantum-limited preamplifier circuits. These nonreciprocal circuits often mimic the behavior of much larger, microwave Y-junction circuits, although without the magnetic fields that must be avoided because of their deleterious effects on quantum-computing systems.

Much of the circulator research reported at cryogenic temperatures for quantum-computing systems mirrors the work being done on the design of circulators and isolators for RF, microwave, and mmWave frequencies for traditional commercial communications, defense, and test-and-measurement applications. However, they're used at much lower power levels and in much smaller package sizes (to better fit within a cryostat with additional superconducting circuitry). The researchers feel that a healthy exchange of design information between the two research groups can greatly aid in the pursuit of high-performance circulator solutions for both applications areas.

See "Circulators at the Quantum Limit," *IEEE Microwave Magazine,* April 2019, pp. 112-122.

BRIAN PETTED | Technology Leader, Laird Connectivity
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Taking a Closer Look at MIMO Radio Systems

What are the factors that push designers to opt for multiple-input, multiple-output systems? Selective and non-selective fading, OFDM, and channel equalization, to name a few.

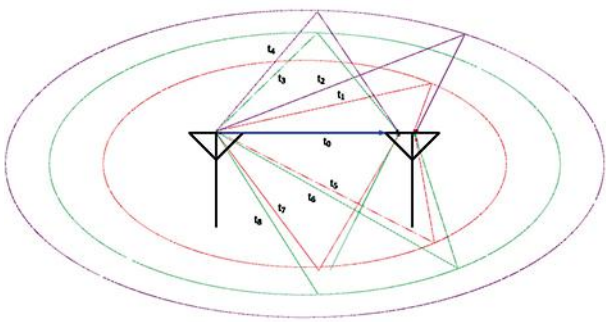
This article introduces the rationale and techniques associated with multiple-input, multiple-output (MIMO) based communication systems. The communication impairments due to multipath channels are discussed to provide the base motivation for the application of the MIMO technique. In particular, it explores the use of orthogonal frequency-division multiplexing (OFDM) and spatial multiplexing for equalizing broadband wireless channels with non-selective fading.

FADING CHANNELS

The presence of multiple reflections and multiple communication paths between two radio terminals causes signal fading impairments to a wireless-communication link. Both *selective* and *non-selective* fading exist. Non-selective fading happens when the frequency components over the signal bandwidth are dynamically attenuated by the same amount and do not create any signal distortion—only temporal signal loss. Selective fading is the case when smaller frequency segments of the signal's spectrum are attenuated relative to the other remaining frequency segments. When this occurs, the signal spectrum is distorted, which in turn creates a communication impairment that's independent of signal level.

For narrowband signals with non-selective fading, the communication impairment can be countered by providing more signal-level margin in the communication link or using selection-diversity techniques to select the best antenna input based on the relative signal strength. However, in the case of non-selective fading, the signal must be equalized to restore the signal fidelity and expected communication performance.

This fading is produced by the arrival of multiple replicas of the transmitted signal at the receiving antenna. The signal replicas are produced by multiple random reflections within the communication medium, such as an indoor communication channel. *Figure 1* shows the multipath concept for reference.



1. This is a multipath channel model illustration.

It's based on the notion of an ellipsoidal fading model.[1]

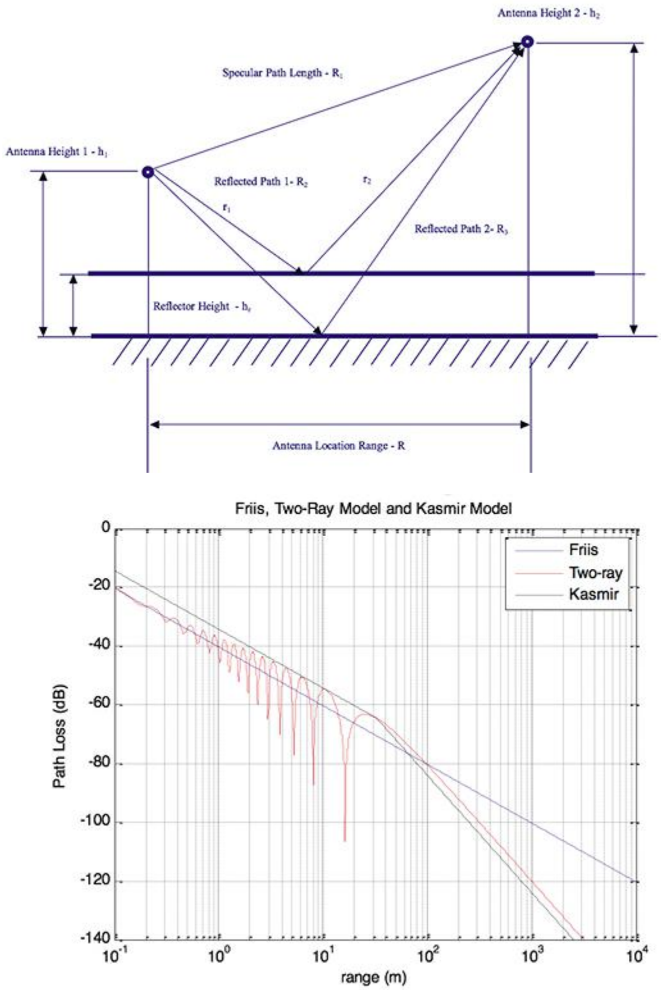
Consider the case in which a simple two-ray fading model is constructed and the signal attenuation versus communication range is able to be generated. One will find the presence of crests and nulls due to the constructive and destructive interference caused by the arrival of the signals at different delay times, leading to difference phase angles. In some cases, the phase angle can be at or near 180 degrees and can cause partial signal cancellation.

Conversely, signals that are in-phase may cause partial signal enhancement. *Figure 2* shows the attenuation profile for a two-ray fading model. Note the periodic signal nulls as the communication range changes. The period of the null spacing is one-half wavelength.

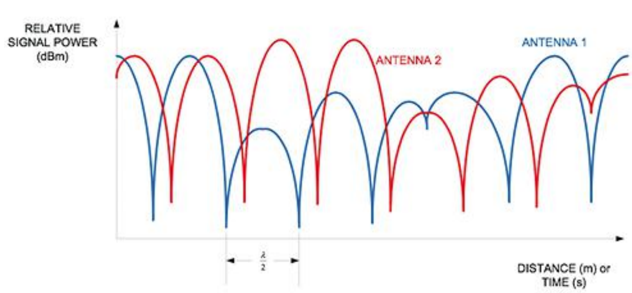
ANTENNA DIVERSITY

As mentioned previously, the effects of this localized and sudden attenuation can be compensated by receiving the signal at two different receiver-antenna placement locations and selecting the best antenna based on the signal strength or some other receiver performance measure. *Figure 3* illustrates this situation by showing the signal strength at two different antenna placements over communication range and/or time. The point of the illustration is that the signal strengths associated with the antennas generally are not correlated in time and/or space. When one signal is in a null, the other can be found near a maximum and selected for communication.

Selecting one antenna over the other based on signal quality, or selection diversity, is a technique that works well for non-selective fading. That's because antenna selection is essentially a signal-strength restoration technique. The effects of antenna diversity for a Rayleigh fading channel result in a 17.5-dB gain in performance. Note that the same performance can be achieved by introducing additional signal-level margin of 27.5 dB without the additional antenna and selection scheme.



2. Shown (above) are multipath effects on attenuation versus communication range for a two-ray model.



3. Relative signal strength is depicted for two receive antenna locations within a multipath channel.

SELECTIVE FADING

However, for broader band signals more commonly used in modern wireless systems like wireless LAN, selection diversity and other signal-strength restoration techniques are not enough to equalize the impairments imposed by the multipath channel due to selective fading.

Selective fading occurs when the signal bandwidth exceeds the coherence bandwidth of the channel.[2] The coherence bandwidth of the channel is approximately the reciprocal of the delay spread of the channel.[2] The delay spread is the rms average of the delay times of the channel's complex impulse response. The channel's impulse response is the received complex envelope at a particular point in space, assuming that a carrier signal is modulated by a Dirac impulse. The arrival of the various signal components can be modeled by a finite-impulse-response (FIR) filter.

Ideally, the channel transfer function only adds a flat fading process (constant attenuation versus frequency) and a single fixed time delay (linear phase). However, some cases result in the creation of a transfer function for the signal that provides asymmetric and frequency-dependent fading of amplitude, as well as a nonlinear phase response, assuming that significant sidebands of the signal are distributed across the entire transfer function.

If the sidebands of a complex modulated signal were distributed across the transfer function, there would be significant signal distortion and modulation conversion (AM to PM and PM to AM). This is again the effect of a multipath channel with a coherence bandwidth that's less than the signal bandwidth.

To compensate for these effects, the transfer function encountered via the communication channel must be equalized at the receiver. Ideally, if the inverse of the transfer function could be applied to the signal prior to detection to flatten the amplitude response and linearize the phase, the signal impairments would be eliminated.

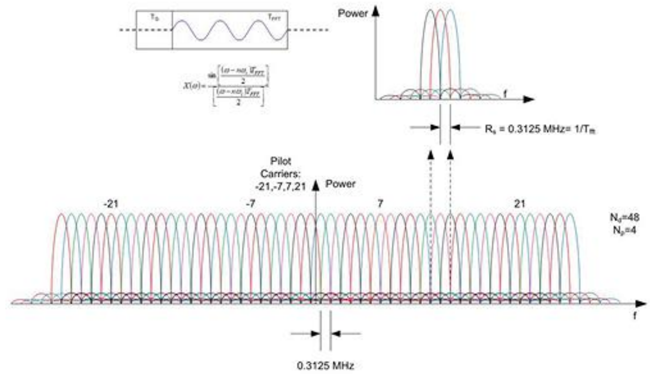
Several different types of transversal equalizers operate on the time-domain representation of the baseband signal to achieve the equalization. However, many rely on training sequences and training periods (receipt of non-information bearing training information that creates communication overhead).

OFDM AND CHANNEL EQUALIZATION

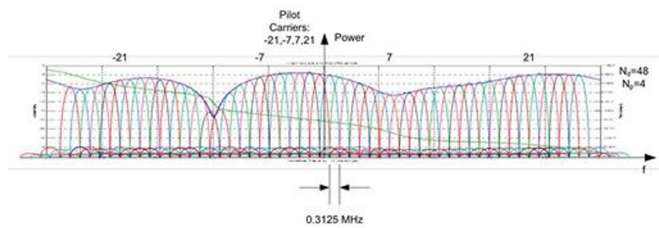
The introduction of OFDM signaling provided a means of spectrally efficient communications and a means for channel equalization in the frequency domain. *Figure 4* shows a diagram of an OFDM spectrum, revealing 48 data subcarriers and four pilot subcarriers. The pilot subcarriers are not information bearing, but rather are used to help maintain the carrier and timing tracking in low-signal-to-noise ratios since they are always BPSK modulated.

OFDM essentially offers a way to sample the magnitude and phase of the channel at any or all of the subcarrier frequencies, since the carrier phase tracked at the receiver and all subcarrier phases are coherent to the main carrier. However, in practice, performing continuous subcarrier phase tracking on each of the subcarriers is not executed. Rather, short and long training symbols with known patterns are transmitted with each packet. Therefore, the receiver can determine the channel transfer function, invert it, and then apply the inverse to the received spectrum to equalize the channel on a packet-by-packet basis.

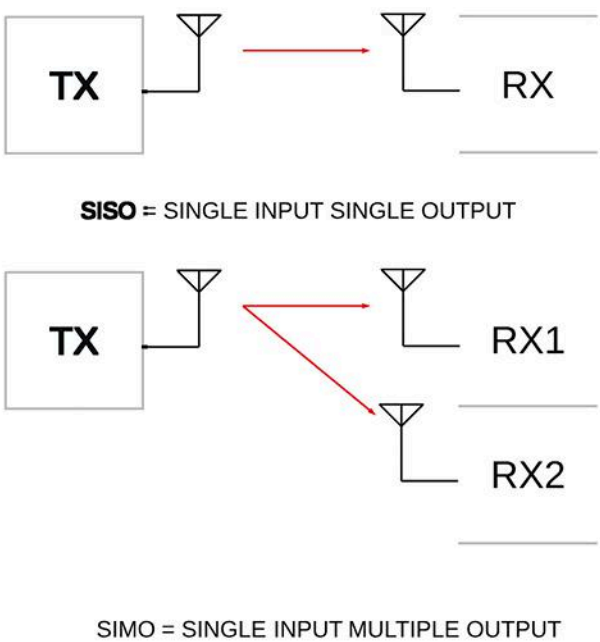
Figure 5 illustrates how the channel transfer function due to selective fading weights the received spectrum. At the receiver, the magnitude and phase of each subcarrier pro-

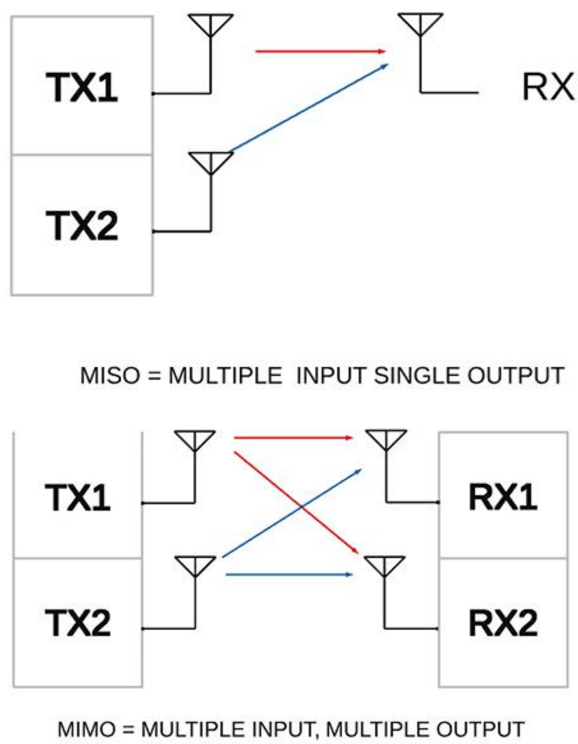


4. Three isolated subcarriers are present in this construct of an entire OFDM spectrum. Revealed is subcarrier spectrum that arises from amplitude masking by FFT interval and guard interval.

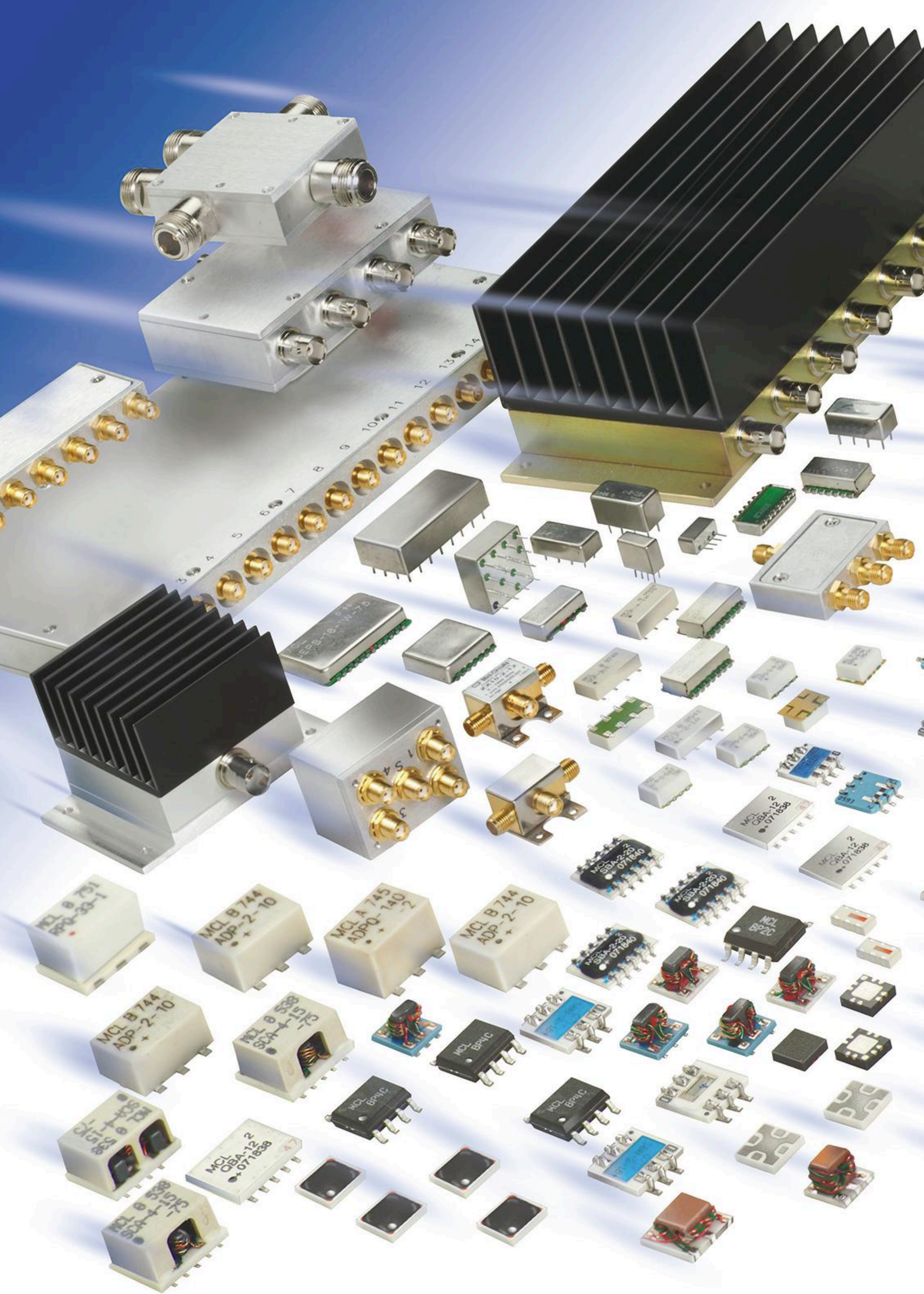


5. Depicted is the channel transfer function effect on OFDM spectrum. Each subcarrier has its magnitude and phase altered, but can be sensed and used to generate an equalization filter transfer function.





6. Shown are several communication system configurations.



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MCL A 745
ADPQ-140
MCL
QBA-12
071838
MCL
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MCL
BP2C
SBA-2-20
071840
SCA-4-15
-75

vide an estimate of the channel transfer function, $H_c(\omega)$. An equalization transfer function, $H_e(\omega)$, can be applied to the channel-weighted spectrum to re-normalize the spectrum in order to reduce or eliminate the effects of the channel.

$$S_{RX}(\omega)=H_c(\omega)S_{TX}(\omega)$$
$$H_c(\omega)=\frac{S_{RX}(\omega)}{S_{TX}(\omega)}$$

$$H_r(\omega)=H_c(\omega)H_e(\omega)$$
$$H_e(\omega)=H_c^{-1}(\omega)$$
$$H_r(\omega)=H_c(\omega)H_c^{-1}(\omega)=1$$

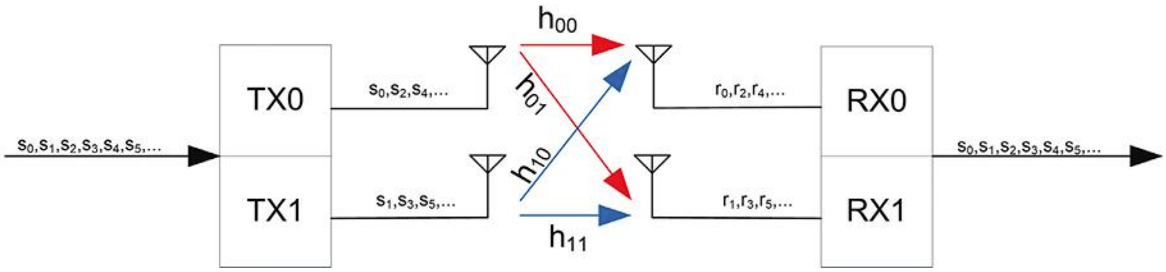
MULTIPLE-INPUT, MULTIPLE-OUTPUT SYSTEMS

The previous sections discussed multipath channels, non-selective fading, selective fading, and OFDM signaling. Furthermore, it was shown that antenna selection diversity is a technique for improving the performance in a non-selective fading channel and that OFDM provides for channel equalization against frequency-selective fading. This section digs into the MIMO technique, essentially bringing two elements together: OFDM and antenna diversity.

In general, different permutations of redundant transmitters and receivers improve the robustness of a communication link as well as its information carrying capacity. *Figure 6* shows the different general redundancy configurations: single-input, single-output (SISO), single-input, multiple-output (SIMO), multiple-input, single-output (MISO), and MIMO.

SISO systems do not provide any type of robustness or capacity improvement. They represent a basic wireless communication link. SIMO systems are configurations that provide receive-side diversity and provide additional robustness, but no capacity improvement. Examples of SIMO systems are receivers with selection-diversity schemes or linear-maximal-ratio-combining (LMRC) schemes.[2]

MISO offers transmitter diversity in that it couples to the channel at different points in space. Thus, the links will not have the same fading characteristics to the receive antenna and the spatial sum of the signals will be dominated by the stronger of the two signals. Or the transmitter signal design can be such that the combining at the single receiver can be made in an optimal fashion, as is done in space-time coding techniques.[2] MIMO systems de-multiplex the source data stream into multiple independent channel streams, allowing for both redundancy and channel-capacity improvement.[3]



7. In this case, 2-×-2 MIMO is a spatial multiplexer.

The MIMO technique is also referred to as spatial division multiplexing. A single source data stream is multiplexed between two spatial streams. As shown in *Figure 6,* direct links and cross links exist between the two transmitters and two receivers. As a result, four different communication channels now connect the two terminals, and the characterization of the channel has a higher complexity. However, the signaling technique when combined with the properties of OFDM modulation can lead to an efficient channel estimation and equalization scheme.

Figure 7 shows the spatial-multiplexing scheme in which even signals are transmitted on TX0 and odd symbols are transmitted on TX1. The two receivers, RX0 and RX1, receive both transmitted streams through four possible channel transfer functions: h_{00}, h_{01}, h_{10}, and h_{11}. These form a channel matrix, [H].

To equalize and extract the source symbol stream, an estimate of the channel matrix, [H], must be made. This can be accomplished by transmitting both streams using a coordinated system of pilot subcarriers and null subcarriers *(Fig. 8)*. *Figure 9* represents the received spectrum, showing that relative levels of each subcarrier indicate relative levels between the direct and cross channel terms in the channel matrix [H].

The received symbols at each of the receive inputs can be computed as follows:

$$r_0 = h_{00}s_0 + h_{10}s_1 \qquad \begin{bmatrix} r_o \\ r_1 \end{bmatrix} = \begin{bmatrix} h_{00} & h_{10} \\ h_{01} & h_{11} \end{bmatrix} \begin{bmatrix} s_o \\ s_1 \end{bmatrix} = [R] = [H][S]$$
$$r_1 = h_{10}s_0 + h_{11}s_1$$

For the case of pilot subcarriers relative to the null subcarriers:

$$r_{00} = h_{00}s_0$$
$$r_{10} = h_{10}s_1$$
$$r_{01} = h_{01}s_0$$
$$r_{11} = h_{11}s_1$$

Since the magnitude and phase of pilot subcarriers is known, the s-terms can be factored out and the elements of the channel matrix are determined. Given the channel matrix, the received signals can be equalized and restored according to:

$$[S] = [H]^{-1}[R] = \left[\frac{adj[H]}{|H|}\right][R] = \left[\frac{\begin{bmatrix} h_{11} & -h_{01} \\ -h_{10} & h_{00} \end{bmatrix}^T}{h_{00}h_{11} - h_{10}h_{01}}\right][R]$$

$$[S] = [H]^{-1}[R] = \left[\frac{adj[H]}{|H|}\right][R] = \left[\frac{\begin{bmatrix} h_{11} & -h_{10} \\ -h_{01} & h_{00} \end{bmatrix}}{h_{00}h_{11} - h_{10}h_{01}}\right][R] = \left[\frac{1}{h_{00}h_{11} - h_{10}h_{01}}\right]\begin{bmatrix} h_{11} & -h_{10} \\ -h_{01} & h_{00} \end{bmatrix}\begin{bmatrix} r_o \\ r_1 \end{bmatrix} = B\begin{bmatrix} h_{11}r_o - h_{10}r_1 \\ -h_{01}r_o + h_{00}r_1 \end{bmatrix}$$

Note that the originally transmitted signals can be restored perfectly if there's a perfect estimation of the channel matrix. One case that does not work due to a singularity in the matrix inversion is when all of the channel elements are equal or correlated:

$$[S] = [H]^{-1}[R] = \left[\frac{1}{h_{00}h_{00} - h_{00}h_{00}}\right]\begin{bmatrix} h_{00} & -h_{00} \\ -h_{00} & h_{00} \end{bmatrix}\begin{bmatrix} r_o \\ r_1 \end{bmatrix} = B\begin{bmatrix} h_{00}r_o - h_{00}r_1 \\ -h_{00}r_o + h_{00}r_1 \end{bmatrix}$$

The denominator of the leading term associated with matrix inversion determinant will equal zero, causing the singularity. Therefore, MIMO systems operate the best when the individual channel elements are not correlated.

The spatial-multiplexing technique associated with MIMO is another method that minimizes the effects of a multipath communication channel through its redundancy and channel-equalization properties. mw

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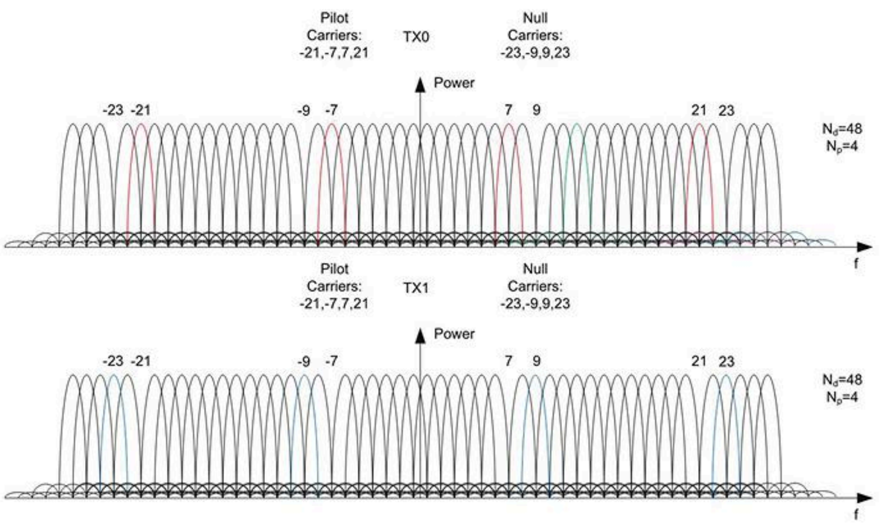
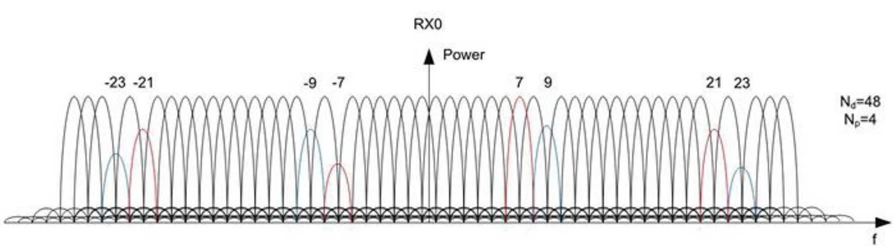


8. (Left) Here, 2-×-2 coordinated pilot subcarriers and null subcarriers are at each transmitter.



9. (Bottom left) The received spectrum at RX0 shows the relative levels of h_{00} and h_{10} from the pilot subcarrier levels.

To equalize and extract the source symbol stream, an estimate of the channel matrix, [H], must be made. This can be accomplished by transmitting both streams using a coordinated system of pilot subcarriers and null subcarriers.

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The Critical Role OTA Testing Will Play in 5G

For 5G applications, over-the-air testing will play a significant role in place of traditional cabled measurements.

In comparison to 4G, the fifth-generation (5G) mobile network is designed to deliver three primary use cases: the capacity to transmit/receive more data, improve responsiveness, and connect millions of devices at once. More specifically, this includes enhanced mobile broadband (eMBB), ultra-reliable, low-latency communications (URLLC), and increased connectivity to allow billions of devices and applications to come online seamlessly and communicate simultaneously.

Over-the-air (OTA) measurements are an essential part of the performance evaluation and certification of these wireless devices by measuring the transmit power and receiver sensitivity performance. With 5G moving from the research and development phase and into deployment, OTA testing for design validation and/or volume production becomes a more critical task. Network operators and device original equipment manufacturers (OEMs) must be able to evaluate and certify the reliability and performance characteristics of devices and base stations in environments that closely resemble those in which they are actually used.

OTA OVERVIEW

As 5G mobile technology evolves to millimeter-wave (mmWave) frequencies of 28 GHz, 39 GHz, and beyond, several drivers will necessitate OTA testing. At mmWave frequencies, signal-absorption rates are much higher, requiring the need for directional transmissions/reception (beam focusing or beamsteering) to boost the gain. Beamsteering will be a key feature in the context of 5G. It's a significant challenge to test the beamsteering capabilities of base stations and user equipment in every phase from research and development through production.

Only test systems that can handle 3D center-of-beam and off-center-of-beam measurements in a radiated environment with extremely accurate positioning systems can properly characterize a 5G device. This includes measuring EIRP/EIS, beam-transmit signal quality, beam-receive performance, beam-acquisition timing, and beam-tracking performance. It also involves side-lobe measurements that affect total radiated power, including in-band and out-of-band spectrum-emissions-related performance.

The level of component integration of a commercial 5G mmWave-capable device under test (DUT) will increase significantly over previous generations, making it almost physically impossible to connect the DUTs to the test equipment by cables. And even if cables could be connected, cable costs and cable losses at mmWave frequencies would be prohibitive. DUT fixtures supporting mmWaves can be extremely fragile. Consequently, test points such as those in the signal path from the output of a power amplifier to the input of an antenna will no longer exist.

Conducted measurements, i.e. measurements that are performed while the DUT is connected to the measurement equipment via cables, will be mainly replaced by OTA measurements, i.e. measurements of electromagnetic (EM) radiation. Test setups are needed for beam characterization and to check beam acquisition and beam-tracking performance. Only OTA test systems will provide this capability.

OTA testing of wireless devices is required by numerous regulatory agencies, standards organizations, industrial bodies, and carriers. To have global access and interoperability of mobile systems, certification tests have been developed so that manufacturers around the world provide the same level of quality in all new mobile devices. The CTIA (Cellular Telephone Industries Association) has set standards for OTA testing of 3G and 4G LTE devices and has certification labs all around the world.

Minimum performance requirements for OTA behavior have previously been defined in terms of radiated power levels during transmission and receiver sensitivity levels so that all calls are received under predefined circumstances. This will certainly need to happen in 5G device testing as well, especially in the U.S., where wireless carriers have also established industry performance requirements that must be met before a new device is permitted to run on its network.

OTA TESTING PRESENTS CHALLENGES

Several challenges exist related to OTA measurements and setting up an OTA test system for design validation and/or volume production. One set of challenges surrounds the antenna system. As the technology advances toward 5G systems, finding the proper setup and positioning for the 3D antennas to test the moving beams, while accounting for interference and scattering, will be difficult.

A new measurement dimension—space, or power versus direction of departure—must be included. One factor that the devices must account for is the blocking effect of the human body on the radiation pattern by using phantoms during OTA tests. OTA tests that measure the 3D antenna pattern can be performed in either near field or far field. Measurements in near field allow for smaller anechoic chambers. However, they require setups capable of measuring both phase and amplitude with high location precision and additional post-processing for the near-field to far-field transformation.

Another challenge is that each individual transceiver in the active antenna system needs to be characterized through an OTA interface, with measurements made for both the transmitter and the receiver. It's necessary that each transceiver turn on for individual verification or a set of transceivers turn on for joint assessment.

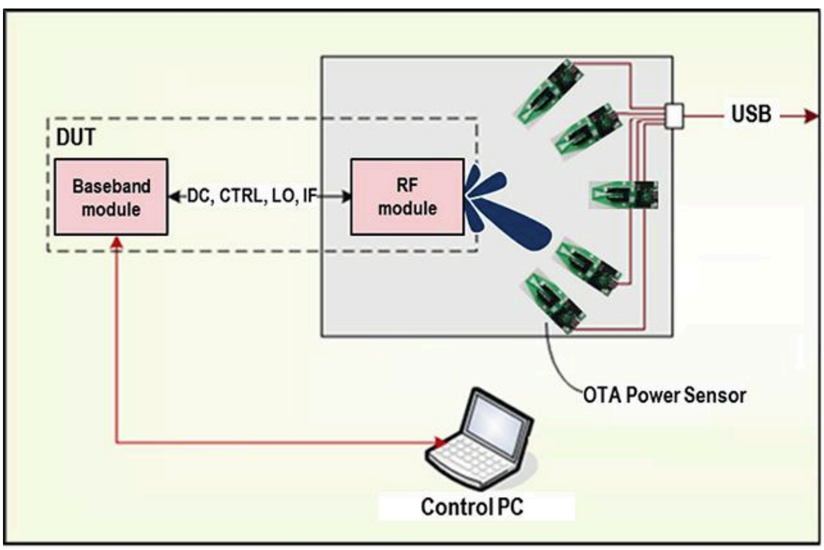
A third challenge relates specifically to beamforming, which will be used heavily in 5G. Due to the high path loss and limited range of a mmWave wireless system, precise beam generation and thus tracking and fast acquisition is required for mobile users. With antenna implementations for existing cellular technologies, static pattern characterization was sufficient. However, mmWave systems will require dynamic beam-measurement systems to accurately characterize beam tracking and beamsteering algorithms *(see figure)*.

A unique set of other challenges surrounds testing the devices for RF conformance, which today relies on well-characterized cabled test port connections to enable repeatable measurements. Such a test setup and the necessary calibration needs to be defined in an OTA environment due to the lack of connectorized RF test ports in 5G devices.

A similar challenge arises during volume production. Radiated device tests must be performed for every wireless-enabled device. Given how rapidly devices are produced, OTA test systems will need to be flexible and quickly adapt to meet the testing needs of future and unforeseen devices without sacrificing any quality or depth in the test methods. Calibration of the antenna system to ensure that the misalignment between RF signal paths is below a specified limit, as well as functional tests of the completely assembled unit, must all be performed.

OTA TESTING FUTURE IS HERE

Although connecting mobile devices to test equipment through cables is the most convenient and cost-effective method, it does not mimic the actual behavior of these devices in the real world. Over time, it will become less and less feasible as devices become more



This block diagram outlines an OTA test setup for a mmWave system.

integrated. This presents significant challenges as mobile operators move to higher frequencies to obtain larger bandwidths for support of 5G.

To test mobile devices in situations similar to what users actually experience, the tests must be executed wirelessly or over the air. As a result, designers can see what truly happens as the radio waves propagate over the air from the user equipment to the base station and from the base station to the user equipment.

New OTA power-measurement systems are accurate, affordable, and scalable to fit most any testing requirement. OTA measurement systems must support a frequency range from 27.5 to 75 GHz, thus covering the 28- and 39-GHz bands for 5G currently under discussion, the 57-to-66 GHz band defined for WLAN IEEE 802.11ad, and frequencies greater than 66 GHz for WLAN IEEE 802.11ay.

Removing the need for expensive test fixtures, OTA power measurement systems enable DUTs to easily be interchanged without impacting test reliability and repeatability. These OTA test systems, like the NRPM power-measurement solution from Rohde & Schwarz, can easily be integrated into a shield box and used to determine the direction of beamforming.

Some OTA power-measurement systems feature an integrated diode detector to measure the power directly on the receive antenna. The number of antenna modules can be selected to scale the system to meet different test requirements. The economical base configuration with one antenna module measures the power of the incident wave from the DUT to the antenna module. More antenna modules can be added to test the beamforming function.

CONCLUSION

As mobile technology evolves toward 5G systems, two main drivers will necessitate OTA testing. The level of integration of the DUT will increase significantly, and it will be physically impossible to connect the DUTs to the test equipment by cables, thus requiring OTA testing. Secondly, at mmWave frequencies, signal-absorption rates are much higher, requiring the need for beam focusing or beamforming to boost the gain.

OTA testing will be a game-changer for 5G networks. It's a prerequisite for the new mobile device and network designs and their certification. For 5G test systems, the basic components are expected to remain essentially the same, but they must be adapted for the higher frequencies. mw

Master the challenges of OTA calibration

Integrating antennas to the radio frequency chipset without connectors is increasingly common with both low cost IoT devices and especially in highly integrated 5G mobile communication equipment operating at mmWave frequencies. This makes testing a device under test (DUT) over the air (OTA) mandatory. To tackle the challenges of OTA testing it is key to understand the demands of antenna measurement and chamber setup.

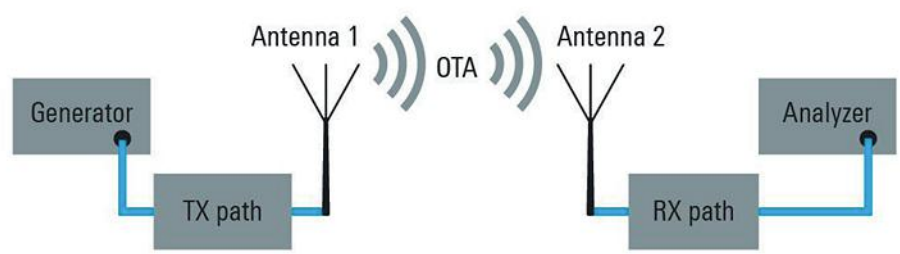
Calibration is an important first step in the preparation for OTA testing. The measurement results of a DUT should not be setup-depended, requiring a calibration for each measurement setup. The OTA link adds a significant amount of attenuation to the measurement setup due to the free space path loss (FSPL), in addition to the losses from cables and other connected components. Unlike with cables, a stable measurement distance and perfect mechanical alignment is crucial for OTA measurement accuracy in order to avoid differences in attenuation caused by positioning errors.

Port calibration, for example by using a network analyzer, cannot be conducted to an air interface. Therefore, another type of calibration is required.

Commonly, antenna gain measurements are conducted by comparing an unknown antenna to a reference antenna. Following this principle, an antenna with known gain is required to identify the calibration information of the OTA test setup and store these calibration data either on the measurement instrument or some external software controlling the measurement setup.

The high FSPL, longer cables due to the required measurement distance as well as the use of high frequencies require excellent dynamic range from the test and measurement equipment.

To address these different challenges, to calibrate OTA test setups and to carry out OTA measurements, Rohde & Schwarz has a diverse portfolio of vector network analyzers like the R&S®ZNA, vector signal generators, such as the R&S®SMW200A and signal and spectrum analyzers such as the R&S®FSW. Rohde & Schwarz also offers complete OTA test solutions, such as the R&S®ATS1000 antenna test chamber. Combined with Rohde & Schwarz test instruments, it is the ideal environment for 5G antenna characterization throughout the entire process from R&D to production for both active and passive devices.



www.rohde-schwarz.com/5G

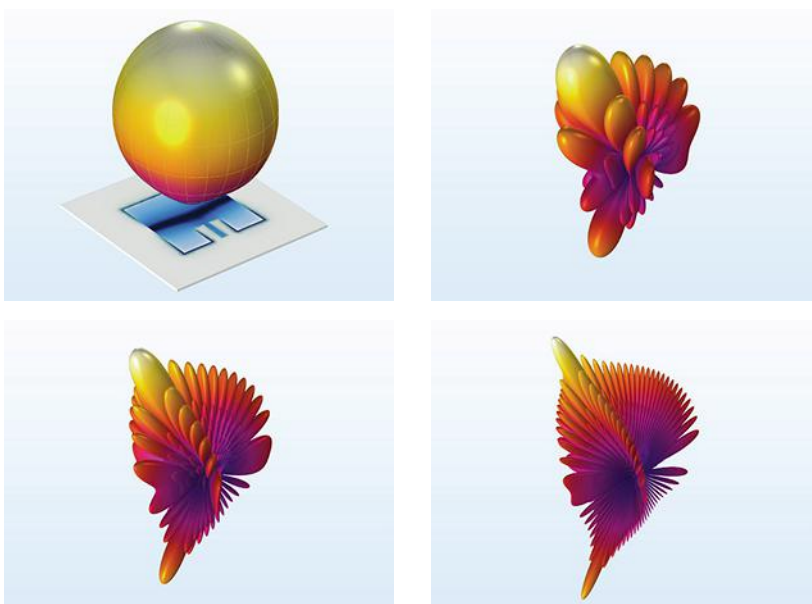
JIYOUN MUNN | RF Technical Product Manager, COMSOL
www.comsol.com

Software Tool Promotes Faster Antenna Evaluation

The latest version of this multiphysics software tool offers features like postprocessing workflows, simulation domain transformation, and more.

5G will likely induce a fundamental shift in a number of markets, including communication, automotive, Internet of Things (IoT), and virtual reality. Simulation and design engineers can address the architecture required to design applications that will bring the network to life using multiphysics modeling. The latest features introduced in the RF Module, a high-frequency electromagnetic (EM) simulation add-on tool that's now available in COMSOL Multiphysics version 5.4, will ultimately lead to more efficient product design for RF/microwave engineers. Highlights include:

- Postprocessing workflows and variables for antenna-array radiation-pattern analysis
- Simulation domain transformation utilizing time-to-frequency and frequency-to-time fast Fourier transform (FFT)
- Expanded material library for microwave and millimeter-wave (mmWave) circuit boards
- Application library updates through the deployment of commercially available connectors in the RF Part Library



1. A single microstrip patch-antenna simulation can be extended to estimate antenna-array performance. Synthesized radiation patterns for 8-x-8, 16-x-16, and 32-x-32 arrays are plotted.

UNIFORM ANTENNA-ARRAY POSTPROCESSING

An antenna array consists of two or more antennas in which signals are combined, thus improving performance in comparison to that of a single antenna. Utilizing an antenna array offers various benefits. An array can increase overall gain, provide reception diversity, eliminate interference, and steer the beam in a particular direction, among other aspects.

The radiation pattern of an antenna array can be quickly evaluated from the radiation pattern of a single antenna element by using an asymptotic approach (*Fig. 1*). This approach multiplies the far field of a single antenna with a uniform array factor during postprocessing. Including just a line of expression during the postprocessing can deliver the visualization of the far-field radiation pattern for an arbitrary number of antenna arrays without running the simulation again. The ability to efficiently visualize and analyze a number of antenna arrays has become more important with the impending 5G network, which will enable multi-beam multiplexing and massive multiple-input, multiple-output (MIMO) technologies.

EFFECTIVE 3D FAR-FIELD AND RCS FUNCTIONS

With the antenna array optimized and ready to go, we can use it to perform a radar-cross-section (RCS) analysis. The RCS characteristics are largely influenced by the electrical size and nature of the target subjected to the radar beam. To achieve accurate results, we must analyze the problem by solving full-wave equations. 3D full-wave equations often require a great deal of computational resources. To ensure accuracy without compromising computational speed, a far-field analysis of a 3D model can be performed by running an equivalent 2D axisymmetric model (*Fig. 2*).

With the introduction of the latest version of COMSOL Multiphysics, 3D far-field norm functions are available in 2D axisymmetric models for the following cases:

- Antenna models excited with circular port type and a positive azimuthal mode number
- Scattered field or RCS analysis computed with the predefined circularly polarized background field

WIDEBAND FAR-FIELD STUDY THROUGH TIME-TO-FREQUENCY FFT

Transmitting and receiving calls, text, and data over wider-bandwidth frequency channels have led communication systems designers to look at multi-band frequencies and their available bandwidths to deliver the communication speeds anticipated for the future. By using simulation tools, engineers can analyze a wideband frequency-domain antenna far-field pattern in the time-domain physics interface, facilitating faster communication speeds for numerous technologies.

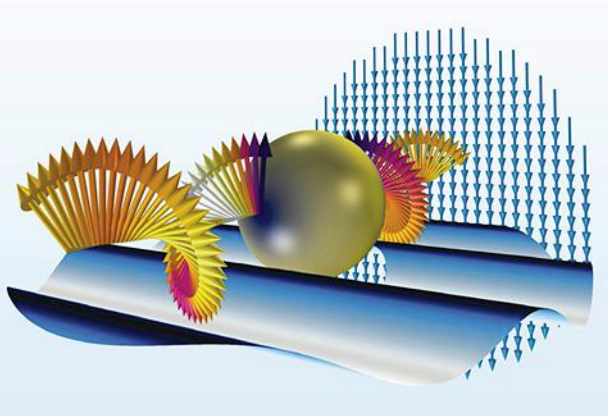
Frequency-domain analysis delivers one result point per frequency. To obtain the results over multiple frequency points, one must run the simulation multiple times in the frequency domain. Therefore, computational time is proportional to the number of frequency points.

However, combining time-to-frequency and FFT will allow for a wideband simulation with a very fine frequency resolution, essentially eliminating the need to run multiple analyses with one simulation (*Fig. 3*). Using this technique, a single simulation in the time domain can achieve a wideband frequency-domain simulation with many frequency steps.

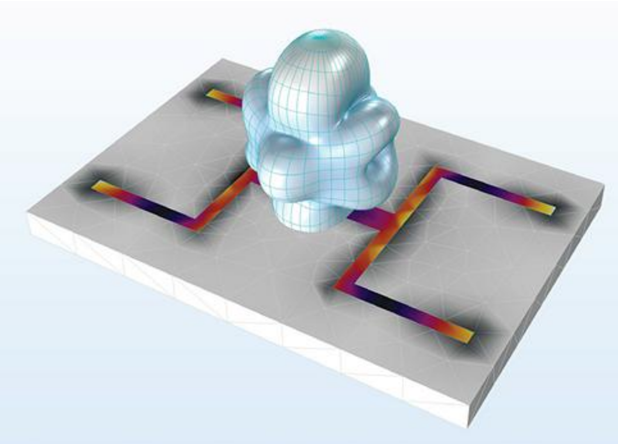
VIRTUAL NETWORK ANALYZER FUNCTIONALITY

The most conventional RF and microwave circuit examples are eventually computed in the frequency domain to calculate S-parameters. To address signal-integrity (SI) problems with regard to time-domain reflectometry (TDR), though, the analyses may require additional transient computation.

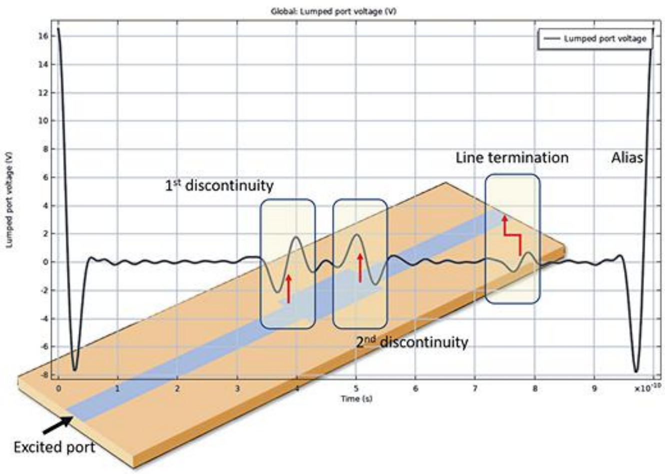
Using the frequency-to-time FFT combined with the frequency-domain study, it's possible to perform TDR analysis. The impedance discontinuities and mismatches on a transmission line can be identified by examining the signal-



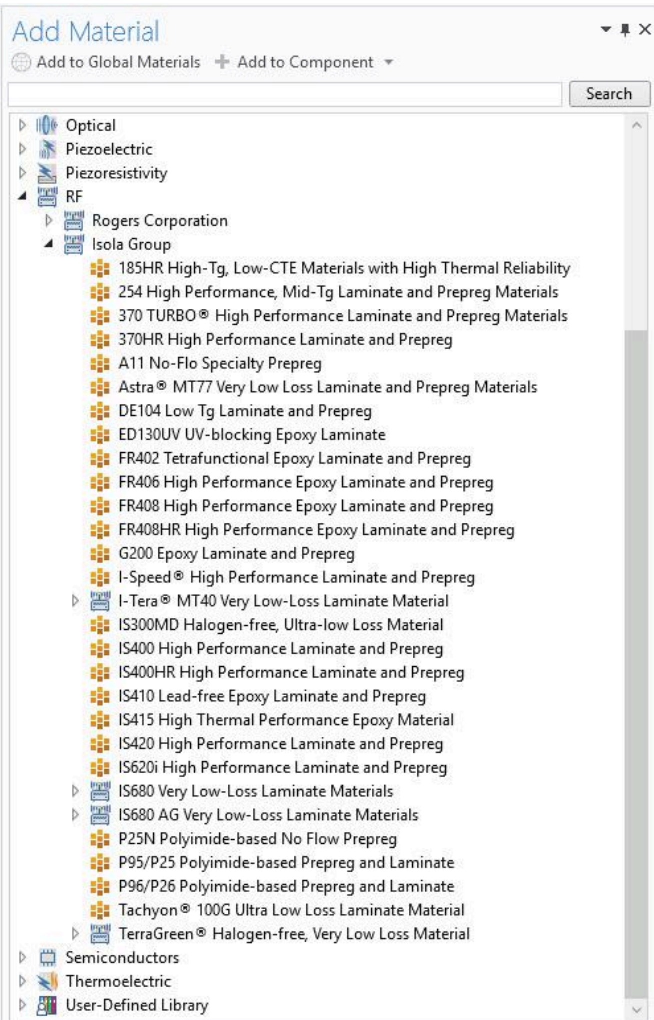
2. This is a 3D representation of a 2D axisymmetric model. Through a 2D axisymmetric model with a circularly polarized background field, it's possible to estimate the scattered field response of a 3D sphere excited by a linearly polarized background field.



3. The far-field radiation pattern at the second resonance is visualized for a printed dual-band antenna strip model. The electric-field norm distribution is also added.



4. This is a defective microstrip line model analyzed with frequency-to-time FFT. The overshoot and undershoot of the signal in the 1D plot describe the discontinuities of the microstrip line.



5. COMSOL expanded the RF Material Library for cicuit-board simulation.

quality variation in the TDR (*Fig. 4*). This allows for more efficient analysis of cables and optical fibers, for example.

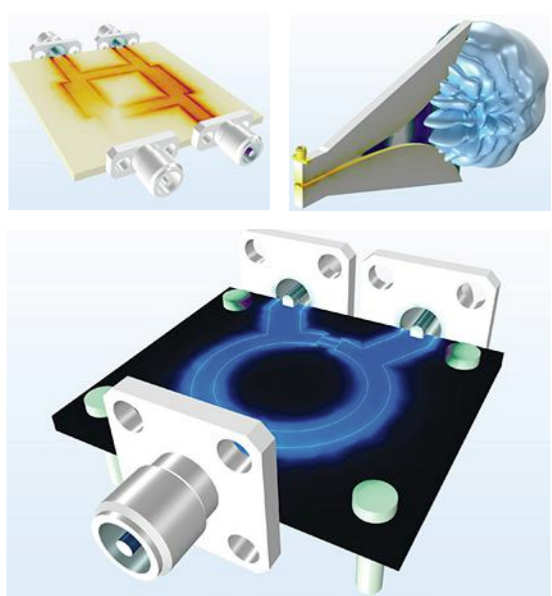
ADDITIONAL SUBSTRATES IN THE RF MATERIAL LIBRARY

As antenna designs become more complex to meet the diverse and demanding needs of the market, the RF Module material library has expanded to include more than 100 substrate materials for modeling printed RF, microwave, and mmWave circuits (*Fig. 5*). In addition, more than 40 substrate materials from the Isola Group (*www.isola-group.com*) were added in this release to support work on circuit board design.

UPDATED APPLICATION LIBRARY WITH COMMERCIAL CONNECTORS

A design task, such as repeatedly setting up identical geometry sequences, can be simplified by utilizing the RF Part Library. The Part Library contains partially parameterized complex shapes, such as connectors, surface-mount devices, and waveguides, that are useful for circuit and antenna simulations. Predefined selections—a group of boundaries—in each part help to easily define the conductive boundary while setting up the physics. A few Application Library examples have been updated to demonstrate the usage of these parts (*Fig. 6*).

Visit *https://www.comsol.com/release/5.4/rf-module* for the full details regarding 5.4 updates in the RF Module. mw



6. Shown are an SMA connectorized branch-line coupler, a double-ridged horn antenna, and a Wilkinson power divider.

JACK BROWNE | Technical Contributor

The Wireless Standard Shuffle from 1G to Wi-Fi 6

Wireless standards set the guidelines and limits for equipment manufacturers seeking to comply with the requirements of the latest wireless-communications networks.

Much is being written and imagined about the many capabilities of future wireless-communications systems and reaching into higher frequency ranges. But current wireless systems are based on well-conceived standards, which have worked for many applications, from simple radio-frequency identification (RFID) tags for tracking goods in warehouses to more elaborate 4G Long Term Evolution (4G LTE) cellular wireless systems. 5G cellular technology may be coming, but existing standards define quite a bit of wireless-communications technology that already works quite well.

Early mobile cellular telephones used analog transmission techniques in 1G systems, switching to digital switching in the following generation. ***(Courtesy of Wikipedia)***

Wireless standards organize radio waves into separate spaces, from the shortest-distance personal area networks (PANs) to longer-distance satellite-communications (satcom) systems, so that those radio waves coexist with minimal interference. Scientific organizations like the IEEE and the International Telecommunications Union (ITU) develop wireless standards for different technologies and applications, for compatibility and efficiency.

Many different working groups may exist within one organization. These include the many IEEE 802.11 wireless local-area-network (WLAN) working groups for different forms of short-range WLAN communications systems, including at mmWave frequencies (the IEEE 802.11ad working group).

The IEEE's working groups lend tremendous support to the continuing development of wireless standards for many different applications. For example, the IEEE 802.11 working group is focused on the enhancement of WLAN technologies and systems, while the IEEE 802.15 working group is devoted to wireless specialty networks. Standards developed by this latter working group include IEEE 802.15.4-2015 for low-power, low-data-rate WPANs and IEEE 802.15.3e.2017 for high-data-rate, multimedia wireless networks, including close-proximity point-to-point communications. For higher frequencies, IEEE 802.15.3c-2009 defines wireless networks capable of data rates in excess of 5 Gb/s using the 60-GHz band.

In many cases, wireless-communications standards are managed by industry groups or forums, such as Bluetooth short-range wireless devices from 2.400 to 2.485 GHz. Initially developed as part of an IEEE standard (IEEE 802.15.1), it's managed by the Bluetooth Special Interest Group (SIG), which boasts more than 30,000 companies as members. Bluetooth is among the most popular short-range wireless standards, replacing cables in many applications.

Similarly, Worldwide Interoperability for Microwave Access (WiMAX) is a family of wireless standards developed by the WiMAX Forum. Based on IEEE 802.16 wide-area-network (WAN) communications standards, WiMAX is one of the most popular wireless WAN standards for various "last-mile" wireless applications, including wireless sensor networks.

By now, all wireless standards are digital, and a common trend is for higher data rates for fixed or mobile communications in whatever bandwidth is available. This need of bandwidth in support of higher data rates has pushed operating frequencies higher, where bandwidths are available. Wireless cellular systems provide a good example of this trend, moving from the sub-1-GHz frequencies of the first-generation analog advanced mobile phone service (AMPS) wireless systems to the multiple-frequency bands of 5G cellular wireless networks, including at millimeter-wave (mmWave) frequencies.

TABLE 1: COMPARING CELLULAR RADIO STANDARDS

Generation	Technologies	Data rates
1G	AMPS, NMT, TACS	2.4 to 14.4 kb/s
2G	GSM, cdmaOne	14.4 kb/s
2.5G	GPRS, EDGE, DECT	144 kb/s
3G	W-CDMA, TD-CDMA, UMTS, 3GPP	3 Mb/s
4G	LTE LTE Advanced	100 Mb/s 300 Mb/s

TABLE 2: A BRIEF LOOK AT WLAN STANDARDS

Standard	Data rate (Mb/s)	Frequency (GHz)	Approximate range (distance from router, ft)
802.11a	54	5.0	50
802.11b	11	2.4	150
802.11g	54	2.4	50
802.11n	300	2.4/5.0	175

WIRELESS EVOLUTION

Early wireless standards such as AMPS were relatively inefficient in their use of bandwidth, employing 30-kHz-wide channels in the 800-MHz band. One of the first wireless mobile telephone standards, the Nordic Mobile Telephone (NMT) service developed for Norway, Sweden, and Denmark, made use of two different frequency bands in its 450-MHz NMT-450 and 900-MHz NMT-900 variants. Many industry and standards organizations have grown throughout the years in support of different wireless cellular telephone standards, such as the Third Generation Partnership Project (3GPP) and its work in aiding the growth of 3G and 4G wireless telephone standards.

As the number of carriers and subscribers expanded, the need for bandwidth would increase. This, in turn, required enhancements in modulation, multiple-access schemes, and digital switching in subsequent generations of cellular communications standards through current 4G Long Term Evolution Advanced (LTE-A) systems. The steady rise to the now billions of worldwide wireless mobile telephone subscribers has led to the somewhat accelerated development of high-speed, high-frequency 5G wireless systems.

Advances in mobile wireless telephone hardware have followed the evolution of cellular standards and their base stations, from large and power-hungry to much smaller, more energy-efficient units with increased computer processing power. Early briefcase-sized mobile telephones *(see figure)* were designed more for use in automobiles than to be carried, and the aggressive power consumption led to extremely short battery recharge cycles.

Those early wireless-communications devices have evolved along with the wireless standards and networks, to the current, microprocessor-managed "smart" wireless systems that double as memory banks and portable computers for many users. A brief comparison of cellular telephone standards shows how data rates have increased even as the size of mobile telephones continues to shrink *(Table 1)*. The most drastic development when moving to the second generation was the change from analog to digital transmission/reception techniques, which also gave rise to the availability of the short-message-service (SMS) function in 2G cellular systems.

The transition from 1G AMPS to 2G cellular systems became known for its change from analog to digital transmission protocols, including code-division multiple access (CDMA) and Global System for Mobile Communications (GSM), a time-division multiple-access (TDMA) scheme in which radio transmissions are broken into different time slots. Techniques such as TDMA and frequency-division multiple access (FDMA) in 2G cellular standards sought more-efficient use of spectrum than in analog AMPS systems.

SEARCHING FOR SPECTRUM

Bandwidth is a precious commodity for any wireless network and available bandwidth tends to be fragmented. Thus, many wireless carriers wind up with "collections" of frequency spectrum that's scattered depending on geography.

The fragmented radio spectrum and continuing quest for higher data rates in wireless standards has encouraged the development of innovative transmission protocols over the years, such as FDMA and TDMA. In addition, wireless network infrastructure has made use of novel design approaches. For example, multiple-input, multiple-output (MIMO) antenna architectures enable the use of beamforming techniques to achieve signal connections even in noise environments, serving simultaneous wireless users without sacrificing data rates.

Later cellular communications standards, such as 4G LTE-A, have also made use of carrier aggregation to combine radio channels and create wider effective bandwidths from the bits and pieces of spectrum, even if they are not continuous. Newer cellular standards such as 3G and 4G have incorporated smaller, closely spaced cells as well. Equipped with smart signal switching, they compensate for growing demands for faster data communications even with limited frequency spectrum resources.

As part of the development of worldwide 5G wireless standards, the IEEE 5G Initiative is compiling a massive database related to 5G technology and applicable standards that will be available via internet access at the IEEE website *(www.ieee.org)*. In addition, the organization is inviting online feedback at *www.5gandbeyonddb@ieee.org* for those wishing to contribute to the development of 5G wireless standards.

Wireless standards differ in terms of communications distance and power, from far-reaching cell- and satellite-based systems to lower-power wireless standards such as single-building WLANs. The IEEE's set of 802.11 WLAN standards are probably the world's most widely followed wireless computer networking guidelines. They're supported by additional non-profit organizations such as the Wi-Fi Alliance, which helps certify the compliance of new electronic products to IEEE 802.11 standards.

The latest generation of consumer and commercial Wi-Fi products claimed to meet IEEE 802.11ax requirements have been branded as Wi-Fi 6—the sixth generation of Wi-Fi *(Table 2)*. Prior to Wi-Fi 6, previous generations of Wi-Fi technology have been Wi-Fi 5, which embodied IEEE 802.11ac technology, and Wi-Fi 4, aided by IEEE 802.11n technology. mw

Cover Feature

JACK BROWNE | Technical Contributor

DIRECTIONAL COUPLER Commands 10 to 110 GHz

This compact coaxial directional coupler maintains flat 10-dB coupling and low mainline insertion loss with consistent directivity across a 100-GHz bandwidth.

Bandwidth is simply becoming a scarcer commodity as consumption of RF and microwave frequencies continues at an ever-quickening pace. As a result, many emerging wireless communications applications are reaching millimeter-wave (mmWave) frequency bands, creating greater demand for higher-frequency components in system and test-and-measurement applications.

One of these vital components is the directional coupler, which led longtime innovator Krytar to develop its model 1100110010 10-dB coaxial directional coupler with impressive 100-GHz bandwidth, from 10 to 110 GHz. It maintains low loss across that wide bandwidth, providing a single coupling solution for many of the emerging applications at mmWave frequencies.

1. Model 1100110010 is a compact 10-dB directional coupler with low loss and high directivity from 10 to 110 GHz.

Three-port directional couplers such as the model 1100110010 *(Fig. 1)* are designed to generate two signal paths from an applied input signal. Directional couplers are often designed with a pair of adjacent transmission lines, such as microstrip or stripline transmission lines. In this architecture, one of the transmission lines is the main or through signal path with most of the power; the transmission line alongside it is the coupled line with one terminated port, often in a load resistor.

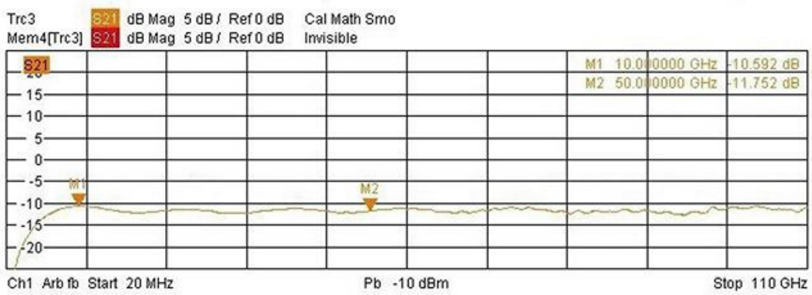
Ideally, the output-power level of the mainline signal would be reduced very little—only by the amount of signal power coupled from the input signal. However, normal insertion loss accounts for some additional loss of mainline power. The power level of the second output signal—the coupled signal path—is reduced by the coupling factor of the coupler along with any insertion loss associated with that signal path. Signal interfaces, such as coaxial connectors, will also contribute to some loss of initial signal power.

Directional couplers are designed to operate within a well-matched system, such as 50 Ω, promoting smooth signal flow from a signal source, through the coupler's input port, and through the output port to additional components in a system, such as a signal analyzer in

Directional couplers are designed to operate within a well-matched system, such as 50 Ω, promoting smooth signal flow from a signal source, through the coupler's input port, and through the output port to additional components in a system, such as a signal analyzer in a test system.

a test system. Again, in real-life applications, some amount of impedance mismatch is inevitable, and signal power will be reflected at impedance mismatches. This results in an increase in return loss as signal power is sent back through the directional coupler, often dissipated as heat.

In designing directional couplers for practical bandwidths, such as 10 GHz, computer modeling and attention to design details help minimize causes of signal loss. Perhaps what makes the performance of the model 1100110010 directional coupler unique is that it's consistent across a 100-GHz bandwidth—not just in loss behavior, but in coupling, VSWR, and other critical parameters that gauge a directional coupler's usefulness.



2. The model 1100110010 directional coupler maintains flat 10-dB coupling across a wide 100-GHz bandwidth.

BROADBAND BUT CONSISTENT

The model 1100110010 directional coupler is only 2.31 in. long (1.55-in. package length with two 0.38-in. long coaxial connectors) and 0.80 in. wide. It weighs a mere 1.2 oz. and is equipped with 1.0-mm female coaxial connectors. It's designed as a directional coupler with 10-dB nominal coupling and extremely flat coupling. Coupling that's flat within 1 or 2 dB is generally considered good for a coupler with one-tenth the bandwidth. But the model 1100110010 directional coupler exhibits nominal coupling of 10 ±1.5 dB from 10 to 90 GHz *(Fig. 2)*, only falling to a slightly wider coupling window of 10 ±1.8 dB from 90 to 110 GHz for the smallest-wavelength signals in its range.

The mainline insertion loss, which includes the power coupled from that line (roughly about 0.5 dB), is only 5.5 dB across the full bandwidth. The maximum VSWR is 1.80:1 at any port 10 to 50 GHz and 2.50:1 at any port 50 to 110 GHz. The directional coupler is rated for maximum continuous wave (CW) of 20 W across the full frequency range and peak power of 3 kW for pulse widths as wide as 100 µs, depending on pulse repetition interval (PRI) and pulse repetition frequency (PRF).

The directional coupler achieves frequency sensitivity (amplitude flatness) of typically ±1.25 dB from 10 to 90 GHz and a still-respectable ±1.80 dB from 90 to 110 GHz. It provides directivity of at least 10 dB from 10 to 55 GHz and at least 7 dB (and typically 10 dB) at higher frequencies from 55 to 110 GHz. For applications requiring multiple couplers on multiple channels, such as high-frequency antenna beamforming systems, the unit-to-unit coupling tolerance (coupling consistency from unit to unit) is also quite good, within ±1.50 dB across the full bandwidth from 10 to 110 GHz.

Broadband directional couplers such as the 1100110010 support a growing number of applications at mmWave frequencies. The component meets MIL-C-15370 environmental requirements for military applications. It will prove useful for power monitoring and leveling in many different systems, including antenna beamforming systems, electronic-warfare (EW) systems, electromagnetic-compatibility (EMC) testing, radar systems, and wireless communications systems.

When combined with a relatively "narrowband" directional coupler such as the model 100312410, which is a 10-dB coupler with ±1-dB coupling flatness from 0.3 to 12.4 GHz, a total frequency range of 300 MHz to 110 GHz can be covered with consistent directivity, low mainline loss, and excellent coupling flatness. The combo would thus meet many present and future test-and-measurement industrial and military applications, and even well beyond the current requirements of emerging commercial mmWave applications such as 5G cellular communications and advanced driver-assistance system (ADAS) front and rear radar systems. mw

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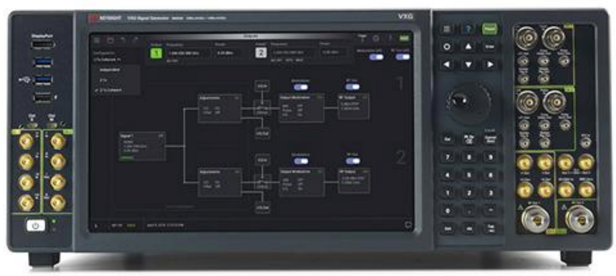
CHRIS DeMARTINO | Technical Engineering Editor

These Microwave Signal Generators are Ready for 5G

A new series of microwave signal generators offers high-frequency, wide-bandwidth performance and other benefits, and is well-equipped to handle 5G applications and more.

Higher frequencies are more important than ever, as 5G communications, satellite communications (satcom), and radar applications all plan to utilize a wide range of frequencies that extends into millimeter-wave (mmWave) bands. That means test-and-measurement companies must keep up by providing equipment that can generate mmWave signals with very wide bandwidths. These companies must also support other components like complex modulation schemes and multiple-antenna techniques.

To satisfy these demands, Keysight Technologies *(www.keysight.com)* recently launched the VXG Series of microwave signal generators. The series consists of the M9384B VXG benchtop instrument *(see figure)* and the M9383B VXG-m modular PXIe version.



The M9384B VXG microwave signal generator offers dual coherent channels.

POWERFUL PERFORMANCE

The VXG microwave signal generators cover a frequency range of 1 MHz to 44 GHz. They also provide modulation bandwidths as high as 2 GHz. The VXG instruments contain dual, phase-coherent, and fully calibrated signal generators, making them well-suited for the test requirements of advanced 5G designs. The fully calibrated dual channels allow for quick execution of receiver blocker and interference testing without changing device setups. And the phase coherency means that relative phase, time, and amplitude offsets can be controlled between the two channels.

High output power is another significant attribute of the VXG Series—the instruments can deliver signals at 28 and 39 GHz with maximum power levels of +24 dBm. Such performance makes them ideal for 5G over-the-air (OTA) testing.

In addition to high output power levels, Keysight emphasizes that the VXG generators achieve low error-vector-magnitude (EVM) and minimal adjacent-channel-power-ratio (ACPR) performance. Specifically, an EVM of 1.0% is achieved for 28- and 39-GHz signals with a 100-MHz bandwidth and an amplitude of +10 dBm. For 28- and 39-GHz signals with a 400-MHz bandwidth and an amplitude of +8 dBm, the EVM is 1.3% and 1.5%, respectively. Furthermore, the ACPR is −50 dBc in the case of a 28-GHz signal with a 100-MHz bandwidth and an amplitude of 0 dBm.

Another key performance metric of the VXG Series is phase noise, which Keysight boasts is "the world's lowest for a mmWave vector signal generator (VSG)." At 10 GHz with a 10-kHz offset, the phase noise is −126 dBc/Hz.

SIMPLIFYING SETUPS AND MORE

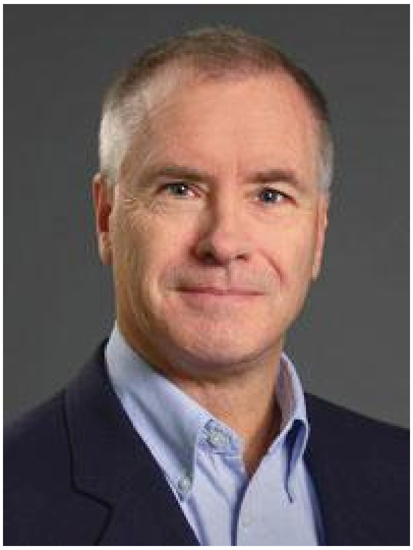
Keysight points out that the VXG Series is essentially a "one-box" approach that can replace multi-box solutions, thereby simplifying measurement setups and complex calibration routines. The company maintains that this approach will save time and reduce measurement errors associated with changing equipment configurations.

Additional aspects of the VXG Series worth mentioning are automatic channel response correction and S-parameter de-embedding. Lastly, embedded signal-generation applications powered by Keysight's PathWave platform allow for simplified 5G waveform generation. mw

THOSE INTERESTED in more information can visit www.keysight.com/find/vxg.

CHRIS DeMARTINO | Technical Engineering Editor

Climbing to the Top in the MMIC Arena



In this Q&A, John Greichen, VP of sales and marketing at Custom MMIC, talks about his company's focus, different strategies being implemented, and more.

Although Custom MMIC has been in existence for a relatively short amount of time, the company is now regarded as a top supplier of monolithic microwave integrated circuits (MMICs). How did the company get to where it is now?

Custom MMIC *(www.custommmic.com)* is a 13-year-old company. We started as a custom design service company in 2006, serving the advanced MMIC technology needs of military radar and communications. Our experience and design expertise provided a strong base to enable a transition into standard products about six years ago.

We focus very heavily on the needs of military, space, and instrumentation customers. Listening to their requirements has strongly driven our roadmap. Custom MMIC has rapidly grown its standard product portfolio with our talented and efficient technical team. We now cover all major functions in a typical microwave signal chain across a broad range of frequencies. Our products are considered performance leaders by our customers, and we continuously push the performance envelope.

Our current market position reflects our effective strategy to bring strong technology to our focus markets quickly with excellent quality, responsiveness, and support. Proof of our position is evidenced by supplier awards received regularly from our customers, including Raytheon, BAE, and Lockheed Martin.

The industry is obviously wrapped up in 5G. However, 5G is not exactly where Custom MMIC's focus lies. Can you talk about the markets being targeted by the company?

Custom MMIC is laser-focused on the military, space, and instrumentation markets. We believe our GaAs/GaN technology and high-performance design capability are a perfect match for these markets. We also believe these markets are underserved by MMIC suppliers in general.

5G has been the perennial huge market for several years—but frankly, few are making money in 5G to date despite huge investments. Custom MMIC has the high-frequency capability to address 5G and will be looking for opportunities to bring value to 5G customers as the market develops.

Let's say a system designer is faced with a situation in which a component that was designed into a system is now obsolete. How is Custom MMIC helping designers cope with this scenario? In addition, the company is executing an "alternate part" strategy to ensure customers that essentially the same component will be available for many years. Can you explain that?

The MMIC market has certainly seen its share of disruption in the last few years. Mergers, acquisitions, and market exits have created real problems for system designers, particularly those requiring long product life such as in military applications. Custom MMIC is helping its military and space customers cope with this reality via two specific strategies.

First, we are rapidly increasing our standard product portfolio. When the customer is faced with an obsolescence situation, they can visit our easy-to-use website and quite often find a product meeting their needs. While we certainly can't replace all obsolete products, our company selectively addresses specific high-demand products by designing a compatible replacement. For example, Custom MMIC quickly created a cross-reference guide when Broadcom/Avago obsoleted its MMIC portfolio in late 2017. Several months later, we introduced a replacement for a particularly popular Avago MMIC.

Second, Custom MMIC began an "alternates" product manufacturing program approximately three years ago. We are often asked to assure supply of our products for 10 years or more by military and instrumentation customers. The possibility of foundry process obsolescence makes that assurance difficult.

> "Our team was very proud to receive a 5-Star Supplier Excellence award from Raytheon Company for our 2018 performance. This is the second consecutive year we received an award from Raytheon. The award focuses on operational and quality excellence with specific expectations and measures."

The alternates program objective is to develop a "form, fit, and function" second source for selected standard products to mitigate the risk of foundry issues. This program protects both Custom MMIC and end customers from obsolescence concerns. Custom MMIC's military and instrumentation customers are impressed and comforted by our unique alternates program.

Custom MMIC utilizes various foundries. What are some of the benefits of taking that approach?

Custom MMIC partners with most of the GaAs and GaN foundries around the world. There are two main benefits to working with a number of different foundries. First, we can select the best process from across the various foundry options to address challenging product requirements. Our history of design service gives us a great perspective on what's the best process to utilize for our standard product portfolio. Being fabless is considered an advantage versus owning a fab, which would present a more limited set of process options.

Second, being fabless allows us to distribute our business across several different foundry partners. This approach avoids overdependence on one or another foundry. Our alternates program as mentioned above adds another layer of risk mitigation.

Custom MMIC recently received a 5-star supplier award from Raytheon. Tell us a little about this accomplishment.

Our team was very proud to receive a 5-Star Supplier Excellence award from Raytheon Company for our 2018 performance. This is the second consecutive year we received an award from Raytheon. The award focuses on operational and quality excellence with specific expectations and measures.

Raytheon's Integrated Defense Systems (IDS) Group has over 3,000 suppliers. Annually, IDS presents 3-, 4-, and 5-Star awards to approximately 5% of those suppliers. Custom MMIC was one of only nine suppliers to receive the 5-Star award in 2018 and was the only GaAs/GaN semiconductor supplier to receive an award.

We are very happy to receive this recognition and strive to maintain this high performance for Raytheon and other key customers.

Can you talk a little about what we might expect to see from the company in the future?

You can expect continuous innovation from Custom MMIC!

We introduced the first of our so-called "ultra-low-noise amplifier" (U-LNA) family in 2018. The 2- to 6-GHz CMD283C3 offers discrete-level noise-figure performance of 0.6 dB in a 3- × 3-mm QFN package, and is a matched, self-biased, single-supply MMIC. We plan to introduce more U-LNA products covering C- to Ka-band later this year.

We are working on broadband amplifiers up to 70 GHz with very flat gain performance. Coming soon are more analog attenuators, as well as expansion of our innovative coarse-/fine-control digital-step-attenuator family, with 6-bit, 0.5-dB step (fine control) and 2-bit, 10-dB step (coarse control) versions.

Custom MMIC will be adding to its high-input-power-handling GaN LNA portfolio, plus will introduce more linear and efficient GaN power amplifiers. Keep your eye out for new MMIC functions in GaN later in 2019! mw

Product Feature

BRANDON MALATEST | COO, Per Vices
SAUSAN AREBI | Per Vices
www.pervices.com

SDR Platform Packs Multifaceted Performance

With its wideband capability and as many as 16 channels, this software-defined radio is primed to meet the needs of many applications.

Software-defined radios (SDRs) offer the flexibility and versatility needed to address the radio and communication needs of a multitude of applications and markets. They come equipped with high radio bandwidth, processing power, digital backhaul, and various radio channels to provide the performance sought by many industries to meet strict project goals. Addressing those needs, Per Vices *(www.pervices.com)* offers Cyan, its latest SDR that it claims offers the highest bandwidth and largest number of independent radio channels available in a commercial-off-the-shelf (COTS) platform *(see figure)*.

The Cyan SDR offers performance at frequencies as high as 18 GHz.

Cyan is a high-channel-count, ultra-wideband, high-gain, direct-conversion transceiver and signal-processing SDR platform that's built in a compact rack-mount enclosure. It offers a tuning range of 100 kHz to 18 GHz along with up to 16 fully independent radio channels that constitute one's choice of receive or transmit channels (i.e., the total number of receive and transmit channels can be as much as 16).

Each chain offers a standard 1-GHz bandwidth, allowing for a total bandwidth as high as 16 GHz if all channels are utilized. This performance is driven by high-speed analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) that both offer as much as 16 bits of resolution along with a top-of-the-line field-programmable-gate-array (FPGA) system-on-chip (SoC).

The Cyan SDR can operate within commercial and military radar, ground stations, (counter) electronic warfare, test-and-measurement, low-latency point-to-point links, and medical imaging applications and systems. It also offers spectrum-monitoring, signal-generation, data-processing, and data-transport capabilities, with host systems designed for advanced data storage and processing. In addition, Cyan is well-suited for spectrum recording and sensing by utilizing the flexible radio architecture in combination with a high bandwidth and a large number of channels.

With the option to use as many as 16 transmit channels, whereby data is sent over the 4- × 40-Gb/s qSFP+ ports, Cyan can support many advanced applications. It provides additional features, such as timed commands, triggering, and a large amount of FPGA resources, for all types of digital signal processing (DSP).

SUPERIOR COMPONENTS PUSH PERFORMANCE

The Cyan SDR can achieve impressive performance due to its implementation of high-quality components. On the digital front, it features the Intel Stratix 10

FPGA with an on-chip Arm Cortex-A53 MPCore processor, enabling various DSP functions and loading of IP cores to be performed on the FPGA. This reduces host-systems specifications, or in some applications, removes the need for a host system entirely.

Cyan was further designed to adhere to size, weight, and power (SwaP) requirements, measuring 482.6 × 402.0 × 133.0 mm in the standard form factor. Its size can be further reduced depending on the application.

The radio-front-end architecture consists of independent radio boards (either receive or transmit). The receive architecture includes a dual-channel ADS54J60 ADC that samples at 1 Gsample/s. Operation from 9 kHz to 18 GHz is possible with the radio-chain architecture. The radio board can be employed as many as 16 times to create 16 independent receive chains that each offer sampling of 1 Gsample/s.

The transmit radio board features the dual-channel AD9163 DAC that samples at 1 Gsample/s. Like the receive board, the transmit board supports operation between 9 kHz and 18 GHz. Cyan can support applications that require many transmit radio chains by utilizing up to 16 of these transmit radio boards. The radio chains combine some of the industry's highest-performance converters and RF synthesizers with synchronization capability and phase coherency among all radio channels.

The timing architecture for Cyan relies on a stable (±5 ppb) and accurate 10-MHz signal delivered by an oven-controlled crystal oscillator (OCXO). Precise tuning from 100 kHz to 18 GHz is supported. The system also supports the use of an external reference clock, provided that the source meets system performance requirements.

The default configuration is factory-calibrated to provide a known (in-phase) deterministic relationship for all LMK04828 clock conditioner outputs. As a result, the leading edge of all outputs and internal VCOs can be synchronized at the reference inputs of all frequency synthesizers, converters, and transceivers.

High-performance SDR systems from Per Vices have been especially useful for applications that require high channel count and RF sampling rates. The company also offers full customization support if higher-performance systems are needed for a specific application. These services include custom hardware, firmware, and software integration support, as well as COTS Linux host systems. The latter enable rapid deployment and are specifically designed to meet data-storage and processing needs. mw

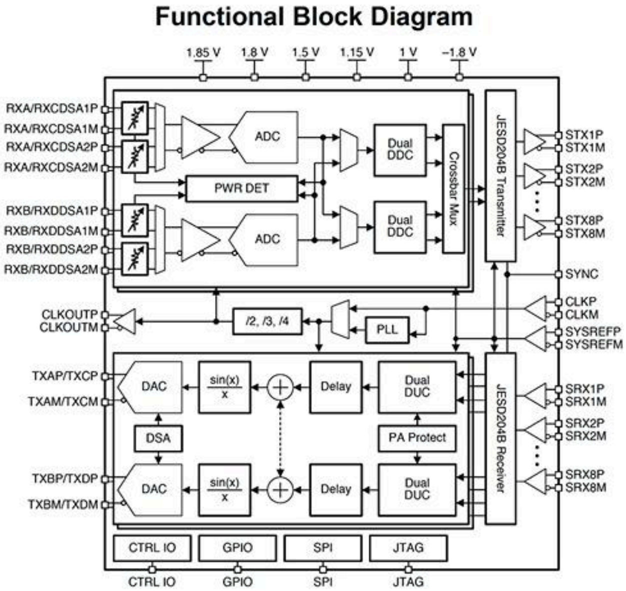
BILL SCHWEBER | Contributing Editor

Wideband, Multichannel Front End Tackles Direct C-Band RF Sampling

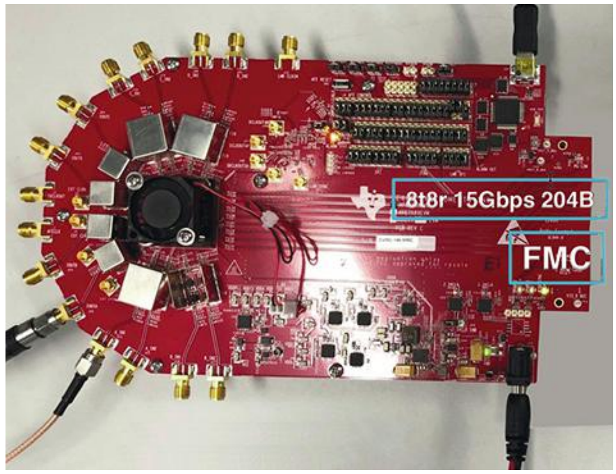
This quad-channel RF front end (and dual-channel sibling) enables direct sampling to 6 GHz without the need for additional frequency-conversion stages, eliminating local oscillators, mixers, amplifiers, and filters.

We're so accustomed to ICs in the $1 price range that it's easy to presume something is wrong when you see one priced above $1000. Still, some ICs have the features, functions, and performance specifications whereby their vendor feels that they can command that amount.

The latest such pair is the highly integrated quad-channel AFE7444 and similar dual-channel AFE7422 RF-sampling transceivers from Texas Instruments *(Fig. 1)*. These devices target wideband systems including multiantenna, direct-sampling radar, and 5G applications, with what TI maintains is industry's widest frequency range and smallest footprint. The level of integration allows for sampling of frequencies to



1. The highly integrated quad-channel AFE7444 from Texas Instruments enables direct-digital sampling into the 6-GHz band; the AFE7422 is a two-channel version.



2. Setting up and exercising an IC such as the AFE7444 calls for great care and attention to RF detail. The AFE7444EM evaluation board is an RF-sampling transceiver platform that can be configured to support up to four transmit and four receive channels simultaneously.

6 GHz (the most-used portion of the C-band, formally defined at 4 to 8 GHz) without the need for additional frequency-conversion stages, thus eliminating local oscillators, mixers, amplifiers, and filters.

The quad-channel IC integrates 14-bit digital-to-analog converters (DACs) and 14-bit analog-to-digital converters (ADCs) that, along with its high instantaneous bandwidth, enables sampling to 9 Gsamples/s per DAC and up to 3 Gsamples/s per ADC. The AFE7444 can receive and transmit up to 800-MHz bandwidth from each of four antennas, while the AFE7422 receives and transmits 1.2 GHz from each of two antennas. Their 8-lane (8 TX + 8 RX) JESD204B interface (subclass-1 compliant) operates at up to 15 Gb/s.

Transmit-side DAC features and performance: The DAC signal paths support interpolation and digital up-conversion options to deliver the wide bandwidth; their differential output path includes a per-channel digital step attenuator (DSA) for optimal tuning of output power. Other DAC features include dual digital upconverters (DUCs), 32-bit NCOs, 8× to 36× interpolation ratio, sin(x)/x correction and configurable delay, and power-amplifier protection (PAP).

Receive-side ADC features and performance: Each ADC path includes dual DSAs to extend dynamic range, along with RF and digital power detectors. ADC noise spectral density (NSD) is –151 dBFS/Hz; while dynamic performance (–3 dBFS at f_{IN} of 2.6 GHz) includes SNR of 55 dBFS; SFDR of 73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IMS2019 and RFIC 2019 Keynote Speakers

RFIC Plenary Session Speaker
Sunday, 2 June 2019

Dr. Greg Henderson – *Senior Vice President Automotive, Communications and Aerospace & Defense, Analog Devices, Inc.*

"The Digital Future of RFICs"

RFIC Plenary Session Speaker
Sunday, 2 June 2019

Dr. Ir. Michael Peeters – *Program Director, Connectivity + Humanized Technology, imec*

"Do the Networks of the Future Care about the Materials of the Past?"

IMS Plenary Session Speaker
Monday, 3 June 2019

Dr. William Chappell – *Director of the Microsystems Technology Office (MTO), Defense Advanced Research Projects Agency (DARPA)*

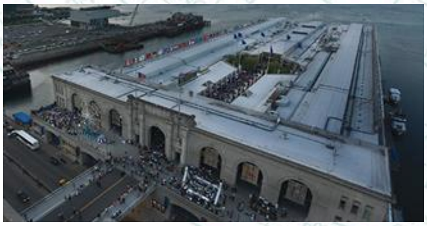
"The Mind and Body of Intelligent RF"

MTT-S Awards Banquet Speaker
Wednesday, 5 June 2019

Dr. Ryan C.C. Chin – *CEO and Co-founder, Optimus Ride Inc.*

IMS Closing Session Speaker
Thursday, 6 June 2019

Dr. Dina Katabi – *Andrew & Erna Viterbi Professor of Electrical Engineering and Computer Science at MIT, Leader of NETMIT research group at CSAIL, Director of the MIT Center for Wireless Networks and Mobile Computing*



The IMS Welcome Reception will be held on Monday, 3 June 2019 at the Seaport World Trade Center Headhouse in Boston. The reception immediately follows the conclusion of the IMS Plenary Session.

For the latest on IMS and Microwave Week visit www.ims-ieee.org

Clocks are critical parts of the transmit and receive signal chain. These ICs include an internal phase-locked loop (PLL) and voltage-controlled oscillator (VCO) with bypass option, along with clock output up to 3 GHz with clock divider. Fast frequency hopping at under 1 μs makes this pair a good fit for the demands of the target applications.

dBc (HD2 and HD3); and worst-spur SFDR of 91 dBc. Flexible decimation options allow for optimization of data bandwidth.

Clocks are critical parts of the transmit and receive signal chain. These ICs include an internal phase-locked loop (PLL) and voltage-controlled oscillator (VCO) with bypass option, along with clock output up to 3 GHz with clock divider. Fast frequency hopping at under 1 μs makes this pair a good fit for the demands of the target applications.

Size and power: An IC such as this one is also characterized by its dissipation and footprint. DAC- and ADC-path dissipation are just under 2 W each at 9 and 3 Gsamples/s, respectively. The devices are housed in 400-contact, 0.8-mm-pitch, 17- × 17- × 2.65-mm flip-chip BGA packages, which TI says will reduce required PCB space by 75% compared to using discrete RF-sampling data converters. Also important, the small size of these ICs makes it possible to place them close to system antennas for improved beamforming in high-frequency/high-density arrays.

Pricing and support: The AFE7444 quad-channel, wideband RF-sampling transceiver is priced at $1,749.90, while the dual-channel AFE7422 sibling goes for $1,249.90, in 100-piece lots. To assist in evaluating these transceivers, TI offers quad/dual-channel evaluation modules, the AFE7444 and AFE7422, at $2,499 and $1,999 respectively *(Fig. 2)*.

Along with other application notes for these transceivers, TIDA-010131 "Multichannel RF transceiver clocking reference design for radars and wireless 5G testers" demonstrates development of the multichannel clocks, which are critical to achieving specified system performance. There's also a video series: "Getting started with the AFE7444 and AFE7422." mw

Monolithic Amplifier Boosts 1 MHz to 1 GHz

MINI-CIRCUITS MODEL TSS-13HLN+ monolithic amplifier combines high output power and low noise figure from 1 MHz to 1 GHz. Based on E-pHEMT technology, the amplifier provides better than +25.2 dBm typical output power at 1-dB compression across the full frequency range, with typical third-order intercept of better than +40 dBm at 1 MHz, better than +41 dBm at 250 MHz, and better than +40 dBm at 1 GHz. The typical noise figure is 3 dB at 1 MHz, 1.4 dB at 500 MHz, and 1.6 dB at 1 GHz with better than 21-dB typical gain across the full frequency range. The RoHS-compliant, 50-Ω amplifier includes a shutdown feature that allows the amplifier to be shut down with pulsed signals to save power. Well-suited for cellular and CATV applications, it features typically 11 dB or better input and output return loss across the full frequency range. The amplifier measures just 3 × 3 mm in a 12-lead MCLP package.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, https://www.minicircuits.com/WebStore/dashboard.html?model=TSS-13HLN%2B

SP4T Switch Matrix Controls DC to 40 GHz

MODEL RC-2SP4T-40 FROM MINI-CIRCUITS is a compact switch matrix formed of a pair of independently controlled, electromechanical single-pole, four-throw (SP4T) switches. The absorptive, fail-safe switches provide high isolation with low loss from dc to 40 GHz. Isolation between ports is at least 50 dB across the full frequency range while insertion loss is no more than 0.2 dB through 6 GHz, no more than 0.5 dB through 18 GHz, and no more than 1.1 dB through 40 GHz. Measuring just 5.5 × 6.0 × 2.25 in. with 10 2.92-mm female coaxial connectors on the front panel, the RoHS-compliant switch matrix can be operated by a PC in Windows or Linux environments under USB or Ethernet control. It handles as much as 20 W input power through 18 GHz, 10 W through 26.5 GHz, and 5 W through 40 GHz, with typical switching speed of 25 ms. The switch matrix, designed for operating temperatures from 0 to +40°C, is well-suited for system and test applications.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, https://www.minicircuits.com/WebStore/dashboard.html?model=RC-2SP4T-40

Coaxial Adapter Links 1.85- and 2.92-mm Ports

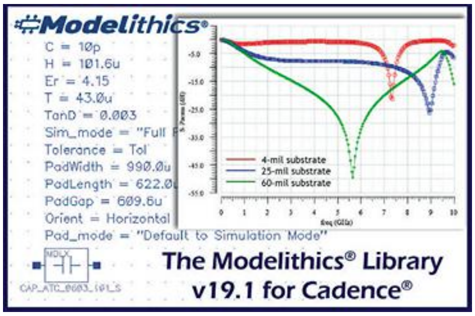
MINI-CIRCUITS' MODEL 185F-KM+ is a coaxial 1.85-mm-female to 2.92-mm-male coaxial adapter with excellent electrical characteristics for a wide range of applications from dc to 40 GHz. The RoHS-compliant coaxial adapter is only 0.79 in. in length with rugged, passivated stainless-steel construction, low insertion loss, and low VSWR. Typical insertion loss is only 0.05 dB from dc to 8 GHz, 0.11 dB from 8 to 18 GHz, 0.15 dB from 18.0 to 26.5 GHz, and 0.20 dB from 26.5 to 40.0 GHz. Typical VSWR is 1.01:1 from dc to 8 GHz, 1.04:1 from 8 to 18 GHz, 1.06:1 from 18 to 26.5 GHz, and 1.05:1 from 26.5 to 40.0 GHz. The broadband coaxial adapter is designed for operating temperatures from –55 to +100°C.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, https://www.minicircuits.com/WebStore/dashboard.html?model=185F-KM%2B

Phase Shifters Control DC to 2 GHz

THE MODEL 3428 coaxial phase shifters provide as much as 360-deg. phase control/GHz over a frequency range of dc to 2 GHz. Two models are available, each with 0.25-in. nontranslating control and choice of minimum insertion delay of 3.6 to 4.6 ns or 1.8 to 2.8 ns. The phase shifters show selected phase shift on a calibrated five-digit readout. Supplied in an aluminum housing with Type N or SMA female connectors, the phase shifters exhibit maximum VSWR of 1.30:1 through 1 GHz and 1.50:1 through 2 GHz and maximum insertion loss of 0.50 through 1 GHz and 0.75 dB through 2 GHz. Both phase shifters are designed to handle maximum input power of 100 W CW and 5 kW peak.

ARRA INC., 15 Harold Court, Bay Shore, NY 11706; (631) 231-8400, FAX: (631) 434-1116, E-mail: sales@arra.com, www.arra.com.



Modelithics Models Run in Cadence Simulators

DESIGNERS WORKING WITH the Cadence Design Systems simulation software can now run models from Modelithics by using the Modelithics Library for the Cadence Spectre RF Option and Virtuoso RF Solution. This library makes Modelithics Microwave Global Models available to Cadence simulation software users. Modelithics Library v19.1 features a large collection of measurement-based models geared to design engineers, with over 300 models for commercial capacitors, inductors, and resistors from over 25 suppliers. In total, the library represents over 17,000 individual components. Once installed, the models are accessible through the Library Manager window in the Cadence Virtuoso custom IC design platform and can be easily placed into the schematic. The models offer extensive capabilities above and beyond those of simple S-parameter models, supporting operating frequencies from RF through and including mmWave frequencies.

MODELITHICS INC., 3802 Spectrum Blvd., Ste. 130, Tampa, FL 33612; (813) 866-6338, FAX: (813) 866-6334, www.modelithics.com.

Waveguide-to-Coaxial Adapters Extend to 110 GHz

A LINE OF waveguide-to-coaxial adaptors has been developed for low-loss transitions between waveguide and coaxial connectors. The transitions include straight and right-angle adapters with round and rectangular flanges in SMA, RPC-2.92, RPC-1.85, RPC-1.35, and RPC-1.00 coaxial interfaces and 11 waveguide bands from WR-112 to WR10.

ROSENBERGER HOCHFREQUENZTECHNIK GMBH & CO. KG, Haupstrasse 1, 83413 Fridolfing, Germany; (49) 8684 180-0, E-mail: info@rosenberger.com, www.rosenberger.com

Upconverter Generates Outputs from 24 to 44 GHz

MODEL ADMV1013 is a frequency upconverter that provides high-frequency output signals from 24 to 44 GHz via direct upconversion from baseband in-phase/quadrature (I/Q) input signals or single-sideband (SSB) frequency upconversion from intermediate-frequency (IF) input signals from 0.8 to 6.0 GHz. It has a local-oscillator (LO) input frequency range from 5.4 to 10.25 GHz. Well-suited for mmWave point-to-point radios, radar systems, and electronic-warfare (EW) systems, the frequency upconverter is also a good match for automatic-test-equipment (ATE) applications. It comes in a 40-terminal land-grid-array (LGA) package and has an operating temperature range of –40 to +85°C.

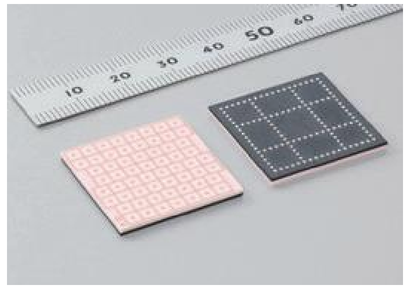
ANALOG DEVICES INC., One Technology Way, P. O. Box 9106, Norwood, MA 02062; (800) 262-5643, (781) 329-4700, www.analog.com

Antenna Assembly Scans 60 to 90 GHz

MODEL SAF-6039031340-141-S1-122-DP is a dual-polarized, rectangular-waveguide WR-12 scalar-feed horn antenna assembly covering several 5G frequency bands from 60 to 90 GHz. The antenna integrates an orthomode transducer (OMT) that makes it possible to separate a circular or elliptical polarized waveform into two linear, orthogonal waveforms or vice versa. It supports vertical or horizontal polarization with more than 25-dB cross polarization rejection and more than 35-dB typical isolation between horizontal and vertical ports. The antenna achieves nominal gain of 13 dBi at center frequency with a typical half-power beamwidth of 40 deg. and sidelobe levels of –25 dB. The horizontal and vertical ports are WR-12 waveguides with UG-387/U flanges and 4-40 threaded holes.

SAGE MILLIMETER INC, 3043 Kashiwa St., Torrance, CA 90505; (424) 757-0168, FAX: (424) 757-0188, www.sagemillimeter.com

Antenna Module Aims at 60-GHz WLANs



MODEL LBKA0ZZ1NH-317 is a high-gain antenna module developed for 60-GHz wireless local-area networks (WLANs) and 5G cellular communications systems. It employs optimized beamforming techniques in support of data rates to 4.62 Gb/s. Fabricated on a low-temperature-cofired-ceramic (LTCC) circuit board, the antenna module handles effective isotropic radiated power (EIRP) to +37.5 dBm.

MURATA ELECTRONICS EUROPE B.V., Wegalaan 2, 2132 JC, Hoofddorp, The Netherlands; +31(0)23-56-98-456, FAX: +31(0) 23-56-98-361, www.murata.com

Waveguide-to-Waveguide Transitions Reach 110 GHz

A LINE OF waveguide-to-waveguide transitions provide connections from 5.85 to 110.00 GHz in 14 bands. Well-suited for test and system applications, a total of 23 models exhibit low loss and VSWR as low as 1.08:1 in waveguide sizes from WR-10 to WR-137. They are offered with UG-style square cover and round cover flanges, CPRG-style flanges, or UBR-style flanges. As an example, model SMW15TS22001makes a transition from WR-15 (50 to 75 GHz) to WR-22 (33 to 50 GHz) waveguide, with a WR-15 waveguide UG-385/U flange and a WR-22 waveguide UG-383/U flange. The worst-case VSWR is 1.15:1 and worst-case insertion loss is 0.75 dB. These waveguide transitions feature gold-plated or painted brass construction, depending on model. All models are REACH- and RoHS-compliant.

FAIRVIEW MICROWAVE, 1130 Junction Dr., #100, Allen, TX 75013; (800) 715-4396, (972) 649-6678, www.fairviewmicrowave.com

IF Amplifier IC Boosts 90 MHz

MODEL ML1350 IS an integrated-circuit (IC) intermediate-frequency (IF) amplifier that's usable through 90 MHz. It provides 50-dB typical gain at 45 MHz and 50-dB typical gain at 58 MHz, with a 60-dB automatic-gain-control (AGC) range from dc to 45 MHz. It's designed to operate on a single-polarity, +12-V dc supply across an operating temperature range of 0 to +75°C. Designed for use as a linear IF amplifier in radios, television, and short-wave equipment, the IC is housed in a multipin plastic package.

LANSDALE SEMICONDUCTOR INC., 5245 South 39th St., Phoenix, AZ 85040-9008; (480) 296-5045, www.lansdale.com

LNAs Feature Input Power Protection

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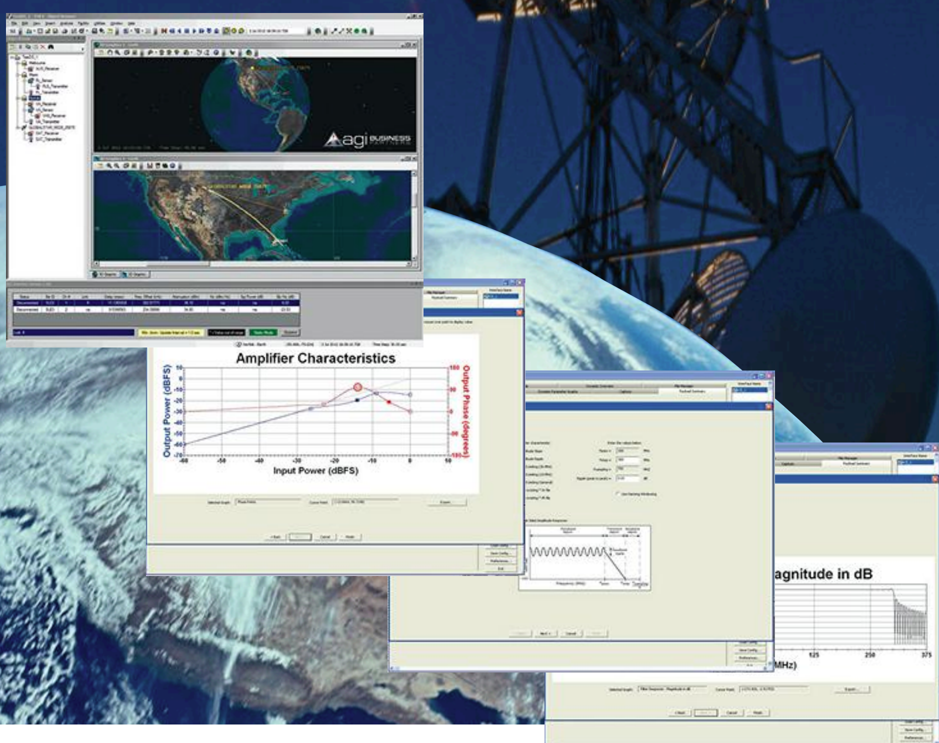

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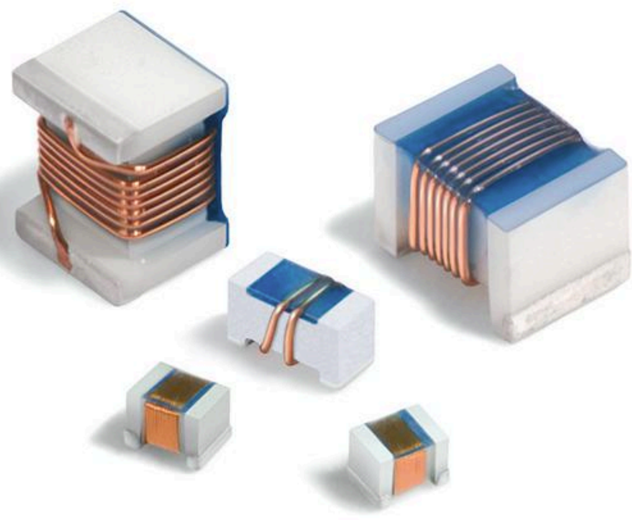

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