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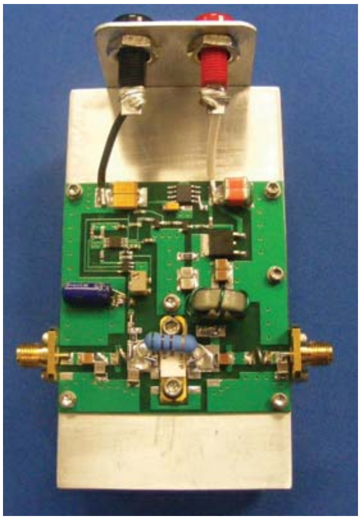
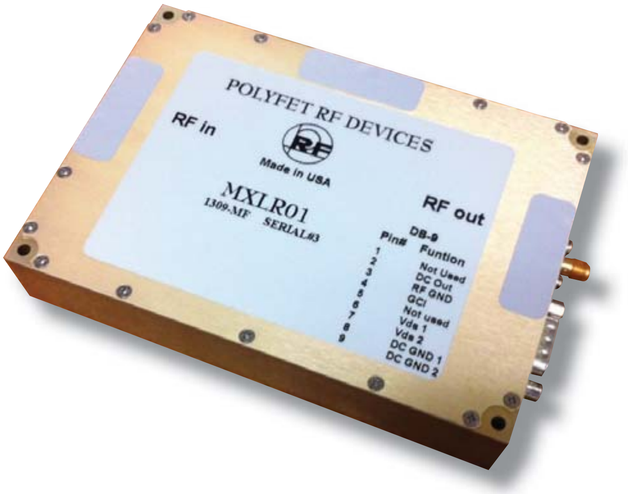


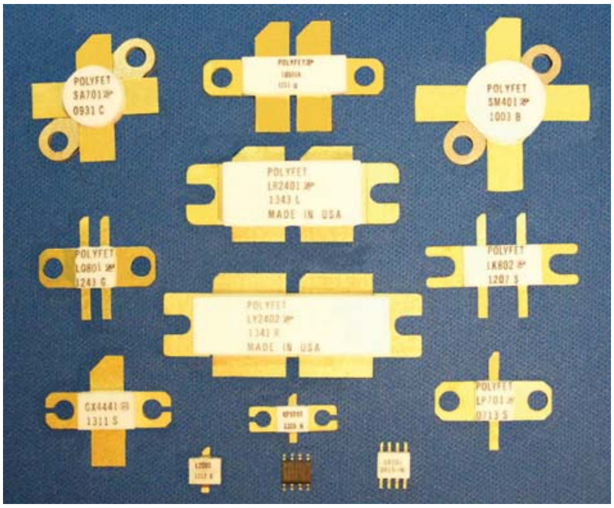
GENERAL COMPANY PROFILE

Polyfet RF Devices is a manufacturer of broad band RF power transistors and power modules. We are a private corporation founded in 1987 and are located in Ventura County California. Our products employ Gallium Nitride, LDMOS, and VDMOS technologies and are manufactured in the US. In 1995, Polyfet was one of the first companies to develop LDMOS power transistors. Today we are one of the few companies to manufacture both 28Vdc and 48Vdc RF power GaN transistors. The maximum operating conditions for our products are up to 50Vdc or 3GHz or 600W. Some of the applications our products are used in are military communications, TV Broadcast, and NMR. Our technical staff is employed to assist our customers with extensive technical support ranging from simple device suggestions to amplifier design assistance. Also available to our customers is access to a wide range of product demonstration amplifiers. Our commitment to long-term production support is welcomed by military contractors who use our products where obsolescence is a concern.

GENERAL PRODUCT INFORMATION

BEING ONE OF the few companies who manufacture both GaN and DMOS devices and modules, Polyfet has a wide range of products to offer. Our transistors are offered in several different package types such as ceramic, plastic, single-ended, push-pull, flanged, and surface-mount. We are one of the few to offer LDMOS devices in compact, push-pull packages. As for our power modules, we offer them in various cases, and are all internally matched to 50ohms.



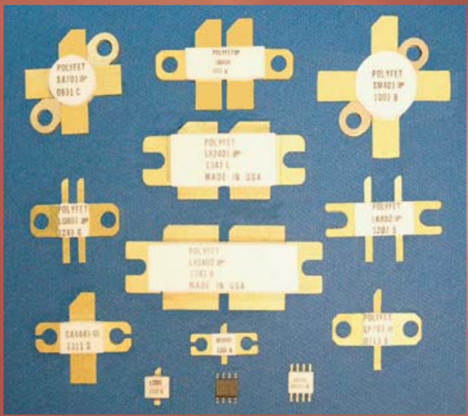


CLOSING SUMMARY

WHEN IT COMES to providing device or module solutions for RF power applications, Polyfet RF Devices is a company to consider. Given that we manufacture vast lines of transistors and modules, the chances are we have a solution for you. We have a long history of manufacturing these products and continue to develop new ones. Thank you to all of our customers for using our products.

polyfet rf devices

Broad band RF power transistors, modules, and evaluation ampliers: Polyfet RF Devices offers them all.



GaN: 28VDC and 48VDC, up to 3GHz, up to 140W CW, single-ended and push-pull.

LDMOS: 5-50VDC, up to 1.5GHz, up tp 600W CW, single-ended and push-pull.

VDMOS: 12.5-50VDC, up to 1GHz, up to 400W CW, single-ended and push-pull.

Broad band RF power modules:
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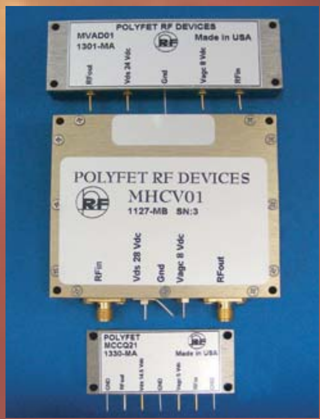

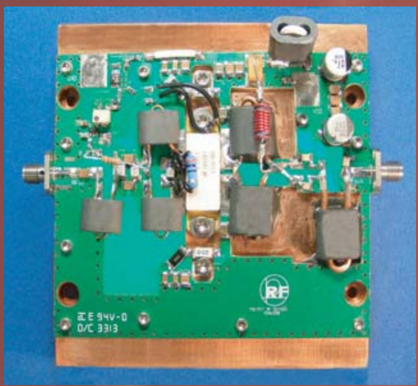

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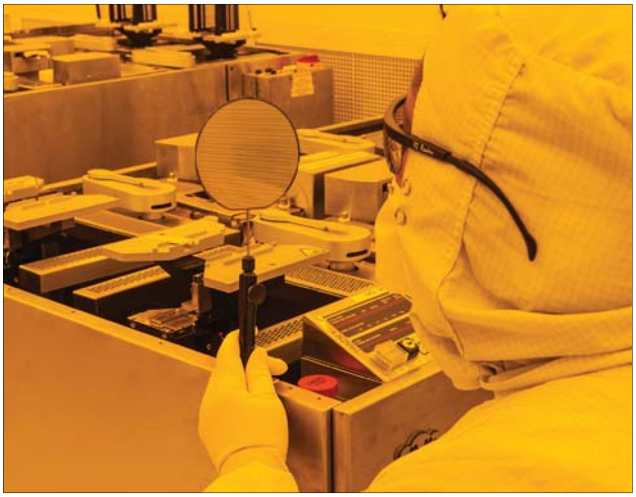

Using Cree's industry-leading GaN-on-SiC foundry services for development and production, customers can develop custom designs by employing an established process design kit (PDK) or having Cree perform the design service. Cree's foundry supports non-linear scalable GaN HEMT models developed using Agilent Technologies' Advanced Design Systems (ADS) or AWR's Microwave Office (MWO), and PDKs are available for both. With a choice of two GaN HEMT MMIC process technologies – 0.4 µm gate HEMT (drain bias 28 to 50V) and 0.25 µm gate HEMT (drain bias 28 to 40V), customers can design high power density transistors (4 – 8W/mm), slot vias, resistors, capacitors, and scalable unit FET cells that operate reliably up to 225°C junction temperatures.

TWO DIFFERENT OPTIONS ARE AVAILABLE FOR ACCESSING CREE'S RF FOUNDRY PROCESS:

1) FULL-WAFER FOUNDRY SERVICE – Using Cree's non-linear, scalable GaN HEMT MMIC models, along with the full capabilities of process design kits from Agilent and AWR, customers can develop their own full-wafer designs with full design support for layout, DRC, and modeling. Reticule size is 10mm x 10mm, with four process control monitoring (PCM) wafers produced for final wafer sort (FWS) testing. Visual screening as well as optional DC/RF on-wafer test services are available.

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Put Cree's extensive GaN-on-SiC experience to work for your next MMIC design. Contact Cree for a comprehensive capabilities evaluation at cree.com/foundry, and ask about new lower prices.

Editorial

NANCY K. FRIEDRICH
Editor-In-Chief
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The Wireless Vision Nears Completion

Back in the early 2000s, I was at a trade show and conference where a speaker talked about then-recent cellular innovations. The presentation noted the impressive developments that had led to better power consumption, thinner cell phones, better screens, etc. The wireless Internet and other connected aspects like location-based services were on the horizon. Yet some commentary was devoted to the fact that no matter how "portable" we thought our devices were, we were still plugged in—or had to be plugged in for at least some point of every day in order to keep our devices up and running. The idea was that true portability would only come when connectivity and power could be delivered wirelessly. The dawn of that day is here and devices will undoubtedly be revolutionized by this capability.

Despite naysayers and fits and starts in terms of technology development, the early days of wireless charging are here. Various standards and technologies are vying to fulfill this need. Charging mats are available and being tried out in applications ranging from vehicle dashboards to airport charging stations. Furniture makers are even getting into the mix, creating tables, desks, and more with built-in wireless-charging capability. Reports are circulating that Apple's new iWatch will be able to charge itself from a distance of 100 m.

The iWatch is an interesting example. If wireless charging can enable designers to shrink and slim down devices, it may make sense for everyone to have a smartphone on their wrist. Implantable communications devices may not be far behind.

This trend counters some recent analysis of the broader consumer electronics and design industry, which points to iterative rather than evolutionary developments. In other words, some analysts and industry followers feel that the "next big thing" being designed is just a glossier, smaller/thinner, longer-battery-life version of the thing that came before it. Take the hype around the newest tablets, for example. Even if consumer electronics makers have succeeded in finding the right combination of look, feel, and features to keep consumers coming back, that does not signal a lack of imagination and inspiration. Great leaps in technology development continue to be witnessed in segments like defense, medical, and automotive. Now, wireless charging is preparing to revolutionize the electronics industry and the way consumers interact with their devices. It's time for the next big change as personal devices truly cut the wires. mw

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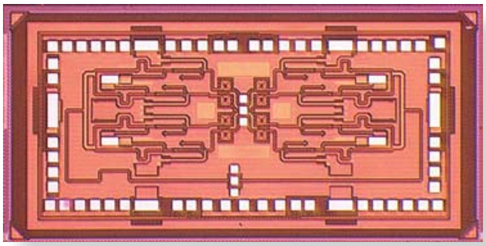

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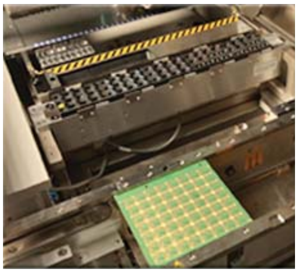

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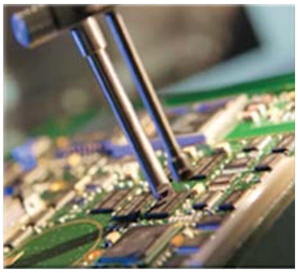

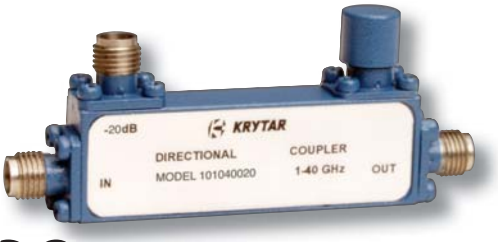

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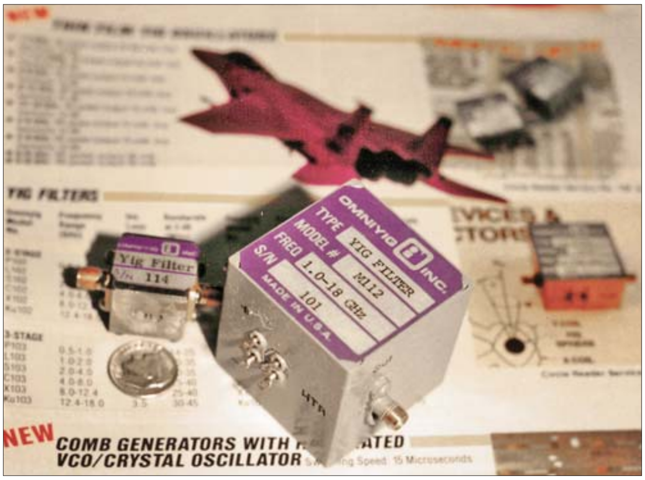

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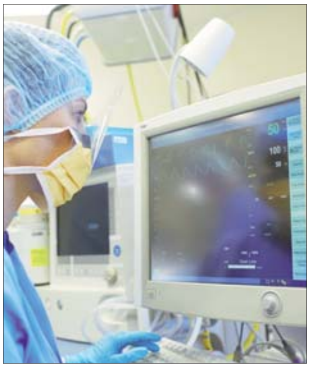

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Founded in 1999, with our origins in the design of broadband and band-specific solid state power amplifiers, Empower RF Systems is a global leader in power amplifier solutions for defense, commercial, and industrial market applications. Our customer base includes market leading OEMs, government agencies, and academic institutions with an array of demanding performance requirements. Empower RF product lines incorporate state-of-the-art GaN, LDMOS, MOSFET, GaAsFET and bipolar device technologies. Our library of product designs includes amplifier solutions ranging from basic-function PA modules to complete, multifunction PA assemblies with embedded software and controllers. The company is a US small business, ITAR registered, and ISO certified. In addition to our Inglewood facility, the company has a fully equipped design center in Holbrook, New York and additional design / manufacturing partnerships in the US and South Korea.

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EMPOWER RF IS proud to introduce next generation hardware and software architecture, known as our "size matters" product family. Size and weight of these amplifiers is superior to anything in the market at these frequencies and power level. User interface and diagnostics capabilities are built around high performance microprocessors and IP addressable, embedded web server. The ''size matters" product portfolio includes 1 kW HPA in a 5U chassis and 500W in 3U. Frequency coverage is 20 – 500 MHz, 500 - 1000 MHz and 20 - 1000 MHz, and (coming soon) 1-3 GHz.

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WE'VE DONE LIVE product demonstrations throughout 2013 at industry tradeshows. We have also designed customer specific configurations of the "size matters" architecture which leverage the standard product platform. If you have not yet gotten a good look at our next generation PA, please come see us at our HQ facilities, in Los Angeles, CA. We would also be pleased to arrange a "virtual tour" via web meeting to show you this product in operation.

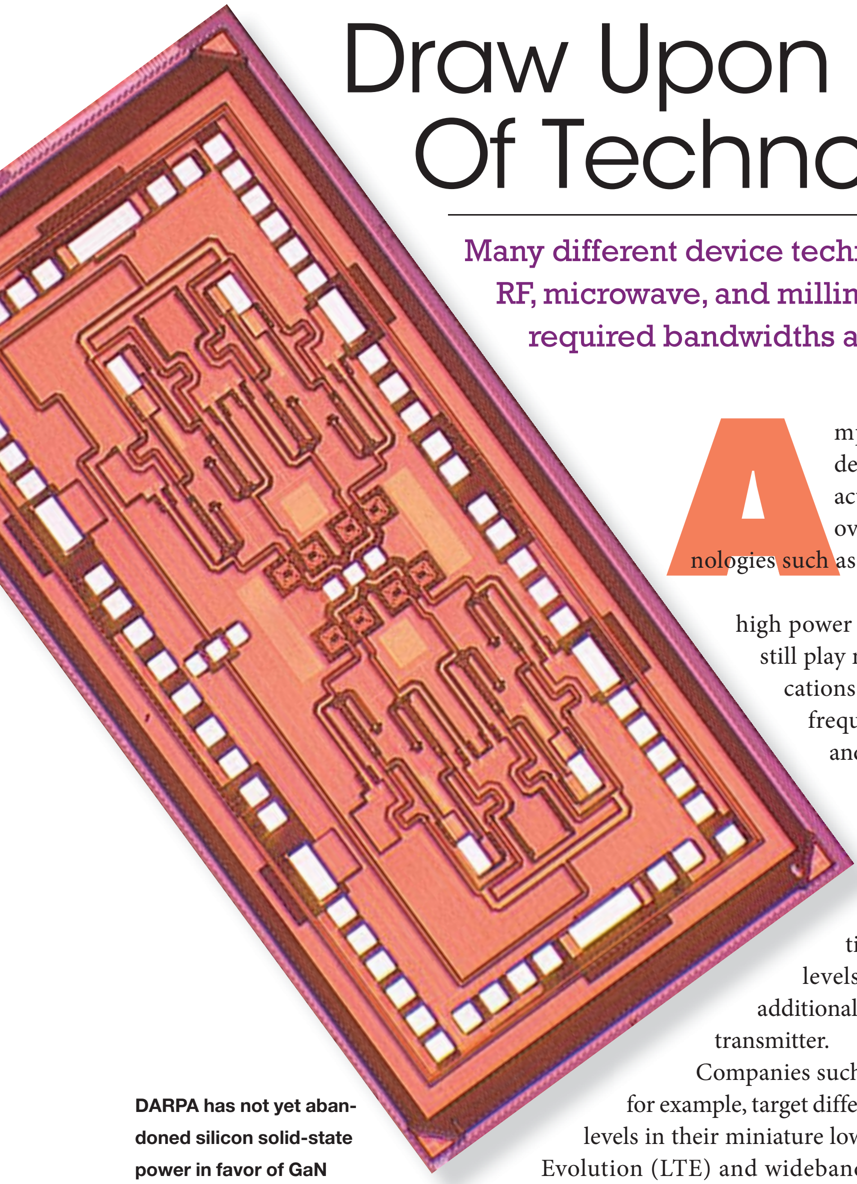
EMPOWER
RF SYSTEMS, INC.

JACK BROWNE | Technical Contributor

AMPLIFIERS

Draw Upon A Variety Of Technologies

Many different device technologies are employed for gain in RF, microwave, and millimeter-wave amplifiers, based on required bandwidths and output-power levels.



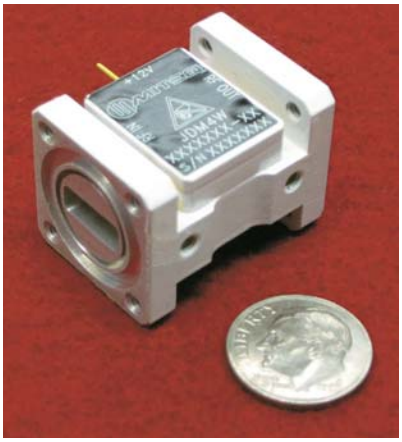
DARPA has not yet abandoned silicon solid-state power in favor of GaN devices, as evidenced by the organization's Efficient Linearized All-Silicon Transmitter ICs (ELASTx) program.

Amplifier technology tends to change over time, depending on the active devices available. Although active-device technologies have advanced a great deal over the past 20 years—with semiconductor technologies such as gallium arsenide (GaAs) maturing, and gallium-devices offering tremendous promise in terms of high power levels at high frequencies—vacuum tube devices still play major roles in RF/microwave amplification applications. A variety of technologies are employed in high-frequency amplifiers, each with its own set of benefits and features.

Amplifiers for RF/microwave applications are available in a wide range of shapes and sizes, as well as frequency ranges and power levels. This diversity stems from the many different needs for these amplifiers, from low-noise amplification in receivers to boosting signals to high power levels in transmitters. Also factoring in are the many additional medium-power stages in between the receiver and transmitter.

Companies such as Skyworks Solutions (www.skyworksinc.com), for example, target different applications with different sets of performance levels in their miniature low-noise amplifiers (LNAs). For use in Long-Term-Evolution (LTE) and wideband-CDMA (W-CDMA) cellular communications infrastructure applications, the firm's model SKY65369-11 surface-mount amplifier features a typical noise figure of just 0.9 dB from 832 to 862 MHz with a 35-dB gain control range. To keep things small, it is supplied in a 16-pin MCM housing measuring just 8 × 8 × 1.3 mm. For broader frequency coverage, the same company's model SKY67015-396LF LNA achieves almost the same noise figure (at typically 1 dB) but covers a frequency range from 30 to 3000 MHz. Suitable for ISM-band applications, it is supplied in a similarly small housing as the model SKY65369-11 amplifier and includes 15.5 dB fixed gain across its frequency range.

Certainly, no solid-state technology has shaken up the RF/microwave amplifier design world in recent years quite like gallium nitride (GaN) active devices. The number of companies now producing GaN amplifiers is large and growing, due to the high power density of the technology and the interest on the part of such customers as the Defense Advanced Research Projects Agency (DARPA). One of those GaN producers, TriQuint Semiconductor (www.triquint.com), which has been working on GaN technology since 1999, recently received a $2.7 million contract from DARPA for the nominal purpose of tripling the power-handling capabilities of GaN circuits. This Near Junction Thermal Transit (NJTT) project will build on TriQuint's GaN on silicon carbide (SiC) technology to achieve higher RF/microwave solid-state power levels than currently available.



1. Amplifiers for satcom applications must be housed in miniature, lightweight packages. [Photo courtesy of MITEQ (www.miteq.com).]

According to James L. Klein, TriQuint's Vice President and General Manager for Infrastructure and Defense Products, "We are very pleased that DARPA selected TriQuint to develop this critical technology. Like other programs we have supported, NJTT will set the stage for substantial MMIC performance enhancements including reduced size, weight, and power consumption while increasing reliability and output power."

TriQuint hopes to combine its GaN-on-SiC process technology with new thermally conductive materials, thus reducing heat buildup around the active GaN devices and permitting higher output-power levels in their GaN amplifiers and devices. TriQuint has several partners in the project, including the University of Bristol (www.bris.ac.uk), Group4Labs (www.group4labs.com), and Lockheed Martin (www.lockheedmartin.com). TriQuint is also heading process and manufacturing projects on GaN devices and amplifiers for the United States Army, Navy, and Air Force laboratories.

Similarly, late last year, RF Micro Devices, Inc. (www.rfmd.com) received a $2.1 million contract from DARPA to enhance the thermal efficiency of GaN circuits used in high power radar and other military systems. Also part of DARPA's NJTT efforts to improve the power-handling capabilities of GaN amplifiers, RFMD believes that a solution will be found as a combination of its GaN-on-SiC device technology and the use of thermally enhanced diamond substrate materials. Jeff Shealy, Vice President and General Manager of RFMD's Power Broadband business unit, said at the time of the contract's announcement that "RFMD is excited to work with DARPA to apply new technologies to our existing portfolio of GaN-based high power RF amplifier products. We expect the NJTT program will result in a new generation of higher performing, more compact RF high power amplifiers (HPAs) with lower operating temperature and greater RF power-per-unit area."

RFMD, which has been involved with GaN technology since 2000, is also working with Group4Labs on the contract, along with the Georgia Institute of Technology (www.gatech.edu), Stanford University (www.stanford.edu), and Boeing Co. (www.boeing.com). The firm has been a strong supplier of GaN-based power amplifiers for cable television applications.

For those seeking an informal education on GaN technology, Advantech Wireless (www.advantechwireless.com) offers an eight-page white paper on GaN amplifiers, "A new generation of Gallium Nitride (GaN) based Solid State Power Amplifiers for Satellite Communication," available for free download from the firm's website. It details how GaN amplifiers fare in satellite-communications (satcom) applications when compared with silicon LDMOS or GaAs-based power amplifiers. The GaN amplifiers are claimed to be about 50% smaller than their technology counterparts, with considerably less power consumption and less generation of heat. Advantech Wireless, which designs and manufactures GaN power amplifiers through Ku-band frequencies for commercial and military use, is currently offering its GaN power amplifiers as replacements for traveling-wave-tube amplifiers (TWTAs) in satcom applications.

2. The large heat sink is required to help dissipate heat from the power amplifier's active devices. [Photo courtesy of Mini-Circuits (www.minicircuits.com).]

In embracing the growing popularity of GaN amplifier technology, EMPower RF (www.empowerrf.com) is selling its lines of GaN power amplifiers as replacements for silicon bipolar, MOSFET, LDMOS, and GaAs FET amplifiers. It is offering the newer GaN amplifiers as smaller, lighter,

(continued on p.43)

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FILTERSOLUTIONS® FOR THE SYNTHESIS OF FILTER CIRCUITS

Nuhertz Technologies is the creator of FilterSolutions, ® the most comprehensive software suite for the synthesis of filter structures. The software comprises six individual sub-modules: Distributed Element; Lumped Element; Active Element; Digital Circuit; Impedance Matching, or Switched Capacitor Resonator filters. These modules can each be purchased separately.

A variety of analysis tools are available in FilterSolutions, including:

- Complex impedances
- Dielectric loss
- Element value and parasitic error
- Electromagnetic analyses (3rd party tools)
- Geometry errors
- Op Amp Gain & BW considerations
- Resistivity
- Sensitivity analyses
- Tuning of Poles and Zeros
- User selected, measurement based parts

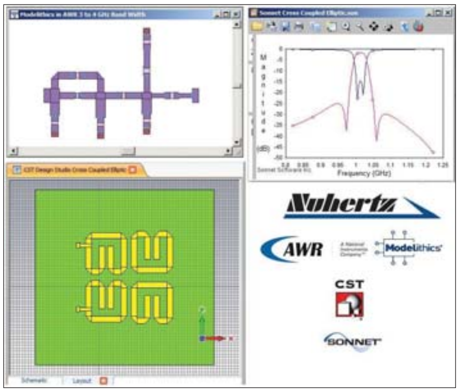
Users are able to synthesize Cross-Coupled resonator structures of 10th, or greater, order with the minimum possible number of cross-couplings. Space-saving "folded", cross-coupled filters can be designed and optimized to minimize PC board space.

In the distributed element mode, Designers can instantly compute distributed geometries in order to build networks from user-defined S or G-transfer functions. Designs include combline, hairpin and interdigital networks in microstrip, stripline or suspended substrate media.

The programs support integration of lumped elements and parallel edge-coupled and shunt stub resonators.

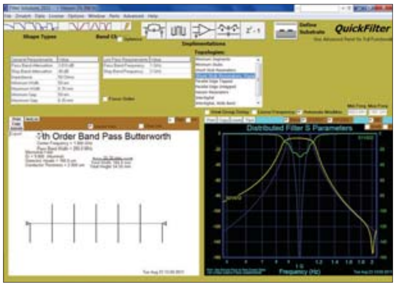
INTEGRATION WITH 3RD PARTY TOOLS

NUHERTZ IS A Sonnet Software EDA Partner. FilterSolutions provides filter geometries in Sonnet Project Format.
FilterSolutions can be integrated into AWR's Microwave Office®
In partnership with CST Microwave, FilterSolutions provides the ability to integrate filter synthesis with a full-wave electromagnetic analysis tool.FilterSolutions provides the ability to optimize filter circuits with the use of Modelithics models as included in AWR's software.



FILTERQUICK

FILTERQUICK IS AN included simplified interface. One begins by pointing to the shape factor and the filter type required. Then, after filling in a fairly simple "requirements" table, the initial design and frequency response will be shown.



The design may then be given further consideration. By selecting "Advanced" from the toolbar, additional design manipulation in FilterSolutions can be achieved.

JACK BROWNE | Technical Contributor

KEEPING POWER LEVELS In Check

Directional couplers and power dividers/combiners are essential components for RF/microwave applications in which signals must be combined or divided.

Power levels often must be maintained and monitored in RF/microwave systems, and those tasks can depend on simple-but-important passive components: directional couplers and power dividers/combiners. They are available in a variety of package styles—including compact surface-mount housings, coaxial packages, and even waveguide housings—with many different frequency ranges, from high-frequency (HF) bands through millimeter-wave frequencies. Suppliers for these components number many; a fundamental knowledge of essential mechanical and electrical characteristics for each component type can help simplify the specification process.

Directional couplers are often used to measure power levels or to monitor signals by tapping off or sampling a small amount of the main signal. It is known as a "directional" coupler since this component can separate and sample signal components based on the direction of signal flow. By placing signal transmission paths close enough in a directional coupler's circuitry, part of the signal from the main-line transmission path can be transferred to a coupled path and made available at a coupled output port. The coupling ratio is the difference between the power level of the main-line signal at its output port and the power level of the coupled signal, or:

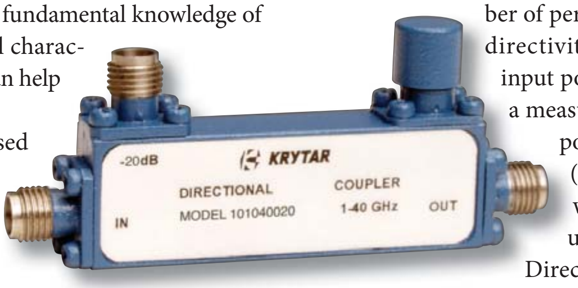
Coupling ratio = 10log(Pout) of the coupled path/Pin)

where:

Pout = the output signal power and
Pin = the input signal power.

Directional couplers are available commercially with different coupling factors or ratios, such as 10, 20, and 30 dB. A 30-dB coupler will provide 30 dB of the input power at its coupled port, or about a factor of 0.001 of the input power at the coupled port. For high-power levels, this is a convenient means of providing a lower-level signal for analysis with a sensitive power meter. Very high-power measurements may even call for a directional coupler with coupling factor as high as 40 dB.

Along with its frequency range and coupling factor, RF/microwave directional couplers can be differentiated by a number of performance parameters, including directivity, loss, VSWR, and maximum input power rating. Directivity, which is a measure (in dB) of how well the component isolates forward and reverse (or reflected) signals, is critical when a directional coupler will be used to measure return-loss levels. Directional couplers with high directivity enable high measurement accuracy when using that coupler in a test system for forward or reflected power measurements.



This is one of the industry's widest-band directional couplers, with 20-dB coupling from 1 to 40 GHz by means of stripline circuitry and SMA coaxial input and output connectors. [Photo courtesy of Krytar (www.krytar.com).]

A directional coupler's voltage standing wave ratio (VSWR) provides an indication of how closely the component is matched to its designed characteristic impedance; this is typically 50 Ω but can be 75 Ω in video and cable-television (CATV) transmission systems. Low VSWR is to be preferred, and using a directional coupler with low VSWR is a way to minimize impedance mismatch errors and to improve power measurement accuracy.

Loss through a coupler represents the amount of signal power that is attenuated due to power dissipated through coaxial connectors, printed-circuit boards (PCBs), and resistive circuit elements. Depending upon the manufacturer, a directional coupler's loss may be defined as insertion loss, which is separate from coupling losses, or as transmission loss, which combines insertion and coupling losses. As with

VSWR, lower values are to be preferred, since they mean that more of the input power to a directional coupler will be preserved at its output ports.

The maximum input power rating of a directional coupler is often dependent on the coupler's package style, with small surface-mount housings offering the lowest input power ratings because of the small size. Couplers with coaxial connectors are limited in power-handling capabilities to some degree by the connectors, with SMA connectors typically handling about 50 W CW power.

As an example of how the key performance parameters appear for a commercial directional coupler, model 101040020 from Krytar (www.krytar.com) is a recently introduced coaxial directional coupler with extremely broadband frequency coverage from 1 to 40 GHz using stripline circuitry and SMA coaxial connectors (*Fig. 1*). It has a nominal coupling value of 20 dB across that frequency range and serves a variety of commercial and military applications, including signal monitoring and measurement, antenna beam forming, and electromagnetic-compatibility (EMC) testing. The 20-dB coupling is flat within a ±1-dB window, while the insertion loss (not including coupling loss) is less than 0.85 dB from 1 to 20 GHz and less than 1.5 dB from 20 to 40 GHz. The directivity is higher than 14 dB from 1 to 20 GHz and higher than 10 dB from 20 to 40 GHz. The maximum VSWR at any port is 1.50:1 to 20 GHz and 1.70:1 to 40 GHz. The directional coupler is rated for maximum average input power of 20 W, but as much as 3 kW peak input power (short pulses).

Power dividers/combiners are often used to create multiple versions of a signal for a system or to combine multiple inputs into one signal for a system. Power dividers are usually designed so that an equal amount of the input power is distributed to the output ports. In a two-way power divider, one-half of the input power is available at each output port; in a four-way power divider, 25% of the input power is available at each output port; and so on.

An ideal two-way power divider would provide two output signals at precisely one-half the power level as the input signal. In the real world, however, a power divider suffers some amount of insertion loss, along with other forms of loss (such as return loss from reflections, and impedance mismatches at connections to and from the power divider). And real power dividers/combiners are sometimes designed with as many as 64 output ports.

The performance of these components is described by similar parameters as for directional couplers, such as insertion loss and VSWR. In addition, ports are characterized by the amount of isolation between them, the amplitude balance (or imbalance) between ports, and the phase balance (or imbalance) between ports. Power dividers/combiners come in many forms, including as quadrature (90-deg.) and 180-deg. hybrid couplers. A quadrature hybrid splits an input signal into two output signals, each at one-half or 3 dB the power level and offset 90 deg. in phase. A 180-deg. hybrid splits an input signal into two equal-amplitude output signals that are offset 180 deg. in phase.

Although many of the basic design concepts behind directional couplers and power dividers/combiners have changed little in several decades, increased attention is being paid to newer parameters—such as passive intermodulation (PIM)—which can impact how these components perform in modern communications systems. Systems using digital modulation formats, for example, require couplers and power dividers/combiners with minimal levels of PIM.

Designers of these components are also exploring the value of different building-block materials, such as low-temperature-cofired-ceramic (LTCC) circuit substrate materials. These materials feature excellent thermal conductivity characteristics for handling high power levels and high operating temperatures compared to conventional PCB materials.

Suppliers of directional couplers, hybrids, and power dividers/combiners offer products in many different package styles, including miniature drop-in and surface-mount housings, coaxial packages, and high-power waveguide enclosures. Suppliers include ARRA (www.arra.com), Bird Technologies (www.bird-electronic.com), Connecticut Microwave (www.connecticutmicrowave.com), Fairview Microwave (www.fairviewmicrowave.com), Innovative Power Products (www.innovativepp.com), JFW Industries (www.jfwindustries.com), Krytar (www.krytar.com), M/A-COM (www.macomtech.com), MCLI (www.mcli.com), Meca (www.e-meca.com), Marki Microwave (www.markimicrowave.com), Mini-Circuits (www.minicircuits.com), MITEQ (www.miteq.com), Narda East (www.nardamicrowave.com), Pasternack (www.pasternack.com), PMI (www.pmi-rf.com), Pulsar Microwave (www.pulsarmicrowave.com), Skyworks Solutions (www.skyworksinc.com), Synergy Microwave Corp. (www.synergymwave.com), TRM Microwave (www.trmmicrowave.com), and Werlatone (www.werlatone.com). The most complete listings for these products can be found online at the Microwaves & RF Product Data Directory (http://mwrf.com/product-data-directory).

For those seeking fundamental background information on directional couplers and power dividers, an eight-page white paper, "Microwave Power Dividers and Couplers Tutorial," is available free of charge from Marki Microwave (http://www.markimicrowave.com/menus/appnotes/microwave_power_dividers_and_couplers_primer.pdf). In addition, Mini-Circuits offers a free application note, "Directional Couplers," which explains the use of these passive components for test and systems applications (http://www.minicircuits.com/app/COUP7-2.pdf). mw

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The unit has low spurious signals and is extremely load tolerant, which enables it to be used in many RF applications such as: RF susceptibility testing, antenna/component testing, and communication testing.

For more detail, vist: http://www.arww-rfmicro.com/html/18200.asp?id=1134.

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Manage Growing EM RADIATION LEVELS

Effective shielding is now a standard requirement for many electronic designs, to prevent EM radiation from those devices from wreaking havoc with other electronic products.

Electromagnetic (EM) and radio-frequency (RF) energy sources surround us in the form of various electronic devices, all of which are capable of causing interference for one another. Fortunately, proper application of EM and RF shielding materials can minimize opportunities for interference. The large number of sources that can generate EM interference (EMI) and RF interference (RFI) often makes it necessary to install multiple levels of EM shielding into a design, from the circuit and package levels through the enclosure level.

Proper use of shielding materials helps a large number of high-frequency circuits co-exist when fairly tightly spaced in the same environment. The right amount of shielding material can prevent leakage of unwanted EM and RF radiation and for most designs the trick is knowing which type of shielding material to use and just how much shielding is enough.

Shielding materials come in many forms, including meshes, foils, cloths, tapes, and heat shrink tubing *(Fig. 1)*. Many of these materials can provide very high suppression of EM and RF radiation levels. Of course, simply adding shielding materials to an electronic design can be expensive; the time-honored tradeoff is to use enough shielding materials to bring EM and RF radiation levels within desired boundaries, but without adding excessive cost to the design.

How well an EM/RF shield performs is usually denoted by a parameter known as shielding effectiveness (SE), which measures the amount of power or field strength around an electronic device before and after shielding has been applied:

$$SE\ (\text{in dB}) = 10\log(P_i/P_e)$$

or

$$SE\ (\text{in dB}) = 10\log(F_i/F_e)$$

where:

1. EMI shielding gaskets and other materials can be added at different stages of a design to limit EMI/RFI radiation. [Photo courtesy of Tech-Etch (www.tech-etch.com).]

P_i = the incident power density,
P_e = the exit power density,
F_i = the incident field strength, before shielding, and
F_e = the exit field strength, after shielding.

A shield can dissipate or absorb energy, and also reflect or redirect energy—the net result is that the shield has reduced the amount of energy around an electronic device. Various means are used to measure the SE of different materials, with probably the best known approach being the military standard MIL-STD-285. This standard is based on a high-level signal source and two antennas (loop, rod, or dipole antennas): one to transmit and one to receive at the frequencies of interest. More severe shielding measurement standards, such as TEMPEST requirements, exist, but these are applied as needed for different applications, such as for US National Security Agency (NSA) applications.

Different techniques developed over the years for measuring SE include the open-field or free-space method (which essentially detects radiation escaping from a finished product), the shielded box method, the shielded room method, and the coaxial transmission-line method. The shielded-box method is often used to compare the performance levels of different shielding materials. It employs a metal box with tight seam and sample port in one wall fitted with a receiving antenna. A transmitting antenna and signal source are placed outside of the box, and measurements are made with and without the material sample over the test port.

2. In some extreme cases, EMI/RFI filters may be needed to perform frequency-selective attenuation of unwanted signal energy in an electronic design. [Photo courtesy of Tech-Etch (www.tech-etch.com).]

Unfortunately, though, this approach does not correlate well from one facility to the next and is limited to about 500 MHz in usable frequency range. The limitations of this method are overcome somewhat by using a larger shielded room, in which the dimensions of everything in the test setup (including the test material sample) are larger.

The coaxial transmission-line method, with measurements performed on small donut-shaped samples, has become the preferred SE test method. Measurements can be made at specific frequencies using a modulated signal generator, crystal detector, and tuned amplifier, or in swept mode with a tracking generator and a spectrum analyzer. A variable attenuator is set to maximum and a measurement made without the sample holder in place. Then the sample is added and the attenuation reduced until the reading is the same.

Shielding materials such as gaskets often provide an environmental seal in addition to suppressing radio interference. These are commonly rubberized materials, such as silicone rubber or fluorosilicone rubber with embedded silver-plated silver or copper particles to enhance conductivity. They are formed into sheets, such as 12 x 12 in., which can then be die-cut into the shapes and forms needed to seal an enclosure. In addition, nickel and graphite are more commonly used in EM/RF shields for their dimensional stability. For example, nickel-graphite-filled silicone rubber is a compressible material that provides a high level of EM/RF shielding; it also forms a reliable environmental seal due to the compression. Shielding solutions continue to evolve over time, with newer base materials (such as graphene) attracting a great deal of attention for its light weight and capability of achieving high SE levels.

Depending upon the requirements, some applications may require EMI/RFI filters *(Fig. 2)* to screen interference, but these are usually more severe cases. Such filters add weight and cost; typically, lower-weight, lower-cost shielding solutions are preferable, such as simple meshes or shielding gaskets. A mesh can be effective at blocking EMI/RFI as long as the size of the mesh is smaller than the wavelength of the frequencies of interest. If it is larger than the wavelengths of the signals of interest, those signals will get through, although they may be somewhat attenuated by the partial action of the mesh.

How much EMI/RFI shielding can be achieved by a gasket or other shielding material at a given frequency? The amount of shielding is a function of the material and the frequency of concern, as well as the form in which the shielding material is applied—such as in the form of a shielding window or gasket. Most suppliers of shielding products, like Chomerics (www.chomerics.com), will work closely with customers to even die-cut shielding gaskets as needed for different product enclosures. As an example, Chomerics offers a 200-page-plus online catalog devoted to shielding products, with materials that include shielding vents and windows, shielding adhesives, wire mesh gaskets, and cable shielding.

The firm also offers design services and supports its analysis through computer-aided-engineering (CAE) tools, such as finite-element-analysis (FEA) software. While shielding solutions tend to vary by material and by frequency, the firm is best known for its standard CHO-SEAL 1310 conductive elastomer material. This provides better than 60 dB SE from 200 MHz to 10 GHz, with higher values of SE available as needed. Similarly, Leader Tech (www.leadertechinc.com) offers a large catalog of conductive elastomer materials for free download from its website.

Due to its expanding use of RF/microwave technologies, the modern automobile is becoming one of the more challenging electronic environments. With its many different systems—from high-frequency (HF) through millimeter-wave frequencies—newer automobiles are resident to a large number of RF/microwave signals within a tightly confined space. That space is also subject to shock, vibration, and wide temperature extremes.

Problems from EMI in a newer automobile can stem from collision-avoidance radar systems, from built-in Global Positioning System (GPS)/navigation systems, fuel control systems, adaptive cruise control systems, and electronic ignition systems, just to name a few. Shielding materials are now essential components in most automotive electronic systems, for proper compliance and operation of those systems along with their coexistence with other automotive electronic systems and other external electronic systems, such as wireless garage-door openers. mw

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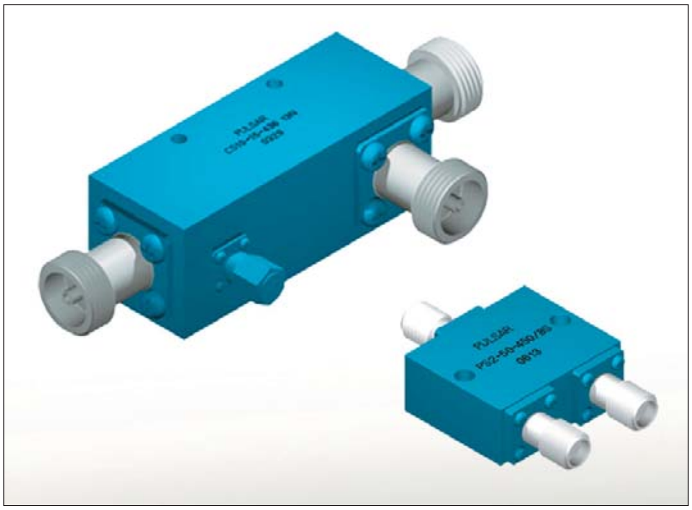
DC-60 GHz POWER DIVIDERS AND COUPLERS

PULSAR'S POWER DIVIDERS and couplers range in frequency from DC to 60 GHz. Lumped elements are used for multi-octave requirements from DC to about 3 GHz with power levels up to 2.5 KW to optimize bandwidth and size. Microstrip circuits are used for frequencies from 250-6000 MHz to obtain low loss, moderate bandwidths and power levels up to a few hundred watts, and air-line is used for power levels up to 600 watts. For multi-octave bandwidths up to 60 GHz, strip-line configurations yield optimum performance. So many designs are available that a customer can easily find one that either fits or that we can modify to fit the application.



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GAN & GAAS AMPLIFIERS: AT THE HEART OF NEXT GENERATION SYSTEM DESIGNS.

CTT supplies customers worldwide with power amplifiers, low-noise amplifiers, frequency converters, frequency multipliers, transmitters, transceivers, and receivers within the frequency spectrum of 10 MHz to 100 GHz.

Since its founding in 1981, CTT has focused on the development and production of these products that have become ready, cost-effective solutions to problems and requirements encountered in defense, commercial and industrial markets. Over three decades of evolution at CTT has resulted in a solid cadre of technical expertise, a long list of satisfied customers and a line of products which gives designers the confidence that overall system performance will be met.

Our volume production ability has increasingly made CTT products the "hardware of choice" in the price-sensitive, broad bandwidth, high linearity, high power and low-noise amplifier markets. This importance of choice, to the designer, is even more critical when understanding that CTT is providing RF functions that account for a significant share of the cost model in system designs.

CTT's history, technical expertise, production know-how and resultant patronage allows the Company to excel in projects of any magnitude. At CTT we're committed to serving the microwave marketplace with a simple goal: Quality, Performance, Reliability, Service and On-Time Delivery of our products.

LEADERSHIP IN DESIGN, DEVELOPMENT & MANUFACTURING

CTT'S FAMILY OF solid-state amplifiers find applications in many of the next generation of high-performance communications, instrumentation, medical and military systems where high power or low-noise is required. CTT's new GaN and GaAs amplifier designs offer cost-effective performance solutions. Both military and commercial applications can benefit from CTT's technological improvements in:

- Increased Sensitivity
- Reduced Size and Weight
- Higher RF Efficiency
- Wider Bandwidth
- Reduced Cost
- System Power Efficiency

Whenever legacy systems are upgraded, whether to address new demands or to benefit from improved technology, in most cases we can provide the exact form, fit and function replacements.

33 YEARS OF SUCCESS – BUILT IN THE USA

CTT HAS SHIPPED thousands of power and low-noise amplifiers into many radar, communications, EW, UAV and data link programs. CTT's proprietary designs are the refinement of decades of amplifier and subassembly experience. In addition to this design heritage, these amplifiers take full advantage of the repeatability and cost effectiveness of CTT's fully-automated in-house production line located in the USA.

You can count on CTT's 33-years of experience in microwave amplification and subsystem integration. Give us a call to find out how our commitment can support your success. It's that simple.

CTT INC.

At the heart of the next generation electronic defense systems.

The next generation air and missile defense radars demand effectiveness, reliability, power efficiency and affordability. You can count on CTT's twenty-five years of experience in microwave amplification and subsystem integration to meet these demands.

CTT offers not only form, fit, function of microwave amplifier replacements for many mature systems, but also incorporates leading-edge technology components such as GaN and GaAs.

CTT has delivered production quantities of amplifiers with power levels of 10, 20, 40, 80, and 100 Watts – and higher – for a variety of radar applications.

CTT is well positioned to offer engineering and production technology solutions – including high-rel manufacturing – to infuse new technology into legacy systems for improved reliability and life cycle costs.

- AMDR-X Radar
- Shipboard Radar
- VLO/FLO Threats
- New Land Radar

More than twenty-five years ago CTT, Inc. made a strong commitment to serve the defense electronics market with a simple goal: quality, performance, reliability, service and on-time delivery of our products.

Give us a call to find out how our commitment can support your success. **It's that simple.**

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GENERATING REALISTIC SIGNALS For Testing

Signal generators for RF/microwave testing are changing in mechanical formats, with a growing number of test sources available in compact housings suitable for on-site testing.

Test signals must be accurate, and they must also be stable. Modern communications systems employ advanced digital modulation formats, and test signal generators must be capable of duplicating the carriers and modulation used in those systems.

In addition, with communications systems based on multiple-input, multiple-output (MIMO) antenna schemes, and with a growing need for creating multitone test signals for checking the linearity of active and passive components and systems, test signal sources must now be available in many forms—from traditional rack-mount units to smaller broadband sources.

Modern communications systems attempt to transmit and receive increasing amounts of information through the use of digital modulation schemes, such as amplitude-shift-keying (ASK), frequency-shift keying (FSK), phase-shift keying (PSK), and quadrature amplitude modulation (QAM). The latter can be generated with at least two signal components that are out of phase—such as in-phase (I) and quadrature (Q) components—with digital bits transmitted by different relative states or symbols formed by the signal components.

To characterize the many active and passive components in the receiving and transmitting portions of these modern communications systems, test-equipment manufacturers must recreate the types of digitally modulated signals used in the systems, in terms of the bandwidth of interest, amplitude range, and modulation schemes. In terms of test signal generators, output signals are also expected to be extremely accurate and stable, maintaining that accuracy over the operating lifetime of the signal source.

Traditionally, RF/microwave test signal generators have been housed in large enclosures which sat on a benchtop or were mounted in a 19-in. rack with other instruments. Such signal generators are still a large part of many test installations, and still available from some of the more trusted names in RF/microwave test. Among these are Agilent Technologies (www.agilent.com), Anritsu Co. (www.anritsu.com), Gigatronics (www.gigatronics.com), Rohde & Schwarz (www.rohde-schwarz.com), and Tektronix (www.tek.com).

For example, the E8267D PSG signal generator from Agilent Technologies (Fig. 1) is available with a frequency range of 250 kHz to 44 GHz that can be tuned or swept with 0.001 Hz resolution. It can be set to minimum output power of −130 dBm, with output levels as high as +23 dBm to 20 GHz and +18 dBm to 40 GHz. It provides all the major digital modulation formats with a modulation bandwidth of 160 MHz. Harmonic levels are typically −55 dBc from 2 to 20 GHz and −45 dBc from 20 to 40 GHz. Spurious content is as low as −80 dBc, and single-sideband (SSB) phase noise is typically better than −100 dBc/Hz offset 20 kHz from carriers through 44 GHz, and specified at −124 dBc/Hz through 2 GHz.

Abandoning tradition, test laboratories and production test departments recently have sought more measurement functionality from a given space in a test rack. As a result, the popularity of smaller, modu-


1. This signal generator is an example of the traditional benchtop housing. This unit operates from 250 kHz to 44 GHz with a host of modulation capabilities. [Photo courtesy of Agilent Technologies (www.agilent.com).]

2. This compact module is representative of RF/microwave instrument functions in PXI form. It is one of a series of units capable of generating signals to 6.6 GHz. [Photo courtesy of National Instruments (www.ni.com).]

lar test instruments communicating by means of LXI, PXI, VME, VXI, and USB interfaces has grown. By designing test equipment into modular housings that use one of these interface standards to communicate, test instrument suppliers can pack multiple functions into a space once occupied by a single function.

The modular approach makes it possible, for example, to assemble a rack of test equipment with multiple signal generators to generate two-tone or multitone test signals useful for linearity testing of components. These modular collections of instruments are typically controlled by an additional personal computer (PC) under the command of a dedicated measurement program.

One such series of modular signal generators is the NI 565x series from National Instruments (www.ni.com), which is based on the PXI format. Several of these test signal modules (Fig. 2) can be slid into a PXI chassis with a control module to create. Signal generator modules are available through 6.6 GHz. By adding frequency upconversion modules, such as the firm's model NI 5610 module, the frequency range can be extended further. The company also offers PXI arbitrary-waveform-generation (AWG) modules for creating complex modulation formats, as well as a single vector-signal-generator module (model PXIe-5673E) based on the high-speed PXI-Express (PXIe) interface.

In addition to the transformation from benchtop instruments to modules, modern RF/microwave signal generators are available increasingly as portable and even battery-powered units designed for use in the laboratory as well as for on-site testing. Some of these test signal sources are being developed by firms once thought of as "components suppliers."

For example, Hittite Microwave Corp. (www.hittite.com) has developed the portable model HMC-T2270 synthesized signal generator with a range of 10 MHz to 70 GHz–impressive considering it fits in a housing measuring only 12 x 8 x 3 in. (305 x 203 x 76.2 mm) and weighing only 8.25 lbs (3.7 kg). The portable source delivers +29 dBm output power at 1 GHz and +3 dBm output power at 70 GHz. In spite of the small size, it features laboratory-grade performance, with SSB phase noise of −118 dBc/Hz offset 10 kHz from a 1-GHz carrier and −79 dBc/Hz offset 100 kHz from a 67-GHz carrier.

The model SSG-4000HP synthesized signal generator from Mini-Circuits (www.minicircuits.com) lacks the carrying handle, but is similarly compact and provides output signals from 250 to 4000 MHz with a 70-dB dynamic range of −50 to +20 dBm. It is powered by an external +24-VDC supply and uses a USB interface.

3. The model APSIN20G signal generator can be controlled by numerous interfaces and provides clean outputs from 9 kHz to 20 GHz. [Photo courtesy of AnaPico (www.anapico.com).]

Two companies offering small-signal generators that are not components suppliers—AnaPico AG (www.anapico.com) and Vaunix (www.vaunix.com)—boast small sources that are suitable for creating multitone sources for such applications as MIMO testing and linearity measurements. The model APSIN20G from AnaPico, for example, is a broadband unit measuring just 172 x 220 x 106 mm but capable of outputs from 9 kHz to 20 GHz (Fig. 3).

Vaunix is one of the few signal generator supplies that offers sources that can be not only controlled by a USB connection, but powered by it as well. Measuring just 4.90 x 3.14 x 1.59 in. (124 x 80 x 40 mm) and weighing less than 1 lb. (0.45 kg), the firm's Lab Brick LSG and LMS lines of signal generators can also operate by means of a battery or external power supply for non-USB applications. The LSG series includes models in bands from 20 MHz to 6 GHz while the LMS series is comprised of a number of units in bands from 0.5 to 20.0 GHz.

These higher-frequency Lab Brick sources, while lacking digital modulation capabilities, can be supplied with optional pulse modulation for radar testing. They offer excellent electrical performance in spite of low power consumption. A model LMS-402D, which operates from 1 to 4 GHz, has phase noise of −98 dBc/Hz offset 10 kHz from any carrier, while a model LMS-203, with output signals from 10 to 20 GHz, has phase noise of −75 dBc/Hz offset 10 kHz from any carrier.

A relative signal-generator newcomer, Pronghorn Solutions (www.pronghorn-solutions.com), has developed a compact, low-power source suitable for using in groups to generate multitone test signals. The firm's model PHS-3000 operates from 150 MHz to 9 GHz in a housing measuring just 3.5 x 5.5 x 1.25 in. and weighing less than 2.5 lbs. It can be powered by means of 110 VAC using an external power supply and can also run 4 hours on its internal battery.

These "pocket-sized" signal generators provide clean, basic output signals that can be readily combined through an N-way power divider, with each signal generator tuned to the desired offset to create a wide range of multiple-tone signals. While generating such signals with traditional benchtop/rack-mount signal generators would be cost-prohibitive, these smaller signal generators can often accommodate such multitone testing at the cost of one or two traditional test signal sources. mw

Editor's Note: To read an expanded version of this article, go to http://mwrf.com/test-amp-measurement-analyzers/generating-realistic-signals-testing.

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KRYTAR is a recognized RF and microwave industry leader, with nearly 40 years of experience, specializing in ultra-broadband microwave components with frequencies ranging from DC to 67 GHz. Our customers have come to expect high performance and top quality products that ensure success for a wide range of military and commercial applications. KRYTAR has created many unique new designs, several of which are patented. KRYTAR was founded in 1975 by Thomas J. Russell, a recognized pioneer in the microwave industry. He developed one of the first proprietary computer aided engineering (CAE) tools for creating microwave couplers and was a recognized leader in high performance designs. Today, KRYTAR has a dedicated facility for the design, manufacture and support of our products. Mr. Russell's original management style was based on trust and respect for both his employees and our customers. The continuation of this philosophy has been essential in building strong relationships with our customers and has resulted in steady growth.

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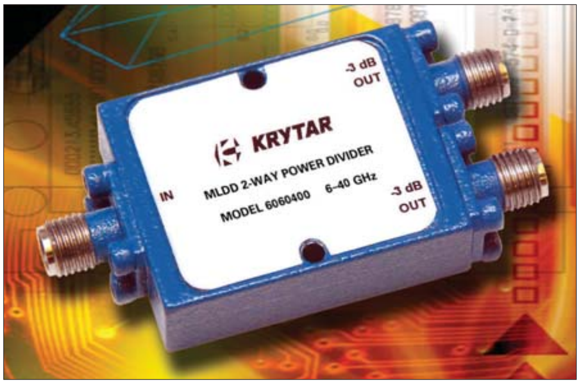
- Detectors: 10 MHz to 40 GHz
- Limiters: 500 MHz to 18 GHz
- Coaxial Terminations & Adapters: DC to 50 GHz
- Power Meter & Sensors: 100 kHz to 40 GHz



CUSTOMIZED SOLUTIONS

KRYTAR'S CLOSE RELATIONSHIP with its customers enables the company to provide superior customer service. Over the years our engineering and manufacturing teams have worked to design custom solutions meeting the highest performance and technical criteria tailored for the most challenging applications, including MIL-qualified requirements. If your application pushes the boundaries of microwave technology, contact KRYTAR today to discuss your needs.

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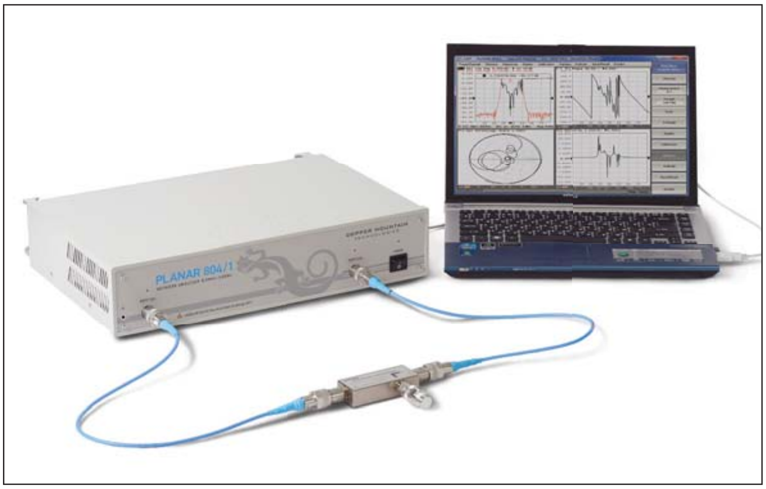
CREATIVE ENGINEERING SOLVING REAL PROBLEMS

Technology is supposed to move. It's supposed to change and update and progress. It's not meant to sit stagnant year after year simply because that's how things have always been done.

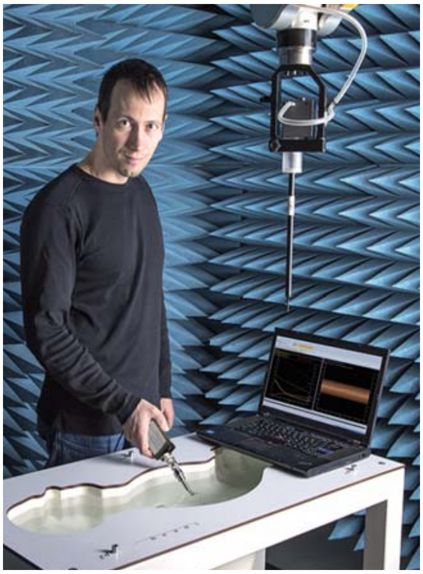
The engineers at Copper Mountain Technologies are creative problem solvers. They are rethinking the way VNAs are developed and used in the RF and Microwave industry. They know the people using VNAs don't just need one giant machine in a lab. They know that VNAs are needed in the field, requiring portability and flexibility. Data needs to be quickly transferred, and a test setup needs to be easily automated and recalled for various applications.



Copper Mountain Technologies' VNAs are designed to work with the Windows PC via USB interface. After installing the test software, it becomes a top-quality VNA at a fraction of the cost of a traditional analyzer. The result is a faster, more effective test process that fits into the modern workspace. This is the creativity that makes Copper Mountain Technologies stand above the crowd and enables engineers to solve real problems that need serious test and measurement instruments.

GLOBAL EXPERTISE BEHIND AN INNOVATIVE APPROACH

COMBINING EXPERT engineers in Chelyabinsk, Russia — some of the most creative and experienced engineers in the world, solving old problems in brand new ways — with a global sales network based in Indianapolis, Indiana and an office in Singapore, Copper Mountain Technologies offers PC-driven VNAs and local support partners around the world.



CUSTOMER SOLUTION: HANDHELD VNA ENABLES DIELECTRIC TESTING

THE PLANAR R140 Vector Reflectometer enabled SPEAG to develop the DAKS-3.5, a portable kit for dielectric testing - a feat that was impossible with traditional bench top instrumentation. The R140 connects directly to a test probe without a test cable and communicates with the DAKS software via USB. The size, high accuracy, and low cost of the reflectometer let SPEAG deliver an innovative product which is now used in various applications in electronic, chemical, and medical industries.

COPPER MOUNTAIN
TECHNOLOGIES

JACK BROWNE | Technical Contributor

Foundries Offer LARGE PROCESS MENUS

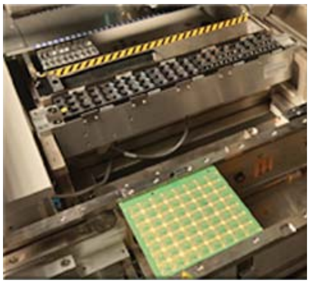
High-frequency chip and device designers can draw on a wide range of process technologies from the large number of semiconductor foundries serving this industry.

High-frequency design engineers currently enjoy access to an unprecedented variety of semiconductor foundries and semiconductor processes. Most commercial foundries provide at least two wafer runs per year for their major processes and, in addition, often offer opportunities to experiment by sharing space on a multiple project wafer with other customers. The electrical functions offered by these many processes range from low-noise and high-power analog circuits to dense, high-speed digital circuits and wafers with combinations of analog and digital circuits. Some of the latter extend well beyond 100 GHz.

Many semiconductor suppliers, notably those without their own foundries, rely on foundry services to create their semiconductor-based products. Not having a foundry on premises has advantages, since it shifts the responsibilities for the care and maintenance of the foundry and its associated test equipment to the vendor. But this also sacrifices total control over the process and the vast opportunities for experimentation. Still, semiconductor foundries that sell their services generally pride themselves on their capabilities. They typically offer customers many levels of service, with as little or as much help as needed.

Most semiconductor foundry services start with a process design kit (PDK). This is a software-based tool built around the latest computer-aided-engineering (CAE) software, such as Microwave Office® from AWR Corp. (www.awrcorp.com), the Advanced Design System (ADS) from Agilent Technologies (www.agilent.com), and Ansoft Designer with Nexxim from Ansoft (www.ansoft.com). When contracting with a gallium-arsenide (GaAs) foundry such as United Monolithic Semiconductors (www.ums-gaas.com), a customer receives a PDK that is designed for a suitable semiconductor process (such as a low-noise or power process), and compliant with the customer's computer operating system and other simulation tools.

The PDK incorporates active and passive device models developed (and known to be effective) by the foundry, and essential to creating GaAs monolithic-microwave-integrated-circuit (MMIC) active and passive circuits with the foundry's various semiconductor processes. Such software design tools are vital for creating a MMIC layout that the foundry can translate into a real wafer, using its own design-rule-check (DRC) process to verify the accuracy and validity of the layout.



RFMD, an open foundry offering services based on III-V semiconductor materials such as GaAs and GaN, promises wafer turnaround in just six weeks. [Photos courtesy of RFMD (www.rfmd.com).]

Following a successful DRC process, the foundry will create a wafer mask that aids in fabricating the many physical levels of a GaAs semiconductor. Then, depending upon the foundry arrangement, the mask is used to produce two or more wafers filled with the customer's design. In the case of the UMS foundry, production wafers are inspected visually, as well as via RF and direct-current (DC) process-control-monitoring (PCM) measurements that help determine final wafer quality and acceptance. UMS provides delivery of wafers by means of a GelPak® box or in diced form on UV film. Of special benefit to many customers, UMS offers two-day training courses that help to convey the foundry's GaAs MMIC design methodology. Topics covered include process, modeling, CAE tools, reliability, electrical measurement, picking, packaging, and industrialization.

Semiconductor foundries share special relationships with CAE software developers because of the strict requirements for PDKs. In many cases, a foundry will support multiple technology processes—each with its own set of PDKs, and each designed for use with a specific commercial electronic-design-automation (EDA) software tool. For example, one of the largest silicon semiconductor foundries, IBM Microelectronics (www-03.ibm.com/technology/), offers RF CMOS, RF silicon-on-insulator (SOI), and silicon-germanium (SiGe) BiCMOS technologies at different locations, using 8-in. wafers for most of the semiconductor processes and 12-in. wafers for its standard silicon CMOS process in its Fishkill, NY facility.

As different as the capabilities of each process are, they all depend on their own PDKs developed for use with the ADS software from Agilent Technologies. In order for the combination to be effective, the performance capabilities of each semiconductor process must be accurately reflected by the simulation capabilities of the EDA software. Any update in the process technology must trigger an update with the EDA tools for this combination of process and software to provide optimum results.

For many years, the choice of foundry for an RF/microwave customer was between high-frequency silicon or GaAs process. But even one of the most successful GaAs foundries, TriQuint Semiconductor (www.triquint.com), now offers a number of different process technologies.

TriQuint, which is one of the world's largest commercial GaAs foundries, offers GaAs pseudomorphic high-electron-mobility-transistor (pHEMT) and metal-epitaxial-semiconductor field-effect-transistor (MESFET) semiconductor technologies. Using 100- and 150-mm wafers, the foundry can deliver both low-noise and high-power GaAs MMIC circuits at frequencies beyond 100 GHz with a 0.6-μm MESFET process and with pHEMT processes supporting device features as small as 0.13 μm. The foundry has combined complementary technologies such as GaAs MESFET and/or pHEMT circuits with indium-gallium-phosphide (InGaP) heterojunction-bipolar-transistors (HBTs) on a single InGaP/GaAs wafer to provide tremendous flexibility for customers. Along with many foundries that started with GaAs, TriQuint now also supports GaN foundry services. For its highest-power devices, TriQuint employs GaN-on-SiC technology to combine the excellent high-frequency, high-power capabilities of GaN material with the excellent thermal conductivity of SiC.

GaN is an attractive building material for both high-frequency and high-power use, and a growing number of foundries offer GaN-based foundry services. For example, RFMD (www.rfmd.com) is another example of a foundry that started with GaAs and has branched into GaN foundry services (*see figure*). Such is also the case with Global Communication Semiconductors (GCS; www.gcsincorp.com), which has long supported GaAs foundry services only to add GaN to its lineup.

One of its customers, Nitronex (www.nitronex.com), recently completed qualification of GCS's GaN-on-silicon foundry process in support of Nitronex's discrete and MMIC GaN devices. The qualification process included extensive DC, RF, thermal, reliability, and other parametric testing to ensure that devices fabricated at GCS are every way equal to devices made at Nitronex's Durham, NC facility. Having the GaN foundry's output in addition to its own capabilities has Nitronex well positioned for sharp growth in power GaN devices. According to Charlie Shalvoy, the company's CEO, "The combination of our proprietary 100-mm GaN-on-Si process, and the full suite of production and new process development capabilities at GCS, gives us the ability to be a leader in the rapidly emerging market of GaN RF power devices."

Silicon-carbide (SiC) substrates were once considered a leading candidate for high-power applications, and a number of foundries provide a full range of services based on SiC wafers, including GSC, Ascatron (www.ascatron.com), Cree (www.cree.com), Raytheon UK (www.raytheon.co.uk), and United Silicon Carbide (www.unitedsic.com). But many of these foundries have worked with higher-frequency GaAs substrates, including GSC and Raytheon, and the relatively low electron mobility of SiC materials relative to some of the other semiconductor substrates results in relatively low cutoff frequencies for SiC devices. Still, for power switching applications and motor drives, or any low-frequency application that requires high power density, SiC represents an attractive starting point.

But even foundries that started with SiC, such as Cree, have considered the benefits of higher-frequency materials like GaN, and have consequently expanded their foundry operations to include services based on GaN wafers. Although CREE is well established as a providing of lighting solutions with its light-emitting-diode (LED) devices and modules, the company also supports foundries for high-power SiC processes suitable for lower-frequency power switching and control and a 50-V GaN HEMT process that has resulted in 100-W GaN HEMT devices for LTE cellular communications applications from 1800 to 2200 MHz.

For lower-power, higher-frequency operation, InP-based HEMTs still show the highest cutoff frequencies and lowest noise of all three-terminal devices, and silicon-germanium (SiGe) transistors and diodes have routinely been fabricated for applications well into the millimeter-wave range—including for integrated-circuit (IC) transceivers at 160 and 165 GHz. But silicon CMOS has also shown a great deal of life at higher frequencies, with 90-nm silicon CMOS capable of fabricating ICs with +1-VDC transistors operating at 60 and 77 GHz, and more expensive 65-nm silicon CMOS processes typically delivering transistors operating beyond 100 GHz. However, for the higher-power levels sought for many microwave and millimeter-wave transmit applications, GaN and the foundries that support it have caught the attention of more than a few customers in both commercial and military applications. mw

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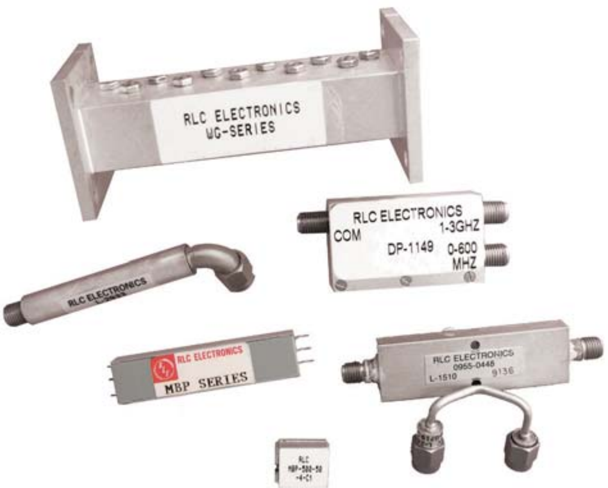
Since its inception in 1959, RLC Electronics has been a leading designer and manufacturer of high quality, state-of-the-art coaxial switches and filters up to 65 GHz, as well as power dividers, couplers, attenuators, detectors and other transmission line components beyond 40 GHz for the microwave industry. Many components are available in either surface mount or connectorized packages, designed to meet specific customer requirements both electrically and mechanically. RLC also has the ability to combine multiple functions into an integrated assembly. Typical applications for military and commercial use include calibration services, ATE, EW and assembly miniaturization and consolidation.

Since RLC has a vertically integrated facility in Mt. Kisco, cycle times for engineering models or prototypes are very short. Through cost containment, RLC is able to provide very competitive pricing. The present plant combines areas for research and development, metal fabrication, assembly, quality control, environmental testing, and general and administrative offices in twenty thousand square feet. RLC is also the only worldwide QPL (Qualified Parts List) switch provider. This is critical because the Quality and Reliability controls that are used to build QPL switches are incorporated into all of the switches that RLC manufactures. In addition, RLC is ISO 9001certified and the assembly technicians have been trained to IPC workmanship standards.



With its broad breadth and depth of RF product and intellectual capital, RLC Electronics is able to support many different requirements. Currently, a large portion of our internal R&D efforts have focused around designing more compact devices (surface mount and connectorized) that have the ability to go higher in frequency. RLC has recently launched a phase trimmer series operating from DC-50 GHz. Additionally, we have continued to expand our switch offerings and can now offer a SP12T latching switch (terminated or un-terminated), in addition to miniature surface mount SPDT or Transfer switches with indicators (less than 1 square inch). Custom assemblies integrating a selection of our components into a single package are part of our ongoing design capabilities, with RLC offering products such as switched filter assemblies, multi-switch modules and switchable couplers, to name a few. As a vertically integrated company, RLC can support the customer through the complete product and program life cycle.

CMOS TRANSCEIVERS WITH ON-CHIP ANTENNAS COULD SUPPORT HYBRID CAR ENGINES

HYBRID CAR ENGINES represent an extreme environment for electronics: High-performance, high-speed, durable designs are required to handle the hostile environments, high voltages, and control requirements of the motor drives. Since motor control systems are necessarily low-voltage systems, the high-voltage motor drive (HVMD) and low-voltage-control (LVC) sections are traditionally connected through photocouplers. Unfortunately, these have an expensive per unit cost and relatively low speeds (1 Mb/s).

At Taiwan's National Changhua University, Kyujin Oh, Swaminathan Sankaran, Hsin-Ta Wu, and Jau-Jr Lin designed a full-duplex crystalless CMOS transceiver with an on-chip antenna using the UMC-130 nm CMOS process. These devices would allow for communication of vital engine data like temperature and faults from the HVMD to the LVC, all the while protecting the LVC from any high-voltage conditions.

The potential for lower costs—as well as for higher data rates up to 400 Mb/s—could make this integrated approach a feasible cost and performance solution for hybrid car motor control. See "Full-Duplex Crystalless CMOS Transceiver With an On-Chip Antenna for Wireless Communication in a Hybrid Engine Controller Board," *IEEE Journal of Solid-State Circuits*, June 2013, p. 1327.

GRAPHENE-BASED PHASE SHIFTERS PAVE THE WAY FOR THz CHIP COMMUNICATION

IN THE NEAR future, vector modulators, beamforming networks, phased-array antennas, and phase discriminators made from integrally gated graphene-based waveguides may allow for the realization of sub mm-wave electronic switches and tunable loaded lines. At the University of Texas at Austin, terahertz (THz) antenna phase shifters made from integrally gated graphene parallel-plate waveguide (GPPWG) transmission lines have been proposed by Pai-Yen Chen, Christos Argyropoulos, and Andrea Alu. They were shown in demonstrations to exhibit low loss, compact size, low phase error, and wide phase shift ranges for enhanced phase tuning capabilities.

These results could be attributed to the strong surface plasmon polariton wave localization of the graphene-based waveguides used in the designs. Other potential advantages include the capability to tune the propagation constant and the characteristic impedance of the waveguides by controlling the doping of the graphene components.

To solve the possible matching issues with loaded-line phase shifters, multistage GPPWG tunable matching networks could be placed between the loaded lines. These matching networks would be tuned by biasing the graphene layers to achieve the desired phase shifts. Analog phase shifters in the THz frequency range could be realized by creating variable inductors from GPPWG by adding a graphene monolayer.

Practical high-speed digital phase shifters require stable high-speed switches. A GPPWG switch could be the solution when integrated with a double gate, enabling the use of the gate voltage for controlling the switch electrically with a biased gate section. See "Terahertz Antenna Phase Shifters Using Integrally-Gated Graphene Transmission-Lines," *IEEE Transactions On Antennas And Propagation*, April 2013, p. 1528.

MM-WAVE OFF-BODY TEXTILE ANTENNA ARRAYS FIND ON-BODY OPPORTUNITIES

WEARABLE ANTENNAS FOR body-centric communications have been attracting increased interest, owing to their potential benefits for firefighters, police, soldiers, and even medical applications. Off-body antennas have the capability of working with on-body communication systems and taking the leap to sharing that information with other networks. At the University of Rennes in Rennes France, James D. Krieger, Chen-Pang Yeang, and Gregory W. Wornell have explored techniques to solve the challenges of fabricating mm-wave antenna arrays on commercially available textiles.

Finding fabric capable of supporting the tight electrical and mechanical requirements of mm-wave technologies is a challenge. With the combined use of ShieldIt Super (a nickel- and copper-plated rip-stop nylon) as a ground plane, and laser-machined copper foils for feed lines and radiating elements, the right amount of performance and flexibility can be achieved.

The performance properties of common textiles (e.g., cotton from T-shirts) were analyzed for substrate properties with an insertion loss of 1.6 dB/cm at 60 GHz, a relative permittivity of 2.0, and a loss tangent of 0.02. A single-layer microstrip-fed four-patch antenna array was chosen for the design; it exhibited less than 10-dB reflection loss in the 57-to-60-GHz range for all prototypes.

A mm-wave semi-solid phantom was used to mimic the properties of the human body, with results showing minimal loss. Though the radiation patterns of the antenna array are affected significantly under several bending and crumpling conditions, the overall reflection coefficient, radiation pattern, and gain performance remain adequate. See "60-GHz Textile Antenna Array for Body-Centric Communications," *IEEE Transaction on Antennas and Propagation*, April 2013, p.1816.

(continued from p.19)

and more reliable units for a given frequency range than any of the other solid-state amplifier types. The firm offers both GaN amplifier modules and complete amplifier systems with power supplies in a rack-mount housing.

As an example of the former, model BBM3K5KKO is a compact Class AB linear GaN power amplifier design capable of 100 W minimum output power and 125 W typical output power from 500 to 2500 MHz. It provides 50-dB minimum power gain with -20 dBc typical harmonic levels and −70 dBc typical spurious levels. At a package size of 7.4 × 3.6 × 1.06 in., it consumes 10 A from an external +28-VDC supply. It is also available as a rack-mount unit with the power supply inside the housing.

Of course, DARPA wouldn't enjoy its successful track record in research without "hedging its bets" and investing in a number of different technologies for high-frequency amplifiers. The organization still believes that silicon technologies will support high-frequency amplification through millimeter-wave frequencies.DARPA's Efficient Linearized All-Silicon Transmitter ICs (ELASTx) program is seeking novel approaches for increases in power amplifier efficiency, while at the same time achieving improved linearity by way of integrated linearization architectures. One of the goals of the program is a silicon-based transmitter with 65% power-added efficiency (PAE) with low distortion for 64-state quadrature-amplitude-modulation (64QAM) waveforms. The program is looking at bandwidths of 3.5 GHz at 45 GHz, 5 GHz at 94 GHz, and 8 GHz at 138 GHz for these next-generation silicon amplifiers and transmitter ICs.

An important design goal for many applications is sufficient amplifier power for a lightweight package, especially in airborne applications or in satcom systems. Amplifiers for the latter, such as the JDMW-Series amplifiers from MITEQ (www.miteq.com), are low-noise amplifiers (LNAs) designed to operate from 18 to 21 GHz with 30-dB gain in a hermetic package measuring just 1.18 × 0.87 in. and weighing just 23 g (*Fig. 1*). These LNAs feature a noise temperature of 97 K (a noise figure of only 1.25 dB) with current consumption of only 75 mA at +12 VDC. The amplifier has an operating temperature range of −30 to +65°C and yields +8 dBm output power at 1-dB compression. The amplifiers are available with numerous options, including RF input limiters and waveguide flanges.

For any RF/microwave amplifier technology, delivering consistent performance levels with high reliability is an important goal whether the amplifier is for low-noise or power applications. As an example, the model ZHL-100W-13+ power amplifier from Mini-Circuits (www.minicircuits.com) is designed to withstand short-circuit and open-circuit operating conditions even when running at full output-power levels, but depends on a heat sink to dissipate excess heat (*Fig. 2*). The amplifier is also designed to be unconditionally stable under a wide range of operating conditions. The transistor amplifier is rated for 100 W typical saturated output power from 800 to 1000 MHz but is also usable from 750 to 1050 MHz. It provides 50-dB typical gain with gain flatness of typically ±1 dB from 800 to 1000 MHz. Supplied with SMA input connectors and Type-N output connectors, it draws 10 A at a typically supply of +28 VDC. The amplifier, which has a typical noise figure of 7 dB, achieves +49 dBm typical output power at 1-dB compression and +50 dBm typical output power at 3-dB compression.

To achieve the high reliability, users are asked to provide proper heat sinking and heat removal from the amplifier, ensuring that its making base-plate temperature is +60°C to ensure proper performance. Users can establish favorable long-term conditions for the amplifier by supplying a heat sink with thermal resistance of 0.035°C/W or better.

In spite of the excitement about GaN technology, solid-state amplifiers have not yet replaced RF/microwave tubes and amplifiers based on vacuum tubes. Such amplifiers may be considerably larger than solid-state amplifiers for the same frequencies, but they are also capable of much higher continuous-wave (CW) and pulsed output-power levels. It is the hope of organizations such as DARPA that vacuum tubes may one day be replaced at high frequencies by solid-state amplifiers with much higher power densities than possible today. But for now, tubes and transistors coexist fruitfully in RF/microwave applications. mw

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