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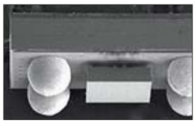

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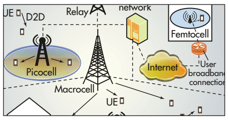

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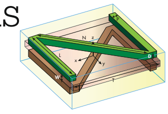

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WIRELESS STANDARDS TESTING ISSUE

IoT Testing Sparks CHALLENGES

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STATE OF THE ART BROADBAND SUCCESSIVE & EXTENDED RANGE DETECTOR LOG VIDEO AMPLIFIERS (SDLVA's & ERDLVA's)

- Amplifiers
- Attenuators - Variable
- DLVA & ERDLVA & SDLVA's
- DTO's & Frequency Synthesizers
- Filters
- Form, Fit & Function Products
- IFM's & Frequency Discriminators
- Integrated MIC/MMIC Modules
- I/Q Vector Modulators
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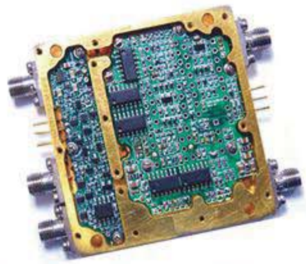
- Receiver Front Ends & Transceivers
- Single Sideband Modulators
- SMT & QFN Products
- Solid-State Switches
- Switch Matrices
- Switch Filter Banks
- Threshold Detectors
- USB Products

SDLVA-100M18G-CW-70-MAH

- Frequency Range: 100 MHz to 18.0 GHz
- Log Range: -65 to +5 dBm min.
- Log Linearity: ±1.75 dB (-40°C to +85°C)
- Log Slope: 10 mV/dB into a 50 Ω load ±1 mV max
- Flatness: ±2.0 dB max.
- TSS: -68 dBm min., -70 dBm typ.
- CW Immunity Range: TSS to -45 dBm (1 dB Degradation)
- Pulse Range: 100 ns to 250 us
- Rise Time: 35 ns max.
- RecoveryTime: 350 ns max.
- Size: 2.30" x 2.20" x 0.36"



Ultra Broadband, CW Immune with Dual RF Outputs

8-Bit Digital Log Output

SDLVA-2020-OPT112

- Frequency Range: 1.0 to 12.0 GHz
- Log Range: -65 dBm to -35 dBm
- Log Linearity: ±1.75 dB max. (-65 dBm to -35 dBm)
- Log Slope: 5 LSB/dB nominal
- Flatness: ±2.0 dB typ., ±2.5 dB max.
- TSS: -65 dBm max.
- Pulse Range: +10 dBm ±2.5 dB typ.
- Rise Time: 20 ns max. (10% to 90%)
- Recovery Time: 200 ns max.
- Size: 3.0" x 3.5" x 0.50"

Millimeter Wave

SDLVA-18G40G-65-CD-SFF

- Frequency Range: 18.0 to 40.0 GHz
- Log Range: -63 dBm to +2 dBm
- Log Linearity: ±2.0 dB @ 25°C, ±3.0 dB Over Temp
- Log Slope: 25 mV/dB nominal
- Flatness: ±2.5 dB max. @ 25°C
- TSS: -65 dBm @ 25°C
- Pulse Range: 30 ns to CW
- Rise Time: 11 ns max., 8 ns typ.
- Recovery Time: 60 ns max., 40 ns typ.
- Size: 2.37" x 1.80" x 0.42"

Ultra-Highspeed

SDLVA-418-65-16MV-12DBM

- Frequency Range: 4.0 to 18.0 GHz
- Log Range: -55 dBm to +10 dBm
- Log Linearity: ±1.8 dB
- Log Slope: 16.7±1.3 mV/dB
- Flatness: ±3 dB max.
- TSS: -64 dBm max.
- Pulse Range: 25 ns to CW
- Rise Time: 10 ns max.
- Recovery Time: 30 ns max.
- RF to Video Delay: < 2 ns
- Simultaneous Signal Suppression: 5 dB
- Size: 4.24" x 0.994" x 0.38"

Thin Film Construction

SDLVA-2D5G4D9G-60-50MV

- Frequency Range: 2.5 to 4.9 GHz
- Log Range: -60 dBm to 0 dBm
- Log Linearity: +1.5 dB max.
- Log Slope: 50.5 ±5% mV/dB
- Flatness: <4.0 dB @ -60 to -50 dBm Input, <6.0 dB @ -50 to 0 dBm Input
- TSS: -70 dBm min.
- Pulse Range: 100 ns to CW
- Rise Time: 20 ns (10% to 90%)
- Fall Time: 50 ns (90% to 10%)
- Size: 2.30" x 1.00" x 0.40"

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ISO9001:2008 REGISTERED
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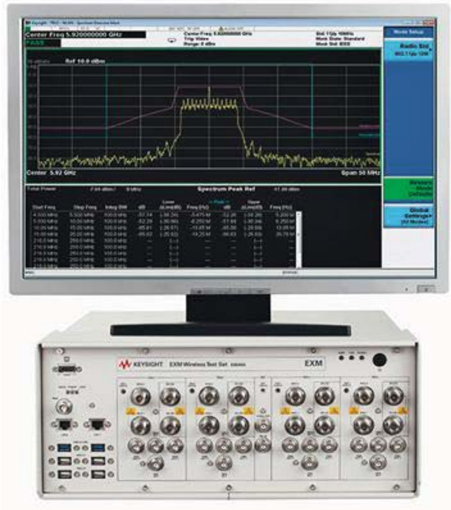

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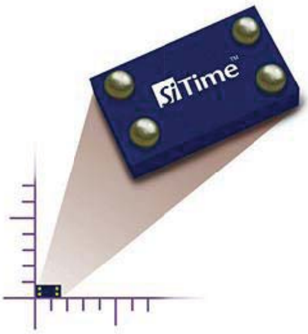

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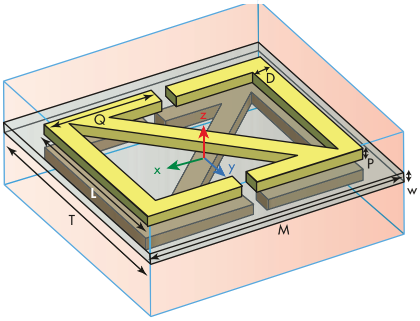

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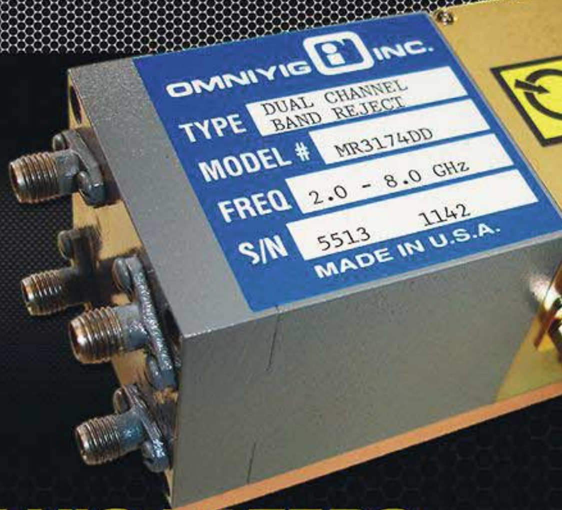

OMNIYIG has been on the forefront of advanced YIG technology with emphasis in manufacturing state-of-the-art technology for over 38 years, producing YIG Components, Detectors & Limiters. We, at OMNIYIG, are constantly manufacturing YIGs for all EW, ECM, ECCM, JAMMERS, RADARS and INSTRUMENTS in critical mission systems such as Airborne, Space, Shipboard and more.

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NEW DUAL BAND REJECT YIG FILTERS AVAILABLE NOW!!

YIG MULTIPLIERS

Omniyig Model No.	Input Frequency (GHz)	Output Frequency (GHz)	Output Power (dBm)
YM1001	1.0 - 2.0	2.0 - 13.0	6
YM1002	0.1	1.0 - 12.0	-33
YM1003	0.2	1.0 - 12.0	-28
YM1004	0.5	1.0 - 12.0	-10
YM1026	1.0 - 2.0	2.0 - 18.0	-4
YM1027	0.1	1.0 - 18.0	-40
YM1028	0.2	1.0 - 18.0	-33
YM1029	0.5	1.0 - 18.0	-22
YM1087	0.1 - 0.2	1.0 - 12.0	-25

RF input power on all models 0.5 to 1.0 watts.
Fast switching, MIL-Spec Hi-Reliability and units integrated with drivers, oscillators or amplifiers also available.

LOW PHASE NOISE YIG OSCILLATORS

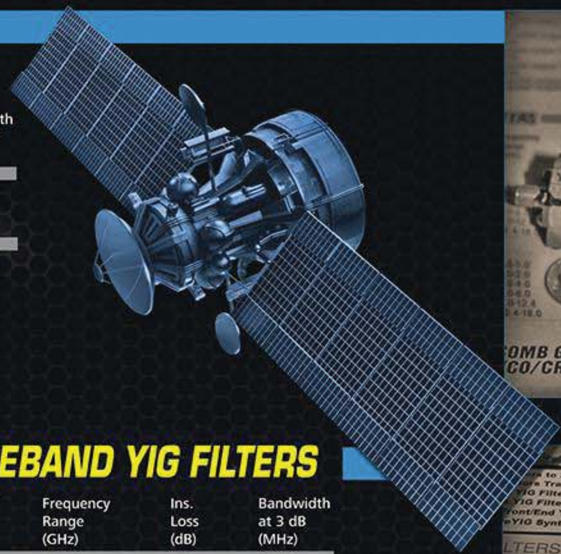
Omniyig Model No.	Frequency Range (GHz)	RF Power Output (mW)	Second Harmonic (dBc)
YOM1517	0.5 - 2.0	20-60	16
YOM1518	1.0 - 4.0	20-60	16
YOM1514	4.0 - 12.0	10	15
YOM3719-5	2.0 - 15.0	20	13
YOM1679	2.0 - 12.4	20	13
YOM83	2.0 - 6.0	20	12
YOM137	2.0 - 8.0	20	12
YOM3719-4	8.0 - 18.0	20	14
YOM3719-2	6.0 - 18.0	20	14
YOM3719-1	4.0 - 18.0	20	13
YOM3719	3.0 - 18.0	10	12
YOM3676	2.0 - 18.0	20	15

We offer other models with Second Harmonic -60 dBc and Oscillators integrated with 2-stage YIG Filters.

YIG BAND REJECT FILTERS

Omniyig Model No.	Frequency Range (GHz)	Ins. Loss (dB)	Bandwidth at 40 dB (MHz)
M107RX	8.0 - 18.0	1.5	20
M104RX	4.0 - 18.0	2.0	8
M105RX	2.0 - 8.0	1.5	10

MIL-SPEC and High Reliability!
Integrated with Analog and 12 Bit Digital Drivers.
MANY other Multioctave designs available.



WIDEBAND YIG FILTERS

Omniyig Model No.	Frequency Range (GHz)	Ins. Loss (dB)	Bandwidth at 3 dB (MHz)
4-STAGE			
M3064	6.0 - 18.0	6.5	500 min
M2997	6.0 - 18.0	6.0	400 min
M3513	8.0 - 18.0	6.5	500 min

Industry-leading bandwidths in multi-octave, YIG units providing the widest 3dB bandwidth available!

STANDARD DETECTORS

Omniyig Model No.	Frequency Range (GHz)	k Factor	TSS (dBm)
Zero-Bias Schottky			
ODZ0004A	0.1 - 18.0	1200	-52
ODZ0328A	2.0 - 18.0	1200	-52
ODZ0441A	6.0 - 26.0	1000	-51

STANDARD LIMITERS

Omniyig Model No.	Frequency Range (GHz)	Insertion Loss (dB)	Leakage Power (dBm)
Pin			
OLP2645A	8.0 - 18.0	2.0	+19
OLP2726A	2.0 - 18.0	1.2	+19
PL473	0.5 - 12.0	1.8	+19
OLP2652	2.0 - 18.0	2.5	+20
Schottky Turn-on			
SL048	2.0 - 26.0	2.5	+14
OLD2635A	4.0 - 18.0	2.5	+14
OLD2733A	0.4 - 18.0	2.5	+14

Leakage Power Measured at P(in) = +30 dBm

STANDARD COMB GENERATORS

Omniyig Model No.	Input Frequency (MHz)	Output Frequency (GHz)	Output Power (dBm)
OHG10118	100	0.1 - 18.0	-40
OHG20218	20	0.2 - 18.0	-35
OHG51026	500	0.5 - 18.0	-28
OHG81026	1000	1.0 - 18.0	-18

Let Omniyig help with any special Limiter or Detector requirements you may have - Zero Bias Schottky Detectors, Limiter-Detectors, Comb Generators and a broad line of YIG-tuned Filters, Oscillators and Multipliers.

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Power Divider/Combiners
MECA offers a variety of Power Divider/Combiners in assorted bands from 20 MHz to 40 GHz with SMA, 2.92mm, QMA, N, TNC, RP-TNC, 4.1/9.5 & 7/16 DIN interfaces. Their rugged construction makes them ideal for both base station, in-building wireless and satellite systems.

Attenuators & Terminations
MECA offers a variety of models capable of operating up to 40 GHz with power handling up to 500 watts with SMA, 2.92mm, QMA, N, TNC, RP-TNC, 4.1/9.5 & 7/16 DIN interfaces. Their rugged construction makes them ideal for both base station, in-building wireless and satellite systems.

Bias Tee & DC Blocks
MECA offers a variety of models capable of handling up to 6 & 18 GHz with SMA, 2.92mm, QMA, N, TNC, RP-TNC & 7/16 DIN interfaces. Their rugged construction makes them ideal for both base station, in-building wireless and satellite systems.

Circulators & Isolators
MECA offers Circulators and Isolators in N, SMA, 2.92mm and 7/16 DIN Female connectors with average power ratings from 2 - 250 watts. The most "popular" frequency bands between 0.698 - 40.0 GHz are readily available and can ship from STOCK.

BETTER BUILDINGS / BETTER NETWORKS

Dr. D.A.S.© Prescribes: MECA Millimeter-Wave Products.

Since 1961 MECA Electronics (Microwave Equipment & Components of America) has served the RF/Microwave industry with equipment and passive components covering Hz to 40 GHz. MECA is a privately held ISO9001:2008 Certified, global designer and manufacturer for the communications industry with products manufactured in the **United States of America**.

DR. D.A.S. prescribes...

MECA Electronics designs and manufactures an extensive line of RF/Microwave Equipment and Components with industry leading performance including D.A.S. Equipment, Low PIM Products, mmWave, Power Dividers & Combiners, Directional & Hybrid Couplers, Fixed & Variable Attenuators, RF Terminations, Circulators/Isolators, DC Blocks & Bias Tees, Adapters & Jumpers. Models available in industry common connector styles: N, SMA, 2.92mm, TNC, BNC, 7/16, 4.1/9.5 & 4.3/10.0 DIN as well as QMA, Reverse Polarity SMA, TNC and various mounting solutions.

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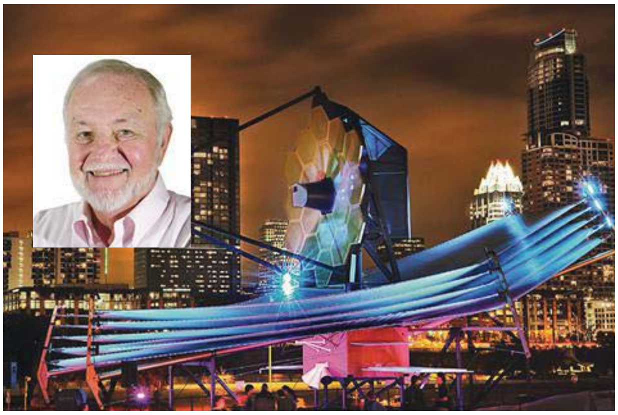
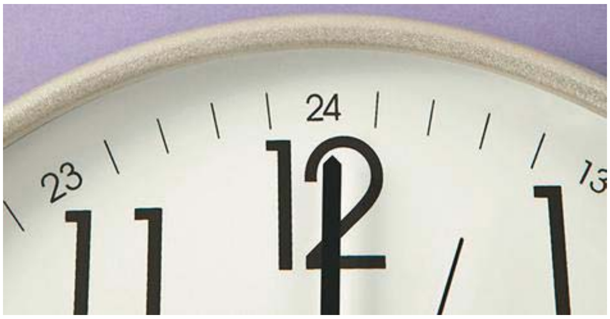


WRAPPING UP IMS 2015

http://mwrf.com/blog/wrapping-ims-2015

The 2015 installment of the International Microwave Symposium (IMS), the premier RF/microwave industry event, took place last month in Phoenix, Ariz. For those who couldn't make it to the show in person, never fear: Contributing Editor Lou Frenzel sums up and assesses all that took place.



KEEPING TIME IS PART OF MEASURING IT

http://mwrf.com/blog/keeping-time-part-measuring-it

Time is an important parameter, whether in engineering, in business, or in life. With regard to engineering, specifically, it is especially critical to be quite precise and accurate about time; the performance of many other components and systems will depend upon it.

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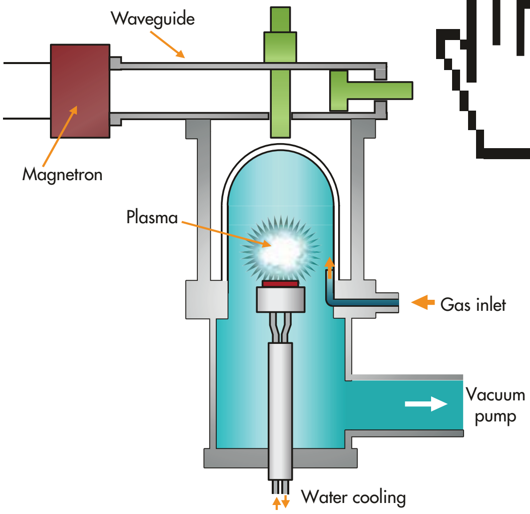

DIAMONDS ARE A GaN PA'S BEST FRIEND

http://mwrf.com/materials/diamonds-are-gan-pa-s-best-friend

Solid-state power amplifiers (PAs) continually push the boundaries on power density in ever-smaller package sizes: The thermal energy for gallium-nitride (GaN)-based devices operating at high power levels is magnitudes greater than prior technologies. To get the most out of these new materials, GaN and passive-device manufacturers are now turning to diamond substrates as a next-generation material.

13 KEY CONSIDERATIONS FOR AEROSPACE DEVICES

http://mwrf.com/active-components/13-key-considerations-aerospace-rfmicrowave-devices

Be it an airplane, drone, jet, satellite, or spacecraft, aerospace platforms put their solid-state electronic components through an extreme range of temperatures and G-forces. Combine those factors with shock, vibration, and pressure changes, and the resulting environment makes it challenging for highly sophisticated RF/microwave devices to perform reliably.

REFERENCES & TOOLS

http://mwrf.com/references-tools

Visit our online References & Tools section to quickly and easily download tables covering topics such as Connector Frequency, which include Coaxial and Waveguide; Frequency Nomenclature: Kilohertz to Terahertz; Frequency Spectrum & Allocations; and Wireless Coexistence: From 300 MHz to 6 GHz.

Editorial

CHRIS DeMARTINO
Technical Editor
chris.demartino@penton.com

Greetings from Our Newest Staff Addition

Allow me to introduce myself: My name is Chris DeMartino, and I am the new technical editor on the staff of *Microwaves & RF* and www.mwrf.com, covering everything that is happening in the RF/microwave industry. I have worked in the industry as an engineer since 2004, after graduating with a B.S. in electrical engineering from the State University of New York at Binghamton. I also have an M.S. in electrical engineering from Polytechnic University.

I have worked at several RF/microwave companies (including MITEQ and Mercury Systems), gaining hands-on experience with this technology. As an engineer, my responsibilities were typically focused on the design and test of RF/microwave components and assemblies, covering different frequency ranges for various programs. I have worked on products for such applications as commercial satellite-communications (satcom) and defense programs, covering frequencies up to Ka-Band for satcom.

As a regular reader of *Microwaves & RF*, I never imagined one day being part of the staff here. The transition from engineer to editor may surprise some, but it's an exciting change. My new role as technical editor provides me with the opportunity to view the entire industry, gaining access into the complete world of microwaves and RF technologies and applications. I am able to view the industry in a new way, gaining a newfound respect and appreciation for those who contribute to everything our community offers.

I had the privilege of attending IMS 2015 in Phoenix my first week on the job, which gave me a taste of what I will be covering in my new position. This gave me the opportunity to meet many people in the industry and to learn about many of the latest products being developed. I came away from the show very impressed, and with greater appreciation for my new role. I look forward to researching the latest topics, news, and ideas, and I will do everything I can to bring this knowledge to you, our audience.

My goal will be to highlight the latest innovative products, which the engineers in our industry work so hard to develop. It is my belief that the engineers should be rewarded for the hard work and long hours they endure. I hope to help accomplish that by recognizing their contributions to the industry and society in general.

I have a strong desire to see the people in our industry benefit from the *Microwaves & RF* brand, and I am proud that my job will allow me to do so. I can be reached at chris.demartino@penton.com. mw


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MAINTAINING SWITCH SEPARATION

Thank you for the "Engineering Essentials" article on RF/microwave switches in the May 2015 issue of *Microwaves & RF* ("6 Degrees of Microwave and RF/Microwave Switch Separation," p. 46). It did a good job of listing the many different types of switches available to designers of high-frequency circuits and systems. But while it provided some basic details on each type of switch, the article was too brief to include the type of information useful in comparing different types of switches, such as which types exhibit lower loss at higher frequencies.

The article lacked the type of information needed by engineers who would specify a switch for an RF/microwave application. For example, electromechanical switches are still widely used in commercial and military applications. Still, only one paragraph was included in the story about electromechanical switches, with no information given about upper and lower frequency limits or values in watts for power-handling capabilities at different frequencies. The first table in the article offered some details on switch performance in general ways, such as switching speeds that were described as "slow" or "fast," but no truly precise details that would help when specifying switches for RF/microwave applications.

John Woodhouse

EDITOR'S NOTE

Switches are obviously vital components for high-frequency systems, controlling the transfer of signals for many different applications. Unfortunately, the special report on switches that you reference was attempting to cover a great deal of information on many different switch types in a small amount of space. This article provided brief details on many different switches, but was limited in total coverage.

Fortunately, a follow-up article in the July issue of *Microwaves & RF* will explore many of the basic switch-specifying parameters, such as insertion loss, frequency range, switching speed, and power-handling capabilities, as well as how the different performance parameters can affect how a switch will operate in a particular system.

Microwaves & RF welcomes mail from its readers. The magazine reserves the right to edit letters appearing in "Feedback." Address letters to:

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Content Director
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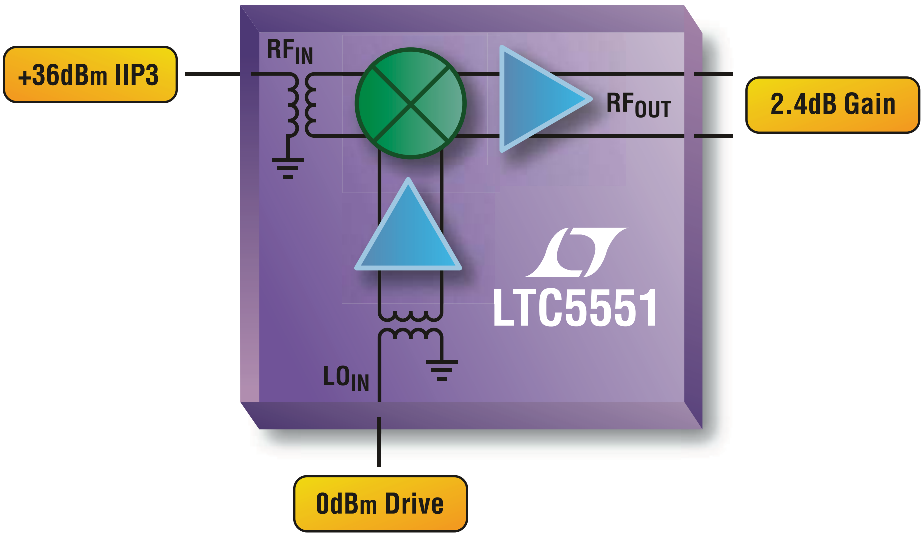
+36dBm IIP3 Mixer Boosts Dynamic Range with 2.4dB Gain



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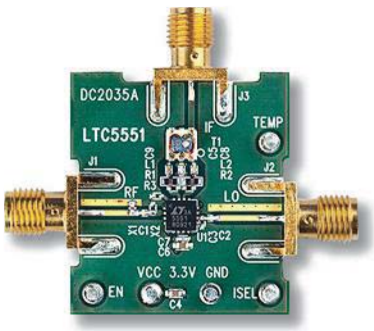

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News

NIST TO DEVELOP
Wireless Platform Manufacturing Guide

While wireless sensor networks provide a variety of advantages to hardwired devices, not all platforms are right for all applications. To help ensure that communications are reliability captured, the National Institute of Standards and Technology (NIST) is working toward developing best practice guidelines for evaluating wireless-sensor-network performance and selecting the best option for a company.

NIST's Wireless Platforms for Smart Manufacturing project will include benchmarking tests and metrics for comparing how well different technologies meet specific sets of requirements. The platforms must reliably capture and communicate measurement data in harsh industrial environments with a variety of interference sources. Such interference can lead to interrupted, delayed, or incomplete critical data hand-offs; in addition to causing production errors, this can potentially endanger workers.

Project members also are in the early stages of commissioning a wireless network test bed that will replicate a smart manufacturing environment. The test bed will recreate conditions representative of a variety of industrial settings to support the development of network-performance measurements and tests. To ensure the test bed accurately represents the complicated, often-messy manufacturing process, the team is asking companies to open their plant doors, enabling researchers to view and characterize the conditions that could impact network performance. ■

Project members also are in the early stages of commissioning a wireless network test bed that will replicate a smart manufacturing environment. *(Image courtesy of Tesla)*

LEGENDARY BOMBER Receives Radar Upgrade

THE SCALABLE AGILE Beam Radar – Global Strike (SABR-GS) is a full-performance, multi-function, active-electronically-scanned-array (AESA) radar. It also has been tapped to replace the APQ-164 radar currently deployed on all U.S. Air Force B-1 bombers. Developed by Northrop Grumman, the SABR-GS offers a variety of enhanced operational capabilities and reliability compared to the legacy passive ESA. The new radar was recently unveiled at the anniversary of the B-1B Lancer.

Unlike traditional mechanically scanned radars, SABR's electronic scanning eliminates the need for moving parts. *(See "F-16 Electronic Scanning Radar Enhances Target Detection, Tracking" on mwrf.com.)* SABR-GS features large synthetic aperture radar maps, advanced image processing, and sensor integration for more robust intelligence, surveillance, reconnaissance, and targeting. It also uses open architecture standards to integrate data from other onboard sensors, a feature that extends the life of the system.

SABR-GS incorporates the hardware and operating and software modes from Northrop Grumman's F-35 and F-22 AESA radars, with about 85% of the suite coming directly from the AN/APG-81 radar. Its image and video processing algorithms will automatically scan entire SAR maps to locate and classify targets of intent, helping to reduce workload. The new radar is approximately three times the size of the former system, offering enhanced target area detail and larger digital maps under all weather conditions.

The SABR-GS' development occurred under a $21-million risk reduction contract awarded by the Air Force's B-1 Systems Program Office. The contract will be completed following the success of the Radar Modernization Improvement Program (RMIP). Northrop Grumman will continue to modernize the radar receivers and processors of the B-1. ■

Unlike traditional mechanically scanned radars, SABR's electronic scanning eliminates the need for moving parts, pictured here on an F-16. *(Image courtesy of Northrop Grumman)*

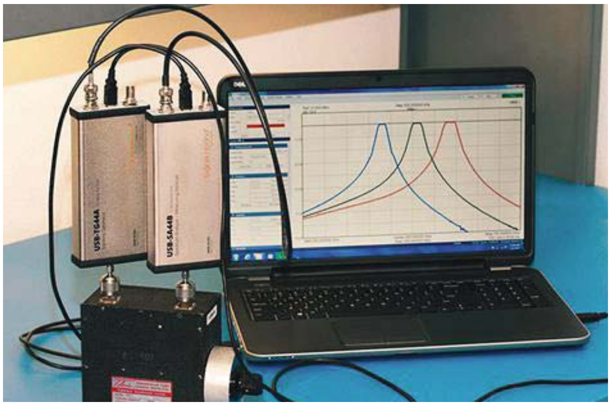
SIGNAL HOUND UNVEILS Digital Modulation Analysis Tools

SIGNAL HOUND has updated its free Spike Spectrum Analysis software. Version 3.0.8 provides a variety of digital modulation analysis tools for Spike's BB60C and BB60A USB-powered real-time spectrum analyzers.

Specifically, the new version offers constellation diagrams, symbol tables, error-vector magnitude (EVM) measurements, and bit pattern matching analysis tools for a wide range of modulation types. When coupled with either of the aforementioned spectrum analyzers, it can analyze digitally modulated signals with bandwidths to 27 MHz and frequencies from 9 kHz to 6 GHz.

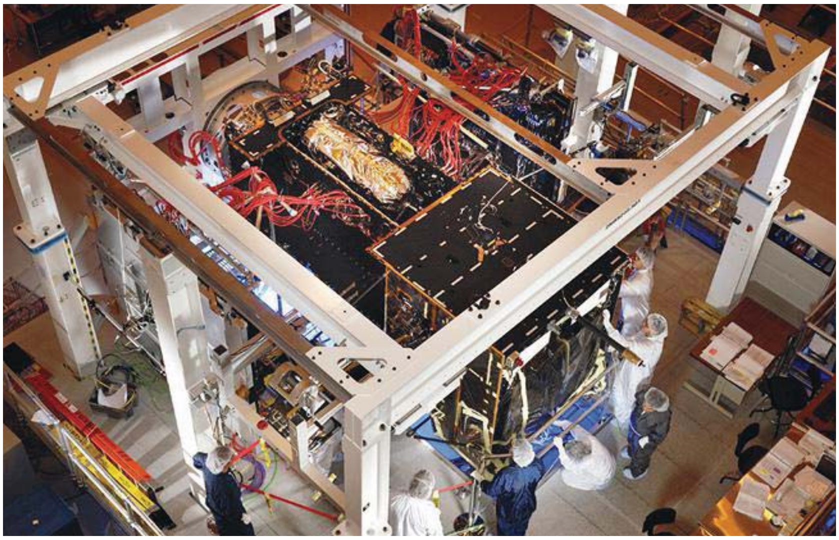
Prior to version 3.0.8, the Spike software was already capable of signal-to-noise and distortion ratio (SINAD), total harmonic distortion (THD), and percentage of modulation measurements. The update unleashes more sophisticated signal analysis of common digital modulations present in cellular telecommunications, Internet-of-things (IoT), machine-to-machine (M2M), and other radio applications.

Along with Spike's application programming interface (API) and graphical user interface (GUI), there is significant third-party customization potential. Future versions of Spike will include sub-1 GHz wireless standard modulation tools, as well as higher order modulation analysis tools for QAM64. ■



Signal Hound has rolled out an update to its free Spike Spectrum Analysis software. *(Image courtesy of Signal Hound)*

SBIRS GROUND STATION Moves on to Testing Phase



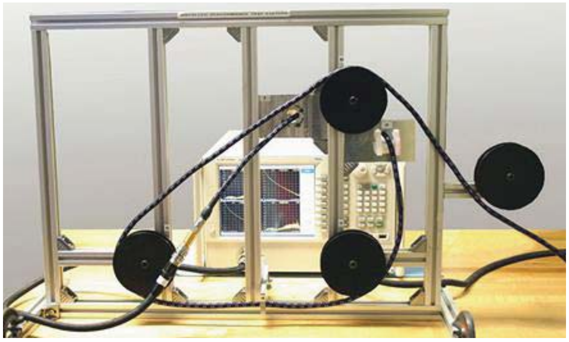
The SBIRS GEO-2 satellite undergoes baseline integration system testing. *(Image courtesy of Lockheed Martin)*

THE U.S. AIR FORCE'S Space Based Infrared System (SBIRS) includes a mix of Geosynchronous-Earth-Orbit (GEO) satellites, hosted payloads in Highly Elliptical Orbit (HEO), and ground hardware and software. The system helps provide information for continuous early warnings of ballistic missile launches and other tactical intelligence. *(See "SBIRS GEO Satellites Track Missiles Using Infrared Data" on mwrf.com.)* Recently, Lockheed Martin completed development of a next-generation ground system, Increment 2, to help increase SBIRS' ability to manage emerging threats.

The legacy ground system currently in place operates from three different locations to manage the Defense Support Program (DSP), SBIRS GEO satellites, and HEO payloads. Increment 2 will consolidate those three separate operations into one control station. During a three-day test, the Air Force's 460th Operations Group successfully used Increment 2 to individually transmit and receive commands to and from each of the DSP and SBIRS assets in orbit from the Mission Control Station (MCS).

Increment 2 will now move on to certification testing, with an end goal of replacing the older system and improving performance by 2016. The system will continue to perform several main functions: mission planning/payload tasking, constellation management, mission processing, event reporting and data distribution, and ground control. The centralized operations will help enable warfighters to efficiently monitor worldwide threats and alert responders for more immediate action. ■

GORE DEMONSTRATES CABLE Installation Simulator Replicates Aircraft Experiences



Gore's Cable Installation Simulator replicates the conditions a cable assembly experiences while being routed during installation in an aircraft. *(Image courtesy of W.L. Gore & Associates)*

VISITORS TO THE IMS 2015 show floor had the opportunity to see W.L. Gore & Associates' new Cable Installation Simulator in action. Because nearly one-third of cable failures occur during installation, this is a crucial risk factor to minimize. Damaged airframe assemblies can lead to compromised signal integrity and failures over time, as well as additional testing, maintenance and replacement costs.

Gore's Cable Installation Simulator replicates the conditions a cable assembly experiences while being routed during installation in an aircraft. The device uses four mandrels to simulate routing an assembly around the internal structure of an airframe. The mandrels replicate minimum bend radius (MBR) conditions that the assembly will encounter in an aircraft.

Several routing guides are used to induce torque into the assembly as it is pulled through the simulator. Next, the assembly is pulled through an abrasion bar to simulate routing across sharp edges or through access holes in the airframe structure.

After being fed through the Installation Simulator, the assembly is ready for testing. The assembly is connected to a vector network analyzer (VNA) to test the insertion loss and VSWR, and the results are compared to the baseline results of the assembly tested prior to installation. Depending on the results of the test, the assembly may be routed through the simulator multiple times and re-tested to verify its durability. ■

GPS III SATELLITE Components Successfully Integrated

Built by Lockheed Martin, the first GPS III space vehicle is now ready for testing in simulated harsh space environments. *(Image courtesy of Lockheed Martin)*

THE U.S. AIR FORCE'S next generation of Global-Positioning-System (GPS) satellites, GPS III, incorporates the new L1C civil signal, making it the first GPS satellite to work interchangeably with other global navigation satellite systems (GNSSs). The satellites will reportedly deliver three times better accuracy and up to eight times improved anti-jamming capabilities than the satellites currently being launched. Built by Lockheed Martin, the first GPS III space vehicle is now ready for testing in simulated harsh space environments.

In a systems integration event, several major, fully functional satellite components were brought together. The Lockheed engineers and technicians successfully lowered the system module of the GPS III satellite into place over the propulsion core, integrating the two into one space vehicle. The system module included the navigation payload, which performs the primary positioning, navigation, and timing mission. The functional bus contained the electronics that manage all satellite operation, and the propulsion core enables maneuvering in orbit. ■

PLATFORM ENABLES BLUETOOTH to Wi-Fi

AS THE INTERNET OF THINGS (IoT) continues to infiltrate every aspect of our lives, some applications are exploiting its entertainment-oriented aspects. To cite one example, Qualcomm Connected Experiences (a subsidiary of Qualcomm Inc.) recently announced new features to the AllPlay smart media platform, including Bluetooth-to-Wi-Fi re-streaming, custom audio settings, and optimized synchronization.

Qualcomm's AllPlay platform enables a variety of audio options including Bluetooth to Wi-Fi re-streaming of local and cloud-based music. *(Image courtesy of Qualcomm)*

The AllPlay platform provides users with multiple streaming options—all local or cloud-based music on a smartphone can be streamed to any Bluetooth-compatible AllPlay speaker, then re-streamed over Wi-Fi to multiple AllPlay speakers harmoniously. This allows for wireless connectivity to individual speakers or an entire audio system over an existing Wi-Fi network, providing an advantage over Bluetooth-only speakers. The platform is built on the AllJoyn software framework, an open-source project headed by the AllSeen Alliance.

With enhanced custom audio settings, manufacturers now have the ability to provide greater control of the music-listening experience with custom sound equalization settings and channel selection capabilities. AllPlay also supports synchronization between devices of under 100 microseconds, making it suitable both for multi-room and multi-channel audio streaming. AllPlay also supports line-in to Wi-Fi re-streaming, allowing manufacturers to build AllPlay-powered devices that take in audio from line-in sources (such as CD players and turntables) with the ability to re-stream to other speakers around the home. Hitachi America, ASUSTeK, Vestel, and Magnat all have plans to introduce AllPlay products into their ecosystems. ■

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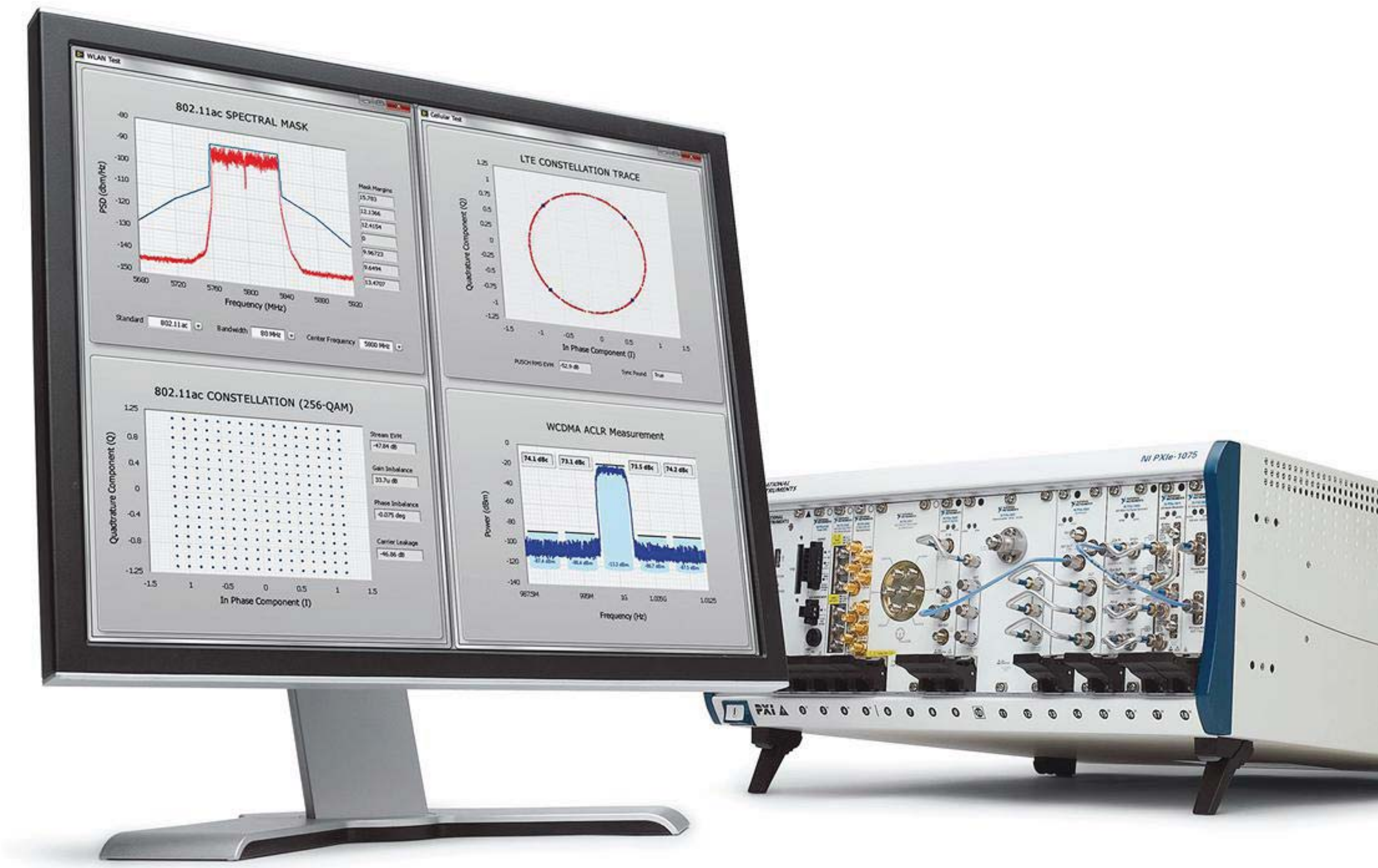

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CONTRACTS

Mercury Systems Inc.—Was awarded a $7.1-million indefinite quantity/indefinite delivery (IDIQ) contract by the U.S. Naval Warfare Center, Crane Division (NSWC) to supply advanced radio frequency (RF) tuners, digital receivers, and related equipment to be used as spares during the installation of the AN/SLQ-32(V)6 electronic countermeasure system on U.S. Navy and Coast Guard ships. Work will be performed at the company's headquarters in Chelmsford, Mass., and is expected to be complete by May 2020. The AN/SLQ-32(V)6 was developed as part of the Navy's Surface Electronic Warfare Improvement Program (SEWIP), which is an upgrade to the AN/SLQ-32 electronic warfare anti-ship missile defense system.

China Telecom—Selected Anite's interoperability and performance test solution, SAS, for LTE data throughput testing. China Telecom will use the solution as a key part of its LTE device acceptance program. SAS supports the China Telecom approved test plan, which consists of two LTE data throughput packages totaling over 200 scripts. These scripts allow China Telecom and any device manufacturer in its ecosystem to ensure that new devices perform as expected on its mobile network. China Telecom also uses Anite's Conformance Toolset as its primary platform for conformance testing, enabling it to run a wide range of pre-qualification test scripts from a single platform, leading to accelerated product releases.

MERCURY Nets Naval Deal

CHINA TELECOM Goes with SAS

Microsemi Corp.—Was awarded a $6.1-million contract from a major U.S. Department of Defense customer to manufacture highly secure receivers for GPS-guided munitions.

FRESH STARTS

NI—Opened the new Wireless Innovation Lab at its Austin, Texas, headquarters. In the lab, NI supports ongoing collaborations with top academic and industry research groups participating in its RF/Communications Lead User program. Researchers at Intel, Lund University, Nokia Networks, NYU Wireless, Samsung, the University of Texas at Austin, and TU Dresden are driving significant advances in the development of next-generation wireless systems and furthering research in 5G. Current demos and projects on display in the lab include mmWave cellular systems, the 5G Massive MIMO Testbed, and the LabVIEW Communications System Design Suite. The Wireless Innovation Lab showcases NI's commitment and investment to help researchers define next-generation wireless communication systems using the power and capability of the NI software defined radio platform with LabVIEW Communications System Design Suite. This platform-based approach helps reduce the time from theory to results by testing designs in a real-world environment.

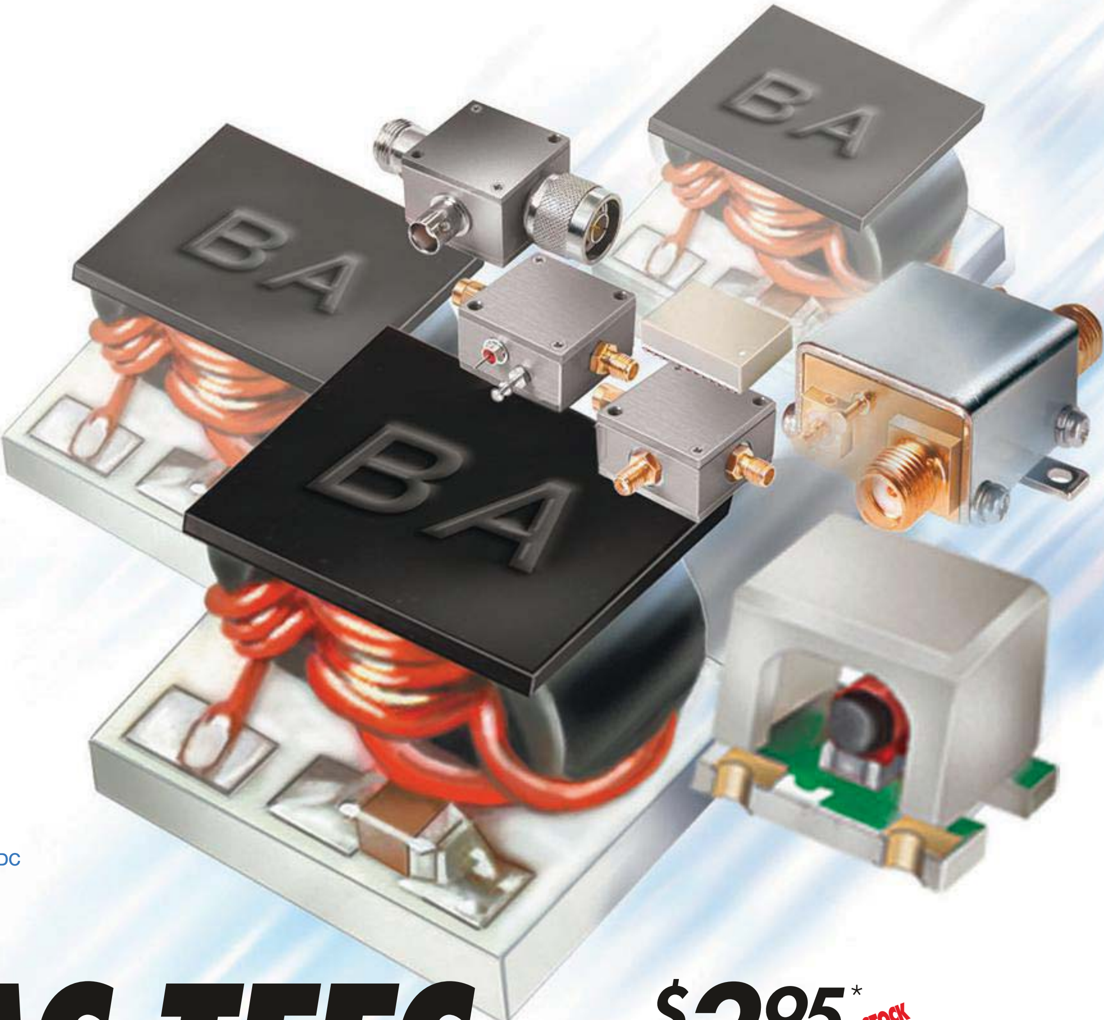
Global Test Equipment—Announced a partnership with ATX Labs to be the exclusive distributor of Velocity Microwave cables and testing products. The entirely new line of equipment brings a new level of accuracy, precision, and value to cables, gages, and torque wrenches. The patent-pending Vector and Conexus series of cables offer innovative modular construction for repairability, flexibility for ease-of-use, and precision. The Continuum Kit offers complete adaptability with in-field replaceable tips. The patent-pending Velocity precision gauges have been designed from the ground up with one goal in mind: user-friendly gauging with the ability to measure both genders relative to all major standards with a single dial face and bushing. Velocity torque wrenches feature a patent-pending automated calibration routine to achieve a best-of-breed tolerance specification before first deployment.

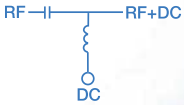
Qorvo—Announced plans, along with Modelithics, to expand the Modelithics Qorvo GaN Library of high-accuracy nonlinear models for Qorvo transistors. The current GaN library version (v1.5) has 29 packaged and die transistor models. New plans include adding over 20 new Qorvo GaN transistor models. The non-linear GaN models feature temperature scaling, intrinsic I-V sensing capability, bias dependence, self-heat scaling factor parameter, and measurement validations including pulsed IV and load pull. Each model comes with a model datasheet, which provides detailed information about the model development, features, parameter settings, and model performance plots.

Coaxicom—Launched its new website, www.coaxicom.com, which includes interactive tools and dynamic product search features including a fully integrated shopping cart. In addition to the e-commerce component, the website offers a custom cable builder, detailed engineering specifications, and a news section for future product releases and announcements.

San-tron Inc.—Announced the appointment of Digiprotech as its new sales representative in India. Digiprotech was founded in 1987 to serve high-reliability and military specifications products for serving exclusively to Indian military, defense, and aerospace markets.

ANSYS—Has been certified by UMC 28- and 40-nanometer (nm) technologies for its simulation tools, which deliver needed accuracy and reduced turnaround time, while ensuring power integrity and electromigration (EM) reliability. As the demand for smart products continues to grow, 28-nanometer process technology is becoming the workhorse for most of the mobile, computing, and Internet-of-Things applications, while 40-nanometer is becoming the lead technology for such automotive applications as microcontrollers.





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TYPICAL SPECIFICATIONS

Model	Freq (MHz)	Insertion Loss (dB)	Isolation (dB)	Max Current mA	Price $ea. Qty.10
TCBT-2R5G+	20-2500	0.35	44	200	6.95*
TCBT-6G+	50-6000	0.7	28	200	9.95
TCBT-14+	10-10,000	0.35	33	200	8.45
TCBT: LTCC, Actual Size .15” x.15”, U.S. Patent 7,012,486.					**Qty.1-9**
JEBT-4R2G+	10-4200	0.6	40	500	39.95
JEBT-4R2GW+	0.1-4200	0.6	40	500	59.95
PBTC-1G+	10-1000	0.3	33	500	25.95
PBTC-3G+	10-3000	0.3	30	500	35.95
PBTC-1GW+	0.1-1000	0.3	33	500	35.95
PBTC-3GW+	0.1-3000	0.3	30	500	46.95
ZFBT-4R2G+	10-4200	0.6	40	500	59.95
ZFBT-6G+	10-6000	0.6	40	500	79.95
ZFBT-4R2GW+	0.1-4200	0.6	40	500	79.95
ZFBT-6GW+	0.1-6000	0.6	40	500	89.95
ZFBT-4R2G-FT+	10-4200	0.6	N/A	500	59.95
ZFBT-6G-FT+	10-6000	0.6	N/A	500	79.95
ZFBT-4R2GW-FT+	0.1-4200	0.6	N/A	500	79.95
ZFBT-6GW-FT+	0.1-6000	0.6	N/A	500	89.95
ZFBT-282-1.5A+	10-2800	0.6	45	1500	56.95
ZFBT-352-FT+	30-3500	0.4	23	4000	48.95
ZNBT-60-1W+	2.5-6000	0.6	45	500	82.95
ZX85-12G+	0.2-12000	0.6	N/A	400	99.95

ZX85: U.S. Patent 6,790,049.

Note: Isolation dB applies to DC to (RF) and DC to (RF+DC) ports.

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OPTICALLY TUNABLE METAMATERIALS FIT FLEXIBLE SUBSTRATES

METAMATERIALS HAVE BEEN gaining attention recently for their capabilities in tuning high-frequency circuits. For extremely high-frequency/optical applications, flexible metamaterials have enabled tuning at frequencies from 0.1 to 10.0 THz. Researchers from Boston University—including Kebin Fan, Xiaoguang Zhao, H.R. Seren, Jingdi Zhang, Xin Zhang, and G. Keiser from Boston University, along with Grace Metcalfe and Michael Wraback from the U.S. Army Research Laboratory in Adelphi, Md.—explain how to develop flexible optically tunable metamaterials for use at THz frequencies.

The responses of flexible tunable metamaterials were characterized with the aid of optical-pump terahertz-probe (OPTP) spectroscopy. Scans were performed with air as the reference, and terahertz frequency pulses were measured. Transmissions were studied at 0.98 THz and at 1.25 THz, using commercial Computer Simulation Technology software.

The research showed that the flexible metamaterials on GaAs substrates could achieve the high resonant frequencies well through 1.25 THz, with outstanding modulation depth over a broad frequency range from 1.1 to 1.8 THz. The computer modeling made it possible to determine the effective permittivities of the different metamaterials used with the GaAs substrates and show how these tuning circuits can help create multilayer nonplanar tunable electromagnetic composite materials for nonlinear and multiple-function applications. See "Optically Tunable Terahertz Metamaterials on Highly Flexible Substrates," *IEEE Transactions on Terahertz Science and Technology*, November 2013, p. 702.

SILICON CMOS SYNTHESIZES SIGNALS AT 60 GHz

DEMAND FOR MILLIMETER-WAVE technology for short-range communications links and automotive safety systems is growing. It was once thought that gallium arsenide (GaAs) semiconductor devices would be the active components of choice here, but silicon CMOS technology is still holding strong. A researcher team supported by the National Research Foundation of Singapore and the School of Electrical and Electronic Engineering of the Nanyang Technological University in Singapore—including Xiang Yi, Chirn Chye Boon, Hang Liu, Jia Fu Lin, and Wei Meng Lim—have demonstrated a frequency synthesizer based on 65-nm silicon CMOS technology. It is capable of high-output signals from 57.9 to 68.3 GHz.

The quadrature phase-lock-loop (PLL) frequency synthesizer exhibits low phase noise at 60 GHz using an in-phase injection-coupled quadrature voltage-controlled oscillator (IPIC-QVCO) with an inductorless divider chain to reduce power consumption. Implemented in standard 65-nm CMOS technology, it uses a 3-b binary-weight switch-capacitor bank for discrete tuning. The inductorless divider chain operates with about 300 mV peak-to-peak voltage and works across a frequency range of 35 to 77 GHz, with at least 3-GHz bandwidth in each subband.

The device was fabricated by means of Global Foundries' 65-nm low-power CMOS process and shows great promise for low-power millimeter-wave communications applications. See "A 57.9-to-68.3 GHz 24.6 mW Frequency Synthesizer With In-Phase Injection-Coupled QVCO in 65 nm CMOS Technology," *IEEE Journal of Solid State Circuits*, February 2014, p. 347.

CMOS TRANSCEIVER TACKLES 210 GHz WITH ON-OFF-KEYWORD MODULATION

AFFORDABLE RADIO COMMUNICATIONS devices for millimeter-wave frequencies will free the way for low-cost communications across short distances in relatively unused frequency bands. Zheng Wang, Pei-Yuan Chiang, Peyman Nazari, Chun-Cheng Wang, Zhiming Chen, and Payam Heydari of the Nanoscale Communication IC (NCIC) Labs at the University of California, Irvine have developed a fundamental-frequency radio transceiver for use at 210 GHz. It is based on a 32-nm SOI silicon CMOS semiconductor process, and employs on-off-keying (OOK) modulation in support of data rates to 10 Gb/s.

This 210-GHz transceiver includes an OOK modulator, a power amplifier driver, a differential power distribution network, four power amplifiers, a voltage-controlled oscillator (VCO), and a 2 × 2 dipole antenna array on the transmit side. The receive side features a receiver with an on-chip antenna, a low-noise amplifier, and a power detector. The LNA exhibits in-band gain of 18 dB and minimum noise figure of 11 dB.

The transceiver was tested under practical conditions, where a modulated continuous-wave (CW) modulated signal from the transmitter was sent to the receiver across a distance of 3.5 cm. The receiver captures the signal and detects the baseband signal. The receiver has a full bandwidth of 20 GHz and is found to achieve receive sensitivity of –47 dBm with receive noise figure of about 12 dB. The transceiver can achieve short-range data rates to 10 Gb/s without filtering and to 20 Gb/s with ideal filtering. See "A CMOS 210-GHz Fundamental Transceiver With OOK Modulation," *IEEE Journal of Solid State Circuits*, March 2014, p. 564.

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	Models	Attenuation Range	Attenuation Accuracy	Step Size	USB Control	Ethernet Control	RS232 Control	Price Qty. 1-9
	RUDAT-6000-30	0-30 dB	±0.4 dB	0.25 dB	✓	-	✓	$395
	RCDAT-6000-30	0-30 dB	±0.4 dB	0.25 dB	✓	✓	-	$495
	RUDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	-	✓	$625
	RCDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	✓	-	$725
	RUDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	-	✓	$695
	RCDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	✓	-	$795
NEW	RUDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	-	✓	$895
NEW	RCDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	✓	-	$995
NEW	RUDAT-4000-120	0-120 dB	±0.5 dB	0.25 dB	✓	-	✓	$895
NEW	RCDAT-4000-120	0-120 dB	±0.5 dB	0.25 dB	✓	✓	-	$995

*120 dB models specified from 1-4000 MHz.
†No drivers required. DLL objects provided for 32/64-bit Windows® and Linux® environments using ActiveX® and .NET® frameworks.

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523 Rev D

JEAN-JACQUES DELISLE | Technical Editor

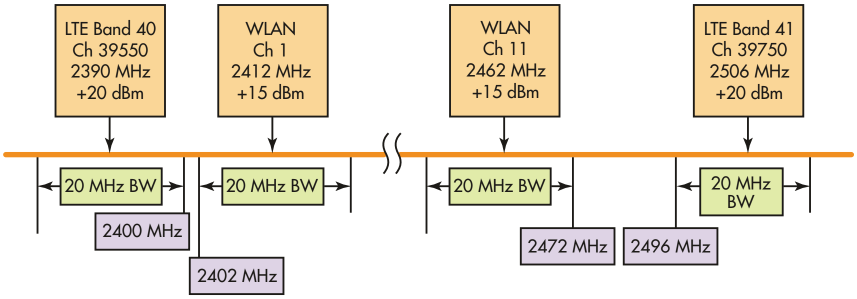
IoT WIRELESS CONVERGENCE

AN INTERCONNECTED WIRELESS world with myriad multifunctional sensors and processing devices is already a reality. A common modern environment isn't complete without its own ecosystem of smartphones, tablets, cameras, RF identification tags, wearable devices, and sensors—all connected through several public and private wireless standards. The wireless technologies enabling the Internet of Things (IoT) and Machine-to-Machine (M2M) devices have customized requirements and performance criteria for each application. In turn, devices based on these wireless technologies must be characterized, compliance-tested, and checked for quality before reaching an end-user. This level of testing requires highly flexible and customizable test systems that can facilitate automation and cost-effective upgrades.

Smartphones and cellular telephones drive a significant amount of communications-based data over several wireless standards and protocols. The most-common standards, such as CDMA, GSM, UMTS, and LTE, are spread across frequencies owned by wireless service providers. Third- and Fourth-generation (3G/4G) Long-Term-Evolution (LTE) wireless technology drives the majority of cellular data traffic, and covers the widest range of frequencies.

LTE is also undergoing advancements that will enable greater data rates, by using multiple LTE channels for a data stream and implementing receiver diversity. With in-building distributed antenna systems (DASs), cellular telecommunication activity is no longer limited to wide open spaces. Unfortunately, signals in these systems tend to suffer from multipath issues and deployment challenges in urban environments or linear internal spaces.

As data demands from cellular telephone users exceed cellular system capacities, a

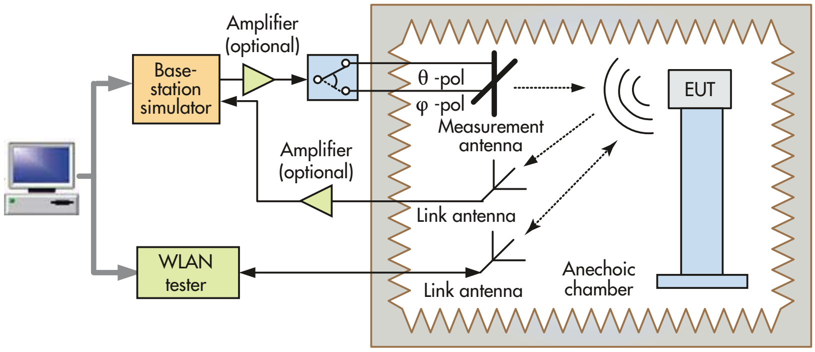


1. Many wireless portable devices contain both Wi-Fi and cellular hardware that may lead to Wi-Fi receiver desensitization if operating simultaneously.

Modular and all-in-one test sets, as well as enhanced automation functions, are enabling effective and low-cost measurements and performance verification for the latest wireless standards.

Sparks Testing Challenges

significant amount of data traffic is being offloaded to Wi-Fi systems. Wi-Fi is the most trafficked wireless solution, with Frost & Sullivan estimating that over 55% of all mobile data will be offloaded to Wi-Fi by 2017. This strain on Wi-Fi has also encouraged the Wi-Fi Alliance to enhance its legacy standards with updated standards and frequencies that better facilitate modern wireless communications. This led to the development of IEEE 802.11ac, a 5-GHz ISM-band Wi-Fi solution with carrier aggregation (CA) and multiple-input, multiple-output (MIMO) protocols within the standard.



2. Over-the-air (OTA) testing is necessary to measure the actual performance and compliance of a complete Wi-Fi module.

Future standards—IEEE 802.11ah and IEEE 802.11af—will incorporate many of these new protocols in the sub-1-GHz and television-white-space frequency ranges. These new advances put very wide bandwidths of Wi-Fi channels in close proximity to cellular communications with channels that are within potential interference ranges. Other standards, such as Zigbee, Thread, and Bluetooth, also operate in close proximity. The 2.5- and 5-GHz ISM bands are also open to other RF applications, which lead to a cluttered spectrum for high-speed, reliable telecommunications.

Hundreds of millions of portable wireless products employ a wide range of these wireless standards. These products often carry multiple radios that operate from frequencies as low as the 13.56 MHz used in near-field communications (NFC) applications to 5.8 GHz Wi-Fi. The density of radios in a single portable electronic product makes power efficiency, coexistence, and spectrum management significant concerns.

3. Several test-and-measurement companies are embracing modular chassis for wireless testing to allow for customization and parallel testing architectures. *(Courtesy of Anritsu)*

Moreover, public safety and military forces have begun adopting commercial wireless connectivity solutions with enhanced security and robustness. These factors leave the designers of this equipment with a battery of compliance and qualification testing from the prototype stage to field-deployments.

HetNet TECH

Adding to the complexity of current portable wireless operation is the recent advance of heterogeneous network technologies. An example of this is carriers developing seamless merging of cellular and Wi-Fi data connections to enhance user experience and support Wi-Fi assuming large amounts of cellular backhaul *(Fig. 1)*. Wi-Fi mobile converged devices will have the capability to hand off from cellular data to Wi-Fi systems in areas where signals are strong enough to sustain a suitable data rate. Since the throughput of a Wi-Fi connection is sensitive to external interference, testing these devices for radio frequency interference (RFI) during a handoff requires additional device testing *(Fig. 2)*.

The number of tests for a highly connected device is at such a high level that automated testing is the only feasible solution to determine the compliance and qualification of each device within a reasonable time *(Fig. 3)*. A challenge for test-and-measurement instrument designers is that these test cases continue to advance and change faster than a testing device could be designed, built, and shipped. Many test and measurement companies—Rohde & Schwarz, Keysight Technologies, Anritsu Corp., National Instruments, and Litepoint, for example—offer highly customizable wideband testing platforms operating to 6 GHz with 160 MHz to 200 MHz of instantaneous bandwidth. The wide bandwidths are necessary for testing CA-based IEEE 802.11ac- and 4G-LTE-enabled devices and products *(Fig. 4)*.

Even with the shift to non-signaling test systems for portable wireless devices, the number and complexity of wire-

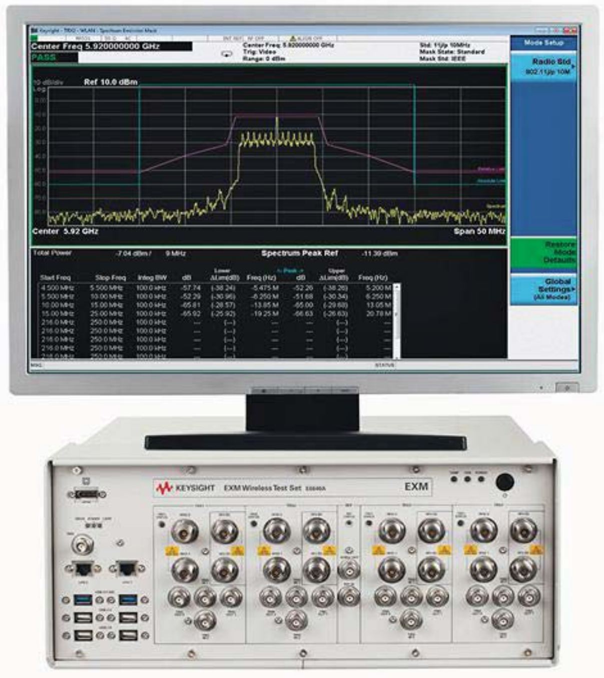
4. A common solution for RF production testing offers a complete all-in-one tester for wireless devices. *(Courtesy of Rohde & Schwarz)*

less standards increases the test time per device. The time a device spends in the test bed directly relates to the costs of test, which in turn drives up device prices. These factors have created an extremely competitive automated test market, where manufacturers have to be confident that the expenses in their test facilities minimally impact overall device prices.

MODULAR SOLUTIONS

Test-and-measurement companies now provide modular wireless test instruments that support a variety of radio test functions *(Fig. 5)*. These modular solutions are computer controlled for enhanced autonomy, and individual instrument cards can be exchanged for rapid maintenance or upgrade. Each of the four modules is a complete transceiver tester independently programmed and controlled. This configurability enables a single chassis to either test several wireless standards in rapid succession or for each module designated to perform radio tests on a single device in parallel.

The majority of these devices are controlled through remote terminals that employ automation software suites with built-in/optional analysis tools. These software tools are often upgradable at cost to the latest wireless standards and analysis methods. Some of these testers incorporate card-key or digital-key unlockers that enable different modulation analy-



5. The capability to upgrade or easily repair tester modules from a common chassis is attractive to many automated test designers. *(Courtesy of Keysight Technologies)*

sis tools, which enable a multiple-instrument owner to swap analysis capability to the devices that require it without having to purchase redundant licenses.

Over-the-air (OTA) updates for these boxes could rapidly increase a test facility's ability to incorporate new wireless standards in its testing protocols. Embracing the need for highly flexible tester use, National Instruments' Wireless Test System incorporates an on-board field-programmable gate array (FPGA) and is capable of advanced signal processing features *(Fig. 6)*. The on-board FPGA architecture has the potential to increase the speed of tests with advanced digital modulations, as modern FPGAs can contain nearly 2 million logic cells and over 5,000 giga-multiple-accumulate applications per second (GMACS) of peak digital-signal-processing (DSP) performance. This and greater processing capability will be required for future wireless standards that are incorporating higher-level digital modulation capabilities to increase spectral efficiency for enhanced data rates.

6. Test and measurement equipment with flexible hardware and software can lead to creating customized wireless standard/protocol test and efficient automated test systems. *(Courtesy of National Instruments)*

THE IEEE 802.11ax STANDARD

An example of a wireless standard geared toward maximizing data rate performance using MIMO and CA is IEEE 802.11ax. Where IEEE 802.11ac's maximum speed is 1.3 Gb/s, IEEE 802.11ax is designed to reach over 10 Gb/s—actively competing with wired data-transfer standards, such as USB 3.1. In a test, Huawei (www.huawei.com) reportedly achieved 10.53 Gb/s, or 1.4-GB, data transfer speeds.

To reach these speeds, IEEE 802.11ax uses 4×4 MIMO and orthogonal-frequency-division-access (OFDA) technology for each multiplexed data stream. Each stream of IEEE 802.11ax is designed for rates to 3.5 Gb/s, which is four times the streaming speed of IEEE 802.11ac. The 802.11ax system occupies the same 5-GHz frequency range as IEEE 802.11ac.

The 802.11ax and other future wireless standards designed to handle the latest data demands will require greater processing power. Wireless testers could rely more on high-powered FPGAs to increase the testing rates and ability to handle complex digital modulation, such as 256-state quadrature-amplitude-multiple (QAM256) formats. Test protocols will also continue to advance to accommodate the volume of wireless standards in security, defense, and M2M applications. This burden will fall on testing facilities to expand their capabilities to test interference and compliance.

For example, ETS-Lindgren (www.ets-lindgren.com) in Malaga, Spain, recently announced the opening of a MIMO OTA test-and-measurement laboratory at AT4 Wireless (www.at4wireless.com) test facilities. The fully anechoic-lined chamber has an array ring of 16 antennas and is designed to test single- and multiple-cluster environments. Multipath and radiated environment testing for portable wireless and cellular device can be placed in simulated real-world scenarios, more accurately depicting modern RF environments.

The theme of most modern test systems has now become the capability to adapt to new testing scenarios through modularity, reprogrammability, PC control, or hardware abstraction. These trends may be a direct result of the increased flexibility of modern radio equipment. With software-defined-radio (SDR) structures increasingly being used for wireless technologies, test equipment must become more agile to confirm the operation of a device under test (DUT) with a virtually infinite number of operating modes.

In addition, the increasing occupation of frequency spectrum has continued to inspire concepts for implementing fully cognitive radio-based spectrum allocation. In such concepts, radios themselves would have the intelligence to assess their present RF environment and decide the best tactics for optimum performance.

The years ahead should continue this trend of the test-and-measurement industry needing to respond quickly to changing communications markets, notably as 5G cellular and millimeter-wave-frequency communications systems become realities. mw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JEAN-JACQUES DESLISE | Technical Editor

Strategies for Measuring Common Signal-Corrupting Distortions

To avoid the performance challenges caused by nonlinearities and distortion, modern measurement techniques can help engineers understand the device mechanics that cause them.

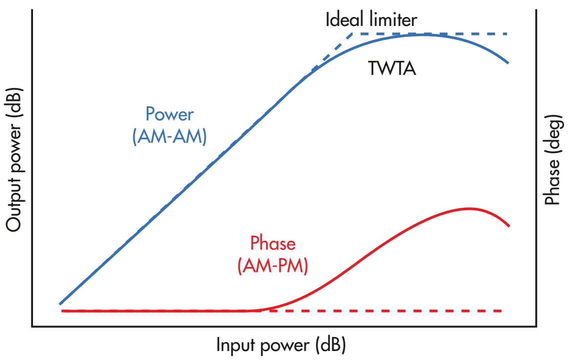
THE INTRINSIC IMPERFECTIONS of devices and the materials that comprise them lead to non-ideal electrical relationships. Nonlinear relationships among power, current, voltage, and phase cause complex responses, which are generally difficult to model. Anything from poorly connected metal structures to internal material properties can induce such relationships.

Ultimately, these nonlinear effects limit component/device performance. Their resultant signals are referred to as distortion products. Engineers must figure out how to effectively measure and mitigate several different categories of distortion products using design or manufacturing techniques. Among the most common distortion challenges are:

HARMONIC DISTORTION

Harmonic implies the development of integer multiples of a series. With harmonic distortion, a distortion product of an input signal appears as the function of a series over an infinite range of frequencies. A nonlinear voltage and current relationship causes harmonic distortion, represented as complex mathematical products. Generally, the first few harmonic products are the most significant—as the power diminishes, the order of the harmonic product rises in parallel. Eventually, these harmonic products fade into the noise floor.

Harmonic-distortion products are generally consistent within a device. Because they are a function of the input signal, careful filtering can often remove the most troublesome harmonic products. Unfortunately, harmonic products may also appear near or within the transmit/receive bands in multi-frequency systems, effectively reducing the dynamic range.



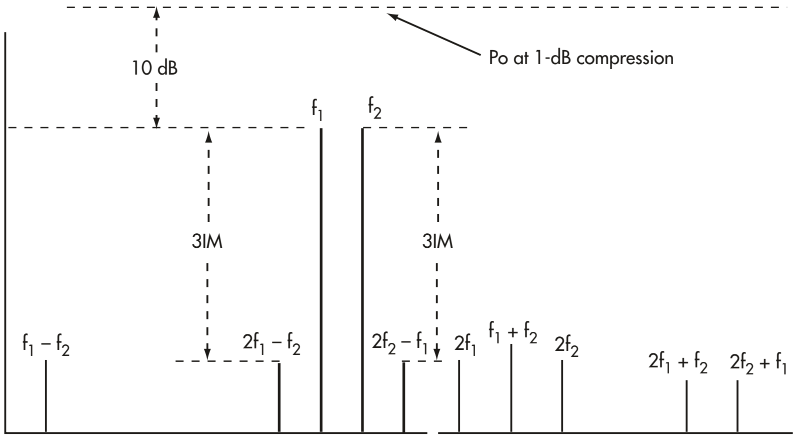
1. Certain materials and active components can induce nonlinear current and voltage relationships, which can cause unwanted signal manipulation.

INTERMODULATION DISTORTION

Intermodulation distortion (IMD) is caused when multiple frequencies are mixed to form sum and difference products of the original signals. These signals occur as integer multiples of the input frequencies (spurs). Often, they impact the operation bands of the devices. Several IMD products can occur within the same receive or transmit band, depending on the input signals and operation bandwidths.

IMD products can be both harmonic and nonharmonic. As a result, predicting and mitigating IMD-generated spurs is both complex and error-prone. If the input signals vary in frequency—in tandem or not—the IMD products will change in both frequency and power. Small component and material imperfections can cause IMD. Examples include dissimilar metal contact, surface corrosion, or intrinsic material properties.

When non-active components cause IMD effects, it's known as passive intermodulation (PIM) distortion. Often, devices and components must be rigorously tested to ensure that they operate with low IMD or low PIM. These



2. Duplex modulation techniques have a higher-power transmission band and a lower-power reception band. Unfortunately, intermodulation-distortion products can appear in the reception band of the device, impairing signal reception.

nonlinear effects tend to increase with cascaded nonlinear component characteristics.

CROSS-MODULATION AND CROSSOVER DISTORTION

Like intermodulation distortion, cross-modulation distortion occurs when two signal characteristics mix together. If two or more input signals are received, the modulation on one signal—caused by nonlinear receiver circuit behavior—can modulate the other input signals. Cross-modulation can dramatically decrease a receiver's dynamic range, especially under high orders of modulation. To limit the effects of this distortion, the receiver front end must be operating linearly.

When a device changes operating modes (such as a transistor switching or changing bias conditions), its characteristic behavior may be nonlinear during that period. This nonlinear transition period can result in intermittent distortion products, known as crossover distortion. The nonlinear transition characteristics of a device may be inconsistent and depend on difficult-to-model effects. As a result, care must be taken to mitigate the nonlinearity of device operating-mode transitions.

PHASE DISTORTION

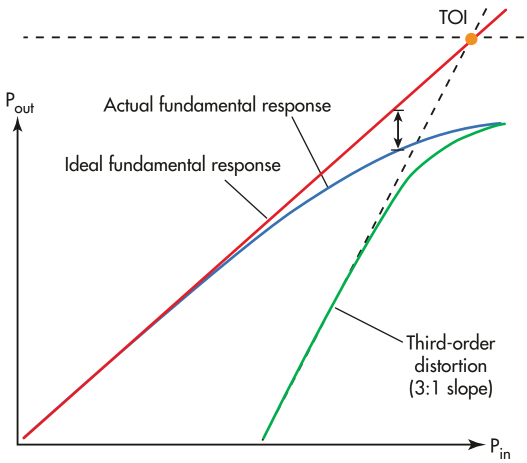
Akin to the nonlinear response between current and voltage, a nonlinear response in the device's phase and frequency response often introduces distortions. These phase distortions can induce "echo" responses in the time domain, which may be difficult to interpret for root cause. Moreover, many wireless technologies rely on time-division duplexing, where the differentiating factor between two signal streams is a frame of time. As signal echoes cascading through such systems, they may degrade subsequent signal streams.

DISTORTION MEMORY AND MEMORY EFFECTS

Some component materials will store small amounts of energy. Over time, this energy may be released at varying frequencies and power levels. These "memory" effects are not always consistent. Occasionally, they will cause distortions or increase the difficulty in modeling a device's distortion-generating characteristics. Memory effects are particularly concerning for power amplifiers, which employ predistortion and envelope-tracking techniques. These techniques rely on data tables based on consistent device behavior that's degraded by memory effects.

MEASURING DISTORTION AND DISTORTION METRICS

To make design or manufacturing changes that mitigate distortion effects, engineers need detailed knowledge of the different root causes of distortion products. Such information is derived from measurements, simulations, and analysis. Because different effects produce the different types of distortion, a battery of tests is needed to effectively detail each distortion contributors: Two-Tone Distortion Measurement (IP3/IPN)

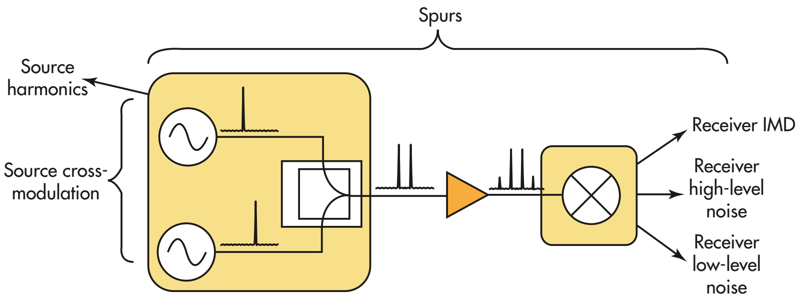


3. A common method of intermodulation-distortion measurement is to stimulate with two equal power tones at different frequencies and measure the power level of the products.

By using two precisely defined and highly linear tones, a signal/spectrum analyzer will be able to measure a device's distortion products. If the total power of the two tones is well known, it's possible to compare the power of the distortion products. Then a relationship can be developed between frequency and power. This two-tone distortion measurement is often performed with two synchronized and symmetrical sources set to a precise difference in frequencies.

An extremely high-isolation power combiner is used to merge the input signals from the sources into the device's input. Next, the device output is input to a signal/spectrum analyzer. Depending on the power levels, an attenuator may be used to lower the input signal's strength to prevent distortion or damage from the analyzer.

Consistent criteria for defining a device's harmonic/intermodulation quality can be beneficial for amplifiers and mixers at various power levels. Typically, employing a power-in/power-out ratio plot with the ideal fundamental response and third-order distortion product can aid an objective comparison. The third order intercept (TOI) is the imaginary point at which the linear slopes of the ideal fundamental response and third-order distortion slope connect. If the TOI is read from the input, it's known as the input intercept point (IIP, IIP3, or IP3). If read from the output, it's defined as the output intercept point (OIP or OIP3). Using the OIP may provide additional insight into the compression effects of a device over multiple measurements.



4. The third-order intercept is a measure of the depth of distortion created by intermodulation products.

NOISE POWER RATIO

Using noise as a stimulus to measure a system's nonlinear effects is a broadband measurement approach that can be performed rapidly over large frequency swaths. In multichannel telecommunications systems, channels can be populated with noise via a broadband noise generator. Comparing the noise in populated channels to an unpopulated channel provides a ratio of the contribution of broadband distortion products to that specific channel (known as noise power ratio, or NPR).

Generally, an arbitrary waveform generator (AWG), synthesizer, and signal/spectrum analyzer perform NPR measurements. The AWG is set to create the noise signal with the desired characteristics. The synthesizer ensures that the noise power is upconverted and placed in the selected channels. And the signal/spectrum analyzer detects the difference in the noise-populated channels and unpopulated channel to deliver the NPR measurement iteratively for various channels.

For telecommunications systems, the NPR can be used to measure the total effects from distortions—possibly replacing IP3 in some cases. After all, the NPR may provide a path to a much faster and more easily automated test.

1-dB COMPRESSION POINT (P1dB)

At some input power level, intrinsic device and material properties will eventually develop a nonlinear power-in/power-out response. To avoid significant nonlinear behavior, such as a power amplifier, receiver, or mixer, most devices are run below a point of significant linearity degradation. This point, the 1-dB compression point, is described as the input power level at which the output power drops 1 dB below the ideal linear response. Generally, a single adjustable power source is swept through a range of input powers to a device. The output of the device is directed to a signal/spectrum analyzer, where the device output is measured. Often, the analyzer has an attenuator at the front end of its receiver to prevent receiver compression, which degrades the measurement accuracy.

ADJACENT-CHANNEL POWER RATIO (ACPR)

Adjacent-channel power ratio best describes highly modulated signals over two-tone sinusoidal measurements. It measures the power at an adjacent channel compared to the primary channel. Such a measurement enables a modulated signal source. It replicates the device's intended use more accurately, since it represents real-world distortion characteristics. Also, alternate-channel power ratio is used to describe the power ratios between the primary channel and the bandwidths spaced two channel distances away from the primary.

ERROR VECTOR MAGNITUDE (EVM)

Error vector magnitude, also referred to as receive constellation error (RCE), is a relatively comprehensive measure of the non-ideal effects of a digitally modulated transmitter or receiver. Thus, distortion products are also embedded within the measurement. Coupling EVM with other distortion-analysis measurements can reveal additional information regarding how the distortion effects impact overall system performance.

EVM is determined by measuring either the power error or percent error difference between the ideal constellation point and the received/transmitted constellation point. The error vector is a vector drawn in the I-Q plane between the ideal and actual constellation point. Generally, the average power of the error vector normalized to the signal power is taken as the power EVM (the root-mean-square, or RMS, average for percentage EVM). Many signal analyzers automatically provide EVM measurements for known forms of modulation, though this type of analysis may require additional software packages. With wireless technologies, understanding and mitigating distortions is critical to reducing signal degradation. mw

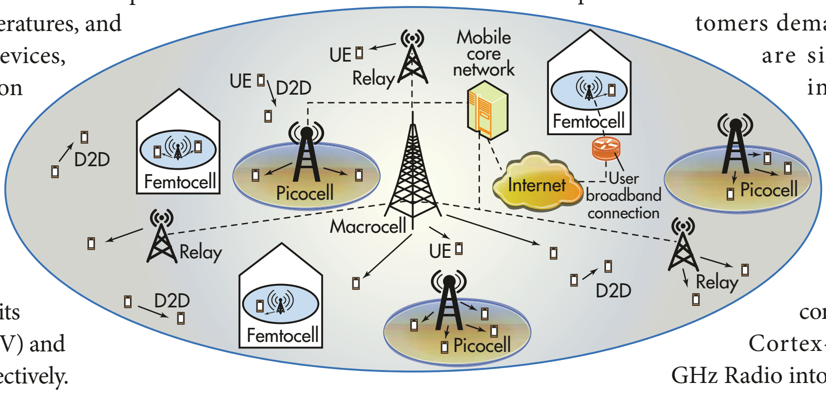
6 Trends Driving Transceiver Design and Development

New technologies, along with innovations and enhancements to existing abilities, lead the list of trends to watch for over the next five years or so.

WHEN IT COMES TO TRANSCEIVERS, the RF communications landscape is always changing, ranging from the seemingly constant turmoil in the commercial cellular market to the somewhat more sedate—yet accelerating—rate of change in the military world. Here are six trends projected to drive changes in transceiver design and development over the next five years.

1. Is the writing on the wall for the power FET? Early predictions of widespread dominance were somewhat premature, but over the next several years, wide-bandgap devices using gallium nitride on silicon (GaN) and silicon carbide (SiC) process technology are expected to gradually replace traditional Si MOSFETs in RF power amplifier applications except for low-end, highly cost-sensitive applications.

Why? GaN and SiC devices operate at higher voltages, temperatures, and frequencies than Si devices, resulting in a reduction in power losses of up to 90%, down to the 1% range. Other competitors, such as super-junction MOSFETs and IGBTs, have technological limits at high voltages (>900 V) and high frequencies, respectively.



Here is a comparison of key parameters for three power-device technologies. *(Source: EEWordsmith)*

A comparison of some key metrics is shown to the right. Johnson's Figure of Merit is a measure of suitability of a semiconductor material for high-frequency power transistor applications and requirements. It's a function of two intrinsic device properties—the electron saturation velocity and the electric breakdown field.

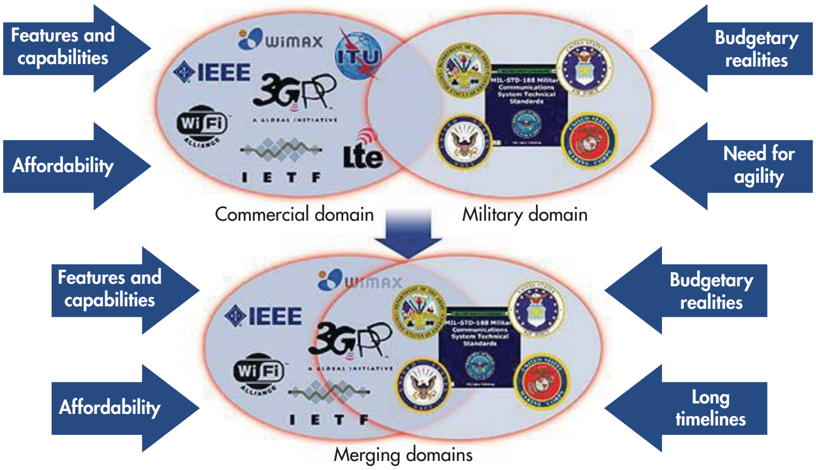
Before you rush out and replace all your MOSFETs, though, be aware that both technologies still have problems to be overcome: GaN has low thermal conductivity and defect issues, while SiC has high wafer costs and low electron mobility.

Expectations are that for mid- and high-end designs, GaN will dominate in lower-power or lower-voltage (200 V) applications, and SiC at higher voltages and powers. Traditional Si devices will still hold sway in low-end designs. Of course, the predicted GaN-SiC switchover point depends on whether your company manufactures GaN or SiC devices.

2. IoT drives reduced power consumption, feature integration. As we've all seen, the Internet of Things (IoT) is ubiquitous these days, and it's leading to a slew of products aimed at space-constrained power-sensitive applications such as fitness and medical monitoring. Improvements in battery technology have been slow in coming, and short battery life continues to be one of the main complaints of consumers. To mitigate the problem while still adding the functions customers demand, manufacturers are simultaneously up-integrating features and reducing power consumption.

For example, Silicon Labs' EZR32WG230 Wireless MCU family combines a 32-bit ARM Cortex-M4 CPU and sub-GHz Radio into a small, form-factor QFN64 package. The features include up to 256kB of Flash, 32kB RAM, and multiple analog peripherals such as a 12-bit 1Msps ADC, a 12-bit 500ksps DAC, 3 op amps, and an on-chip temperature sensor. The RF section is IEEE 802.15.4g compliant, and features a frequency range from 142-1050 MHz, receiver sensitivity of –133dBm, up to +20dBm max output power, a data rate of up to 1Mbps, and a range of modulation schemes. To minimize power consumption, the EZR32WG230 features a flexible energy management system with run, stop, and shutoff modes; shutoff mode consumes only 40nA at 3V.

For Bluetooth LE applications in the sports/fitness and human interface areas, NXP's QN902X is an ultra-low power system-on-chip (SoC) combining a 2.4GHz transceiver with a Cortex-M0 microcontroller in QFN48 or QFN32 packages. It includes 64kB system memory, a four-channel 10-bit ADC, up to 31 general purpose I/O pins, and user-controllable code protection. The RF section features −95dBm RX sensitivity, TX output power from −24dBm to 4dBm, and up to eight simultaneous links in master mode.



Various factors are leading to the convergence of military and commercial communications. *(Source: Johns Hopkins University)*

3. The connected vehicle considers V2I and V2V communication. Vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications are moving closer to reality after a long gestation period. In 1999, the FCC allocated 75MHz of spectrum in the 5.9GHz band (5.850-5.925 GHz) for intelligent transportation systems (ITSs); ETSI followed suit with a 30-MHz allocation in 2008.

Many readers will be familiar with communication from a vehicle to a fixed ground station: GM's OnStar has been around since 1995, utilizing CDMA mobile phone technology for voice and data communication. But dedicated short-range communication (DSRC) systems for V2V/V2I use differ from conventional mobile communication systems in several ways: Users (vehicles) may communicate with each other without relying on a dedicated base station or access point; both source and destination stations are mobile. and they can move at high vehicular speeds (>120 km/h); communications between users take place at ground level, so that the effects of three-dimensional scattering become significant; and the system's range is small, typically about 400 meters.These differences call for the design of novel transceivers for V2V DRSC systems that achieve a high spectral efficiency under harsh propagation conditions.

IEEE 802.11p defines enhancements to 802.11 (Wi-Fi standard) to support ITS, using 10MHz channels. This is half the bandwidth, or double the transmission time for a specific data symbol, than specified in 802.11a. This allows the receiver to better cope with the characteristics of the radio channel in vehicular communications environments.

Due to the potentially very brief time available for communications, the authentication and data confidentiality mechanisms provided by the IEEE 802.11 cannot be used, so they must be provided by higher network layers. Accordingly, the IEEE 1609 family of standards for Wireless Access in Vehicular Environments (WAVE) standards defines an architecture and a complementary, standardized set of protocols, services, and interfaces that collectively enable secure V2V and vehicle-to-infrastructure V2I wireless communications.

IC manufacturers are already developing transceivers to meet the anticipated need. For example, Austrian manufacturer Kapsch's 5.9 GHz transceiver MTX-9450 supports both the 802.11p WAVE standard and IEEE 1609.2 security protocols. Key features include: +33dBm EIRP maximum radiated power; 6 x 10 MHz channels (172, 174, 178, 180, 182,184) and 6 × 20 MHz channels (173, 175, 177, 179, 181, 183); 24V or 48V supply voltage; 3DES, AES, and optional ECC encryption; external or built-in directional antenna; and GPS, 10/100 Ethernet, and RS422 interfaces.

Lest you think that all of this is pie-in-the sky, GM CEO Mary Barra announced at the Intelligent Transport System World Congress in Detroit last September that V2V technology would be included in the 2017 Cadillac CTS. The system will be provided by Delphi using application software from Cohda Wireless and NXP's wireless chipset. And this month, U.S. Transportation Secretary Anthony Foxx announced an accelerated schedule for NHTSA's proposal to require V2V equipment on new vehicles.

4. 5G on the horizon. At IMS 2015 in Phoenix last month, "5G" was on everyone's lips. Even though it's five years away from implementation, some key concepts are emerging that promise to drive changes in transceiver design:

Millimeter-wave communications. Given the full utilization of the spectrum currently allocated for cellular communications (as noted elsewhere in this article) and since 5G single-user peak data rates will be in the 10Gbps range, it's anticipated that expansion into millimeter-wave frequency bands (e.g., the 28-GHz, 60-GHz, or 71-GHz bands) will be needed, since it allows wider bandwidth transmission than the 20MHz used for 4G systems. There are hardware problems to be solved, though, including the high power consumption of mixed-signal components such as ADCs and DACs.

Massive MIMO. This is a type of MIMO where the number of BS antennas is much larger than the number of devices. Its implementation involves replacing the expensive, high-performance BS RF amplifier with hundreds or thousands of low-cost amplifiers with much lower power levels. This approach renders the channels to the different devices quasi-orthogonal, giving large gains in spectral efficiency. Studies have shown that a 4 × 4 MIMO array gives 100% improvement in gain for a single user over a 50MHz bandwidth channel versus a single antenna. An 8192-antenna array serving 1,000 users randomly in a 6-km radius cell gives a 7,000% improvement compared to the 4 × 4 baseline. The downside is increased complexity of the transceiver hardware and the complexity and energy consumption of the signal processing at both ends.

Heterogeneous networks (HetNets). 5G network proposals envision a wide range of communication channels—a combination of femo, pico, and macrocells, and direct device-to-device (D2D) communications including other channels such as Bluetooth and Wi-Fi Direct. It's also likely that Downlink/Uplink Decoupling (DUDe) will be employed to maximize network throughput and reduce power consumption.

5. LTE spectrum wars lead to transceiver design complexity.

The Long Term Evolution (LTE) standard provides significantly increased peak data rates, with the potential for 300 Mbps downstream and 75 Mbps upstream, reduced latency, scalable bandwidth capacity, and backwards compatibility with existing GSM and UMTS technology. Following the initial proposal in 2004 by NTT DoCoMo in Japan, implementation plans are proceeding across the globe with South Korea, Japan, and Australia leading the way, followed closely by the United States.

Finally! A common international standard. Worldwide roaming is just around the corner, right? Not so fast. The allocation of radio spectrum for LTE usage varies widely from country to country, even within countries. With the demise of UHF TV and the auctioning off of its spectrum, it was hoped that 700MHz would become an international roaming standard for LTE. Currently, though, spectrum used for LTE ranges from 700MHz to 2.6GHz with 700MHz coming in at No. 3.

Even in the U.S., the 700MHz band is divided into a lower band at 698-746MHz and an upper band at 746-806MHz. The large nationwide suppliers use slightly different paired blocks, but can afford to have transceivers developed specifically for their phones.

These varying LTE bands, plus the need to accommodate differing legacy systems, are driving increased complexity in transceiver design. Current transceivers must support multiband operation, both TDD and FDD technologies, and legacy systems such as GSM, EVDO, and CDMA.

6. Military communications leverage commercial applications. Certain elements seem to be common to military systems, whether wireless or not: They're designed to meet a rigorous set of performance requirements; they have to operate in harsh environmental conditions; and they must include extreme levels of security and resistance against being compromised, including the likelihood that they will fall into the hands of an enemy. To that list the cynic might add that they usually take many years to come to fruition, are often massively over-budget, and trail behind the commercial sector in performance.

Perhaps no longer. The military is increasingly adapting commercial wireless technology for its own use. There are many reasons for this trend, including:

Cost. In an era of budget constraints, there is heightened awareness in both the military and the government of the need to make better use of taxpayer dollars.

Life cycle. Military operations have changed significantly over the past decade. Today's soldiers must confront a range of small-scale opponents who adapt and change continually.

Features. With their compressed development cycles, commercial technologies are often far superior to military equipment first proposed 10 or 20 years ago.

Recognizing that military equipment has unique security and environmental requirements that cannot be met by purely commercial solutions, military and government communications systems are taking the best commercial devices and embedding them within a secure framework. To help in this effort, the National Security Agency (NSA) established NSA Commercial Solutions for Classified Communications (CSFC) guidelines to enable commercial products to be used in layered solutions.

For example, the Motorola Solutions Assured Mobile Environment (AME) 2000 Secure Mobile Solution combines a commercial-off-the shelf (COTS) device based on the Android OS with hardware and software to provide end-to-end encrypted voice and data communications through private or public wireless networks to support the missions of federal agencies.

And in another project, investigations are underway to use commercial frequency agile transceivers for multi-GNSS (Global Navigation Satellite System) military applications while still meeting military anti-jamming and anti-spoofing requirements.

The bright side to this varied list of trends? Continued employment for transceiver design engineers. mw

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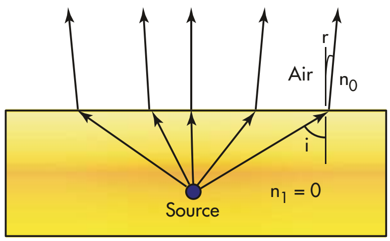
METAMATERIALS Forge High-Directivity Antenna

By adding metamaterials to different parts of a microstrip antenna structure, it is possible to boost both gain and directivity, even while reducing the physical size.

Metamaterials offer great promise in the design of high-frequency components, such as antennas. If properly applied, these engineered materials can enable, for example, enhanced antenna directivity for compact microstrip designs.

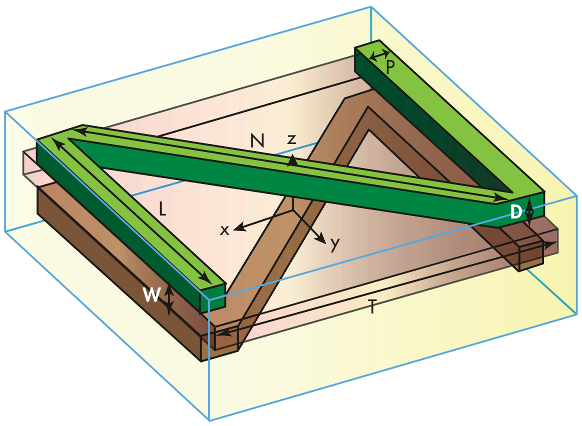


1. Metamaterials can be used as covering layers to achieve directional propagation in a microstrip antenna.

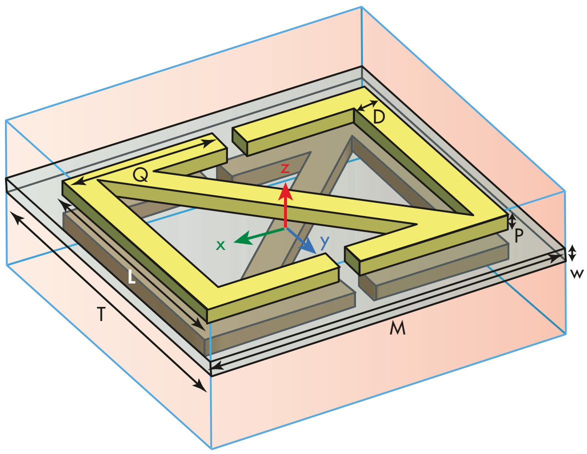
To demonstrate, Z-type and quasi-triangular metamaterials were applied to conventional microstrip circuitry to produce an antenna substrate with improved electromagnetic (EM) radiation characteristics. These metamaterials minimize backward-wave radiation while increasing forward antenna radiation, resulting in a directivity factor increase of 92.6% and gain increase of 3.03 dB for an experimental 6-GHz microstrip antenna.

Metamaterials have been considered part of certain design efforts since 1968, as a potential means of improving antenna performance.[1] Because of their small size and ease of integration into many different high-frequency circuits, microstrip antennas have been quite popular for use at microwave frequencies. Unfortunately, the low directivity and high loss of microstrip antennas has limited their use in some applications.

To increase the usefulness of microstrip antennas, research was performed to better understand how metamaterials might be used to increase antenna gain and directivity. Traditional methods of antenna optimization have rarely improved upon the limits of physical size, bandwidth, and gain, so it was thought that using metamaterials as part of the construction might improve microstrip antenna performance.[2-6]

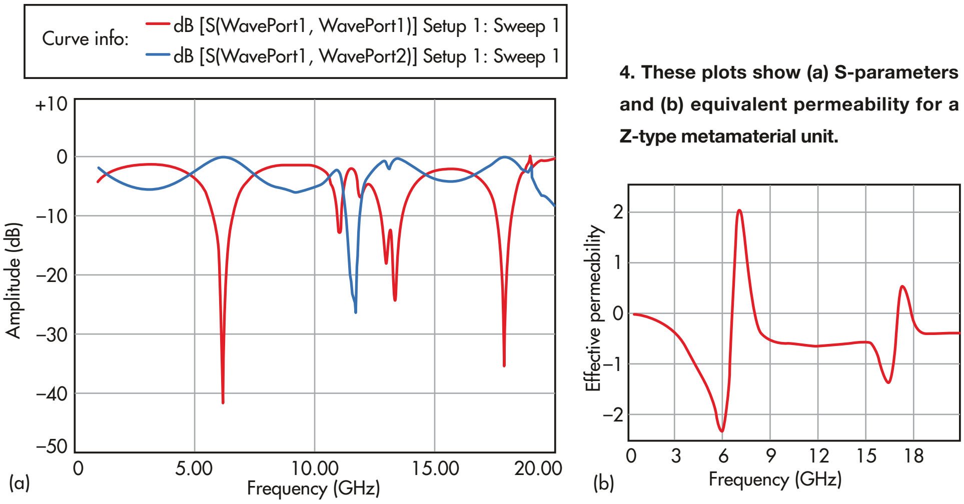


2. This is a Z-type metamaterial antenna structure.



3. This is a quasi-triangular metamaterial antenna structure.

Some research groups have made use of convergence effects to improve antenna performance with metamaterials,[7-13] while other groups have employed metamaterials and the backward-wave characteristics of different antenna designs to achieve smaller physical designs.[14-16] Some workers have proposed the use of absorbing materials to reduce antenna loss.[17] Some studies have used metamaterials both as an antenna substrate material and as an overlay material for the antenna, but those studies have lacked details on covering materials for those antenna designs.



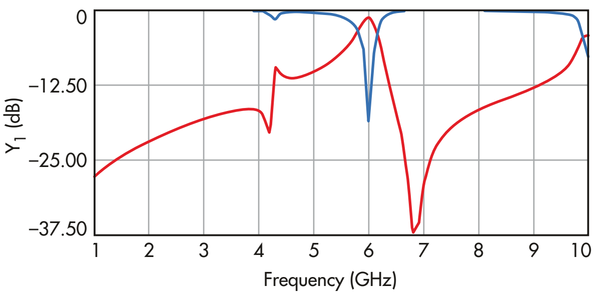
4. These plots show (a) S-parameters and (b) equivalent permeability for a Z-type metamaterial unit.

The current report presents a microwave frequency microstrip antenna built on a metamateral medium. Metamaterials are used both for the substrate and the cover layer. Computer-aided-engineering (CAE) simulation was performed to explore the influence of the metamaterials, including the cover layer, on antenna performance. The analysis reveals that the use of metamaterials in the substrate and covering layer significantly improves the gain, directivity, and radiation efficiency of the antenna compared with a microstrip antenna fabricated on conventional circuit materials.

By using the optical properties of metamaterials, it is possible to control the permittivity and permeability of the materials to a degree. Using metamaterials as an antenna cover layer improves antenna directivity based mainly on the near-zero refractive characteristic of the materials.

According to Snell's law, which describes the angles of incidence for different waves and their refraction through different materials, EM waves build to propagate in a particular direction. Assuming that an EM wave from a metamaterial medium is incident to an air medium, and the EM wave vector is in the x-z vector, the wave vector can be described as

$$\hat{k} = \hat{x}k_x + \hat{z}k_z$$



5. These are the transmission coefficients of the quasi-triangular metamaterial unit.

With the metamaterials and the air medium interface forming the z axis and the EM wave in the incident direction as the x axis—namely, the air dielectric x > 0 plane wave incident to the metamaterials from the x < 0 plane—when the spindle is parallel to the metamaterial medium, the EM parameters of the metamaterials can be expressed as

$$\overline{\overline{\varepsilon}} = \varepsilon_0 \overline{\overline{\varepsilon_r}} = \varepsilon_0 \operatorname{diag}[\varepsilon_{rx};\ \varepsilon_{ry};\ \varepsilon_{rz}]$$

$$\overline{\overline{\mu}} = \mu_0 \overline{\overline{\mu_r}} = \mu_0 \operatorname{diag}[\mu_{rx};\ \mu_{ry};\ \mu_{rz}]$$

For transverse electromagnetic (TE) wave propagation, the polarization direction of the electric field is along the y-axis direction, where $k_y = 0$, and

$$\frac{k_x^2}{\mu_{rz}\varepsilon_{ry}} + \frac{k_z^2}{\mu_{rx}\varepsilon_{ry}} = k_0^2$$

The two components of the refractive index are

$$n_x = \sqrt{\mu_{rz}\varepsilon_{ry}},\ n_z = \sqrt{\mu_{rx}\varepsilon_{ry}}$$

When

$$|\mu_{rz}| << 1$$

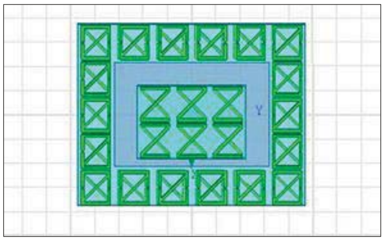
$$n_z \approx 0,\ n_x \neq 0$$

then

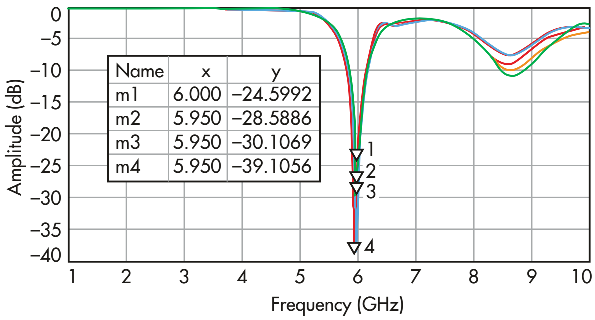
$$k_z \approx 0,\ k_x > 0$$

Since the propagation of EM waves must comply with the phase-matching conditions and the z-axis of the antenna structure is along the surface between the metamaterials and the air medium, the EM wave radiation builds near the normal vector of the interface between the air and the EM propagating medium *(Fig. 1)*.

The use of metamaterials for an antenna substrate can minimize problems caused by strong surface waves. When an EM



6. This is the design of a metamaterial-based microstrip antenna.



7. This is a plot of the return loss for the antenna design.

wave is incident to the surface of a lossy medium or nonideal conductor, a surface wave is generated. It usually appears as part of the TM wave on a capacitive surface, or a TM wave on an inductive surface. It is commonly used as part of the nonzero thickness of the dielectric substrate.

When the relative permittivity of the substrate is $\varepsilon_r > 1$ (higher than air), at least one transverse-magnetic (TM) propagating mode has a cutoff frequency of zero, which is known as the TM_0 mode. In practice, a substrate's length is limited. A substrate edge antenna will produce large amounts of radiation sidelobes with a zero corner, while the substrate back edge will produce EM radiation. Consequently, much energy is wasted in the back hemisphere, which impacts on antenna performance.

Metamaterials used as antenna substrates are optimized according to their negative permittivity characteristics. They are optimized to suppress the undesired radiation generated by any surface waves. Any metamaterial design can be analyzed by the equivalent-circuit method, where the design of a circuit with metamaterials is essentially the same as an equivalent circuit with impedance of

$$Z = \frac{j\omega L}{1 - \omega_0^2 LC}, \quad f_0 = \frac{1}{2\pi\sqrt{LC}}$$

From this impedance formula, it can be seen that the impedance approaches infinity when metamaterial unit reaches the resonant frequency, thus prohibiting the radiation of a surface wave.

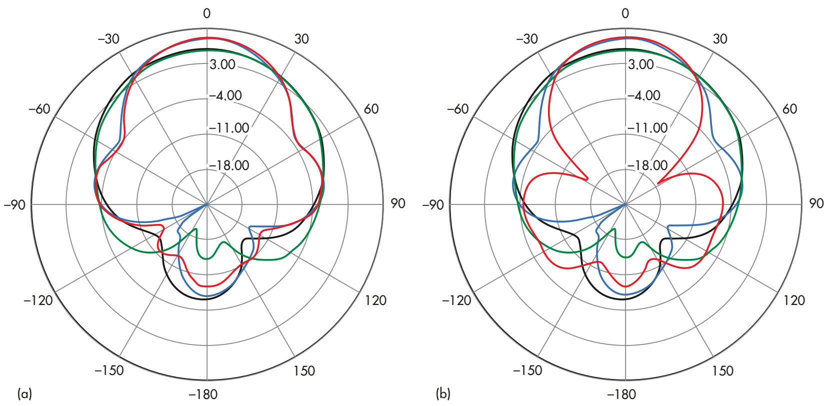
Several metamaterial antenna units were designed, including Z-type and quasi-triangular metamaterial units *(Figs. 2 and 3)*. These units feature three layers perpendicular to the z-axis of the medium. Two planes parallel to the z-axis are set to the wave excitation port. The load impedance is 50 Ω.

Parallel to the y-axis, two planes were set for perfect magnetic conductor (PMC), two planes parallel to the x-axis is set for perfect electric conductor (PEC). Metal structures on both sides of the substrate in the magnetic field induce antiparallel currents to achieve magnetic resonance. The structure of the metal rod will produce an electric-field-induced resonance. By optimizing and adjusting the dimensional parameters, a desired resonant frequency can be achieved with these structures.

The Z-type structure was printed on both sides of double-sided FR-4 printed-circuit-board (PCB) material. The FR-4 was 1.6-mm thick with relative dielectric constant, ε_r, of 4.4. The geometric parameters of the Z-type structure were T = 7.5 mm; W = 1.6 mm; L = 6 mm; N = $(2)^{0.5}$L; P = 0.2 mm; and D = 0.3 mm. The quasi-triangular structure was printed on both sides of a 1.6-mm-thick FR-4 board with ε_r of 4.4. The geometric parameters for this structure were T = 8 mm; W = 1.6 mm; M = 8 mm; P = 0.3 mm; L = 6.5 mm; D = 0.5 mm; and Q = 2.8 mm.

The cladding layer for the Z-type unit was based on the principle of the zero refractive property of metamaterials; the antenna substrate production of the quasi-triangular metamaterial unit is due to the use of the transmission bandgap effect. An ASUS computer running the High Frequency Structure Simulator (HFSS) electromagnetic (EM) simulation software from ANSYS (www.ansys.com) was used for the simulation of these structures, based on the finite-element method of simulation.

These simulations yielded S-parameters for the Z-type structure *[Fig. 4(a)]*. In addition, the permittivity of the Z-type unit was calculated *[Fig. 4(b)]* by means of the Matlab software from Mathworks (www.mathworks.com) and the use of the NRW algorithm.[17] The results show that a zero refractive index can be achieved at 6 GHz. The S-parameters for the Z-type unit *(Fig. 5)* indicate that the 6-GHz band gap that appeared in these



8. These plots show the gain of the antenna design in (a) the E plane and (b) in the H plane.

results can be used to improve the performance of that antenna structure.

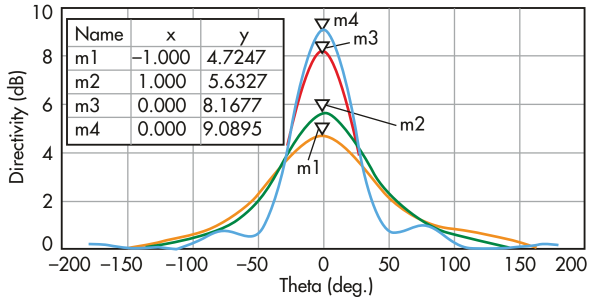
A form of reverse thinking helped to design the metamaterial antenna structural units. First, the specific requirements of an application are determined, then the structure is designed, and finally the structure's parameters are adjusted to meet the requirements of the application. HFSS was used to design and simulate the performance of a microstrip antenna with center frequency of 6 GHz. The antenna, which was based on FR-4 PCB material with relative dielectric constant, ε_r, of 4.4 at 10 GHz in the z-axis (thickness) of the material.

The material was 1.6-mm thick and a 50-Ω feeder was designed as part of the antenna. The width of the antenna's radiation patch was w = 16 m with length, L, of 10.8 mm. The feed point position for the antenna was at $L_1 = 2.7$ mm. The width and length of the dielectric substrate were $W_0 = 47$ mm and $L_0 = 37.5$ mm, respectively.

In keeping with the 6-GHz center frequency, the cover layer of the Z-type structure is disposed above the microstrip antenna by means of a double-layer structure. A distance of 3 mm is between the two cover layers. The lower distance between the cover and the antenna is 33 mm.

Adjusted quasi-triangular metamaterial units were printed on a substrate, with the metamaterial unit printed around the radiation patch. To ensure use of the material's zero refractive properties and bandgap characteristics, the microstrip antenna's center frequency should be the same as that of that of the two metamaterial units *(Fig. 6)*.

Simulations provided return-loss values for four types of experimental antennas: one with the metamaterial layer and substrate as a covering, the metamaterial unit with the substrate alone, the unit with separate loading cover layer, and the original antenna *(Fig. 7)*. The maximum return loss for all four devices occurred at the center of each microstrip antenna, with the peak value of loss at different values for the four approaches. The results show that the impedance matching performance of the antenna has been optimized.



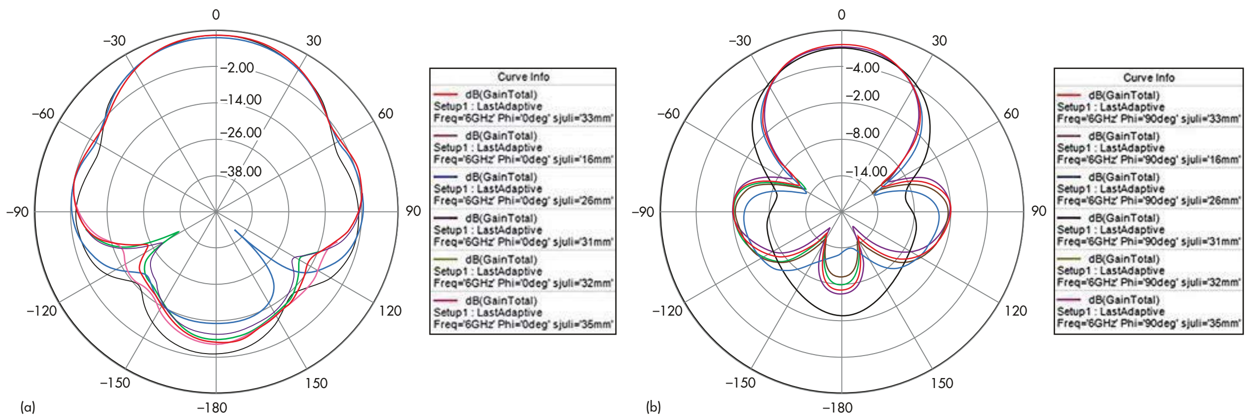
9. These plots show the directivity of the antenna design.

Gain patterns were also obtained at the center frequency for these four antenna configurations *(Fig. 8)*. Compared to an standard microstrip antenna, using metamaterials to cover both the layer and the substrate, the E- and H-plane half-power (−3-dB) beamwidths of the antenna were reduced by 47.5 and 37.1 deg., respectively. If the metamaterials are only used as overlay for the antenna, the half-power beamwidths are reduced by 36.7 and 28.3 deg., respectively. If the metamaterials are only used for the antenna substrate, the radiation will be 9.7 and 7.57 deg., respectively.

Directivity coefficients were also plotted *(Fig. 9)*. When using metamaterials, both as the dielectric layer and the substrate loading covering layer alone, and making substrate alone—as well as dividing the directivity of the original antenna as 9.09, 8.17, and 5.63 dB—it can be seen that the directivity coefficients are increased by 4.37, 3.45, and 0.91, respectively.

The geometry of these metamaterial antenna units must be optimized to match the center frequency of a microstrip antenna for optimum results. Also, the metamaterial cover layer must be loaded over the top of the antenna, at an optimum distance to the antenna along with optimum number of cover layers and optimum distance between layers.

The back radiation of an antenna loaded with cover increases with the increase in spacing between the cover layer and the antenna. This is due to the restriction of EM radiation and the fact that the EM energy forms a loop between the antenna substrate and the cover layer. The back radiation of the antenna substrate to



10. These plots show how the distance between cover layers and the antenna impacts gain in (a) the E plane and (b) in the H plane.

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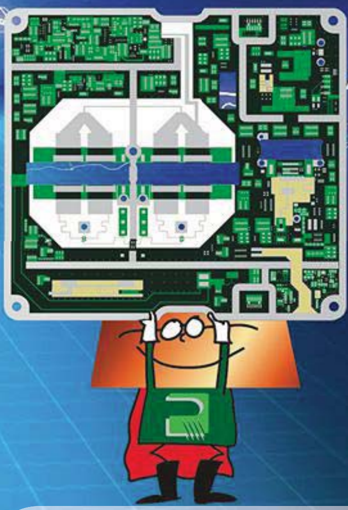

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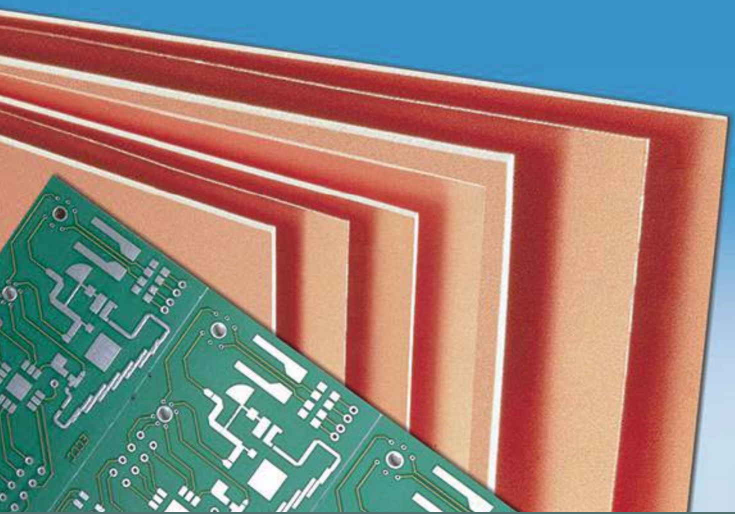

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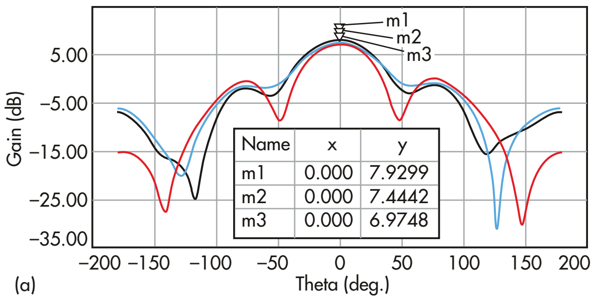

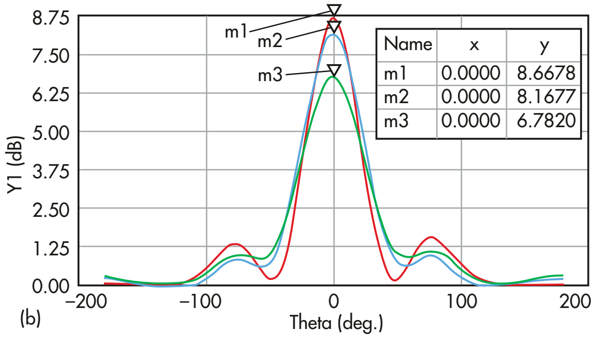

11. These plots show how the number of covering layers affects (a) gain and (b) directivity.

the EM wave increases.

In the experimental covered design, the distance between the middle and the experimental layer was 3 mm *[Fig. 11(a)]*. The simulations were limited to three covering layers due to the capabilities of the computers used in the simulation. Even with only three layers, the trends show increased control of the EM wave propagation orientation for the antenna. The gain tends to decrease, however, with the addition of more covering layers.

The antenna gain was evaluated for two covering layers, with gain varying with the distance between the covering layers *(Fig. 12)*. With the increasing distance between the two cover layers, the antenna gain and directivity coefficients first increase, then decrease. There are two reasons for this: On one hand, reflection of the EM waves is large with large distance between the covering layers. On the other hand, if the distance is too small, resonance occurs between the different units. As a result, the resonant frequency shifts so that the center frequency of the metamaterial structure and the antenna are not properly matched. mw

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ACKNOWLEDGMENTS

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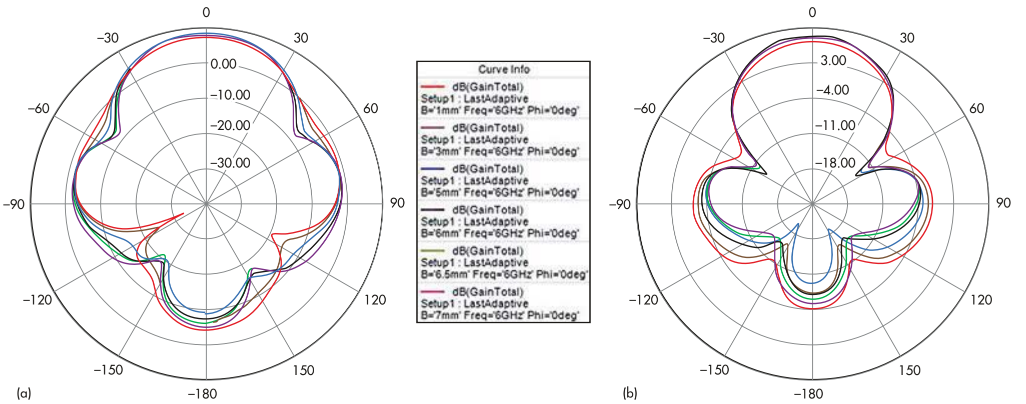

12. The distance between the covering layers and the antenna affects gain in (a) the E plane and (b) in the H plane.

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Picking PCB Materials for Microwave Amps

Requirements are somewhat different for circuit materials supporting RF/microwave power amplifiers compared to materials for low-noise amplifiers.

Microwave amplifiers come in many shapes and sizes, with low-noise amplifiers (LNAs) and power amplifiers (PAs) perhaps two of the most commonly used high-frequency varieties. One of the most essential components in implementing both types of amplifiers in hybrid circuit form is the printed-circuit board (PCB) which can contribute a great deal to the final performance of both LNAs and PAs, of course in different ways.

By reviewing some basic PCB material characteristics and parameters, it can be possible to locate available PCBs that are well suited to LNA and PA circuit designs for a wide range of commercial, industrial, and military applications.

Consistency and stability are two properties that might be considered good starting points for any circuit material being considered as a foundation for either an LNA or a PA *(Fig. 1)*. The power levels and the heat generated by the two types of amplifiers will differ, but maintaining consistent behavior across frequency and temperature for critical PCB material parameters—such as dielectric constant (Dk or ε_r), temperature coefficient of dielectric constant (TCDk), or dissipation factor (Df)—can benefit the performance of either type of amplifier.

1. Circuit materials must provide consistent physical and electrical characteristics when fabricating power amplifiers such as these as well as for low-noise amplifiers.

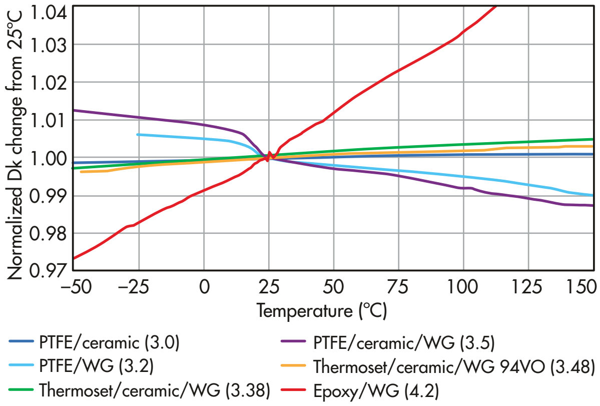
LNAs are typically compared for a given bandwidth by a number of key performance parameters, including noise figure, small-signal gain, and output power at 1-dB compression. Ideally, noise figure remains consistently low even with increasing frequency and temperature. LNA noise figure is highly dependent on tight impedance control of the LNA circuitry (often at 50 Ω), and tight impedance depends on a number of different circuit material characteristics. These include variations in PCB material thickness, variations in Dk across the material, and changes in Dk as a function of temperature.

Minimizing circuit material loss will contribute to minimizing the noise figure of an LNA fabricated on that material.[1] PCBs suffer losses from various components of the material, including dielectric loss from the dielectric material. For that reason, PCBs with lower Df values are usually specified for RF/microwave LNA designs.

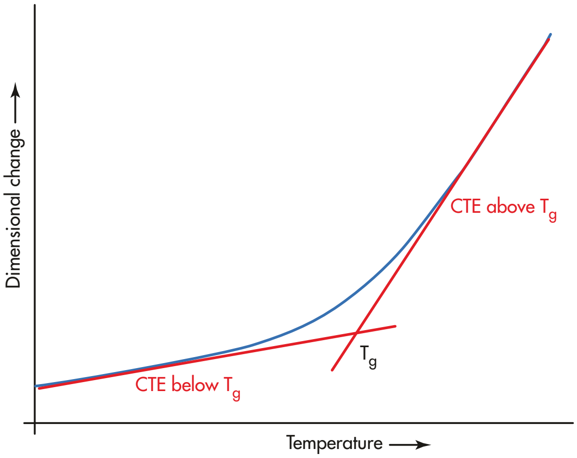
Variations in material thickness can produce variations in the impedance of transmission lines fabricated on those circuit materials, so a candidate PCB material for an LNA design should have tightly controlled thickness to enable tight impedance control for those PCBs. Materials with thickness tolerances of ±10% or better are considered quite good for many high-frequency applications.

For a PCB with a given Dk value, the circuit characteristic impedance is determined by the width of the transmission-line conductors and the Dk value. For lower-Dk materials, wider conductors are needed to achieve a given impedance (such as 50 Ω) compared to narrower conductors for the same impedance with higher-Dk materials. Although these wider transmission lines may occupy more space on the PCB, they also suffer lower loss than narrower transmission lines.

Of course, a circuit material's Df also contributes to the material's loss calculations. Achieving tight impedance control



2. Maintaining tight control of Dk over a wide temperature range is a key characteristic for PCB materials for PAs and LNAs.



3. Maintaining consistent coefficient of thermal expansion (CTE) with temperature is beneficial for circuit materials for PAs and LNAs.

for a particular PCB material requires minimizing variations in PCB conductor width and minimizing the variations in the thickness of the copper used to form those conductors. The impact of conductor and copper thickness variations on impedance is greater for thinner PCB materials than for thicker PCB materials, although those thicker PCB materials will have greater dielectric losses than the thinner circuit materials.

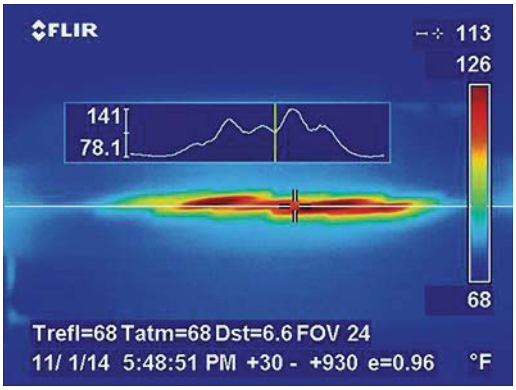
Circuit impedance also varies with changes in circuit Dk, so a candidate PCB material for an LNA should offer fairly tight Dk tolerance. Fortunately, commercial PCB materials are available with Dk values held within fairly tight tolerances across the material. For example, RT/duroid 6035HTC material from Rogers Corp. (www.rogerscorp.com) exhibits a Dk of 3.5 through the z-axis (thickness) of the material at 10 GHz, with a Dk tolerance within ±0.05 across the material. The tightly controlled Dk makes possible LNA circuits with tightly controlled impedance for strong noise-figure performance.

The RT/duroid 6035HTC material maintains tight Dk across a wide temperature range *(Fig. 2)*, with a TCDk of −66 ppm/°C in the z-axis from −50 to +150°C. The material also exhibits low loss, with a Df of 0.0013 at 10 GHz. This material and these characteristics are good examples of the types of material specifications that can combine for good LNA performance.

PA MATERIALS

Circuit materials for RF/microwave PAs have a somewhat different set of priorities for their critical characteris-

tics since they are processing much higher power levels than LNAs.[2] As with circuit materials for LNAs, tight Dk and impedance control are important parameters for materials being considered for PA circuits. Thermal conductivity becomes a bit more important for PA designs owing to the greater heat generated by these types of amplifiers. In fact, key PCB material parameters to consider for PAs are thermally related, including thermal conductivity, TCDk, and coefficient of thermal expansion (CTE).



Microstrip edge-coupled bandpass filter at 3.34 GHz with 50 W using 20-mil RT/duroid 6035HTC laminate

4. As this thermal display for a 50-W filter shows, RT/duroid 6035HTC material promises reliable PTHs even at the power/temperature levels of microwave PAs.

High-frequency circuit materials are often referred to as thermally resistive materials since they typically offer low thermal conductivity. A typical minimum value of thermal conductivity for a circuit material for a PA is about 0.30 W/m/K. But commercial PCB materials are being developed with increasing values of thermal conductivity in support of PA circuit designers.[3] Ideally, PCB materials for PAs can exceed that 0.30 W/m/K value of thermal conductivity, to aid in the thermal management of the active devices, such as gallium-nitride (GaN) transistors, that amplify high-frequency signals and generate heat in solid-state RF/microwave PAs. The RT/duroid 6035HTC circuit material referenced earlier actually has a remarkably high thermal conductivity compared to most commercial circuit materials—1.44 W/m-K at +80°C—which makes this material a strong candidate for RF/microwave PA circuits especially at higher power levels where more heat must be removed from the PCB.

The same material's TCDk characteristics indicate that, as it does for LNAs, it will maintain consistent Dk behavior for PAs across a wide operating temperature range *(Fig. 3)*. In addition, with CTE that is closely matched in the x and y axes (19 ppm/°C) to the CTE of the copper (17 ppm/°C) that forms the conductors for the circuit material, RT/duroid 6035HTC material *(Fig. 4)* promises to provide reliable plated through holes (PTHs).

This holds true even with the thermal stress that can be exerted by some high-frequency PA circuits. Such PTHs may be needed for conducting heat from active devices and PA circuitry, through the PCB dielectric material, and to a metal base plate where the heat can be dissipated as part of a thermal-management arrangement.

PCB material loss plays a role in the amount of gain and output power that can be achieved for a given PA circuit, with circuit material loss varying with material thickness. Circuit materials have numerous loss components, such as conductor and dielectric losses, that vary in their percentage of the total PCB loss as a function of material thickness.

For example, with thicker PCB materials, dielectric losses comprise a larger portion of the total loss, whereas with thinner PCB materials, conductor losses are more dominant. Selecting PCB materials with lower total losses can help to optimize PA performance in terms of both gain and output power.

A PCB material's copper surface roughness can play a role in the material's conductor-loss performance. A mate-

rial with rough copper surface will have increased conductor loss compared to the same circuit material with smooth copper surface. Again, it will have greater effect on the total PCB loss for thinner circuits rather than thicker ones, where dielectric losses are more dominant.

Building PAs on PCB materials with high loss not only can rob the design of output power and gain, but also contribute to thermal-management challenges, since the higher loss means that more power through the amplifier is translated into heat. One material parameter that serves as a reliable guideline for the thermal management of a PCB PA design is the PCB's maximum-operating-temperature (MOT) specification, which should not be exceeded for any length of time if at all possible.

The heat generated by a PA design can be decreased by selecting a PCB material with thickness and loss that are optimum for the PA's expected output-power levels. Otherwise, thermal-management steps must be taken, such as the addition of heat sinks to the PCB, to ensure that the PCB MOT is not exceeded.

HIGHER DK MATERIALS

In the search for PCB materials for LNAs and PAs, circuit materials with higher Dk values offer the opportunity to miniaturize circuit dimensions for a given impedance and frequency range when physical size is critical.[4] The wavelength of a circuit is frequency dependent and material dependent, and PCB materials with higher Dk values result in circuit structures operating at shorter wavelengths for a given frequency.

For various circuit elements that are wavelength dependent, such as antennas and filters, the use of higher-Dk circuit materials can result in smaller PCBs. Commercial PCB materials for RF/microwave applications are typically in the Dk range of 2 to 6, so "high-Dk" circuit materials are generally considered to be those with Dk of 6 or higher.

As an example, RO4360G2 circuit material from Rogers Corp. has a Dk of 6.15 in the z-axis at 10 GHz (with a tight Dk tolerance of ±0.15) with thermal conductivity of 0.75 W/m/K and low Df of 0.0038. The higher Dk of the material enables smaller dimensions for wavelength-dependent structures. The material is often combined with lower-Dk circuit materials in multilayer circuit designs and it can be processed with the same approaches as used for lower-cost circuit materials, such as FR-4.

For an even higher Dk value, RO3210 circuit material from Rogers Corp. has Dk of 10.2 in the z-axis at 10 GHz, held to a tolerance of ±0.50. It has very low loss, with Df of 0.0027, and slightly higher thermal conductivity than the RO4360G2 material, at 0.81 W/m/K. The very high Dk value of this material enables dramatic reductions in wavelength-dependent circuit structures when circuit miniaturization is an issue.

In short, when designing an RF/microwave amplifier—whether an LNA or a PA—the quest for a suitable PCB material involves reviewing many of the same material parameters, with consistent Dk critical for maintaining the stable impedance needed for both types of amplifiers. Circuit materials capable of maintaining Dk within a tight tolerance window over wide temperature ranges can help achieve the low noise figure and flat gain desirable for high-frequency LNA designs.

In the case of PA designs, materials with tight Dk and consistent thermal properties (including TCDk and CTE) and low loss (low Df) can serve as excellent starting points for high-power amplifiers that can effectively dissipate generated heat. mw

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JACK BROWNE | Technical Contributor

Gauging IMD/PIM in Microwave Components

Understanding the causes and effects of IMD and PIM can motivate designers to seek out new ways to minimize distortion in components and systems for wireless applications.

Intermodulation distortion (IMD) indicates the nonlinear behavior of different RF/microwave devices and components. IMD occurs when two or more signals occupy the same transmission path and the signals mix, creating additional signals. The added signals can disrupt a system's performance, for example, by limiting the sensitivity of a high-frequency receiver. IMD can take place in active components, such as amplifiers, as well as in passive components like cables and connectors.

In recent years, passive components have been given their own IMD category, commonly known as passive intermodulation (PIM). Understanding the causes for IMD and PIM, and how to measure the amplitude levels of these types of distortion, can become positive steps toward minimizing or eliminating IMD and PIM from high-frequency designs.

"A number of factors can contribute to IMD and PIM, including the composition of conductors and rough edges on conductive contacts in components."

Ideally, an active or passive component would provide the same signal quality at both its output port (albeit at a different amplitude) and input port. Unfortunately, nonlinear effects contribute to the creation of additional, harmonically related signal content when multiple signals mix, and these additional signals can be a concern when they create noise levels above the sensitivity of a communications system's receiver.

A number of factors can contribute to IMD and PIM, including the composition of conductors and rough edges on conductive contacts in components. High levels of ferromagnetic materials, such as nickel, can yield nonlinear voltage effects and distortion in conductors, and higher power levels can also raise the noise levels produced by IMD and PIM. IMD is typically not a concern at lower power levels, since effective filtering can minimize the effects from the additional signal content.

PIM refers to the nonlinear distortion effects that can take place in passive components, such as cables and connectors, power combiners/dividers, and antennas. The distortion results from mixing of two or more tones, including even-order and odd-order tones. Typically, third-order nonlinear effects stem from the mixing of the harmonic and fundamental tones of two signals, f1 and f2, such as the difference of second-harmonic and fundamental tones: 2f1 – f2 or 2f2 – f1.

As with IMD, PIM may be caused by the ferromagnetic material content of a component, the use of dissimilar metals in a conductive path, poor conductor contact junctions, and even poor contact pres-

1. Testing for PIM often involves a measurement system with low-PIM cables. *(Photo courtesy of Microlab)*

sure in connectors. Dirt can play a major role in the generation of PIM, in terms of contaminated conductor contact surfaces. Poor crimping on cables and connectors can create multiple contact points with air gaps that elevate PIM levels. PIM often changes over time as components age and change with corrosion, and due to the diminishing quality of the electrical contact points.

Simple remedies to PIM include maintaining clean contact points; avoiding the use of dissimilar metals in conductive paths; and utilizing conductive paths that are machined to tight tolerances to minimize air gaps in the electrical contact points of RF/microwave components. A thorough introduction to IMD, as it occurs in coaxial connectors, comes by way of RF Connectors, a division of RF Industries (www.rfindustries.com), in a six-page application note titled “Intermodulation Distortion in RF Connectors.”

Ironically, when preparing to measure IMD or PIM on components such as antennas or cables, it’s often necessary to equip a test system with jumper cables that have low PIM distortion. A number of suppliers offer low-PIM cable assemblies that have been carefully tested and validated to perform within tight tolerances. For example, the JA and JB series cables *(Fig. 1)* from Microlab (www.microlab.fxr.com), which come with different connectors, are designed for use from dc to 6 GHz with PIM performance of better than –153 dBc at 1800 MHz. PIM performance, when tested with two tones at +43 dBm, is typically better than –158 dBc. The cables include tri-metal plated connectors built to MIL-C-39012 specifications.

MEASURING DISTORTION

Creating a measurement system to evaluate a device under test (DUT) for IMD and PIM involves at least two signal sources: a power combiner to feed the signals to the DUT; and some form of test receiver or analyzer to examine the results of the combined signals at the DUT’s output. Isolators between the generators and the power combiner can help keep the test tones clean.

The traditional test receiver for IMD and PIM measurements is the spectrum analyzer, although more dedicated test

> **"Dirt can play a major role in the generation of PIM, in terms of contaminated conductor surfaces."**

instruments have emerged in recent years, such as the PIM Master model MW82119B analyzer from Anritsu Co. (www.anritsu.com). The portable, battery-powered instrument contains signal sources and a receiver, and is available for applications at different frequencies from 2 MHz to 3 GHz, including for testing PIM in components for LTE 800-MHz, UMTS 2100-MHz, and LTE 2600-MHz systems.

The MW82119B can analyze third-, fifth-, and seventh-order IMD and PIM products (an additional option enables second-order IMD measurements). It can also function as a cable and antenna analyzer (with the Site Master option) for swept measurements from 2 MHz to 3 GHz. The analyzer's measurements include PIM, distance to PIM, and noise floor, while cable and antenna measurements include cable loss, distance to fault, return loss, and VSWR. The analyzer, which can measure PIM versus time, will run for more than three hours on (rechargeable) battery power. This example of portable measurement equipment offers an alternative to a spectrum analyzer, with its ability to perform on-site testing of IMD and PIM.

Perhaps representative of the trend to add more measurement capabilities to existing test products, the same company recently introduced options for IMD measurements in a pair of its VectorStar vector network analyzers (VNAs). Since independent control of multiple test signal sources is required to perform IMD or PIM measurements, the options allow measurements of harmonics, spurious products, and IMD using a frequency-offset function to create two precisely spaced test tones. In addition, the firm introduced IMDView software to simplify IMD measurements with the VNAs.

Similarly, Keysight Technologies (www.keysight.com) simplifies PIM measurements with its desktop E5072A ENA Series VNAs *(Fig. 2)*, which actually combine PIM testing with S-parameter measurements. The combination is meant to replace conventional PIM measurements and enable fast swept-frequency PIM measurements across wide bandwidths.

2. The E5072A ENA Series of vector network analyzers combine PIM testing with S-parameter measurements through 8.5 GHz. ***(Photo courtesy of Keysight Technologies)***

These rack-mount analyzers are available for use from 30 kHz to 4.5 GHz or 30 kHz to 8.5 GHz. They are complete systems, with multiple test-signal sources and VNA receivers. The instruments use a frequency-offset mode option to create the required multitone test signals, and can make measurements with fixed test tones and swept-frequency test signals, as well as in a PIM spectrum mode that permits simultaneous viewing of third-, fifth-, and seventh-order IMD products.

These instruments are just two examples of the many measurement solutions currently available as dedicated instruments or as add-on options for performing IMD and PIM measurements. Other examples include the iPA series of portable battery-powered PIM testers from Kaelus (www.kaelus.com) with application-specific transmit and receive frequencies (such as for LTE 800 and LTE 2600 testing), and the portable PIM 21 series of test sets from Boonton (www.boonton.com) of the Wireless Telecom Group. These testers, which show PIM levels from –80 to –153 dBc at 850 MHz, can be ordered with two CW carrier frequencies between 800 and 2200 MHz. mw

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Sorting Through Computer Engineering Software

High-frequency designers can choose from an array of computer software tools to model and simulate the performance of circuits and/or systems.

Knowing some of the differences among the myriad simulation software solutions for RF/microwave devices, circuits, and systems makes it much easier to match a high-frequency design software program to a problem or application. Many of these computer-aided-engineering (CAE) tools were on display at the recent 2015 IEEE International Microwave Symposium (IMS) in Phoenix, Ariz., which provided some perspective on the wealth of computer-based design software that applies at RF and microwave frequencies.

Developers of modern CAE software tools all desire to have easy-to-use products, even though many of these software tools contain complex capabilities and vast collections of simulation functions. Challenges in providing lots of simulation power include designing a straightforward graphical user interface (GUI) that allows for simple control of the software and easy access to different routines, capabilities, and models.

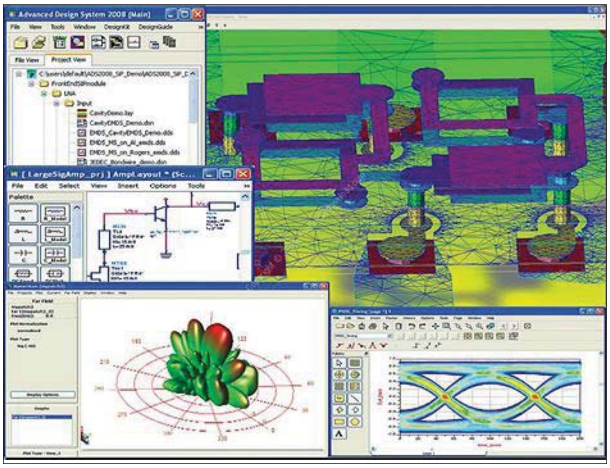
In some cases, it's desirable that different software tools, such as circuit- and system-level simulators, are capable of working with each other. Therefore, GUIs with common features and formats among different software tools can at least make it easier for two different CAE software tools to work together.

Often CAE tools contribute to the specification process, enabling designers to investigate the effects of, say, material parameters like relative dielectric constant tolerance or even thickness tolerance on circuit performance. Prior to CAE software, of course, this meant actually fabricating several circuits on different PCB materials and then testing the results. But with software, simulations have become so accurate that most high-frequency designers trust simulation predictions to be within 1% or better of measured results on a final fabricated circuit.

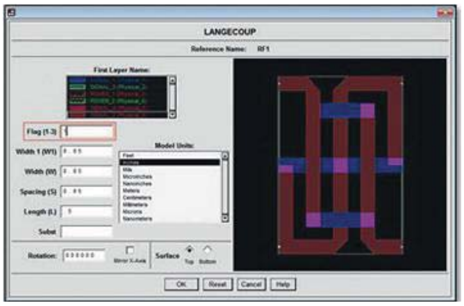
A STOCKED TOOL "CHEST"

As with business software programs (e.g., spreadsheets, word processors), CAE tools have strengths and weaknesses, and their capabilities vary widely, prompting many designers to carry multiple simulation tools. Starting points may be a more or less generic modeling tool like MATLAB from MathWorks (www.mathworks.com), essentially a mathematics-based modeling tool for computers with Windows, Mac, and Linux OSs.

Among high-level system simulators, there's the Advanced Design System (ADS) software (*Fig. 1*) from Keysight Technologies (www.keysight.com). It's a simple 32- and 64-b program with minimal computer system requirements of 1 GB hard-disk space for just MATLAB and 3 to 4 GB for a typical instal-



1. The Advanced Design System (ADS) software can model everything from devices through complete systems, using reasonable computer requirements. *(Photo courtesy of Keysight Technologies)* lation, with at least 2 GB of random access memory (RAM). The program can run on a personal computer (PC) with almost any OS, even older tools such as Windows XP. In contrast, the ADSsimulator—which supports a number of platforms including Windows, Linux, and Solaris—requires a computer with at least 4 GB of RAM; 10 GB of hard-disk storage; a 1.66-GHz, 64-b processor; and even a high-resolution display screen to show results.

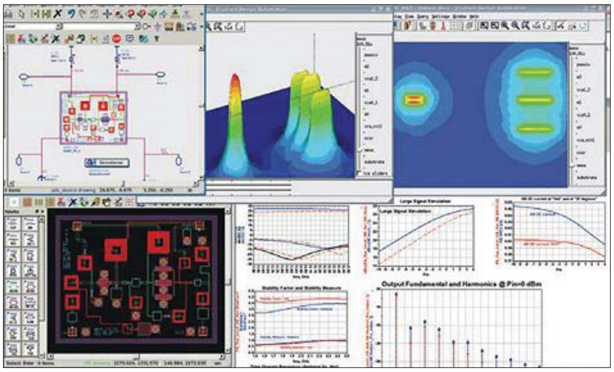


2. The Pantheon circuit-design program can work with macros from Keysight's ADS Board Link software so that files from Pantheon will work in ADS. *(Photo courtesy of Intercept Technology)*

The ADS simulator is one of numerous CAE circuit/system simulator programs offered by Keysight (others include GoldenGate, Genesys, EMPro, and SystemVue), in addition to several device modeling programs (e.g., IC-CAP and WaferPro Express). As a large company (and formerly part of Agilent Technologies), Keysight supports the development of, or acquires from other companies, different software tools to provide different approaches to high-frequency modeling and simulation.

To maximize the effectiveness of CAE software, it must be compatible with other software tools. On that front, Keysight recently announced an agreement with CAE developer Intercept Technology (www.intercept-technology.com) to integrate Keysight ADS Board Link macros within Intercept's Pantheon program (*Fig. 2*). ADS Board Link is a PCB integration program for bidirectional transfer of layouts, schematics, and model libraries between ADS software and enterprise PCB tools, such as Pantheon.

This trend will continue through the vast array of CAE programs currently available to RF/microwave designers, even as CAE software suppliers such as Keysight marches on with advances to its own tools. At IMS, for example, Keysight demonstrated the capabilities of its ADS Electro-Thermal Simulator for modeling and simulating the effects of temperature and thermal coupling on RF integrated circuits (ICs) and packaged devices. Based on thermal-solver technology, the ADS Electro-Thermal Simulator (*Fig. 3*) has been applied to a variety of device technologies, including silicon (Si), gallium arsenide (GaAs), and silicon-germanium (SiGe) processes.



3. The ADS Electro-Thermal Simulator models and simulates temperature effects on RF/microwave ICs. *(Photo courtesy of Keysight Technologies)*

One of the older, and still popular, CAE programs is Spice, which provides ac and dc analysis of analog circuits. A number of companies still support some form of Spice-based simulation program, such as Cadence Design Systems (www.cadence.com) and its PSpice software. It offers analog and mixed-signal circuit simulation, simulating circuit performance based on ac, dc, and noise analysis. Additional suppliers of Spice-based simulation tools include Silvaco (www.silvaco.com) and its SmartSPICE RF software, and AnaSoft Ltd. (www.anasoft.co.uk) with "SuperSpice" software. Also, several suppliers offer tools for analog, digital, and mixed-signal circuit simulation, including DesignSoft (www.tina.com) with the TINA Pro simulator; Intusoft (www.intusoft.com) and its ICAP/4 mixed-signal simulator; and Helic (www.helic.com) with its VeloceRF software for modeling RFICs and system-in-package designs.

Another powerful group of software design tools is based on electromagnetic (EM) simulation. Recent enhancements include the ability to perform three-dimensional (3D) modeling and simulation of circuits and structures.

Sonnet Software (www.sonnetsoftware.com)has long offered 3D planar EM simulation software based on method-of-moments (MoM) EM analysis. This standalone software has proven to be highly accurate in modeling devices, circuits, and assemblies in terms of high-frequency performance. But the EM simulator is also fully integrated within many other CAE platforms, including ADS, Cadence Virtuoso, the NI AWR Microwave Office design environment from National Instruments (www.ni.com) and Applied Wave Research (www.awrcorp.com), and even MATLAB, enabling an integrated design flow for EM analysis with those tools.

In the case of Ansoft (www.ansoft.com) and its Ansoft Designer collection of CAE tools, 3D planar EM simulation software became the basis for a complete suite of circuit-through-system modeling and simulation tools. Similarly, Mentor Graphics (www.mentor.com) evolved its EM simulation capabilities into the System Vision software, which can perform mixed-signal modeling and simulation. Remcom (www.remcom.com) recently reported on its XFdtd EM simulation software contributing to the design of a high-frequency automotive radar system. And IMST GmbH (www.imst.com) enhanced its EMPIRE XPU 7.10 3D EM software with an improved GUI. mw

INVESTIGATING ICs
FOR TOMORROW'S RADIOS

PORTABLE APPLICATIONS LIKE high-frequency radios require integrated circuits (ICs) for transmit and receive functions that effectively conserve power. Fortunately, application note AN629 from Silicon Labs (www.silabs.com), "Si4460/61/63/64/67/68 RF ICs Layout Design Guide," uses some of the firm's transmit and receive ICs to examine different radio circuit layouts. Specifically, it looks at how layouts and choices of components can affect power consumption for the final radio design.

Some of the rules of thumb provided for the firm's ICs can be applied to many different radio designs and IC products. These include using as much continuous ground-plane metallization as possible; avoiding separation of ground-plane metallization; avoiding the use of overly long transmission lines to connect components (since the distributed parasitic inductance from long transmission lines can cause detuning effects); and trying to avoid placing nearly inductors in the same orientation, so as to reduce coupling.

The application note provide several example circuit layouts based on the topic ICs and explains how these layouts can be refined for improved performance. These corrective actions can be as simple as adding a few capacitors to improve the grounding effects.

The 32-page application note provides practice guidance for improving circuit performance with these devices and transmit and receive ICs like them, such as using 50-Ω grounded coplanar transmission lines whenever possible for connecting SMA connectors to a matching network, as well as for reducing radiation and coupling effects in the connection.

The application note is generously illustrated with different types of layouts and schematic diagrams to provide specific advice for the company's ICs, but the advice is also applicable to many other transmit and receive ICs from many other vendors.

Silicon Laboratories, Inc., 400 West Cesar Chavez, Austin, TX 78701; (512) 416-8500, (877) 444-3032, FAX: (512) 416-9669, www.silabs.com

PAIRING THE RIGHT OSCILLATOR
WITH THE RIGHT APPLICATION

OSCILLATOR SELECTION CAN be challenging, what with so many different frequency and time-keeping components available for many different frequency ranges. To simplify the process, many designers automatically reach for temperature-compensated quartz-oscillator (TCXO) sources; these oscillators have dropped in price over recent years, yet continue to provide excellent signal stability and noise performance while consuming low power levels.

However, EndRun Technologies (www.endruntechnologies.com) has found that when applications require more demanding performance levels than are available from TCXOs, many customers opt to specify oven-controlled crystal oscillators (OCXOs) for their system's reference oscillators.

The firm's four-page application note, "Oscillator Selection Guide," provides a brief comparison of TCXOs, OCXOs, and even rubidium-based reference oscillators for a variety of different high-frequency applications. These include computer networks and both wired and wireless communications systems.

The application note reviews some of the specifications that are typically used to compare different types of oscillators. For example, a "disciplined" oscillator is one in which the oscillator's frequency is being controlled by an internal microprocessor based on measurements relative to a CDMA or Global Positioning System (GPS) signal. Holdover accuracy refers to any time error that a transfer standard accumulates when operating without a reference signal and relative to an absolute time reference standard. A typical period for checking the holdover accuracy of an oscillator is one day.

Short-term stability refers to the movement of zero crossings of a source signal relative to those of a reference frequency standard. This is measured over short time intervals, such as less than one second. Short-time stability for an oscillator is usually referred to as its jitter performance. When measured in terms of phase, it is referred to as an oscillator's phase noise.

The application note reviews some of the performance options available for different types of oscillators. OCXOs, for example, can be specified as medium-stability source, high-stability OCXOs, and ultra stable OCXOs. All of the OCXO source types are high-performance oscillators that use SC-cut crystals for fast warm-up, low aging rate, and reduced sensitivity to ambient temperature fluctuations.

Key differences in performance include differences in temperature stability and in close-in phase-noise performance. The four-page application note provides a brief summary of the different oscillator types and how the different types fit well into different types of applications.

EndRun Technologies, 2270 Northpoint Pkwy., Santa Rosa, CA 95407; (877) 749-3878, FAX: (707) 573-8619, e-mail: sales@endruntechnologies.com, www.endruntechnologies.com

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482 Rev. J

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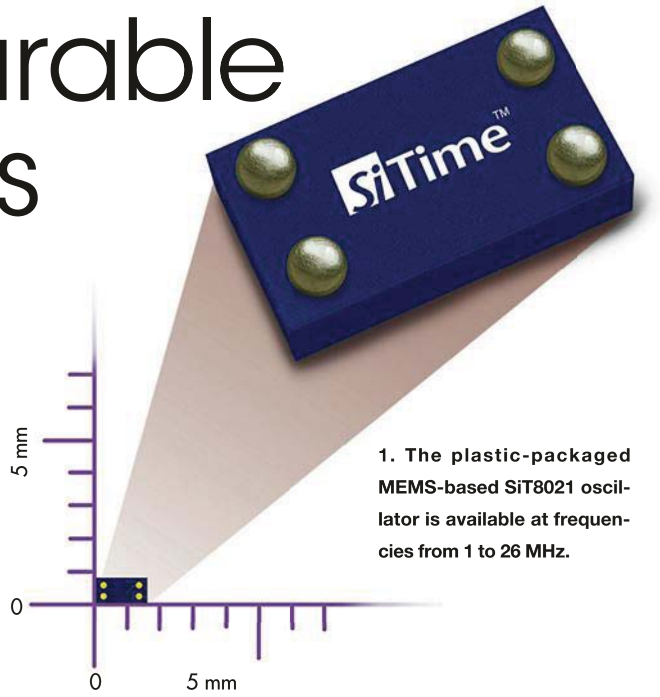
MEMS Source Clocks Wearable Applications

This miniature MEMS-based oscillator provides clock signals from 1 to 26 MHz with reduced power and size compared to traditional quartz-crystal oscillators.

Many emerging electronic applications, including wearable electronic circuitry on clothing, must maintain low-power operation. But achieving such operation requires low-power components, including clock oscillators for timing and frequency control.

Fortunately, SiTime Corp. (www.sitime.com), a firm known for its work in microelectromechanical-systems (MEMS) technology, applied its MEMS prowess to the development of an extremely small, low-power oscillator capable of frequencies from 1 to 26 MHz. The model SiT8021 oscillator *(Fig. 1)* is a fraction of the size of crystal oscillators and resonators in this frequency range and consumes a fraction of the power, making it ideal for wearable electronics, mobile products, and devices for Internet of Things (IoT) applications.

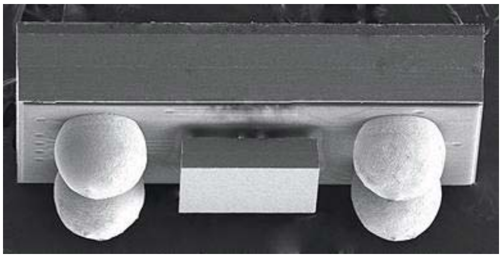
The MEMS-based SiT8021 is the first member of the company's μPower family of low-power, miniature, megahertz-frequency oscillators. It's particularly well-suited for battery-powered products in which small size and low-power operation is critical. When used in place of quartz-based crystal oscillators and resonators, the SiT8021 reduces size by about 40% and power consumption by around 90%. It employs a 524-kHz MEMS resonator (based on TempFlat MEMS technology) and a highly optimized phase-locked loop (PLL) to reach high performance levels at megahertz frequencies.



1. The plastic-packaged MEMS-based SiT8021 oscillator is available at frequencies from 1 to 26 MHz.

By incorporating MEMS technology, the SiT8021 oscillator is much smaller than its traditional quartz-crystal counterparts. With quartz-crystal oscillators, physics dictates that lower-frequency resonators have larger crystal resonators than higher-frequency resonators. However, MEMS-based resonators do not follow those same guidelines. The typical die size of SiTime's MEMS resonators measures 0.4 × 0.4 mm, and its mass is 1/3000th that of a typical quartz-crystal resonator.

Because SiTime's MEMS-based resonators are fully encapsulated in silicon and manufactured in silicon CMOS fabrication facilities, they can be packaged with modern integrated-circuit (IC) packaging techniques, including wafer-level chip-scale packaging (WLCSP). As a result, the SiT8021 oscillator comes in a chip-scale package (CSP) measuring just 1.5 × 0.8 mm—the industry's smallest oscillator package *(Fig. 2)*.

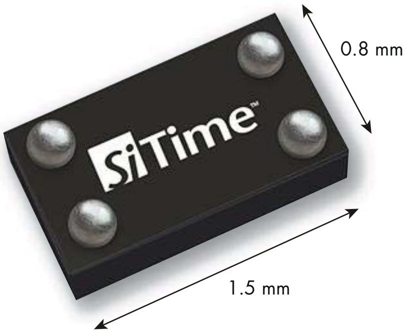


2. The SiT8021 oscillator comes in a plastic chip-scale package (CSP) measuring just 1.5 × 0.8 mm.

As with the firm's earlier model SiT1552 MEMS-based temperature-compensated crystal oscillator (TCXO), which delivers stable sig-

nals at 32.768 kHz with less than 1-µA current consumption for supply voltages of +1.50 to +3.63 V dc *(see "MEMS TCXO Runs on Micro Current," at mwrf.com; Microwaves & RF, July 2014, p. 90)*, the new SiT8021 oscillator provides stable, low-power signals at somewhat higher frequencies. Since it is composed of all-silicon dies mounted together *(Fig. 3)*, it can be integrated into a compact system-in-package (SIP) module.

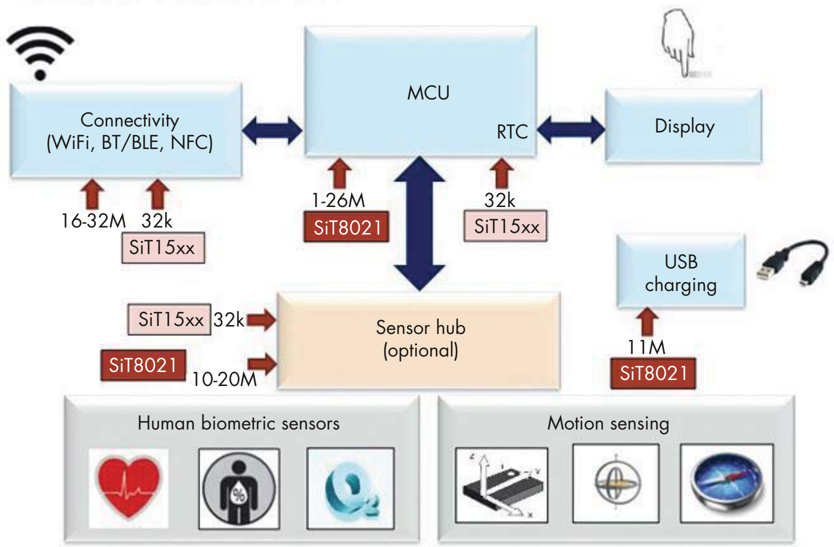
The SiT8021 oscillator weighs only 1.28 mg, which is about 70% lighter than the lightest quartz-based oscillator, making the SiT8021 a strong candidate for wearable electronic applications. In fact, the SiT1552 and SiT8021 support a wide range of applications for wearable and IoT products *(Fig. 4)*.



3. The SiT821, the first member of the µPower oscillator line, is a fraction of the size and power level of a similar-frequency crystal oscillator or resonator.

The SiT8021 oscillator's frequency stability of 100 ppm for frequencies from 1 to 26 MHz in turn provides low-voltage complementary metal-oxide-semiconductor (LVCMOS) outputs. It's designed for use at +1.8 V dc ±10% and can handle an operating temperature range of –40 to +85°C. The device draws about 100 µA current in operation, or about 90% less current than a megahertz-frequency quartz-crystal oscillator.

With its wide frequency range, the SiT8021 can even supply output frequencies of less than 5 MHz in plastic CSP housings, not typically available from quartz-crystal oscillators. In addition, the oscillator provides suitable programmable drive levels for multiple loads. As a result, one clock source can be used in place of several, thus saving on a design's bill of materials (BOM) and in-circuit board space.



4. The lower-frequency model SiT1552 and 1-to-26-MHz model SiT8021 MEMS-based oscillators can serve a wide range of wearable, IoT, and mobile electronic products.

In an evaluation for a low-power audio digital-to-analog-converter (DAC) application, a SiT8021 oscillator operating at 3.072 MHz was compared with a traditional quartz-crystal oscillators—and it educed some of the former's advantages. For example, the SiT8021 MEMS-based source alone consumes about 100-µA current and total power consumption was 30 mW. This translates into an effective battery life of 202 hours for the system when using the SiT8021.

A quartz-crystal oscillator, on the other hand, operating at the same 3.072-MHz frequency draws about 2.5-mA current, with power consumption of 34 mW for the same lineup of DAC, oscillator, and amplifier. Such consumption translates into an effective battery life of 177 hours. The comparison assumes a 2000-mAh lithium-ion battery typically used in portable devices. Of course, this represents just one application example for a battery-powered audio product. Nonetheless, it offers a glimpse into the gains and advantages that lie ahead for designers working with these low-power MEMS-based frequency sources.

SiTime, a fabless analog IC company, has been a creative supplier of MEMS-based silicon timing solutions since about 2005. *(For more on the company, see the "Inside Track" interview with Aaron Partridge, founder and chief scientist of SiTime, at mwrf.com; Microwaves & RF, January 2015, p. 34.)* Since 2007, the firm has developed and used a 5-MHz MEMS resonator in its oscillator products, and since 2011, a 48-MHz resonator in its oscillator products that offer less than 1-ps jitter.

The company's MEMS-based oscillators, all of which come with a lifetime warranty, offer high shock and vibration resistance and extremely high reliability for a wide range of low-power applications, notably for battery-powered applications. With the growth of wearable electronics and IoT applications (such as wireless IP cameras designed to operate at extremely low current levels), there's little doubt the demand for the low power, tight stability, and small size offered by MEMS-based oscillators will continue to intensify. mw

SITIME CORP., 990 Almanor Ave., Sunnyvale, CA 94085; (408) 328-4400, FAX: (408) 328-4439, *www.sitime.com*

JEAN-JACQUES DELISLE | Technical Engineering Editor

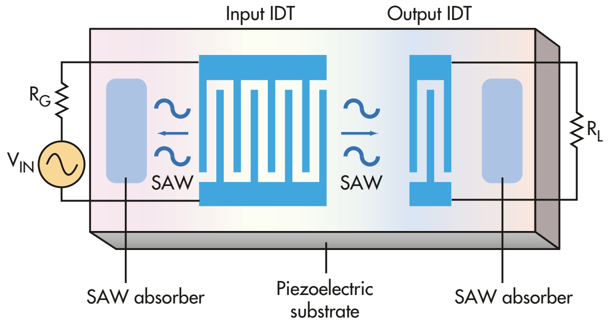
Portable Wireless Products Drive Filter Miniaturization

4G LTE and the proliferation of handheld wireless standards are pushing filter designers to shrink filter packages without sacrificing performance.

THE ARRIVAL OF new wireless standards and their narrowly spaced channels has filter manufacturers scrambling to enhance the performance and footprint of high-quality-factor (high-Q) surface-mount filter technologies. These performance requirements push the limits of discrete, surface-acoustic-wave (SAW), and bulk-acoustic-wave (BAW) filters, forcing filter manufacturers to look to other technologies to meet the needs of handset providers. In pursuit of advanced filter technologies, manufacturers are developing enhanced temperature-coefficient SAW/BAW devices, complete CMOS RF front-end solutions, and RF microelectromechanical-system (MEMS) filters.

Fourth-generation (4G) Long Term Evolution (LTE) wireless systems alone have 20 frequency-division-duplex (FDD) bands, with another seven time-division-duplex (TDD) bands. The LTE bands range from 0.7 to beyond 2.6 GHz—a very wide range for a single-filter technology to meet all necessary performance criteria. Various IEEE 802.11 standards, including 802.11ac/af/ad/ah, are also adopting under-1-GHz frequencies, as well as higher frequencies into the millimeter-wave ranges. Compact filter solutions that cover the large number of frequency bands in these wireless systems simply aren't feasible with discrete filter technologies.

Moreover, recent modifications to LTE and Wi-Fi standards incorporate carrier-aggregation (CA) and multiple-input, multiple-output (MIMO) techniques to enhance data rates with the limited and narrowly packed spectrum resources available. Though CA and MIMO are promising options to boost data rates, these techniques also increase the isolation and out-of-band rejection requirements of the filters. In addition, MIMO systems will require reduced reflections, reduced insertion loss, and enhanced tunability of each additional filter system for each antenna in the MIMO configuration.



SAW filters employ interdigital transducers to create mechanical acoustic waves from electrical signals.

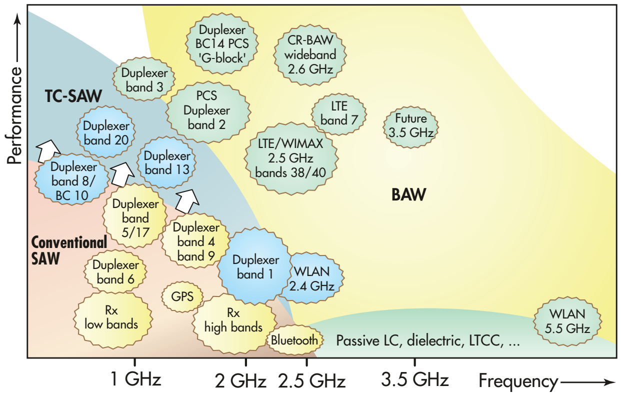
SAW, BAW TEMPERATURE OVER-COMPENSATION

These wireless-system constraints leave surface-mount-packaged or die-level solutions as the apparent viable options. Unfortunately, silicon filters tend to exhibit very low Qs, and the size constraints of capacitive and inductive circuit elements limit lower-frequency silicon-filter performance.

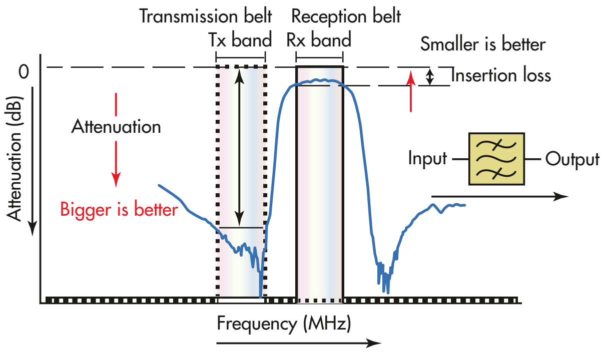
As a result, handset manufacturers today most often turn to SAW and BAW filters. SAW filters tend to operate well at lower frequencies and are more cost-effective than other filter technologies. BAW filters can perform with extremely high Qs at higher frequencies and occupy much smaller packages over SAW devices. However, both SAW and BAW filters suffer from relatively unstable temperature performance, since the material properties of the resonant structures change significantly with temperature.

Qorvo (www.qorvo.com) recently released SAW and BAW devices with temperature coefficients below −20 and −17 ppm/°C, respectively. Enhanced versions of Qorvo's new BAW and SAW filters can also reach temperature coefficients as tight as −1 and −2.5 ppm/°C, respectively.

Although they represent promising technologies, the filters are generally a few millimeters on a side and designed for wireless infrastructure and repeater markets rather than portable wireless products (e.g., handsets). Also, tunability functions with filter technologies are being used to replace several filters with a single tunable element. This aspect requires a highly integrated filter device, which can be quite a challenge with BAW and SAW fabrication methods.



SAW and BAW filter technologies generally perform with high Qs and low insertion loss compared to other filter technologies in similar form factors.



The use of BAW technology for wireless telecommunications has enabled higher Q filters at higher frequencies, and with lower form factors, than alternative filter technologies at similar frequencies.

RF SOI INTEGRATED SOLUTIONS

One benefit of RF silicon-on-insulator (SOI) technology is enhanced performance, compared to traditional silicon, for RF/microwave frequency utilization. On the other hand, though, it's rather difficult to develop a cost-effective method that makes silicon circuits behave well at higher frequencies and with reliable performance. But, by taking advantage of CMOS integration and advanced digital control, the benefits of operating on common CMOS fabrication platforms can outweigh material limitations.

Aiming for the highly integrated and advanced control approach, Peregrine/Murata introduced a complete 3G/4G LTE RF-SOI front-end with tunable power amplifiers (PAs), PA switches, filter banks, and antenna switches based on its UltraCMOS Global 1 technology. With a tunable PA for low-, mid-, and high-band use and selectable filters, a reconfigurable RF front-end can cover the three 3G/4G LTE frequency ranges.

Even though UltraCMOS Global 1 technology isn't a solution for the handset market, the movement toward implementing a highly integrated system with switching elements and filters may be a promising track for RF SOI use in handsets in the future.

RF MEMS SWITCHES AND FILTERS

The concept of integrating switches and filters using a silicon CMOS process isn't solely targeted at RF SOI. In the case of RF MEMS, this technology has the potential to incorporate switches and high-Q filter elements in extremely small packages. Tunable elements can also be included in many RF MEMS solutions, leading to reconfigurable switch and filter technologies that may even be able to meet CA and MIMO bandwidth and filter performance demands.

Following this trend, DelfMEMs (www.delfmems.com) developed a MEMS solution with highly compact ohmic switches, with as many as 12 switch throws. Although still in the research and development phase, MEMS tunable-filter elements will most likely be realizable within the next few years at reasonable cost. With the increased number and proximity of wireless bands, RF MEMS filters may become viable front-end components for mass-manufactured handsets.

CASCADABLE ABSORPTIVE FILTER TECHNOLOGY

Using passive gallium-arsenide (GaAs) technology, the National Radio Astronomy Observatory (NRAO) developed a filter technology with extremely low reflections that can operate from dc to 40 GHz. Mini-Circuits (www.minicircuits.com) recently licensed NRAO's filter technology, which has the potential to deliver a low-reflection and temperature-stable filter technology with a return loss of less than 20 dB and in-band insertion loss under 0.5 dB.

In this technology, a single filter typically measures 1 × 1 mm on a die. As many as four filters can be cascaded and housed in a QFN package measuring 6 × 6 mm, according to NRAO. While the cascading of filters does inflate in-band insertion loss, stop-band attenuation also increases with a greater number of cascaded filters. A four-filter package is able to produce greater than 50 dB of attenuation at a frequency of interest.

Placing absorptive filters within a RF signal chain doesn't carry any major concern in terms of reflected energy adversely affecting sensitive components or nonlinear components. In a highly integrated environment, this could lead to very tight packing of filter, switch, and transmitter/receiver elements for a more optimal footprint reduction.

Although advances in SAW and BAW filters may fulfill current demands for performance and physical size, future wireless standards will require greater tunability and smaller package sizes. RF SOI solutions achieve the highly integrated and tunable aspects of future wireless standards. Unfortunately, RF SOI filter solutions aren't yet cost-effective and reconfigurable enough for mobile handsets and multiple wireless standards. In addition, RF SOI technology may need more development before CMOS filter Q factors can reach the levels of BAW and SAW devices.

RF MEMS technology researchers recently demonstrated the ability to produce high-performance filters and switches in compact packages that operate over a wide bandwidth. Though only RF MEMS switch components are currently available on the market, RF MEMS filters and tunable integrated RF MEMS modules should be viable in time to meet high-bandwidth CA and MIMO wireless demands. mw

JACK BROWNE | Technical Contributor

GaN Devices Provide Broadband Power

Available in chip and packaged formats, these high-power GaN amplifiers are suitable for CW and pulsed applications through 14.5 GHz.

GALLIUM-NITRIDE (GAN) SOLID-STATE devices continue to gain in power at increasing frequencies, supporting a growing number of applications for radar, test, and communications systems for both continuous-wave (CW) and pulsed signals. The latest line of GaN devices from Cree provides generous output power levels at frequencies through 14.5 GHz.

The lowest-frequency device in the product line is an impedance-unmatched GaN transistor, model CGHV40050, intended for CW applications from DC to 4 GHz. The GaN high electron mobility transistor (HEMT) is designed for +50-VDC supplies and can provide as much as 50 W output power across the frequency range. It can be supplied either in a two-lead flange or a pill package. Examples of the performance possible with this transistor based on a reference design for 800 MHz to 2.5 GHz include 17.6-dB gain at 800 MHz with 65 W saturated output power and 63% drain efficiency (PAE). The gain remains high at 1.4 GHz, at 17.7 dB, with 63 W saturated output power and 60% PAE. At 2 GHz the gain drops somewhat, to 14.8 dB, although the saturated output power is still 60 W and the PAE is 52%.

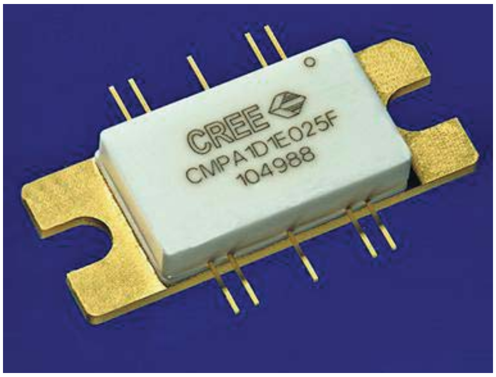
For those who prefer an impedance-matched device, model CMPA1D1E025F is a Ku-band GaN monolithic-microwave-integrated-circuit (MMIC) amplifier on silicon-carbide (SiC) substrate that delivers 25 W modulated output power from 13.75 to 14.50 GHz *(Fig. 1)*.

This MMIC amplifier is supplied in a 10-lead 25 × 9.9 mm metal/ceramic flanged package. It is capable of small-signal gain of 26 dB at 13.75 GHz, 27 dB at 14.25 GHz, and 26 dB at 14.50 GHz. The linear output power is 19 W at 13.75 GHz, 20 W at 14.25 GHz, and 18 W at 14.50 GHz, while the PAE is 18% at 13.75 GHz, 17% at 14.25 GHz, and 16% at 14.50 GHz.

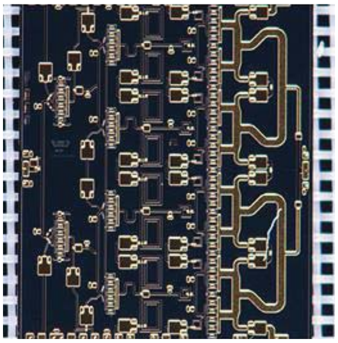
Model CMPA1D1E030D *(Fig. 2)* can provide 30 W output power from 13.5 to 14.5 GHz when running from a +40-VDC supply. The amplifier achieves small-signal gain of 27 dB at 13.5 GHz and 25 dB at 14.5 GHz, with saturated output power of 33 W at 13.5 GHz and 30 W at 14.5 GHz. It boasts PAE of 24% at 13.5 GHz and 22% at 14.5 GHz when measured with +26-dBm input power.

The CMPA601CO25D is capable of 30 W saturated output power from 6 to 12 GHz.It operates with small-signal gain of 40 dB at 6 GHz and 36 dB at 12 GHz. When evaluated with a 10-μs pulse at 0.1% duty cycle and powered with +19-dBm input power, it delivers +48-dBm output power at 6 GHz and +47.3-dBm output power at 12 GHz. With the same +19-dBm signal, the PAE is 33% at 6 GHz and 32% at 12 GHz.

Model CMPA601C025F is available in a 10-lead ceramic package for use from 6 to 12 GHz and +28 VDC. When measured with CW signals, it provides small-signal gain of 35 dB at 6 GHz and 31 dB at 12 GHz. When fed with a +22-dBm input signal, the output power is +42 dBm at 6 GHz and +34 dBm at 12 GHz, with PAE of 27% at 6 GHz and 25% at 12 GHz. mw



1. Supplied in a metal/ceramic flange package, model CMPA1D1E025F is an impedance-matched GaN-on-SiC MMIC amplifier for use from 13.75 to 14.50 GHz.



2. Model CMPA1D1E030D is a GaN MMIC amplifier chip on a SiC substrate capable of 30 W output power from 13.5 to 14.5 GHz.

CREE, 4600 Silicon Dr., Durham, NC 27703; (919) 313-5300, www.cree.com

JACK BROWNE | Technical Contributorr

Vector Signal Generators Hit 6 GHz

This cost-effective line of vector signal generators provides bandwidths as wide as dc to 6 GHz with generous modulation capabilities, including analog and digital modulation formats.

VECTOR SIGNAL GENERATORS are test-signal sources essential for evaluating modern communications systems and their components, with their many forms of modulation. The new TSG4100A series of vector signal generators from Tektronix includes three models with frequency coverage of dc to 2 GHz (model TSG4102A), dc to 4 GHz (model TSG4104A), and dc to 6 GHz (model TSG4106A).

All three vector signal generators *(see figure)* are suitable for high-frequency measurements on components and systems when teamed with the firm's analysis instruments—specifically, its model RSA306 USB spectrum analyzer and its line of high-speed oscilloscopes. The signal generators provide quite respectable performance at entry-level prices.

All three models include a front-panel BNC connector port with access to output signals from DC to 62.5 MHz for low-frequency testing. These low-frequency signals feature amplitude accuracy of ±0.7 dB with typical harmonic levels of better than –40 dBc and typical spurious levels of better than –65 dBc.

Higher-frequency signals are available on all models at an N-type coaxial connector, with frequency tuning to 1-µHz resolution and better than 8 ms switching speed to within 1 ppm of a tuned frequency. All three signal sources provide signals with dynamic range of –110 to +16.5 dBm. For output levels from –100 to +10 dBm, the amplitude accuracy is ±0.45 dB through 2 GHz, ±0.6 dB through 4 GHz, and ±0.75 dB through 6 GHz.

The generators allow signal phase to be set with 0.01-deg. resolution from DC to 100 MHz, 0.1-deg. resolution from 100 MHz to 1 GHz, and 1-deg. resolution from 1 to 6 GHz. Output signals are relatively clean, with maximum single-sideband (SSB) phase noise of –106 dBc/Hz offset 10 kHz from a 1-GHz carrier and –120 dBc/Hz offset 1 MHz from a 1-GHz carrier for all three generator models.

All three models are equipped with analog modulation capabilities for amplitude modulation (AM), frequency modulation (FM), pulse modulation, and phase modulation. As options, they can be equipped for more advanced vector and digital modulation capabilities, including in-phase/quadrature (I/Q) vector modulation. One option allows the use of external I/Q modulation signals to RF bandwidths of 400 MHz for the 2-, 4-, and 6-GHz signal-generator models.

Model TSG4106A is the highest-frequency model of the new vector signal generator trio from Tektronix, with a total frequency range of DC to 6 GHz at two connectors.

All three signal generators command phase modulation across a range of 0 to 360 deg., with better than 3% phase deviation accuracy for all carrier frequencies and modulation bandwidths as wide as 500 kHz. The three sources support pulse modulation at on-off ratios of better than 57 dB through 1 GHz, better than 40 dB through 4 GHz, and better than 35 dB through 6 GHz. The typical pulse rise/fall time is 20 ns.

Standard signal generator models are equipped with an oven-controlled crystal oscillator (OCXO) frequency reference for increased frequency stability. The OCXO time base features better than ±0.02 ppm frequency accuracy at calibration after a 20-minute warm up time. All three signal generators include GPIB, USB 2.0, Ethernet (LAN), and ES-232 interface connectors. P&A: $7,300 and up; stock.

TEKTRONIX INC., 14200 SW Karl Braun Dr., P.O. Box 500, Beaverton, OR 97077; (877) 977-0425; *www.tek.com*

Crystal Oscillators Shrink In Size and Phase Noise

FOR APPLICATIONS IN need of smaller, more stable oscillators, the evacuated miniature crystal oscillator (EMXO) line of sources has been extended to 100 MHz, and is now available in compact surface-mount-technology (SMT) housings. As an example, the EX-421 product family includes the EX-4210 series of SMT oven-controlled crystal oscillators (OCXOs) in frequencies through 100 MHz, with standard frequencies of 10, 20, and 100 MHz. Additional configurations, such as EX-4211 OCXOs with through-hole mounting, also are available.

These RoHS-compliant crystal oscillators feature low phase noise and fast warmup times with low power consumption. The sources are available with HCMOS and sine-wave output signals. The HCMOS rise/fall time (10% to 80%) is 5 ns while the standard sine wave output level is +4 dBm (with +7 dBm available as an option). The oscillators, which weigh a mere 5 g in a 13 × 13 mm housing, operate on typical supply voltage of +5 VDC with 1.5 W maximum power consumption and as little as 0.25 W power consumption.

Well suited for portable military radios, airborne systems, avionics systems, satellite communications (satcom) equipment, and instrumentation, these SMT OCXOs exhibit maximum harmonics of –30 dBc. They feature initial accuracy (at time of shipment of ±0.2 ppm and are designed for operating temperatures. The single-sideband (SSB) phase-noise measured at a 10-MHz carrier is –90 dBc/Hz offset 1 Hz from the carrier, –125 dBc/Hz offset 10 Hz from the carrier, –160 dBc/Hz offset 1 kHz from the carrier, and –165 dBc/Hz offset 10 kHz from the carrier.

VECTRON INTERNATIONAL, 267 Lowell Rd., Unit 102, Hudson, NH 03051; (888) VECTRON-1, (888) 328-7661, FAX: (888) 329-8328, *www.vectron.com*

High-Linearity Mixer Upconverts 3 to 8 GHz

MODEL 5576 IS an active mixer optimized for producing low-noise signals from 3 to 8 GHz. The high-linearity upconversion mixer handles input signals from 30 MHz to 8 GHz and single-ended local oscillator (LO) signals from 1 to 8 GHz at levels to +10 dBm, producing single-ended output signals from 3 to 8 GHz. The mixer achieves an output third-order intercept point of +25 dBm with 14.1-dB noise figure at 5.8 GHz. It has an output noise floor of –154 dBm/Hz. The active mixer is optimized for +5 Vdc but can also work with a +3.3-Vdc supply with slightly reduced performance.

The active mixer is suitable for wideband transmitters, in fixed wireless access equipment, and in 4G/5G wireless communications infrastructure equipment. It offers RF-to-LO isolation of better than 35 dB and –0.6-dB conversion gain over an operating temperature range of –40 to +105°C. Input 1-dB compression is +8.4 dBm at an output frequency of 3.5 GHz and +8.5 dBm at an output frequency of 5.8 GHz. The mixer is supplied in a 4 × 4 mm 16-lead QFN package.

LINEAR TECHNOLOGY CORP., 1630 McCarthy Blvd., Milpitas, CA 95035-7417; (408) 432-1900, FAX: (408) 434-0507, *www.linear.com*

Dual Directional Couplers Hit 2.5 GHz

A PAIR OF low-loss surface-mount dual directional couplers provides generous power-handling capabilities from 500 to 2500 MHz. These unique couplers provide separate coupled ports for both forward and reflected signals using internal terminations. Model IPP-8057 handles 50 W CW input power across the full frequency range. It exhibits 33-dB coupling which is maintained within ±1.5 dB across the operating frequency range. The dual directional coupler suffers insertion loss of less than 0.25 dB with maximum VSWR of 1.25:1. The minimum directivity is better than 20 dB. The surface-mount coupler measures 0.50 × 1.00 in.

The higher-power dual directional coupler, model IPP-8041, handles 200 W CW input power from 500 to 2500 MHz. The component offers minimum directivity of 20 dB across the 2-GHz bandwidth. It provides 36-dB coupling with better than 0.75-dB coupling flatness. It suffers insertion loss of less than 0.25 dB and maximum VSWR of 1.25:1. The compact directional coupler measures just 1.00 × 1.50 in. in its surface-mount housing. Both couplers can be provided in volume quantities in tape-and-reel format. P&A: stock to 5 wks.

INNOVATIVE POWER PRODUCTS, 1170-8 Lincoln Ave., Holbrook, NY 11741; (631) 563-0088, e-mail: sales@innovativepp.com, *www.innovativepp.com*

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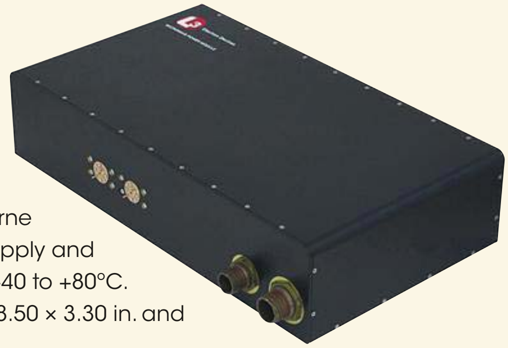
Microwave Modules Drive 100 W to 96 GHz



TWO MICROWAVE power modules (MPMs) have been developed for millimeter-wave applications at E- and W-band frequencies. The E-band unit provides 50 W output power from 81 to 86 GHz while the W-band unit delivers 100 W output power from 92 to 96 GHz. These are complete amplifier subsystems with size, weight, and power (SWaP) advantages, making them well suited for airborne applications. They operate from a conventional +28-VDC power supply and can handle altitudes to 50,000 ft. and operating temperatures of –40 to +80°C. The basic form factor of these amplifier modules measures 14.5 × 8.50 × 3.30 in. and weighs 20 lb.

L-3 ELECTRON DEVICES, 960 Industrial Rd., San Carlos, CA 94070; (650) 486-5585, *www.L-3com.om/edd*

DLVA Grabs 0.5 to 2.0 GHz

MODEL GMDA-D1007 is an extended-range detector-log-video amplifier (DLVA) with frequency range of 0.5 to 2.0 GHz. It features a signal logging range of –60 to +7 dBm with tangential signal sensitivity (TSS) of –65 dBm. It delivers logging linearity of ±1.5 dB at room temperature and ±2.0 dB over the full operating temperature range of –54 to +85˚C. The amplifier can handle input power to +23 dBm CW and provides +2.5 VDC maximum output voltage. The DLVA operates with video load impedance of typically 75 Ω and draws 300 mA at +12 to +15.5 VDC. Built to MIL-STD-202F, the DLVA achieves video rise time of 30 ns and recovery time of 1 µs, with maximum throughput time of 30 ns.

PLANAR MONOLITHICS INDUSTRIES, 7311-F Grove Rd., Frederick, MD 21704; (301) 662-5019, FAX: (301) 662-1731, e-mail: sales@pmi-rf.com, *www.pmi-rf.com*

Coaxial Resonator Oscillator Cuts Noise at 3.5 GHz

MODEL CVCO55CCQ-3500-3500 is a coaxial resonator oscillator designed for use at 3500 MHz. It operates on tuning voltages of +0.3 to +4.9 VDC with tuning sensitivity of 8 MHz/V, delivering +6 dBm output power that remains flat within ±2 dB. The oscillator features typical phase noise of –115 dBc/Hz offset 10 kHz from the carrier and –135 dBc/Hz offset 100 kHz from the carrier. Second harmonics are no worse than –8 dBc. The oscillator draws 27 mA current from a supply voltage of +5 ± 0.25 VDC and is built for an operating temperature range of –40 to +85˚C. It is supplied in a surface-mount housing measuring 0.50 × 0.50 in. (12.70 × 12.70 mm).

CRYSTEK CORP., 12730 Commonwealth Dr., Fort Meyers, FL 33913; (239) 561-3311, (800) 237-3061, FAX: (239) 561-1025, *www.crystek.com*

Compact Antennas Are Almost Invisible

THE INVISILINE small-form antenna (SFA) product family is designed to provide high-frequency coverage while blending with their surroundings. As an example, model SFA04-W800 is an E-band antenna developed for 80-GHz application. Its light weight and low profile make is ideal for small-cell, front-haul, and backhaul communications applications. The antenna provides a beamwidth of about 2 deg. at 80 GHz and meets ETSI Class-3 requirements. The antenna, which operates from 71 to 86 GHz, has a 0.5-ft. (166-mm) radome diameter, enabling it to be unobtrusive in almost any surroundings. It weighs just 11 lb. (5 kg) and is relatively easy to install. Once mounted, it can withstand winds to 320 km/h (nearly 200 mph).

RADIO FREQUENCY SYSTEMS, 200 Pondview Dr., Meriden, CT 06450-7195; (203) 630-3311, FAX: (203) 634-2273, *www.rfsworld.com*

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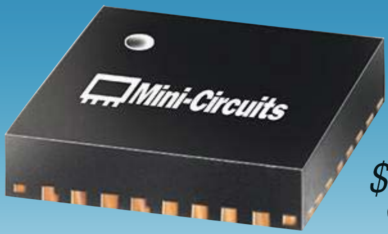
1.8 to 12.5 GHz



$5.56 ea. (qty.1000)

EP2C+

- ✓ 2-way 0º, 1.8 to 12.5 GHz
- ✓ 1.1 dB insertion loss
- ✓ Port-to-port isolation, 16 dB
- ✓ DC current passing up to 0.4A
- ✓ Tiny size, 4 x 4mm

MMIC Amplifiers
Noise Figure, 0.46 dB
1.1 to 4.0 GHz

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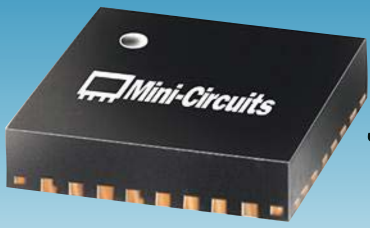
PMA2-43LN+

- ✓ Ultra-low noise figure, 0.46 dB
- ✓ High gain, up to 23 dB
- ✓ P1dB up to +19 dBm
- ✓ High IP3, up to +33 dBm
- ✓ Low power consumption, +5V, 51mA
- ✓ Tiny size, 2 x 2mm

MMIC Mixers
2200 to 7000 MHz

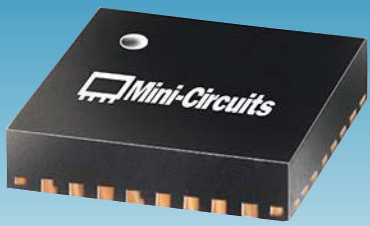


$2.74 ea. (qty. 1000)

MDB-73H+

- ✓ Low conversion loss, 8 dB
- ✓ High L-R Isolation, 39 dB
- ✓ High L-I Isolation, 46 dB
- ✓ IF bandwidth, DC to 1600 MHz
- ✓ LO power, +15 dBm
- ✓ Tiny Size, 4 x 4mm

MMIC Mixer-Amplifiers
2200 to 7500 MHz



$10.25 ea. (qty.1000)

MDA4-752H+

- ✓ Integrated mixer, LO amplifier, and IF amplifier in one package
- ✓ Conversion gain up to 9.7 dB
- ✓ High L-I Isolation, 61 dB
- ✓ Hi R-I Isolation, 51 dB
- ✓ LO power, 0 dBm
- ✓ Tiny size, 4 x 4mm

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539 rev A

LO Driver Amp Boosts 1 to 26.5 GHz

SUITABLE FOR working with a variety of diode-based mixers, model ADM-0126MSM is a broadband local-oscillator (LO) driver amplifier that delivers +17-dBm power from 1.0 to 26.5 GHz. In saturated mode, it can also be used as a square-wave LO amplifier as needed. It reaches its rated output-power levels with +8 to +12 dBm input power and offers 11-dB typical small-signal gain with typical 4-dB noise figure. The typical return loss is 10 dB. Typical third-order intercept point is +25 dBm. It can be biased with a positive +5 to +8 VDC at 120 mA or operated with an optional -0.2-VDC bias to reduce the current consumption to 85 mA. The LO driver amplifier is supplied in a 4-mm QFN package. A module test board is available for the amplifier, complete with connectors for ease of testing.

MARKI MICROWAVE, 215 Vineyard Ct., Morgan Hill, CA 95037; (408) 778-4200, FAX: (408) 778-4300, e-mail: info@markimicrowave.com, *www.markimicrowave.com*

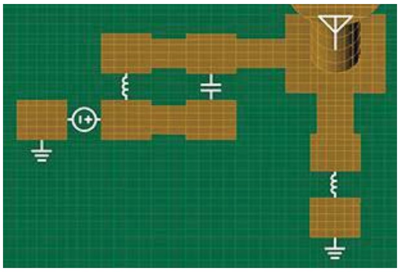
Receiver Tracks Frequency and Time

BASED ON the ptf 3203A and ptf 3204A GlobalTyme receivers, the ptf 3207A GlobalTyme2 Global Positioning System (GPS) receiver provides 12 parallel channels of GPS tracking. Available in 1U and 2U rack-mount versions, the GlobalTyme 2 receiver can be configured as a frequency standard, as a time standard, or both. It is equipped with a 10-MHz temperature-compensated crystal oscillator (TCXO) as a frequency reference, with options for an oven-controlled crystal oscillator (OCXO); rubidium frequency standards; and options for 100 kHz, 1 MHz, and 5 MHz frequency standards. The receiver provides 1-pps and IRIG B output ports with an optional NTP(v4) port. The 1-pps output is accurate within better than 20 ns of Universal Time Code (UTC). For monitoring and control, the receiver provides RS-232 and 100/10 BaseT Ethernet ports.

PRECISION TIME AND FREQUENCY, INC., 50L Audubon Rd., Wakefield, MA 01880; (781) 245-9090, FAX: (781) 245-9099; *www.ptfinc.com*

Software Helps Optimize Matching Circuit Elements

A NEW circuit element optimizer for the XFdtd Electromagnetic Simulation Software provides the capability to optimize impedance matching circuits for several antennas serving multiple bands simultaneously. The XFdtd Circuit Element Optimizer software determines lumped-element values based on a number of different goals, including radiation efficiency, system efficiency, and S-parameters. The software helps simplify antenna design by allowing circuit elements to remain in the electromagnetic (EM) layout of an antenna design during the optimization process. Typical antenna matching circuits have been optimized in schematic diagrams that are separated from the EM simulations for the antenna. The new software enables designers to optimize lumped-circuit elements directly on a physical matching circuit layout, taking into account both EM coupling from multiple antennas and ground return current paths. The new Circuit Element Optimizer is available as an add-on module for the XFdtd CAE software.



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