Vol. 58 • No. 12

December 2015

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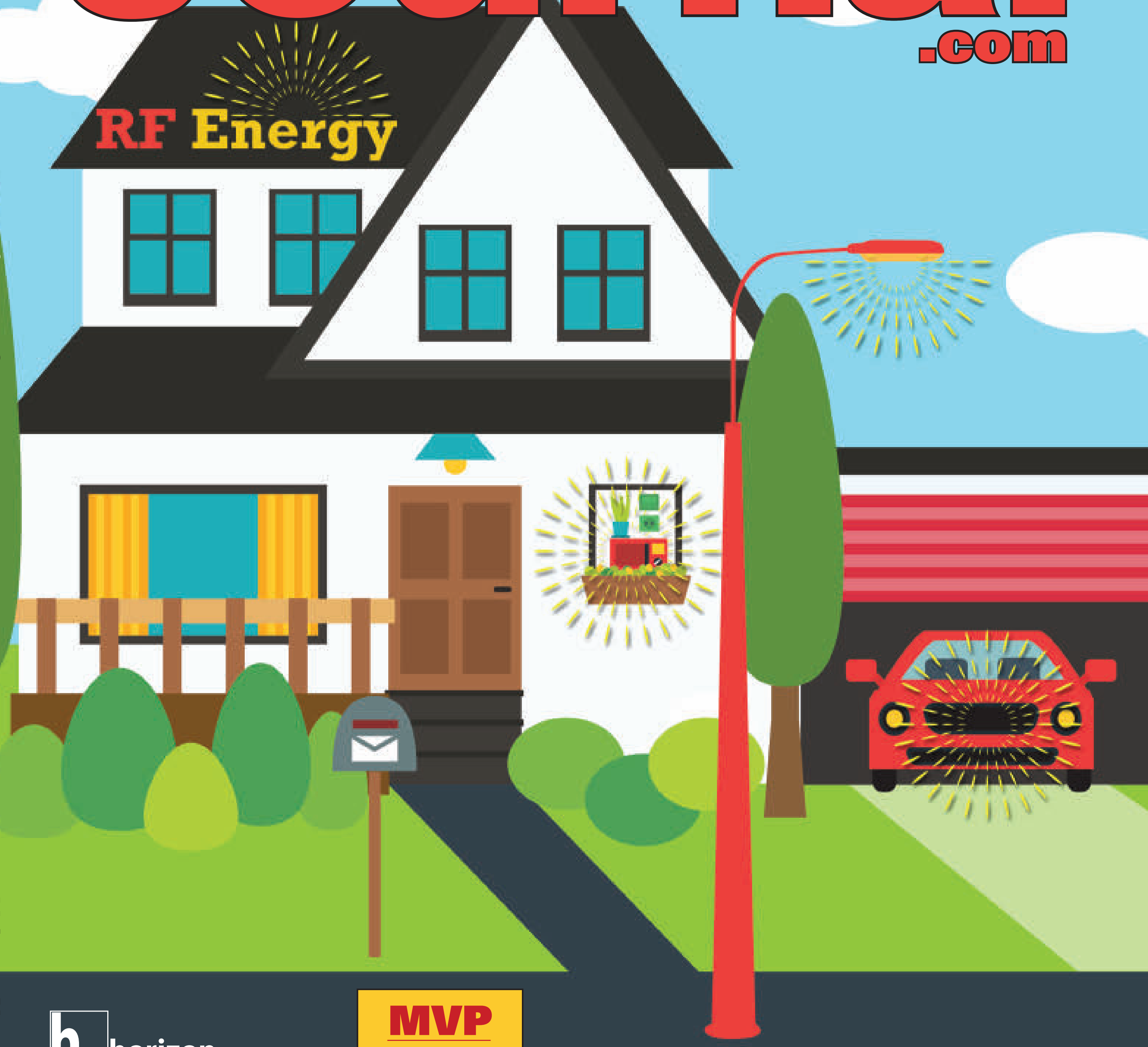

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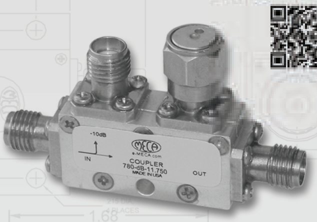

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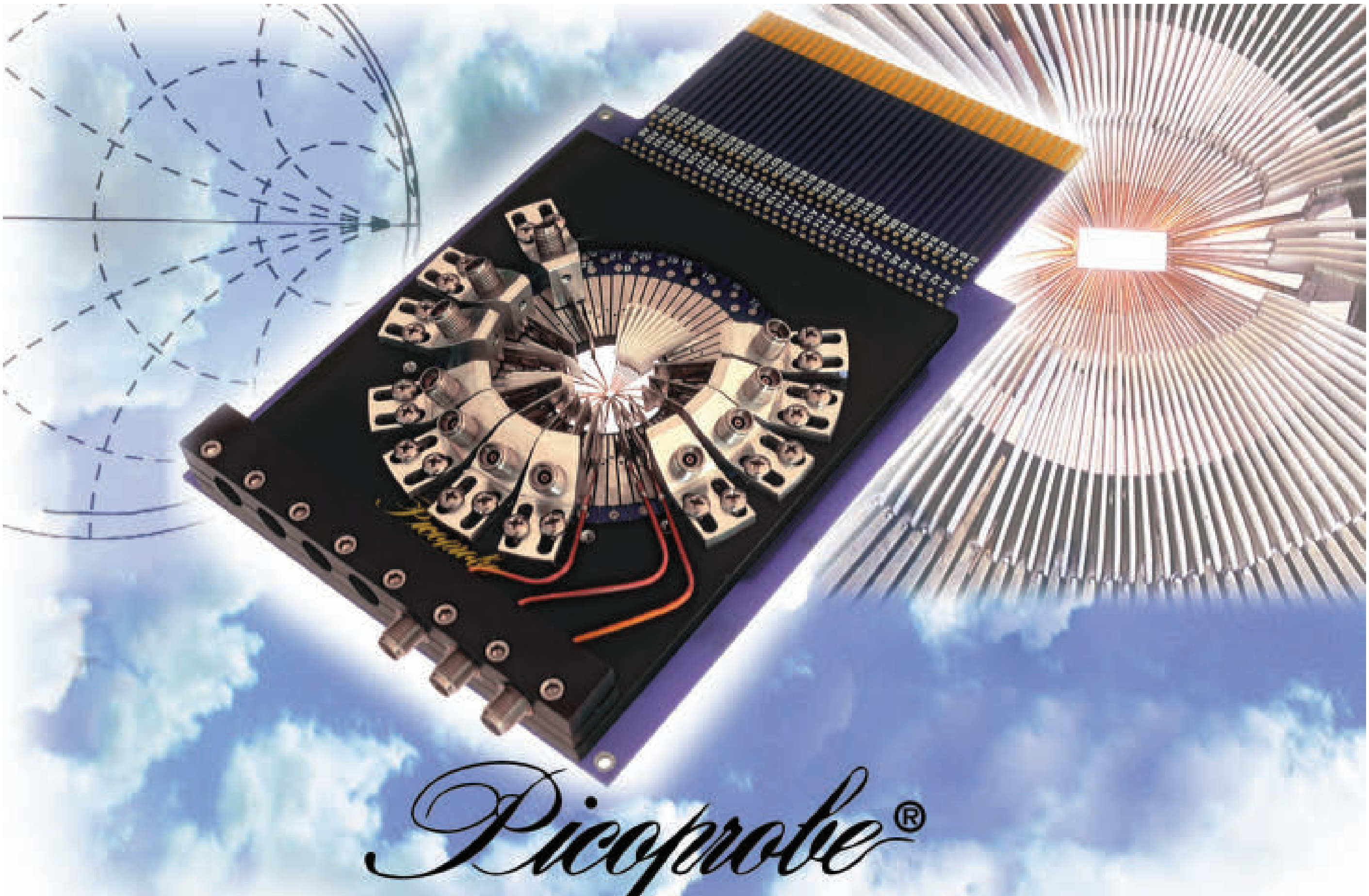

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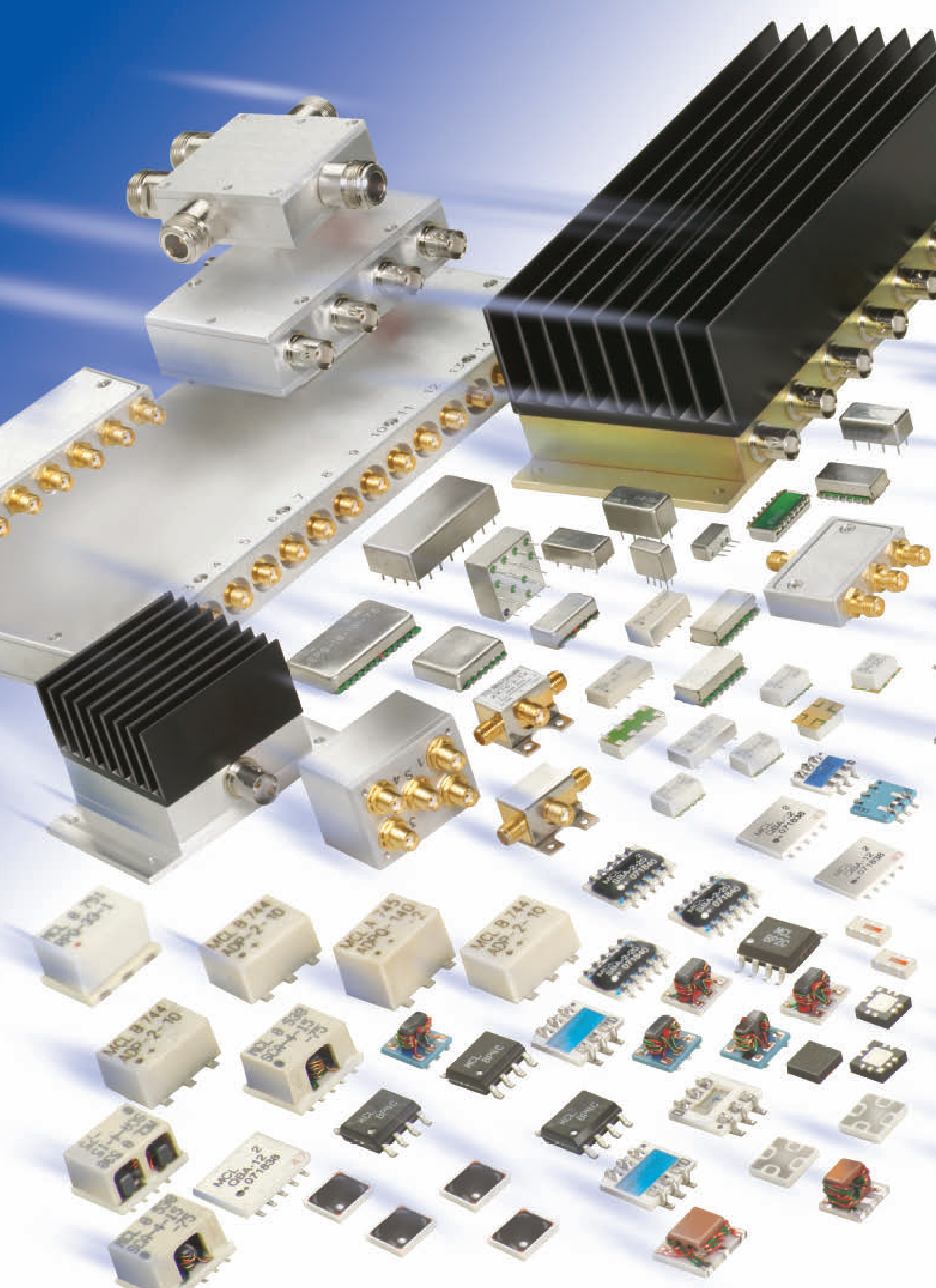
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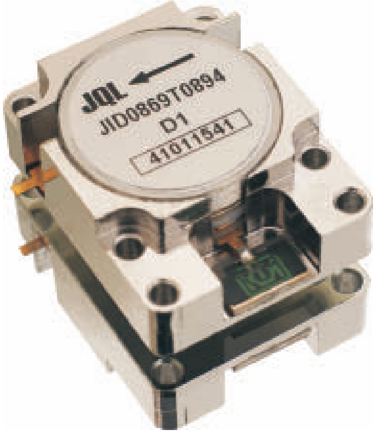

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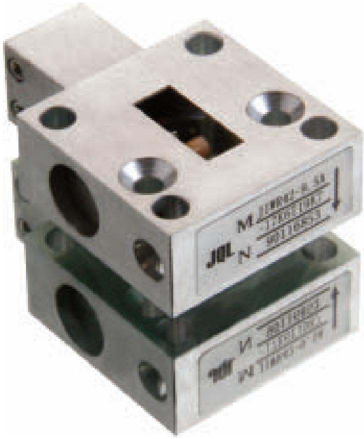
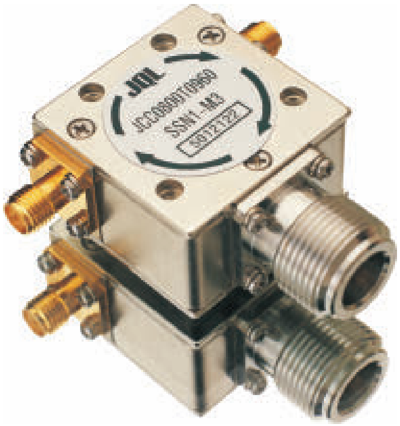
Cavity Filters

Surface Mount Circulators



Waveguide Isolators

Power Combiners



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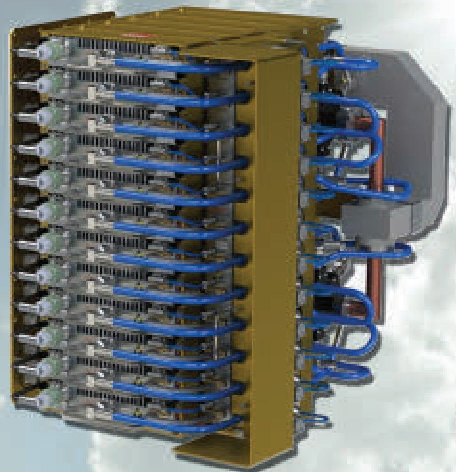
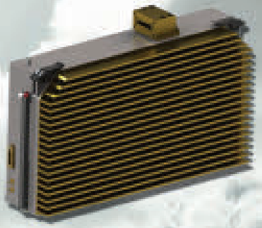
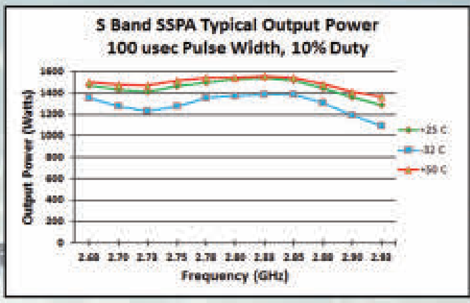
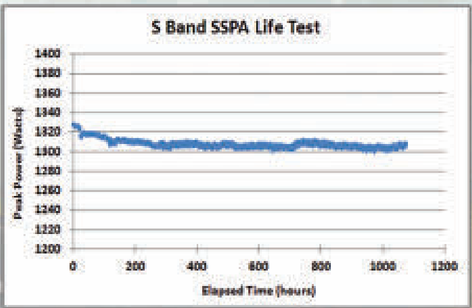


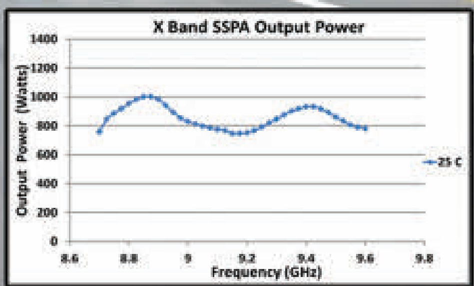


X-Band

GaN Solid State Amplifiers







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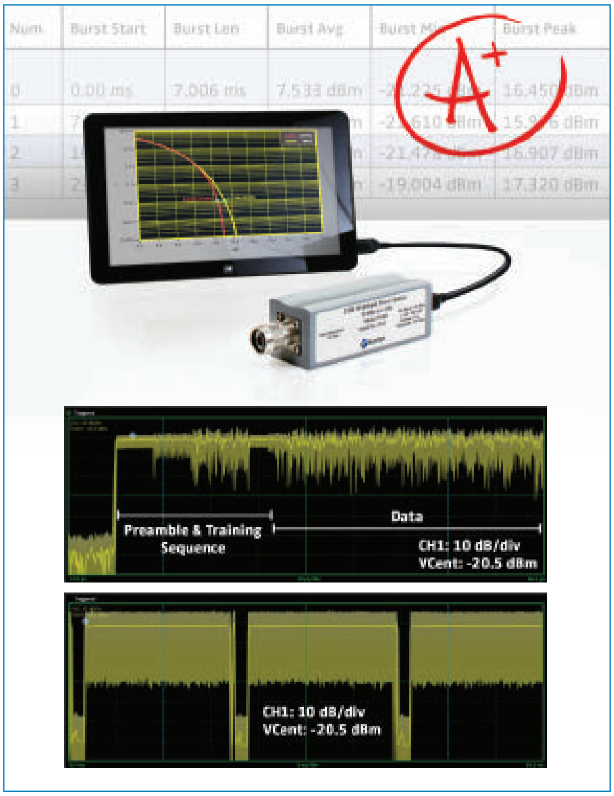

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CONTENTS

December 2015
Vol. 58 • No. 12
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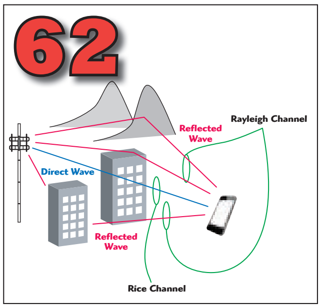

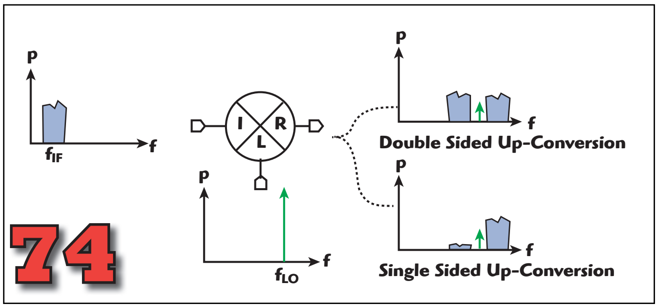

Editor's Note

Cover Feature

MVP: Most Valuable Product

Technical Feature

Application Note

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CONTENTS

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Critical Aspects of Dielectric Constant Properties for High Frequency Circuit Design
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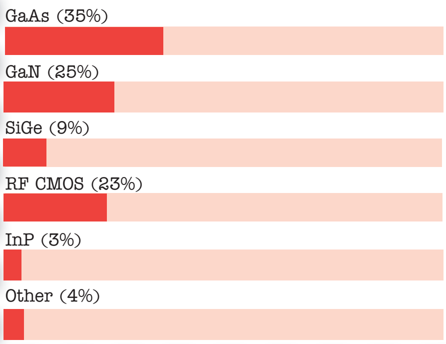
October Survey

What IC process technology are you principally designing with?



Executive Interviews

Oren Hagai, founder and CEO of **Interlligent RF & Microwave Solutions** explains the motivation for originating the company in Israel in 2000, the establishment of a U.K. subsidiary and his plans for the future.

Yu-Chi Wang, CEO of **WIN Semiconductors**, discusses how the world's largest compound semiconductor foundry is serving the present and future needs of the RF market.

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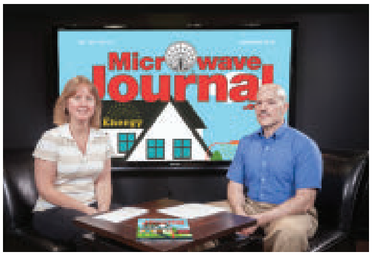

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4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4.5dB
4.0dB
2.8dB
2.8dB
2.5dB
1.8dB
1.5dB
1.3dB
1.2dB
1.2dB
0.9dB
0.7dB
0.5dB
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A Year of Transformation

Patrick Hindle, Microwave Journal *Editor*

The RF/microwave industry saw a year of chaos with unprecedented industry consolidation, especially in the semiconductor arena. Early 2015 marked the launch of Qorvo as a result of the merger between TriQuint and RFMD. The big move of the year was NXP's acquisition of Freescale. This resulted in such a large market share in the RF power area that NXP was forced to sell its RF power business in order to avoid possible regulatory issues. Cree is planning an IPO for its power and RF GaN business, now known as Wolfspeed, so that it can concentrate on the semiconductor market without being distracted by the much larger LED business. Murata acquired Peregrine to add a semiconductor supply to its module business. MACOM has transformed itself into a serious player in the optical market with acquisitions over the last few years including Mindspeed, FiBest and BinOptics. The company is also continuing its push to mainstream GaN on Si technology with its previous acquisition of Nitronex. At press time, Skyworks and Microsemi were bidding against each other for PMC-Sierra, but Skyworks' agreement was terminated by PMC-Sierra so looks like Microsemi will win the bidding war. And it looks like the last GaAs company from the 80's has been bought as John Ocampo's GaAs Labs is acquiring Anadigics.

There were other large acquisitions peripheral to our industry such as the Broadcom purchase by Avago, Altera acquisition by Intel and Fairchild acquisition by ON Semiconductor. I think the consolidation will continue into 2016 and expect it to spill over into other sectors such as software and test equipment — we have already seen some acquisitions such as Focus acquiring Mesuro and the assets of Auriga followed by Maury acquiring Anteverta-MW. Keysight Technologies had a couple of significant acquisitions — acquiring test and measurement company Anite and service market company Electroservices Enterprises. The Anite acquisition strengthens Keysight's 5G capabilities, and their expansion into the services market is a key area for future growth. National Instruments also made an acquisition of BEEcube, further strengthening their 5G efforts as Keysight and NI joust for leadership in the 5G test arena.

The hot topics this year were certainly 5G and the Internet of Things (IoT). As 5G research continued its strong momentum into 2015, IoT finally emerged as an active area for broad commercialization. This includes a wide variety of applications such as M2M, V2V, smart cities, IIoT and wearables. The Industrial Internet of Things (IIoT) is projected by some to be the largest single sector for wireless devices, rivaling the size of all of the others put together, so look for many companies to concentrate on this sector.

Some key enabling technologies are very low power devices/networks, AESA radios, alternative modulation schemes, highly integrated RF Si platforms and low cost GaN. The commercialization of previously expensive RF technologies will allow these new applications to take off. A couple of examples are the highly integrated, low cost AESA chips available from Peregrine (monolithic phase and amplitude controllers) and Anokiwave (X-Band radar quad core ICs) in addition to low cost GaN platforms from Qorvo (6 inch GaN line) and MACOM (GaN on Si, possible 8 inch GaN) both using plastic packaging to 100 W.

For the last year we have been following the RF Energy Alliance (RFEA), an organization dedicated to fostering solid-state RF energy's potential as a clean, highly efficient and controllable heat and power source. As our cover feature reviews this area of development, the RFEA envisions a fast growing, innovative marketplace built around this sustainable technology, one that will be a huge contributor to quality of life across many applications. The non-profit technical association was founded in September 2014 by E.G.O. Elektro-Gerätebau GmbH, Huber+Suhner, ITW, NXP Semiconductors, Rogers Corp. and Whirlpool Corp. Along with fellow members, these companies standardize, promote and educate target audiences in solid-state RF energy systems such as heating and power generators.

One of the largest markets that could benefit from solid-state RF power is the cooking/drying industry that currently uses less efficient and less reliable magnetrons. There are 70 million microwave ovens

Solid-state microwave oven demonstration video

sold globally each year, so this is a very large market in itself. Microwave ovens with solid-state RF power sources can precisely control the amount of energy delivered to different parts of the chamber and dynamically adjust the power so that different types of foods cook evenly together in the chamber. It is envisioned that these new ovens would eventually be connected to the Internet, equipped with the capability of downloading recipes and cooking times automatically. There are also more than 11 million industrial drying machines sold each year, so this is another large market with similar needs.

One of the key technologies that would enable these changes is designing a highly efficient, low cost solid-state RF amplifier. The goal that has been set by the RFEA is to develop amplifiers with an output power of 300 W (CW) with better than 70 percent efficiency at a price point of $12 per module (using 2.54 GHz as a standard frequency). This is a tall order but with improvements in LDMOS and GaN technology, it could be possible in the near future to reach these technical goals. With GaN going to 6 (and maybe 8) inch wafers soon and new high power plastic packages being developed, we could see a huge price reduction in high power RF modules. The RFEA expects to create an RF amplifier specification by the end of 2015 and system integration guidelines by the end of first quarter 2016. We will keep an eye on these developments as we may all be using RF solid-state technology very soon.

It was a big year for *Microwave Journal* as we strengthened our presence as the top media company in the RF/microwave industry as well as our leadership in organizing RF/microwave events. With the completion of our third successful EDI CON China event in Beijing this year, we announced the launch of EDI CON USA, taking place in Boston, Mass., September 20-22, 2016 at the Hynes Convention Center. *Microwave Journal*/Horizon House now organizes EDI CON China, EDI CON USA and European Microwave Week (on behalf of the European Microwave Association), covering the world of microwave technology. We look forward to another successful year serving our loyal readers and clients. We hope to see you at one of our events in 2016. Happy Holidays! ■

COVER FEATURE
INVITED PAPER

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RF Energy Systems: Realizing New Applications

Klaus Werner
RF Energy Alliance, Beaverton, Ore.

With an ever-increasing performance-to-price ratio, coupled with unprecedented, precise radio frequency (RF) signal control, practical use cases for solid-state RF technology are expanding to include heating and power delivery. As a result, the technology is penetrating fields that were previously considered impossible, such as tube-based systems (for example, automotive ignition, medical imaging and cancer treatment) or high barrier markets (for example, industrial and consumer microwave furnaces/ovens) that are dominated by cost-effective magnetron sources.

The new markets present ultra-high volume opportunities for businesses operating directly and peripherally in the RF technology industry. They also present alternative revenue potential to currently maturing markets such as cellular infrastructure.

The design of solid-state RF energy systems requires engineering knowledge that is not generally available, due to RF engineers occupied with "linearized amplifier" systems for data transmission or concerned with magnetron sources for heating applications. There is a general lack of design knowledge with respect to applying solid-state generated RF to additional, less-focused-upon RF energy systems.

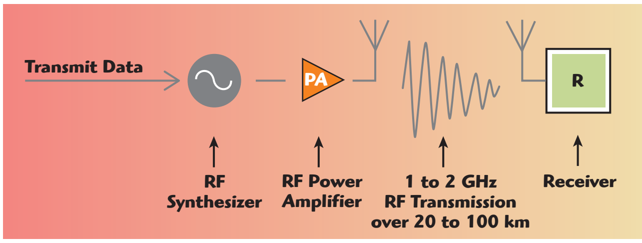


Fig. 1 Typical data transmission block diagram.

This article will cover a number of economic and technical challenges associated with the system design of a solid-state RF energy system. It will also present the RF Energy Alliance's vision on how the solid-state PA module will develop into a commodity in the next three to five years. Throughout the discussion, RF and microwave are used synonymously.

TECHNOLOGY BACKGROUND

All modern communications — cellular telecommunications, radio and video broadcasting, Wi-Fi and Bluetooth at a lower power level — make use of complex, highly modulated RF signals that are generated and amplified by solid-state, semiconductor devices. Solid-state technology replaced the legacy, tube-based technologies some time ago for reasons of reliability and ease of use.[1]

Solid-state RF generation and amplification technology can also be used to "power" a localized chemical or physical process, rather than to transmit data. This gives rise to the notion of "RF energy" applications in contrast to the data transmitting uses. Examples of RF energy applications are industrial heating,[15,16] microwave furnaces,[11,15,16] RF plasma lighting,[4,5] automotive plasma ignition,[6] microwave assisted chemistry,[17] medical cancer treatment,[7] and many others.

Figure 1 shows the different building blocks for high power RF generation and radiation for either data transmission or RF energy use. An important distinction between the data transmission systems and the RF energy sys-

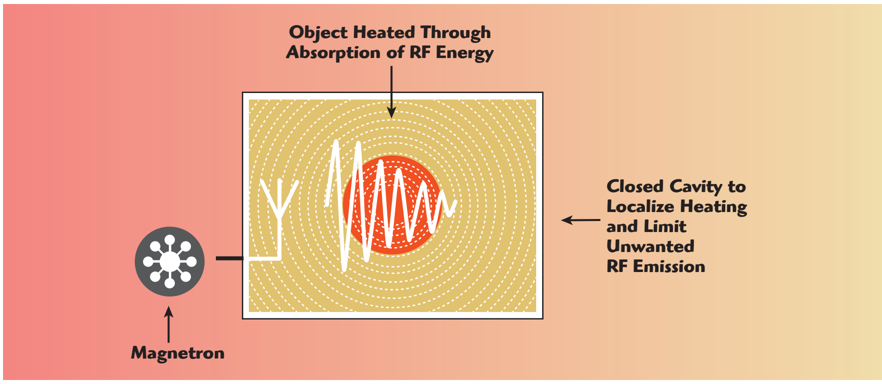


Fig. 2 Magnetron tube powering RF energy application.

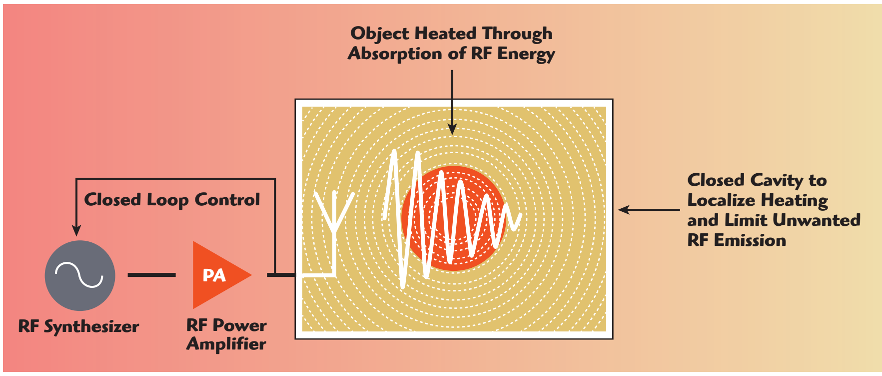


Fig. 3 Solid-state powered RF energy application.

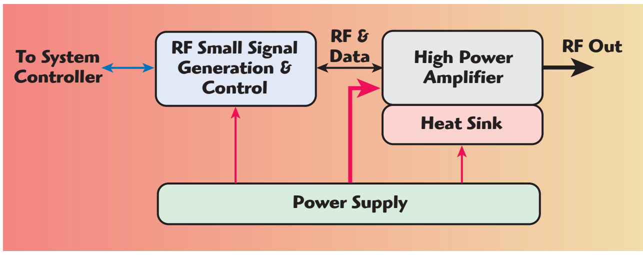


Fig. 4 Block diagram of a solid-state RF generator system.

tems, shown in ***Figures 2*** and ***3***, is the need for highly modulated signals in the data transmission case. Power amplifiers must run "backed-off," which means that they are less efficient than amplifiers that run saturated, which is easily achieved for RF energy applications. RF energy applications typically make use of an RF-tight cavity that contains the load to be processed and into which the RF is irradiated with an antenna. In contrast, the RF used for data transmission is irradiated into free space (see Figure 1).

Another important difference between tube-driven and solid-state-driven RF energy applications (see Figures 2 and 3) is the presence of feedback for the solid-state driven applications. Forward and reflected power levels can easily be assessed; energy levels put into the load can be readily measured and tracked during the process.

The next difference is the capability of solid-state systems to change the frequency — typically within an industrial, scientific and medical (ISM), unlicensed frequency band. The application controller is able to determine the exact cavity/load conditions during the process (VSWR), and can react accordingly.

Solid-state systems are relatively flexible with respect to the number of channels and/or solid-state power amplifiers "around" a processing cavity. This allows power scaling with the number of channels, and the independent (different frequencies per channel) or coherent (same frequency with particular phase offset) RF drive of the process. With the multimode cavity (a high Q structure), this offers system designers a choice to actively control the electromagnetic field distribution inside, which is one of the formidable technological challenges to these systems.

A complete solid-state RF generator subsystem typically consists of:

- Small-signal generation part optionally co-located with a microcontroller
- High power amplifier (basically a gain block) connected to a heat sink
- Power supply to deliver the various voltages and currents to drive the respective electronics.

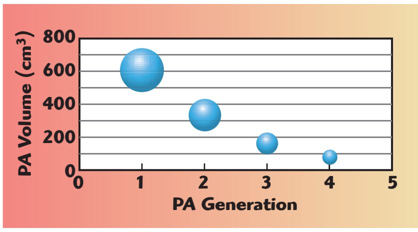
Figure 4 depicts a block diagram for such a system. The "RFout" connection leads into an RF applicator that is a cavity or otherwise confined environment holding the medium to absorb the RF radiation and provide the necessary EMC shielding.

The solid-state RF power generator allows complete freedom and control over the frequency, output power level, phase and "modulation" of the RF signal. "Modulation" here means switching the RF signal (on/off) over time and/or changing the output power level — both can happen very quickly within microseconds. Furthermore, feedback on forward and reflected RF power is usually built into the amplifier; in more involved cases, even phase measurements can be carried out for complex S-parameter measurements.

VALUE PROPOSITION

The previously mentioned measurements, extreme degree of control of RF signal parameters and solid-state semiconductor nature of the system lead to the following possibilities and advantages over magnetron-powered systems:

- Great reproducibility and repeatability
- Precise control over power levels and energy doses
- Enhanced process control — higher yields
- Very high reliability of the generator — no unpredicted down time or production loss
- No single point of failure in industrial or scientific systems
- Utilization of full ISM band bandwidth
- Dynamic frequency "hopping" and/or phase shifting
- Homogeneous energy distribution inside cavity
- Efficient use of the generated RF energy
- Very agile control of the RF signal (frequency, phase, on/off, gain,



▲ *Fig. 5 Size/volume development of PA modules over time.*

etc.)

- Fast load condition feedback to tune RF signal and process; for example, prevent damage upon arcing
- Spectrally clean frequency source; predictive use of frequency hops; benefit to co-existent wireless communications technologies
- Low voltage electronics – easier maintenance, easier integration, smaller size
- Compatible with electronics cost base.

ECONOMICAL ASPECTS

Although the process advantages of the technology are compelling, widespread use has yet to catch on. So far, the technology can be found within medical and professional applications. Industrial use (replacing large magnetron tubes) is slowly taking hold, and applications for the consumer space are currently in development.[8] The foremost reason for the slow adaption is cost — next to the knowledge gap.

The RF Energy Alliance[8] has set out to tackle this chicken-or-egg problem by bringing together all stakeholders in the solid-state RF supply chains and ecosystems. The organization presents a leadership role to create awareness and roadmaps to overcome these barriers to entry. The alliance works towards standardization of RF energy components, such as PA modules, their respective software and hardware interfaces, integration with power supplies, cooling systems and overall spec points. This will enable the original equipment manufacturers (OEM) to focus on the application development, knowing exactly what will be available in terms of functionality, size, efficiency and price. This strategy avoids investments in the "wrong" technologies, allows perfect timing of volume manufacturing investments and greatly simplifies the integration work for the OEM. Ideally, the resulting ease of use will give rise to swift development of current and new applications such as RF lighting, medical ablation and RF plasma ignition for automobiles.

Existing applications for the higher volume markets will benefit from standardization. Reduced prices, improved performance and standardized components will also allow a competitive landscape with small barriers to switch among hardware suppliers. The latter may cause some concern, but the opposite is true: the markets are so large that there will be enough business for a number of suppliers. The OEMs will demand a flexible supply chain with at least two suppliers so that manufacturing and/or quality problems can be alleviated, ramp-ups can be faster and the business risk reduced. Standardization will enable seamless transitions.

The Alliance is currently finalizing its "power amplifier roadmap" that will specify sizes, efficiencies, RF output power levels, RF power measurement and ruggedness, cost targets and availability, amongst various other functionalities. ***Figure 5*** shows the development of the power amplifier module volume (length × depth × height) across the currently foreseen generations. RFEA-Gen1 corresponds to currently available, state-of-the-art PA modules. We see a stunning reduction in size that will greatly enhance the designer's freedom to place the PAs.

Interestingly, the target cost for the PA modules follows a similar graph. The Alliance targets $12 per 300 W power amplifier module with 70 percent efficiency in the near future. As unrealistic as this number currently sounds, the Alliance remains confident and defends this claim.[8]

DESIGNING AN RF ENERGY SYSTEM

When it comes to conceiving an RF energy system, a system architect must cover the "usual suspects" like power supplies, thermals, digital interfaces, microcontrollers and firmware, as well as the intricacies around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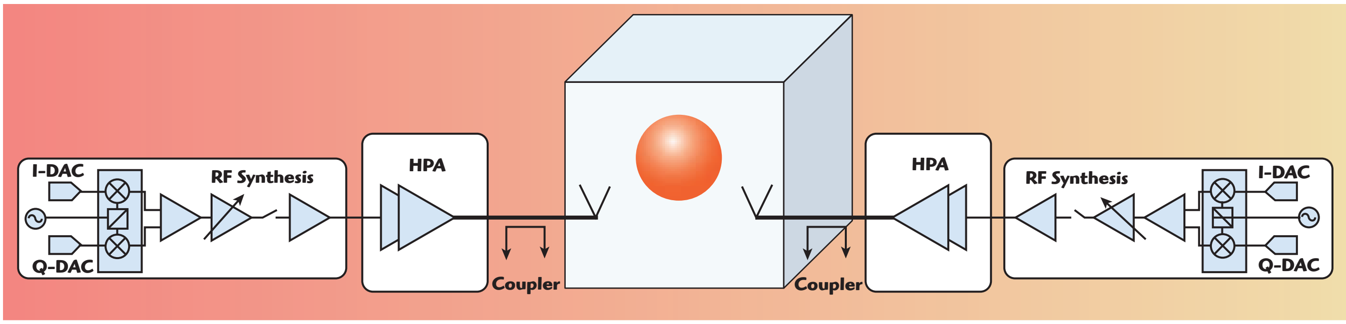


Fig. 6 *Schematic of applicator with two RF feed lines, i.e., two channels.*

RF signal generation, amplification and "injection" into the applicator. Here, we will concentrate on the RF system aspects, rather than the more common ones:

- Applicator used
- Number of RF channels
- RF signal generation (frequency, gain, phase, resolution, etc.)
- Total RF power required
- PA thermals
- RF operation
- Ruggedness
- Homogeneous energy distribution
- Real-time process control.

Applicator

The "applicator" in the RF Energy system denotes the enclosure or, more generally, the environment in which the RF radiation is applied towards a particular load. The load can be most anything: to make sense, however, it should absorb all or at least part of the incident radiation.

In general, the applicator environment is a metal casing that encloses the load to define the "active processing volume" and to prevent RF radiation leaking into the environment (see ***Figure 6***). RF energy systems are running up to megawatts of RF power – there is no room for leakage. A more subtle requirement along these lines is imposed by the necessary coexistence with communication technology like Wi-Fi, Bluetooth and ZigBee. The applicator brings about a number of design choices, boundary conditions and issues concerning the industry.

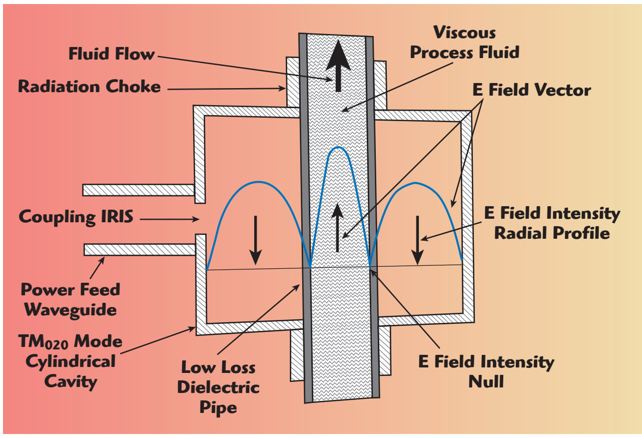


Fig. 7 *TM_{020} cavity to process liquids.*[10]

Enclosed Volume = Cavity

In our frequency range of interest, typically enclosed volumes with metal walls are used to establish a resonating structure with quality factor Q and maintain eigenmodes, that is standing wave patterns, which in turn depend on the geometry of the cavity in connection with the wavelength of the irradiated RF.[9]

On the one hand, a cavity width cannot be smaller than roughly half the wavelength of the RF signal to be injected; below this cutoff, no RF

energy can be injected. Above this cutoff, "single mode" cavities take shape, which can be round or rectangular waveguide structures. Depending on the chosen geometry, either transverse electric modes like TE_{101} or transverse magnetic modes TM_{010} develop that can be used for efficient energy transfer and/or sensitive measurements of dielectric properties. To give an example (see ***Figure 7***), liquids can be heated efficiently when flown through the highest field volume inside the cavity, in this case a TM_{020} applicator.[10]

On the other side of the spectrum, there are cavities that are large in comparison to the deployed wavelengths: multi-mode cavities. As the name indicates, a number of modes can be excited within the cavities depending on the geometry, the absorption of the load and the RF frequency. Generally speaking, the larger the cavities with respect to the wavelength, the more modes can be formed. For a typical household 2.45 GHz magnetron cavity, the number of modes is on the order of 15.[9]

The frequencies at which resonance can occur for an empty cavity are governed by the following equation:

$$f_0 = \frac{c_0}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{k}{l}\right)^2} \quad (1)$$

where f_0 (Hz) is the resonant frequency of mode TE_{mnk} or TM_{mnk} for a rectangular cavity with dimensions a, b, and l (meters), and c_0 is the speed of light. Please note that "double-zero" modes cannot exist and others may be degenerate (TM and TE modes at the same frequency).[11]

Ruggedness

The existence of the modes also implies RF generators can only deliver energy into the cavities at frequencies corresponding to modes — at other frequencies, the cavity is not impedance matched and the RF power is reflected. This behavior is shown in ***Figure 8***: for an empty cavity (zero or little dissipative load inside) a return loss sweep across the frequency range of 2.4 to 2.5 GHz reveals a number of dips where the cavity is actually matched.

This emphasizes a demanding requirement for all types of RF power amplifiers feeding various RF energy applications. The amplifiers need to be extremely rugged, because more often than not, RF power may simply be reflected. However, it must be accommodated in order to avoid destruction of the power amplifier. A circulator may be used for that purpose. Ideally it should be designed out of the PA to save cost and size. However, without the circulator, the PA design needs to be rugged enough to withstand worst case VSWR ratings, a challenge for both the PA design as well as system level control. For a single channel system (just one amplifier delivering the RF power), the maximum reflected power is as large as the PA's output power. The required ruggedness specification can easily exceed a 10:1 VSWR. This appears manageable with the latest LDMOS[12,13] and GaN transistor technologies.

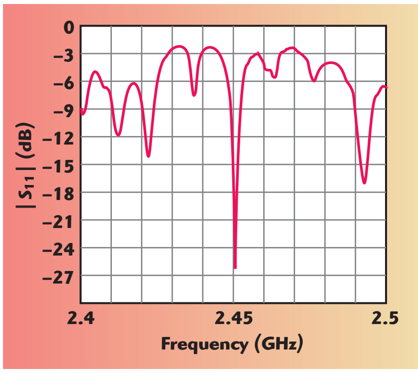


Fig. 8 Empty cavity return loss sweep.

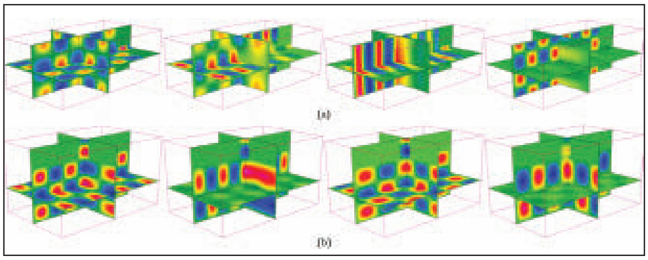
In case of multi-channel systems (more than one amplifier delivering power), the amount of reflected power is not limited to the output of a single PA; rather, it depends on the "matching" of a particular PA via the cavity to the peers surrounding the cavity. Proper system level control algorithms and low level (at the PA), fast protection mechanisms need to be built-in to avoid catastrophic failures.

Number of Power Amplifiers

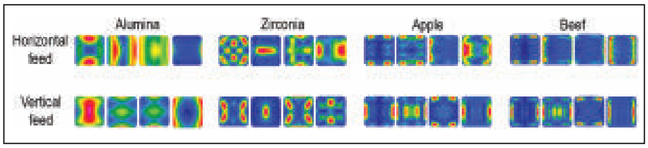
The previous discussion assumed "one" and "more than one" power amplifiers delivering power into a cavity. However, power scaling is a viable option. Current LDMOS power transis-

tors deliver up to 300 W of power at 2.5 GHz out of small packages (2 cm^2). Using a household microwave oven as a reference, three or four RF generator chains are needed to match the power of a typical magnetron.

The total power should always be determined based on the process' needs. The 1 kW for household microwaves, for example, is not an efficient means to cook — it is too much power for most of the cooking/reheating needs. Limited regulation capabilities of the magnetrons do not help either. The surface of food gets superheated most of the time, which leads to dry and overcooked food. 500 to 600 W completely suffices for this purpose. The exception here is for defrosting.



▲ *Fig. 9 Patterns of instantaneous electric field in the rectangular (612 × 400 × 300 mm) cavity excited by a rectangular waveguide centrally connected with the side wall (a) and the top wall (b) at four resonant frequencies in the range of 2.35 to 2.55 GHz.*[14]



▲ *Fig. 10 Patterns of dissipated power in the central horizontal plane through the rectangular (100 × 100 × 20 mm) load centered on the FR4 shelf in the cavity (see Figure 9) at four resonant frequencies in the range of 2.35 to 2.55 GHz.*[14]

One could argue that it might be easier to combine all the PAs' output powers externally or even combine a number of final power transistors inside a single PA module. For the latter, the unwieldy 7/16 connector and associated cable would not be easily integrated for residential use. For industrial use, this is certainly an option, yet still demands very precise design and manufacturing of the high power transmission line structures inside the PA. The main argument to use multiple RF generators, however, is because of the modes inside the cavity and the intention to achieve a homogeneous energy distribution inside the cavity and inside the load.

Homogeneity

The previously discussed modes in multi-modal cavities, which are typically used for heating, cooking and drying processes, do not by themselves provide homogeneous heating inside the load. On the contrary, the localized energy distribution associated with a particular mode will only deliver energy to dissipative loads at those spots. ***Figure 9*** shows the electrical field distribution inside a cavity for various possible modes for a particular cavity.[14] In this case the fields were calculated using the real cavity dimensions and antenna openings, providing a more realistic result than using the empty cavity formula. A single mode will not provide homogeneity, but a number of complementary modes will. By tuning into various modes, the fields inside the cavity can be stirred to an extent that promotes homogeneous energy delivery to the food. The shape and dielectric constant of loads play an important role with respect to homogeneity as well (see ***Figure 10***). Via frequency and phase we have a clear handle on the energy distribution inside both the cavities and load.

We have addressed frequency agility, but the relative phase of the RF signal between the channels in case of a coherently-driven system must be addressed. Coherency here means RF signals for different channels are derived from the same local oscillator, thus running at the exact same frequency. The inter-channel phase difference now becomes a parameter to vary. It is easy to see this phase difference is necessary in this case to optimize the energy delivery — the excitation of a mode needs to happen "in sync" out of the various antenna ports. Electromagnetic simulations (and measurements) show a variation of the phase also affects energy distribution inside the cavity and can be used to enhance homogeneity, albeit less strongly than frequency variations. In that sense, a multi-channel system

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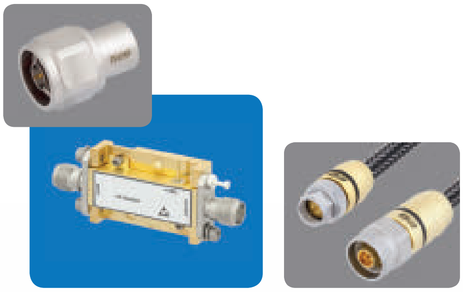

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starts to resemble an "antenna array" which can be electronically scanned.

Briefly returning to the incoherent control mode (different channel frequencies), one should take good care of the intermodulation products created. Out of band frequencies should be avoided unless the shielding comes to rescue. Depending on the position of the various antenna ports, not all possible modes inside a cavity will be excited. The very shape of the mode and its character at the opening of the antenna port may be at odds. In any case, a return loss sweep (see Figure 8) will bring clarity to the current cavity/load situation. Algorithms to promote homogeneity and efficient energy delivery (i.e., at low return loss values) can then be devised and used for proper process control. Given the speed of microcontroller-based systems, the scanning and algorithm development will take very little time and does not interfere with the main process.

The clear discernibility of modes or resonances is a typical feature of a more or less empty cavity (high Q). An increasing dissipative load becomes part of the electrical length of the cavity and the resonance conditions change. Existing modes are shifted to lower frequencies, broaden and eventually vanish completely (low Q),[10] because the RF signal is directly absorbed and does not have a chance to develop a standing wave pattern. In the extreme case of a fully loaded cavity, we end up with no mode spectrum and the homogeneity now becomes a function of penetration depth into the load. Slow thermal conduction or convection inside the load will reduce the temperature gradients.

CONCLUSION

There is a great opportunity to develop a new industry revolving around RF energy applications, and an equally impressive number of potential job opportunities to deploy this technology. The technologies are available, a number of promising applications are being developed and, if things are done correctly, we will soon find this clean, efficient, highly controllable, contactless and selective energy source in our daily lives.

The implementation in a number of possible applications is currently limited by economics and our ability to realize them, rather than by the technology itself. The envisioned standardization driven by the RF Energy Alliance will help reduce barriers to entry and enable the applications of the technologies.

The challenges to build those systems are numerous, requiring significant knowledge on electromagnetics, control and applications. The overall application is an intricate interplay of RF sources with an applicator and variable load/processing conditions in the cavity. The design ingredients covered here hold for all kinds of RF energy systems. Be it an automotive plasma ignition source or an industrial heater, the RF source needs to continuously adapt to the changing cavity/load/resonance conditions to "stay tuned." ■

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New Laminates Enable 79 GHz Technology Advancements

Rogers Corp.
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Millimeter wave (mmWave) applications are looming large on the horizon, from increased use in automotive electronic systems, including automated steering and collision avoidance, to providing bandwidth so severely needed for improved data throughput and video performance in fifth generation (5G) wireless communications systems. But first, new techniques must be developed to affordably fabricate circuits, devices and components for use above 30 GHz. RO3003™ laminates from Rogers Corp. is a circuit board material that provides that much-needed combination of performance and affordability to help bolster current and emerging mmWave applications.

RO3003 laminates are already well established as a circuit material of choice for mmWave automotive sensors and radar systems through 79 GHz because of outstanding performance and material characteristics well suited to those higher frequencies. These ceramic-filled PTFE laminates exhibit a dielectric constant (Dk) of 3.00 in the z-direction (thickness) measured at 10 GHz, with a tightly controlled tolerance of ±0.04. They are affordable because they can be transformed into high frequency circuits using standard PTFE circuit board processing techniques.

The performance of these materials is good at mmWave frequencies because of various material features and characteristics. For example, RO3003 laminates offer low insertion loss (especially with rolled-copper conductors), even at 79 GHz. The material has low coefficient of thermal expansion (CTE), low moisture absorption, low thermal coefficient of dielectric constant (TCDk) and low dissipation factor. Since the material does not rely on glass reinforcement, there is no concern for performance degradation due to glass weave effects. This combination of factors adds up to a circuit material

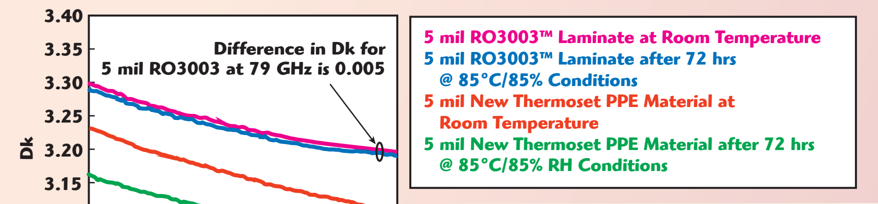

Fig. 1 PPE thermoset circuit materials can lack stability of dielectric constant (Dk) with changing temperature and humidity conditions compared to RO3003.

that is well suited for mmWave applications and can be processed with affordable circuit fabrication techniques.

The low CTE of RO3003 laminates contributes to high printed circuit board (PCB) reliability, especially for circuits using plated-through holes (PTH). Higher CTE values indicate a dielectric material that will expand and contract more as temperatures change, rather than a conductor such as copper, and result in mechanical stresses of the conductor on the substrate and in PTHs over wide temperature ranges. A laminate with CTE of 70 ppm/°C or less is considered good, with an ideal number closer to 17 ppm/°C to match the CTE of copper. RO3003 laminate features CTE values of 17, 16 and 25 for the x, y and z axes, respectively, which are all closely matched to the 17 ppm/°C of copper, yielding excellent reliability of PTHs and other circuit features. Having three-axis CTEs so closely matched to copper is one reason why RO3003 laminate has been used extensively in multilayer PCBs (and their PTH interconnections) for so many years with such good results.

Low moisture absorption is an important trait for high frequency circuit board materials since the Dk of water (≈80) absorbed into the material increases its Dk and dissipation factor. Circuit materials exposed to high humidity environments can absorb water and suffer variations in phase response and insertion loss. When tested at mmWave frequencies, RO3003 laminate fared well compared to a new polyphenylene ether (PPE) thermoset material developed for high frequency use (see Figures 1 and 2). The materials were compared at room temperature (+25°C) and 50 percent relative humidity (RH) and then at elevated temperature (+85°C) and 85 percent RH. In both cases, the RO3003 laminate outperformed the PPE circuit material.

Another important circuit material parameter to consider for mmWave applications is TCDk, which is a measure of how much a material's Dk will change with temperature. For example, the TCDk of RO3003 is -3 ppm/°C. While a value of 0 would be ideal, this TCDk for RO3003 is an extremely low value and less than 50 ppm/°C as an absolute value. It indicates minimal change in the material's Dk over

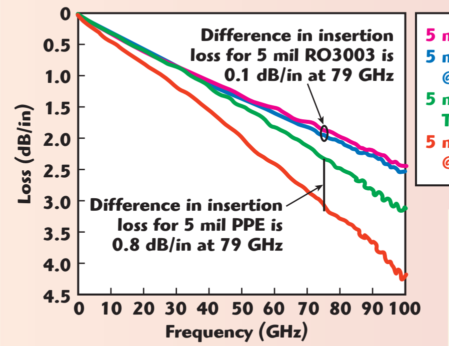

Fig. 2 The insertion loss of RO3003 laminate is considerably less and more stable with temperature and humidity at 79 GHz compared to PPE thermoset material.

its operating temperature range for stable electrical performance, even in hostile environmental conditions faced by many automotive mmWave applications.

Wavelengths decrease with increasing frequency and wavelengths at mmWave frequencies are extremely small, requiring small circuit features. At 79 GHz, for example, and using 5 mil thick circuit material with Dk of about 3, a 50 Ω microstrip transmission line will have a wavelength of about 0.095" or 2.413 mm. A quarter-wavelength 0.024" or 0.603 mm at 79 GHz can cause unwanted resonances and some glass-reinforced laminates may employ glass cloth with features within this dimensional range, resulting in performance problems at mmWave frequencies. Known as the glass-weave effect, such circuit materials can suffer areas with variations in Dk that result in impedance and phase variations in a circuit at mmWave frequencies. The effect is typically exhibited as a circuit-to-circuit variation. RO3003 laminate does not employ glass reinforcement and therefore suffers no glass-weave effect.

RO3003 material features outstanding Dk consistency with tight Dk tolerance for excellent repeatability of circuit performance from board to board. Such consistency not only supports predictable circuit performance at mmWave frequencies but also enables the use of commercial computer simulation software for designing circuits at those higher frequencies, with results that closely match actual measurements of fabricated circuits.

In addition, RO3003 laminate has very low dissipation factor which contributes to the low loss characteristics. The dissipation factor of RO3003 is 0.001 when tested at 10 GHz using a clamped stripline test per IPC-TM-650 2.5.5.5c. The different material characteristics of RO3003 combine in a circuit material well-suited for mmWave circuits, especially in automotive applications where environmental conditions, such as wide temperature ranges, can be quite challenging to the reliable and consistent performance of such high frequency circuits.

VENDORVIEW

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NGC Receives Contract to Add Ground Capabilities to G/ATOR

VIEW VIDEO

The ground weapons locating radar (GWLR) mode is a software update that brings additional mission capability to the ground-based multi-mission Active Electronically Scanned Array (AESA) radar developed by the Department of Defense (DoD). The Ground/Air Task Oriented Radar (G/ATOR) will perform four principal missions using the same hardware. Software loads optimize the operation of the radar to perform each mission. When all modes are fully implemented, Marine Corps operators will have a common hardware solution with the ability to switch between air surveillance, air defense, ground weapon locating and air traffic control through software.

"Inserting this capability into G/ATOR is an important step toward providing the Marines with a highly capable and highly versatile system," said Roshan Roeder, director, Ground Based Tactical Radars, Land and Self Protection Systems Division, Northrop Grumman Electronic Systems. "Using an open architecture approach, we're bringing together the best of technology and design experience from ground and airborne applications to create a system that seamlessly facilitates capability upgrades and the insertion of emerging technologies."

The GWLR mode enables G/ATOR to detect and track time-critical incoming threats, such as rockets, mortars and artillery rounds.

The GWLR mode enables G/ATOR to detect and track time-critical incoming threats, such as rockets, mortars and artillery rounds. Once the radar has detected incoming threats, the system rapidly analyzes their ballistic trajectories and computes their impact points, which enables rapid and accurate threat engagement by counterfire forces.

The G/ATOR system entered low rate initial production in 2014 and additional low rate initial production systems were placed under contract in early 2015. As planned, the G/ATOR program is incrementally incorporating additional mission capabilities via software updates.

AESA Radar With 360-Degree Coverage Moves Toward Production Readiness

Threats such as drones, aircraft, and cruise and ballistic missiles may simultaneously attack deployed U.S. forces or America's allies from multiple directions in the future. Using Raytheon Co. funding, an upgrade to the combat-proven Patriot Air and Missile Defense System's radar that provides 360-degrees of protection from those threats will soon be production ready, thanks to a recently completed series of engineering milestones.

The milestones involve upgrading the Patriot radar main array with gallium nitride (GaN) based Active Electronically Scanned Array (AESA) technology. Completion of those milestones keep Raytheon engineers, who are currently constructing a GaN-based AESA full size main panel radar array, on track to having a full-scale main array demonstrator operational in early 2016.

"The Raytheon-developed GaN-based AESA radar builds on the more than $150 million invested in GaN technology, and will be a simple upgrade for the more than 220 Patriot fire units fielded by the U.S. and the 12 other Patriot partner nations," Ralph Acaba, vice president of Integrated Air and Missile Defense at Raytheon's Integrated Defense Systems business. "This upgrade is approved for export to all current Patriot partners and a number of future Patriot partner nations such as Poland. It enables 360 degrees of protection, while retaining Patriot's mobility and reducing operation and maintenance costs by as much as 50 percent."

"The Raytheon-developed GaN-based AESA radar builds on the more than $150 million invested in GaN technology, and will be a simple upgrade for the more than 220 Patriot fire units fielded by the U.S. and the 12 other Patriot partner nations..."

The Raytheon-built GaN-based AESA Patriot uses three antenna arrays mounted on a mobile radar shelter to provide 360 degrees of radar coverage. The main AESA array is a bolt-on replacement antenna for the current Gallium Arsenide based antenna. The GaN-based AESA array measures roughly 9' wide × 13' tall, and is oriented toward the primary threat. Patriot's new rear panel arrays are a quarter the size of the main array and let the system look behind and to the sides of the main array, enabling Patriot to engage threats in all directions.

Earlier this year, Raytheon built a GaN-based AESA Patriot rear-panel array, integrated it with the current Patriot radar using the existing, recently modernized, back-end processing hardware and software, and tracked targets of opportunity to seamlessly create a 360-degree view.

Raytheon's GaN-based AESA Patriot radar will work with future open architectures as an Integrated Air and Missile Defense Battle Command System and retains backward compatibility with the current Patriot Engagement Control Station. It is also fully interoperable with NATO.

Wolfspeed GaN HPAs Provide 24/7/365 Reliability for Space Fence

VIEW VIDEO

Wolfspeed, a Cree Company and a leading global supplier of GaN-on-SiC high electron mobility transistors (HEMT) and monolithic microwave integrated

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> "GaN HPAs provide significant advantages for active phased array radar systems like Space Fence..."

circuits (MMIC) has partnered with Lockheed Martin to provide GaN high power amplifiers (HPA) for the U.S. Air Force's Space Fence, which will significantly improve the timeliness with which operators can detect space events that could potentially threaten GPS satellites or the International Space Station.

Scheduled to go online from Kwajalein Atoll in the Marshall Islands in 2018, Space Fence will accurately track the estimated 500,000 objects — such as spent rocket boosters, stray hardware, and other debris — that are floating in the same space as the satellites that so much modern technology depends on. Developed by Lockheed Martin in partnership with Space Military Command and the U.S. Air Force Life Cycle Management Center/Space Command Control and Surveillance Division, Space Fence incorporates a scalable, solid-state S-Band radar with a high wavelength frequency that is capable of detecting much smaller objects than the current system, and will thus improve accuracy, quicken response time, and expand surveillance coverage.

Having completed the critical design review and begun construction, Lockheed Martin's Space Fence team is currently focused on the production of technology that will bring the system online, and has recently reached a major design milestone by confirming the long-term reliability of Wolfspeed's GaN HPA technology, which is integral to meeting the project's efficiency and availability requirements and will allow Space Fence to track 10 times more space junk than the current system. After more than 5,000 hours (or nearly seven months) of accelerated stress testing, Lockheed Martin has demonstrated with greater than 99 percent confidence that Wolfspeed's GaN HPAs will meet the long-term reliability goals for the Space Fence program.

"These test results represent the culmination of more than a decade of shared investment in GaN technology," said Steve Bruce, vice president, Advanced Systems at Lockheed Martin Mission Systems and Training. "GaN HPAs provide significant advantages for active phased array radar systems like Space Fence, including higher power density, greater efficiency and improved reliability over previous technologies."

Photo Courtesy of Lockheed Martin

Loughborough University to Revolutionise Electronic Communications Circuitry

Loughborough University, UK, has been awarded £3.9 million to develop a totally new way of designing and fabricating high frequency communications circuitry. The funding from the UK's Engineering and Physical Sciences Research Council (EPSRC) will be used to establish the SYnthesizing 3D METAmaterials for RF, microwave and THz applications (SYMETA) research programme.

SYMETA's aim is to employ metamaterial technology to construct the circuits and reduce significantly both the number of processes involved in the circuit manufacture and the components soldered onto the boards. The research has the potential for significant academic, economic, societal and environmental impacts. With rapid advancements in the development of metamaterials the possibilities for innovative applications across many sectors are significant.

Industries that could benefit from the research include aviation, space, healthcare and the military. Employing the advanced manufacturing techniques that the consortium will develop will also remove the need for the harsh chemicals typically used in the manufacture of traditional circuit boards, thereby offering significant environmental benefits.

> "...a radical new way of designing and manufacturing electronics at low cost."

The SYMETA team will be led by Professor Yiannis Vardaxoglou from Loughborough University, with other research partners including the Universities of Exeter, Oxford, Sheffield and Queen Mary, University of London.

Speaking about the consortium, Professor Vardaxoglou said, "Introducing these novel structures into the complex world of electronic design will offer a radical new way of designing and manufacturing electronics at low cost. We are grateful to EPSRC for supporting such an innovative and timely project."

Finnish 5G Test Networks Join Forces to Boost Competitiveness

Coordinated by VTT Technical Research Centre of Finland, the 5G Test Network Finland (5GTNF) test environment is promoting research and technology development by interconnecting 5G test networks belonging to the 5thGear programme funded by Tekes. This integrated test environment will provide industry, SMEs and start-ups with their first taste of 5G mobile technology functionalities well before 5G becomes commercially available.

The 5GTNF test environment is a joint effort between industry, the academic world and the Finnish government. The consortiums of the 5thGear test network projects collaborating in 5GTNF include global telecommunications vendors, Finnish SMEs, network operators, public authorities, universities and research institutes.

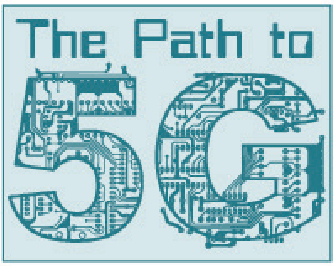
There are four 5thGear test network projects. There is the 5G Test Network (5GTN) – a scalable environment enabling future business model piloting and service development in real-life-like use cases. The test network will also provide a platform for testing and developing the 5G system's technology components. The test network of the Cognitive Radio Trial Environment (CORE++) project provides a testing environment for trialing new spectrum-sharing concepts for future mobile broadband systems.

> ...spectrum-sharing concepts for future mobile broadband...

The Future of UHF Frequency Band (FUHF) project explores and tests the impacts of the changing media environment and future media consumption formats on the business models of various actors in mobile communications and broadcasting ecosystems, while the 5th Evolution Take of Wireless Communication Networks (TAKE-5) project creates a multidisciplinary and open research platform for the investigation and experimental evaluation of innovative ideas in networking, services and new business models for 5G.

ITU Assembly Endorses IMT-2020 Process for Development of 5G

The Radiocommunication Assembly of the International Telecommunications Union (ITU) endorsed a resolution that establishes the roadmap for the development of 5G mobile and the term that will apply to it: IMT-2020. The overall 'vision' for 5G systems, along with the goals, process and timeline for its development, is now in place.



The detailed technical performance requirements for the radio systems to support 5G will be developed, in close collaboration with industry and national and regional standards organizations, following the stringent timelines defined by ITU.

"The new ITU-R resolution sets the stage for the future development of 5G mobile technologies," said ITU Secretary-General Hou-

> ...the new 5G standards aim at maintaining high quality service at high mobility...

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lin Zhao. "The vision for IMT-2020 and beyond opens the doors to innovation that will determine how we communicate in the future, meeting the trend towards high data traffic in the Age of the Internet of Things," said François Rancy, director of the ITU Radiocommunication Bureau.

Recognizing that a connected society in the years beyond 2020 will need to accommodate a similar user experience for end-users regardless of whether they are on the move or stationary, the new 5G standards aim at maintaining high quality service at high mobility, enabling the successful deployment of applications on a moving platform, such as in cars or high-speed trains.

PICS Project Delivers Innovative ALD Materials and Industrialization

Three European SMEs, IPDiA, Picosun and SENTECH Instruments, along with CEA-Leti and Fraunhofer IPMS-CNT announced the major technological results achieved by the PICS project. The project focused on developing innovative dielectric materials deposited by atomic layer deposition (ALD) and related tools (ALD batch tool and etching tool) to bring to mass production a new technology of high-density and high-voltage 3D trench capacitors targeting high-end markets like medical or aeronautics.

Capacitors are key components presented in every electronic module. The integrated silicon capacitors technology offered by the SME IPDiA is claimed to outperform current technologies (using ceramic or tantalum substrates) in stability in temperature, voltage, aging and reliability and enables highly integrated and high-performance electronic modules to be built.

As a result of the PICS project a novel ALD batch tool was developed by Picosun and Fraunhofer IPMS-CNT. It reduces cost-of-ownership and delivers better uniformity and step coverage for high-K dielectrics into 3D structures. A new process for accurately etching high-K dielectrics, which are very specific materials, was demonstrated by SENTECH with the help of Fraunhofer IPMS-CNT.

Also, two new dielectric stacks were developed and integrated into the IPDiA 3D trench capacitors by IPDiA, CEA-Leti and Fraunhofer IPMS-CNT. The initial specifications were fulfilled and proven by electrical measurements and a new record for capacitance density (>500 nF/mm^2 at 3.3 V) and an extended operation voltage (10 V with 150 nF/mm^2) were obtained.

...targeting high-end markets...

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Smart City ICT Revenues Forecast to Reach $977B by 2022

The worldwide population shift to urban centers is spurring the adoption of "Smart Cities" to maximize the efficiency of crucial resources like utilities, water supply and transportation services. These cities of the future will combine and leverage Internet of Things (IoT) and Information and Communications (ICT).

A new Strategy Analytics report "The Future of Smart Cities — Opportunities, Solutions and Players," forecasts that Urban ICT revenues will reach $977 billion by 2022. Currently, about one million people are added each week to the world's cities.

The study reveals that North America and Europe will dominate urban ICT revenue by 2022, with Asia-Pacific the fastest growing market. Smart health, smart infrastructure and smart government represent the largest ICT opportunities.

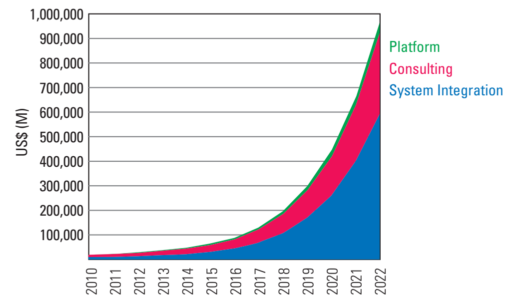
City infrastructures grow more slowly than the population they seek to serve, but faster than the city's land area, said Andrew Brown, executive director of Enterprise and IoT research at Strategy Analytics. "Parking sensors, for example, can together with traffic management platforms and big data warn of, and ward off, inner city traffic congestion before it becomes unmanageable," Brown said, adding, "Smart street lighting can be set to operate only when there are people nearby who need it. The smart lamp post itself can become a sensor platform for other services such as surveillance or smart parking."

Smart grids can play a vital part in controlling urban energy supply and demand. At the same time, utilities are seeking to reinvent themselves to be service providers for urban customers.

"Smart water" offers effective end-to-end monitoring and control for an increasingly valuable resource. Water utility companies using smarter solutions could save between $7.1 billion and $12.5 billion each year, engaging multiple IoT vendors, the SA report found.

The report also explores the role of urban-centric solutions such as Uber and AirBnB. This foundational study examines the 'smart city' approaches of ICT and IoT vendors and service providers. It describes solutions and business models and provides recommendations for the future.

Total Smart City ICT Revenue by Solution Area (US$ Millions)



Source: Strategy Analytics, October 2015

Telematics to Power More than 73 Million Commercial Vehicles by 2020

VIEW VIDEO

The commercial telematics industry is set for very strong growth in the next five years, especially in the enterprise and SMB segments, with players such as Telogis and Fleetmatics leading the way in these respective verticals in the United States. It is just a matter of time before the first vendor exceeds 1 million vehicles under management, with Fleetmatics having set a target of 1.2 million subscriptions by 2020.

"We are witnessing the emergence of a very dynamic ecosystem characterized by cut-throat competition, aggressive marketing, mergers and acquisitions galore, and high levels of equity investment with high expectations about quick returns. This results in accelerating awareness about the many benefits of telematics far beyond the traditional asset tracking, diagnostics and fuel saving paradigms," says VP and GM Dominique Bonte.

Technologies such as onboard diagnostics (OBD) dongles and Cloud/SaaS solutions linked to hardware agnostic approaches leveraging third party application developer ecosystems on smartphones and ruggedized tablets are critical growth drivers. They allow vendors such as Telogis, PeopleNet (Trimble), Astrata, Zonar, CalAmp and Geotab to cost-efficiently address wide ranging requirements across a large number of segments, including the growing commercial vehicle OEM opportunity.

> "We are witnessing the emergence of a very dynamic ecosystem characterized by cut-throat competition, aggressive marketing, mergers and acquisitions galore..."

Optimized routing and truck-based navigation capabilities enabling low-cost delivery are becoming critical assets for addressing exploding e-commerce retail models, goods distribution and work flow management. However, while telematics increasingly empowers the knowledge worker, new smart mobility paradigms are already appearing on the horizon, threatening to disrupt the status-quo with autonomous trucks and self-driving taxis expected to redefine the role of the driver or even removing it completely.

Finally, commercial telematics and fleet management solutions are no longer mainly confined to the United States and Western Europe with China, Southeast Asia, Africa and the Middle East, and Eastern Europe representing increasingly important opportunities for both local and foreign players.

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GaAs RF Device Revenue Reaches Record Levels

Driven by increasing GaAs content in cellular terminals, the GaAs device market experienced another year of record revenues. The recently released Strategy Analytics Advanced Semiconductor Applications (ASA) spreadsheet model and Forecast and Outlook report, "GaAs Device Forecast and Outlook: 2014–2019," forecasts that GaAs device revenue will break the $7 billion barrier this year and surpass $8 billion before the end of the forecast period. The report states that GaAs device revenue will grow, even though price erosion and competitive technologies will slow the growth rates.

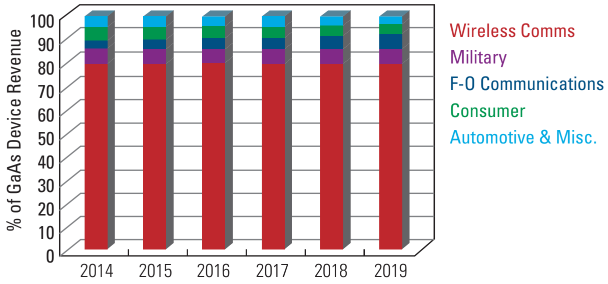
The report concludes:

- Wireless applications remain the dominant segment of GaAs device market, accounting for just slightly less than 80 percent of all revenue.
- The cellular terminal portion of the wireless segment accounts for slightly more than 50 percent of all GaAs device revenue. New architectures will increase the GaAs content in cellular terminals and even though CMOS PAs will continue capturing market share, the cellular terminal share of the market will grow to slightly more than 55 percent by the end of the forecast period.
- In response to price erosion and losing market share to competitive technologies, GaAs device revenue will peak in 2018 at just over $8 billion, before declining by less than 1 percent in 2019.

> Cellular growth will push revenue past $7 billion in 2015.

According to Eric Higham, service director, Advanced Semiconductor Applications, "Despite continuing concern in some quarters about the future of GaAs devices, the market saw its second consecutive year of double-digit growth. Other technologies are capturing market share, but evolving device and network architectures need increasing GaAs content and this is offsetting some of the share loss."

GaAs Device Revenue



Source: Strategy Analytics

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

National Instruments announced its acquisition of **Micropross**, a company based near Lille, France, a technology innovator and leading supplier of test systems for Near Field Communications (NFC), smart cards and wireless charging test systems. Micropross will continue to operate as a wholly owned NI subsidiary under the leadership of the existing management team. As more and more consumer and IoT devices incorporate capabilities such as mobile payment and wireless charging, Micropross' technology and expertise in these areas will complement NI's broad test platform to offer customers solutions that will help speed their time to market and lower their cost of test.

Skyworks Solutions Inc., an innovator of high performance analog semiconductors connecting people, places and things, announced that it decided not to modify its amended and restated merger agreement with **PMC-Sierra Inc.**, entered into on October 29, 2015. PMC terminated the amended and restated merger agreement and, as a result, Skyworks is entitled to an $88.5 million termination fee from PMC.

Nokia announced that it has received antitrust clearance from the Chinese Ministry of Commerce (MOFCOM) for its proposed acquisition of **Alcatel-Lucent**. The clearance in China completes the material antitrust review process required for the transaction. Nokia and Alcatel-Lucent will continue to cooperate with the French government to obtain formal approval from the Ministry of Economy (MINEFI), after which Nokia will proceed with the filing of the previously announced public exchange offer for Alcatel-Lucent securities. Once the offer period opens, the proposed transaction will remain subject to approval by Nokia shareholders and the successful closing of the exchange offer, and is expected to close in the first half of 2016.

mWAVE Industries LLC announced that it has acquired all of the assets and IP of the **Gabriel and Mark microwave antenna brands**, which includes parabolic grids, solid parabolic and directional panel antennas. These two leading terrestrial microwave antenna brands are recognized worldwide for their robust designs and reliability. The merging of the Gabriel and Mark microwave antenna brands into the mWAVE portfolio offers global customers a one stop source for commercial and military antenna product lines, as well as access to the strength and knowledge of the mWAVE antenna design and customization engineering professionals.

COLLABORATIONS

Keysight Technologies Inc. announced it is collaborating with the **University of Bristol** on 5G millimeter wave research. The two organizations are already deeply involved in the 5G ecosystem in Europe and the U.S. and will now be working closely together on multiple 5G millimeter wave technologies. The pursuit of more bandwidth for ever-faster digital wireless communications has pushed the research community to explore how to use much higher frequencies for commercial mobile multiple-access performance. The collaboration combines Bristol's leading-edge wireless research with Keysight's deep experience and capability in millimeter wave and ultra-broadband simulation, design, test and measurement.

Sivers IMA announced that they are launching a new strategic partnership with **Cirtek Advanced Technologies & Solutions Inc.** for manufacturing of its E- and V-Band converters. Cirtek is known for its high quality production of micro- and millimeter wave products. The company has a long experience from volume production having manufactured over one million radio links deployed worldwide.

ACHIEVEMENTS

Anite has been selected by **CETECOM** for its anechoic MIMO Over-the-Air (OTA) test laboratory in the U.S. The laboratory has been set up to perform device testing compliant with the CTIA standardized MIMO OTA test plan previously released. Propsim F32 supports all CTIA channel model requirements (both MIMO and Transmit Diversity testing) allowing users to comprehensively and quickly verify that mobile devices meet expected industry requirements. CETECOM selected Anite's Propsim F32 for its unique ability to support LTE and LTE-Advanced device testing, incorporating up to 32 channels in a single unit, thereby simplifying set-up and reducing cost.

Advantech Wireless was selected by **Raytheon** to supply Transcend™ 800 microwave radio subsystem for point-to-point microwave communications as part of Raytheon's ongoing microwave development infrastructure. Transcend 800 microwave radios are fully capable to operate in harsh environments and sustain significant electromagnetic interferences while still reliably operating in high availability networks.

CONTRACTS

The Missile Defense Agency (MDA) awarded a team, led by **Lockheed Martin**, a contract to develop, build and test the Long Range Discrimination Radar (LRDR). The radar system will support a layered ballistic missile defense strategy to protect the U.S. homeland from ballistic missile attacks. The nine-year contract, with options, will have the potential contract value of approximately $784 million. Work on the contract will be primarily performed in New Jersey, Alaska, Alabama, Florida and New York.

Lockheed Martin has received a $305.4 million contract from the **U.S. Air Force** for continued production

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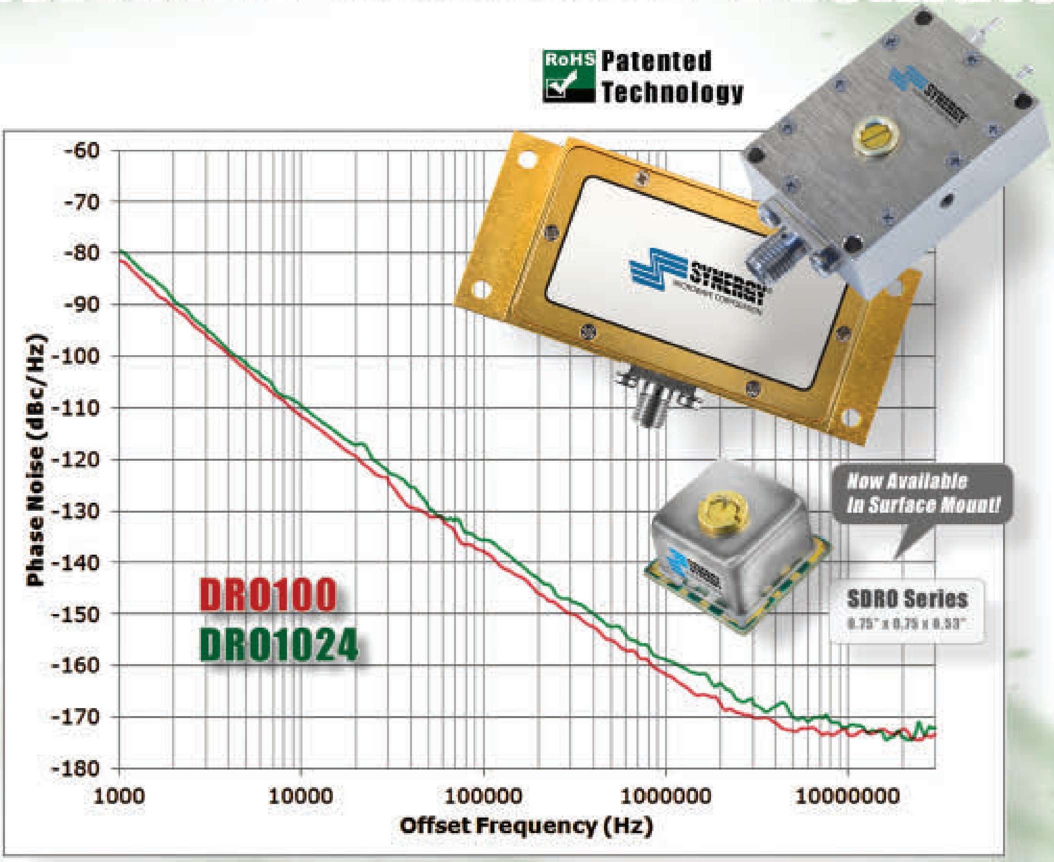

Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @10kHz (dBc/Hz)
Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	-107
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-111
Connectorized Models				
DRO100	10	1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10	1 - 15	+7 - 10 @ 70 mA	-109

Model	Center Frequency (GHz)	Mechanical Tuning (MHz)	Supply Voltage (VDC / Current)	Typical Phase Noise @10kHz (dBc/Hz)
Mechanical Tuning Connectorized Model				
KDRO145-15-411M	14.5	±10 MHz	15 V / 130 mA (Max.)	-88

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of the Joint Air-to-Surface Standoff Missile (JASSM) and its Extended Range (ER) version. The Lot 13 contract includes 140 baseline JASSMs for U.S. and international partners, 140 JASSM-ER missiles, data, tooling and test equipment. The Lot 13 award represents the largest JASSM-ER order to date and brings total missiles under contract to more than 2,300. The contract represents the fifth production lot for JASSM-ER, which received full-rate production approval last year.

The **U.S. Navy** awarded **Raytheon Co.** a $159.9 million contract to manufacture, inspect and test Phalanx Close-in Weapon Systems (CIWS). The contract, which provides for a $10 million option in FY15 and another valued at $291 million in FY16, includes support equipment for the Phalanx and SeaRAM Weapon Systems, Block 1B radar upgrades and kits for reliability, maintainability, and availability. The contract also covers overhaul of four Land-based Phalanx Weapon Systems. Work under the contract, which was signed in the third quarter of 2015, is expected to be completed by August 2018 in Louisville, Ky.

Officials of the **U.S. Air Force Research Laboratory** at Wright-Patterson Air Force Base, Ohio, has awarded contracts and task orders to the **General Dynamics Corp.** Information Technology segment in Fairfax, Va.; **Azimuth Corp.** in Beavercreek, Ohio; and to **UES Inc.** in Dayton, Ohio, to advance materials technologies that control and protect light and electromagnetic energy sources. The the three companies will share as much as $121.1 million for materials research and survivability studies involving hardened materials, survivability and photonic materials. The project involves materials to create and protect from electro-optical weapons and RF and microwave weapons.

The **U.S. Navy** has awarded **Northrop Grumman Corp.** a $95 million contract for low-rate initial production of the Joint Counter Radio-Controlled Improvised Explosive Device (RCIED) Electronic Warfare (JCREW) Increment 1 Block 1 (I1B1). The contract, awarded by the U.S. Naval Sea Systems Command (NAVSEA), includes options which, if exercised, would bring the total value to $213 million. Work is expected to be completed by January 2017. JCREW systems are software-programmable jammers that provide protection from device-triggered improvised explosive devices (IED). Northrop Grumman developed mounted, dismounted and fixed-site variants to protect vehicles, warfighters and permanent structures for the Navy and the U.S. Air Force.

Sierra Nevada Corp. has been awarded a $73.2 million contract by the **United States Marine Corps.** Fulfillment includes providing the USMC's Mobile Expeditionary Units (MEU) with the most modern and highly-capable dismounted Electronic Countermeasure (ECM) system in the DoD inventory, the Modi II. The delivery order on this indefinite-delivery/indefinite-quantity contract is for 581 systems, including spares and training. Work is expected to be completed by August 2016. Modi II is one of SNC's Electronic Warfare and Range Instrumentation (EWR) solutions. It is used both offensively and defensively to disrupt enemy communications on the battlefield.

Harris Corp. received $66 million in orders to provide wideband tactical radios and support services to nations in Eastern Europe, the Middle East and Africa. Harris received the orders during the first quarter of the company's fiscal 2016. Harris will provide a wide range of Falcon® multiband handheld, manpack, vehicular and airborne radios, as well as related equipment, training and maintenance services. The radios will provide users with increased situational awareness and support high-bandwidth voice, video and data communications.

Cobham recently received a series of orders from **BAE Systems** for microelectronic products totaling approximately $51 million for the F-35 Lightning II platform. The work will be performed by Cobham Microelectronic Solutions, a business unit of the Cobham Advanced Electronics Solutions sector. Cobham's offering for the recent orders on the F-35 platform includes microelectronic components and integrated microelectronic assemblies for radar and EW. More than 100 Cobham components are onboard every F-35 Lightning II, including microelectronic components, microwave systems, motion control solutions for the Electro-optical Targeting System (EOTS) gimbal, communications cryptography chips, pilot survival products and aerial refueling equipment.

The **U.S. Army** awarded **Honeywell Aerospace** $41 million to continue supplying its combat-proven radar altimeters for use across the Army's full fleet of helicopter platforms. Honeywell's lightweight, compact APN-209 radar altimeter is a critical piece of safety and awareness equipment designed to work well in a helicopter's operating environment, specifically in the hover phase and low-level flight. The APN-209 provides the pilot and flight control computer with an indication of height above the nearest terrain point below the aircraft, such as a tower or building. This information ensures that the pilot and crew have the most accurate information about the landscape around their helicopter.

AR RF/Microwave Instrumentation of Souderton, Pa., has been awarded the contract to provide large broadband RF amplifiers as part of the U.S. Army Electromagnetic Environmental Effects Systems Modernization Program at White Sands Missile Range, Electromagnetic Radiation Effects (EMRE) test complex in New Mexico. For more than 20 years AR has been developing reliable power amplifiers for the U.S. Army. The $37 million award was made through an open competition RFQ, and was based on the criteria of technical solution, risk management, past performance and best value.

Mercury Systems Inc. received a $22.7 million follow-on order from a leading defense prime contractor for advanced radio frequency microwave tuners and intermediate frequency (IF) receivers for a naval electronic warfare (EW) application. The orders were booked in the company's fiscal 2015 first quarter and are expected to be shipped over the next several quarters.

GigOptix Inc., a supplier of advanced high speed semiconductor components for use in long-haul, metro, Cloud connectivity, data centers, consumer electronics links and interactive applications, through optical and wireless communications networks, announced the booking of a $6.1 million order with one of the world's leading suppliers of

Around the **Circuit**

advanced aerospace and defense technology to deliver advanced ASIC products with applications in avionics for the next two years. This order is in addition to the $7.9 million order GigOptix announced in May 2015 from another major supplier in this same industry.

Comtech Telecommunications Corp. announced that its Santa Clara, Calif.-based subsidiary, **Comtech Xicom Technology Inc.**, has received a production contract for more than $3.2 million from a U.S. military integrator to supply high-power traveling wave tube amplifiers (TWTA). This is the first installment of a multi-year program for tactical military transportable satellite terminals.

Norsat International Inc., a provider of innovative communication solutions that enable the transmission of data, audio and video for remote and challenging applications, announced it was awarded a $2.7 million contract from a major U.S. military contractor for its Ku-Band and Wideband Global SATCOM (WGS)-certified X-Band marine VSAT terminals. Under the agreement, Norsat will supply its MarineLink COM12 1.2m and MarineLink COM15X 1.5m dual antenna maritime VSAT terminals to support sea-borne communications. Norsat's newest generation of MarineLink COM terminals provide the most reliable high throughput satellite communications available in the market today for maritime vessels, including naval ships.

The **Air Force** announced the contract award of Engineering and Manufacturing Development (EMD) and early production for the Long Range Strike Bomber to **Northrop Grumman Corp.** The future threat will evolve through the introduction of advanced air defense systems and development of more capable surface to air missile systems. The LRS-B is designed to replace the Air Force's aging fleets of bombers – ranging in age from 50+ years for the B-52 to 17+ years for the B-2 – with a long range, highly survivable bomber capable of penetrating and operating in tomorrow's anti-access, area denial environment.

NuWaves Engineering, a veteran-owned small business delivering advanced RF and microwave solutions, announced that the company has been awarded a Phase II Small Business Innovation Research (SBIR) contract from the **U.S. Air Force Research Laboratory** (AFRL) to develop and test an advanced triplexer in support of AFRL's Global Positioning System (GPS) technology development program. Under the AFRL-sponsored technology development effort, NuWaves Engineering and Exelis Inc., a wholly owned subsidiary of Harris Corp., will investigate, design, fabricate and test an innovative broadband, high-power-handling, low-insertion-loss triplexer designed to work on the GPS navigation payload.

PEOPLE

Astrodyne TDI has appointed **Jeffrey A. Beck** to president and CEO. He succeeds **Pete Kaczmarek** who has been president and CEO since September 2012. Beck joins Astrodyne TDI from Presstek LLC, and previously served as chief operating officer for iRobot Corp., where

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▲ *Jeffrey A. Beck*

he architected and implemented strategies that created the world's leading pure play consumer robotics company. Beck holds an MBA from Boston University and a BS in mechanical engineering from New Jersey Institute of Technology. He currently serves on the board of directors for Sun Edison Semiconductor.

▲ *Kirby Jefferson*

3D Glass Solutions, a leader in glass-based systems integration for electronic packaging, announced the addition of **Kirby Jefferson** to their board of advisors. Jefferson joins 3D Glass Solutions after spending the last 35 years with Intel Corp. in the applied technology and high-tech manufacturing industries. From 2013 to 2015, Jefferson served as vice president of the Technology and Management Group as well as general manager of Intel's Fab 11× complex in Rio Rancho. He and his team fabricated many of Intel's state-of-the-art semiconductor products with an emphasis in the mobile market segments.

REP APPOINTMENTS

Custom MMIC, a developer of performance driven monolithic microwave integrated circuits (MMIC), announced the appointment of **Special-Ind** as their new technical representative in Italy. Special-Ind, a flagship for high technology in Italy, was founded in 1955 and specializes in highly advanced technology for the telecom, automotive, aerospace, industrial and medical industries.

Integrated Device Technology Inc.® announced it is partnering with **Richardson Electronics Ltd.** to distribute IDT's leading RF and RF timing products throughout North America, Europe and Asia. The LaFox, Ill.-based distributor has a large team of experienced RF specialists to work with customers interested in IDT's rapidly expanding portfolio of innovation-driven RF products. IDT's RF portfolio is entirely silicon based, offering distinct advantages over older RF devices built around gallium arsenide. IDT's RF products include attenuators, mixers, modulators and demodulators, variable gain amplifiers, switches and RF timing devices. The devices are used in a myriad of applications that demand innovative high-performance RF solutions.

W. L. Gore & Associates Inc. announced that **WireMasters Inc.** has been named the North American distributor for Gore's bulk wire and cable products. Serving the military, aerospace and defense markets, WireMasters will now be a stocking distributor of Gore's high-performance bulk wire and cable products, offering same day shipping to all customers across the globe. WireMasters Inc. is a leading international distributor of high-performance and high-temperature military specification wire, cable and associated accessories. Headquartered in Columbia, Tenn., WireMasters operates additional warehouses in Grapevine, Texas; Mesa, Ariz. and Cranston, R.I., stocking well over 70 million feet of wire and cable inventory.

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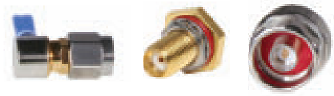

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Ensuring the "Omnipresence" of the Future Car Through Mobile Networks

Victor Fernandez
Anritsu (U.K.)

Autonomous driving is expected to become part of our society from 2020 onwards. In Europe, the Horizon 2020 project considers the further reduction of traffic fatalities during the current decade as one of the main targets, as it suggests with the slogan "The Decade of Action for Road Safety." Any autonomous car will have a sophisticated vehicle-to-whatever (V2X) communication infrastructure that will ensure the monitoring and even control of these vehicles at any time and under any conditions.

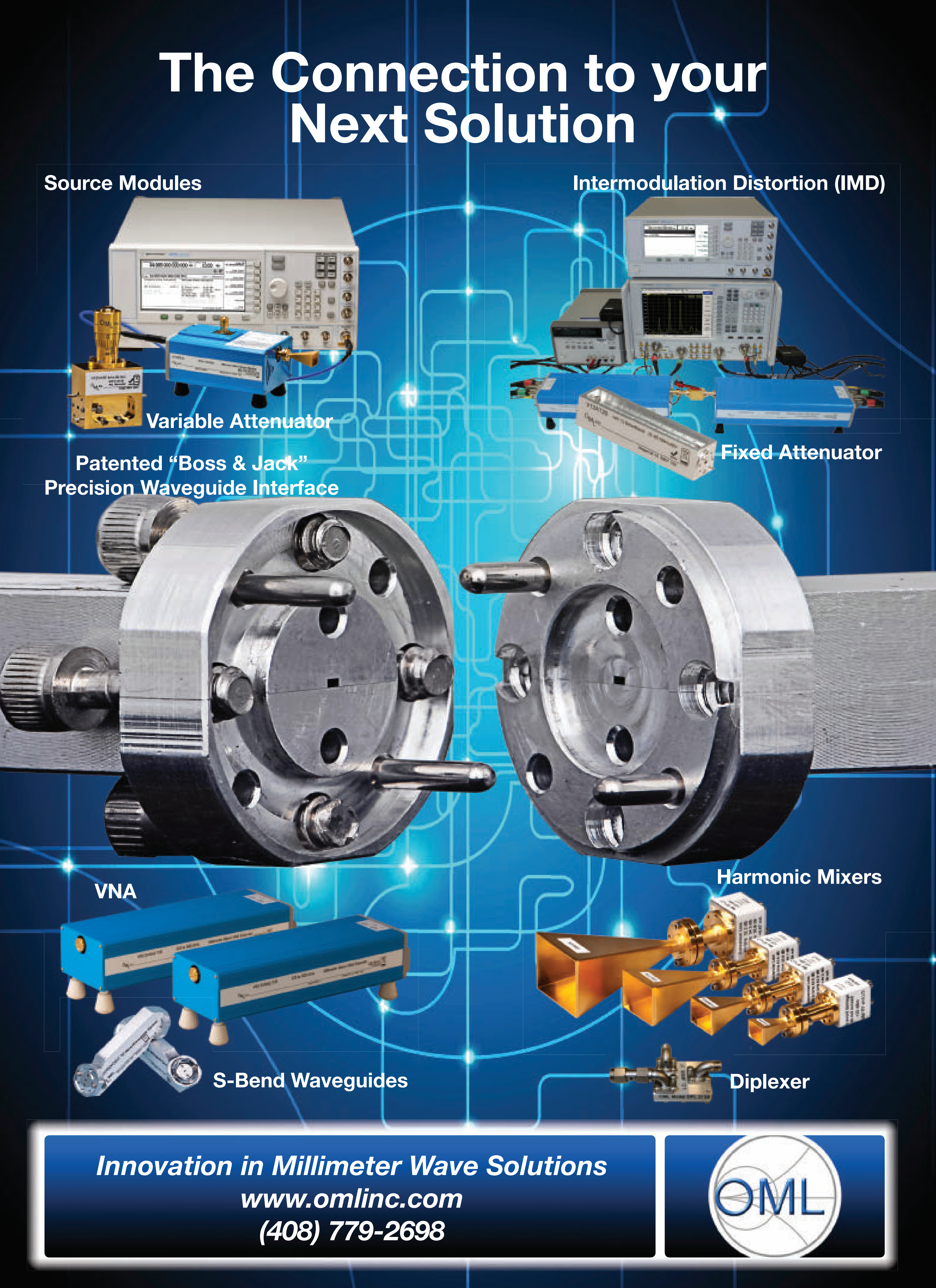
LTE technology is already playing a crucial role in connected vehicles, mainly for navigation, telematics and infotainment applications. By the end of 2015, connected vehicle growth is expected to reach 10 million and will be around 69 million by 2020.[1]

Next Generation Mobile Networks (NGMN), the forum that specified the requirements for 4G and selected LTE as the preferred standard, announced in its 5G whitepaper that civil aviation will implement commercial connectivity services starting in 2020, and passenger services offered will comprise similar applications to those available on the ground. This technology, referred to as direct-air-to-ground (DA2G) communication is relayed on cellular networks independent of the altitude or speed.

Ericsson[2] launched some tests on LTE under extreme conditions, which consisted of testing the connectivity of LTE dongles fitted on an aircraft flying fast at low altitude. They demonstrated a maximum downlink speed of 19 Mbps internet connection while flying at 700 km/h against quite challenging Doppler scenarios. The tests also proved that a seamless handover from one radio base station to the next was possible while flying at a speed of 500 km/h.

Similar to DA2G communication, new flavors of V2X or vehicle-to-vehicle (V2V) based on cellular networks could be considered, offering an alternative to 802.11 systems. Connectivity on cars should be capable of handling all possible applications that could be ongoing inside a car simultaneously: emails, chat, web browsing, video streaming or infrastructure communications.

Under this scope, on-board-diagnostic (OBD) devices will play a key role in the autonomous car. Using the cellular network, they can provide real-time information of the status of the car at the precise location it is encountered. This information could be sent to any device within the surrounding infrastructure or to a cloud server for real-time monitoring, therefore highly appropriate for V2X or V2V systems.



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This article proposes a laboratory test-bed solution for testing the robustness and performance of V2X and fleet tracking systems after analyzing the different sources of fading and network handovers as the main disturbers of communication while driving. The lab-based environment should play a big part in the whole testing process, as it provides several benefits over open road testing.

SOURCES OF FADING

Cellular chipsets integrated into OBDs within a vehicle moving at speeds around 100 km/h are heavily impacted by multipath propagation problems. This phenomenon can give rise to interference that can reduce the signal-to-noise ratio (SNR) and degrade the bit error rate (BER) for digital signals.

In most wireless communication systems, the transmitter antenna does not have a fully directive radiation diagram, which can make the same signal arrive at the receiver through different paths at different times and with different amplitudes. As a result, the overall signal coming into the receiver will be the composition of all these components. This resulting signal can be an augmented or an attenuated copy of the original source depending on whether the multiple components are constructively or destructively combined.

The different amplitude and phase of the signals arriving at the receiver will determine this behavior. In most cases, the quality of the combined signal at the receiver deteriorates. As an example, the received signal power may vary by as much as three or four orders of magnitude (30 or 40 dB) when the receiver is moved by only a fraction of a wavelength.

Radio propagation models start initially looking at propagation path loss in free space (~ $1/r^2$). This model looks just at the signal strength when transmitter and receiver are in line-of-sight (LOS) condition. However, this model is not appropriate for describing the journey of a signal through different obstructions such as buildings, tunnels, hills or trees. The so called "shadowing effect" needs to be taken into account.

On one hand, the large scale propagation models or long-term fading models, which predict the mean signal strength for an arbitrary transmitter-receiver separation distance, improve the accuracy of the free space model by adding a lognormal distribution onto the strength of the received signals in decibels. Some examples are Okumura, Hata and Lee models.

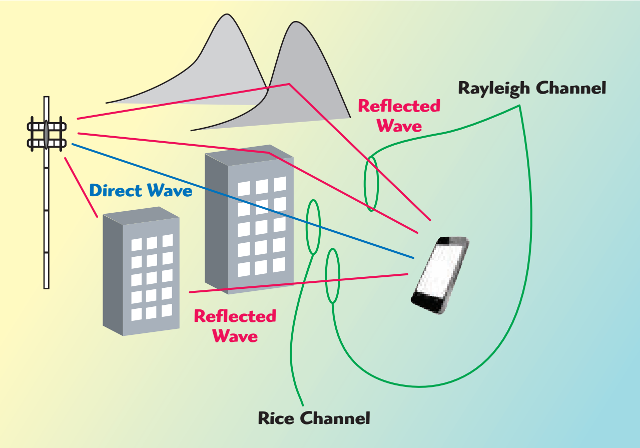


Fig. 1 Difference between Rayleigh and Rice channels.

On the other hand, propagation models that characterize the rapid fluctuations of the received signal strength over very short travel distances (~λ) or short time durations (~s) are called small scale or fading models. These models apply perfectly to automotive applications where transmitter and receiver positions are constantly changing. Small scale fading considers two main problems.

The first is multipath signals inducing inter-symbol interference (ISI) and delay spread. In these circumstances, linear filters with time varying impulse responses are used for modeling the mobile radio channels. Here, the time variation is due to receiver motion in space. In reality, the filtering nature of the channel comes from the summation of amplitudes and delays of the multiple arriving waves at any instant in time.

In this context, the term "flat fading" is used to describe the scenario in which the bandwidth of the signal is smaller than the bandwidth of the channel and/or the delay spread is smaller than the symbol period. Frequency selective fading is the term used for the opposite situation. Normally, frequency selective fading is modeled as the sum of several flat fading channels with different delays.

Rayleigh fading is usually considered as a flat fading channel model whose amplitude response follows the Rayleigh distribution, which can be seen as the envelope of the sum of two quadrature Gaussian noise signals. This model is commonly used to describe the statistical time-varying nature of the received envelope of a flat fading signal, or as the envelope of an individual multipath component.

In a situation where there is a dominant stationary (non-fading) signal component present, such as a line-of-sight propagation path, the small-scale fading envelope distribution is considered to be Rician. The channel, in this case, adopts the name of Rice channel. This model, very similar to Rayleigh, differentiates itself by way of a strong dominant component.

Having a transmitted continuous wave s(t),

$$s(t) = \cos \omega_c t$$

If the signal s(t) goes through a Rician multipath channel, the received signal r(t) can be expressed as:

$$r(t) = L \cos \omega_c t + \Sigma^N_{n=1} \alpha_n \cos(\omega_c t + \phi_n)$$

Where:

L is the amplitude of the line-of-sight component.

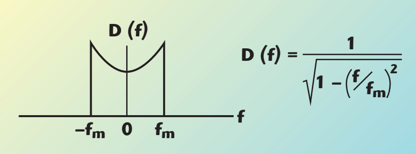
α_n is the amplitude of the n^{th} reflected wave and will follow a Rayleigh distribution.

ϕ_n is the phase of the n^{th} reflected wave.

n = 1 ... N identifies the number of reflected, scattered waves.

Using this mathematical model, Rayleigh fading can be recovered for L = 0. ***Figure 1*** represents both models.

The Rician K-factor is defined as the ratio between the power of the dominant component over the average scattered power at the receiver. Normally, the K-factor is expressed in dB. For indoor channels with an unobstructed line-of-sight between transmit and receive antenna the K-factor often settles between 6 and 12 dB. Rayleigh fading applies for K = 0



▲ *Fig. 2 Equivalent transfer function for a Doppler channel.*

(-∞ dB).

A V2V radio link can be modeled statistically as a Rician fading channel with large K-factor. In these situations, the delay spread is expected to be relatively small because reflections will occur mainly in the immediate vicinity between the transmitter and receiver antennas. In general, the propagation channel is modeled with the following items[3]

- A dominant component consisting of a direct line-of-sight wave plus a ground reflected wave
- A group of early reflected waves
- ISI caused by the multiple delays between waves.

The second problem relates to a V2V system, where a moving receiver induces fading effects (Doppler shift) for each arriving wave component. When a pure sinusoidal tone of frequency f_c is transmitted, the spectrum shape of the received signal, called the Doppler spectrum, will cover the range f_c-f_m to f_c+f_m, where f_m is Doppler shift. The Doppler spread is caused by this Doppler Shift and can be expressed as a filter with the transfer function shown in ***Figure 2***.

Where the Doppler shift corresponds to the widely known formula:

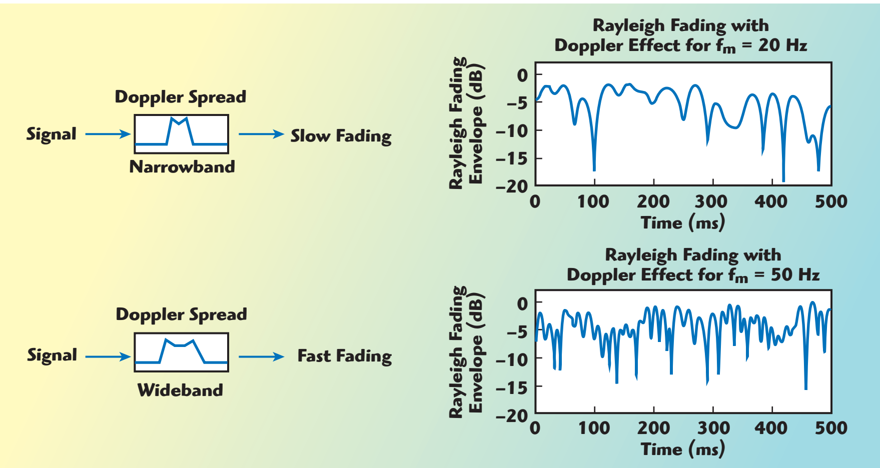
$$f_m = \frac{Vf_c}{C}$$

Having understood this, fast fading is referred to as a scenario with a high Doppler spread (large f_m caused by high speed) and channel variations faster than baseband variations. Slow fading is just the opposite. These concepts are represented in ***Figure 3***.[4]

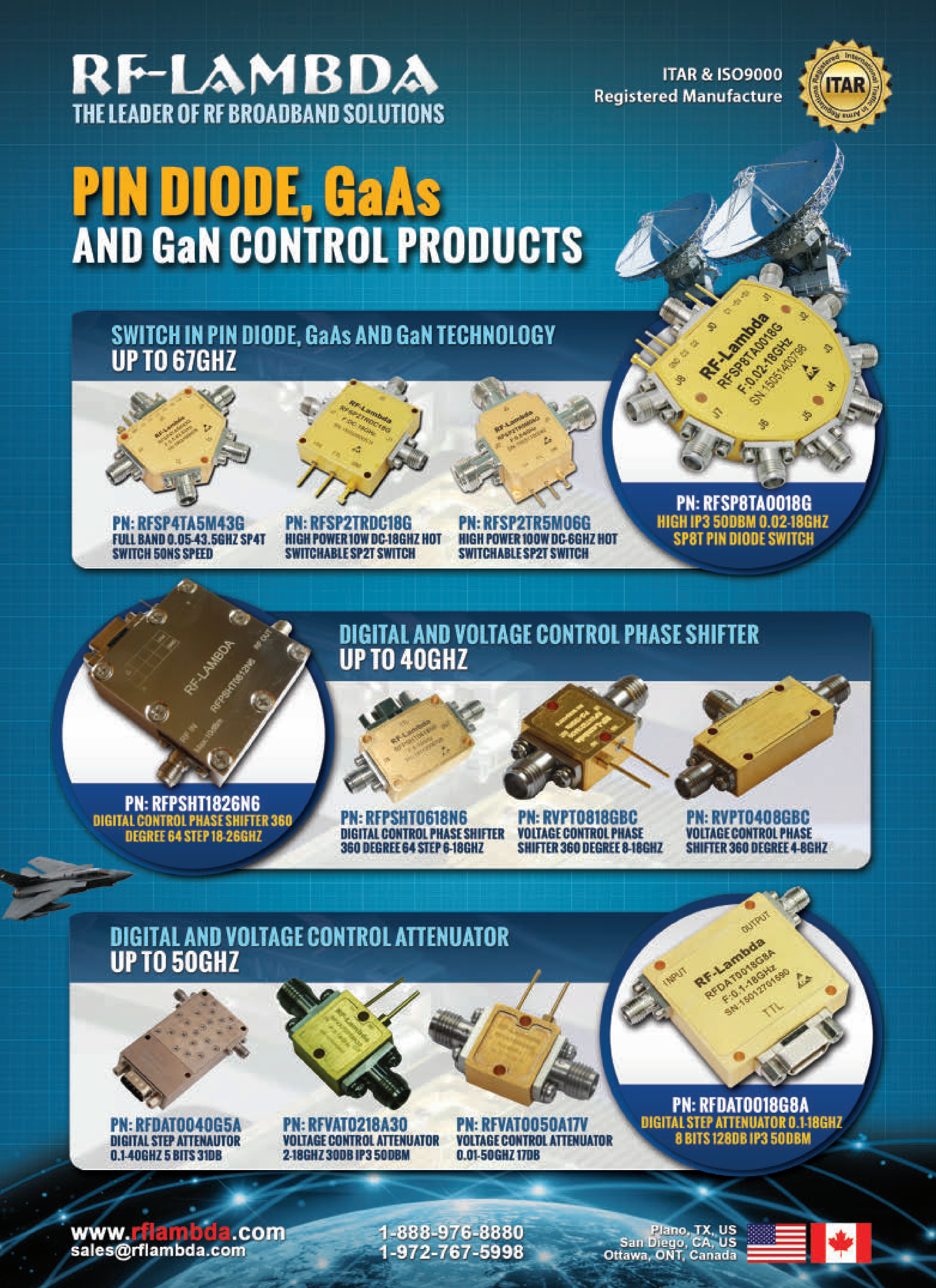
Average fade duration is defined as the average period of time for which the received signal is below a specified level R. Average fade duration primarily depends upon the speed of the mobile (v), and decreases as the maximum Doppler frequency f_m becomes large (at high speeds).

All these models and concepts were put in place for laboratory measurements via a fading simulator capable of simulating several fading types such as constant phase, pure Doppler, Rayleigh or Rice model, which were applied depending on different parameters like moving speed or angle of arrival. This fading simulator can be also used for conformance following the 3GPP TS36.521 where performance tests are specified against different multipath fading propagation conditions and delay profiles such as extended pedestrian A model (EPA), extended typical urban model (ETU) or extended vehicular A model (EVA).

These multipath delay profiles map the relative power with the delay of any tap relative to the first. In most cases a multipath fading propagation condition will be defined by a combination of a multipath delay profile and a maximum Doppler frequency which can be either 5, 70 or 300 Hz. The 3GPP TS36.521 specification also considers a high speed train condition with three scenarios: open space, tunnel with leaky cable and tunnel with multiple antennas. Only the second



▲ *Fig. 3 Difference between slow and fast fading.*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scenario is studied as a fading propagation channel, in which a Rician model is used for only one tap, with a Rician factor K = 10 dB, a Doppler frequency of 1500 Hz and a top speed of 300 km/h.

MOBILITY PROBLEMS

Since the deployment of the first 2G systems, mobility has been one of the key targets taken into account when designing the network. The second and third generations of mobile communications were developed targeting mobility support up to 100 km/h.

However, when 4G was deployed, even though its OFDM access scheme is robust against multipath interference, mobility scenarios switching the connectivity from 4G to 3G/2G were subject to studies. Furthermore, 3G and 2G still have a far better coverage than 4G (mainly present in big urban areas), and so many handovers can be expected when using cellular communications inside a car.

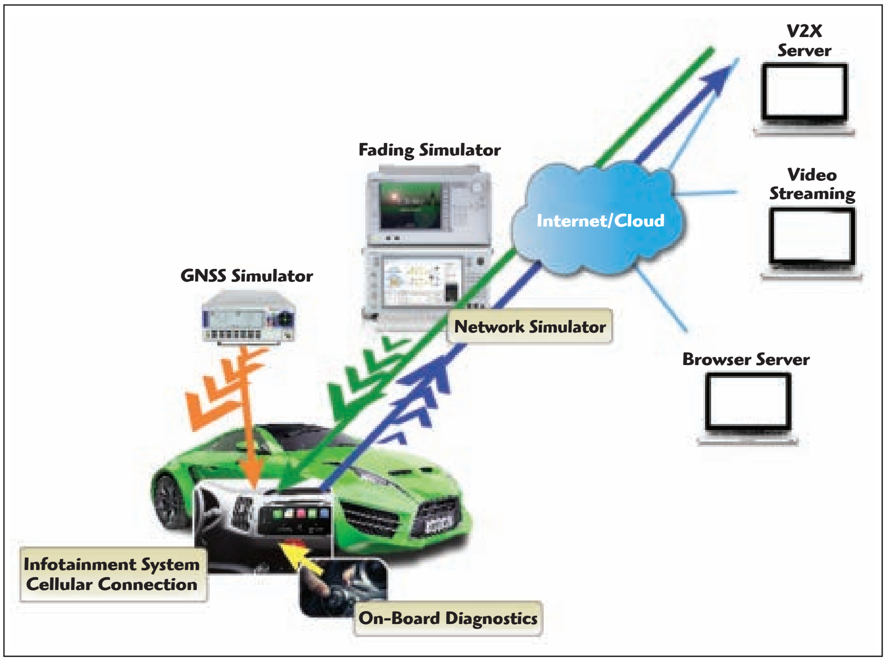
Under this scope[5] it has been demonstrated how a change from 4G to 3G in mobile broadband affects the active connections. Some results show that transmission control protocol (TCP) has a slower throughput growth after a handover, when compared to user datagram protocol (UDP), and can suffer from extended periods of inactivity, also referred to as stalling. Since TCP is one of the core protocols of the Internet Protocol suite, used mainly by world wide web applications, it is essential to check that the vehicle applications transmit all their data to the infrastructure or cloud services at any time.

A key test that any OBD system should pass is when the car is going through tunnels. In tunnels, a modem might lose connection to 4G while still having decent 3G coverage. Other times, even the 3G connection is lost. All these imaginable scenarios can be tested in the laboratory by using the proper instrumentation.

LABORATORY APPROACH

The lab-based test system proposed in this article is essential for exposing the car's V2X infrastructure and infotainment system against a fully controlled test environment which will represent real-life situations a user might experience while driving.

It is important to understand the key benefit of a lab-based testing approach, which is a controlled environment. Field testing can be very difficult to address and should be left for a second stage in order to confirm what has been predicted in the lab. Any solution aimed at testing on the open road brings several challenges such as finding the exact signal conditions to put the car under, logistic difficulties or even the safety of the environment, especially when sending control commands to the car. Lab-based solutions



▲ *Fig. 4 Proposed lab-based testing approach for V2X and infotainment systems.*

can be much more efficient. ***Figure 4*** shows the proposed solution.

In order to explain how the lab-based approach is built, it is first necessary to understand the simulated operation for OBD applications. Initially, the infotainment system in the car will normally gather the OBD information via CAN buses. The GPS signal will be then collected from the integrated GPS receiver in the car's communications module. Finally, a combination of both location data and OBD data will be taken by the infotainment application and uploaded to the V2X server hosted in the cloud.

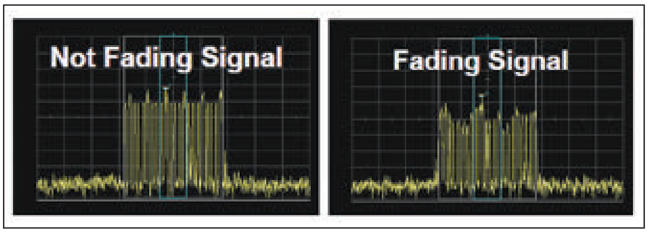


Fig. 5 Differences in the cellular signal with and without fading simulator.

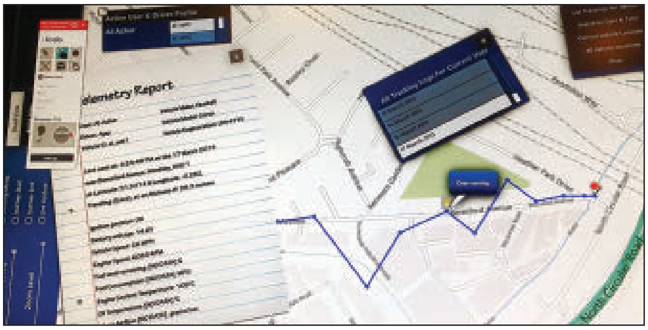
The V2X server will be responsible for distributing the arriving data to the fleet tracking nodes settled along the whole infrastructure and will also communicate back to the vehicle(s) for reporting any information or, even, for control purposes. For example, the V2X server would be constantly analyzing the vehicles' reports in order to share back information about the traffic. Also, if the V2X server detects speeding of a certain vehicle it could send a command to the OBD in order to decrease it automatically.

In the lab-based testing environment, the CAN port at the infotainment system will be connected to an OBD simulator in order to provide arbitrary OBD data. The network simulator will be used for testing the correct functionality and response of the system against stressed conditions, such as high AWGN level, low BTS power, cell interference or mobility scenarios. Thanks to the fading simulator, the RF signal being outputted from the network simulator will be disrupted depending on different fading conditions.

The adaptation of the signal for the different fading conditions is done digitally over the I/Q data of the transceivers. In this case, the fading simulator is connected to the network simulator by a LVDS cable for the baseband data and a BNC cable for synchronization. Once the BTS parameters have been configured on the network simulator, the fading profile is selected on the fading simulator. The fading simulator can be also adjusted for multi-antenna channel models. ***Figure 5*** shows the differences in the cellular signal when not using a fading simulator and when using it.

The network simulator would be set up for simulating two cells of the same or different technologies in order to test the OBD system under more advanced scenarios, such as handovers or cell interference, plus adding complex fading channels on top.

The GNSS simulator will simulate the trajectory of a vehicle. Even though these simulators also support the addition of fading profiles, AWGN and antenna diagram imperfections, those details have not been included in this article.



▲ *Fig. 6 Capture of the real-time telemetry report on V2X server from the University of Hertfordshire, U.K.*

Based on this idea, Anritsu and the University of Hertfordshire started a collaboration for implementing the proposed system. The University of Hertfordshire provided the OBD simulator and V2X server, and Anritsu provided the test instruments.

The V2X server can be further developed for analyzing the performance and functionality of the system against the different RF configurations. By saving the location along with the OBD data before it is transmitted from the infotainment system, the V2X server would be able to check that the arrival of the information has been successful and the information delivered is correct. Then the application on the V2X server could determine whether to send back a command to the vehicle or distribute the received information to real-time displays for fleet tracking purposes.

In ***Figure 6***, a capture of the real-time V2X server developed by the University of Hertfordshire shows the trajectory being followed by the vehicle with a detailed telemetry report at every single captured point. This application can also detect some events as the one appearing at the picture and labeled as "over-revving," which could eventually trigger a control message back to the vehicle in order to stop this behavior.

CONCLUSION

This article has shown a laboratory-based testing system for V2X and infotainment systems relying on cellular networks, which overcomes the challenges that testing on the open road brings. The most common sources of fading have been explained as well as how a fading simulator can be used within a test setup. Mobility problems can be also stimulated and addressed by using a network simulator capable of simulating two independent cells simultaneously. Finally, an example from the University of Hertfordshire's real-time V2X server has been shown as a proof of concept of the proposed system. ■

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An Introduction to Passive I/Q, Single Sideband and Image Reject Mixers

Marki Microwave
Morgan Hill, Calif.

In the realm of RF and microwave circuits, the I/Q mixer architecture is among the most intricate, complex and useful constructions RF engineers have devised in analog hardware. In the early 1900s, noted communication theorist John Carson performed the calculations that led him to conclude that amplitude modulated waves consist of two redundant sidebands. Eleven years later electronics researcher Ralph V.L. Hartley patented the essential structure that remains the basis for these types of modulators today.[1] Numerous applications have utilized the basic Hartley architecture since then, ranging from image rejection down-conversion for improved noise performance to single sideband up-conversion for simplified filtering, to I/Q modulation for complex wireless digital transmissions. Consisting of a delicate manipulation and recombination of in-phase, out-of-phase and quadrature-phased signals, the I/Q mixer architecture can be easily represented in a circuit diagram but is extremely difficult to realize in a physical layout. Creating compact I/Q structures with high performance over a broad bandwidth is a challenging task that remains the subject of ongoing research and development.

In this article, we answer the most common questions about I/Q, single sideband (SSB) and image reject (IR) mixers. We describe what each of these mixers does, how the passive implementations are constructed, common applications and considerations for each. We reference basic characteristics of double balanced mixers and quadrature hybrids used to construct these devices from Marki tutorials "Mixer Basics Primer"[2] and "Power Dividers and Couplers Primer."[3]

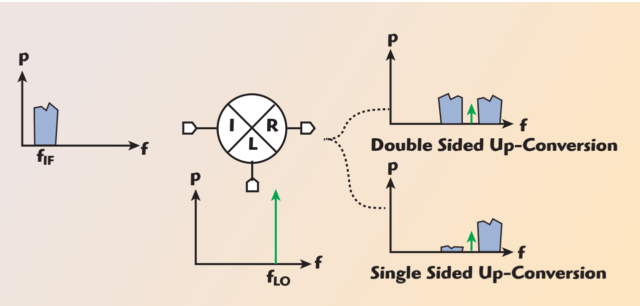

Fig. 1 Single sided vs. double sided up-conversion spectrum.

WHAT DOES AN I/Q-SSB-IR MIXER DO?

Single Sideband Up-Conversion

As discussed in the "Mixer Basics Primer," a normal mixer converts a given input signal at f_{in} to two signals at $f_{out} = f_{LO} \pm f_{in}$ (see ***Figure 1***). One of these signals (called "sidebands" for the way they appear on each side of the LO on a spectrum analyzer) is at the desired frequency, and the other "undesired sideband" is filtered

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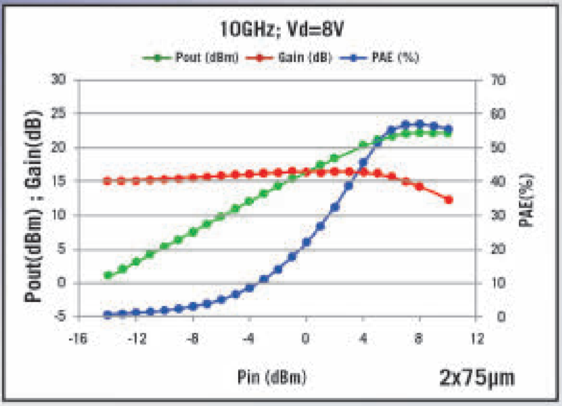
PP25/-21 0.25μm Power pHEMT

- 0.25μm PHEMT process on 100μm substrates
- Power performance at 8V and 10GHz: >1W/mm, PAE 56%, 14dB Gain

PP25-21 (Class-AB) Tuned for Pout



Gain (dB)	P1dB (dBm)	P1dB (mW/mm)	Psat (dBm)	Psat (mW/mm)	PAE Max(%)
15.0	22.1	1086	22.2	1114	56.8

2x75μm device @8V, 10GHz, 150 mA/mm

Summary of WIN mmWave pHEMT portfolio

	PP25-21	PP15-50/51	PL15-12	PP10-10/11
Gate length	0.25 μm	0.15 μm	0.15 μm	0.1 μm
Max Drain Bias	8 V	6 V	4 V	4 V
Idmax (Vg=0.5V)	490 mA/mm	620 mA/mm	525 mA/mm	760 mA/mm
Peak Gm	410 mS/mm	460 mS/mm	580 mS/mm	725 mS/mm
Vto	-1.15 V	-1.3 V	-0.7 V	-0.95 V
BVGD	20V(18V min)	16V(14V min)	9V(8V min)	10V(8V min)
f_T	65 GHz	90 GHz	100 GHz	130 GHz
f_{max}	190 GHz	185 GHz	150 GHz	180 GHz
Power Density (2x75μm)	1100 mW/mm @ 8V, 10GHz	870 mW/mm @ 6V, 29GHz	580 mW/mm @ 4V, 29GHz	860 mW/mm @ 4V, 29GHz (2x50μm)

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out to prevent signal transmission in adjacent channels. An ideal single sideband mixer translates the input signal to just one single frequency, at $f_{LO} - f_{in}$ or $f_{LO} + f_{in}$, eliminating the requirement to filter out the undesired sideband.

Image Reject Down-Conversion

Conversely, the output of a normal mixer at f_{out} consists of two signals $f_{in} = f_{LO} \pm f_{out}$, meaning that both the signal at $f_{LO} - f_{out}$ and $f_{LO} + f_{out}$ are converted to the same output frequency. Generally one of these is the desired signal, and the other is the undesired "image" that must be filtered out before the conversion. Therefore an ideal image reject mixer (IR mixer) converts only one sideband and eliminates the image signal without an image filter before the conversion (see ***Figure 2***).

I/Q Signal Transmission

The function of an I/Q mixer is more difficult to describe. It can be shown either mathematically or experimentally that if both sidebands are transmitted to the receiver side of a normal mixer, a phase-locked LO is required to demodulate the incoming signal. If the LO used is 90 degrees out-of-phase (in "quadrature") with the transmitted LO, the two sidebands cancel each other and no signal is seen due to the way each sideband inherits phase from the LO (see ***Figure 3***).

I/Q mixers use this phenomenon to transmit two channels of data, one in-phase (I) and one with quadrature-phase (Q), without filtering out either sideband. As you can see in Figure 3, the I channel is modulated and demodulated with the same in-phase LO, while the Q channel is modulated and demodulated with the same LO 90 degrees out-of-phase.

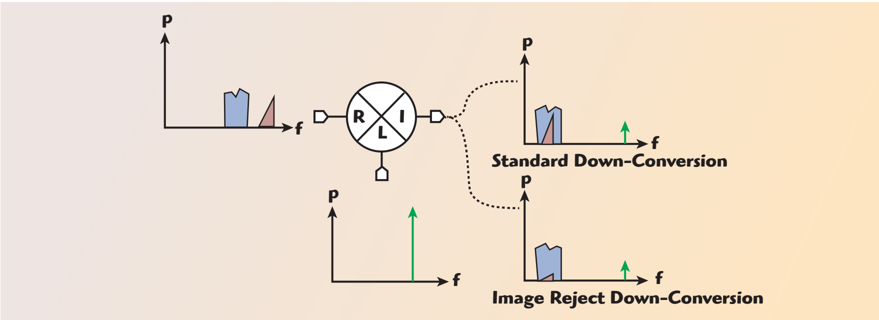


Fig. 2 Standard vs. image reject down-conversion.

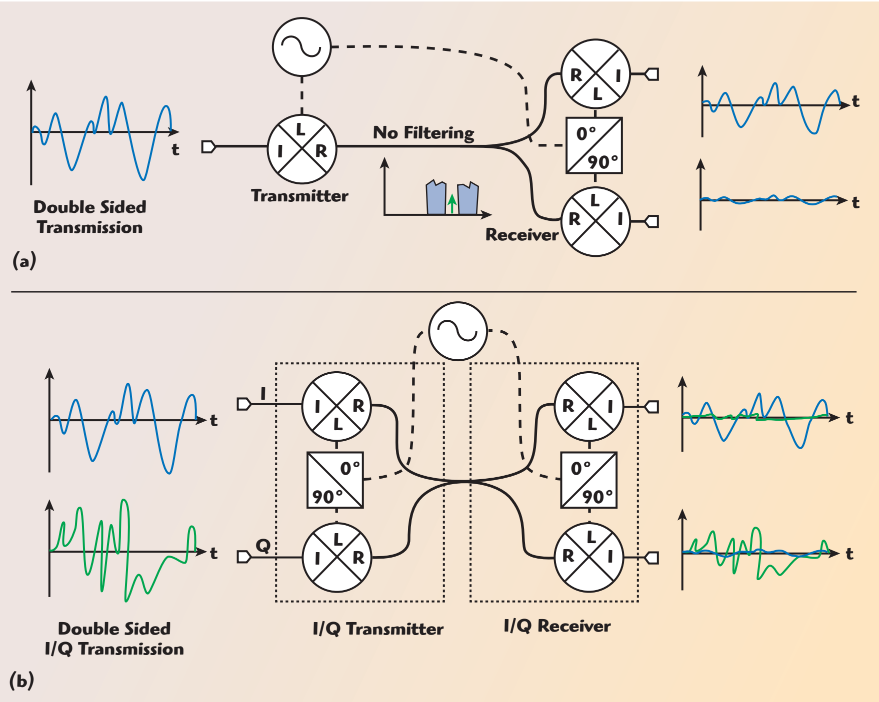


Fig. 3 Double sided (a) and I/Q (b) signal transmission.

WHAT IS THE DIFFERENCE BETWEEN I/Q, SSB AND IR MIXERS/MODULATORS?

Passive SSB and IR mixers are identical, but SSB mixers are used for up-conversion while IR mixers are used for down-conversion. While every passive SSB/IR mixer contains the structure of an I/Q mixer (as shown in the next section), they are used for different applications. An I/Q modulation always creates a double sided signal, and an I/Q demodulation always down-converts both sidebands. The term "modulator" generally refers to a device with an integrated LO amplifier or even an LO signal generator, while a "mixer" is always without the LO signal generation. Sometimes I/Q mixers or modulators are advertised as image reject mixers, with the expectation that the user will supply the IF quadrature combiner.

HOW DOES AN I/Q-SSB-IR MIXER DO IT?

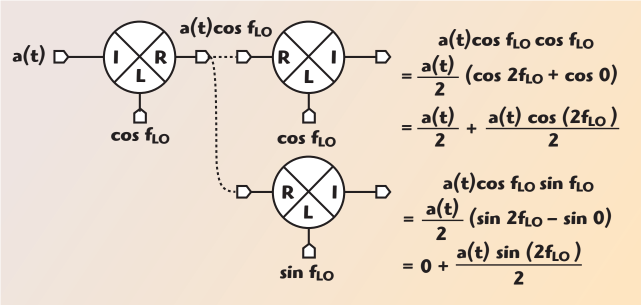
Using phased power splitters and combiners to cancel undesired products is a common practice throughout microwave, RF and even optical engineering. A double balanced mixer uses a balun and a magic tee to cancel LO feedthrough and spurious mixing products. A triple balanced mixer essentially uses two double balanced mixers driven in a push-pull configuration to provide for overlapping LO, RF and IF frequency bands.[2]

I/Q, SSB and IR mixers extend the vectorial cancellation concept using 90 degree phase shifts in addition to the 180 degree phase shifts in the balanced mixers. Two identical signals that are 180 degrees out-of-phase with each other will cancel when combined together, leading to isolations and spurious cancellation in mixers. I/Q-SSB-IR mixers use clever combinations of 90 degree phase shifts, applied differently to the different sidebands, to create cancellation of unwanted components.

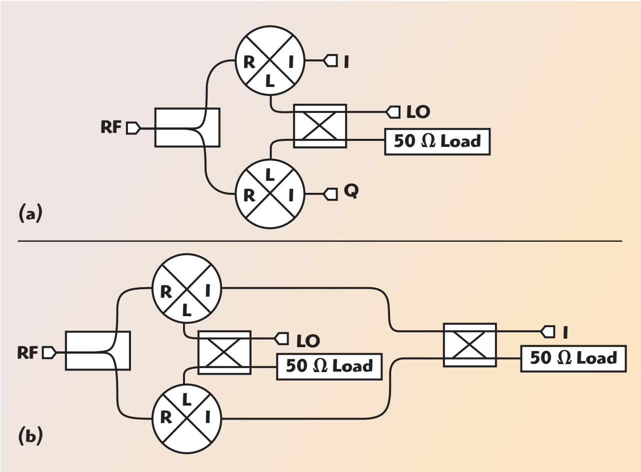
The simplest way to understand an I/Q mixer is to imagine a mixer as performing a simple signal multiplication to the two inputs (see ***Figure 4***). In this case a signal that is multiplied by an in-phase LO at the transmitter appears undistorted after multiplication by an in-phase LO and lowpass filtering at the receiver, but it is not present if it is multiplied by an out-of-

phase LO. The implementation used in Marki I/Q mixers is shown in ***Figure 5***.

Another way to understand I/Q mixers is to assume a sinusoidal input signal at the IF instead of an arbitrary time dependent function. This is useful for understanding SSB-IR mixers. In an I/Q up-conversion, the out-of-phase LO causes the upper sideband to be 90 degrees out-of-phase and the lower sideband to be -90 degrees out-of-phase



▲ *Fig. 4 Double sided signal transmission with in-phase and out-of-phase LO.*



▲ *Fig. 5 I/Q mixer structure (a) and image reject/single sideband mixer structure (b).*

with the input signal. At the receiver side, an in-phase LO converts them as is, leading to cancellation since they are 180 degrees out-of-phase with each other. A quadrature LO causes them to rotate back into place, adding constructively. You can see now that since the two sidebands have a phase difference of 180 degrees, we can eliminate one without eliminating the other by rotating both sidebands by either 90 degrees or -90 degrees and adding them back to an un-rotated copy of themselves (that is, one converted by an in-phase LO). Indeed this is the function that the IF hybrid in an SSB-IR mixer performs.

This additional quadrature hybrid placed between the I and Q ports introduces a second 90 degree phase shift to one signal, then recombines the identical, out-of-phase copies. After the additional phase rotation, one sideband is 180 degrees out-of-phase while the other is in-phase, causing one set of sidebands to add constructively and the other set of sidebands to add destructively.

The deceptively simple block diagram form of these structures masks a deep complexity intrinsic to their component elements. Let's consider each component in turn, focusing on the miniaturized, integrated, planar and multi-octave form of these circuits (see ***Table 1***):

RF In-Phase Power Divider: This is certainly the simplest component in the structure. I/Q mixer operation requires excellent phase match and low loss across the RF operating band, and isolation is desirable to reduce spurious products. A resistive power divider is possible but has higher loss than a reactive tee. The obvious solution, however, is the Wilkinson power divider, which provides low loss, phase matching and isolation, although it requires resistors and quarter-wave transmission lines that can contribute to a larger required circuit area.

Matched Mixers: Options for mixers are abundant (single diode, balanced FET, Gilbert Cell, triple balanced, etc.), but for most microwave applications the obvious choice is the double balanced diode mixer. This mixer can be planarized, offers good isolation and spurious rejection, high P_{1dB}, excellent repeatability of phase delay and amplitude

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Td	360°C	360°C	360°C	390°C	360°C
Dk @ 10 GHz	2.80 - 3.45	3.38, 3.45 & 3.56	3.45*	3.45*	3.00
Df @ 10 GHz	0.0028 - 0.0036	0.0028, 0.0031 & 0.0034	0.0031*	0.0030*	0.0017
CTE Z-axis (50 to 260°C)	2.90%	2.80%	2.80%	2.90%	2.90%
T-260 & T-288	>60	>60	>60	>60	>60
Halogen free	No	No	No	Yes	No
VLP-2 (2 micron Rz copper)	Available	Available	Available	Standard	Standard
Stable Dk & Df over the temperature range	-55°C to +125°C	-55°C to +125°C	-55°C to +125°C	-55°C to +125°C	-40°C to +140°C
Optimized global constructions for Pb-free assembly	Yes	Yes	Yes	Yes	Yes
Compatible with other Isola products for hybrid designs	For use in double-sided applications	Yes	Yes	Yes	Yes
Low PIM < -155 dBc	Yes	Yes	Yes	Yes	Yes

* Dk & Df are dependent on resin content NOTE: Dk/Df is at one resin %. Please refer to the Isola website for a complete list of Dk/Df values. The data, while believed to be accurate & based on analytical methods considered to be reliable, is for information purposes only. Any sales of these products will be governed by the terms & conditions of the agreement under which they are sold.

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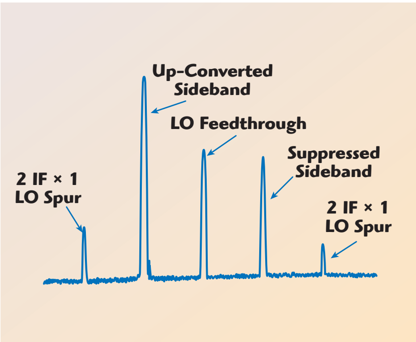
TABLE I
COMPARISON OF MIXER STRUCTURES

Structure	Complexity	Components	Benefits	IF Bandwidth Limitation	LO/RF Bandwidth Limitation
Double Balanced Mixer	Medium	1 Balun, 1 Magic Tee / Diplexer	Spurious Cancellation	Magic Tee (Diplexed IF)	Magic Tee (Diplexed RF/ LO)
Triple Balanced Mixer	High	5 Baluns, 2 Power Splitters	Spurious Cancellation	IF Balun	RF/LO Balun (can be Ferrite or Quarter Wave)
In-Phase/ Quadrature (I/Q) Mixer	High	2 Mixers, 1 Quadrature Hybrid, 1 In-Phase Splitter	Quadrature Signal Modulation / Demodulation	Mixer IF Bandwidth	LO Quadrature Hybrid
Single Sideband (SSB) Mixer	Very High	2 Mixers, 2 Quadrature Hybrids, 1 In-Phase Splitter	Up-Conversion with Sideband Cancellation	IF Quadrature Hybrid	LO Quadrature Hybrid
Image Reject (IR) Mixer	Very High	2 Mixers, 2 Quadrature Hybrids, 1 In-Phase Splitter	Down-Conversion with Image Cancellation	IF Quadrature Hybrid	LO Quadrature Hybrid



▲ *Fig. 6 Realistic single sideband up-conversion spectrum.*

balance and single ended operation on all three ports. One downside is that its frequency range is limited by the magic tee structure on its IF port, but this is usually not the main frequency limitation in the I/Q-SSB-IR mixer structure.

LO Quadrature Hybrid: This is where things go from tough to ridiculous in terms of integration. Making multi-octave Wilkinson power dividers is possible with microstrip circuits, and the multioctave baluns necessary for double balanced mixers have been achieved in a planar form in MMICs and to a greater extent in the Microlithic® platform.[4] A quadrature hybrid (essentially a 3 dB directional coupler with 90 degree phasing) is more difficult to realize, particularly beyond an octave bandwidth. This has only been achieved in the Microlithic platform. Most available surface-mount quadrature hybrids are narrowband, designed for balanced amplifiers. However, there are many legitimate ways to perform this quadrature signal generation, and we expect to see more of them implemented at microwave frequencies in the future.

IF Quadrature Hybrid: This is where integration goes from ridiculous to impossible. The IF is at a lower frequency than the LO, which means that a quarter wavelength is significantly longer. This makes implementation of a stripline quadrature hybrid more difficult, and generally engineers use magnetic assistance in these situations. Ferrites or absorbers cannot be integrated into a planar structure, however, so a passive SSB-IR structure generally requires an external IF hybrid. The preferred solution to this problem is to connect the I and Q ports directly to a high speed digital-to-analog converter (DAC) that implements the quadrature phase shift digitally. This also allows for calibration to compensate for imbalance in the I/Q structure.

WHEN TO USE AN I/Q-SSB-IR MIXER

The fundamental challenge of up-conversion is the translation of an input low frequency signal to a distortion free higher frequency output with high power, and the fundamental challenge of down-conversion is the translation of a high frequency signal to a lower frequency output with maximum dynamic range. The problem here is that mixers (and sometimes amplifiers) generate spurious products which need to be removed, necessitating a heterodyne or superheterodyne architecture with an intermediate frequency high enough so that the undesired image or sideband signal can be adequately filtered out without heavily attenuating the desired signal. An SSB-IR transmission system eliminates this filtering requirement by canceling out the image/sideband signal with balance, eliminating the need for filters that tend to be large and expensive. For IF frequencies much lower than the LO frequency, the two output sidebands will be too close together to filter, requiring SSB-IR mixers. An IR mixer also improves the noise figure of the system by 3 dB by eliminating the sideband noise.

Do not be fooled into thinking that the SSB-IR is a panacea, however (see ***Figure 6***). In a single sideband up-conversion the SSB mixer does not improve LO-RF isolation and the 2IF × 1 LO spur is only suppressed by an additional 3 dBc due to the RF power split.[5] Since the LO feedthrough and the 2IF × 1 LO spur are both separated from the desired sideband by f_{IF}, there are two spurs closer to the desired sideband signal than the undesired sideband, which is separated by $2 \cdot f_{IF}$. If more spurious rejection is required than that provided by LO isolation, then a heterodyne structure is required. Similarly the 2 RF × 2 LO spur is not suppressed by the image reject mixer. This requires a lowpass filter to remove it, limiting the dynamic range of very low IF systems. Finally, the image or undesired sideband is only suppressed by 20 to 50 dB (more for narrowband, low frequency systems and less for wideband systems). This is limited by the amplitude and phase balance of the mixer, which varies over frequency, temperature

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and time. Regardless, IR/SSB mixers are important for applications such as Doppler weather radar and quantum computing, which use low IF frequencies and have reasonable dynamic range requirements.

An I/Q transmission system addresses the problem of spurious and image products in a different way. Since it uses both sidebands to modulate the RF signal, there is no requirement to filter out the image or undesired sideband. The main limitation of this system is that the I channel will leak into the Q output and vice versa, limiting the dynamic range to this suppression ratio which is related to the sideband suppression ratio. This suppression is typically much less than the spurious, multitone intermodulation, or any other noise source, so spurs are not a meaningful problem. Similarly some unsuppressed carrier feedthrough is necessary to lock the receiver LO to the transmitted LO, meaning that LO-RF suppression is not as important. All of this limits dynamic range, but for the vast majority of communications systems the cost savings from the elimination of filters and additional conversion steps significantly outweighs the dynamic range limitation that the I/Q mixer imposes on the system (particularly after compensation). That is why every major modern communication system, including all cell phone and Wi-Fi standards, use some variation of advanced I/Q modulation such as QAM, QPSK or OFDM.

WHAT CAN I DO WITH AN I/Q-SSB-IR?

The most obvious application of an I/Q mixer is communications. However, there are many other niche applications for these products, including:

Synthesizers/Pulse/Signal Generators: A single sideband mixer can be combined with a fixed high frequency LO and a tunable low frequency signal generator to create an easy-to-use synthesizer/high frequency arbitrary waveform generator (AWG). This is especially true if you have a dual channel DAC that supports this application.

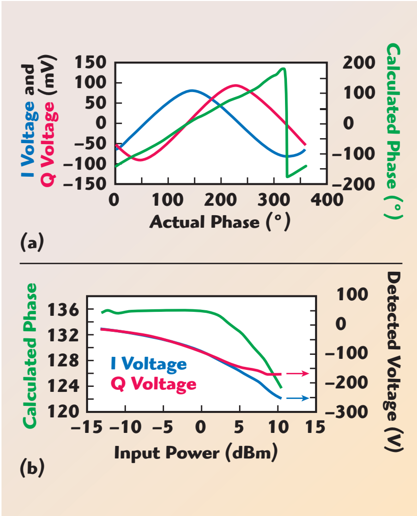
Wideband Scanners: This is the opposite application of the synthesizer. Both high performance synthesizers and scanners typically employ multiple conversion stages with switched filter banks and complicated frequency plans. Less demanding applications with lower dynamic range requirements can use a single image reject mixer to scan across the entire RF/LO bandwidth of the mixer, which is as wide as 2 to 18 GHz in the case of the Microlithic.

Phase Detectors: As mentioned, I/Q mixers are frequently used for communications applications as phase modulators (QPSK, for example). Double balanced mixers are frequently used as phase detectors in phase-locked loops due to their ability to generate an error signal that can keep two signals in quadrature. They provide incomplete information, however, since a given voltage output can correspond to two different phase values, and this varies with input power. However, these ambiguities can be resolved with an I/Q mixer. The two output signals can be used to determine both the incoming signal amplitude and unique phase (see ***Figure 7***).

Optical Transmission Systems: In many ways, an optical transmission network is an ideal transmission medium for an I/Q system. Since stray light does not couple into a fiber optic system, the only impairments come from the signals themselves. This is the ideal situation for an I/Q mixer, since noise filtering for stray signals is unnecessary (some filtering is usually employed for self-generated and amplifier noise). This means that twice the data rate can be provided in the same bandwidth that would be required for a double sided transmission. This is one of many reasons that I/Q data transmission schemes are being employed for high data rate optical communication systems.

WHAT IS THE FUTURE OF I/Q MIXERS?

In almost all situations, the main limitation of I/Q architectures is



▲ *Fig. 7 An I/Q mixer as a phase detector, with calculated phase vs. I and Q voltages (a) and vs. input power (b).*

the ability to produce well matched quadrature-phased signals over very large bandwidths. Therefore, future I/Q mixers will require advancement in quadrature signal generation. As digital signal generation becomes practical at higher frequencies, we expect to see more circuits that combine the best of these digital circuits (excellent phase and amplitude balance with digital compensation) with the best of passive analog circuits (high power handling and single ended operation). Already the IF hybrid is largely eliminated as a result of high speed analog-to-digital converters (ADC) and DACs, and there is no indication that these are at the end of the line.

The dream I/Q mixer of the future will have amazing image rejection across a massive bandwidth, with incredible spurious rejection, linearity and power handling, all in one tiny package. ■

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Small Form Factor Spectrum Analyzer Handles Big Tasks

Rohde & Schwarz
Munich, Germany

The handheld spectrum analyzer market is growing for numerous reasons, not just because the performance of these devices is being significantly improved through available technology. The growing number of wireless applications is crowding the spectrum, the demand for measuring is increasing and the development of new application fields such as electro-mobility and the Internet of Things (IoT) is growing rapidly.

The markets and applications for handheld spectrum analyzers, both in the field and in the lab include:

- Telecom and broadcast, including base station installation and maintenance, spectrum monitoring and interference hunting
- Aerospace and defense, from basic transmitter station maintenance through spectrum monitoring and interference hunting and radio link testing
- Education, ranging from basic general-purpose spectrum analysis applications to higher education and training
- Basic R&D, including RF design and development and EMC pre-compliance.

The R&S Spectrum Rider has been engineered to address these markets and applications by utilizing state-of-the-art technology and paying specific attention to providing usability and flexibility, all contained in a robust, lightweight instrument. Versatility assists users during RF transmitter installation and maintenance as well as supporting measurement tasks in RF development labs and in service. It features a measurement accuracy of 0.5 dB and a high sensitivity, with a displayed average noise level (DANL) typically less than -163 dBm up to 3 GHz.

Significantly, the frequency range of the R&S Spectrum Rider can be extended via software upgrades. The base model covers the frequency range from 5 kHz to 2 GHz, which can be expanded to 3 or 4 GHz to support applications that require higher frequencies, such as measuring radio signals above 2 GHz or signals above 3 GHz in TD-LTE bands.

IN THE FIELD

The spectrum analyzer has been optimized for mobility and use in the field. The robust instrument weighs just 2.5 kg and has a battery that lasts up to eight hours, making it capable of working a full day without recharging. The backlit keypad allows users to work in the dark (see ***Figure 1***), and the non-reflective display sup-

▲ *Fig. 1 The backlit keypad of the R&S Spectrum Rider enables users to work comfortably and efficiently in the dark.*

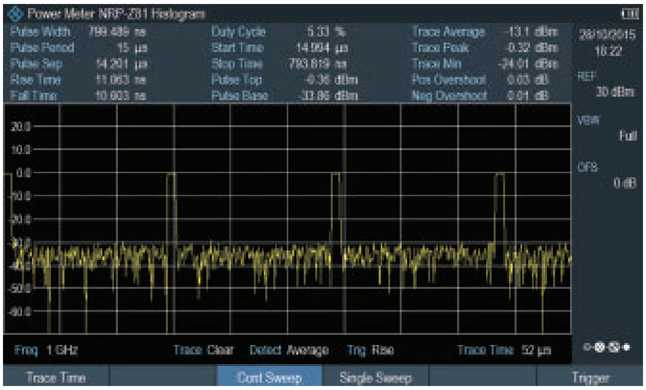
ports a black-and-white mode for good readability in direct sunlight. The unit features a 7 inch full color capacitive touchscreen that allows smartphone-like intuitive gesturing – pinch to zoom, cross to delete, etc. Its large buttons and practical multifunction wheel make it easy to operate with gloves in outdoor environments. Portability is aided by the options of a side strap, soft carrying bag or hard case. The R&S Spectrum Rider has been field-tested in line with MIL-PRF-28800F Class 2, comes with protected interfaces and ports and features IP51 shock-resistant, protected connectors and has no vents or fans.

Leveraging the handheld spectrum analyzer's unique features, field strength measurements as well as monitoring and locating a signal of interest become more convenient and

▲ *Fig. 2 All measurement parameters can be set in the configuration menu, which makes it easy for the user to get an overview of the main measurement settings.*

▲ *Fig. 3 The R&S Spectrum Rider requires only minimum bench space in the lab.*

easier. To save time and effort, a built-in wizard automates measurements, reducing measurement times and enables even novice users and operators with little RF expertise to reliably carry out measurement tasks. Users can preconfigure measurement sequences before setting off to take measurements. This reduces human error and increases efficiency with automated measurements. For documentation, the R&S Instrument View bundled software has a report generator function to generate a complete measurement report in a few seconds. For post-processing, the software can add markers to saved traces for a detailed analysis of collected signals.



▲ *Fig. 4 The R&S FPH-K29 option enables precise pulse and peak power measurements using the R&S NRP-Z8x wideband power sensor family.*

IN THE LAB

The R&S Spectrum Rider is claimed to be the industry's first handheld spectrum analyzer to offer a large-format capacitive touchscreen that enables lab users to easily and intuitively adjust settings such as frequency, span and reference level and to set markers. It offers diagnostics capability for service or even in the development lab and can be used for EMI debugging to determine disturbance from a device under test during development. A handy configuration overview menu (see ***Figure 2***) shows the flow of spectrum measurements at different receiver stages, along with the relevant parameters that impact each stage.

Requiring only minimum bench space (see ***Figure 3***), the spectrum analyzer can be used for a wide range of measurements, such as frequency, level and spurious. The R&S Spectrum Rider can easily be controlled remotely via LAN or USB, which enables users to automate measurement scenarios. Using the R&S Instrument View software, it is also possible to project the display on a larger screen, ideal for classes in schools and universities.

Available options include pulse measurements (see ***Figure 4***) with peak and average power levels. The main pulse parameters such as pulse width, rise and fall times and duty cycle are displayed automatically. It is also possible to use the trigger function and markers and to zoom in on pulses by reducing the trace time. This is convenient for installation and maintenance measurements of radar systems.

The instrument has appeal for field technicians and lab engineers alike, as it supports everyday measurement tasks in aerospace and defense, wireless communications and broadcasting and within regulatory authorities. The R&S Spectrum Rider, which comes with a number of convenient options, is a handy tool for users in diverse industries.

VENDORVIEW

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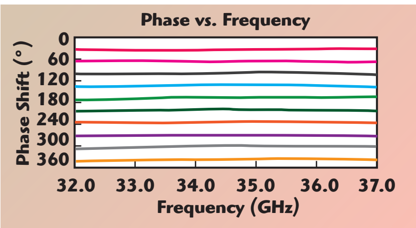
Pasternack
Irvine, Calif.

The latest military and industrial radar and microwave to millimeter wave backhaul applications require precise control of the input and output phase of their antenna arrays over a wide range of frequencies. These applications benefit from high performance antenna arrays that reduce size, weight, power and cost (SWAP-C) over prior technologies, while increasing effective range and sensitivity. Without this technology, the latest electronic warfare (EW) active electronically scanned arrays (AESA) employed for mission critical jamming operations on modern fighters would not be possible. A pivotal device enabling these systems is the digital phase shifter, used to ensure the precise control and beam forming of the antenna array.



▲ *Fig. 1 The PE82P5003 digital phase shifter provides flat phase shift over 32 to 37 GHz, ensuring accurate operation of broadband antenna array systems.*

To serve the demands of this market, Pasternack is now offering highly accurate 8-bit digital phase shifters with broadband frequency ranges starting at 500 MHz and extending to 37 GHz. Four models are currently available, each offering a full 360° phase shift range with 1.41° phase resolution. Key to Pasternack's offering is in-stock, same-day shipping available for all RF products, critical when a long lead time could delay impending project deadlines and increase costs.

Pasternack's four models offer extremely flat phase over 0.5 to 2 GHz (PE82P5000), 8.5 to 11 GHz (PE82P5001), 6 to 18 GHz (PE82P5002) and 32 to 37 GHz (PE82P5003). The 256-step, 360° phase range enables precise digital control with an 8-bit TTL logic input. ***Figure 1*** shows the performance of the millimeter wave model. The control voltage range is 0 to 10 V DC and interfaces with an industry standard 15-pin Micro-D connector, which enables easy system integration and ensures a robust physical design. Switching speeds as low as 30 to 500 ns also ensures rapid response and agile beam forming from an antenna array.

Along with flat phase response over frequency, these phase shifters achieve low insertion loss with low variation typical throughout the operating range. Low insertion loss in a phase shifter benefits an antenna array application by decreasing the demand on the power amplifiers that drive the array. This can lead to greater linearity, reduced SWAP-C, lower noise and greater sensitivity. Additionally, the highly integrated hybrid MMIC design architecture provides noise and linearity benefits.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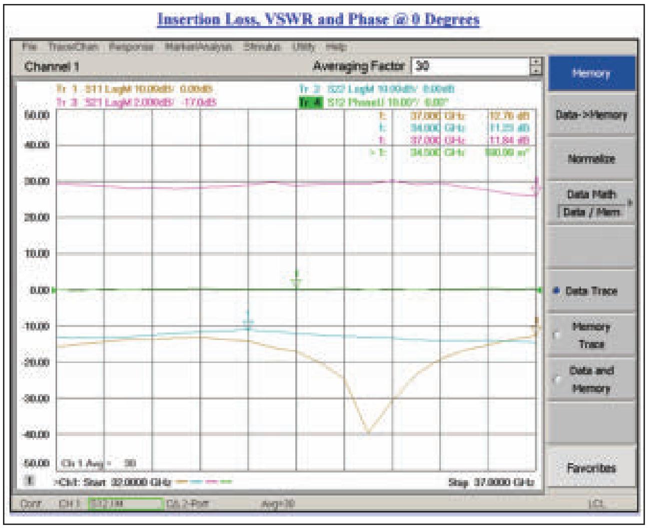

Fig. 2 Insertion loss and VSWR at the 0° phase state of the PE82P5003 digital phase shifter.

The architecture offers enhanced noise immunity from the control lines and greater unit-to-unit performance consistency. The architecture responds with little delay to the digital control logic, enabling faster switching speeds. As a flatter phase response over the broadband frequency range and high power handling enable improved linearity performance, these phase shifters add less of a burden on other components in the system. For example, when embedded in a system with imperfectly impedance-matched components, this phase shifter architecture will demonstrate less susceptibility to phase pulling.

Rugged enough for many EW, military communications and test and measurement applications, Pasternack's phase shifters have durable packages with field-replaceable coaxial connectors: SMA female for all but the PE82P5003, which employs 2.92 mm female connectors for better millimeter wave performance. The phase shifters operate from –55° to +85°C and meet or surpass many MIL-STD-202F environmental specifications for humidity, shock, vibration, altitude and temperature cycling. The hybrid MMIC design also enables a small footprint and thin package, ideal for compact systems with many elements.

All phase shifters in this series operate with ±15 DC bias. The four digital phase shifters have a maximum CW input power of 3 (PE82P5000), 13 (PE82P5001), 20 (PE82P5002) and 10 dBm (PE82P5003). Typical insertion loss is 8.5, 10, 10 and 13 dB, respectively. Amplitude errors are low: ±1, ±1, ±2.5 and ±1.5 dB.

The PE82P5000 employs a digital-to-analog (D/A) converter and an analog phase shifter to offer a digitally-controlled analog phase shifter with 8-bit accuracy and 256 discrete values. Over the 0.5 to 2 GHz frequency range, the device has a low amplitude error of ±1 dB and maximum phase shift error of ±10°. Insertion loss is a maximum of 13 dB and input power handling is1 W CW maximum.

The PE82P5001 demonstrates a low switching speed of 100 ns within its 8.5 to 11 GHz frequency range. Input and output VSWR is typically 1.8:1, with a passband phase accuracy of ±9 dB and a phase error less than ±2°. Additionally, the spurious content of this device is better than –130 dBm without input or control updates.

The PE82P5002 covers 6 to 18 GHz with a maximum input VSWR of 2:1. When employed as a frequency translator, this phase shifter typically has a translation rate of 500 kHz, carrier suppression of 18 dB and sideband suppression of 15 dB. A low harmonic distortion of –25 dBc demonstrates the high linearity over the 12 GHz of bandwidth.

The PE82P5003 operates in the millimeter wave band from 32 to 37 GHz, with typical insertion loss of 13 dB across the passband (see ***Figure 2***). For the highest performance, a 2.92 mm female connector is used for the input and output ports, which generally achieves an input VSWR of 2:1 and output VSWR of 2.5:1. This device typically has a phase resolution of 1.41° and low phase error of ±5°, with a switching speed of 500 ns maximum.

VENDOR**VIEW**

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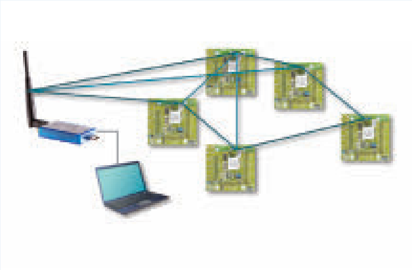

SmartMesh IP™ Wireless Network Manager Available as a USB Dongle

Linear Technology's DC2274A USB dongle serves as a network manager for a SmartMesh IP™ wireless sensor network. With its compact USB dongle form factor, the DC2274A, along with SmartMesh IP wireless nodes, makes it easy to rapidly deploy a wireless mesh network for field trials and to accelerate sensor product development.

Based on 6LoWPAN, SmartMesh IP mesh networking products deliver >99.999 percent network reliability at ultra-low power, with no network stack development required. This is particularly important for industrial IoT applications, where wireless sensor networks may be deployed in harsh and remote environments. Linear Technology's Dust Networks product group develops low power and highly reliable standards-based wireless sensor networking products. Dust Networks products are field proven, with over 45,000 customer networks in 120 countries. With an average power consumption of less than 50 µA in heavy usage applications, SmartMesh IP products deliver over 10 years of battery life, enabling wireless sensor nodes to be placed anywhere. Since all SmartMesh products include secure precompiled network stacks, dynamic mesh optimization software and network diagnostics software, developers can focus on rapid industrial IoT application development and rely on Dust Networks' years of mesh networking expertise embedded in every product.

The DC2274A USB Network Manager is available individually or as part of the DC9000B SmartMesh IP Starter Kit, which includes five wireless mesh nodes and retails at $750. With a SmartMesh IP Starter Kit, users can set up a wireless mesh network in minutes and quickly evaluate the network performance in their own application environments.

VENDORVIEW

Linear Technology
Milpitas, Calif.
www.linear.com/DC2274

LDMOS Transistor Replaces Tubes in 2450 MHz Industrial Systems

Freescale's MRF7S24250N LDMOS power transistor operates from 2.4 to 2.5 GHz with 250 W CW output power at 1 dB compression. It replaces magnetrons and other vacuum tubes that currently power industrial heating, drying and welding equipment as well as medical systems used for skin treatment, bloodless surgery and cancer therapies.

The product provides accurate power control over its full dynamic range up to 250 W and allows both the frequency and phase to be changed. This enables the host system to direct RF energy only where needed. The transistor also has an operating life of hundreds of thousands of hours significantly greater than magnetrons. During its lifetime, the RF output power and other performance characteristics will not degrade, providing a stable operating environment and virtually eliminating the need for periodic maintenance or replacement.

With a drain bias of 32 V, the MRF7S24250N has 14.7 dB gain and 55 percent drain efficiency. Internally matched at the input and output, the device will withstand an impedance mismatch greater than 10:1 with 3 dB overdrive without degradation. It is housed in an OM-780 overmolded plastic package, which has up to 30 percent lower thermal resistance than air-cavity ceramic packages, reducing heat dissipation and allowing the transistor to operate at lower junction temperatures.

To ease the transition from vacuum tubes to solid-state, the MRF7S24250N is supported by Freescale's RF Power Tool system. The tool is an easy-to-use PC-driven hardware and software platform that modifies and evaluates the characteristics of an amplifier using the MRF7S24250N (or another compatible Freescale LDMOS transistor), without requiring expensive test equipment or extensive RF technical knowledge.

Freescale Semiconductor
Tempe, Ariz.
www.freescale.com/mrf7s24250n

New Coaxial Switches Cover DC to 46 GHz

Ducommun has developed a new switch series that covers DC to 46 GHz, with SPDT, multi-throw (SP3T to SP6T) and transfer configurations. These switches can be used in commercial and ruggedized environments, including electronic warfare (EW), navigation, radar, satellite and communication systems. The DL series is a broadband electro-mechanical switch with a common input that is switchable to one of two outputs; the QL series is designed to switch a microwave signal from a common input to any of three through six output ports; and the TL series connects two ports together. These coaxial switches offer low insertion loss and good high frequency isolation: 50 dB at 46 GHz for the DL series.

All switches are 50 Ω with 2.4 mm female connectors. Connections are break-before-make, with 15 ms maximum switching time. Operating life is 1 million cycles. The standard operating temperature range is -35° to -85°C, with wider ranges available. The switches are designed in accordance with the requirements of MIL-DTL-3928.

Multiple options are available in addition to the standard versions. These include RoHS compliance, compatibility with TTL logic, suppression diodes, indicators, D-Sub terminals, and either fail-safe, latching self cut-off or pulse latching actuation.

Ducommun RF switches are known for reliability and are used in a wide variety of aerospace, defense, industrial and space applications. Ducommun's RF product group designs and manufactures both active and passive products that span DC to 110 GHz.

Ducommun Inc.
Carson, Calif.
www.ducommun.com

Preamplifiers for MRI Coil Applications

MicroWave Technology has added two preamplifiers to their line of preamps for magnetic resonance imaging (MRI). Both are built using advanced, low noise GaAs devices and components with very low magnetism, a critical requirement for MRI coil applications.

The MSM series preamp achieves 0.45 dB noise figure with 28 dB gain at 1.5T (64 MHz), 3T (123 to 128 MHz) and 7T (298 MHz). It has a low input impedance of 2 Ω. Bias current is 15 mA at 10 V. The preamp is housed in a miniature surface-mount package with a footprint of 0.43 in. × 0.36 in. The MPE preamp was designed for 3T (123 to 128 MHz) applications and achieves noise figure as low as 0.4 dB with 27 dB gain, drawing 12 mA at 10 V. This preamp has a footprint of 0.74 in. × 0.5 in. Both the MSM and MPE preamplifiers have excellent linearity, 20 dBm IP3, and can withstand input power as high as 30 dBm.

The small size of the MSM series is ideal for MRI coils with a large number of channels. The MPE preamp is targeted at the low cost MRI coil market, yet it maintains excellent RF performance. Microwave Technology has been a major preamplifier supplier to MRI system and coil manufacturers for over 15 years and remains committed to supporting the medical equipment market.

MicroWave Technology Inc., an IXYS Co.
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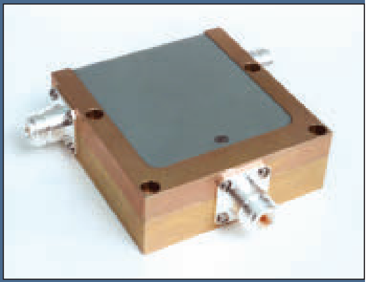
HIGH POWER
100 MHz to 20 GHz

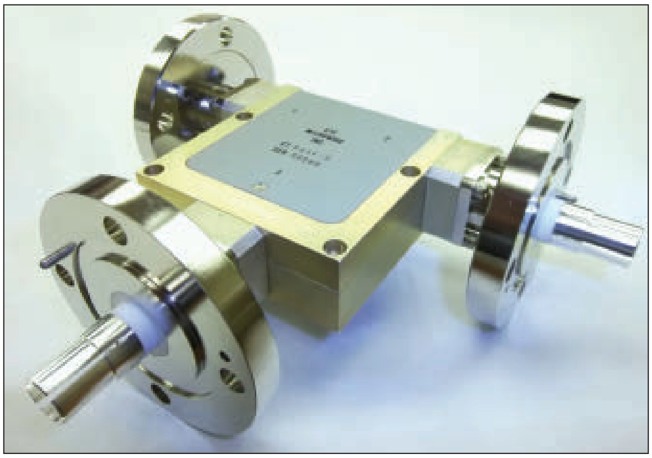


For Military/Radar Applications.

Isolators/Circulators

As one of the leading suppliers of ferrite components in the industry, UTE Microwave has pioneered innovative designs, quality craftsmanship and exceptionally high quality products. Custom designs, standards...many of them off-the-shelf, are the result of over 35 years of experience in the industry. UTE Microwave continues this tradition with new products for ever changing applications. Our broad line of HIGH POWER, low loss circulators and isolators spans the spectrum from below 100 MHz in coax/stripline units to waveguide devices at 18 GHz for both peak and average powers.

325 MHz NEW HIGH POWER Circulator for Radar & UHF Frequencies



Model CT-1864-S is rated at 60kW peak and 600W average power at 325 MHz. The unit provides 20 dB minimum isolation, 0.2 dB insertion loss and 1.20:1 maximum VSWR. Its extremely compact design has flange to flange insertion length of only 6-3/4" and a height of 5-1/4". For use in radar applications, it has 1-5/8" EIA connectors. It is also available at other UHF frequencies and connector types.

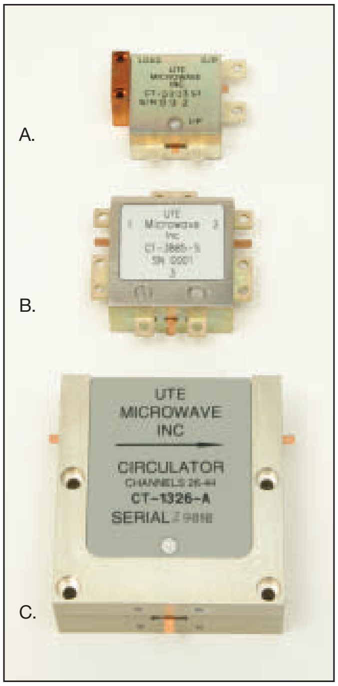
HIGH POWER Drop-in Series

A broad line of low loss HIGH POWER Drop-in circulators are available from VHF to Ku band including Kilowatt average power levels at VHF thru S band. L and S band radar are a specialty. A few of these are shown here.

A) 2.7–3.1 GHZ 1 kW pk, 100 W av

B) 1.2–1.4 GHZ 3 kW pk, 300 W av

C) UHF TV Band 5 kW pk, 500 W av



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CT-3877-S	2.5 Kw Pk 250 W Av	"Drop-in"	2.7–3.1 GHz
CT-3838-N	5 Kw Pk 500 W Av	N Conn.	2.7–3.1 GHz
CT-1645-N	250 W Satcom	N Conn.	240–320 MHz
CT-1739-D	20 Kw Pk 1 Kw Av	DIN 7/16	128 MHz Medical

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Find it Fast Guides

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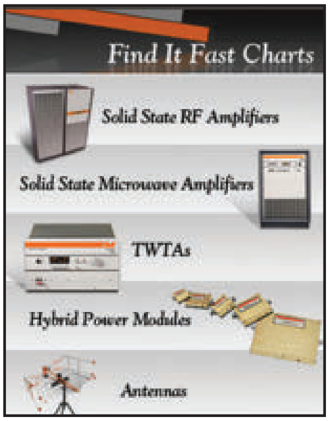


AR's Find It Fast guides allow users to quickly find the appropriate RF or microwave power amplifier, TWTA, hybrid power module or antenna to meet your most demanding applications. Their website features a wide range of both solid-state and TWTA wideband amplifier designs to satisfy EMC and various other markets. The menu system is easy to read and the sites are search engine friendly. Visit www.arworld.us or www.arww-rfmicro.com.

AR RF/Microwave Instrumentation
www.arworld.us

Website Redesign

VENDORVIEW

Crane's Microwave Components & Integrated Assemblies has redesigned its website. No more searching, searching and searching — the redesign helps you find the datasheet you need quicker than ever before! Product lines, product specifications and datasheets are all right at your fingertips. Looking for integrated assemblies, component and single function devices or space qualified passive products? Visit www.craneae.com/mw for more information.

Crane Aerospace & Electronics
www.craneae.com/mw

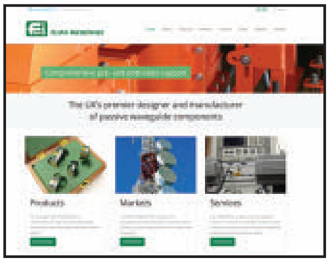
Advanced GaN and GaAs MMICs

VENDORVIEW

Custom MMIC has added several new MMIC solutions to their rapidly growing product library on their website. New, balanced, low noise amplifiers (LNA) operate from 9 to 18 GHz. A new GaN LNA operates from 4 to 8 GHz with a gain of 22.5 dB, and can withstand RF input power levels of up to 5 W. A 15 to 30 GHz frequency doubler is "active," so there's no loss. Many more new MMIC releases can be found online.

Custom MMIC
www.custommmic.com

21st Century Functionality



Flann Microwave Ltd., a leading manufacturer of passive waveguide components up to 500 GHz, announced the launch of its new website. Delivering 21st century functionality and easy access to product, market and services information, the new website represents the next step in Flann's plans to modernize its online and social media presence. Significant improvements have been made to ease access to product data as well as contact and representative information. The site also features an enhanced news portal.

Flann Microwave Ltd.
www.flann.com

Demonstration Videos

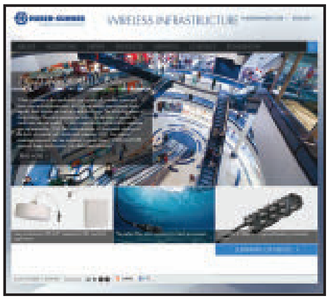
VENDORVIEW

High Speed Interconnects (HSI) is custom extruding phase stable, low loss, micro-coaxial and coaxial cable assemblies to order. These ultra-flexible cable assemblies are designed to withstand less than 0.25" bend radiuses and exceed 90 percent velocity of propagation while delivering phase stability of < 1.5° and insertion loss of < 0.9 dB per foot @ 40 GHz. HSI is encouraging non-believers to request a live demonstration to see the phase stability, loss and capacitance of these assemblies in real-time. Watch the recorded videos on their website at www.highspeedint.com/videos.

High Speed Interconnects
www.highspeedint.com/videos

Small Cells/IBC/DAS Solutions

VENDORVIEW



Due to the fast growing need for broadband networks everywhere in the world, the build-up of indoor and outdoor small cell networks is in progress right now and for the next few years. HUBER+SUHNER supports these initiatives with dedicated solutions based on fiber optic technology as well as on radio frequency technology. Find IBC/DAS and small cell solutions on the company's wireless infrastructure microsite at http://wirelessinfrastructure.hubersuhner.com.

HUBER+SUHNER
http://wirelessinfrastructure.hubersuhner.com

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From first simulation through first customer shipment, design & test software from Keysight delivers the tools needed to quickly move from data to information to actionable insight. You can try out a software package for free for 30 days, just by downloading a free trial from Keysight's newly updated software website. Trial software is available in the following application areas: cellular & wireless connectivity applications and technology; digital design & interconnect standards; aerospace & defense applications; and digital video technology and applications.

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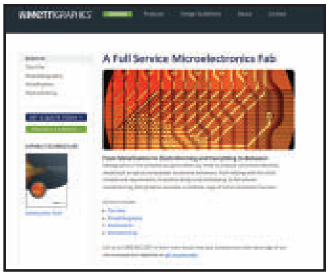
Micro-flex and Thin-film Circuits

VENDORVIEW

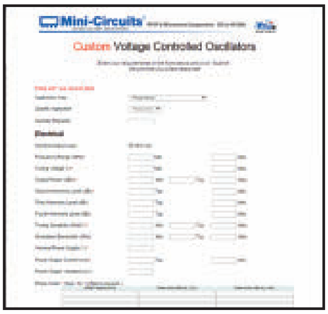


Today's antennas are getting smaller and more flexible, circuits are fitting into tighter and weird spaces, and signal integrity still is job one. Metrigraphics is addressing this market requirement with micron-scale flexible circuits that are flexible enough to wrap around objects with diameters as small as a pencil. To manufacture flexible circuits with high-resolution, Metrigraphics employs a mix of proprietary and industry-standard processes. These include high-resolution photolithography as well as sputtered thin-film and plated metal deposition. Visit their website for more information.

Metrigraphics LLC
www.metrigraphicsllc.com

Custom VCO Spec Checklist

VENDORVIEW



Need a VCO custom designed for your project? Visit minicircuits.com and try their online custom VCO spec checklist. Simply enter your requirements and a little information about your project, then click submit for a fast response. Mini-Circuits' engineers will review your application, determine feasibility and provide a proposal. They can optimize models for wideband, linear tuning, dual output, low phase noise and more for low cost and with fast turnaround.

Mini-Circuits
www.minicircuits.com

Website Launch

P1dB's website has been designed to meet customer demand for an easy product search, consumer level e-commerce check-out and 24/7 availability. P1dB will continue to increase and develop its product line based on market feedback in order to become the leading RF and microwave component supplier supporting customers' immediate requirements. Back-end support has also been installed to permit easy interfacing with P1dB's franchised distributor, RFMW Ltd., which will improve customer experience and support.

P1dB Inc.
www.p1dB.com

S-parameter Data

VENDORVIEW

Passive Plus Inc. (PPI), is a manufacturer of high-performance RF/microwave passive components, and serves the medical, semiconductor, military, broadcast and telecommunications industries. PPI has partnered with Modelithics to provide S-parameter data that is currently downloadable free on PPI's website for the following: 0505C/P and 1111C/P series of Hi-Q (>10,000)/low ESR capacitors; 0201N, 0402N, 0603N, 0805N and the 1111N series of EIA Hi-Q/low ESR capacitors; and 1005BB, 0201BB and 0402BB series of broadband capacitors.

Passive Plus Inc.
www.passiveplus.com

Scope of the Art

VENDORVIEW

Discover the continuously expanding Rohde & Schwarz oscilloscope portfolio on their re-launched "Scope of the Art" website. Find the perfect oscilloscope, applications and accessories to meet your requirements. The website features all the information you need about the extensive portfolio of oscilloscopes with bandwidths from 50 MHz to 4 GHz, as well as high-quality active and passive probes and other accessories. Plus, it keeps you informed about current promotions that save you money.

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WebUpdate

Connectors and Assemblies

VENDORVIEW

San-tron has several innovative connectors and assemblies available on their website. These include the SRX family of low-PIM adapters, connectors (including new 4.1/9.5 mini-DINs) and cable assemblies. Assemblies feature intermodulation performance as low as -168 dBc. San-tron's pSeries™ pressurized connectors provide low-loss, high-stability performance through 30 GHz at ±65 psi. These pressurized connectors meet the IP68 standard. High performance custom cable assemblies for communications and microwave test stands are also available. Visit www.santron.com for more information.

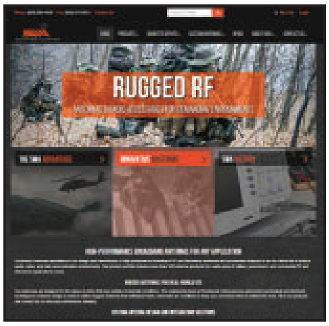
San-tron Inc.
www.santron.com

Connector Support

Signal Microwave has a new website, www.signalmicrowave.com, with resources for 2.92 mm (40 GHz) and 1.85 mm (70 GHz) connectors and test boards. The website provides technical data for these recently released edge launch and vertical launch connectors. These connectors are solderless board mounted connectors intended for test and measurement applications. Outline drawings, test data and test board resources, and other design resources to support the connectors are all available on the new site.

Signal Microwave
www.signalmicrowave.com

New Corporate Website



Southwest Antennas announced the launch of their new corporate website. Designed from the ground-up, the site delivers technical information about SWA's full line of rugged antennas and accessories to engineers, buyers, or anyone who needs robust antenna solutions for their RF or microwave communication systems. Full product specifications, technical datasheets and STEP files are available for over 500 products, and a full e-commerce system allows for easy quotes and purchases online, at any time. Visit www.southwestantennas.com.

Southwest Antennas
www.southwestantennas.com

Spotlight Going Digital

VENDORVIEW

SPINNER's Spotlight newsletter is going digital. Experience a unique variety of topics in the world of RF technology. Stay informed about new SPINNER products and its wide range of applications in the fields of communication, rotating solutions and test & measurement. The Spotlight newsletter will be sent by email once every six to eight weeks. Register now and stay tuned at spinner-group.com/newsletter.

SPINNER GmbH
spinner-group.com/newsletter

Subassemblies and Timing Modules

VENDORVIEW

TRAK Microwave's newly released microwave, aerospace and SATCOM communication system subassemblies and precision network timing products are available on their website. These new products demonstrate the latest size, weight and performance (SWaP) requirements for integrated microwave assemblies, and synchronization in both civilian and military communications. These new products include a Ku-Band block up-converter and down-converter, a Stratum 1 network time server, a Ka-Band latching circulator-isolator and a compact time and frequency reference module.

TRAK Microwave Corp.
www.trak.com

E-commerce Purchasing

VENDORVIEW

Vaunix provides e-commerce purchasing of their entire catalog of programmable and portable ATE "LabBricks" on their website. Their latest designs include attenuators with 120 dB of programmable attenuation through 6,000 MHz; -50 and -75 ohm single pole, double throw and single pole, four throw switches; 2 to 4 and 4 to 8 GHz phase shifters, and a 0.5 to 270 MHz signal generator with a 100-microsecond switching time and 100 Hz frequency resolution. These products are powered by USB and controlled by easy-to-use, graphical-user-interface (GUI) software.

Vaunix Technology Corp.
www.vaunix.com

New Products

FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE

FEATURING VENDORVIEW STOREFRONTS

Components/ICs

50 W Fixed Attenuator

BroadWave Technologies added model series 351-319-XXX (insert desired attenuation value to complete the model number) to its portfolio of 50 ohm fixed attenuators. Standard attenuation values are 3, 6, 10, 20, 30 and 50 dB. The average power rating is 50 W at 25°C with 1000 W peak power. Maximum VSWR is 1.40:1. Other attenuation values and connector configurations are available upon request.

BroadWave Technologies

www.broadwavetechnologies.com

Reliant Switch Series

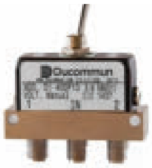
VENDORVIEW

Dow-Key Microwave released its new product series called Reliant Switch™, with an SPDT being the first RF switch in this series made available to the RF and test industry. Today's RF and wireless devices are equipped with many RF signal paths between input and output ports that need to undergo vigorous and complex testing. Therefore the use of coaxial switches is essential in allowing the user to easily switch between I/O ports, and avoiding the cumbersome task of having to disconnect and reconnect RF cables.

Dow-Key Microwave

www.dowkey.com

Manual Coaxial Switches SPDT

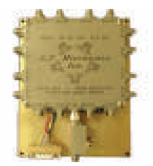


Ducommun offers two types of single-pole-double-throw (SPDT) manual coaxial switches for all applications. Current options range from DC to 3 GHz up to 50 W (CW) of power. For additional information regarding Ducommun's manual coaxial switches, please contact a sales representative. Ducommun's design engineers can create custom versions for your specific applications. Contact Ducommun at (310) 513-7256 or (310) 513-7200 for more information.

Ducommun Inc.

www.ducommun.com

SP32T Reflective PIN Diode Switch



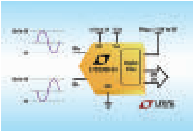
Model SA-50-0JK is a 4.385 to 4.885 GHz, SP32T, reflective, PIN diode switch. This subassembly consists of two SP16T switches, one SPDT switch and a power/logic connector all mounted together on a single plate. It exhibits an insertion loss less than 3 dB, a VSWR less than 1.5:1 in 50 Ohms and a minimum isolation of 60 dB. This SP32T switch is capable of handling 10 W CW, hot switching, 200 W peak, a 5 percent duty cycle and a 1.0 µSec pulse width.

G.T. Microwave Inc.

www.gtmicrowave.com

Analog-to-Digital Converter

VENDORVIEW



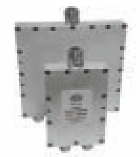
Linear Technology Corp. introduced the LTC2380-24, a breakthrough no latency 24-bit 2 Msps successive approximation register (SAR) analog-to-digital converter (ADC). The LTC2380-24 features an integrated digital filter that averages 1 to 65,536 conversion results real-time, dramatically improving the dynamic range from 101 dB at 1.5 Msps to 145 dB at an output data rate of 30.5 sps. This makes the LTC2380-24 ideal for seismic, medical and many other applications demanding high dynamic range. Using an on-chip digital filter to average conversion results, the LTC2380-24 eliminates the processing burden from the digital host, conserving digital resources and the associated power.

Linear Technology Corp.

www.linear.com

RF/Microwave Power Dividers

VENDORVIEW



MECA announced the latest addition to its broadband line of power dividers with the type N model (80X-4-3.250WWP). Available in 2, 4, 8 and 16-way, 30 W Wilkinson power dividers, optimized for excellent performance with industry leading specifications from 500 MHz to 6 GHz IP67 rated and suited for indoor and outdoor applications. Offering typical VSWR ranging from 1.20:1 to 1.30:1, isolation of 17 to 20 dB minimum while offering phase and amplitude balance typically only seen in narrower/octave band models.

MECA Electronics Inc.

www.e-meca.com

Full Band Mixers

Millitech Inc. takes mixer technology to the next level with an improved new lineup of high efficiency, full-waveguide bandwidth, fundamental mixers covering the waveguide bands of WR-22 through WR-08. The latest advanced technology MXP mixer series offers unprecedented mixer efficiency and can be used as either up-converters or down-converters.

Millitech Inc.

www.millitech.com

Coaxial Limiter

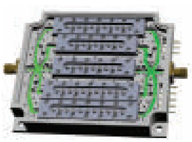
VENDORVIEW

Mini-Circuits' coaxial limiter features wideband, 20 to 4000 MHz, low insertion loss 0.36 dB typical, fast recovery time, 33 nsec typical, excellent VSWR of 1.2:1 typical, low output power and 12 dBm typical. Applications include military, hi-rel applications, stabilizing generator outputs and reducing amplitude variations. Protects low noise amplifiers and other devices from ESD or input power damage.

Mini-Circuits

www.minicircuits.com

Hi-Rel Switched Filter Bank



NIC introduced a high performance five channel switched filter bank that operates in the 9000 to 16000 MHz frequency range. This RF assembly offers low insertion loss, excellent passband flatness, fast switching speeds and high out of band selectivity. The unit's enclosure is compact, laser-sealed and ruggedized, which makes it a perfect fit for high reliability radar, EW and space applications. NIC offers custom designs which are available for 2-to-10 channel switched filter banks that cover 1 MHz to 18 GHz.

Networks International Corp.

www.nickc.com

SMA Two-Way Power Divider

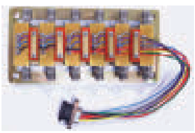
P1dB released a new ultra-broadband 2-way SMA power divider that operates from 1 to 18 GHz. The P1PD-SAF-0118G30W-2 SMA power divider is a Wilkinson RF splitter that is capable of handling 30 W of RF power. The RF power divider is available now and in stock.

P1dB

www.p1db.com

Switchable RF Attenuator

VENDORVIEW



PMI's switchable RF attenuator with six signal paths, operates from 2 to 18 GHz, and is designed to be switched between a low loss state (2 dB loss typical) and a high loss state (20 dB loss typical). The settings will be selected by six digital control bits.

Planar Monolithics Industries

www.pmi-rf.com

New**Products**

3 dB Quad Hybrid

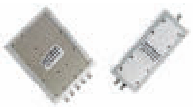
Response Microwave Inc. announced the availability of its new 3 dB, 90° quadrature hybrids for use in various applications within the FCC and ETSI sanctioned international science and medical band. The new RMHY3.2400-2500Sf covers the 2.4 to 2.5 GHz band offering typical electrical performance of 0.3 dB insertion loss, VSWR of 1.25:1 and isolation of 20 dB. Average power handling is 100 W and the unit is operational over the 40° to +85°C range. Mechanical package is a small 1.58" × 0.87" × 0.43", plus SMA female connectors per MIL-C-39012. A drop-in package is also available.

Response Microwave Inc.

www.responsemicrowave.com

Wi-Fi Optimized Power Dividers

VENDORVIEW



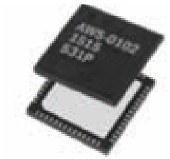
RFMW Ltd. announced design and sales support for Wi-Fi optimized, coaxial power dividers from P1dB. Offered as a 2-way divider (P1PD-SAF-0206G30W-2) and 4-way divider (P1PD-SAF-0206G30W-4), both span an operating frequency range of 2 to 6 GHz yet are optimized at 2.4 and 5 GHz with increased isolation and improved insertion loss. Configured with SMA connectors, the P1PD-SAF-0206G30W-2 and P1PD-SAF-0206G30W-4 meet the demands of production test systems for routers, cell phones, tablets and other Wi-Fi enabled products.

RFMW Ltd.

www.rfmw.com

SATCOM Rx Quad-Core IC

Richardson Electronics Ltd. announced the availability of a new K-Band silicon SATCOM Rx quad-core integrated circuit from Anokiwave Inc.



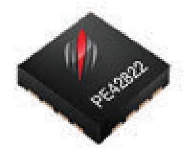
The device supports four dual-polarization radiating elements with full programmable polarization flexibility. It provides 22 dB gain with a noise figure of 3.4 dB. Additional features include gain compensation over temperature and temperature reporting. The new IC offers ESD protection on all pins, operates from +1.8 V, and is packaged in a 56-lead, 7 × 7 mm PQFN for easy installation in planar phased array antennas.

Richardson Electronics Ltd.

www.rell.com

High Power Handling SPDT Switch

VENDORVIEW



Richardson RFPD Inc. announced the availability and full design support capabilities for a new 700 to 3800 MHz, UltraCMOS® SPDT RF switch from Peregrine Semiconductor Corp. The PE42822 is a HaRP™ technology-enhanced absorptive 50 Ω SPDT RF protection switch designed for use in high power and high performance wireless infrastructure and small cell applications, supporting frequencies up to 3800 MHz. The new switch features high linearity, which remains invariant across the full supply range, as well as exceptional isolation and fast switching time.

Richardson RFPD

www.richardsonrfpd.com

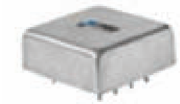
Surface-Mount Cavity Filter

RLC Electronics introduced a series of high frequency surface-mount cavity filters for small scale, low profile system integration. Designs are created and constructed using proprietary techniques resulting in rugged, stable performance over a full range of environmental stresses. High Q cavity filter performance is available up to 30 GHz with profile height as low as 200 mm. The surface-mount design is suitable for reflow attachment, providing savings on size, cost and weight.

RLC Electronics

www.rlcelectronics.com

Ultra-Wide Bandwidth 90° Hybrid

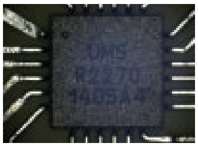


DQP-2-125 is an ultra-wide bandwidth 90 degree hybrid ideally suited for applications in HF and VHF bands. This product is an essential building block for wideband amplifiers, phase shifters, SSB modulators, image rejection mixers and vector modulators. This model covers a phenomenal 125:1 bandwidth between 2 and 250 MHz and handles 1 W of input power. The typical insertion loss across the specified band is 1.8 dB with a typical amplitude unbalance of 1 dB.

Synergy Microwave Corp.

www.synergymwave.com

Communication Transponder



The CHR2270-QRG digital short range communication transponder is a third generation product that combines the advantages of key technologies such as SiGe and a QFN plastic package that provides a multi-normative fully compliant device. It operates at 5.8 GHz and features a single RF antenna port to allow compact systems, integrated high selectivity wake-up, ultra low standby current, 3 V battery bias voltage range, downlink RF input power monitoring, uplink gain control, an operating temperature range of -25° to +90°C, ESD protection and a battery life of more than five years.

United Monolithic Semiconductors (UMS)

www.ums-gaas.com

High Power SP2T Pin Switch

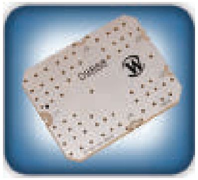
UMCC model SR-D080-2S is a reflective switch with TTL-driver. Switch features include: 2 to 4 GHz operating band, 40 W CW/AVG hot switching, 0.8 dB loss, 65 dB isolation, 500 ns rise/fall time, unit measures 1.80" × 3.00" × 0.38".

Universal Microwave Component Corp.

www.umcc111.com

NewProducts

SMT Two-Way Combiner

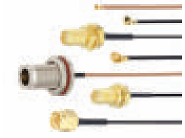


Werlatone introduced the surface-mount, 2-way in-phase combiner/divider, model D9888. This high power design covers the full 1000 to 3000 MHz band, and is rated at 500 W CW. Operating with less than 0.35 dB insertion loss, the unit is compact, measuring just 2.8" × 2.2" × 0.27", and supplies full port-to-port isolation of 15 dB minimum.

Werlatone
www.werlatone.com

Cables & Connectors

Ultra-Miniature Cable Assemblies



Fairview Microwave Inc. introduced a brand new family of ultra-miniature UMCX, WMCX and HMCX32 cable assemblies. Commonly used to connect an external antenna to a mini-PCB, these flexible micro-coax jumpers offer operation from DC to 6 GHz and are ideal for use in wireless communications systems. Additional wireless applications include antennas for GPS and other radio systems, Wi-Fi, wireless LAN, Bluetooth, ZigBee, LTE, mini-PCI and PDA/PCS/cellular handset applications.

Fairview Microwave Inc.
www.fairviewmicrowave.com

Amplifiers

25 to 100 W, 1 to 6 GHz Amplifier

VENDORVIEW

Models 25S1G6AB, 50S1G6AB and 100S1G6AB are solid-state 25, 50, and 100 W Class AB amplifier designs that instantaneously cover the 1 to 6 GHz frequency band in single benchtop unit. These amplifiers provide 25, 50 or 100 W output power, depending on model, in approximately half the size of a traditional Class A design with increased efficiency at a more economical price.

AR RF/Microwave Instrumentation
www.arworld.us

X-Band Solid-State PA

COMTECH PST introduced another new GaN amplifier for X-Band applications. This class AB linear design operates over the full 9 to 10 GHz frequency range and is ideal for use in phase array radar applications, as a TWT replacement or for a microwave communication link. The amplifier features phase and amplitude control, internal DC to DC converters and DC filtering, PA self-test and LED fault indications, unique waveguide coupling circuits, an internal isolator and digital control via a magic tee.

COMTECH PST
www.comtechpst.com

RF Amplifier

VENDORVIEW

Empower RF announced it is shipping an RF amplifier system that complements the frequency coverage and power level footprint of its next generation, high power PA product family. Model 2180, covering 1 to 2.5 GHz and delivering an unprecedented 2 kW CW of broadband output power in an 8U, air cooled chassis, is its latest market release. Offering unrivaled size, weight, and power advantages and building on a design architecture that has been a catalyst for technology upgrades from customers with diverse requirements from multiple markets.

Empower RF
www.empowerrf.com

Coaxial Packaged RF Amplifiers

VENDORVIEW

Pasternack announced the release of new affordable coaxial packaged RF amplifiers. Both low noise and gain block amplifiers are offered and display excellent performance covering wide octave frequency bands from 9 KHz to 3 GHz. All of these new amplifiers provide an outstanding value and are all priced at less than $500 for a single unit.

Pasternack
www.pasternack.com

Systems

PXIe-XMC Adapter

The PXIe XMC adapter can be utilized with all Innovative XMC cards including its newest generation models which provide 5 GHz analog I/O and use the Kintex XCKU060/XCKU085 UltraScale FPGA. This allows extremely rapid configuration of wide-channel count FPGA-accelerated wireless communications, RADAR, LIDAR and real-time control applications, spring-boarding the development of medical imaging, IP development, high speed data recording and playback, wireless receiver, WLAN, W-CDMA and WiMAX front-ends and turnkey systems.

Innovative Integration
www.innovative-dsp.com

Sources

Signal Generator up to 6 GHz

VENDORVIEW

The BPSG RF generator series offers up to +8 dBm, 65 dB dynamic range and internal TCXO

New**Products**

(or external reference). Remotely controllable via USB or stand-alone (internal battery) batch program operation the RF signal generator fits to all manufacturers antenna to produce an active field-strength generator. Also, intelligent batch programs (sweep, ramp, modulation and frequency lists) start automatically after every power on.

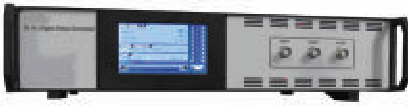
Aaronia AG
www.aaronia.com

watch-MEMS® kHz MEMS Oscillators

A globally preferred, leading supplier of frequency control and magnetic components, Abracon has introduced its new series of watch-MEMS® kHz MEMS oscillators, featuring the world's smallest CSP (1.5 × 0.8 mm) and SMD (2.0 × 1.2 mm) packages. These devices are ideally suited for tuning fork crystal replacement in space constrained designs. Optimized for wearable, IoT and consumer solutions, these devices provide a temperature stabilized alternative to tuning fork crystal based timing devices, while eliminating the oscillator loop capacitors, saving significant surface area, complexity and frequency variation over temperature.

Abracon LLC
www.abracon.com

Digital Delay Generator



The model 745-20C digital delay generator provides users with an amazing 20 independent channels of delay and width (pulses). The delay resolution on the standard unit is 100 picoseconds (ps) with an optional 250 femtosecond (fs) timing upgrade on 10 channels. The jitter is also industry leading, with < 5 ps using short delays and an internal clock, or < 25 ps with longer delays or external triggers. The model 745-20 delivers 6 V into 50 ohms, meeting all TTL applications.

Berkeley Nucleonics
www.BerkeleyNucleonics.com

Ultra-Broadband Frequency Synthesizer

Luff's model SLSM5-0520 is a new frequency synthesizer assembly employing the latest fractional N technology to realize a miniature high performance, ultra-broadband signal source. This unit covers the entire 500 MHz to 20 GHz band with a resolution of 1 kHz. The frequency control is via RS-485 (multi-drop) or USB (with available converter), and a custom GUI which allows virtually out of the box operation. This versatile synthesizer provides outstanding performance and reliability in a high quality compact package.

Luff Research
www.luffresearch.com

E-Band Transceiver Modules

VENDORVIEW

Model SSC-7737731200-1212-C1 is an E-Band transceiver. It has a minimum transmit output power of -30 dBm in the frequency range of 76 to 78 GHz with an IF input power of 0 dBm in the frequency range of 550 to 950 MHz. The

typical receive conversion loss is -12 dB with a typical RF input power of -20 dBm in the frequency range of 76 to 78 GHz and a IF output frequency range of 550 to 950 MHz.

SAGE Millimeter Inc.
www.sagemillimeter.com

Antennas

Isotropic Antennas

VENDORVIEW

Anritsu Co. expands its electromagnetic field (EMF) measurement system with the introduction of isotropic antennas that provide frequency coverage from 9 kHz to 6 GHz. Compatible with

certain LMR Master™, Spectrum Master™ and Cell Master™ handheld analyzers, the new antennas support measurements of EMF radiation to ensure wireless networks are in compliance with various national standards for personal safety established by government regulatory authorities. The two

NewProducts

isotropic antennas employ tri-axis sensors with an integrated RF switch device, microcontroller and memory.

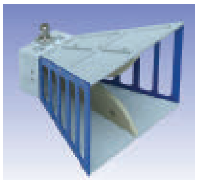
Anritsu Co.
www.anritsu.com

Dielectric Antennas

MCV Microwave dielectric antennas are compact size, high performance, reliable and cost competitive. MCV offers patch antennas in various sizes for GPS applications. MCV's rectangular microstrip designed patch antenna has excellent stability and sensitivity through the use of high-performance, proprietary dielectric materials with strict dimensional accuracy, excellent tolerance in dielectric constant and temperature stability.

MCV Microwave
www.mcv-microwave.com

EMC Horn Antenna



A new EMC horn antennas suitable for EMC testing and general measurement applications is available. The QWH-DL-2-18-S-SG is a 2 to 18 GHz dual linearly polarized open boundary quad-ridged wideband horn antenna in a compact package that offers polarization diversity and the ability to measure two orthogonally polarized fields simultaneously. The antenna provides isolation of > 30 dB between connectors and gain of 3.9 to 15.9 dBi.

Steatite Antennas
www.steatite.co.uk

Materials

NorCLAD Microwave Laminates

NorCLAD is perfectly suited for use with patch antennas, and it has been used worldwide in land, sea and airborne applications. NorCLAD has an ideal dielectric constant of 2.55, and as its thickness is proportional to bandwidth NorCLAD provides designers with a wide range of flexibility for antenna arrays up 0.5" thick. It is also widely used in stacking patch antennas of different thicknesses, is highly stable over temperature, has very uniform and repeatable electrical properties, and is extremely cost-effective when compared to PTFE.

Crane Polyflon
www.polyflon.com

Building the FirstNet Public Safety Broadband Network

Robert I. Desourdis, Jr., Robert A. Dew, Mark O'Brien and Holger Hinsch

Among the many tragedies that occurred on 9/11, the difficulty federal, state, regional and local agencies had communicating with each other was certainly not the worst. Nonetheless, 9/11 exposed both technical and human failings that amplified the chaos of the catastrophe. The clear need for interoperability led the 9/11 Commission to recommend creating a nationwide, interoperable public safety communications network. Despite the compelling need, it took 11 years for Congress to create and fund the First Responder Network Authority (FirstNet). FirstNet is tasked to "build, operate and maintain the first high speed, nationwide wireless broadband network dedicated to public safety." The legislation also licensed 20 MHz of spectrum near 800 MHz to carry the voice and data traffic.

Prior to 9/11, the need for interoperability was recognized. States such as Pennsylvania had started the development of statewide networks to connect all state and local government entities. Now, whether states have deployed integrated communications networks or communities and agencies are using individual land mobile radio (LMR) systems, state and local governments will have to adopt the nationwide network. With this transformation just beginning, Robert Desourdis, Robert Dew, Mark O'Brien and Holger Hinsch wrote "Building the FirstNet Public Safety Broadband Network" to explain the steps required to plan, design, implement and sustain the nationwide public safety broadband network (NPSBN).

Targeting a varied audience not familiar with wireless technology — in government agencies, non-profits, universities and companies — they begin with a tutorial about the technologies that will power NPSBN: LTE combined with digital television's packet data broadcasting. Chapter 2 outlines best practices that should be adopted to successfully plan and deploy the NPSBN system. Chapter 3 addresses building the business case necessary to help communities and agencies justify funding the system. Chapters 4 through 6 discuss defining and documenting the requirements for the NPSBN, developing a nominal design and then completing the design and deploying the system. Once operational, the system will need to be maintained for decades, which Chapter 7 addresses. The final chapter discusses how LTE and datacasting are likely to evolve and how these trends should be comprehended.

The successful development of the NPSBN will require navigating the technology through the minefield of politics — technology likely the least source of problems. The inability of governmental agencies to cooperate has historically been the Achilles heel of such multi-agency projects. Although it can't solve the political issues, "Building the FirstNet Public Safety Broadband Network" is a comprehensive reference that will be useful for those charged with realizing the mission of FirstNet.

To order this book, contact:

Artech House
www.artechhouse.com
266 pages

$149 for the hardcover edition
Also available in eBook format
ISBN: 978-1-60807-742-7

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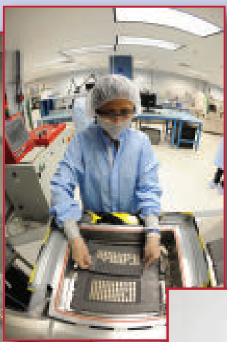
FABS and LABS

Qorvo's Advanced Microwave Modules Assembly: Speed, Quality, Performance



This is the story of a problem needing a solution, a solution that fixes the problem and becomes a much bigger strategic advantage. When TriQuint (now Qorvo) began shipping GaN die, some customers reported device failures in their assemblies. Poor die attach was the root cause. The high power density of GaN requires a void-free eutectic bond between the die and package to transfer the heat from the transistor channel — otherwise the device will fail prematurely. The criticality and sophistication of the die attach process led TriQuint to offer GaN die eutectically mounted on thermal spreaders, assuring their customers the quality of the most critical thermal interface.

That vacuum reflow process expanded into a complete assembly and test capability that serves Qorvo's own need for rapid prototypes and a production source for moderate volume and high performance products. Called AMMA (Advanced Microwave Modules Assembly), the 9,000 square foot facility is housed with Qorvo's GaN, GaAs and BAW wafer fabs in Richardson, Texas. The paperless factory, where all key performance data is online in real-time, shares the wafer fabs' commitment to automation, lean manufacturing and statistical process control.

From that first eutectic die attach process, AMMA's processes now include epoxy attach, ball bonding, Cu bump flip-chip, surface-mount assembly, solder and seam sealing for hermetic packages, plastic overmolding and mechanical integration of complex assemblies. X-ray and acoustic microscopy (CSAM) are available as QC steps to help assure the critical die attach process. For commercial applications demanding low cost plastic packaging, AMMA developed a highly reliable process to attach GaN on SiC power die to Cu lead frames. Despite the CTE mismatch between SiC and Cu, assemblies pass 1,000 temperature cycles without delamination. Once the products are assembled, AMMA also performs the RF acceptance testing, assuring a tight feedback loop between assembly and test.

AMMA's assembly and test capabilities have been accredited as a "trusted source" by the U.S. Defense Microelectronics Activity (DMEA), an important endorsement for the defense industry. The success of the operation is reflected in the broad portfolio of Qorvo products that AMMA produces: die on tab and packaged devices for defense and aerospace programs, Spatium™ spatially-combined PAs, GaN PAs for base stations, modulator drivers for transport and metro optical networks, and millimeter wave amplifiers for point-to-point radio — virtually everything in the catalog except for the highest volume and lowest cost.

Qorvo's investment in AMMA provides many returns. Product development moves from prototype to production in the same facility, co-located with many of the designers. Time to market is faster, with no expensive and time-consuming trips to offshore subcontractors. AMMA yields are higher, especially for high performance and high frequency products. With an internal assembly capability, designers and process engineers can collaborate on new, non-standard packaging approaches that better meet RF requirements — rather than being constrained by the industry standards set for lower frequency silicon.

AMMA enables a vertical integration strategy that differentiates Qorvo's infrastructure and defense products. It's an example that moving semiconductor assembly back to the U.S. can be a competitive advantage, even in a global market.

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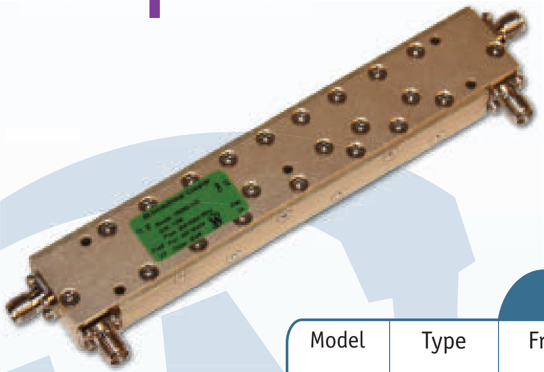

NEW

Directional Couplers

Model	Type	Frequency (MHz)	Power (W CW)	Coupling (dB)	Insertion Loss (dB)	VSWR (ML)	Size (Inches)
C6021	Dual	0.01-1000	500	40	0.45	1.30:1	6.7 x 2.27 x 1.69
C5725	Dual	0.1-1000	500	40	0.5	1.25:1	5.2 x 2.67 x 1.69
C9688	Dual	1-1000	800	40	0.5	1.20:1	6 x 2.2 x 2.2
C7734	Dual	30-2500	100	43	0.35	1.25:1	3.5 x 2.6 x 0.7
C8188	Uni	30-3000	20	20	2.4	1.35:1	6 x 1.5 x 1.1
C3910	Dual	80-1000	200	40	0.2	1.20:1	3 x 3 x 1.09
C8373	Bi	100-2500	200	20	0.8	1.25:1	9.58 x 1.48 x 0.88
C7711	Dual	100-3000	100	40	0.35	1.25:1	3 x 2.2 x 0.7
C7058	Bi	200-2000	200	10	0.3	1.25:1	6.4 x 1.6 x 0.72
C8060	Bi	200-6000	200	20	1.1	1.40:1	4.8 x 0.88 x 0.5
C7248	Bi	300-3000	100	6	0.35	1.25:1	6 x 2 x 0.85
C8000	Bi	600-6000	100	30	0.4	1.25:1	1.8 x 1 x 0.56
C8214	Bi	700-2500	100	6	0.35	1.25:1	6 x 2 x 0.85
C10462	Dual	700-4200	250	40	0.2	1.30:1	2 x 2 x 1.06
C10525	Dual	700-4200	700	50	0.2	1.35:1	2.15 x 2 x 1.36
C10536	Dual	700-4200	1000	50	0.2	1.35:1	2.15 x 2 x 1.36
C10006	Dual	700-4200	2000	50	0.2	1.35:1	3 x 3 x 1.59
C10117	Dual	700-6000	250	40	0.2	1.30:1	2 x 2 x 1.06
C10364	Dual	700-6000	500	50	0.2	1.35:1	2.15 x 2 x 1.36
C8644	Bi	1800-6100	60	20	0.4	1.25:1	1.1 x 0.75 x 0.48

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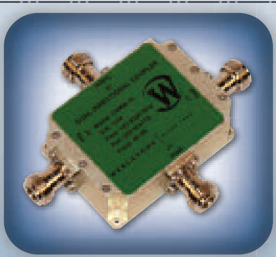

Directional Couplers

0° Combiners/Dividers

90° Hybrid Couplers

180° Hybrid Combiners

Absorptive Filters