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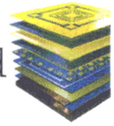
Gain insights on amplifiers and oscillators | **40**



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AMPLIFIERS & OSCILLATORS ISSUE

COMPACT VNAs Cut Test Costs To 40 GHz

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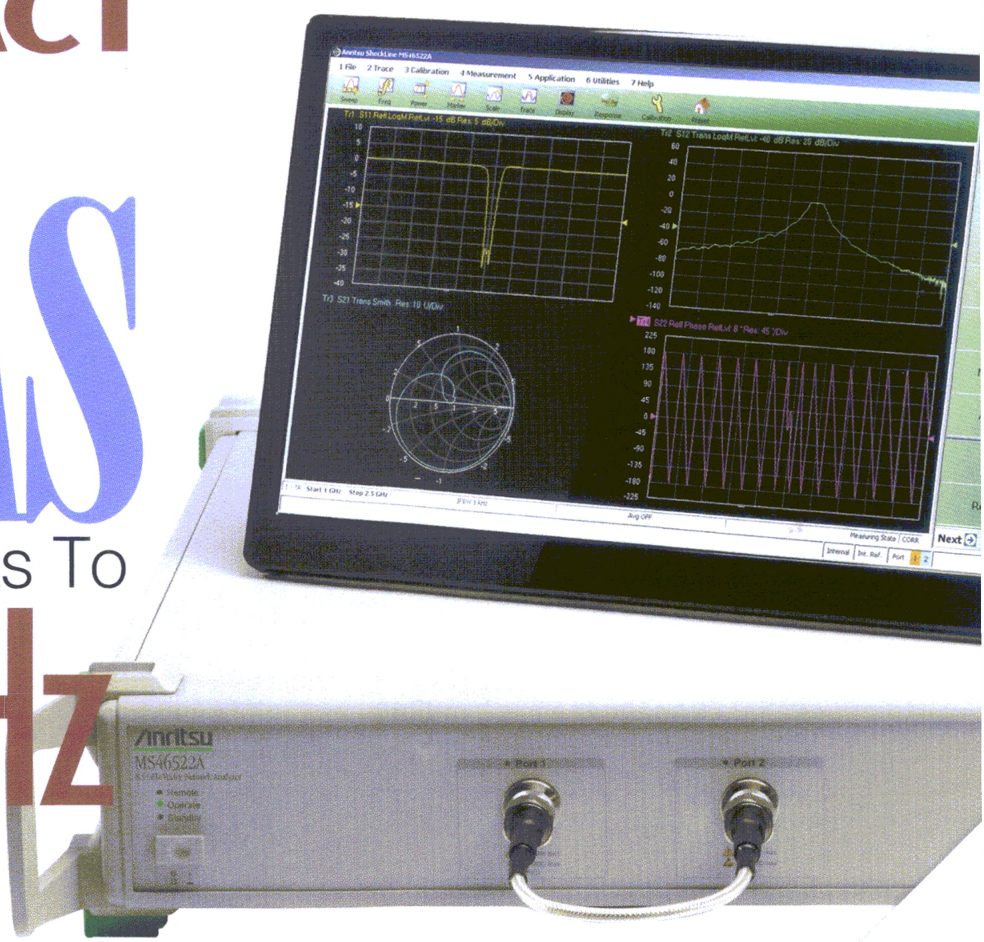

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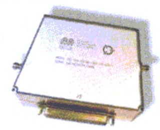
0.5GHz to 2.0GHz & 2.0 to 18.0 GHz I/Q Modulators
Model No: PIQ-0R5G2G-360-20-CD-1 & PIQ-2G18G-360-16-CD-1

- Frequency Range:
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  +/3.5dB Typ. (2.0 to 18.0 GHz)
- Phase vs. Frequency:
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  +/-20 deg. Typ. (2.0 to 18.0 GHz)
- Switching Speed: 500 ns Max.
- Size: 5.0" X 5.0" X 1.0" (0.5 to 2.0 GHz)
  4.25" X 3.5" X 1.0" (2.0 to 18.0 GHz)

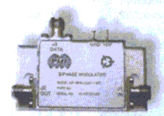
50MHz to 1.0 GHz & 0.5 to 2.5 GHz Single Sideband Modulators
Model No: PSM-50M1G-CD-1 & PSM-0R5G2R5G-CD-1


- Frequency Range:
  50MHz to 1.0 GHz & 0.5 to 2.5 GHz
- Quadrature Phase Accuracy:
  7.5deg. Typ. (50 MHz to 1.0 GHz)
  7.0deg. Typ. (0.5 to 2.5 GHz)
- Quadrature Amplitude Accuracy:
  +/-1.5dB Typ.
- Carrier Suppression:
  15dBc Min. (50 MHz to 1.0 GHz)
  20dBc Min. (0.5 to 2.5 GHz)
- IF Modulation Frequency Range:
  DC to 10MHz (50MHz to 1.0 GHz)
  DC to 500MHz (0.5 to 2.5 GHz)
- Size: 6.0" X 3.5" X 1.0" (50MHz to 1.0 GHz)
  2.5" X 2.0" X 0.5" (0.5 to 2.5 GHz)

85MHz to 18GHz I/Q Modulator
Model No: PIQ-85M18G-360/20-CD-2

- Frequency Range: 85 MHz to 18.0 GHz
- Phase Range: 360 deg.
- Attenuation Range: 20dB
- Attenuation Resolution: 0.1dB Max.
- Phase Resolution: 0.8 deg. Max.
- Size: 6.0" X 3.0" X 1.0"

1.0 to 2.0GHz Bi-Phase Modulator
Model No: BPM-1G2G-1-SFF



- Frequency Range: 1.0 to 2.0 GHz
- Amplitude Balance: 0.75 dB Max.
- Phase Balance: +/-5deg. Max.
- Carrier Suppression: -30dBc Typ.
- Switching Speed: 5 ns Typ.
- Size: 2.0" X 1.0" X 0.5"

2.0 to 6.0 GHz & 50MHz to 14.0GHz Phase Shifters
PMI Model No: PS-2G6G-8B-SFF & PS-50M14G-10B-SFF

- Frequency Range:
  2.0 to 6.0 GHz & 50 MHz to 14 GHz
- Phase Range: 360 deg.
- Control:
  8 Bit TTL (2.0 to 6.0GHz)
  10 Bit TTL (50 MHz to 14.0 GHz)
- Switching Speed: 500 ns Typ
- Phase Accuracy: 0.5 deg. Typ.
- Size: 3.25" X 3.25" X 0.84"

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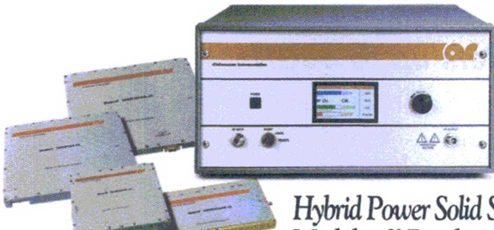
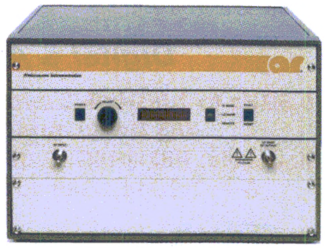


Hybrid Power Solid State Modules & Benchtop Amplifiers

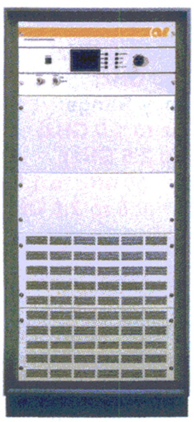
700 MHz to 6 GHz and 4-18 GHz Single Band Units

Now you can have Class A designs when linearity is the driving force, as in EMC and wireless applications *OR* Class AB designs when increased power and efficiency is paramount for EW applications. Standard 6 GHz modular designs provide up to 50 watts P out while benchtops are capable of over 200 watts. 18 GHz products deliver up to 10 watts in a modular package and 40 watts in a benchtop.



Dual Band Amplifiers

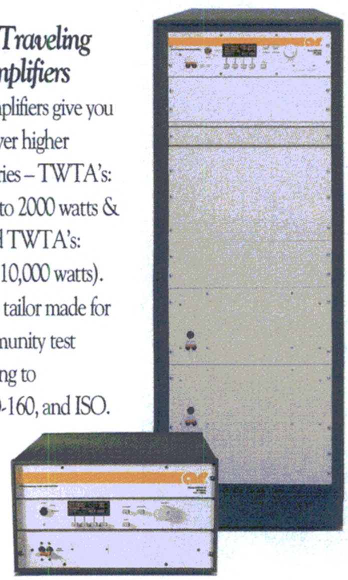
AR now offers the widest Class A solid state frequency range coverage in a single amplifier housing. Our widest bandwidth designs now cover 0.7 to 18 GHz in a dual band configuration. These amplifiers come in two different band split configurations from 0.7 to 4.2 GHz and 4 to 18 GHz, or from 0.7 to 6 GHz and 6 to 18 GHz. Output powers provide up to 80 watts for the lower band split while the higher band provides up to 40 watts.



"S" Series Solid State

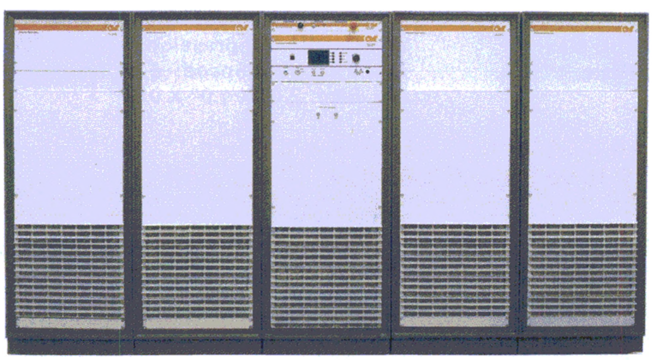
Numerous models from 0.7 to 18 GHz, 1 to 1200 Watts. For Immunity, Wireless Testing and TWTA replacements.
Our "S" Series amplifiers are Mismatch Tolerant providing 100% of rated power without foldback.
These amplifiers will reproduce input signals and remain stable with any magnitude and phase load impedance, without damage.

1000S1G2z5 (1000 watts, from 1 to 2.5 GHz)



"T" and "TP" Traveling Wave Tube Amplifiers

AR's microwave amplifiers give you more power and cover higher frequencies ("T" Series – TWTA's: 1- 45 GHz; CW 15 to 2000 watts & "TP" Series – Pulsed TWTA's: 1- 18 GHz; 1000 to 10,000 watts). These amplifiers are tailor made for various radiated immunity test applications according to MIL-STD-461, DO-160, and ISO.



"A" Series Solid State

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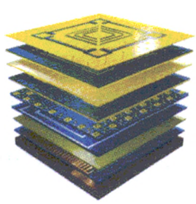

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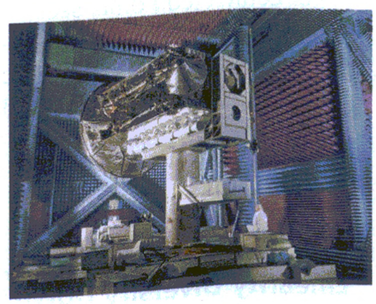

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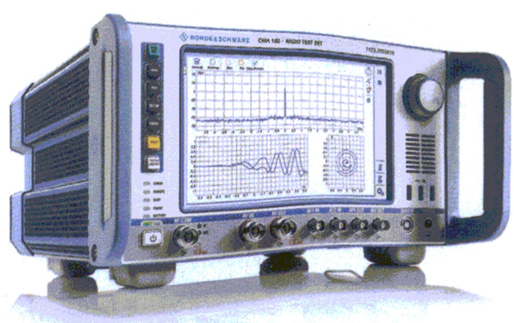

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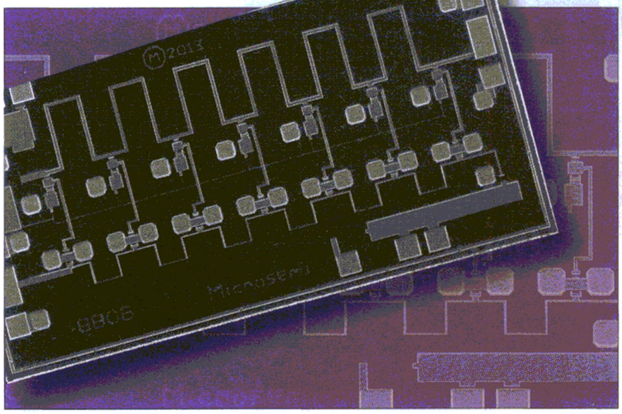
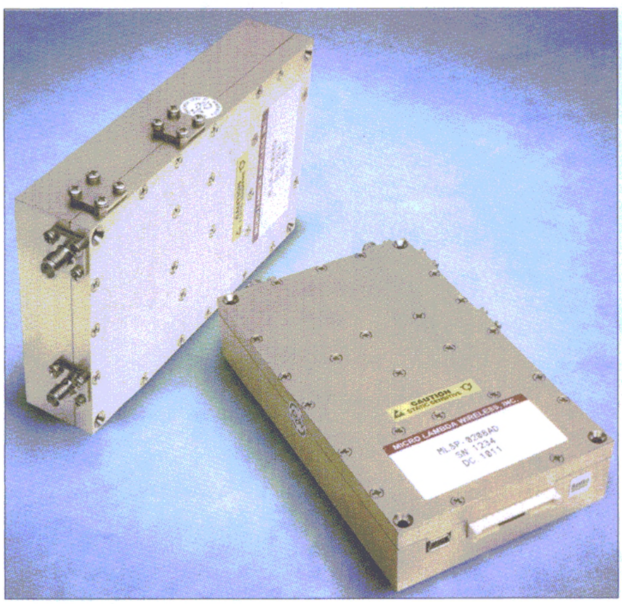


A GUIDE TO WAVEGUIDES – COUPLERS AND FILTERS

In this series of videos, Jim McGregor from Microtech shows examples of coupler and filter waveguides and offers examples of applications they are used in.

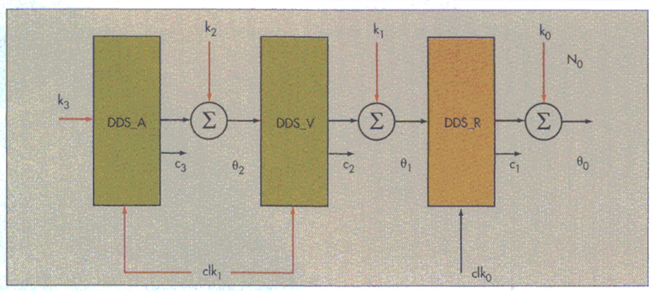


TOP PRODUCTS FEATURED AT IMS 2014

This year's International Microwave Symposium showcased everything from digital-to-analog converters to gallium-nitride power amplifiers and a whole gamut of innovative and inventive products in between.

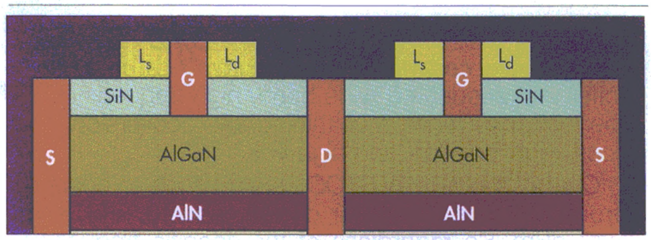
TABLET WIRELESS CHARGER ENABLES FREE POSITIONING

New developments continue to improve wireless charging. Currently, the new 3 DOM iTablet kit adds wireless charging capabilities to devices—including the Apple iPad 4, Air, or Mini—without adding any extra weight or the use of a special sleeve.



DDS MODEL TUNES DOPPLER SIMULATION

Testing satellite navigation receivers usually depends on signal simulation to evaluate a satellite-communications (satcom) receiver under high-dynamic-range conditions. A third-order direct-digital synthesizer (DDS) is invaluable for such simulation and testing.



DESIGNING ALGaN/GaN HEMTS FOR W-BAND

This device model provides accurate DC and large-signal parameters as compared to measurements on fabricated semiconductors, showing it to be an effective tool for building W-band HEMTs.

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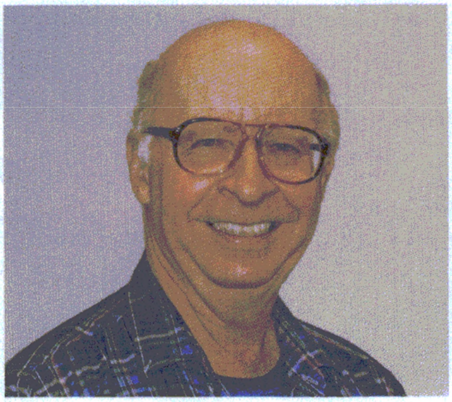


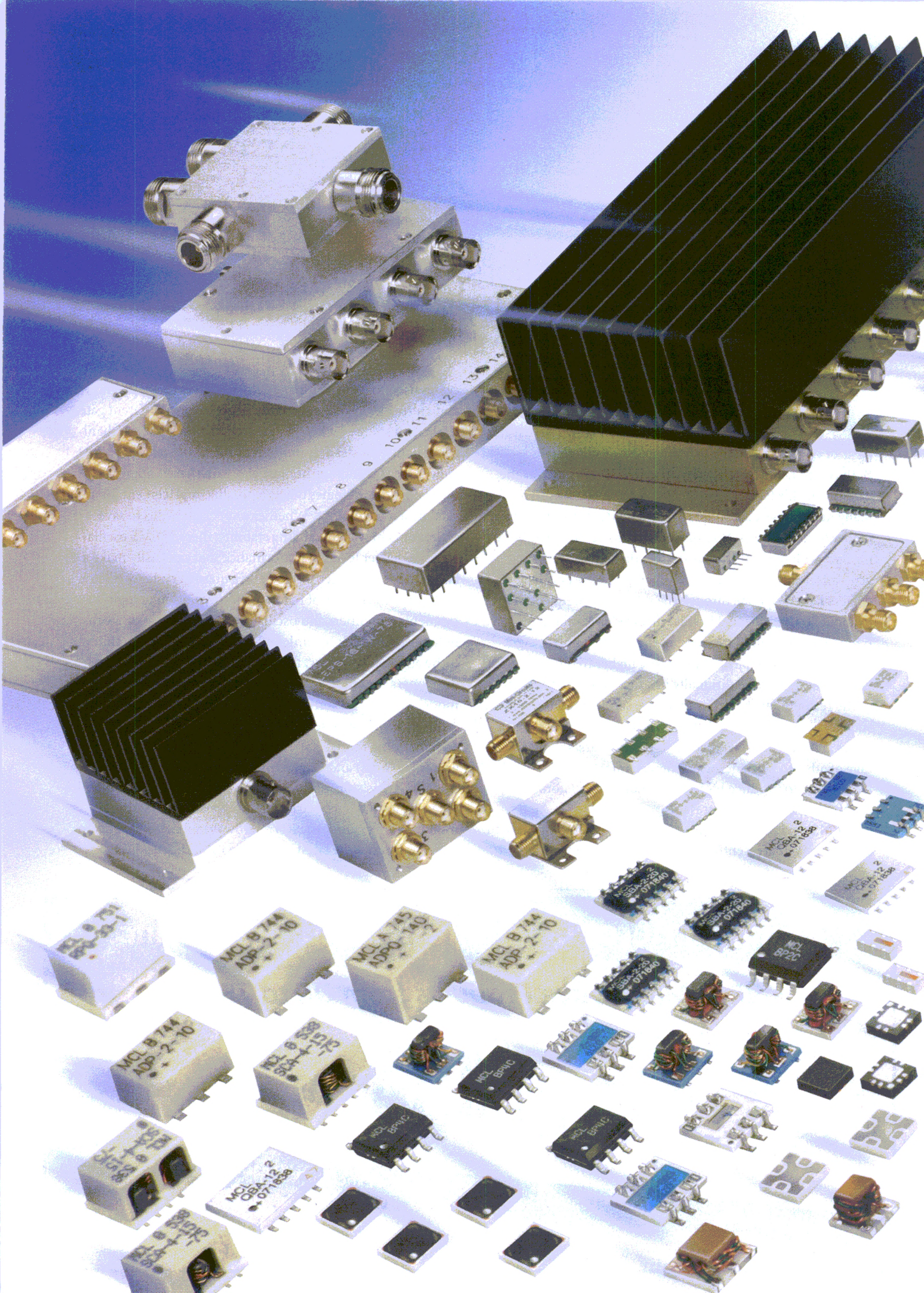
Amplifiers, Oscillators Evolve with Technology

Amplifiers and oscillators can be found at the very heart of many RF/microwave systems and subsystems, and both components are among the first parts of any system design to leverage new technologies. Both components typically rely on active devices, such as the gallium-nitride (GaN) transistors that are currently driving many newer power amplifiers to higher output-power levels at higher frequencies. GaN semiconductor materials are improving and, with them, the active devices that power the latest generation of RF/microwave power amplifiers. At present, these devices largely operate through the microwave frequency range to about 20 GHz; inevitably, this will extend to millimeter-wave frequency bands and in support of the growing line-of-sight communications applications at those higher frequencies.

Oscillators have traditionally produced their output signals as the result of feedback within active semiconductor devices, such as silicon bipolar transistors. But high-frequency oscillators are evolving even further in recent years, taking advantage of advances in microelectromechanical-systems (MEMS) technology to produce high-performance oscillators from nominally passive structures.

MEMS devices may seem novel, but the technology is actually not new. It is essentially a way to apply many of the processes used to form semiconductors, such as the deposition and cutting away of conductive metals to form different gate, drain, and source regions, in the manufacturing of mechanical structures instead. A number of MEMS developers have viewed this technology not just as an alternative approach to existing technologies but as a possible replacement for an established technology. Whether a specifier needs to save power or achieve outstanding stability, these MEMS oscillators can deliver levels of performance that can easily make a circuit designer forget about using a quartz crystal oscillator.

Perhaps the beauty of following the evolution of high-frequency amplifiers and oscillators as they grow with technologies such as GaN semiconductors and MEMS circuitry is the aggressive support from model makers and software developers. Creating accurate models can be difficult, but the model makers and software developers in the RF/microwave industry have long risen to the occasion. They have succeeded in building models for emerging devices, such as gallium arsenide (GaAs) and GaN pseudomorphic high-electron-mobility-transistor (pHEMTs) active devices. Though often regarded as "old-school electronics" because of its ties to military applications, the RF/microwave industry is quick to adopt and adapt the latest applicable technologies. mw


MCL B 744
ADP-2-10
MCL A 745
ADPQ-140
MCL B 744
ADP-2-10
MCL B 744
ADP-2-10
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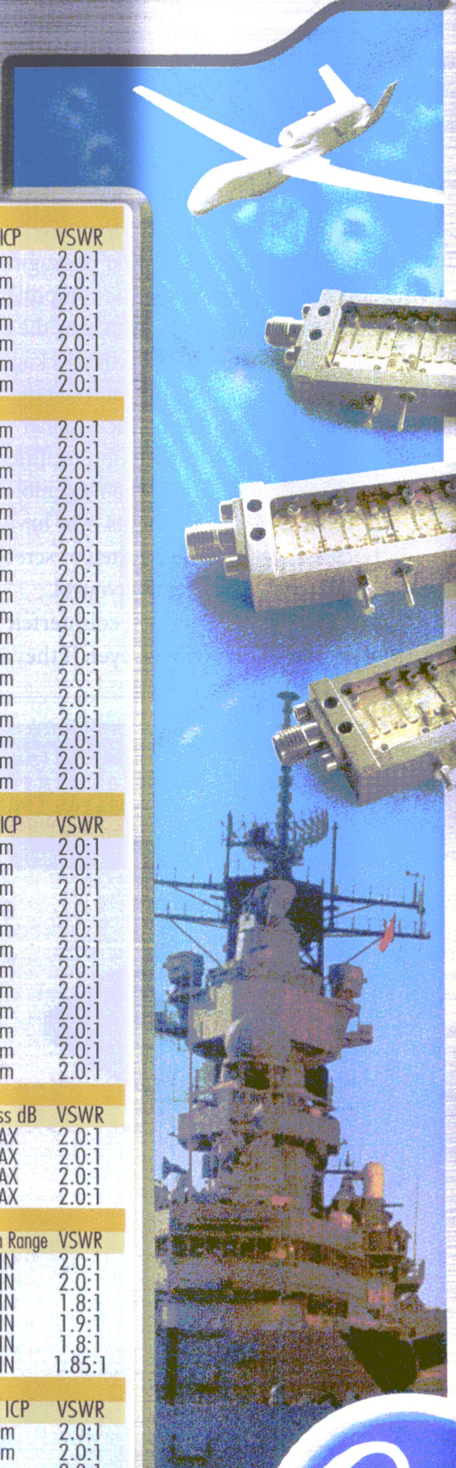

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CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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Feedback

TRYING TO CURB COUNTERFEITS

Thank you for the many practical articles that you have run in recent years. It is helpful when the articles include schematic diagrams with component listings. This allows circuit designers to develop a parts list and even find alternative components from secondary component suppliers, so that they can run performance simulations on commercial computer-aided-engineering (CAE) software and compare the effects of using different types of components.

There are many reputable suppliers of active and passive components in the RF/microwave industry, with components that perform reliably and at the electrical levels as advertised. Unfortunately, in recent years, there has been an increasing number of counterfeit components. These are devices that may be supplied in similar packaging as the authentic components, and may even bear the company logo on the package, but are manufactured outside of the authentic supplier company's production facilities and have been assembled with shortcuts. Nor have they been tested or screened for quality control.

Such counterfeit components, even if they initially meet the mechanical and electrical performance requirements of the authentic components, will typically fail in short order. Such failure leaves a poor impression on the manufacturer of the end product.

Counterfeit components are obviously a growing concern in the RF/microwave industry. Is there any way to effectively avoid using these components, and is anything being done to stem their flow throughout the industry?

LeBron Miller

EDITOR'S NOTE

Concern about counterfeiting electronic components has grown to the point where the United States Defense Advanced Research Projects Agency (DARPA; www.DARPA.mil) is now inviting proposals for some identifying mark or dialet that could be used to authenticate a component. The solution must be low in cost but reliable in function.

Component manufacturers and distributors can apply improved quality-control methods to avoid counterfeits, as well as better control of the supply chain. Technologies such as radio-frequency identification (RFIC) and invisible ink can also be employed with model numbers to make counterfeiting more difficult.

News

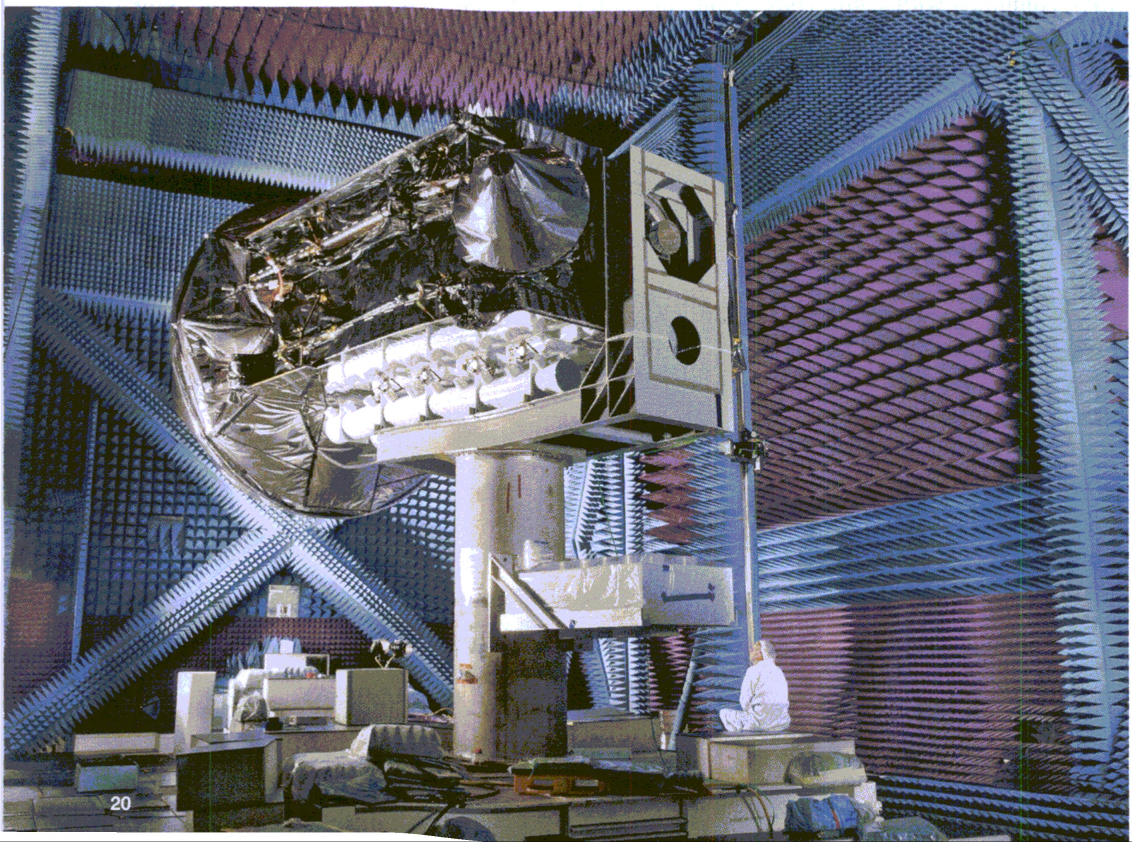
MUOS SATELLITES
Transfer Huge Data Files in the Arctic

Development teams within the defense and industrial sectors continue to explore ways to bring satellite coverage to the far reaches of the globe. One such region—the Arctic—has experienced a major increase in traffic as nations stake claims farther and farther north, according to Lockheed Martin. Since the environment is so extreme, most geosynchronous satellites can't reach users.

One potential solution comes via Mobile User Objective System (MUOS) satellites: The U.S. Navy demonstrated the transfer of megabyte data files in the Arctic for the first time using these secure satellite connections. MUOS is particularly known for its wideband-code-division-multiple-access communications payload. A part of the Navy's Ice Exercise program, MUOS satellites have already provided nearly 150 hours of secure data connections.

From March 17 to 27, MUOS delivered over 8800 minutes of service to "Ice Camp Nautilus," a floating ice camp above the Arctic Circle. Users at the camp connected to both secure and classified communication systems, as well as sent data files. Multiple files—up to 20 Mbytes—were downloaded. The stream of photos, maps, and generally large pieces of data were sent securely over the connection—a virtual impossibility for legacy communications satellites in that region.

MUOS's Arctic capabilities were first demonstrated in 2013; tests showed a significant gain in signal reach from the required latitude of 65 degrees north (roughly Fairbanks, Alaska). The coverage helps support growth in shipping, tourism, resource exploration, and search-and-rescue, as well as defense needs. Lockheed Martin Space Systems, located in Sunnyvale, Calif., is MUOS's prime contractor and system integrator. ■



A MUOS satellite completes testing in an anechoic test chamber. (Photo courtesy of Lockheed Martin)

NETWORKED WEAPONRY
Relays Info with Smartphone Components

RESEARCH TEAMS CONSISTENTLY find success when basing defense technology on smartphone functionality. Two cases in point are Mobile User Objective System (MUOS) satellites and CubeSats, which take advantage of commercial off-the-shelf (COTS) smartphone components. In that vein, General Dynamics and Colt Canada combined their respective messaging and device platforms—the Variable Message Format (VMF) and the Solider Weapon & Observer Reconnaissance Devices (SWORD) system—to extend data exchange range to dismounted soldiers.

Colt Canada developed its SWORD system as an alternative to radio-centric

individual soldier systems. It integrates weapon-mounted surveillance and targeting devices with ruggedized smartphone technology, helping deliver critical situational awareness information to soldiers via their rifle. The VMF method, already adopted by several nations, also provides critical information directly to soldiers. Combining the two ensures compatibility with higher-level command-and-control (C2) systems.

According to Colt Canada, the use of smartphone components makes the transition to the new system much more seamless, since soldiers are already comfortable using the devices. Enhanced with the technology, the SWORD system provides power, data, and navigation infrastructure within the weapon, including GPS and inertial navigation for GPS-denied situations. The networked rifles serve to essentially deliver the information the soldiers need to execute missions safely and successfully.

The tri-mode seeker is capable of peering through storm clouds or battlefield dust and debris to engage fixed or moving targets.

SUCCESSFUL SMALL DIAMETER BOMB II
Tests Augur Production Phase

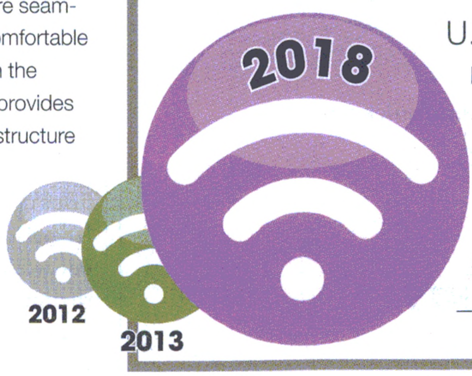
A series of flight tests for the Small Diameter Bomb II (SDB II), conducted by Raytheon and the U.S. Air Force, resulted in direct hits on stationary land targets. The successful tests will likely further move the SDB II program from the engineering/manufacturing/development phase to low-rate initial production.

Upgraded electronics for the SDB II center around Raytheon's tri-mode seeker, which fuses millimeter-wave radar, uncooled infrared imaging, and digital semi-active laser sensors on a single gimbal. The seeker seamlessly shares targeting information between all three modes, which enables weapons to engage fixed, relocatable, or moving targets at any time during the day and in adverse weather conditions.

For example, the tri-mode seeker can peer through storm clouds or battlefield dust and debris to engage fixed or moving targets. Therefore, a warfighter and the weapon will remain unaffected by changing conditions in the ground or in the air. The potential of the SDB II led to its validation by the U.S. Department of Defense, which invested more than $700 million in the program.

As of now, SDB II can hit targets from a range of more than 40 nautical miles. Its warhead can destroy armored targets, yet minimize collateral damage due to a small explosive footprint. In addition, the SDB II's accuracy allows warfighters to change targets through a datalink that passes in-flight updates to the weapon. ■

MARKET QUOTE



U.S. wireless providers handled more than **3.2 trillion megabytes** (MB) of data in 2013, a 120% increase from the previous year. **By 2018, data usage will increase eight times** the 2013 figure.

–CTIA-The Wireless Association

SIXTH SATELLITE AUGMENTS GPS IIF System Capabilities

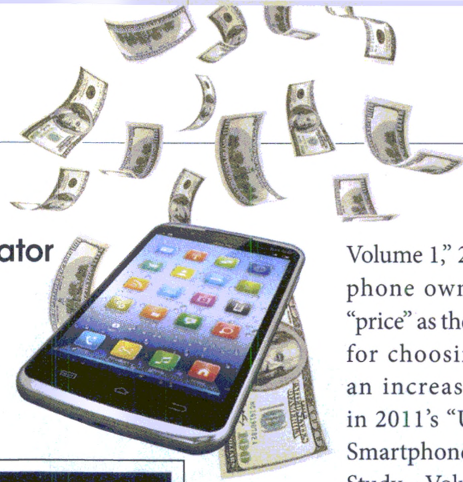
THE GLOBAL POSITIONING Satellite (GPS) IIF system from Boeing, which brings next-generation capabilities to the space-based, navigation constellation, recently welcomed its sixth satellite. Launched by the United Launch Alliance for the U.S. Air Force, the satellite joins a worldwide timing and navigation system of 24 satellites in six different planes that orbits approximately 11,000 miles above Earth's surface. The satellites help improve accuracy and enhance performance for GPS users.

The GPS IIF satellite offers both an improved military signal as well as the delivery of a new civilian signal.

According to Boeing, GPS IIF satellites carry with them five specific mission directives.

1. Greater navigational accuracy, made possible through improvements in atomic clock technology.
2. Delivery of a new civilian L5 signal that aids in commercial aviation and search-and-rescue operations.
3. An improved military signal, which, along with variable power, enhances resistance to jamming in hostile environments.
4. Each satellite features a 12-year design life to provide long-term service and reduce operation costs.
5. An on-orbit, reprogrammable processor that makes it possible to receive software uploads.

Boeing is currently under contact with the Air Force to build 12 more GPS Block IIF satellites. The company's pulse-line manufacturing approach helps deliver the fleet on schedule—the IIF pulse line moves a satellite from one work area to the next in a steady rhythm. The launch of GPS IIF-6 marks the program's sixth successful launch since the launch of IIF-1 in 2010. ■



PRICE BECOMES KEY Smartphone Differentiator

WITH WIRELESS OEMs focusing on advanced technology and carrying similar technologies, smartphone owners now more than ever are looking for the best price. In J.D. Power's recently released "2014 U.S. Wireless Smartphone Satisfaction Study—Volume 1," 21% of smartphone owners marked "price" as the main reason for choosing a device, an increase from 13% in 2011's "U.S. Wireless Smartphone Satisfaction Study—Volume 2."

These survey findings form the latest addition to a study that's been ongoing since 2011. In the past three years, J.D. Power surveyed users of the four Tier 1 wireless carriers: AT&T, Sprint, T-Mobile, and Verizon. Between September 2013 and February 2014, J.D. Power surveyed 13,237 customers of the aforementioned wireless carriers who have owned a smartphone device for less than one year. Satisfaction was measured using four factors: performance (31%); physical design (23%); features (23%); and, ease of operation (23%). On a 1000-point scale, overall satisfaction among phone owners came in at 837.

Although cost is important, those who chose smartphones based on price have a lower level of satisfaction (rating of 808) and a repurchase rate of 18%. That said, in 2014, the average price of smartphone devices increased to $202 (only 52% of owners got a discounted rate)—an increase from $174 in the 2011 report (60% of consumers received a discount).

Features still represent an important part of smartphone selection. However, in the 2014 survey, 35% reported it as their primary reason, which is a sharp drop-off from the 57% in 2011.

What features would smartphone owners like to see on their next device? According to the report, the most desired were seamless voice control (35%); built-in sensors that can gauge temperature, lighting, noise, and moods to customize settings to environment (35%); and facial recognition and biometric security (28%).

In addition, when customers selected a smartphone based on operating system or other product-specific reasons,

they experienced lower satisfaction levels (860 out of 1000) and a repurchase rate of 35%. In terms of carriers, AT&T had the highest overall satisfaction rate with a score of 844, followed by Sprint (839), T-Mobile (835), and Verizon (829).

Smartphone owners also ranked smartphones based on carrier. Overall, Apple received the highest rating across the carriers, with Samsung a close second. In addition, J.D. Power included power circle ratings from 1 to 5. Apple again received the highest score of 5 across all carriers, with Samsung receiving full marks from all carriers except Sprint. LG and Motorola both averaged a 2. ■

"CLASSROOM ON WHEELS" Provides Students with Extended Connectivity

IN AN EFFORT to provide students with new, affordable, learning experiences, AT&T and Alcatel-Lucent Enterprise have teamed up to offer "Connected Buses" to K-12 school districts. The technology aims to turn the traditional school-bus experience into a learning opportunity that also helps improve student safety. It combines wireless technology, AT&T's 4G LTE, and a variety of devices to increase students' access to information.

Each Connected Bus has onboard WiFi, allowing students to access the Internet on their own devices. They can then communicate with friends or family, complete homework, or access information on their way to a field trip. The buses also offer real-time streaming video and broadcast speakers to allow schools to deliver individual or district-wide broadcast announcements. In terms of safety, the buses allow for the remote monitoring of both driver and student behavior to limit the potential for accidents and bullying.

Previously, AT&T had pledged $100 million to ConnectED, a White House initiative to connect 99% of classrooms by 2017. The money will provide 50,000 middle and high school students in Title 1 schools with free Internet connectivity for educational devices over the 4G mobile broadband network. ■

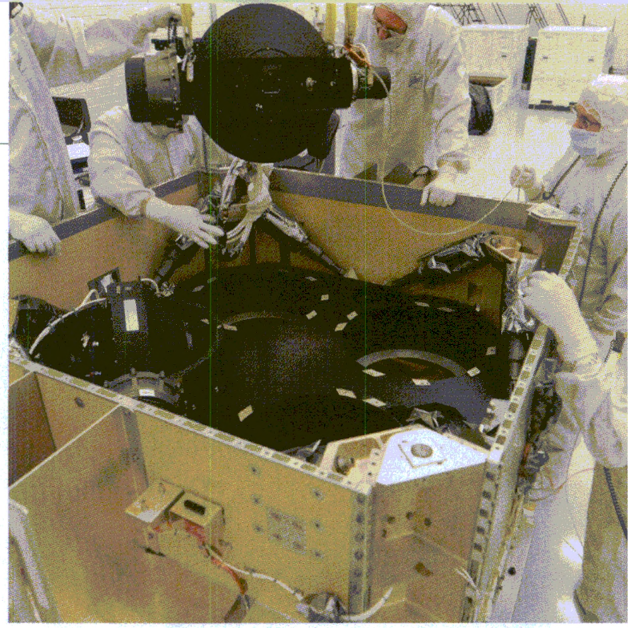
PEOPLE

ANRITSU CORP.—Named Wade Hulon president of Anritsu Co., the U.S. subsidiary of Anritsu Corp., and vice president of Anritsu Corp. Hulon will oversee all sales, marketing, and business operations of Anritsu throughout the Americas, as well as the design and manufacturing operations of Anritsu's Microwave Measurement Division, based in Morgan Hill, Calif.


HULON

AR EUROPE—Appointed Jerome Surowiec European Sales Manager. Surowiec will travel across Europe supporting both the sales associates and customers, managing the day-to-day sales activities and quality of products delivered by ARE and third parties, as well as coordinating the European marketing activity.


SUROWIEC


On August 13, Lockheed Martin Commercial Launch Services (LMCLS) will launch WorldView-3 aboard an Atlas V.

EARTH OBSERVATION SATELLITE Features Atmospheric Sensing

Delivering high spatial resolution, multispectral satellite imagery for earth observations and advanced geospatial solutions, the WorldView-3 satellite employs advanced remote sensing that includes CAVIS, a new cloud, aerosol, water vapor, ice, and snow atmospheric sensing instrument.

WorldView-3, developed by Ball Aerospace for DigitalGlobe, is built on the Ball Configurable Platform BCP 5000 spacecraft designed for next-generation optical and synthetic aperture radar remote sensing payloads. The new CAVIS instrument will monitor the atmosphere and provide correction data to improve the satellite's imagery through haze, soot, dust, and other obstacles.

The new satellite and its integrated sensors successfully completed thermal vacuum, acoustic, vibration, and pyro-separation testing to confirm design integrity. Electromagnetic-interference and electromagnetic-compatibility testing will soon follow.

At an expected operational altitude of 617 km, WorldView-3 collects imagery with 31-cm panchromatic resolution, 1.24-m multispectral resolution, 3.7-m short-wave infrared (SWIR) resolution, and 30-m CAVIS resolution. This is made possible by a 1.1-m aperture Exelis-built telescope carried by the satellite. Extensive viewing into both the visible spectrum and the infrared spectrum extends the range of the satellite's customer applications. Specifically, it will help accelerate DigitalGlobe's Geospatial Big Data program, a living digital inventory of the Earth's surface.

On August 13, Lockheed Martin Commercial Launch Services (LMCLS) will launch WorldView-3 aboard an Atlas V. LMCLS is the exclusive provider of Atlas rockets to all non-U.S. government customers. ■

CONTRACTS

The Malibu Division of Communications & Power Industries LLC (CPI)—Has been selected by an international defense technologies company to provide airborne data links for the RQ-4 Global Hawk unmanned aircraft system (UAS). CPI Malibu Division is providing dual-axis Ku-band high-gain airborne data links for the NATO Alliance Ground Surveillance (AGS) version of the Global Hawk.

Northrop Grumman Corp.—Was awarded a $238 million modification to a previously awarded firm-fixed-price contract from the U.S. Air Force to provide hardware and support for the Large Aircraft Infrared Countermeasure (LAIRCM) system. Critical to the safe return of troops abroad, LAIRCM automatically detects a missile launch, determines if it is a threat, and activates a high-intensity laser-based countermeasure system to track and defeat the missile. Under the terms of the contract modification, Northrop Grumman will deliver additional transmitters, missile warning sensors, processors, lasers, control interface units, and supporting equipment to the Air Force through April 2016.

NORTHROP GRUMMAN
USAF deal gets bigger

RAYTHEON
Inks Navy deal worth $115.5 million

Huawei—Announced that its GSM-R solution has won the bid for the Turkmenistan Buzhun-Serehtyaka and Bereket-Cilmammet integrated railway communications project, which will soon commence. Following the successful implementation of GSM-R technologies in Turkmenistan's Turkmenbasy-Ashgabat (east-west) Line and Cilmammet-Buzhun (south-north) Line in 2012, the new project marks another breakthrough of Huawei's GSM-R technologies in the Turkmenistan railway industry.

Raytheon Co.—Was awarded a $115.5 million contract from the U.S. Navy to remanufacture, overhaul, and provide upgrades to Phalanx Close-in Weapon Systems (CIWS). The CIWS is an integral element of the Navy's Fleet Defense In-Depth concept and the Ship Self-Defense Program. Work under the contract is expected to be completed by September 2017.

SGS—Selected Anite's Propsim channel emulators for its new anechoic MIMO Over-The-Air (OTA) test laboratory in Taiwan. Propsim and its related MIMO OTA Modeling Tool enable SGS to provide accurate and reliable testing services to the global wireless ecosystem in readiness for the upcoming CTIA-standardized MIMO OTA performance test plan.

FRESH STARTS

Elbit Systems Co.—Has been selected by the Swiss Armed Forces to replace its ADS 95 Ranger reconnaissance drone system, which the Swiss have been operating since 2001, with the Israel-based manufacturer's Hermes 900 HFE system, an all-weather unarmed reconnaissance drone system that is more flexible, has longer endurance in the air and a wider operational range than the system currently in use. The Hermes 900 system is expected to be fully in place by 2020.

e2v—Has announced that qualification has been completed on several devices created as part of an agreement with Maxim Integrated Products, including the DG305AAA/883B, a CMOS Analog Switch, and the DG506AAK/883B and DG507AAK/883B CMOS Analog Multiplexers. e2v will also qualify additional Maxim ICs to provide ruggedized versions of multiple product types to support harsh environment applications

Lockheed Martin—Acquired Deposition Sciences (DSI), a Santa Rosa, Calif.-based provider of thin film coatings. The terms of the agreement were not disclosed and are not material to Lockheed Martin operations. DSI will be integrated into the Aeronautics business area.

Spreadtrum Communications—Introduced the SC883XG, a highly integrated TD-SCDMA/GSM/GPRS/EDGE multi-mode quad-core smartphone platform designed with advanced 28 nm process technology.

Altera Corp.—Has entered into a Strategic Cooperation Agreement with Lime Microsystems focused on jointly developing and promoting programmable solutions for a diverse range of broadband wireless markets. As part of the agreement, San Jose, Calif.-based Altera has also made an equity investment in UK-based Lime Microsystems.

NetAmerica Alliance LLC—Formed SMART (Small Market Alliance for Rural Transformation), a shared network alliance with Sprint that provides NetAmerica Members (rural communications service providers) the capabilities they need to deliver 4G LTE mobile broadband services to their communities.

u-blox—Announced that its ultra-compact TOBY-L100 4G LTE module has been certified by Verizon Wireless, enabling customers to leverage the Verizon Wireless network to develop Internet of Things and M2M applications.

Insulated Wire—Has expanded its capabilities to produce customized composite cables featuring low-smoke/zero-halogen polyurethane jackets, often used in naval applications, both on submarine and surface vessels.

ANSYS Inc.—Announced that its RedHawk and Totem products are certified for production version 1.0 of Design Rule Manual and SPICE model tool certification for TSMC 16-nanometer FinFET technology.

RFMW Ltd.—Will distribute Aviacomm's portfolio of smart transceivers including the ARF1020, ARF2010 and ARF3010, as part of a new agreement that initially covers customers in North America, Europe, and South East Asia with the possibility of future expansion.

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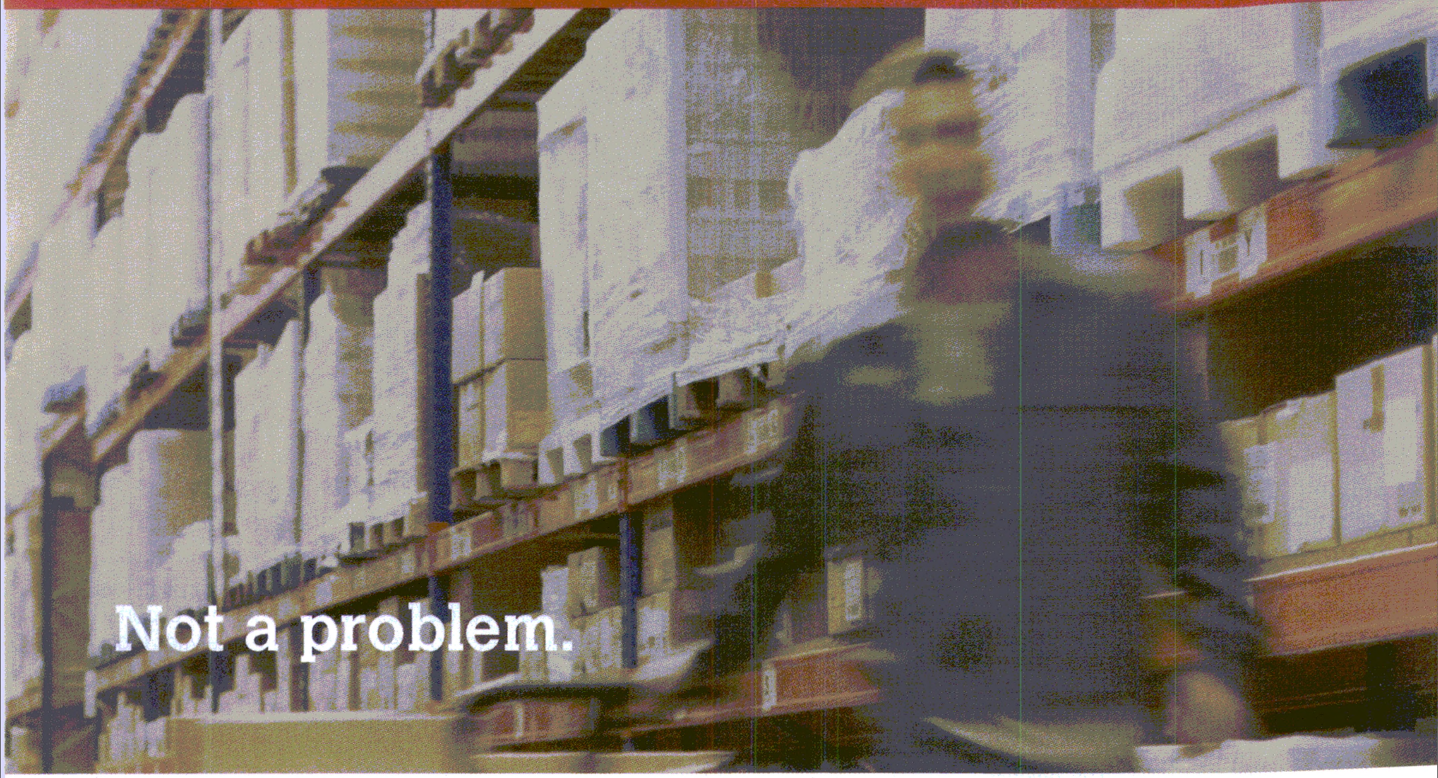

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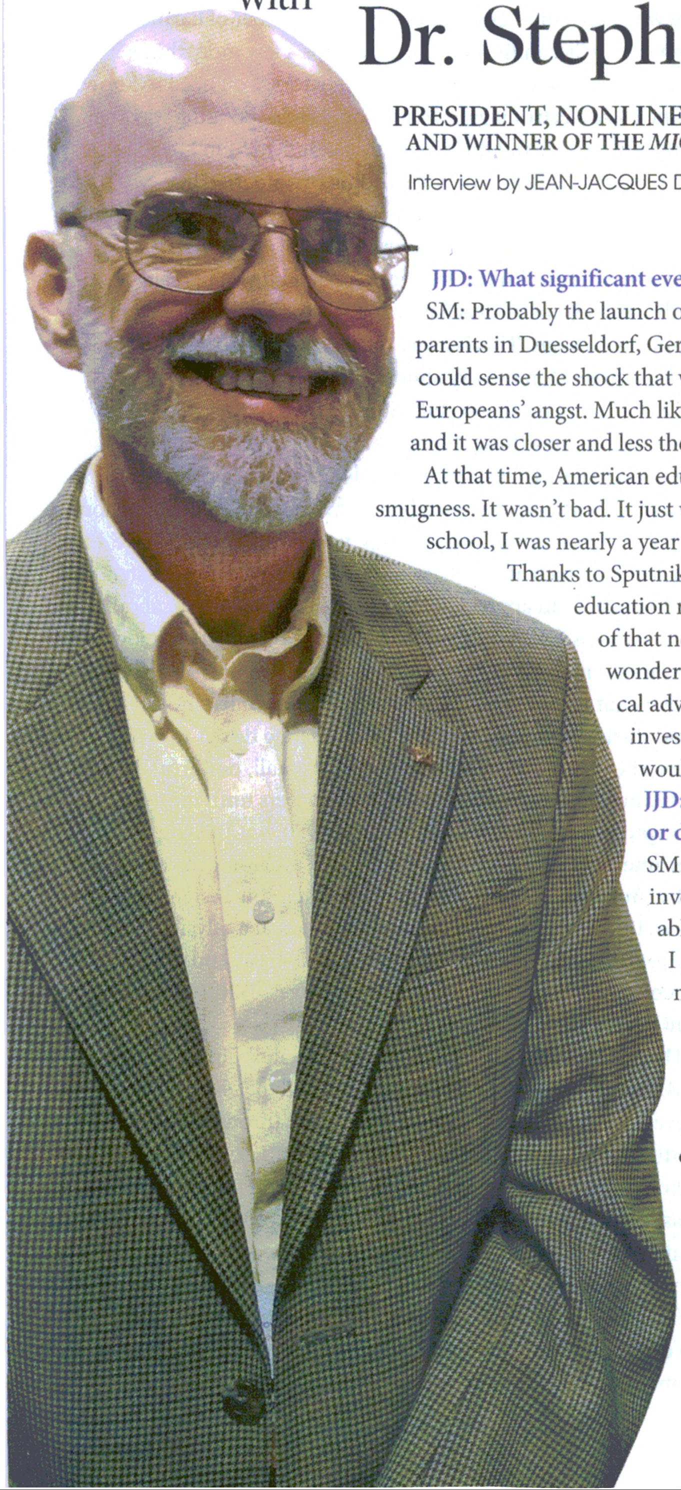
Inside TRACK with Dr. Stephen Maas



PRESIDENT, NONLINEAR TECHNOLOGIES INC., AND WINNER OF THE *MICROWAVES & RF* LIVING LEGENDS AWARD

Interview by JEAN-JACQUES DELISLE

JJD: What significant event most influenced your career?

SM: Probably the launch of Sputnik in 1957. I was eight years old, living with my parents in Duesseldorf, Germany. Even from the opposite side of the Atlantic, we could sense the shock that went through American society, and we especially felt the Europeans' angst. Much like Americans, Europeans perceived a "Communist threat," and it was closer and less theoretical for them than for Americans.

At that time, American education had evolved into complacency and self-satisfied smugness. It wasn't bad. It just wasn't very good. After only two years in a European school, I was nearly a year ahead of my classmates when I returned to the U.S.

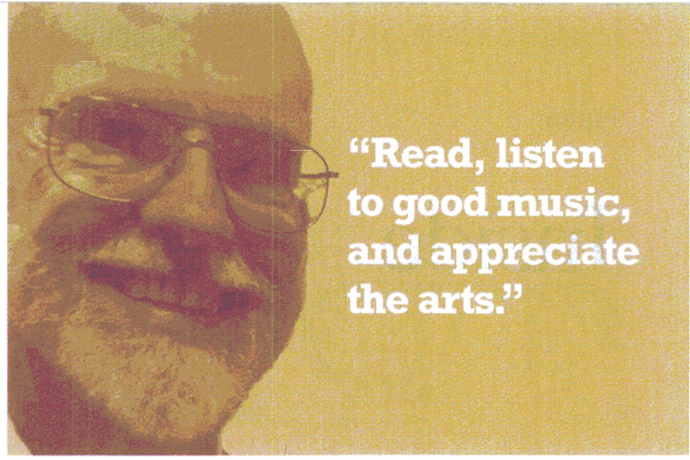
Thanks to Sputnik, though, all that started to change. Math and science education received the boost it needed, and I was a direct beneficiary of that new emphasis. I couldn't have been born at a better time. I wonder how many people understand that the huge technological advances of the last 30 years or so are the direct result of the investment in science education of the 1960s. Without that, we wouldn't be where we are. Someone else would be, but not us.

JJD: If you could have worked with anyone in the field, alive or dead, who would it be and why?

SM: An obvious choice would be Edwin Armstrong, the inventor of not just the superheterodyne receiver but arguably of modern radio technology. When I read his papers, I get the feeling that I think much like he did. Another of my heroes has always been Benjamin Franklin: a genuine Renaissance man and radical thinker with a penchant for wise, dry humor. Beyond that, many people I admire are from very different fields: the Philadelphia artist Thomas Eakins, who knew exactly what needed to be done and didn't let the people who set the styles dissuade him; Jacob Bronowski; Bertrand Russell... I could go on, but I guess that's a decent sampling.

JJD: What led you to focus on nonlinear circuits?

SM: I had developed an interest in low-noise mixers, primarily from working in radio astronomy in the 1970s. In those days, mixers were a hot research topic. Of course,



in dealing with mixers, you come face to face with nonlinearity. There's no way to avoid it. By the 1980s, microwave FETs were good enough that low-noise mixers weren't needed below about 15 GHz. But putting substantial, low-noise gain ahead of a mixer exacerbated distortion. As FETs got better, they got smaller and distortion got worse.

In spite of this, academic research in the '80s remained focused on low noise. But in industry, distortion was the greater problem, and no one seemed to be addressing it. It sounded new and interesting to me, and I had a bit of a head start from the mixer work, so I began working on it. *The Nonlinear Microwave Circuits* book was one result. It helped me organize my thinking, figure out things I didn't know, and put the field into a coherent form.

JJD: How did you come to write your first book?

SM: I returned to graduate school to finish my Ph.D. after several years in industry. By then, I had acquired a wife, a kid, and a mortgage, so I couldn't afford to stop working and become a full-time student. I worked all day and studied all night. Then, when it was over, I was completely at loose ends. I didn't know what to do with myself. I needed some kind of project. I discovered that Artech House was open to new proposals, so I put together a proposal for the mixer book. Despite the fact that mixer theory had been a hot research topic for the previous decade, no one had written a comprehensive book on the subject. So there was a clear opportunity. Perhaps for that reason, Artech was willing to take a chance with someone they had never heard of, and they accepted the proposal.

Your readers might be amused to hear that I wrote the mixer book and, to a large degree, the later ones so that I could use them as a reference myself. I don't have all that information at the top of my head, so I often have to refresh my memory. It's nice to have a book that explains things the way I understand them. The process of writing a book also required getting my thoughts in order and filling gaps in my knowledge. It's a nice way to develop a deeper understanding of a subject.

I was unprepared for what happened when the book hit the streets. Suddenly, I was "the guy who wrote the mixer book," and lots of people knew who I was. I received quite a few unsolicited offers to consult, job offers, and so on. As a person who is generally pretty reserved, I found it all a little scary.

JJD: Would you say many engineers avoid "hard" problems like nonlinearity? Is this hurting development in the field?

SM: I don't think that's really a problem. Many technologies have a high intellectual cost of entrance—for example, electromagnetics and solid-state device physics, as well as nonlinear circuit theory. In spite of their difficulty, there's no shortage of people entering those fields. It is important, however, that we develop the tools that make those fields accessible to everyone who needs to deal with them. We also must make sure that they understand the fundamentals necessary to use them.

In my case, that means developing circuit-analysis software. Using that software effectively does not require knowing nonlinear circuit theory in detail. But it does require knowing a few things about termination criteria, number of harmonics, preventing ill-conditioning, and perhaps a few more things. Same story with electromagnetic simulators: You need to know some basic electromagnetics and some facts about the way the simulators work and their limitations. But you don't need to understand the details of what's going on underneath.

JJD: What would you recommend to young engineers after all of the experiences in your career?

SM: **One:** Stay technical. It's more fun, and if you're really good technically, you'll always have a job. **Two:** Develop your communication skills. This is every bit as important as technical skills. **Three:** Don't worry about money, glory, status, career, or any of that peripheral stuff. Stick to the knitting, and you'll be surprised how those things take care of themselves. **Four:** Develop a sense of history. Technologies evolve as much for historical reasons as technical ones. An understanding of history will show you, among other things, which technologies have a future and which are likely to be dead ends. **Five:** Read, listen to good music, and appreciate the arts. This tells you a lot about how humans think and create. It's not as far from technology as you might imagine.

JJD: What technological innovation had the most impact in the field during your career? How did it change things for you?

SM: The computer—and especially the small, powerful desktop computer. I didn't do much with computers until minicomputers became common around 1980, but they rapidly became a big part of my life. I probably don't have to explain why. But I should note that virtually all circuit design these days, linear or nonlinear, involves numerical analysis. The ability to have easy, quick access to circuit analysis and other kinds of computation has changed all of our lives. Without it, we'd still be, technologically, in 1963.

JJD: What was the greatest challenge you faced in your career?

SM: Probably the fact that I'm really not all that smart. I was never one of those guys who seem to waltz through school effortlessly. I always harbored a boundless jealousy for the people who did. It took me a long time to understand things, and I was continually struggling to keep up and keep my head above water. Eventually, though, I realized that it was an advantage, as I had to learn how to dig into a subject and explain it to myself, get the subtleties, and avoid conventional wisdom. I'm still not so quick on the uptake sometimes. But when I finally figure something out, I usually know it in good depth. mw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60-GHz PLL-BASED MODULATOR BOOSTS RADAR APPLICATIONS

SIGNIFICANT RESEARCH EFFORTS have been made to realize a cost-effective CMOS IC radar for automotive, security, and presence-detection applications. At 60 GHz, sufficient bandwidth is available to achieve the range resolutions needed for high-resolution velocity detection. To realize this capability, Wanghua Wu, Robert Bogdan Staszewski, and John R. Long from Marvell Semiconductor Inc. have designed and implemented a 60-GHz frequency-modulated, continuous-wave (FMCW), digitally intensive transmit modulator. This modulator is based upon a multi-rate, all-digital phase-locked-loop (PLL) architecture.

To improve the system's chirp linearity, a high-rate digitally controlled oscillator (DCO) clock is used. This DCO is realized from switched-metal capacitors, which are distributed across a transformer-coupled resonator for a 10% tuning range with roughly 1-MHz resolution at 60 GHz. This feature allows the modulated paths to have clock-cycle precision in time.

The measured root-mean-square (RMS) frequency error of the FMCW signal reaches 117 kHz for a 62-GHz carrier. The modulator covers 1.22 GHz with RMS jitter response of 590.2 fs. Settling time was measured down to 3 μs with reference spur levels of −74 dBc and no other significant spurs. See "A 56.4-to-63.4 GHz Multi-Rate All-Digital Fractional-N PLL for FMCW Radar Applications in 65 nm CMOS," *IEEE Journal Of Solid-State Circuits*, May 2014, p. 1081.

OPTICAL-TO-ELECTRICAL TERAHERTZ LINK ENABLES SISO COMMUNICATION

MANY PHOTONIC, TERAHERTZ, and RF solutions have been proposed to solve the accelerating bandwidth demand of mobile-communications technologies. For example, optical wireless communications (OWC) using near infrared (NIR) technology can support the necessary data rates. Yet fog effects and dust scattering can cause significant fading effects. Using a hybrid photonic-to-electronic terahertz communications link, a 46-Gb/s data channel has been implemented at 400 GHz by the following researchers from the Institute of Electronics, Micro Electronics, and Nanotechnology and Lille 1 University of France: Guillaume Ducournau; Pascal Szriftgiser; Alexandre Beck; Denis Bacquet; Fabio Pavanello; Emilien Peytavit; Mohammed Zaknoune; Tahsin Akalin; and Jean-Francois Lampin.

The system is composed of two lasers at 193.6 and 194 THz, which are modulated by a Mach-Zehnder optical modulator. The photonic signal is then passed through an optical amplifier and a photomixer. That photomixer emits a 400-GHz carrier with a maximum 92 GHz of bandwidth.

Transmission and reception terahertz polymer lenses are used to create the terahertz point-to-point link. A WR 2.2 conical-horn receiver feeds the received signal to a subharmonic mixer. That signal is then amplified and sent to a 120-GSample/s analog-to-digital converter (ADC) inside a 45-GHz real-time serial data analyzer. See "Ultrawide-Bandwidth Single-Channel 0.4-THz Wireless Link Combining Broadband Quasi-Optic Photomixer and Coherent Detection," *IEEE Transactions on Terahertz Science and Technology*, May 2014, p. 328.

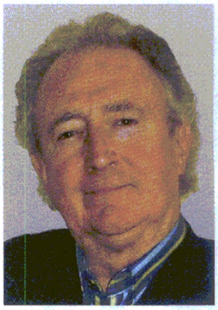
DUAL-ISM-BAND ON-BODY ANTENNA RELIES ON TEXTILES

TEXTILE-BASED WEARABLE ANTENNAS could help to enable advanced solutions for firefighting, rescue systems, and embedded medical devices. For these antennas to avoid signal degradation and a high specific absorption rate (SAR), they often require an additional grounding structure or significant separation from the body. Recently, Sam Agneessens and Hendrik Rogier from Ghent University teamed to meet the small size, flexibility, performance, and feasibility requirements of on-body antennas. They designed and tested a half-mode-substrate integrated-waveguide (HWSIW) antenna that is capable of dual-ISM-band operation.

The antenna spans 2.4 to 2.5 GHz and 5.725 to 5.875 GHz in the industrial, scientific, and medical (ISM) bands. To meet regulatory requirements, it must satisfy certain criteria in terms of low weight, flexibility, and SAR. Other critical factors include robust electrical operation during movement, variations in body morphology, and a consistent radiation pattern. To reduce size and thus better facilitate these requirements, a cavity-backed slot antenna typology was chosen.

A virtual magnetic wall is used to compress the footprint. For more enhanced reduction, brass shorting pins are distributed evenly along the structure's periphery. An additional slot is cut into the design to increase bandwidth at higher frequencies and fine-tune resonant behavior. The experimental results revealed a 4.9% and 5.1% measured bandwidth at the 2.4-GHz and 5.8-GHz bands. Maximum measured gains of 4.1 and 5.8 dBi were achieved. See "Compact Half Diamond Dual-Band Textile HMSIW On-Body Antenna," *IEEE Transactions on Antennas and Propagation*, May 2014, p. 2374.

PAUL WHYTOCK | European Editor


PAUL WHYTOCK

First Channel Models Published for 5G

At the opening plenary at the METIS April 2014 meeting in Valencia, Spain, are (l to r) Professor Narciso Cardona Marcet, Professor Francisco Jose Mora, and Dr. Afif Osseiran.

WIRELESS EQUIPMENT test specialist Anite plc (www.anite.com) has published what it claims are the world's first channel models for Fifth-Generation (5G) cellular communications systems. This is seen as a major step toward further development of candidate 5G technologies.

Anite is a member of the European Union (EU) Mobile and wireless communications Enablers for the Twenty-Twenty Information Society (METIS) project. The interim channel models were co-authored by eight METIS partners and approved by other key members of the project for publication.

Co-funded by the European Commission, METIS aims to lay the foundation for future mobile and wireless communications systems for 2020 and beyond. It is a consortium of 29 partners and is coordinated by Ericsson. It regularly holds international meetings to advance the development of 5G, the next-generation mobile and wireless communications technology. There is no doubt that 5G has extremely challenging technical requirements, but it is expected that it will be designed to adapt to various radio channel conditions more efficiently than current radio technologies, using all the aspects of the radio channel such as delay, frequency, time, location, elevation, and polarization.

One of the METIS project's overall technical goals is to provide a system concept that supports higher mobile data volume. Accurate radio channel model development enables higher data transmission volumes, which is why the definition of the radio channel model is seen as a key constituent in the perfecting of 5G. The interim 5G channel models announced by Anite are part of the METIS Deliverable D1.2 and are available for 5G technology developers worldwide. "The interim 5G channel models defined under Anite's leadership have wide industry acceptance and will help to meet the requirements of higher data volume and develop a system concept for 5G," says Olav Queseth, senior researcher at Ericsson and project coordinator at METIS.

Greater radio spectrum for mobile networks is vital to meet expected increased capacity and coverage demands. Without sufficient spectrum, users and conurbations beyond the scope of wired broadband applications will not benefit from future service advantages.

INCREASING THE SPECTRUM

So how is this increase in spectrum going to be achieved? Adoption of new frequency bands is essential as is the efficient use of existing bands. Industry observers are also saying that because networks will consist of a greater number of cells, 5G will need to use an increased number of base stations. All of these requirements are expected to be critical, given that the number of smartphone users is predicted to grow to nearly 5 billion by the end of this decade. This will, of course, hugely increase the amount of data traffic, which is expected to multiply tenfold by 2020.

Because of these predicted increased user demands and network challenges, METIS has outlined an essential list of requirements regarding the implementation of 5G.

They are:

1. Ten to 100 times higher typical user data rates wherein a dense urban environment the typical user data rate will range from 1 to 10 Gb/s;
2. One thousand times more mobile data per user where the volume per area per user will be over 100 Gb/s/km2;
3. Ten to 100 times more connected devices and 10 times longer battery life for low-power massive machine communications where machines such as sensors or pagers will have a battery life of a decade;
4. Support of ultra-fast application response times where the end-to-end latency will be less than 5 ms with high reliability. A key challenge with this will be to fulfill the previous requirements under a similar cost and energy dissipation per area as in today's cellular systems. mw

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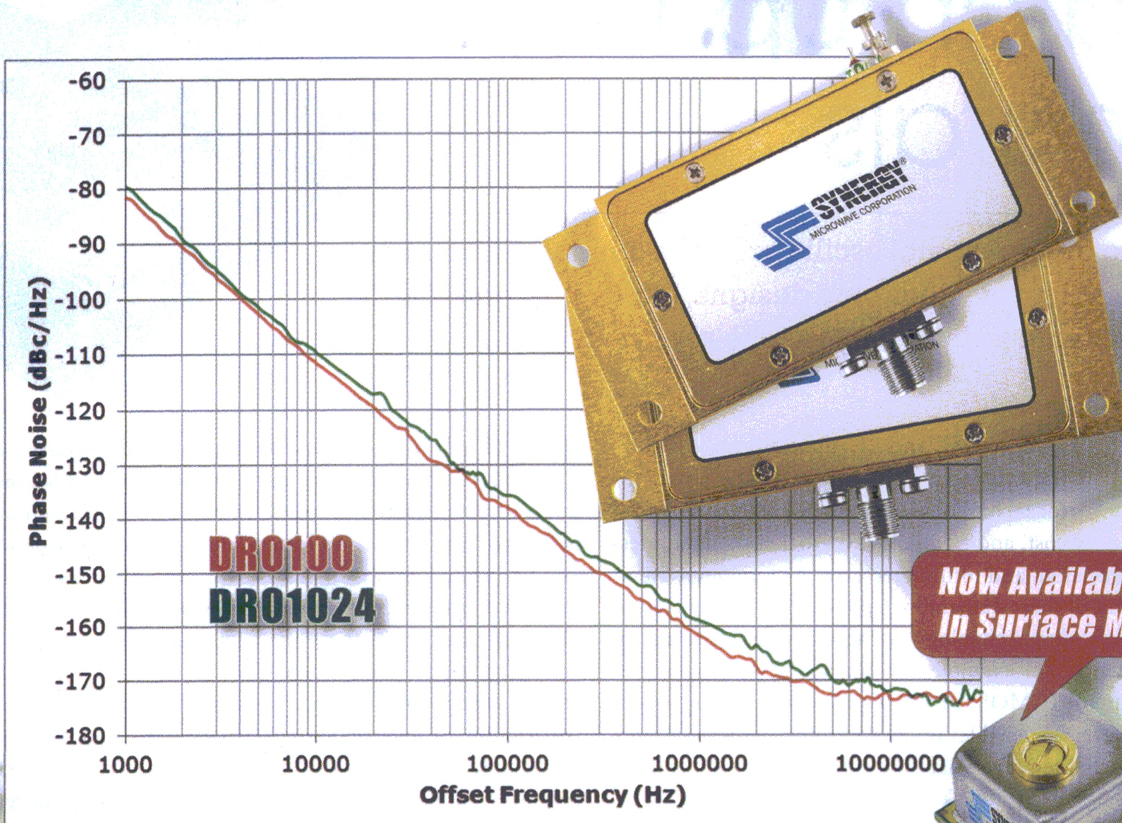

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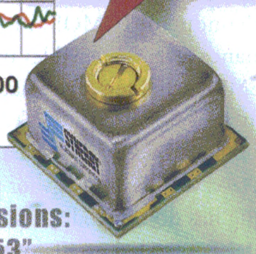

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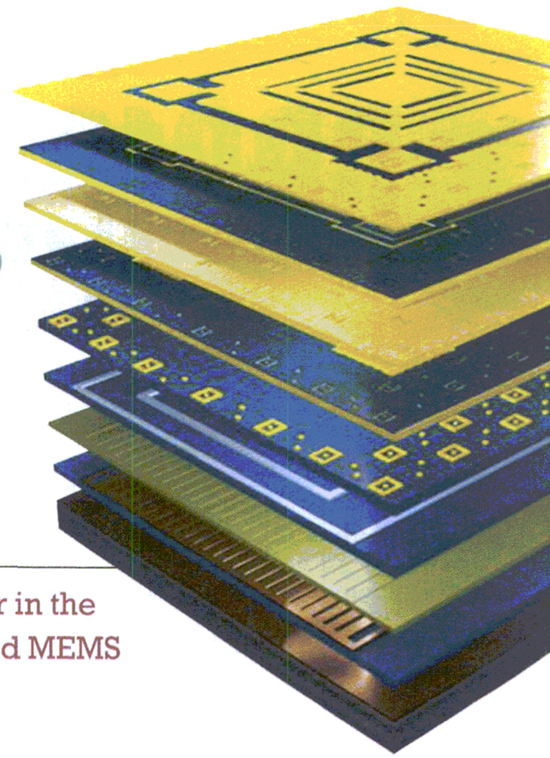
JEAN-JACQUES DELISLE | Technical Engineering Editor

Enhanced MEMS Oscillators Catch Up to Crystals



Because quartz-crystal oscillators are a limiting factor in the footprint of many electronic designs, highly integrated MEMS oscillators are being developed to replace them.

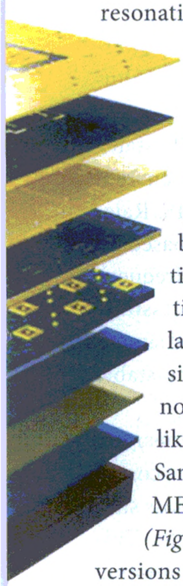
Digital, analog, and RF applications are requiring ever-greater performance from oscillator technology—specifically in terms of size, cost, and frequency. Skyrocketing data rates, military precision, and millimeter-wave technologies are at the forefront of these demanding applications. Fortunately, a consistently scaling technology method may be able to satisfy these demands. For example, complementary-metal-oxide-semiconductor (CMOS) processes may be reaching a performance level that enables microelectromechanical-systems (MEMS) technology to replace the comparatively bulky crystals in the latest oscillators *(Figs. 1-2)*.

Such a move would drastically change the industry, as quartz-crystal technology for precision frequency control and timing has dominated the market since 1917 (when the first crystal-controlled oscillator was patented). The first quartz-crystal clock was developed in 1928. In the 1950s, atomic clocks were used, although their materials are generally too large and costly for use in most modern electronic applications. In the early 2000s, other technologies finally began catching up to the resonate performance of quartz crystals.

Quartz-crystal resonators operate according to the principle dictating that elastic materials have resonant frequencies of vibration. The resonant frequency of a material depends upon its size, elasticity, speed of sound, and shape. As long as they are properly cut and mounted, quartz crystals will physically distort in the presence of an electric field when a voltage is applied to an electrode near the crystal. This electrostriction, or inverse piezoelectricity effect, causes a resistive, capacitive, and inductive (RLC) resonant-circuit-like response at a very precise resonant frequency. Crystal resonators can be manufactured to resonant frequencies ranging from a few kilohertz to several hundred megahertz.

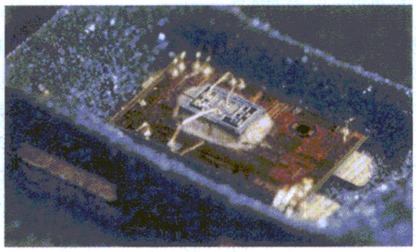
1. Using CMOS process technology, modern MEMS resonators can be incorporated into a low-cost and high-yield structure with enhanced feedback and control. *(Courtesy of Silicon Labs)*

The manufacturing process for performance crystals requires specialized equipment and hermetic sealing. Often, it also demands temperature-control technologies in complex packages that can support these options. Such specialized manufacturing stages are required to mitigate the limitations of quartz-crystal technology. The higher the frequency of resonance, the more susceptible this technology is to interference from parasitics. After all, any additional capacitance or inductance will cause shifting in the resonant frequency. Further-



more, a higher frequency of operation tends to lead to sensitivities and loss of performance at temperature and vibration variations. Compensating for these limitations requires ever-greater steps to control the temperature and buoy the resonating element to provide protection from vibrations.

With the telecommunications, test and measurement, military, and space markets demanding ever-smaller footprints for oscillator technologies, development has been increasing for technologies without these limitations. Surface-acoustic-wave (SAW) and bulk-acoustic-wave (BAW) resonators have been used for oscillation technologies. Yet they suffer many of the same size, cost, and reliability issues as quartz-crystal technologies. Other methods have surfaced at companies like Silicon Labs, Toshiba, Vectron, SiTime, Synergy, Sand9, Micrel, Discera, and others. They are producing MEMS-based oscillators in very small and flat packages *(Fig. 3)*. To create the final oscillator device, the earlier versions of this technology still rely on a MEMS resonator chip packaged with another IC in a multichip module (MCM).



2. The size and functionality of frequency components are being optimized by MEMS technologies. *(Courtesy of NXP)*

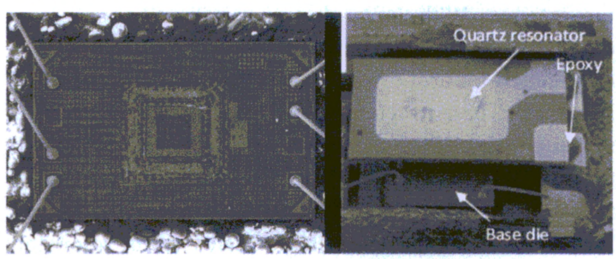
MEMS MCM specialized packages require fabrication facilities with unique capabilities. Unfortunately, relying on non-mainstream technology tends to drive up costs while slowing iterative improvements. Additionally, strain and rapid temperature fluctuations are still significant performance degraders for MEMS MCM technology, which has only just reached quartz-crystal-oscillator capabilities *(Figs. 4-5)*. A logical next step is to integrate all of the oscillator elements onto a single die that can be manufactured in a standard process. CMOS technology nodes, for instance, continue to increase in performance and capabilities. As a result, many technologies are moving to CMOS to enable the development of miniature and cost-effective solutions.

Developing clever circuit techniques and process investigation may be a large R&D expense. Yet the wide adoption, low costs, high yield, fabrication options, and upgradability of using a CMOS process for oscillator technologies could outweigh the initial investments. Among the companies that are already developing high-performing CMOS MEMS oscillators, which are resilient and take advantage of the advanced circuit techniques enabled by CMOS processing, are Silicon Labs, Toshiba, Discera, and Micrel. Because the addition of MEMS would occur at a post-processing stage for CMOS circuitry, the CMOS MEMS can be integrated into the latest mixed-signal/RF technologies.

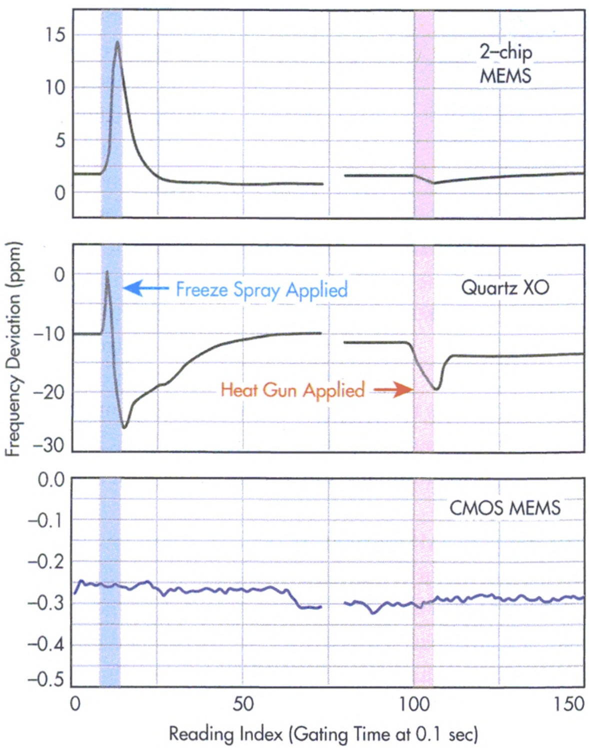
Silicon and polycrystalline silicon germanium (poly-SiGe) are common structural materials for CMOS-based MEMS oscillators. Poly-SiGe lends itself to sophisticated multistep processing, as it exhibits low thermal losses, high fracture strength, and limited hysteresis/creep when subjected to multiple stress cycles. These traits also are desirable for frequency-control applications, thanks to their propensity for long-term stability. In addition, the CMOS MEMS process provides the ability to integrate a frequency-control structure directly into a mainstream device. This aspect eliminates the need for costly and bulky interconnects between the frequency control device and the ICs that need control. It also eliminates any potential parasitics that could occur as a result.

Initially, MEMS resonators suffered from low transduction efficiency, large frequency temperature coefficients, and difficulty with trimming. Such issues were a function of the small size and special processing that was needed. All of these drawbacks can, and have, been effectively mitigated by the use of clever circuit techniques and the processing stages enabled by the CMOS integration. For example, temperature susceptibility can be reduced by mechanically compensating for the physical effects of the temperature on the substrate using a material with an opposite temperature coefficient. For frequency-control devices, CMOS MEMS provide benefits beyond high-performance oscillators. They could even enable highly precise and small-form-factor sensors and transducers.

With the increasing frequency range and miniaturization of the latest RF/microwave/millimeter-wave technologies, there is a demand for technologies that provide even higher frequency and performance. The Resonant MEMS Group, part of the Wireless Integrated MicroSensing & Systems (WIMS2) Center at the University of Michigan, is looking to gallium nitride (GaN) and phase-change compounds to enable the next-generation RF MEMS devices. According to Dr. Mina Rais-Zadeh, head of the Resonant MEMS Group, "An interesting direction for GaN research, which is largely unexplored,

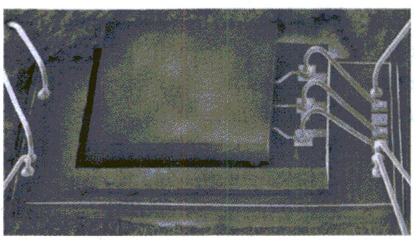


3. CMOS MEMS frequency technology can enable higher levels of ruggedization than quartz-based resonators with comparable performance. The key is that the transducing element in MEMS devices does not require a suspended element with complex fixturing. *(Courtesy of Silicon Labs)*



4. With active control circuitry, the temperature stability of frequency devices could be enhanced with on-chip heaters and temperature compensation. *(Courtesy of Silicon Labs)*

is GaN-based microelectromechanical-systems devices. To fully unlock the potential of GaN and realize new, advanced, all-GaN ICs, it is essential to co-integrate passive devices (such as resonators and filters), sensors (such as temperature and gas sensors), and other more-than-Moore functional devices with GaN active electronics."



5. In MEMS multichip-module devices, a resonator chip is placed on an IC using a bondwire interconnect. *(Courtesy of Discera)*

A wide-bandgap semiconductor, such as GaN, has greater ability than silicon (Si) to handle high power and temperature extremes. With similar electron mobilities and an already developed industrial presence that is second only to Si, GaN can be used to form thin aluminum (Al) GaN/GaN heterostructures. These structures exhibit the 2D electron-gas phenomenon, which enables them to form high-electron mobility transistors (HEMTs) with a high Johnsons' figure of merit.

GaN also boasts piezoelectric properties and low acoustic loss, which make it ideal for high-quality-factor resonators and low-phase-noise oscillators. "While not having sufficient piezoelectric coupling for filter applications, the piezoelectric constant of GaN is large enough to implement low-power oscillators," notes Rais-Zadeh. "Besides, GaN bulk acoustic wave resonators are small in size and can be monolithically integrated with GaN/AlGaN HEMTs to implement a small-form-factor, very linear, and low-noise oscillator."

Other factors that may enable very-high-performing frequency-control devices from GaN technology include the material's high electrical breakdown field, high electron-sheet charge density, the absence of ionized impurities in the undoped hetero-structure, and the ability to develop high-Q MEMS resonators. These traits could enable higher power-density signals from GaN devices while limiting the nonlinearities that are introduced into those signals.

Developing a time-invariant and environmentally stable frequency-control device is a challenge with every current technology, and it is no different with GaN MEMS. Rais-Zadeh states, "The other challenge with oscillators based on MEMS resonators, in general, is the stability of the frequency with environmental changes. This has been successfully addressed using silicon as the resonating material. And similar techniques can be adapted to implement frequency-stable GaN-based oscillators."

Until the performance enhancements are more apparent, additional adoption challenges may surface due to the cost of growing GaN on an easily micromachined and low-loss substrate in a cost-effective manner. Rais-Zadeh comments, "This technology offers lower noise and lower power consumption compared to competitive RF/microwave oscillators. However, because the technology is not as mature, the cost may be higher now. But the cost can be substantially reduced if one goes to large-volume manufacturing." With GaN technology being adopted more rapidly throughout the RF/microwave industry, more devices may be using this semiconductor technology in the not-too-distant future. The desire to have modules with completely integrated RF/microwave electronics and the growth of highly integrated millimeter-wave applications also may drive the rapid development of this technology.

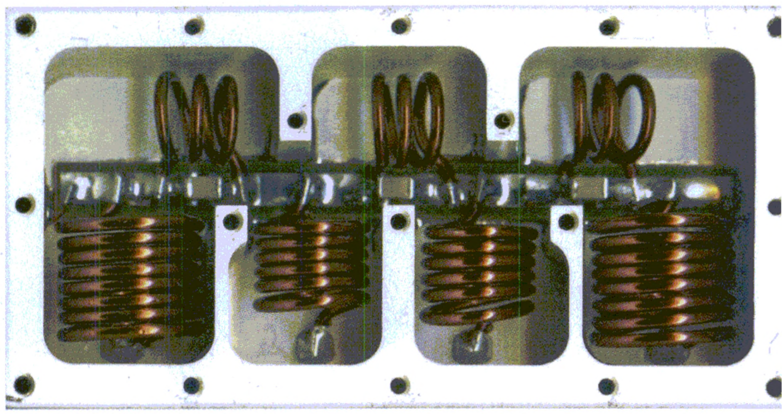
In fact, many companies and research groups are backing the use of MEMS to replace a lot of the larger, more costly, power-consuming, and difficult-to-integrate technologies. Frequency-control products, such as oscillators, are a hot topic for innovation because they are necessary components in almost every electronic device. Quartz-crystal-based oscillators—though highly refined—are still limited in their SWaP-C performance. In addition, the latest applications are demanding higher frequencies and more scalable technologies. It may only be a matter of time before more mainstreamed RF/microwave technologies, such as CMOS and GaN MEMS devices, outstrip crystal performance and herald an age of smaller, higher-frequency, and better-performing frequency-control devices. mw

JEAN-JACQUES DELISLE | Technical Engineering Editor

Filter Assemblies Boost Performance

When facing extreme performance and size requirements, filter assemblies can provide a customized solution for the most demanding applications.

WHEN VERY HIGH standards of performance and frequency response are required, it is often difficult to achieve the desired specifications by adding a filter component to a pre-existing design. This is the case with military, space, telecommunications, and public-safety systems. All of these applications tend to require reliable performance under a wide range of conditions. A solution to these challenges is to design filter components into a combined assembly, which is known as an integrated filter assembly (IFA; *Fig. 1*). Considering the demanding specifications of modern applications due to size, weight, and power (SWaP) constraints, many other components are incorporated into the filter assemblies. In fact, an integrated multi-function assembly (IMA) can house amplifiers, mixers, couplers, and other components.



1. These wirewound inductors can be easily tuned in an open package by manipulating the coil elements with an insulating tool.

Filter components tend to be highly reflective circuit elements. As a result, their electrical behavior is very sensitive to the impedances and parasitics at the filter's internal and external ports. Jon Scoglio, engineering manager with API Technologies, comments, "If you tune a filter component considering an ideal system, and then drop it into the next-level assembly, you hope that everything plays well from an impedance standpoint. But that is never the case."

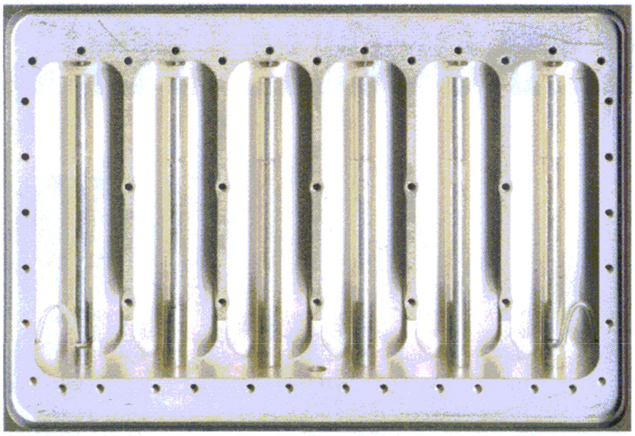
This scenario requires the careful design of the filter components and IFAs, so that each individual block can be tuned throughout the assembly process for optimized performance. Many factors play into the critical aspects of IFA/IMA designs including materials, interconnect, filter type, added functions, tuning, and application.

The design of IFAs, like any system, is divided into functional blocks and modeled around the most limiting structures. The goal of modeling the filter electrically is to gauge the interaction between the filter elements and the electrical components. This approach enables the up-front analysis of the design, so that some of the adjustment of the filter structure into the surrounding circuitry can be performed preemptively.

The mechanical portions of the filter are designed using advanced 3D modeling techniques to model the complete structure. Even the filter elements are modeled to scale, so that the IFA can be made as compact as possible if needed. Other desired properties can be optimized using these design techniques as well. The IFA or IMA application heavily influences the design criteria of the assembly.

Filters for military and space applications in particular center around broadband, powerful, and reliable performance under an extreme range of temperature and environmental conditions. An IFA enables a filter to meet such performance criteria by being accurately tuned and compensated for environmental conditions. In addition, the assembly can be equipped with a ruggedized housing that meets environmental criteria. Weight and size can be more readily controlled with an IFA, as there are techniques that can bend filter stages into small and complex shapes.

For their part, public-safety radio systems generally differ from military requirements in that they need to have very precise and narrow filter responses around set frequencies. They also have slightly less stringent ruggedness requirements. The narrowband response requirement is caused by the intense spectrum competition around the frequencies in which public-safety radio systems operate. Achieving a high-Q filter response in a small and light footprint is a difficult task with discrete designs, considering the reliability and ruggedness requirements of public-safety systems.



2. To enable highly precise performance, the screw elements at the end of the metallic rods in the cavity-resonator filters are adjusted outside of the housing.

In contrast, the filter requirements for telecommunications applications focus on high-power and extremely high-Q designs. Here, an individual frequency channel—only a few megahertz wide—may need to be filtered. The higher Q or power requirements generally increase the size of the individual filter components. These complex and bulky designs often must fit into a compressed rack-mount profile with high electromagnetic-interference (EMI) specifications. Custom filter assemblies using multi-technology filters and integrated amplifiers/mixers can reduce the part counts needed as well as the overall size of the systems.

Together with other factors, this compacting method makes filter components very dependent upon their mechanical structure and the way they are physically housed. Most IFAs are designed and built in machined metal housings. Naturally, there are tradeoffs between the different metals used for the housing of the assembly. The primary metal of choice for IFAs is aluminum, as it is low in both cost and weight. Brass would be the second-most common choice. More specialized metals like stainless steel, Invar, and Kovar follow. For extreme-temperature purposes, it may be necessary to use lower-thermal-coefficient-of-expansion metals like Invar or Kovar.

The level of intricacy of these designs and lack of competent machinery leaves IFAs with predominantly custom construction. IFAs are generally hand-assembled from the component level. Some manufacturers use semi-automation, such as desktop-type conductive reflow machines, to perform some soldering operations to set components. On a lumped-element filter, for example, surface-mount capacitors may be soldered to the floor of the housing. This approach will be used if volume dictates the cost of using conduction benchtop reflow machines to perform some of the solder operations.

Wherever possible, the filter sub-assemblies are tuned by hand, individually, to 50 ohms. To save manufacturing steps, the filter is built and tuned in its own machine-level housing. The filter subassembly is then integrated into the next level of assembly and hand-tuned to the required performance. Such tuning requires skilled technicians, who use network analyzers to observe the performance of the IFA in real time.

Each type of filter requires a different approach to tuning. After all, only certain filter elements can be cost effectively changed in a way that will reliably affect the filter's performance. With lumped-element filters, a technician manipulates the coils of the inductive-filter elements using a wooden or fiberglass stick at the turns of the inductors. In the case of a cavity filter, a technician is generally turning tuning screws, which allow him or her to adjust the air-loaded capacitances at the end of each resonator rod *(Fig. 2)*. Tuning dielectric resonators may seem like a less delicate operation, as a rotary grinding tool is used to remove the ceramic resonator body while its electrical behavior is observed live.

The filter elements used in an IFA design are chosen by SWaP, electrical properties, and the ability to tune key elements. When considering lumped elements, standard monolithic surface-mount-type capacitors and single-layer capacitors made of alumina or higher-dielectric-constant materials are common. Generally, inductive elements are limited to the types that can be manipulated and tuned, which limits the use of surface-mount wirewound inductors. The inclusion of air-wound inductors or toroids is dictated by the amount of inductance and the design's size constraints.

Cavity and dielectric-based filters are more dependent upon their physical construction—as an aspect of the housing design. As a result, the manufacturing of the housing becomes part of the tuning process. For cavity filters, the metal rods inside the cavity are acting as the resonant elements. The end of the rod is picking up capacitances to a set screw coming through the chassis wall. Turning the screw adjusts the air gap at the end of the rod and, subsequently, the capacitances. The dimensions of the rod and the metal housing around it are what set the relative frequency response of the filter element.

Regarding dielectric resonators, these filters are constructed of pressed ceramics that are metallized. A cutout section is designed to achieve the specified resonance, and that hole is the resonant element. To tune these structures, grinders adjust the frequency of resonance by removing the metallization from one end of the element. Because this tuning process is a one-way function, skilled technicians are needed to achieve sufficient yields in a manufacturing setting.

In summary, it is good practice to build and tune filters into the IFA's subassembly and perform coarse tuning with the filter individually at the subassembly level. This pre-tuning can be comprehensive and include all of the tunable components. The subassemblies are mechanically designed. As a result, they can be adjusted within the next level of assembly to account for impedance variations and parasitics in the interconnections between assembly components. mw

JEAN-JACQUES DELISLE | Technical Editor

Unmanned Aerial Systems' Capabilities Soar

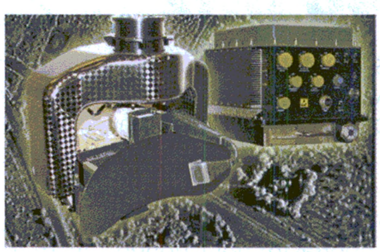
UASs demand the highest speed, lightest weight, and most efficient communications technology in footprints that are furthering the industry's capabilities.

MANY FACTORS ARE contributing to the rise and use of unmanned systems across a variety of industries. Air, sea, and land vehicles can provide relief, intelligence, speed, and efficiency in environments where manned operation may be infeasible or too costly *(Fig. 1)*. Because artificial intelligence systems are still incapable of providing complete mission-ready and adaptable robots, manned control of these vehicles is still necessary.

To enable this control, reliable and feature-rich advanced communications and sensing systems are being heavily developed. RF/microwave/millimeter-wave communications and sensing technologies form the backbone of these modern systems. These technologies are being reviewed by military and commercial entities in order to increase the operational ability of unmanned aerial systems (UASs).

UASs have come a long way since the first simple unmanned aerial vehicles (UAVs)—WWII drone bombers and remote-control planes. Modern demands on these systems have increased the complexity of the radio control and electromagnetic sensors alike. They also have moved the development of these technologies out of the strictly military space. The requirements of small form factor, high configurability, low power, low weight, and broadband operation are all enabling more advanced UAS technologies. In addition, millimeter-wave technology is surfacing on UAV platforms in the form of higher-resolution radar for ground-moving-target-indicator (GMTI) operations *(Fig. 2)*. Because millimeter-wave imagers are very compact and lightweight, they lend themselves to mobile platforms. Notably, synthetic-aperture-radar, or SAR-based, millimeter-wave systems are capable of photographic-quality images in a mixture of harsh environments. They also operate regardless of ambient light level. General Atomics Aeronautics (www.ga-asi.com) manufactures its Lynx multi-mode radar using this technology.

1. With so much focus on unmanned aerial systems, it is easy to forget that there are many other unmanned platforms for land and sea that are bringing revolutionary abilities to those environments. (Courtesy of Lockheed Martin)



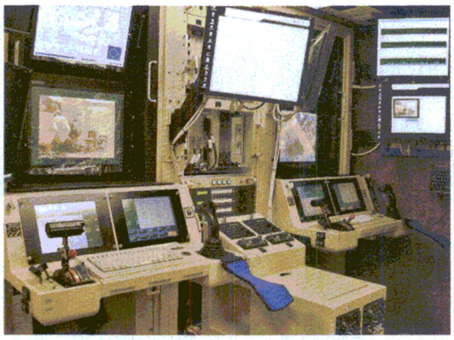
2. Taking high-resolution images in rain, dust, snow, or fog is possible with millimeter-wave imagers. (Courtesy of General Atomics Aeronautical)

COMMUNICATIONS BACKBONE

In 2012, the Defense Advanced Research Projects Agency (DARPA) issued a project aimed at providing mobile hotspots with advanced communications capabilities to support troops and warfighters in remote locations. Implementing reliable communications and data infrastructure has been a challenge for military personnel in remote geographic areas and diverse environments. The amount of tactical equipment and protocols that depend on a strong data backbone are rapidly increasing. Fortunately, the use of commercial-off-the-shelf (COTS) WiFi or Long-Term-Evolution (LTE) systems could bring a level of tactical connectivity not yet experienced. Building a mobile infrastructure capable of supporting reliable wireless technologies in remote tactical regions may be a costly and inflexible option. As a result, using UASs to create flying nodes for the mobile high-speed backbone has become a main target of this DARPA project.

The present vision for the project is to implement and demonstrate a scalable and mobile millimeter-wave communications-backhaul network. This network features nodes mounted on small UAVs that can provide reliable, long-range 1-Gbps capacity. To succeed in providing such capacity, several technologies required development. Among those are steerable millimeter-wave antennas that could rapidly establish a communications link between moving platforms while maintaining low power and a small footprint.

3. According to Lockheed Martin, 1.1 million of the U.S. military's 2 million UAS flight hours were aided by its Vehicle Control Station software (VCS).



4. For the latest in UAS-guided control, advanced cockpit controls must be deployable to be within reach of the UAS's communications link. (Courtesy of General Atomics Aeronautical)

Other innovations included more efficient power amplifiers, lower-noise amplifiers, and overall SWaP reductions. The current phase of this project, led by L-3 Communications and FIRST RF, is the incorporation of these technologies into aerial pods and ground vehicles. The next phase focuses on multi-UAV field testing using SRQ-7 Shadow UAVs and mobile ground vehicles.

Outside of DARPA, many companies are working on technologies that are well suited to UAS networking applications. Octasic Inc. (www.octasic.com) has recently upgraded its line of embedded software-defined-radio (SDR) platforms with the OCT-BTS 3000, thereby enabling LTE, OFDM, CDMA, HSPA, or GSM base-station capability. This SDR features packages capable of 400-MHz-to-6-GHz operation.

Northrup Grumman also embraced the COTS approach with its high-altitude, long-endurance (HALE) UAV platforms when the company redesigned its integrated mission management computer (IMMC). The IMMC acts as the central data interface for on-board sensors, relays, and the UAV communications link. Using COTS parts and actively relying on feedback with commercial vendors, the firm achieved a new IMMC design that improves cost, SWaP, and reliability by using scalable commercial technology nodes. At the same time, it reduces design risk and limits combat obsolescence.

Adapting technologies to UASs requires additional design considerations, which often fall outside of commercial applications. Solid-state power amplifiers (SSPAs) can offer many SWaP benefits for communications links for UAV systems. But they come with their own share of implementation difficulties. According to Ian Brassell, director of business development for Teledyne Microwave (www.teledyne.com), "All of our devices are hermetically sealed, and that has proved to be an advantage. It helps to keep when altitude is involved and also to keep the muck and the dirt out." Weatherproofing and ruggedness are not new concepts for military applications. As more commercial technologies are integrated in these platforms, however, the designs may need to be adapted to more rigorous requirements.

There also are electronic considerations for high reliability that commercial applications rarely see. "Our biggest design challenge is with dirty airborne power supplies operating with lots of spikes and transients," Brassell explains. "An electromagnetic interference filter is needed to clean up the supply, and it often has to be incorporated in the same footprint as the PA."

As the hardware for UASs requires careful design, so do the software backbones that support these evolving platforms. To overcome the challenges of operating these systems with a host of controls and sensors, for example, Lockheed Martin (www.lockheedmartin.com) developed its vehicle control station (VCS) software. This fully integrated COTS command, control, and information suite serves ground control operators of unmanned vehicle systems (UVSs).

Out of the more than two million UAS mission flight hours flown by the U.S. military, over a million hours are attributed to the VCS. Many of its features help an operator generate more autonomous functions so that he or she can focus on the mission-critical aspects of the deployment. Examples of such functions include target management, zone restriction, network capability, mission editor, and video/sensor integration.

The sophistication of UAS hardware and software platforms has advanced to the point where the U.S. Navy officially released a solicitation for the design of an unmanned carrier launched airborne surveillance and strike (UCLASS) aircraft. It called for a competition of the four leading UAS providers: Boeing (www.boeing.com), Lockheed Martin, General Atomics, and Northrop Grumman (www.northropgrumman.com). The system requirements include reconnaissance, surveillance, targeting, and strike capability.

To meet the deadline of a contract reward for 2015, these companies will most likely continue using COTS technology to enable rapid, SWaP-centric, and cost-effective designs. It also is likely that they will borrow some communications capabilities and techniques from the commercial market. mw

JACK BROWNE | Technical Contributor
JEAN-JACQUES DELISLE | Technical Engineering Editor

Tampa IMS 2014 Demonstrates A Strong And Evolving Industry

Judy Kennamer/iStock/Thinkstock

IMS 2014 offered the best of the industry from student design competitions, outstanding technical sessions, amazing technology demonstrations, and even a few boat rides. The technical progress and growth in the industry was certainly evident by the wide array of new technologies and advanced solutions. *Microwaves & RF* was even able to recognize a few high performers in the industry and looks forward to saluting the leaders in the industry next year.

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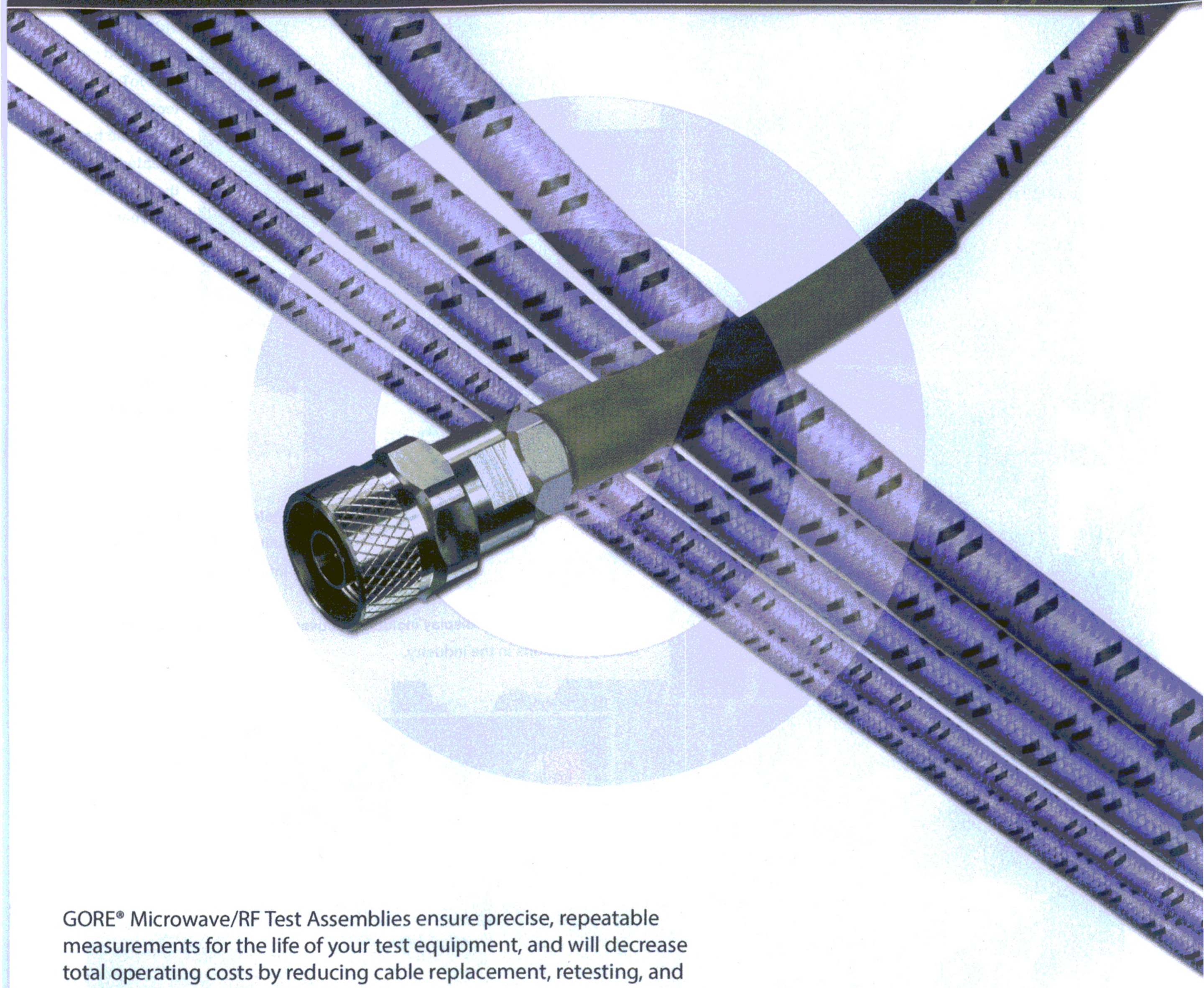
Performance Over Time

GORE® Microwave/RF Test Assemblies offer unmatched precision, repeatability and durability.



GORE® Microwave/RF Test Assemblies ensure precise, repeatable measurements for the life of your test equipment, and will decrease total operating costs by reducing cable replacement, retesting, and recalibration. Gore's portfolio includes:

- **GORE® PHASEFLEX® Microwave/RF Test Assemblies** – Provide excellent phase and amplitude stability with flexure.
- **110 GHz Test Assemblies** – Engineered to be flexed, formed and repositioned while maintaining excellent electrical performance.
- **VNA Microwave Test Assemblies** – Provide exceptional performance for precision test applications with frequencies through 67 GHz.
- **General Purpose Test Assemblies** – Excellent electrical performance for everyday test applications.

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Choose GORE® Microwave/RF Test Assemblies.
For the life of your test equipment.

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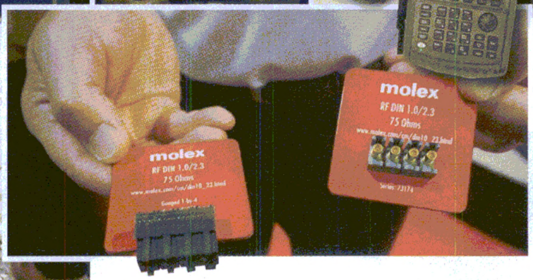
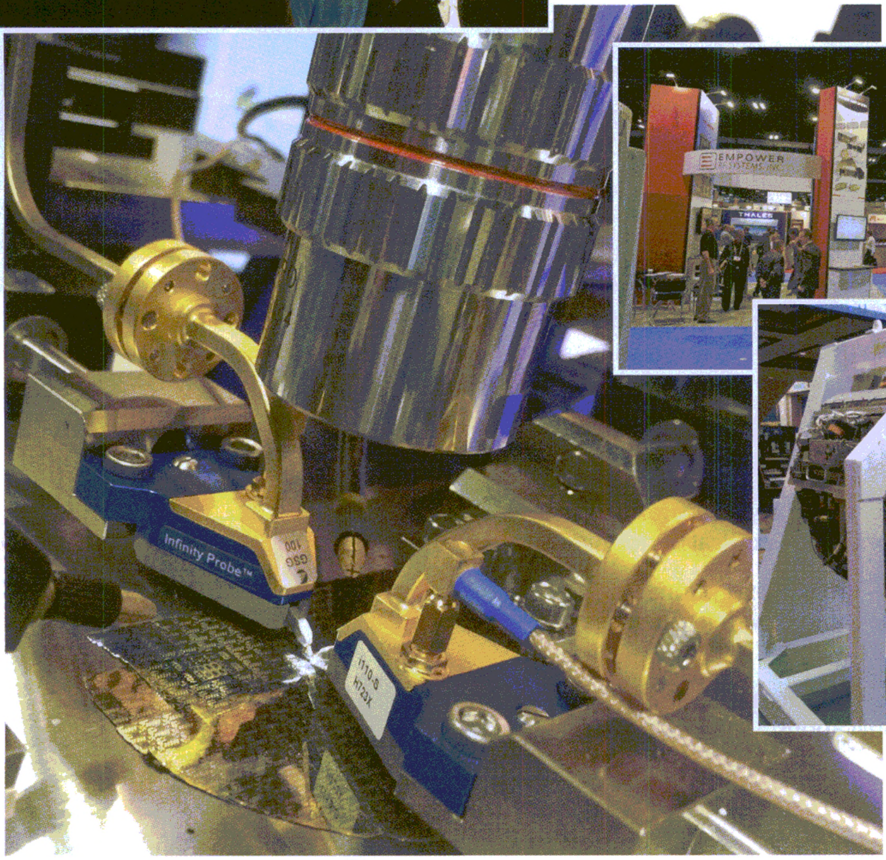
The IMS plenary speaker, Vida Ilderem, discussed how IoT technology could be adopted in the next several years.

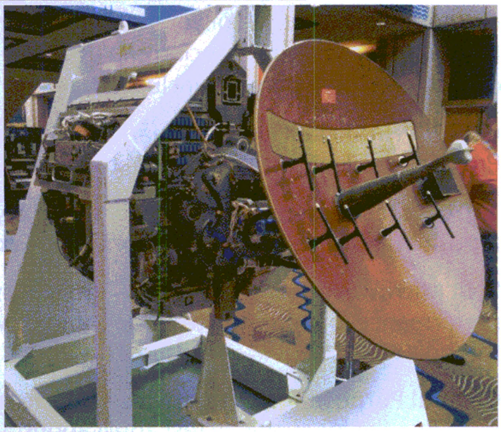
Agilent's field-test equipment brought a rugged perspective to the show.



Molex demonstrated many of its custom RF/microwave interconnect solutions.

National Instruments' display included focused test demo areas on leading test applications in the industry.





The AN/AWG-10 Missile Control System was first deployed in 1968.

Cascade Microtech's Infinity waveguide probes demonstrate on-chip millimeter-wave testing.

THE "BEST OF" THE BEST

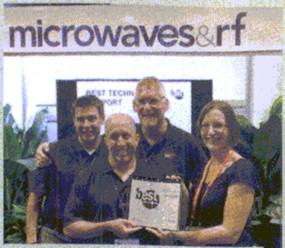
THE RF/MICROWAVE INDUSTRY continues to change, and these changes strongly impact the way engineers stay current on the latest developments. To highlight companies and engineers that rise to the challenge and provide cutting-edge value to the industry, *Microwaves & RF* created the "Best of" industry awards, which were presented during this year's IMS 2014 show in Tampa. Among the highlights of the awards was the presentation of the Living Legend honor to author, scientist, and consultant Dr. Stephen Maas. (For our one-on-one interview, turn to "Inside Track" on page 33.)

Here's a complete list of winners and runners-up.

- **Best Industry Website:**
  Winner: Cobham Antenna Systems
  Runner-Up: AR World
- **Best Industry Blog**
  Winner: Steve Huettner at www.microwaves101.com
  Runner-up: The PIM Source, Anritsu
- **Best Social Media**
  Winner: Agilent Technologies
  Runner-up: RFMD
- **Best Online Educational Tools**
  Winner: Texas Instruments
  Runner-up: Rohde & Schwarz
- **Best Technical Support**
  Winner: Linear Technology Corp.
  Runner-up: W.L. Gore & Associates
- **Best Technical Application Video**
  Winner: Analog Devices
  Runner-up: National Instruments
- **Best Custom Solutions**
  Winner: Analog Devices
  Runner-up: Mini-Circuits

For detailed information on all the winners and runners-up, as well as photos and videos, visit mwrf.com/services/best-microwaves-rf-2014-industry-award-finalists.

best microwaves&rf 2014



Microwaves & RF **Living Legend Dr. Stephen Maas (left)**

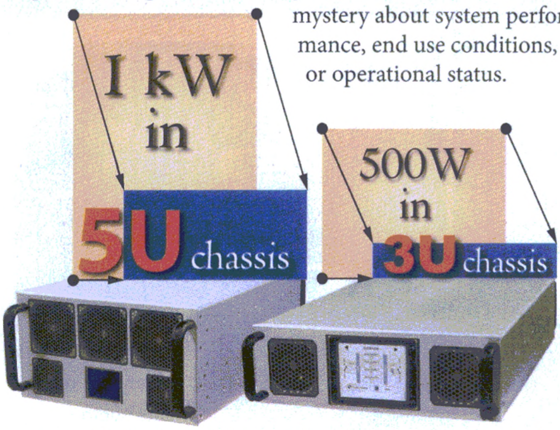
NEXT GENERATION
POWER AMPLIFIERS

What is it that makes these Power Amplifiers NEXT GENERATION Power Amplifiers?

Significant size reduction

Empower RF Systems power amplifier systems sizes reduced by 40-70%

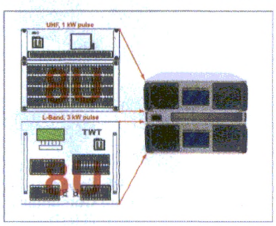
1 kW of broadband output power in a 5U chassis and 500 W of power packaged in a 3U chassis is unprecedented. Specs are guaranteed across full bandwidth and over temperature. Embedded controls and user access that are standard with Empower next generation designs ensure that there is no mystery about system performance, end use conditions, or operational status.



Empower RF Systems is hosting live demonstrations of selected models from the list below at ***EMC 2014, Booth 311.***

→ **SKU 2126**	1 kW	20 - 500	MHz	5U
→ **SKU 2066**	1 kW	500 - 1000	MHz	5U
→ **SKU 2162**	1 kW	20 - 1000	MHz	5U
→ **SKU 2170**	800 W	1000 - 3000	MHz	5U
→ **SKU 2175**	500 W	20 - 1000	MHz	3U
→ **SKU 2179**	250 W	2000 - 6000	MHz	4U

EMC 2014, where the "Size Matters" PA demonstrations are being conducted, lends itself well to validating the exceptional performance of these broadband, power amplifiers. Come see for yourself and consider the possibilities for your application with a *high power amplifier that is 40 to 70% smaller* than what's available in the market. To illustrate the point, consider the advantages of a 7U next generation solution versus legacy systems totaling 16U. A major improvement for an airborne platform, UHF and L-Band pulse amplifiers tied to a shared, 1U power supply.



Amplifier Software

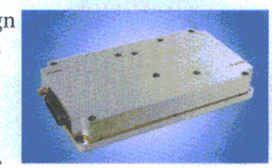
Embedded web server
Real time power amplifier diagnostics
Remote monitoring and control

User interface capabilities of Empower Next Generation power amplifiers allow the user to initiate remote management and diagnostics via an embedded web server, enabling network managed site status and control simply by connecting the unit's Ethernet port to a LAN or accessing the unit's IP address. For machine to machine interface (M2M), Empower offers TCP/IP or UDP protocol sockets accessed through the Ethernet port.

The feature rich menu that is available on these high power amplifiers includes real time monitoring, protection and control, sensor driven dynamic adjustments to the amplifier while in operation, remote user access, and a selection of communications protocols that can be enabled by the end user during system set up. Software updates can be delivered via a "direct connect" link, if permitted by the customer, from Empower to the fielded amplifier via the amplifier's embedded web server or updated via a USB drive inserted directly into the back panel of the amplifier. The USB upload process is streamlined for "ease of use" with a self extracting and self loading program.

Scalable output power architecture

Next Generation Building Block Modules



Our advances in RF system design are complimented with advances in RF module design. Integral to our systems designs and also sold as building block modules, Empower's latest PA modules are a "minimal touch" design which incorporate latest devices, circuit topologies and thermal management techniques.

→ **SKU 1163**	125 W	20 - 520	MHz	7x4x1.2"
→ **SKU 1193**	100 W	20 - 1000	MHz	7x4x1.2"
→ **SKU 1199**	100 W	1000 - 3000	MHz	7x4x1.2"
→ **SKU 1191**	100 W	2500 - 6000	MHz	8x6.5x1"

Booth #311

EMPOWER
RF SYSTEMS, INC.

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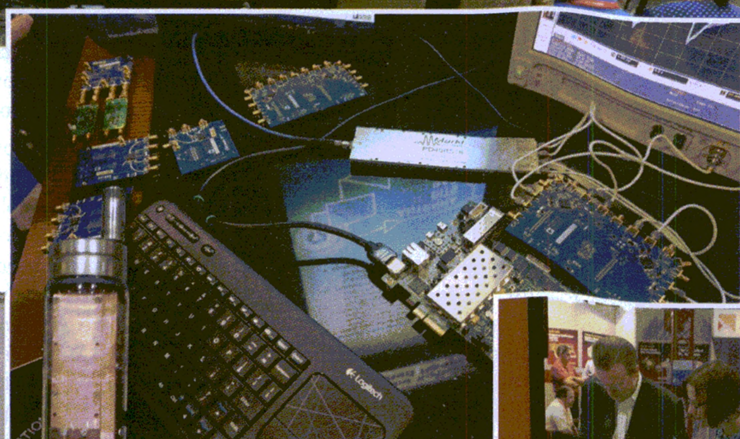
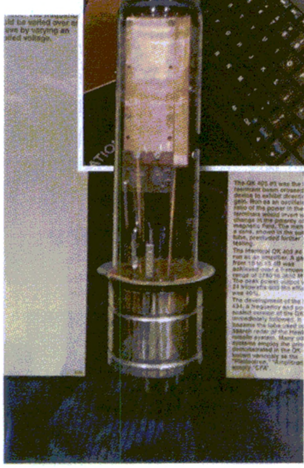
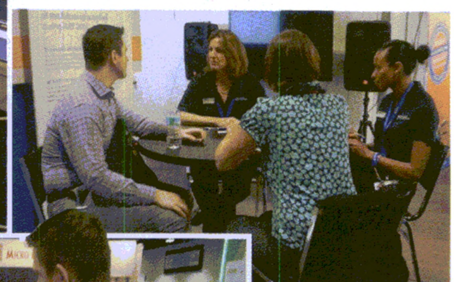


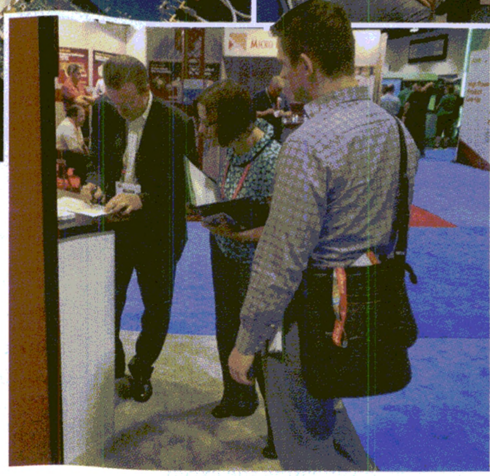


Analog Devices has recently released many programmable RF transceiver ICs.

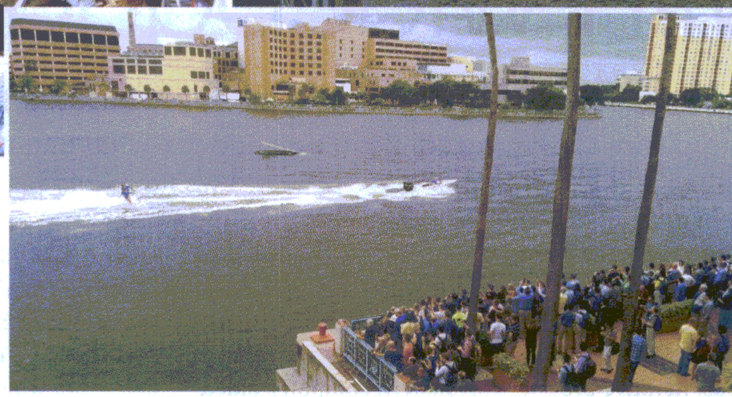
The Carcinotron is a type of traveling wave tube implemented as a backward wave oscillator.



Microwaves & RF at the National Instruments booth.



Jon Jacocks, president and CEO of Empower RF, setting up a meeting with *Microwaves & RF*.



Many detailed technology sessions occurred in the Grand Ballroom of the symposium to a packed audience.

While in Tampa, IMS attendees enjoyed attractions on the water, such as an open water show and many scenic boat rides.

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Synthesize Filters With Wideband Success

The use of accurate circuit-element models with straightforward filter design software can help trim the time and effort needed for what can normally be a grueling and iterative design process.

Filter designers for RF/microwave requirements have long been challenged with meeting an often-conflicting set of performance demands. Often a final RF/microwave filter design is the result of a tedious, iterative process. Fortunately, computer-aided-engineering (CAE) software tools continue to improve, and a new semi-automated filter design and layout procedure may help ease the journey to that final filter.

The procedure involves the integrated use of three commercial software tools and separately addresses filter synthesis, working with component models, and performing accurate circuit and electromagnetic (EM) analysis on the design. To demonstrate the effectiveness of the new procedure, a bandpass filter was synthesized from the models.

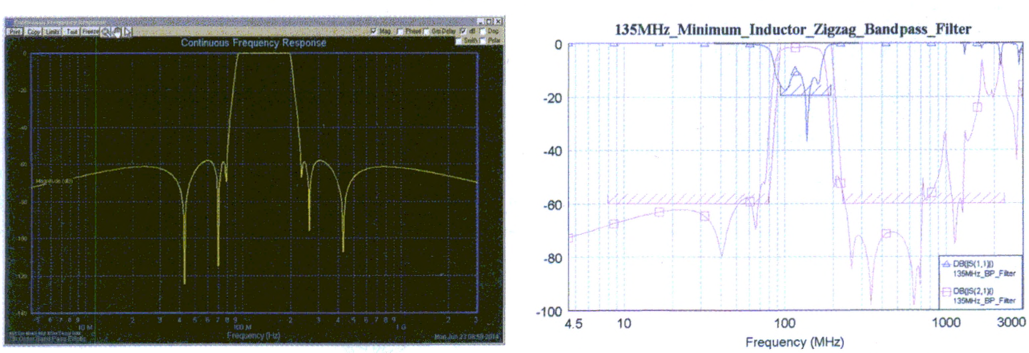
Filter synthesis is rarely easy or automatic, even for an experienced filter designer. Starting with just basic filter types, and then trying to achieve a particular set of performance parameters for one of these filter types, can turn into an almost endless iterative design process. As some designers learn, often the simplest and most straightforward design approach builds upon a classic filter architecture. Still, classical filter topologies can suffer from any number of drawbacks that must be tackled, such as an excessive number of inductors.

Fortunately, modern CAE software tools can create filter designs in which computer predictions come consistently close to the measured results. For example, such tools as Filter Solutions fron Nuhertz Technology (www.nuhertz.com), coupled with component and device models such as the Global Models from Modelithics (www.modelithics.com), can greatly assist filter designers in need of shaving time and effort.

The design process starts by establishing and entering design requirements into the filter design software, such as filter center frequency, passband bandwidth, and stopband attenuation. A designer must select a filter type, topology, and other design options; the software will suggest a filter design based on ideal components.

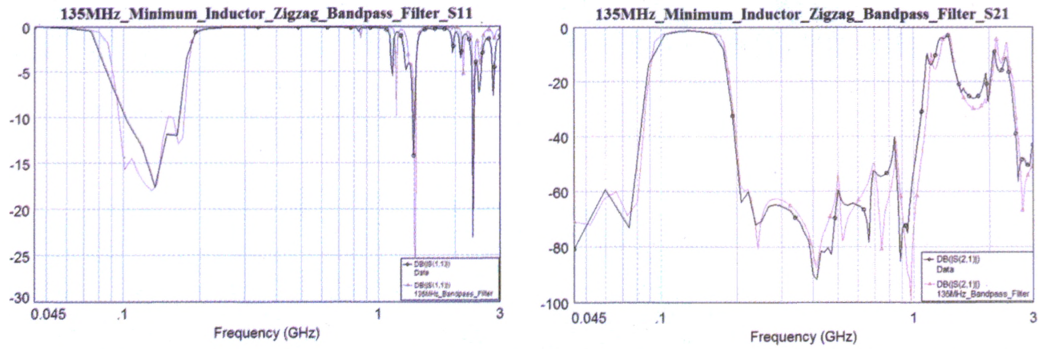
A desired substrate material and the Modelithics models are then selected and the design schematic diagram and layout will be exported to Microwave Office from AWR (www.awrcorp.com) for further analysis. The AWR software will predict the impact of parasitic effects that might have been missed earlier in the design process and plot the expected results (*Fig. 1*).

Changes that can occur due to this software "fine-tuning" can include, as in this case, a shift of the entire fil-

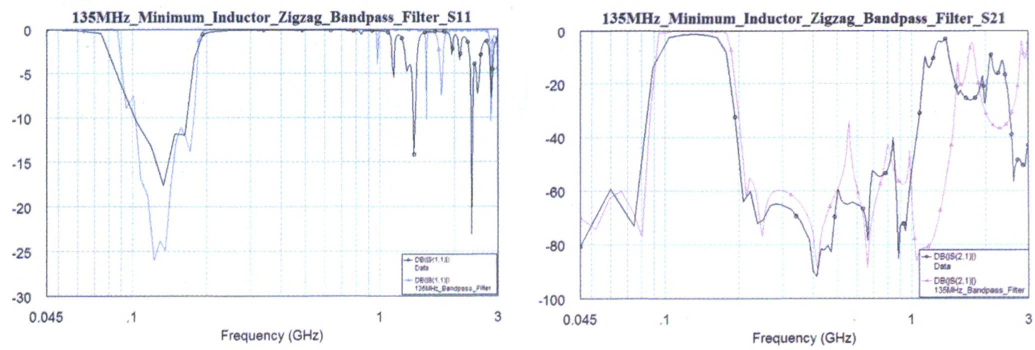


1. These plots compare the ideal response from Filter Solutions software (left) with simulations from Microwave Office software featuring a design using Modelithics circuit-element models (right).

ter passband to a lower frequency range from the ideal filter response presented earlier. The AWR schematic diagram must go through several optimizations to correct for this frequency shift, first for component part values, after which the Filter Solutions software will select the closest available component part values and update the schematic circuit diagram and then optimize the circuit. The Filter Solutions software then automatically produces a layout for a filter schematic diagram.



2. The simulations (with Modelithics Global Models) match closely with the measured results for a fabricated 135-MHz bandpass filter.



3. Simulations with ideal models are compared here with measured results for the 135-MHz bandpass filter.

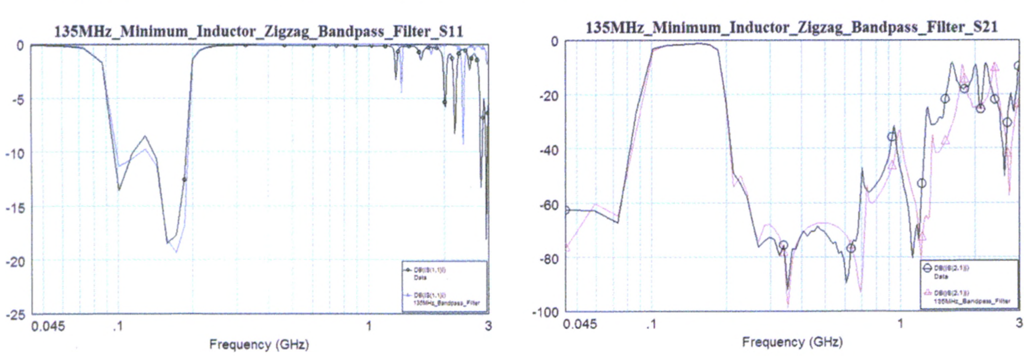
To demonstrate the effectiveness of this filter design process, a 135-MHz minimum-inductor zigzag bandpass filter was designed with the Filter Solutions software and the Modelithics device and circuit-element models. The 135-MHz bandpass filter was built and tested, well beyond its nominal passband, to 3 GHz. This was done to study not only the passband response, but also to check the accuracy of the out-of-band response. The measured filter response agrees quite closely with the simulated filter response *(Fig. 2)*.

Although designed and fabricated for a relatively low passband of 135 MHz, the filter's response in the stopband was correctly predicted across a very wide frequency range. When this is compared to the results from ideal models *(Fig. 3)*, the simulated passband response appears to be quite close to the responses from the ideal models. However, the out-of-band responses based on the ideal models shows an over-estimation of performance past 1 GHz.

Success in filter synthesis depends on a large number of variables, during the initial design stages but also at the layout stages. To demonstrate, the 135-MHz filter was simulated with a different layout and compared to the measured response of the original design *(Fig. 4)*. The filter's passband is somewhat broader and shifted lower in frequency for this new layout.

Using these software design tools, the effects of parasitic circuit elements, substrates, and even layouts can be handled and accounted for in a single design cycle. This helps to greatly simplify the entire RF/microwave filter design process.

Editor's Note: *Figure 5*, displaying the filter design, can be seen online at www.mwrf.com/software/synthesize-filters-wideband-success. mw



4. Using a different layout, the simulated responses of the 135-MHz bandpass filter are compared to the measured results, to show the impact of the changed layout.

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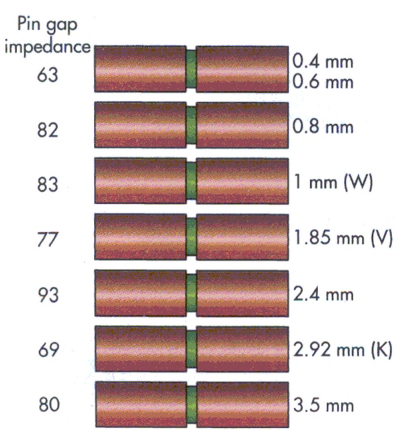
Reaching Beyond 100 GHz With Coaxial Connectors

With microwave technology reaching into "triple-digit" frequency ranges with coaxial components and test gear, coaxial connectors represent one of the critical starting points for component designers.



1. The pin gap impedance of different connectors can be compared quickly.

Coaxial connectors continue to move higher in frequency, with ever-smaller dimensions, driven in part by the development of test equipment such as vector network analyzers (VNAs) for higher-frequency use. But designing reliable higher-frequency coaxial connectors is more than simply a matter of shrinking connector dimensions and developing novel connector interfaces. Connectors reaching toward higher millimeter-wave frequencies have been helped by VNA advances, but also by solid mechanical design of shrinking connector components—to the point where coaxial VNA testing at 100 GHz and beyond is becoming almost trivial.

As coaxial connectors have risen in frequency, they have historically relied on two approaches to mating center conductors: hermaphroditic contact and male-pin/slotted-female contact. The non-sexed approach offered many advantages—the main advantage being that only one type of connector was required. As frequencies increased, these connectors were made smaller to remain in single-mode operation.

The success of the sub-miniature version A (SMA) connector essentially foretold the end of non-sexed connectors. As connectors became smaller for higher-frequency use, it became difficult to make butt-type connectors—pin depth tolerances were critical and the smaller sizes made it difficult to achieve a resilient contact. Such factors would raise the cost of the connectors well above the simple male-pin/slotted-female contact.

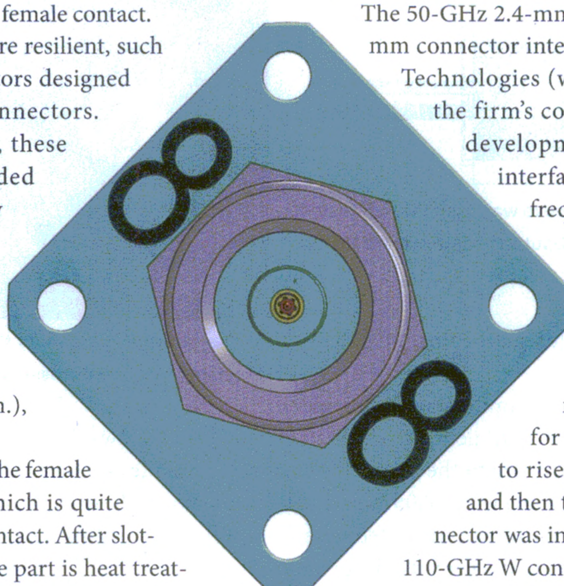
The male/female contact approach became the standard for connectors at higher frequencies. For metrology applications, a slot-less female design was introduced, but it became impractical following the 50-GHz 2.4-mm connector. Slotted connectors are not without problems, however. Designs such as the SMA connector and its two-slot female contact are inexpensive to produce, but easy to damage. A half-round feature is not very flexible, and the SMA connector was initially rated for a lifetime of only 500 connections. SMA designs with a long male pin, which allowed the center conductors to engage before the outer conductors aligned the connectors, meant that careless mating would damage the female contact.

A four-slot contact is much more resilient, such as those used in 3.5-mm connectors designed for compatibility with SMA connectors. With their air-interface design, these precision connectors were needed for calibrated VNA use, but they had their own problems. For SMA compatibility, the size of the male pin was set at 0.914 mm (0.036 in.). The 3.5-mm connector center conductor diameter is 1.52 mm (0.060 in.), which creates problems.

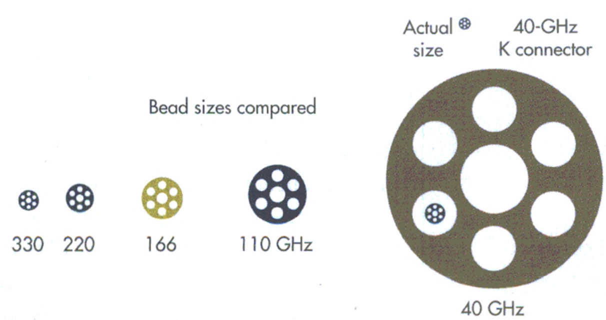
Primarily, the wall thickness of the female fingers is 0.3 mm (0.012 in.), which is quite thick for such a small-diameter contact. After slotting, the fingers are closed and the part is heat treated. If it's closed by too little, the contact will be unreliable. If it's closed by even slightly too much, the insertion force that's required to mate the connectors will become quite high.

Such high force introduces excess wear and may even distort the support beads holding the center conductors in place. The large wall thickness of the 3.5-mm connector introduced more pin gap reflection. The impedance of the gap section is 80 Ω. The higher-impedance line section created by the exposed male pin also yields pin gap reflections.

The 40-GHz 2.92-mm K connector, introduced around 1985, minimized many of these problems. A short male pin ensured that, before center conductors could engage, the outer conductor parts aligned the two connectors so the male pin could not damage the female section by being inserted at an angle. The center-conductor diameter of the K connector was designed as 1.27 mm (0.050 in.), leading to a finger wall thickness of 0.18 mm (0.007 in.). This meant that the fingers were more flexible and the insertion pressure was greatly reduced. As a result, K connectors were rated for 4000 connections.



2. As connectors are made smaller, they can include a laser-engraved number to identify connector size.



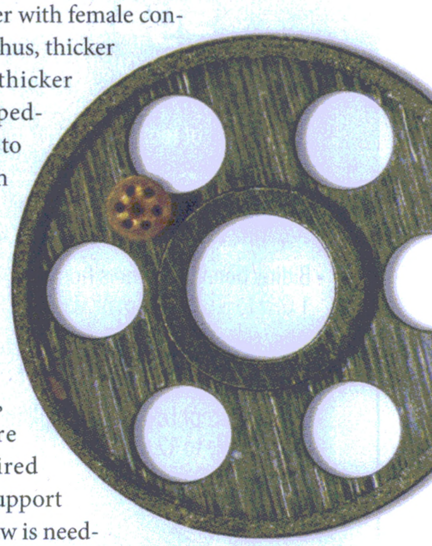
3. Connector support beads continue to shrink in size with increasing connector frequencies.

The 50-GHz 2.4-mm connector and the 65-GHz 1.85-mm connector interfaces were introduced by Agilent Technologies (www.agilent.com). The launch of the firm's coaxial 50-GHz VNA required the development of the 2.4-GHz connector interface in support of millimeter-wave frequencies.

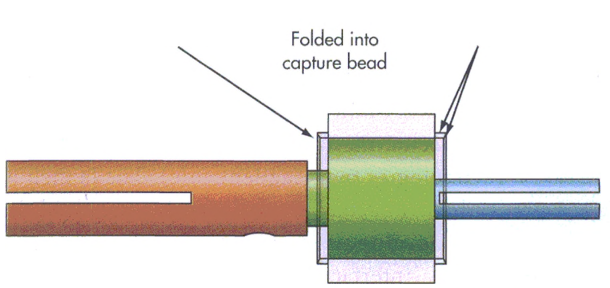
The 1.85-mm V connector was introduced in support of a coaxial 60-GHz VNA by Anritsu/Wiltron Co. (www.anritsu.com). Improvements in V connector bead design made it possible for coaxial VNA frequency coverage to rise first to 65 GHz, then to 67 GHz, and then to 70 GHz. A 110-GHz 1-mm connector was introduced by Agilent, followed by a 110-GHz W connector from Anritsu with the introduction of its 110-GHz coaxial VNA. In development of a 70-kHz-to-145-GHz coaxial VNA system, Anritsu has presented a 0.8-mm coaxial connector.

As connector dimensions shrink, however, they also become more fragile. The thinner wall designs of the K-band and V-band connectors yielded connectors at 1 mm and smaller with female contacts that were too fragile; thus, thicker walls were required. But thicker walls raise the pin gap impedance. Still, it was preferable to a fragile female contact with very thin walls. These connectors are quite expensive and a distorted contact is very undesirable.

Finding machine tools to produce such connectors becomes a challenge, although small drills are available. Drills are required to make the holes in the support beads. In addition, a fine saw is needed to cut slots in the female center conductor, with the capacity to cut deep enough to make long enough slots. The finest-dimensioned saw is 0.05 mm; the resulting slotted female contact would be very fragile. With a thin-walled design, the insertion force would be very slight, as would be the contact pressure. With a thick-walled connector design,



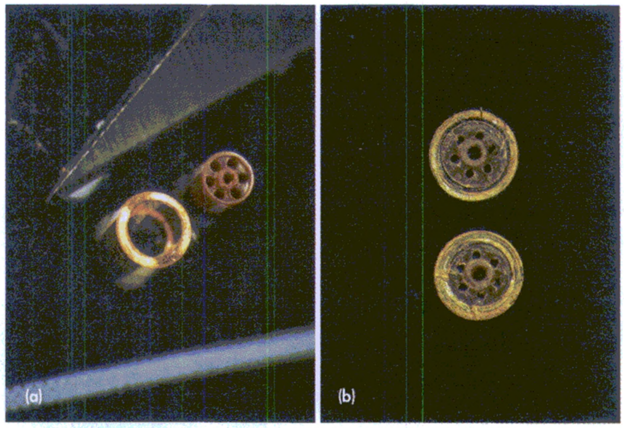
4. The support bead for a 0.6-mm connector is shown on the bead for a K connector.



5. In designing smaller connectors, a sleeve was used that contained the bead and had an outer diameter about the same size as the air outer conductor.

the contact pressure would be greater but the finger flexibility would be slight.

Higher-frequency connector design options include making the female contact wall very thin, with no slots. The male pin could therefore be large, close in size to the main center conductor. Such a pin could be machined with a 0.05-mm slot. It would employ a slotted portion within an unslotted hole, which would be robust, with no tendency to spread out like the standard slotted female contact. The impedance of this pin gap is 65 Ω, much lower than the lower frequency designs. This makes the connector less sensitive to pin depth reflections.



6. The photograph shows the bottom of the swaged connector assembly (left) and the assembly after swaged (right).

Figure 1 shows different connector dimensions, while the table provides further details on existing and experimental connectors. These experimental 0.6- and 0.4-mm connector designs employ this new slotted male "lobster claw" contact approach. The outer parts of these smaller connectors use dimensions similar to 1-mm connectors to ease handling. But they are also designed so that they cannot be destructively connected. The connectors are identified by a laser-engraved number that shows the connector size *(Fig. 2)*. The number is also etched on the coupling nuts, which have grooves in them identifying the type.

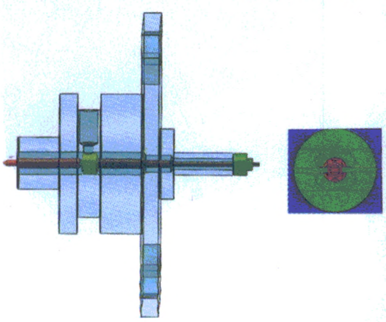
Connectors at frequencies above that of the 1-mm connector will be designed with support beads for maximum rated frequency that is the same as the air-dielectric cutoff frequency, F_{co}. Lower-frequency connectors have support beads that are larger than the air-dielectric outer conductor size, which means they are capable of an F_{co} that is substantially lower than the air F_{co}. The cutoff frequency is inversely proportional to the square root of the dielectric constant of the dielectric material between the center conductor and the outer conductor. The new designs have support beads that are substantially smaller than the size of the air outer conductor. They are designed to have an F_{co} that is the same frequency as the air F_{co} *(Fig. 3)*.

One issue with making the connector bead size smaller than the air dielectric outer conductor size involves how to captivate the bead *(Fig. 4)*. Making a hole in the outer conductor containing the bead presents two problems of its own. First, boring such a small hole deep down in the outer conductor is difficult. Second, the bead is only held mechanically in one direction. The old designs where the bead is larger than the air outer conductor allowed mechanical capture in both directions. The solution was a sleeve that contained the bead and had an outer diameter about the same size as the air outer conductor *(Fig. 5)*. The sleeves have very thin lips on both ends and are swaged to hold the bead in place. The assembly can then be soldered in place; the beads use high-temperature plastics.

Figure 6 shows a higher-frequency connector, an 0.8-mm assembly that does not use the lobster-claw design. On the left, the bottom is swaged, while the right side shows the assembly after swaging, with the tip of an Xacto blade shown as a size reference. The backside of the connector is a coplanar-waveguide (CPW) design similar to a wafer probe. The center conductor is common, but the outer conductor end cap can be configured to accommodate different CPW designs.

It can be seen how the bead sleeve is soldered into the outer conductor. A connector mates with a component's internal circuitry by means of its backside interface. This is a critical part of the connector—even more critical at higher frequencies. Substrate traces of 0.1 mm and smaller must be connected repeatably and reliably to these backside interfaces, often with CPW circuitry being used in wafer probes for test systems at higher frequencies. For connectors and components at these higher frequencies, the backside of these connectors is a wafer probe built into the connector.

Boring of the outer conductor hole presented the problem related to the difficulty of driving a small boring bar as deep as required. Rather, a drill was used and the transition



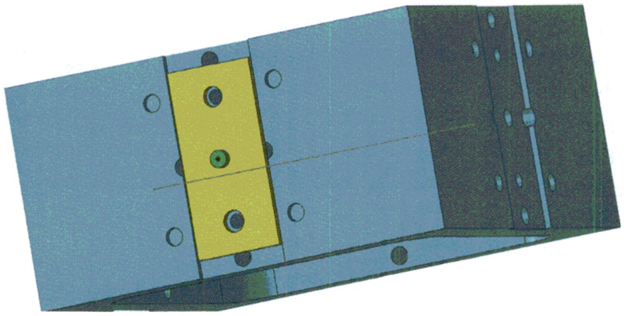
7. The use of adjustable backside CPW interfaces helps achieve optimum alignment of the connector to the circuit to be connected.

COMPARING CURRENT CONNECTORS WITH THOSE UNDER DEVELOPMENT

Connector	Air cutoff frequency (GHz)	Maximum rated frequency (GHz)	Pin gap impedance (Ω)	Center conductor (mm)	Size of bead (mm)
Type N	19.4	18	NA	3.04	NA
SMA	NA	18	NA	1.27	NA
3.5 mm	38.8	33	80	1.52	3.6
2.92 mm	46	40	69	1.27	3.05
2.4 mm	56	50	93	1.042	2.1
1.85 mm	73	70	77	0.803	1.5
1 mm	133	110	83	0.434	1.15
0.8 mm	166	TBD	82	0.347	0.559
0.6 mm	222	TBD	65	0.26	0.406
0.4 mm	332	TBD	63	0.174	0.28

between sizes was left as a taper. Modeling performed with the High-Frequency Structure Simulator (HFSS) three-dimensional (3D) electromagnetic (EM) simulation software from ANSYS (www.ansys.com) showed that the connector design was less sensitive to tolerance than using a flat bottom created by a boring bar. The center conductor was also tapered and found even less sensitive to tolerance. This design simplification yielded positive RF/microwave performance results.

Fortunately, these new connector designs can adjust their backside CPW interfaces, achieving the proper positioning of the connector to the component substrate needed for optimum performance. In this approach *(Fig. 7)*, holes are located at the edge of the flange, centered on the flange edge. A tapered pin allows the flange to be moved up, down, left, and right for proper alignment. When the connector is properly connected to the CPW substrate, the flange screws are tightened *(Fig. 8)*.

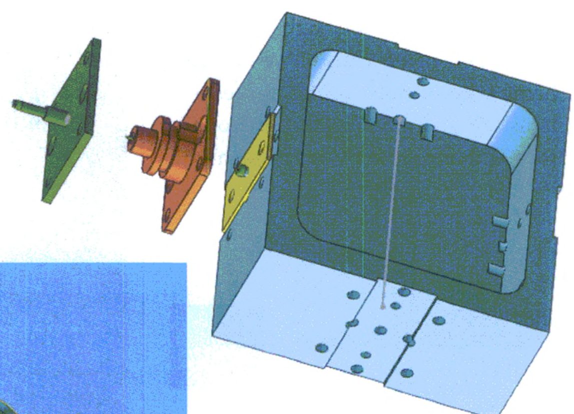


8. This adjustable backside design shows the adjustment holes.

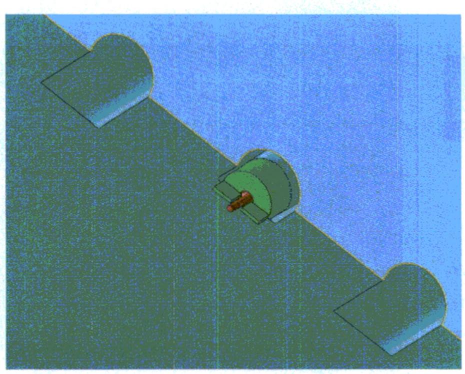
Figure 9 shows a design allowing different front-end connectors to be connected to the housing. It allows wafer probes with different connectors to be attached to a common broadband VNA module. It accepts wafer probes with male and female 0.8- and 1-mm connectors as well as special probes. It can also be used with single-design connectors.

These smaller, higher-frequency connectors may not be used in the traditional manner of lower-frequency connectors, but it is likely they will be used in special system applications and for testing with higher-frequency VNAs. As an example, a currently available Anritsu VectorStar VNA system covers 70-kHz to 125-GHz in one sweep with 1-mm coaxial connectors. The firm has also given a technology demonstration of a 70 kHz to 145 GHz VectorStar system featuring 0.8-mm connectors. Waveguide modules extend that coverage to 1.1 THz. These "lobster-claw" connectors are intended for broadband coverage from 70 kHz to 332 GHz.

As electronic applications reach higher in frequency, coaxial connectors are also extended in frequency. Frequencies once considered exclusive to waveguide are now handled by coaxial connectors. In 1983, for example, a published report (see *Microwaves & RF*, May 1983, p. 94) said a coaxial connector operating as high as 40 GHz in frequency would be unlikely because of mechanical limitations. But connectors almost 10 times that high in frequency are now being designed. As applications reach higher, designers will find ways to extend coaxial connectors to meet those needs. **mw**



9. The right diagram offers how different front-side connectors can be used with a common module, while the left diagram shows a backside CPW interface.



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Picking Proper PCB Materials For LNAs

The choice of printed-circuit-board material can have an impact on the performance possible from an RF/microwave high-frequency LNA design.

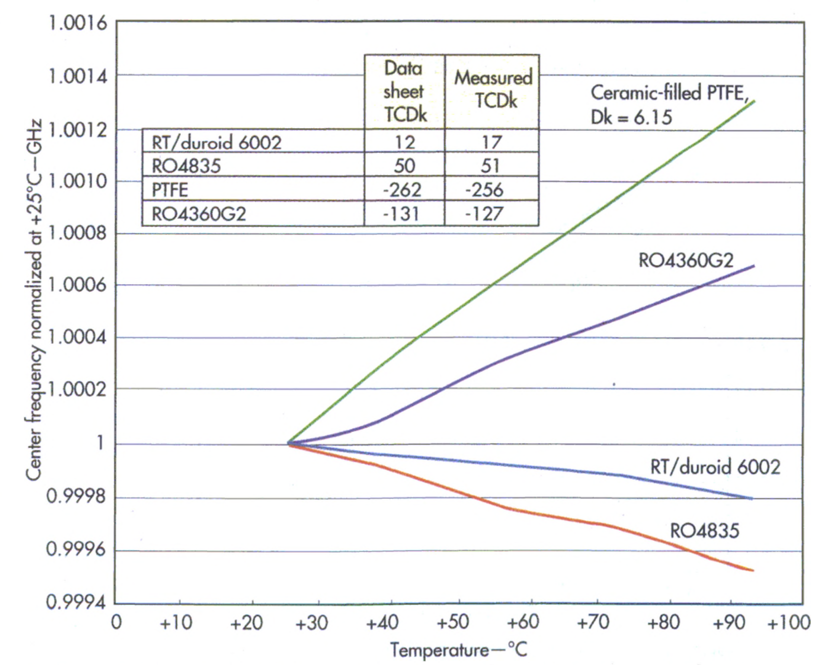
Low-noise amplifiers (LNAs) are essential to many RF/microwave wireless systems, typically employed in receivers to boost low-level signals without adding noise. Although LNA designers and specifiers often think of these amplifiers in terms of their active devices, the choice of printed-circuit-board (PCB) material can play a large role in the ultimate performance achieved from an LNA, with the PCB design typically focused on providing good impedance-matching networks for the active devices, low loss from the active devices to the antenna, and minimal electromagnetic interference (EMI).

A suitable PCB material can also aid an LNA design by minimizing the effects of heat on such amplifier performance parameters as noise figure and gain. All in all, PCB selection can contribute quite a bit to the final performance levels possible from an LNA design.

MAKING THE RIGHT CHOICE

A number of different PCB material properties should be considered for any LNA "design candidate," including dielectric constant (Dk or ε_r), temperature coefficient of Dk, dissipation factor (Df), thermal conductivity, and even substrate thickness tolerance. For example, to achieve the tight impedance matching often needed to maintain low amplifier noise figures, a PCB material's Dk should be tightly controlled across the material. These impedance-matching networks—and an LNA's noise figure—can also be affected by a PCB material's temperature coefficient of dielectric constant (TCDk).

In addition, impedance-matching circuits are impacted by variations in substrate thickness, so tighter substrate thickness tolerances are recommended for LNA designs. Low circuit-



1. Microstrip edge-coupled bandpass filters show shifts in center frequency with changes in temperature; their corresponding TCDk values also are shown.

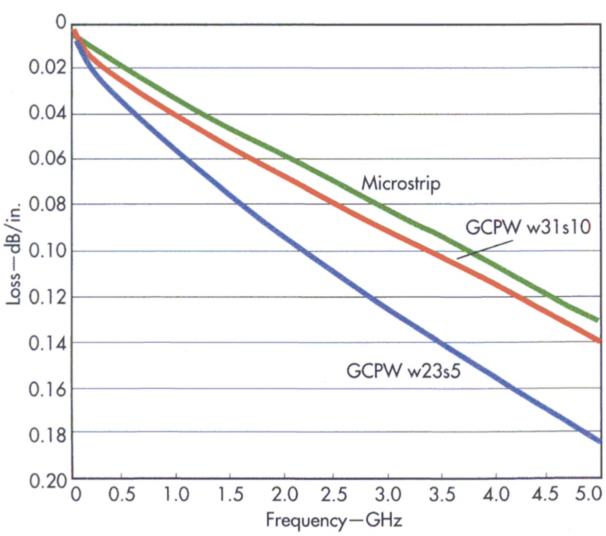
> "Circuit laminates designed for high-frequency applications usually feature tight control of Dk across the material, but materials can differ in terms of their levels of Dk tolerance."

material Df and smooth PCB copper surfaces also can help minimize loss from a feed line to an LNA, so as to help maintain low noise figure. Since an LNA's noise floor can rise with temperature, high PCB thermal conductivity helps to minimize these noise-figure-elevating temperature rises at higher signal levels.

Circuit laminates designed for high-frequency applications usually feature tight control of Dk across the material, but materials can differ in terms of their levels of Dk tolerance. Although most materials provide Dk tolerance within ±10%, materials with tighter Dk tolerance are also available.

Ironically, although Dk control and tolerance is often directly related to achieving the impedance-matching networks needed for LNAs, it is often the variations in substrate thickness that have greater impact on achieving tight impedance-matching networks. While variations in thick circuit substrates can have less of an effect on impedance-matching networks, thinner substrates are typically used for minimizing noise in LNA circuits, and the thickness tolerance of these thinner substrates is important for achieving tight impedance matching networks.

Other circuit-material tolerances that can affect impedance-matching circuitry include conductor width tolerances, copper thickness tolerances, and issues associated with circuit fabrication. The weight of such tolerances depends on the particular LNA circuit design. The copper thickness tolerance, for



2. These plots compare the transmission-line insertion loss of two GCPW configurations and a microstrip circuit using the same high-frequency circuit material.

example, has more influence on coupled circuit features such as coplanar circuits while the effects of conductor width on a circuit are related to the substrate thickness: thinner circuits will exhibit more change in impedance for a change in conductor width than thicker circuits.

As the *table* shows, a number of variables can affect the characteristic impedance of a PCB. Comparing the variables in the table reveals that substrate thickness has the most significant effect on the circuit impedance. For many circuit laminates, a thickness variation of ±10% is a realistic value, although high-frequency laminates are available with tighter thickness tolerances.

Another PCB material parameter that can affect the impedance-matching networks needed in LNA designs is the Dk tolerance. The table shows materials with Dk values within 10% of their nominal values, although high-frequency laminates are available with tighter Dk tolerances.

Some circuit laminates are available with Dk controlled within ±0.05 of the Dk value, which, for a circuit material with Dk of 3.5, translates to a variation within about ±1.4%. Using a material with such tight Dk tolerance minimizes the effect of this material parameter on LNA performance by enabling tight impedance-matching networks.

As the *table* shows, two items specific to PCB fabrication can affect impedance matching and LNA performance. Copper thickness variations of 1 to 2 mils are not unusual, although circuit fabrication with tighter specifications are available. Also, variations in conductor width can also affect impedance matching, and a difference of 1 mil in conductor width is not unusual for different PCBs.

The top and bottom parts of the table compare microstrip circuits fabricated on 20-mil-thick (top) and 10-mil-thick (bottom) substrate materials. The differences in circuit-material thickness are affected differently by the variables, such as copper thickness and conductor width. Basically, the thinner circuits are more sensitive to conductor effects and changes in copper thickness and conductor width.

The TCDk of a PCB material is an important parameter to consider when choosing circuit laminates for LNAs. Especially in applications with changing operating temperatures, in which changes in Dk can affect impedance-matching networks and possible LNA gain and noise figure, TCDk must be compared for candidate materials. It can denote a positive or negative change for a material's Dk value. For some materials, the Dk will increase with an increase in temperature and, for some, the Dk will decrease with rising temperature.

Nearly pure polytetrafluoroethylene (PTFE) circuit materials typically exhibit high TCDk values that are in the range of 400 ppm/°C. Some PTFE-based circuit materials employ special fillers to minimize TCDk effects. Many high-frequency laminates that have high Dk values also possess high TCDk values, although special formulations are available when they're needed.

To better understand the effects of PCB material TCDk variations on high-frequency performance, a simple study was undertaken by fabricating edge-coupled microstrip bandpass filters on different laminates. Filters were designed with a center frequency of 2.5 GHz and were heated from room temperature to about +200°F. Then, the resulting shifts in center frequency were monitored. From the shifts, the circuit material Dk values were extrapolated *(Fig. 1)*.

The ceramic-filled PTFE laminate with higher Dk value (6.15) exhibits the greatest difference in TCDk. Improved TCDk behavior is available from the hydrocarbon material having a similar Dk value (the RO4360G2 laminate from Rogers Corp. with Dk of 6.4). The best material in this study is a specially formulated PTFE laminate, with the RO4835 laminate showing very good results.

COMPARING CIRCUIT MATERIAL IMPEDANCE VALUES

Dk	Substrate thickness (mils)	Copper thickness (mils)	Conductor width (mils)	Characteristic impedance (Ω)	Difference of impedance (Ω)	Comments
Microstrip transmission line circuit using 20-mil thick high-frequency laminate						
3.50	20	2	43	50.07	0	Baseline
3.50	18	2	43	46.86	3.21	Substrate 10% thinner than baseline
3.15	20	2	43	52.40	2.33	Dk 10% lower than baseline
3.45	20	2	43	50.39	0.32	Dk 1.4% lower than baseline
3.50	20	1	43	50.70	0.63	Copper 1 mil thinner than baseline
3.50	20	2	42	50.78	0.71	Conductor width 1 mil less than baseline
Microstrip transmission line circuit using 10-mil thick high-frequency laminate						
3.50	10	2	21	49.74	0	Baseline
3.50	9	2	21	46.57	3.21	Substrate 10% thinner than baseline
3.15	10	2	21	52.02	2.33	Dk 10% lower than baseline
3.45	10	2	21	50.05	0.32	Dk 1.4% lower than baseline
3.50	20	1	21	50.78	0.63	Copper 1 mil thinner than baseline
3.50	20	2	20	51.16	0.71	Conductor width 1 mil less than baseline

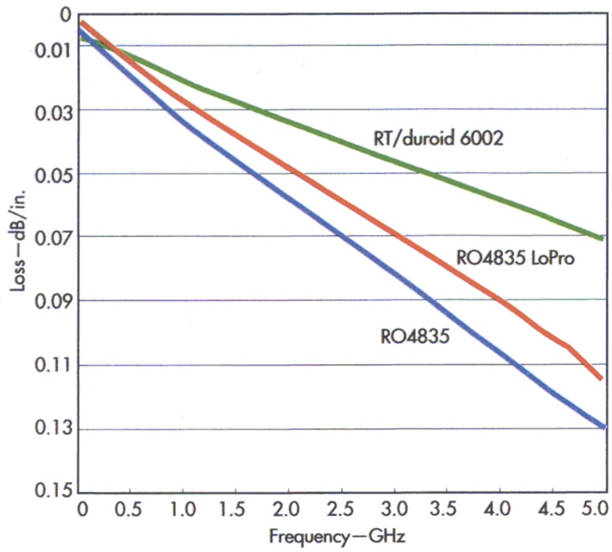
MINIMIZING LOSS

For any PCB design for an LNA, the feed line from the antenna or other input port to the LNA's active devices should have the lowest loss possible, since additional loss will raise the amplifier's noise floor. The feed line should also be shielded from outside EMI as well as on-board EM radiation to minimize those sources of noise.

To minimize noise, a grounded-coplanar-waveguide (GCPW) transmission line is often used for the feed line instead of lower-loss microstrip transmission line. The GCPW has ground planes near the signal conductor and on the same layer, which can help minimize added noise on the feed line due to EMI. To compare, *Fig. 2* shows transmission-line insertion loss from two GCPW circuits and one microstrip configuration.

As *Fig. 2* shows, the microstrip transmission line has the lowest loss. The two GCPW configurations have different ground-signal-ground (GSG) geometries on the signal plane, while both have a solid ground plane below the signal plane. The nomenclature of w31s10 indicates the GSG configuration has a 31-mil-wide signal conductor and 10-mil-wide space between the adjacent ground planes. The w23s5 material is a 23-mil-wide signal conductor with 5-mil spacing to the adjacent ground planes.

The tighter-coupled GCPW (w23s5) circuit is better for minimizing EMI concerns. Unfortunately, it also suffers an



3. These curves compare microstrip insertion loss using 20-mil-thick high-frequency laminates.

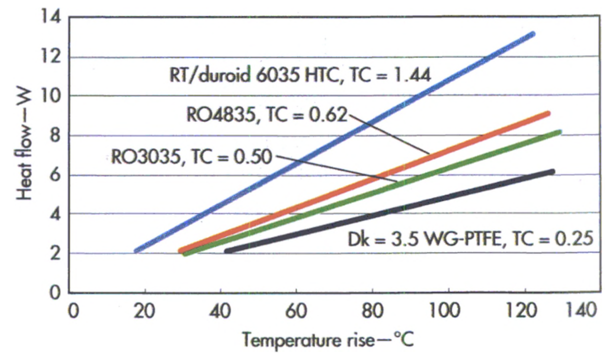
increase in conductor loss (and insertion loss). The other GCPW configuration represents a good tradeoff between the microstrip circuit and the tightly coupled GCPW version.

The high-frequency circuit material used in Fig. 2 has a Df of 0.0037 when tested at 10 GHz and is considered a low-loss microwave material. But this same material can achieve improved insertion loss by using a different copper type with a smoother copper surface. The smoother surface yields a lower conductor loss and lower insertion loss. A circuit with lower insertion loss is advantageous for not adding to the noise floor, and there are alternative high-frequency circuit materials with lower Df to be considered.

Figure 3 compares microstrip transmission-line circuits using the same thickness but different materials. The red and blue curves are based on the same circuit substrate, although RO4835 LoPro features circuit laminate with smooth copper surface for lower loss. The RT/duroid 6002 circuit material is a very low-loss laminate with Df of 0.0012 at 10 GHz, with smooth copper surface to minimize loss.

THERMAL MANAGEMENT

Although LNAs are not associated with the need for thermal management in the same manner as power amplifiers (PAs), LNAs can be affected by the generation of heat and its effects on noise performance. Of the different aspects to consider as part of the thermal management of a PCB material, substrate thermal conductivity is one of the key material properties. Most circuit materials are considered a thermal insulator with thermal conductivity values of 0.20 to 0.3 W/m/K. In comparison, copper has a thermal conductivity value of about 400 W/m/K. The difference in value shows why PCB substrates are considered thermal insulators rather than conductors.



4. These curves compare 20-mil-thick microstrip circuits using materials with significantly different TC.

However, the heat flow path is very often through the PCB substrate, in which case the substrate is acting like a thermal conductor (with poor thermal conductivity properties). Any significant increase in substrate thermal conductivity can improve the heat flow in the PCB and allow the circuit to remain cooler, assuming it is attached to a heat sink or some other cooling mechanism.

To understand the importance of thermal conductivity (TC), a study was performed on the heat flow of a 20-mil-thick microstrip circuit fabricated on different high-frequency circuit materials. *Figure 4* plots the TC values for the different materials, with the material having the best thermal conductivity (TC = 1.44 W/m/K) exhibiting the highest heat flow. High heat flow helps keep a circuit cooler and minimize thermal effects on amplifier noise figure.

The WG-PTFE material shown in *Fig. 4* has a thermal conductivity that is about the average in the high-frequency circuit material industry. Materials with thermal conductivity in the range of 0.50 to 0.62 W/m/K are considered quite good. A circuit material with a value of 1.44 W/m/K is considered exceptionally good.

CONCLUSION

Circuit-material properties can have an impact on the performance of an LNA. In general, LNA applications are sensitive to impedance differences, due to critical impedance-matching networks that are necessary to tune the circuit to optimum performance.

Circuit-material TCDk performance is important, since it is an indication of how Dk—and impedance—will change with temperature. Insertion loss is yet another important material parameter that can affect LNA noise figure. And thermal management is critical, since thermal effects can also influence LNA noise-figure performance.

In short, some circuit materials are better suited than others for LNAs. An ideal circuit material for an RF/microwave LNA should provide tight control of Dk, small thickness variation, low loss, and outstanding thermal conductivity. mw

Design Feature

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8 Errors Common to Spectrum Analysis

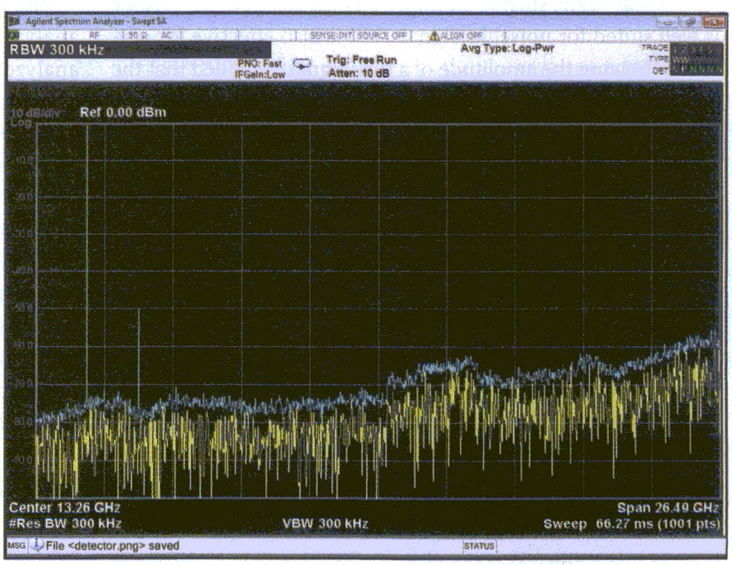
When performing RF/microwave spectrum-analyzer measurements, be sure to avoid these eight common mistakes.

Spectrum analysis is essential for understanding the frequency-domain characteristics of components, circuits, and systems, but these instruments and their measurements are not foolproof. In fact, eight common mistakes plague the accuracy and effectiveness of spectrum-analyzer measurements—errors that can lead to improperly adjusting a device under test (DUT) or shipping a device to a customer that has not met its required specifications. Yet some simple guidelines can be followed to ensure that the spectrum analyzer is being used properly and performing to expectations.

Many of the mistakes made when using a spectrum analyzer have to do with using the wrong equipment or else using the analyzer's controls incorrectly. The eight common errors mentioned above are as follows:

1. Using the wrong detector.
2. Using the wrong averaging type.
3. Measuring the analyzer's own internally generated distortion products.
4. Incorrect mixer level for EVM measurements.
5. Not using single sweep when remotely controlling the analyzer.
6. Not synchronizing measurements with *OPC.
7. Turning the display off and using binary data types when transferring data for speed.
8. Feeding too much power to the input of the spectrum analyzer.

Such errors are innocent and easy to make. The first one (using the wrong detector) can lead to wrong results simply by not matching the detector to the needs of the measurement. Modern spectrum analyzers operate with a variety of different detectors, for different signal types, including peak, sample, average, and normal detectors. Using the wrong detector type can produce incorrect results, potentially leading to incorrectly adjusting a DUT or missing a present but undetected signal.



1. The yellow trace utilizes sample detection in a wide span and a narrow RBW, causing signals to be missed that are detected with the blue trace using peak detection.

PICKING A DETECTOR

Selecting the proper detector for a spectrum analyzer is a simple enough task when some general rules are followed. A sample detector, for example, provides a single sample for each trace point on the analyzer display. If the display is set for 1001 trace points (#Pnts), each trace point will represent a single sample evenly spaced across the span of the instrument in the frequency domain. The interval in frequency bandwidth between trace points will be given by the frequency span divided by the number of trace points, or SPAN/(#Pnts-1). A sample detector is effective for measuring noiselike signals.

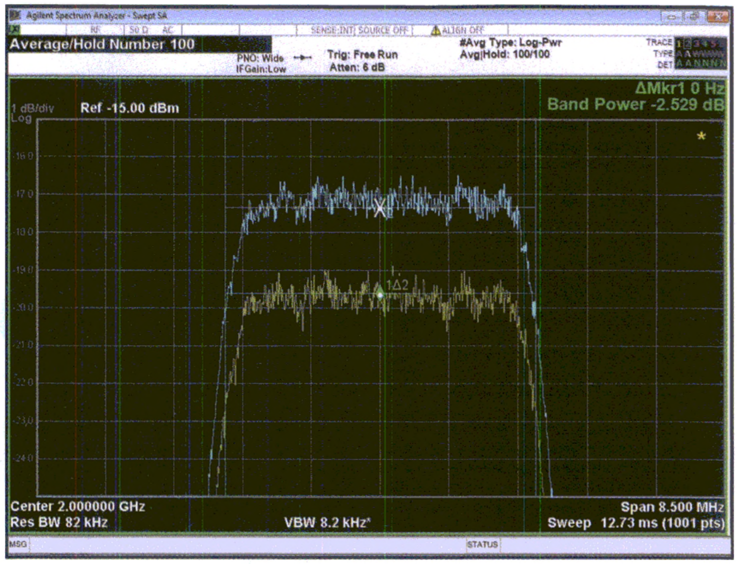
When measuring continuous-wave (CW) signals, however, the analyzer's resolution bandwidth (RBW) must be set wider than the trace interval. If the RBW is too narrow, a CW signal amplitude measured with a sample detector may appear too low or be missed altogether *(Fig. 1)*. Most spectrum analyzers will automatically select the sample detector when trace averaging is applied, so it is possible to unknowingly be using the sample detector while measuring CW signals.

In contrast, a peak detector maintains the highest amplitude value in each measurement interval and displays this value in the trace point. A peak detector is effective for measuring CW signals, but can provide incorrect levels when measuring noiselike signals, unless it is a "max hold" type measurement where the analyzer is being used to read worst-case maximum power.

An average detector averages the power between two trace points and displays the mean power that has been averaged on a linear scale, such as in milliwatts (mW). Such a detector is well suited for noiselike signals, but is also effective for correctly showing the amplitude of a CW signal, provided that the RBW is at least as wide as the trace interval. As with the sample detector, an average detector can show too low a reading for the amplitude of a CW signal if the RBW is set too narrow.

A normal detector, in most cases, is the default detector for a spectrum analyzer. A normal detector always shows the correct amplitude for a CW signal regardless of the RBW selected relative to the trace interval. It is also effective when measuring noiselike signals. It does this by displaying the peak value of a signal that rises and falls in level during an odd trace point and shows the minimum value of the signal during the even trace point. This causes the peak-to-peak value of a noiselike signal to be accurately represented on the analyzer's display.

For trace intervals where a signal only rises or falls, the peak value will be displayed. This occurs when a CW signal is swept through the trace and the amplitude is retained. A normal detector should not be used when integrating noise power—such as for channel-power or adjacent-channel-power measurements—since the alternating peaks and minimums will improperly represent the distribution of power in a noiselike signal.



2. The WCDMA signal is averaged in the yellow trace using log-video averaging, resulting in a –2.5-dB error compared to the same signal correctly averaged using power (RMS) averaging in the blue trace.

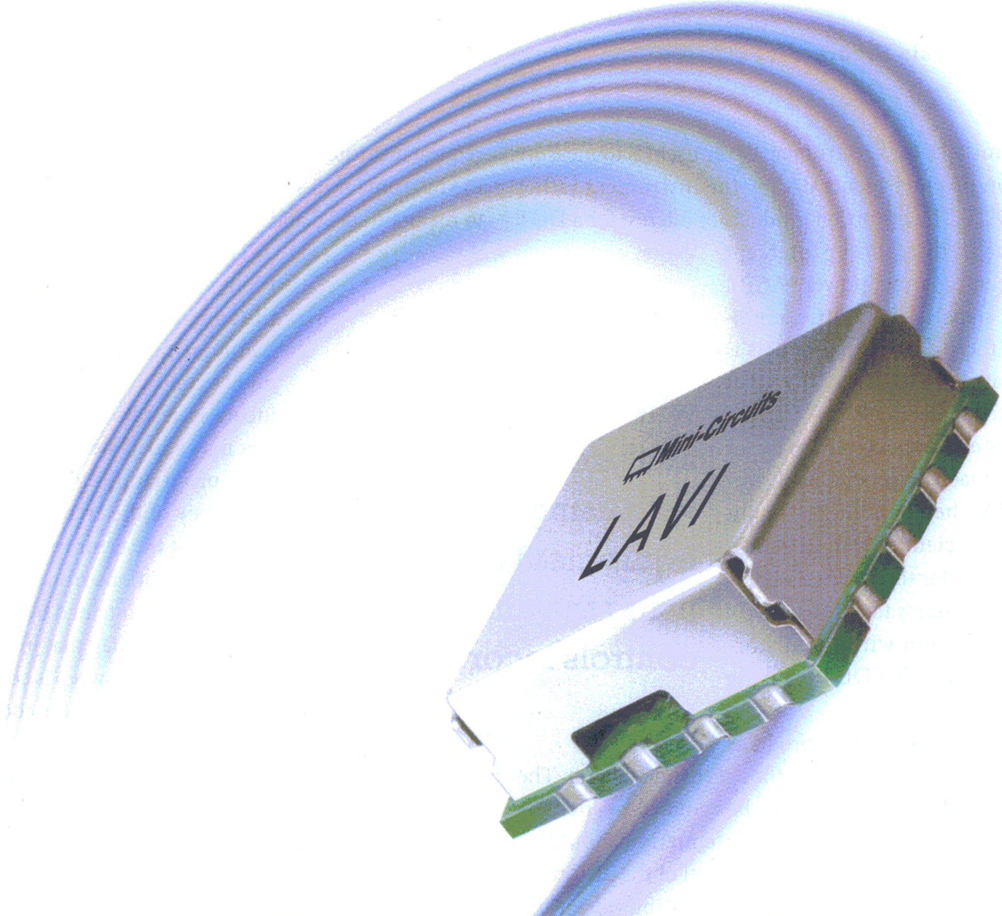
In general, unless there is certainty about the type of detector to use for a particular measurement, it is best to use the default detector selected by the spectrum analyzer. And if there is some uncertainty, the peak detector can be used for measuring CW signals and the average detector selected for noiselike signals.

AVERAGING OUT

The second common mistake connected with a spectrum analyzer is using the wrong averaging type. Most spectrum analyzers offer a choice of log-video or power (RMS) display averaging type. Log-video averaging implies that averaging will be performed on a logarithmic scale. This will cause a noiselike signal, such as the noise floor of the analyzer or a wideband code-division-multiple-access (WCDMA) signal, to be measured as much as 2.51 dB below the actual level of the signal.

However, log-video averaging will not affect measurements and display of a CW signal. For this reason, using log-video averaging on a CW signal that is close to the noise floor of the spectrum analyzer can be beneficial. Log-video averaging will reduce the noise floor and improve the instrument's signal-to-noise-ratio (SNR) performance *(Fig. 2)*.

In most cases, when measuring noiselike signals, power (RMS) averaging should be used if averaging is being applied. Averaging could be simply trace averaging, or else averaging caused by reducing the analyzer's video bandwidth (VBW) to less than the RBW. In general, log-video averaging is best suited for CW signals and power (RMS) averaging for noiselike signals.



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The third mistake for spectrum analyzer users is to measure the distortion products generated by the instrument rather than of the DUT. The distortion products of interest for a DUT might be due to third-order intercept (TOI), adjacent-channel power (ACP), or harmonic signals. The relative amplitude level of these distortion products is normally related to the level of the input signal being fed to the DUT.

Unfortunately, a spectrum analyzer may also be capable of generating distortion products when handling an input signal with sufficient power. In such a case, it is possible for the analyzer's internal distortion products to constructively or destructively sum with the distortion products from the DUT, causing incorrect results.

> "Many of the mistakes made when using a spectrum analyzer have to do with using the wrong equipment or else using the analyzer's controls incorrectly."

Internal generated distortion products are a function of the mixer level in the spectrum analyzer. The level of test signals to the mixer can be reduced by increasing internal or external attenuation. Attenuation should be increased to the point where the relative level of the distortion product no longer changes. This attenuator setting will ensure that distortion measurements are being performed on the DUT alone, and not the combination of the DUT and analyzer.

The analyzer's mixer also plays a part in the fourth common mistake for spectrum analyzer measurements: using an incorrect mixer level when performing EVM measurements. Such EVM measurements are achieved by using the VSA capabilities within a spectrum analyzer. In this mode, a signal under test is downconverted directly to the analog-to-digital converter (ADC) in the signal analyzer.

In most cases, the appropriate bandwidth is selected. But in some cases, the measurement may not be optimized in the signal analyzer. A mixer level that is too low or too high can degrade the performance of the measurement.

To optimize an EVM measurement with a spectrum analyzer, the input attenuation should be reduced until an ADC overload condition is met; the attenuation is then increased until the overload condition is resolved. At this level of attenuation, the full range of the ADC is being effectively used. Reaching the optimum level may require turning on preamplifiers or adding additional gain to the system for low-level signals.

Another common analyzer mistake is not using single-sweep mode when the instrument is under remote control. It seems intuitive that a measurement that is continuously sweeping must run faster. But under remote control, a spectrum analyzer will actually run slower in continuous-sweep rather than in single-sweep mode.

When an INITIATE command is sent, the instrument must abort the current sweep mode and then reinitiate the current request measurement. In many cases, it may be desirable to have the instrument in single sweep and initiate any measurements to maintain speed and synchronization.

The sixth common analyzer mistake is not synchronizing measurements with the "operation complete" flag (*OPC). Automating signal analysis measurements can be confusing and, at times, incorrect results can occur. Some operators may add a "sleep" statement to delay their programming code to reduce the frequency of the error or resolve it altogether. But the error may be the result of a synchronization error, and synchronization can be maintained by using the operation complete flag that indicates when a measurement or sweep is complete.

Programmatically, the code should be:

INIT:CONT OFF set the measurement to single sweep
INITIATE:<measurement>initiate the measurement
*OPC?Request a 1 returned after the measurement completes
Read the 1 that is returned when the sweep or measurement is complete
FETCH:<measurement>?Fetch the measurement results or place a marker on the trace

The seventh common mistake is turning the display off and using binary data types when trying to gain speed when transferring data. In almost all cases, when attempting to maximize the throughput of a test, the display will be turned off and binary data used to reduce the amount of data that is transferred. The following commands can improve throughput significantly:

INIT:CONT OFFset the measurement to single sweep
FORMAT:DATA REAL,32set the data results to binary block real 32 data
DISPLAY:ENABLE OFFturn off the display

The last of the eight errors (feeding too much power into the input port) can be the most expensive of them all. The damage level of most spectrum analyzers is approximately 1 W or +30 dBm. Those who have plugged a signal into the input port of their spectrum analyzer—only to watch spurious signals dance across the screen and then the screen goes blank—can get a sick feeling when they realize they have channeled 5 W into a relatively new instrument and overloaded its front-end electronics.

When working with signals that are known to be greater than the rated damage level of the instrument, using limiters at the input of the instruments can save a lot of time and money in the long run. mw

Design Feature

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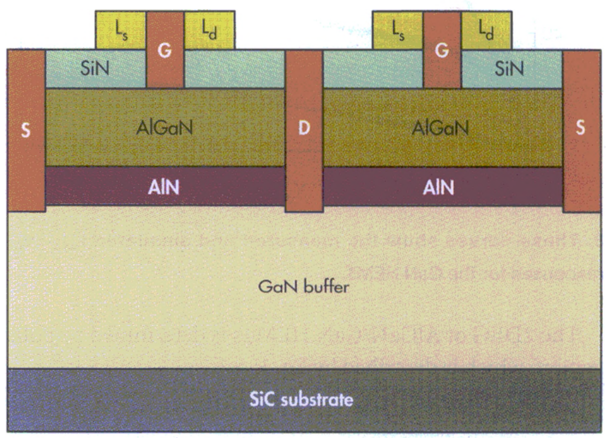
Designing AlGaN/GaN HEMTs for W-Band

This device model provides accurate DC and large-signal parameters as compared to measurements on fabricated semiconductors, showing it to be an effective tool for building W-band HEMTs.

Semiconductor devices such as AlGaN/GaN high-electron-mobility transistors (HEMTs) have attracted a great deal of attention for applications reaching through W-band frequencies. Such devices feature a high two-dimensional electron gas (2DEG) structure, high saturation drift velocity, high breakdown voltage, and good high-temperature resistance for use in high-frequency amplifier circuits. Millimeter-wave HEMTs have become a focal point for research in recent years.[1]

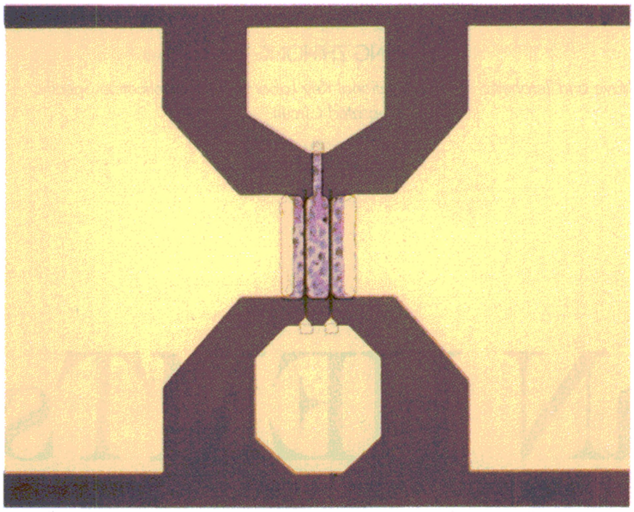
Based on this, a 2 × 50 μm AlGaN/GaN HEMT with 0.1-μm gate length and 2 μm between the source and drain is 2 μm was designed and simulated with the aid of the Technology Computer Aided Design (TCAD) computer-aided-engineering (CAE) software from Silvaco (www.silvaco.com). The device was taped out using actual semiconductor processing technology, and the DC and signal characteristics were measured. A novel symbolically defined device (SDD) large-signal model was created which obtains excellent DC and S-parameter results. With this model, device large-signal characteristics can be known through source and load-pull simulations.

Figure 1 shows the cross-sectional structure of a double-finger AlGaN/GaN HEMT. The gate-length is 0.1 μm and the gate cap is 0.35 μm long. The silicon-nitride (SiN) passivation layer helps reduce surface defects and isolation boost electrode isolation. A single-finger gate width of 50 μm was used based on the principle that the phase difference be no more than π/16 at W-band frequencies. The distance between the source and drain is 2 μm and the lateral structure of the HEMT is symmetric.[2]

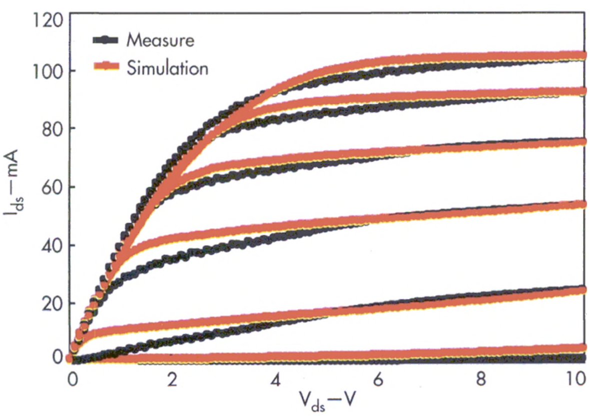


1. Depicted is the cross-sectional structure of the HEMT.

The device heterostructure consists of a 1.5-μm-thick GaN buffer layer and a 23-nm-thick AlGaN barrier layer with 24% Al content. To enhance 2DEG channel characteristics, the AlN layer is inserted between the barrier layer and the 1-nm-thick buffer layer. All the vertical layers are unintentionally doped. The 2DEG mobility and sheet carrier concentration are 2000 $cm^2/V \cdot s$ and $1.1 \times 10^{13} cm^{-2}$, respectively. A silicon-carbide (SiC) substrate was chosen for its thermal conductivity.



2. This photograph shows the fabricated HEMT device used for comparisons with the model.



3. These curves show the measured and simulated I_{ds} – V_{ds} responses for the GaN HEMT.

The 2DEG of AlGaN/GaN HEMTs is determined by polarization, which is described by Eq. 1:

$$P_t = P_{SP} + P_{pi} \quad (1)$$

where P_{sp} represents spontaneous polarization for the GaN materials and P_{pi} is the piezoelectric polarization between AlGaN and GaN materials which is given by Eq. 2:

$$P_{pi} = 2\frac{a_s - a_0}{a_0}(E31 - \frac{C13}{C33}E33) \quad (2)$$

where α, C, and E represent lattice constants, elastic constants, and piezoelectric constants, respectively; their values can be obtained according to the material statement so that polarization can be calculated.[3]

The channel, regarded as a thin layer, is formed in the buffer layer approaching to surface of the barrier layer because of polarization effect. Empirical fitting function can be used to describe mobility models of the GaN channel.[4]

For low-field analysis, the Farahmand Modified Caughey Thomas model depicted in Eq. 3 has been used:

$$\mu_{n0}(T_L,N) = M_1(\frac{T_L}{300})^B + \frac{(M_2 - M_1)(\frac{T_L}{300})^C}{1 + [\frac{N}{E(\frac{T_L}{300})^F}]^{A(T_L/300)^D}} \quad (3)$$

where T_L and N represent the junction temperature and doping concentration, respectively; and parameters A through F, M1, and M2 are fitting coefficients for the low-field model. For high-field analysis, the model based on the Monte Carlo method and shown in Eq. 4 has been used:

$$\mu_n(T_L,N,E) = \frac{\mu_{n0}(T_L,N) + VSATN\frac{E^{N1N-1}}{ECN^{N1N}}}{1 + ANN(\frac{E}{ECN})^{N2N} + (\frac{E}{ECN})^{N1N}} \quad (4)$$

where E represents electric field. VSATN, ECN, N1N, N2N, and ANN are fitting coefficients for the high-field model.

The current density of electrons and holes are defined to express change of lattice temperature (Eq. 5):

$$\overline{J_n} = -q\mu_n n(\nabla\phi_n + P_n\nabla T_L)$$
$$\overline{J_p} = -q\mu_p p(\nabla\phi_p + P_p\nabla T_L) \quad (5)$$

where q is quantity of electric charge. Parameters μ_n, n, ϕ_n, and P_n represent electron mobility, concentration, potential, and absolute thermoelectric power, while μ_p, p, ϕ_p, and P_p are the mobility, concentration, potential, and absolute thermoelectric powers for the semiconductor holes.

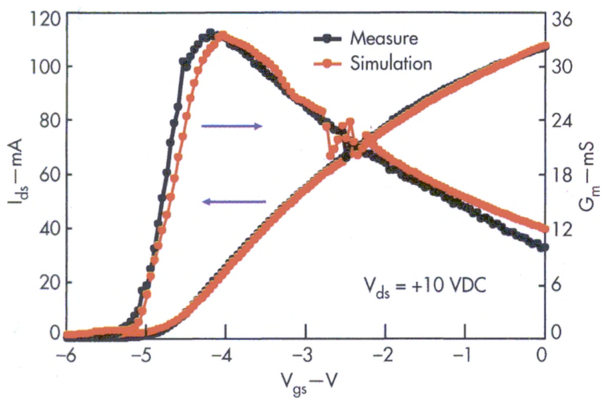
The total heat is a result of the sum of the Joule heating term, the recombination and generation heating and cooling term, and the Peltier and Joule-Thomson effects. The expression is described as follows[5]:

$$H = [\frac{|\overline{J_n}|^2}{q\mu_n n} + \frac{|\overline{J_p}|^2}{q\mu_p p}] + q(R-G)[\phi_p - \phi_n + T_L(P_p - P_n)] - T_L(\overline{J_n}\nabla P_n + \overline{J_p}\nabla P_p) \quad (6)$$

where R represents the heating recombination rate and G is the heating generation rate.

The TCAD software was used to simulate the HEMT; all of these physical models will be included in the design procedure. The work function of the gate metal was set 4.8 eV and the SBH can be ensured at 1.5 eV. The background doping concentrations of all the layers were set 10^{15} cm^{-3}. The GaN buffer layer has exhibited high resistance characteristics and the mobility was set at 300 $cm^2/V\cdot s$.

All epitaxial layers were grown on an SiC substrate by



4. These curves show the measured and simulated $I_{ds} - V_{gs}$ and $G_m - V_{gs}$ responses for the HEMT.

means of rapid thermal metal-organic chemical vapor deposition (MOCVD). Ti/Al/Ni/Au is evaporated to form the source and drain electrodes as a result of a rapid thermal anneal at +900°C for 35 s. A transmission-line matrix measurement method determined the ohmic contact resistant at 0.3 Ω-mm. The gate was formed by electronic-beam lithography and Ni/Au was chosen as the gate metal. *Figure 2* shows a photo of the fabricated device.

Figure 3 displays measured and simulated curves for I_{ds} - V_{ds} for the HEMT structure and device models. The gate voltage was simulated from −5 to 0 VDC and drain voltage from 0 to +10 VDC. The device channel enters the on-state at a gate voltage of −5 VDC, essentially the threshold voltage. The saturation drain current can reach 1.05 A/mm and the knee voltage is 5 V at a 0-VDC gate voltage. This indicates strong depletion-type characteristics for the HEMT device. Measurements indicate a current collapse effect for the HEMT, and further researching will be needed to solve this problem.

In the meantime, the $I_{ds} - V_{gs}$ and $G_m - V_{gs}$ curves were measured and simulated, and are shown in *Fig. 4*. When the drain voltage is +10 VDC, the maximum transconductance may reach 338 mS/mm, and this peak value appears at a gate voltage of −4.2 VDC. The measured curves are close to the simulation curves, indicating the validity of the device simulation, and that the TCAD simulation technology is valuable for the design of AlGaN/GaN HEMTs.

The current gain cutoff frequency (f_T) and maximum frequency of oscillation (f_{max}) are determined by the current gain (H21) and maximum available power gain (MAG), respectively, both calculated by the S-parameters according to Eqs. 7-9:

$$H_{21} = \frac{-2S_{21}}{(1-S_{11})(1+S_{22})+S_{12}S_{21}} \quad (7)$$

$$MAG = \left|\frac{S_{21}}{S_{12}}\right|(K-\sqrt{K^2-1}) \quad (8)$$

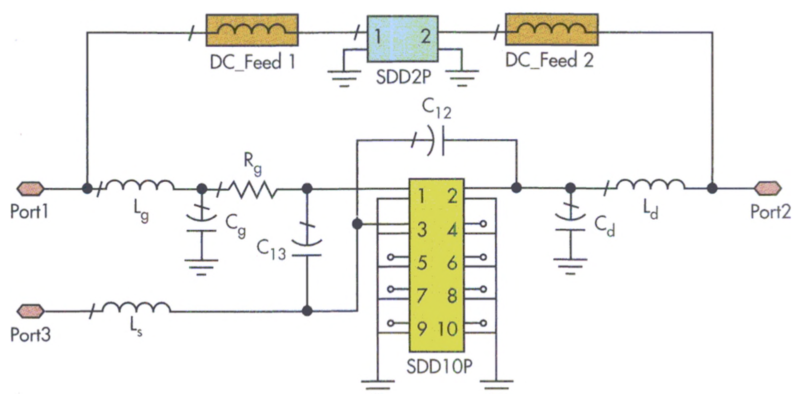
$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|S_{11}S_{22}-S_{12}S_{21}|^2}{2|S_{12}S_{21}|} \quad (9)$$

where K represents the stable factor. The best gate voltage operating point may be determined based on the maximum transconductance. After analysis according to H21 (dB) declining to zero and MAG (dB) declining to zero, f_T) and f_{max}) can reach 118 and 192 GHz, respectively, at V_{gs} = −4.2 VDC and V_{ds} = +10 VDC. With a MAG of 8.2 dB at 75 GHz and 5.7 dB at 100 GHz, this HEMT appears well suited for W-band amplifier applications.

Figure 5 shows a novel SDD large-signal model of the HEMT. The SDD10P portion is used to express the intrinsic region while external resistances, capacitances, and inductances are used to express the parasitic parameters, respectively. For high-frequency HEMT devices, it cannot be ignored that the coupling capacitance between the gate and drain (C12) and the coupling capacitance between the gate and source (C13) must accurately fit the high-frequency S-parameters.

The source resistance (R_s) and drain resistance (R_d) are both deleted because the current between the source and drain in the SDD10P section can reflect the effect of these parameters, so that the large-signal model is simplified. Meanwhile, the SDD2P section compensates the DC characteristics by superposition with the SDD10P section. The two RF isolation inductances must be in series with the SDD2P section so that the RF characteristics cannot be affected.

The port parameters for the SDD10P are presented in the online version of this article at www.mwrf.com/analog-semiconductors/designing-algangan-hemts-w-band It should be noted that parameters I_{ds0}, C_{gs}, C_{gd}, C_{ds}, R_i, R_{ds}, and τ repre-



5. This block diagram shows an SDD large-signal model for the W-band HEMT.

sent the current between the source and drain, the capacitance between the gate and source, the capacitance between the gate and drain, the capacitance between the drain and source, the intrinsic channel resistance, the output resistance, and the delay time, respectively. Parameters I_{ds0}, C_{gs}, and C_{gd} all change with changing V_{gs} and V_{ds} in the model. Their relationships can be expressed according to Eq. 10[6]:

$$I_{ds0} = \frac{\beta(V_{gs} - V_{TO})^2}{1 + b(V_{gs} - V_{TO})}(1 + \lambda V_{ds})K_t \quad (10)$$

In the linear region, $0 < V_{ds} < 3/\alpha$:

$$K_t = 1 - (1 - \alpha V_{ds}/3)^3$$

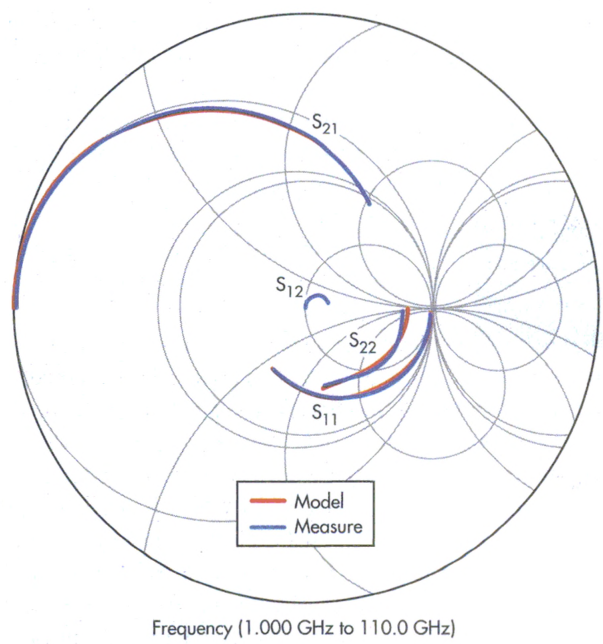
In the saturation region, $V_{ds} \geq 3/\alpha$:

$$K_t = 1$$

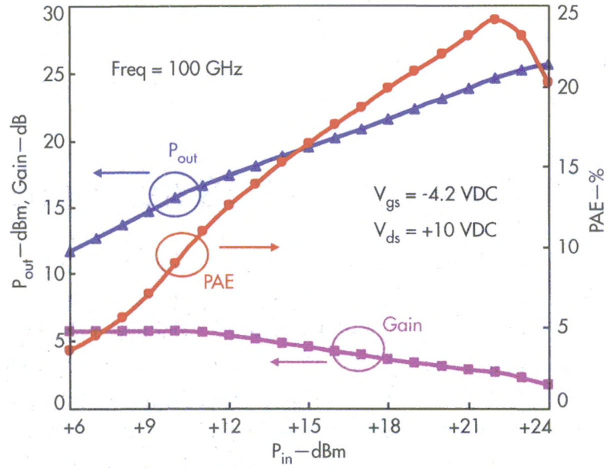
where V_{TO}, β, α, b, and λ represent the threshold voltage, the transconductance, the saturation voltage, the doping tailing factor, and the channel length modulation coefficient:

$$C_{gs} = \frac{C_{gs0}}{\sqrt{1 - \frac{V_{new}}{V_{bi}}}}\frac{1}{4}(1 + k_1)(1 + k_2) + \frac{1}{2}C_{gd0}(1 - k_2) \quad (11)$$

$$C_{gd} = \frac{C_{gs0}}{\sqrt{1 - \frac{V_{new}}{V_{bi}}}}\frac{1}{4}(1 + k_1)(1 - k_2) + \frac{1}{2}C_{gd0}(1 + k_2) \quad (12)$$



6. These are the S-parameters fitting curves for the HEMT at V_{gs} = –4.2 VDC and V_{ds} = +10 VDC.



7. These are the large-signal characteristics for the HEMT at V_{gs} = –4.2 VDC and V_{ds} = +10 VDC.

where C_{gs0} and C_{gd0} represent the capacitance between the gate and the source and the capacitance between the gate and the drain, respectively. Parameter δ is the fitting coefficient. For the SDD2P, the port parameters can be described as

$$I[1,0] = -I_{ds} + I_{ds0} \text{ and } I[2,0] = I_{ds} - I_{ds0}$$

In this case, drain-source current I_{ds} can express the DC characteristics accurately at different gate and drain voltages. The S-parameters are shown in *Fig. 6*.

Figure 7 shows output characteristics of the HEMT device at 100 GHz with source and load-pull simulation. The linear gain may reach 5.7 dB at small signal state until the input power is +11 dBm. The 1-dB compression point occurs when the input power rises to +15 dBm. The output power is close to +20 dBm and the power-added efficiency (PAE) may reach 16% to the 1-dB compression point. The PAE reaches its highest level when the input power is +22 dBm, a level of approximately 24%. In short, this HEMT represents a good device for higher-frequency MMICs, especially for W-band applications. mw

ACKNOWLEDGMENTS

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RF POWER MOSFETS GET PUT TO THE VSWR TEST

TO ENSURE PROPER operation under real-world conditions, RF power MOSFETs undergo voltage-standing-wave-ratio (VSWR) testing to reveal considerable details about their failure modes. Such testing identifies device weakness while enabling a more rugged design. In "Application Note 1820: VSWR Testing of RF Power MOSFETs," Microsemi discusses these VSWR test failure modes as well as a new VSWR ruggedness test method.

Various load conditions produce three dominant failure modes under the VSWR testing of RF power MOSFETs. Over-voltage failure of either the periphery or die body can be avoided by using a nominal supply voltage fit for the amplifier circuit's class of operation. Thermal over-dissipation failure, which arises when the safe operating area (SOA) of the device is exceeded, is inevitable at some point of operation. This failure is a function of the inefficiencies of an amplifier under certain phases of the reflection coefficient of the load. Latch-up, which is sometimes difficult to distinguish from over-voltage failure, is a product of the bipolar elements within an RF power MOSFET and can cause device failure.

A typical VSWR test uses a gate and drain power supply to bias and power the device under test (DUT). A signal generator boosted by a power amplifier is often used to drive the DUT. To induce the various ranges of reflection, a load switch between a 50-Ω dummy load attenuator and RF power meter with a loss pad routed into a reactive load are used. To test latch-up, an unclamped-inductive-surge (UIS) test is performed using an inductor between the supply and drain voltage of the MOSFET. The inductor is charged while the gate is on. When the gate is switched off, the inductor surges power into the device.

Microsemi, 1 Enterprise, Aliso Viejo, CA 92656, (800) 713-4113, www.microsemi.com

To de-embed the changes in efficiency and power dissipation in the test amplifier from the voltage breakdown failure, which results from VSWR testing, a 20% duty pulse of 200 μs can be used. For phase adjustment, a split variable capacitor in a tunable, dual-LC network could replace several lengths of coaxial line, which is the traditional approach. This method would enable the VSWR test to reach nearly 100% reflection efficiency with reasonable Q inductors at nearly any phase angle.

See "Microsemi VSWR - Load Mismatch Ruggedness" at www.youtube.com/watch?v=bMEsEATudgM.

DETAILED THERMAL MODELS BENEFIT IC PACKAGE DESIGNS

GENERATING HIGH-QUALITY PREDICTIONS of component temperatures can let circuit and package designers optimize their designs and avoid temperature-related failures. Various methods for thermally modeling components are available, and choosing the appropriate methods to balance simulation times and the fidelity of the prediction is a critical step. An application note by Mentor Graphics, "10 Tips For Predicting Component Temperatures... A High-Level 'How To' Guide," discusses the benefits of a detailed thermal model along with a step-by-step approach to predictive thermal modeling.

Choosing the appropriate method of modeling for each component in the design could optimize the prediction simulation timing, as well as allow for more detailed analysis of higher-profile components. To simplify the model, low-power density components may be described using background thermal profiles, where larger components that disrupt airflow may need to be modeled with 3D techniques. High-power and large components may need to be evaluated in a detailed discrete basis. Using good power estimates for these components in initial thermal planning could save significant time and effort costs later in the design cycle.

Mentor Graphics, 8005 SW Boeckman Road Wilsonville, OR 97070, +1-501-685-7000, www.mentor.com

A way to estimate the thermal effect of components early on when the final design is still nebulous is to use package thermal models, which can be increased in detail as the design progresses. Types of models include two-resistor, RC-ladder, DELPHI, and detailed. The thermal significance of the component often dictates the detail of the model. Sometimes, customized thermal models may be necessary. Using maps of the power distribution through the die could lead to more viable thermal predictions, along with calibrating model data using experimentally derived thermal profiles.

The final recommended steps consider heatsink solutions, thermal interface material (TIM) resistance, and thermal profiles of mechanical stress prediction. Design considerations like pressure drop, the wake region formed by the heatsink, and increased contact area could lead to a custom solution being more thermally viable for the design. The thermal resistance of the TIM could be a significant contributor of junction temperature, and a quality thermal prediction could lead to a suitable TIM choice. Finally, thermally induced stress on the packaging and substrate of the die based on the application environment may be critical in design decisions.

JACK BROWNE | Technical Contributor

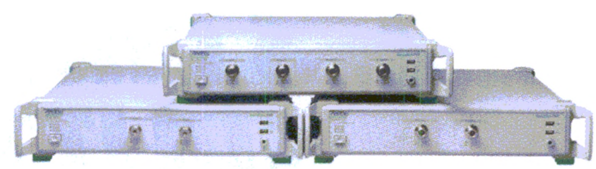
Microwave VNAs Aim At Budget-Minded Measurements

These VNAs are available in two- and four-port versions suitable for cost-sensitive passive component measurements with coverage through millimeter-wave frequencies.

Vector network analyzers (VNAs) may be among the hardest-working and vital test instruments in the RF/microwave industry. They have long been used to measure the amplitude and phase responses of active and passive RF/microwave devices, components, and circuits, generating plots versus frequency that can be very revealing. But VNAs have traditionally also been among the most expensive of RF/microwave test instruments—until now. Anritsu Co. (www.anritsu.com) has developed its ShockLine Series of VNAs, and the "shock" might be that these simple instruments make accurate RF/microwave measurements without breaking the bank.

Designed for testing passive components, ShockLine VNAs are available in two- and four-port versions and in a variety of different frequency ranges, as high as 40 GHz. Just add a keyboard, mouse, and a display monitor as needed, and be ready for simple engineering, manufacturing, and cost-sensitive applications with the speed and performance levels of those "more-expensive" analyzers.

The new ShockLine VNAs include the MS46522A VNAs for two-port testing from 50 kHz to 8.5 GHz, the MS46524A VNAs, capable of four-port measurements from 50 kHz to 8.5 GHz, and the ShockLine MS46322A VNAs for two-port testing as wide as 1 MHz to 40 GHz (and many subbands within that range). Unlike traditional VNAs with incorporated keypads, touchscreens, and other accessories, these analyzers are simple in form and format *(Fig. 1)*. They fit into a compact 2U-high chassis, which can be easily modified for a rack-mount setup. They are designed for testing passive devices and components, such as antennas, cables, connectors, and filters. They are ready for a wide variety of engineering, manufacturing, and educational applications simply by connecting the VNA to a test controller via a LAN for remote use or to a touchscreen monitor for manual use *(Fig. 2)*.



1. Low-cost ShockLine VNAs include the two-port MS46522A, four-port MS46524A, and two-port, high-frequency MS46322A for two-port testing as wide as 1 MHz to 40 GHz.

Users can even select precisely the frequency coverage they need. As an example, the ShockLine MS46522A two-port VNAs are available in two different frequency ranges. One version operates from 50 kHz to 4.5 GHz while the other extends the frequency coverage from 50 kHz to 8.5 GHz. Both units provide full S-parameter measurements on passive devices and components, and either VNA can be used to conduct path-loss characterization of complex systems. Both of these two-port VNAs deliver better than 110-dB dynamic range and corrected directivity of better than 42 dB, with sweep speeds as fast as 70 μsec/point that are sure to keep any manufacturing line moving. The ShockLine MS46522A

2. The ShockLine VNAs, such as the MS46522A Models, can be equipped with a monitor to simplify testing.

3. The ShockLine MS46524A Models provide four-port capability for test frequencies through 8.5 GHz.

4. The ShockLine MS46322A Series VNAs provide simplified test-port-power adjustments as high as 40 GHz.

VNAs can even offer time-domain analysis capabilities when equipped with a time-gating option.

When four-port measurement capability is needed, the ShockLine MS46524A VNAs provide similar performance levels to the MS46522A instruments, but with two additional test ports each *(Fig. 3)*. They are available in the similar frequency ranges of 10 MHz to 4.5 GHz and 10 MHz to 8.5 GHz, and provide similar levels of performance in terms of dynamic range, directivity, and even sweep speeds.

When even greater frequency coverage is needed, the ShockLine MS46322A Series of economy instruments bring two-port passive VNA measurements across a total frequency range of 1 MHz to 40 GHz, for a starting price that suggests a VNA accessory rather than the VNA itself: $12,950 (for the 4-GHz entry-level model). Six models are initially available in the two-port MS46322A Series *(Fig. 4)*, with frequency ranges of 1 MHz to 4 GHz, 1 MHz to 8 GHz, 1 MHz to 14 GHz, 1 MHz to 20 GHz, 1 MHz to 30 GHz, and 1 MHz to 40 GHz.

In terms of test port power, the two-port MS46522A provides –30 to 15 dBm from 0.3 to 6.0 GHz, –30 to 12 dBm from 6 to 8 GHz, and –30 to 10 dBm from 8.0 to 8.5 GHz. The four-port MS46524A offers the same test-power ranges at its test ports, with the additional ports ideal for testing differential cables and multiport devices and components. The two-port MS46322A VNAs simplify power control even further with high and low-state test power levels rather than a range of available power levels. The test-port power in the high state is –3 dBm while the test-port power in the low state is –20 dBm.

The ShockLine VNAs represent a great deal of variety in terms of measurement power and capability (see *table*), allowing engineers to select suitable measurement power for a current application. In the case of the ShockLine MS46322A VNAs, it is a straightforward solution to upgrade most ShockLine models (except the highest-frequency unit) to a higher-frequency range, so that the capabilities of a VNA system can be modified as needed.

In spite of the differences, the analyzers share many features which serve them well, such as the use of a local-area-network (LAN) interface—rather than the slower general-purpose-interface-bus connection—for remote control. The VNAs share a common graphical-user interface and all use Standard Commands for Programmable Instruments programming code for remote program control. All of the low-cost VNAs perform linear, continuous-wave, and segmented frequency sweeps; in addition, the ShockLine MS46522A and MS46524A VNAs perform linear power sweeps.

The high-frequency VNAs are supported by measurement receivers using nonlinear-transmission-line sampling for excellent long-term calibration stability and accurate measurements, even when working within widely varying environments. Different calibration methods are used among the various ShockLine VNAs, with many sharing waveguide calibrations, line-reflect-line, line-reflect-match, short-open-load-through, and short-open-load-reflect methods. To reinforce user confidence, each of the VNAs is shipped with a three-year warranty as standard. All of the VNAs offer options for rack-mount capability and time-domain functionality. P&A: $12,950 and up; stock to 4 weeks. mw

SHOCKLINE VNAs AT A GLANCE

Models	MS46522A/MS46524A	MS46322A
Frequency range	50 kHz/10 MHz to 4.5 GHz 50 kHz/10 MHz to 8.5 GHz	1 MHz to 4, 8, 14, 20, 30, or 40 GHz
Ports	Two and four	Two
Test-port power	-30 to +15 dBm (0.3 to 6 GHz) 30 to +12 dBm (6 to 8 GHz) -30 to +10 dBm (8 to 8.5 GHz)	-3 dBm (high state) -20 dBm (low state)
Dynamic range	100 dB (500 kHz to 3 MHz) 110 dB (3 MHz to 6 GHz) 105 dB (6 to 8 GHz) 90 dB (8.0 to 8.5 GHz)	>85 dB (1 to 20 MHz) >100 dB (20 MHz to 40 GHz)
Corrected directivity	>42 dB	>42 dB
Sweep speed	70 µsec/point and 77 µsec/point	220 µsec/point
Maximum test points	20,000	16,000

ANRITSU CO., 490 Jarvis Dr., Morgan Hill, CA 95037-2809; (408) 778-2000, FAX: (408) 776-1744; *www.anritsu.com*

JEAN-JACQUES DELISLE | Technical Editor

Power-Amplifier Systems Get Smarter

RF/microwave power-amplifier systems traditionally have been chosen based on their SWaP-C characteristics. But recently, factors like intelligent features are being added to the mix.

FOR MILITARY RADAR, test and measurement, and telecommunications applications, a full-featured RF/microwave power-amplifier (PA) system is necessary and critical in the design chain. These systems often are driven by reliability, efficiency, size, and cost of installation. Understandably, the growth of the telecommunications industry has influenced the evolution of PA systems.

To keep pace with the RF/microwave industry while providing better size, weight, power, and cost (SWaP-C) modular assembly techniques, engineers are increasingly leveraging intelligent system monitoring and the latest semiconductor technologies. To reduce size and increase power efficiency at higher frequencies, for example, gallium-nitride (GaN) PA technology is being readily adopted by the industry.

GAN VS. LDMOS

"For broadband scenarios with higher than 1-GHz frequency requirements, implementing an amplifier using LDMOS (laterally diffused metal oxide semiconductor) is difficult," says Paulo Correa, chief technology officer of Empower RF. "Broadband LDMOS can be used below 1 GHz, whereas GaN (gallium nitride) for broadband becomes very attractive above 1 GHz. You do see LDMOS being used successfully in narrowband applications (e.g., wireless infrastructure, ISM [industrial, scientific, medical], etc.) at frequencies above 1 GHz."

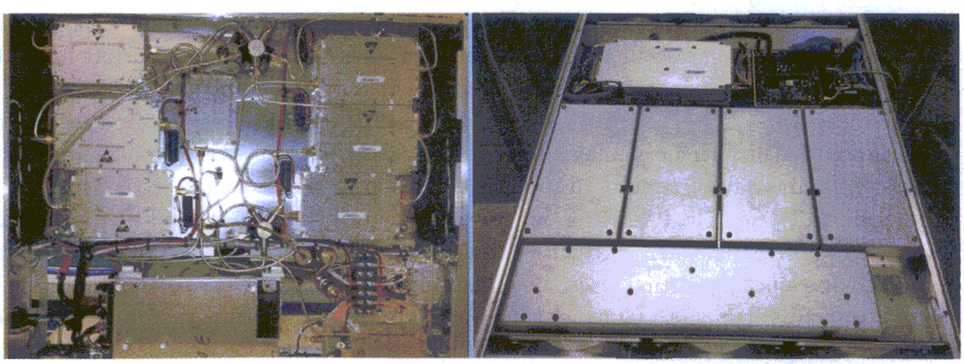
Most PA manufacturers have offerings in various package technologies for GaN PAs, including TriQuint, Cree, MACOM, Microsemi, RFHIC, RFMD, NXP, Toshiba, and Miteq. GaN devices are primarily used in systems that require large amounts of wideband power to high frequencies. To some extent, these technologies have replaced more expensive gallium-arsenide (GaAs) FETs, although these legacy devices are still used in certain applications.

In PA system design, the passive components surrounding the amplifier often can't handle the frequency performance, heat, or power of which GaN PAs are capable. This generally leads to significant design efforts to achieve the highest efficiencies and performance for a GaN-based PA system.

"Attention to losses between the active devices and the output of the system are critical for providing clean RF power and maximizing efficiencies," says Correa.

With the increased heat flux of GaN PAs, more consideration is being devoted to reducing the thermal resistance at a device/component level. The whole thermal stack has become a significant design problem, as the individual junction temperatures from the die to the system assembly can affect the amplifier's performance.

"How fast you can extract the heat from the PA in your device is where you gain a competitive advantage, or not," says Correa.



1. By using modular interconnect techniques in amplifier systems, the wiring and feedthrough leading to loss and interference can be decreased dramatically. (courtesy of Empower RF)

In cases where the wideband frequency range is lower, PAs that are based on LDMOS are still very common. This is predominantly due to the cost and proven technology factor. For certain satellite-communications (satcom) applications, TWT-based (traveling-wave-tube) amplifiers are still used. Here, several kilowatts of RF power are needed to 50 GHz, or Q-band, frequencies.

2. Using modern mobile devices, amplifier-system controls can be enhanced to increase interface functionality and control methods as these features scale in complexity. (courtesy of Res-Ingenium)

AMPLIFIER TYPOLOGIES

Currently, the typologies of amplifier designs also are shifting. Class A and AB are still used with radar, test and measurement, and electronic-warfare (EW) applications. The linearity of a Class-A amplifier is often desired with these applications. The balance required for gain, power, and efficiency, however, could lead to an AB amplifier system being the best fit for the design.

For telecommunications, the efficiency boost of Doherty configurations has taken the foremost position. Here, the cost-per-bit considerations for mobile data have contributed to a price-driven market. Most GaN PA manufacturers provide Doherty-based PAs as a result of this trend. To avoid high costs and increase the available market of goods, techniques that utilize the commonalities between designs could lower the hands-on costs of PA systems.

NEW TECHNIQUES

To reduce the manufacturing and design costs of building systems on a customized per-customer basis, platforming techniques have arisen in the industry *(Fig. 1)*.

"The dollars per watt for most power amplifiers is the same value regardless," notes Jon Jacocks, president and CEO of Empower RF. "How you can achieve better costs is in volume production, reusing components in multiple designs, and reducing labor costs by making the design more manufacturable." For example, Xicom Technologies uses a universal and field-replaceable power supply in its rack-mount, solid-state PA (SSPA) products.

As has occurred in other areas of the RF/microwave industry, cost pressures have driven innovations in PA-system integration and assembly. PA-system manufacturers are beginning to differentiate their products by using the same techniques developed by test and measurement manufacturers to reduce costs and increase functionality: trading wires for fixtures, using a standard chassis with modular packages, adding low-level sensor feedback, and including compact computers to add software features within an assembly.

One example hails from RES-Ingenium, which includes an option with its 300-W DVB-T2 OEM broadcasting transmitter for a wireless interface that is compatible with a tablet. In addition, the software boasts many enhanced graphical-user-interface (GUI) options *(Fig. 2)*.

OTHER FACTORS

Additionally, component-level diagnostic and control features are increasingly in demand. These features are being integrated to leverage the computation-based control and optimization capability as more advanced computers are included within a PA system.

"Our customers have an insatiable desire for data, and they want to drill down into the design. They want to monitor operational status down to a component level and isolate faults if something occurs," says Jacocks. Empower RF, for example, now offers a Web-based diagnostic and control-based system in its newest line of PA systems.

"Doing that in a remote setting without having to physically remove your amplifier is of great interest to customers. You are fielding expensive systems, and they must be easy to operate and troubleshoot," Jacocks says. Built-in tests and enhanced stability controls also are building their capability to monitor PA system conditions and even correct for thermal and other drifting effects.

When purchasing a complex and high-performing system, such as PA systems, more factors need to be considered beyond simple power, frequency, linearity, intermodulation distortion, and cost. Many other criteria may be present, such as efficiency, drift, size, and weight, depending upon the installation footprint.

Thermal management, automation, control, and remote sensing may be high-value features for installations in harsh environments or remote conditions. In addition, the PA system configuration will be influenced by user expertise and the specific considerations for the devices with which the PA system will be interfacing.

"Be clear on your specified requirements, how you have measured them, and under what conditions you will be operating," Jacocks recommends.

As PA systems may excel in certain applications or fields, consulting with a manufacturer's technical experts also can be a critical part of the acquisition.

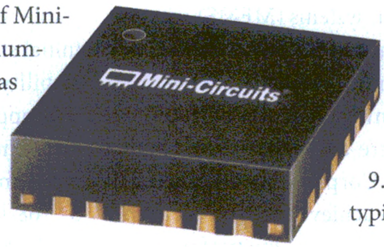
"When you address your questions to the amplifier provider, try to understand the implications of the waveforms you will be transmitting and the tradeoffs with performance, efficiency, and bandwidth," Jacocks says. mw

JACK BROWNE | Technical Contributor

Monolithic InGaP Mixer Converts 2.2 to 7.0 GHz

Based on an advanced semiconductor process, this mixer promises batch-to-batch repeatability and consistency of performance for a wide frequency range.

MIXERS HAVE LONG been the lifeblood of Mini-Circuits, dating back to the company's humble beginnings. Even as the company has evolved to develop a wide range of active and passive components and test equipment, RF mixers have remained almost synonymous with the name "Mini-Circuits." Traditionally, those mixers have been based on discrete device technology rather than on the use of integrated circuits (ICs). With the model MDB-73H+, however, the firm unveils its first monolithic-microwave-integrated-circuit (MMIC) mixer—and what a mixer it is.



Based on InGaP semiconductor technology, the MMIC HBT model MDB-73H+ double-balanced mixer measures just 4 × 4 × 1 mm in a SMT package.

Housed in a tiny 4-×-4-×-1 mm, 24-lead MCLP surface-mount-technology (SMT) package, the model MDB-73H+ double-balanced mixer handles RF and local oscillator (LO) frequencies from 2.2 to 7.0 GHz, with an intermediate-frequency (IF) range of DC to 1.6 GHz. It achieves low, flat conversion loss across that broad frequency range for outstanding performance in a wide range of applications, from communications to radar systems.

The model MDB-73H+ double-balanced mixer *(see figure)* makes use of indium-gallium-phosphide (InGaP)/gallium-arsenide (GaAs) semiconductor materials. Although InGaP/GaAs materials might be best known for their use in solar cells, their outstanding electron velocity characteristics makes them excellent candidates for high-frequency and high-power devices, including high-electron-mobility-transistor (HEMT) and heterojunction-bipolar-transistor (HBT) devices.

In fact, the model MDB-73H+ mixer employs an InGaP HBT structure with integrated LO and RF baluns to achieve its broad frequency range with almost negligible conversion loss. Combined with the mixer's small size and convenient packaging, the component can be used for frequency upconversion and downconversion in a wide range of commercial and defense-related applications.

The model MDB-73H+ mixer is referred to as a "Level 15" mixer, rated for typical LO power of +15 dBm. When measured with an IF of 30 MHz, the conversion loss was typically 8.8 dB at 2.2 GHz; 8.2 dB at 4.0 GHz; 9.3 dB at 6.0 GHz; and 8.9 dB at 7.0 GHz. The typical LO-to-RF isolation is 38 dB at 2.2 GHz; 39 dB at 4 GHz; 35 dB at 6 GHz; and 34 dB at 7 GHz. The typical isolation between the LO and IF ports is 36 dB at 2.2 GHz; 46 dB at 4 GHz; 46 dB at 6 GHz; and 33 dB at 7 GHz. The typical isolation between the RF and IF ports is 8 dB at 2.2 GHz; 17 dB at 4 GHz; 13 dB at 6 GHz; and 12 dB at 7 GHz.

The double-balanced mixer typically reaches its 1-dB compression point with +10-dBm input (RF or IF) power. The mixer achieves typical input third-order-intercept (IP3) point of +18 dBm at 2.2 GHz; +24 dBm at 4.0 GHz; +23 dBm at 6.0 GHz; and +22 dBm at 7.0 GHz. It has a noise figure of 8.9 dB at 2.2 GHz and 9.0 dB when measured at 4 GHz. The thermal resistance, as measured from the junction to the ground lead, is typically +105°C/W.

The tiny InGaP/GaAs mixer is rated for maximum RF power of +21 dBm and maximum LO power of +21 dBm, with maximum IF current of 30 mA. The mixer has an operating temperature range of −40 to +85°C, making it a candidate for many commercial and military applications. For a firm with a long history based on discrete RF mixer technology, this first high-frequency mixer based on MMIC technology is a good first step in the direction of IC mixers and its broadband bandwidth and level conversion loss offer a hint of what lies ahead. The MDB-73H+ is certainly a double-balanced mixer—one that can be made to fit easily within any application in its frequency range. P&A: $6.95 each (20 qty.); stock. mw

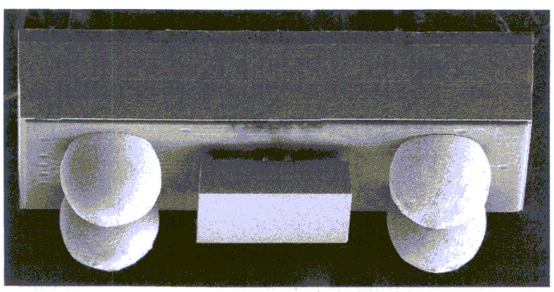
MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, FAX: (718) 332-4661, *www.minicircuits.com*

JACK BROWNE | Technical Contributor

MEMS TCXO Runs On Micro Current

This tiny clock oscillator takes advantage of MEMS technology to achieve excellent stability while drawing minimal current for battery-powered applications.

ALTHOUGH IT IS still a relatively new technology, microelectromechanical systems (MEMS) components are making a splash in many different applications within the RF/microwave field, including for oscillation and timing. As demonstrated by the SiT1552 temperature-compensated oscillator (TCXO) from SiTime Corp. (www.sitime.com), MEMS technology can achieve superb timekeeping performance with very little power. This MEMS TCXO runs at an output frequency of 32.768 kHz with less than 1 μA current consumption (typically 0.99 μA) for supply voltages of +1.50 to +3.63 VDC.



The combination of chip-scale packaging (CSP) and silicon MEMS technology make these TCXOs extremely small, boasting very low power consumption for an output frequency of 32.768 kHz for timing applications.

The TCXO is an excellent low-power fit for a variety of timekeeping applications, from sleep clocks in wireless communications equipment to reference clocks in medical electronic equipment. The low current and low power consumption translate into extended operating periods for any electronic device needing the timekeeping function while operating on battery power.

Each SiT1552 MEMS TCXO consists of a MEMS resonator and programmable analog circuitry packed within one of a number of different packages offered by the company, including an ultra small chip-scale package (CSP; see *photo*). Output signals exhibit worst-case 10%-to-90% rise/fall time of 200 ns, with typical rise/fall time of 100 ns. The MEMS oscillators are impressively stable with time, temperature, and voltage, with initial stability tolerance of ±5 ppm and frequency stability maintained within ±1.5 ppm across the full supply voltage range. The TCXO is available in different stability versions, with frequency stability ratings of ±5, ±10, and ±20 ppm for the one 32.768-kHz output frequency.

The MEMS oscillator requires only 200 ms typical startup time at power up and suffers worst-case long-term jitter of only 2.5 μs. Versions are available for a commercial operating temperature range of 0 to +70°C and an industrial operating temperature range of −40 to +85°C. The MEMS TCXO is available in a CSP housing measuring only 1.5 × 0.8 mm. For other package options, such as an SOT-23-5 package or a surface-mount package measuring just 2.0 × 1.2 mm, contact SiTime.

The miniature MEMS TCXOs are lead-free components that are both RoHS and REACH compliant. They offer two output voltage options: a standard LVCMOS output swing and the firm's patented NanoDrive reduced output swing. The output swing for the latter is customer specific and factory programmed for an output between 200 and 800 mV for reduced power consumption. The silicon MEMS technology in these oscillators provides an output clock duty cycle ranging from a minimum of 48% to a maximum of 52%.

In addition to the low-power operation, they are designed and constructed for outstanding shock resistance and reliability compared to quartz crystal oscillators, with expected mean time before failure (MTBF) of more than 500 million hours. mw

SITIME CORP., 990 Almanor Ave., Sunnyvale, CA 94088; (408) 328-4400, *www.sitime.com*

The R&S CMA180 radio test set generates and analyzes complex modulated signals from 0.1 MHz to 3 GHz for testing different types of radios.

Test Set Exercises Radios to 3 GHz

RADIO-BASED EQUIPMENT OPERATING through 3 GHz is expanding into many different markets, creating a growing demand for maintenance and service for this radio equipment. Fortunately, Rohde & Schwarz (www.rohde-schwarz.us) has squeezed the equivalent of a measurement laboratory—with analyzer, power meter, and test signal sources—into its R&S CMA180 radio test set. It can check and maintain microwave radios from 100 kHz to 3 GHz by generating test signals with bandwidths as wide as 20 MHz, passing them through the equipment or radio under test, and then evaluating the returns at power levels as high as 150 W through 3 GHz. All this performance is packed into a housing light enough for portability but with an option for rack mounting in a standard 19-in. equipment enclosure.

The R&S CMA180 radio test set offers the flexibility of an integrated arbitrary waveform generator that can produce different types of radio test signals under local or remote control. It generates signals from 0.1 MHz to 3 GHz with 1-Hz frequency resolution, and can produce signals with amplitude modulation, frequency modulation, phase modulation, and single-sideband modulation. These test signals are clean and stable, with less than –130 dBc/Hz phase noise in a 1-Hz bandwidth offset 10 kHz from carriers of 0.1 to 30 MHz, less than –113 dBc/Hz offset 10 kHz from 30 to 890 MHz, and less than –110 dBc/Hz offset 10 kHz from 890 to 3000 MHz. Test-signal output levels can be set with 0.01 dB resolution across wide output-level ranges. From 0.1 to 30.0 MHz, the output level range is –120 to + 8 dBm; from 30 to 2000 MHz, it is –120 to +10 dBm; and from 2000 to 3000 MHz, the output level range is –112 to +5 dBm. The output level uncertainty is less than 1.5 dB at any power setting and frequency.

The test set also includes a large touchscreen and straightforward control menu to simplify testing and setup. The arbitrary waveform generator can create signals with a wide range of modulation types as well as signals with interference and other impediments for testing equipment under realistic signal environments. The radio test set has an integrated sequencer to configure and manage automatic test sequences to simplify repetitive measurements.

ROHDE & SCHWARZ USA, INC., 6821 Benjamin Franklin Dr., Columbia, MD 21046; (410) 910-7800; fax: (410) 910-7801; e-mail: info@rsa.rohde-schwarz.com; *www.rohde-schwarz.us*

GaN Amplifier Reaches 50 W Output at 18 GHz

FOR APPLICATIONS THAT require healthy signal levels through 18 GHz, model BME69189-50 is a compact broadband power amplifier from COMTECH PST (www.comtechpst.com) capable of as much as 50 W continuous output power from 6 to 18 GHz. Based on gallium-nitride (GaN) semiconductor technology, the amplifier provides typical gain of more than 47 dB across its frequency range and works under Class AB linear conditions.

This miniature GaN power amplifier requires only +10 dBm input power to achieve overdrive output-power levels. It maintains gain flatness within ±4 dB at 40 W output power across the frequency range. Input and output VSWR remain at 2.0:1 or less under all operating conditions. The amplifier minimizes unwanted signal additions, with second harmonics of typically less than –15 dBc and third harmonics of typically less than –25 dBc. Spurious signal levels are less than –60 dBc.

The high power density of this miniature amplifier module can be credited on the GaN technology, which is growing in popularity for its high output levels at RF/microwave frequencies. The model BME69189-50 amplifier is well suited for a wide range of applications, including communications, electronic-warfare, and radar systems—essentially, for designs where high output levels are required from a unit with small size and limited cooling capabilities within the system.

This amplifier module includes control circuitry and GaN devices with capability of providing 50 W output power from 6 to 18 GHz.

The GaN amplifier measures just 6.56 × 3.50 × 0.84 in. and has an operating temperature range of –4 to +55° C. It weighs 1.5 lbs. with a 7-pin Combo D DC/control interface and field replaceable SMA female input and output connectors, and is constructed to MIL-STD-810F requirements for shock and vibration. It operates from +28 VDC DC input voltage and consumes less than 15 W in standby mode, using a 5-V TTL enable/disable control.

COMTECH PST, 105 Baylis Rd., Melville, NY 11747; (631) 777-8900; fax: (631) 777-8877; *www.comtechpst.com*

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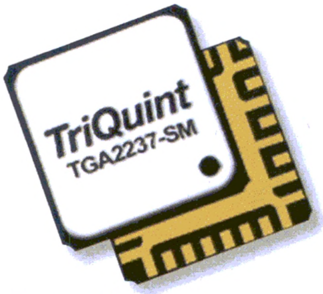


GaN Amplifier Powers 2.5 GHz

MODEL TGA2237-SM is a broadband distributed GaN power amplifier (PA) suitable for commercial and defense applications. It provides 10-W saturated output power from 0.03 to 2.5 GHz in a 32-lead, 5-x-5 mm ceramic QFN housing. With large-signal gain of 13 dB and small-signal gain of 19 dB, the GaN amplifier exhibits input return loss of better than 10 dB and output return loss of better than 12 dB. The amplifier, which is fabricated on the firm's GaN-on-silicon-carbide (GaN-on-SiC) technology, draws 360 mA current from a +32-VDC supply. The amplifier is lead free and RoHS compliant.

TRIQUINT SEMICONDUCTOR, 2300 NE Brookwood Pkwy., Hillsboro, OR 97124; (503) 615-9000, *www.triquint.com*

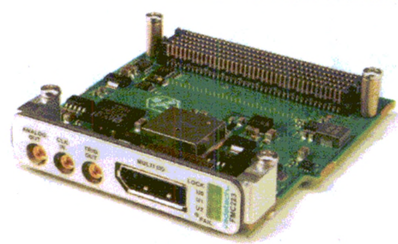
Four-Way Iso-Divider Channels 10.7 To 14.8 GHz

A FOUR-WAY isolator-divider (iso-divider) developed by Crane Aerospace & Electronics for applications from 10.7 to 14.8 GHz achieves better than 38-dB isolation between output ports while only suffering 1.2-dB maximum insertion loss above the theoretical 6-dB power split. Supplied with SMA female connectors in a compact housing measuring just 2.64 × 1.52 × 0.56 in., this iso-divider handles power levels to 2 W (+33 dBm) with at least 80-dBi electromagnetic (EMI) shielding. The space-qualified component allows a satellite-communications (satcom) receiver or transmitter to share antennas in a redundant configuration. The iso-divider, which is also available as an iso-combiner for combining signals, is designed for an operating temperature range of -55 to +85°C.

CRANE AEROSPACE & ELECTRONICS, MICROWAVE SOLUTIONS - SIGNAL TECHNOLOGY, 340 North Roosevelt Ave., Chandler, AZ 85226; (480) 961-6269, e-mail: mw@crane-eg.com, *www.craneae.com/mw*

DAC Delivers 14 b at 2.5 GSamples/s

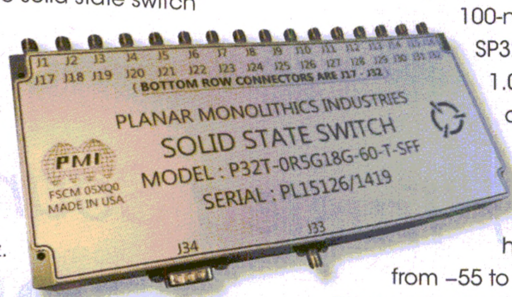
MODEL FMC223 is a digital-to-analog converter (DAC) in field-programmable-gate-array (FPGA) mezzanine card (FMC) format per VITA 57 requirements. The board is based on the AD9739 DAC from Analog Devices (www.analog.com) and designed for synthesizing broadband signals. It operates at 2.5 GSamples/s with 14-b resolution and operates with a 10-MHz clock input signal. It can achieve a 2-V peak-to-peak differential analog output swing with single-tone noise level of −166 dBm/Hz at a 100-MHz IF and −162 dBm/Hz at a 1 GHz IF. The board, which is RoHS compliant, features a programmable digital-signal-processing (DSP) clock. It measures 2.71 × 3.01 in. (69.0 × 76.5 mm).



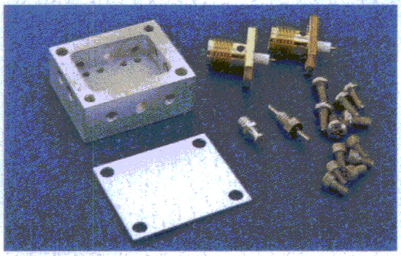
VADATECH, INC., 198 North Gibson Rd., Henderson, NV 89014; (702) 896-3337, FAX: (702) 896-0332, e-mail: info@vadatech.com, *www.vadatech.com*

Switch Commands 0.5 To 18.0 GHz

MODEL P32T-0R5G18G-60-T-SFF is a high-speed, single-pole, 32-throw (SP32T) absorptive solid-state switch with low loss and high isolation between ports from 0.5 to 18.0 GHz. It exhibits 8.5-dB typical insertion loss across that frequency range, with typical isolation of 78 dB. The minimum isolation is 60 dB from 0.5 to 2.0 GHz and 70 dB from 2 to 18 GHz. It is rated for maximum input power of +20 dBm CW and will survive input power levels to 1 W (+30 dBm). The switch, which is designed for maximum VSWR of 2.0:1, achieves 100-ns maximum switching speed. The SP32T switch measures 8.0 × 3.5 × 1.0 in. with SMA female connectors and is controlled by 5-b decoded transistor-transistor-logic (TTL) signals. It draws 1600 mA at +5 VDC and 200 mA at −5 VDC and handles operating temperatures from −55 to +85°C.



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



Housing Holds Prototype Circuits

THE MICROAMP MH-1 housing from Twin Industries is designed to hold a single MB series two-port circuit to speed and simplify prototyping efforts. Circuit boards are available for a variety of different RF/microwave components, including amplifiers, filters, logarithmic detectors, and power dividers. Assembly is as simple as installing a completed circuit board into the housing cavity, screwing the circuit board in place, and adding the coaxial connectors. Each housing is supplied with SMA female connectors, ground terminal, and bias feedthrough, and includes cover and mounting hardware. The firm offers MB series prototyping circuit boards that are usable for applications beyond 21 GHz.

TWIN INDUSTRIES, 2303 Camino Ramon, Ste. 106, San Ramon, CA 94583; (925) 866-8946, FAX: (925) 866-8937, e-mail: sales@twinind.com, *www.twinind.com*

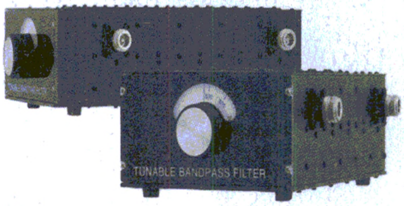
DIN Adapters Control PIM Levels

DEVELOPED FOR applications requiring low passive-intermodulation (PIM) distortion, several DIN adapters have been introduced by RF Industries (www.rfindustries.com). The firm now offers 4.1/9.5 (Mini) DIN male to female right-angle and straight adapters, compact versions of the 7/16 DIN adapter/connector with similar electrical performance. The adapters are suitable for wireless infrastructure equipment and distributed antenna systems (DAS). They feature large hex nuts on the male interface for easy mating with a torque wrench and achieve PIM levels of less than −160 dBc when tested with two tones at 20 W power. The right-angle DIN adapter provides optimum performance through 7.5 GHz.

RF INDUSTRIES, 7610 Miramar Rd., San Diego, CA 92126; (800) 233-1728, (858) 549-6340, *www.rfindustries.com*

Tunable Filters Screen 0.1 To 3.0 GHz

LINES OF tunable band-stop and bandpass filters have been developed for test and other applications from 100 MHz to 3 GHz. A total of six bandpass filters offer octave-band tuning from 125 MHz to 3 GHz and 5% pass bands. These five-section mechanical designs achieve mechanical dial accuracy within 1%. Five new band-reject filters range from 100 MHz

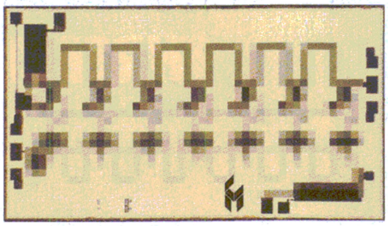


to 2 GHz with 1% rejection bandwidths. These three-section designs boast mechanical dial tuner accuracy to 0.5%. These durable, silver-plated filters, which are capable of more than 50-dB attenuation, are supplied with Type-N connectors. Each is rated for 50 W CW RF/microwave power.

FAIRVIEW MICROWAVE, INC., 1130 Junction Dr., Ste. 100, Allen, TX 75013; (800) 715-4396, (972) 649-6678, FAX: (972) 649-6689, e-mail: sales@fairviewmicrowave.com, *www.fairviewmicrowave.com*

GaN Amp Boosts 0.5 To 20 GHz

MODEL CMD184 is a broadband gallium-nitride (GaN) monolithic-microwave-integrated-circuit (MMIC) amplifier with broad frequency range of 500 MHz to 20 GHz. It provides



more than +34 dBm output power at 1-dB compression across that frequency range, with flat gain of 13 dB. The third-order intercept point is typically +42 dBm. Ideal for use in commercial and military radios, test equipment, and telecommunications applications, the amplifier is supplied in die form and draws 530 mA current from a +28 VDC supply. It is matched to 50 Ω and fully passivated for moisture protection.

CUSTOM MMIC, 1 Park Dr., Unit 12, Westford, MA 01886; (978) 467-4290, *www.CustomMMIC.com*

Pulse Generators Guard Delay Times

THE 9250 Series "Emerald Series" of digital delay pulse generators from Quantum Composers are shipped standard with a 280-ppb temperature-compensated crystal oscillator (TCXO) for stability and accuracy. Pulses are based on an internal 25-MHz oscillator. The pulse generators provide four independent output channels with 5-ps relay resolution and rise times in excess of 2 ns. Delay accuracy can be maintained to better than 1 ns. The pulse jitter is less than 15 ps RMS. The generator can control eight independent pulses (in terms of width and delay) using built-in virtual timers, and can handle external trigger rates to 20 MHz. The signal sources are available with wireless control as part of a Bluetooth option.

QUANTUM COMPOSERS, INC., P.O. Box 4248, Bozeman, MT 59772; (406) 582-0227, (800) 510-6530, FAX: (406) 582-0237, e-mail: sales@quantumcomposers.com, *www.quantumcomposers.com*