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January 2017

Microwave Journal

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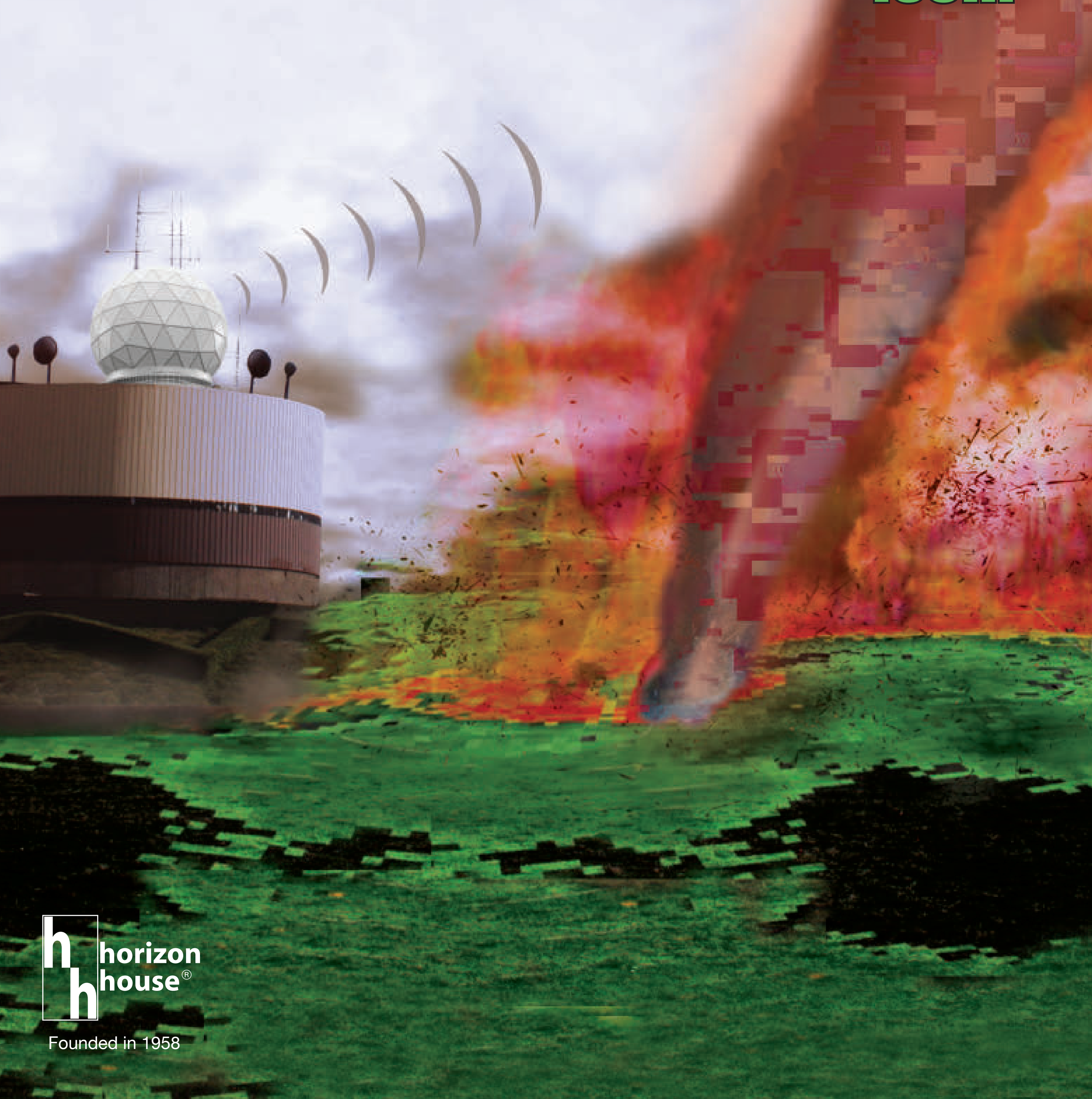

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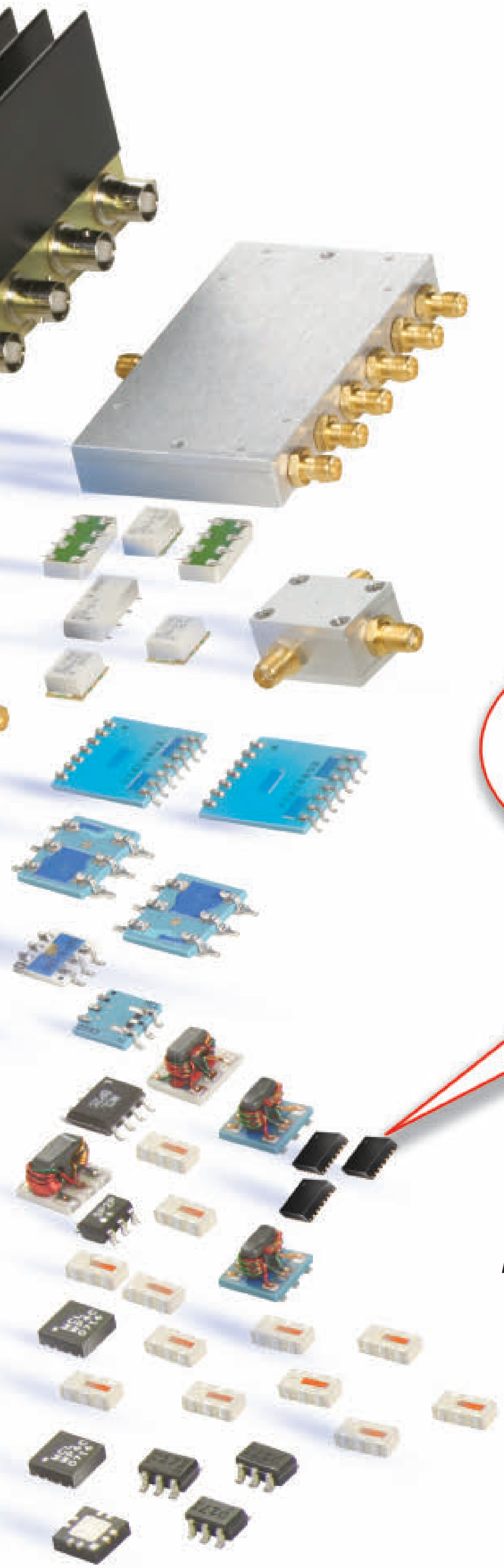

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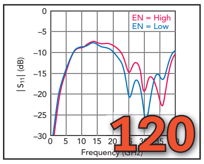

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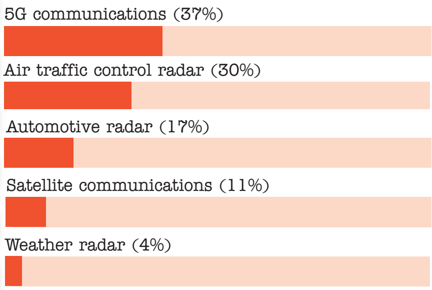
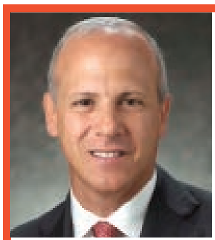
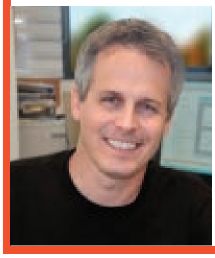


Executive Interviews



Larry Sala, CEO of **Anaren Microwave Inc.**, discusses the company's 50th anniversary including a short history of the company, their unique process technologies and his thoughts on the various markets they are participating in.



Ben Zickel, chief technology officer of **Goji Research**, reviews the revolutionary changes being made to microwave ovens incorporating solid-state amplifier technology and its impact on the food preparation process and consumer oven market.

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The New Year Brings a New Look

Carl Sheffres
Microwave Journal *Publisher*

We embark on the New Year with our traditional "Radar and Antennas" themed issue, highlighted by a cover feature contributed by MACOM and entitled, "Tile Arrays Accelerate the Evolution to Next-Generation Radar." ADI furthers discussion on this topic with their technical feature "Digital Beamforming Accelerates the Evolution to Next-Generation Radar." Keysight Technologies authors a special report on "Addressing the Challenges Facing IoT Adoption," while the RF Energy Alliance discusses "The Challenges of SSRFE Design: Residential and Industrial Cooking Applications." Rogers Corp. discusses "Opportunities for High Frequency Materials in 5G and the IoT" in their technical feature. You'll find exciting advances on legacy technologies and continued coverage of emerging technologies in this issue, along with the latest industry news, products and event coverage.

You'll also notice an updated look to the magazine, with new fonts and other subtle changes to enhance your reading pleasure. Watch for additional improvements to the print/digital edition in the coming months.

Speaking of changes, we'll be rolling out a redesigned website early this year, with a new look and new features that can be easily viewed on all devices. This follows the launch of our *Signal Integrity Journal* website (signalintegrityjournal.com) this past September. This unique site covers the Signal Integrity, Power Integrity and EMC/EMI world with the same high quality technical content that you've grown accustomed to from *Microwave Journal*. Industry icon Eric Bogatin leads a distinguished group of experts in directing this new venture. I encourage you to check out the site and Eric's latest blog, entitled, "When Worlds Collide: Why RF Design Is Very Different from High-Speed Digital Design."

SI and RF/microwave professionals checked out the debut of the Electronic Design Innovation Conference (EDI CON USA) this past September in Boston and found an impressive group of exhibitors and speakers during the three-day event. Mark your calendar for September 11-13 in Boston this year, where high frequency and high-speed design engineers will once again converge to learn, network and enjoy fall in New England.

The fifth annual EDI CON China event takes place April 25-27 in Shanghai, after a record-setting event in Beijing last year. Attendees will find over 100 exhibiting companies from China and around the globe, along with more than 100 technical sessions and workshops covering RF, microwave, EMC/EMI, radar and high-speed digital design topics. EDI CON has evolved to become the premier event for our industry in China and I encourage you to join the growing global audience of professionals.

European Microwave Week enjoyed record-setting attendance and its largest exhibition ever in its return to London in 2016. This year's event takes place in Nuremberg, Germany on October 8-13, with paper submissions accepted through February 13.

Our video coverage of these events and many others continues to grow. You can view hundreds of videos by event or company on our website, providing product demos and tutorials at your convenience. You can also view the "Frequency Matters" series, the popular bi-weekly program covering the latest industry news and exclusive interviews with industry executives.

The RF/microwave community on LinkedIn continues to grow, topping 32,000 members and serving as a platform for discussion and networking. The signal and power integrity community has been launched to provide similar discourse for that sector.

Lastly, I ask you to take a few minutes to renew your subscription to *Microwave Journal*. The publication is free, but you must renew each year for audit purposes and if you do so now, we won't need to bother you later.

I hope that you had an enjoyable holiday season and wish you a prosperous and Happy New Year.■

Cover Feature
Invited Paper

Editor's Note: This month's theme of radar and antennas features two articles discussing architectural changes that are accelerating the evolution to the next-generation of phased array radar. The first, by Doug Carlson of MACOM, discusses the development of a tile array built with commercial manufacturing processes. This approach yields a system that can perform multiple radar functions with a single aperture, at a cost lower than the traditional slat array. MACOM and MIT Lincoln Laboratory are developing this scalable tile array for the next generation of weather and air traffic control radar. The second article, by Peter Delos of Analog Devices, discusses how the continuing evolution of semiconductor and packaging technologies is enabling digital beamforming at every element in the array – through S-Band today, to X-Band in the not-too-distant future. Digital beamforming promises improved system performance, greater flexibility and lower cost.

Tile Arrays Accelerate the Evolution to Next-Generation Radar

Doug Carlson
MACOM, Lowell, Mass.

Defense and civil radar infrastructure has historically evolved over lengthy cycles, fueled by massive investments of time, innovation and capital. Defense applications have been chiefly responsible for driving this development, yielding significant radar performance improvements, often with concomitant increases in total system cost. These initiatives have catalyzed the transition from conventional, mechanically-steered radar architectures to active electronically scanned array (AESA)—or active antenna array—that enable huge gains in temporal and spatial precision, leveraging advanced multi-beam capabilities. AESAs' multi-function capability is similarly compelling, affording newfound agility to consolidate disparate radar systems onto a single platform (see ***Figure 1***).

The performance characteristics of AESAs position this technology as the clear successor to legacy defense radar systems, and AESA implementations are already well underway in this domain. Deployable across ground, sea and air, AESA technology dramatically strengthens the sensor mesh network and improves situational awareness throughout the modern battlefield. Propagated to civil radar infrastructure, AESAs have the potential to profoundly affect the safety and security of citizens. A single network of multifunction AESA radars can improve air traffic control, providing direct economic benefit to the country and bolstering homeland defense capabilities, while simultaneously dramatically improving weather surveillance. With AESA technology, meteorologists can better predict and assess severe storms and save lives. AESAs will also provide the sensor capability that will bring drones and unmanned vehicles into the mainstream. This will transform society, fundamentally altering transportation and commerce.

Fig. 1 The active phased array architecture enables the beam to be electronically steered and multiple radars to be combined in a single system.

For AESAs to successfully transition from defense to civil and commercial applications, however, there are technical and economic hurdles to overcome. Continued reliance on conventional RF components and cumbersome assembly techniques, among other factors, has blocked the path to mainstream adoption. To gain a perspective on where this development activity is headed, it's helpful to understand its origins and roadmap to date.

R&D ROADMAP

Next-generation active antenna technology has its roots in development programs dating back to the 1960s. With the maturing of GaAs monolithic microwave integrated circuit (MMIC) technology in the 1980s, AESA development accelerated. The U.S. Defense Advanced Research Projects Agency (DARPA) worked in partnership with MACOM and other technology companies on the Microwave/Millimeter-wave Monolithic Integrated Circuits (MIMIC) program and then the Microwave Analog Front End Technology (MAFET) program. These initiatives helped advanced compound semiconductor technologies make the leap from laboratory research to commercially manufactured RF devices, yielding the industry's first multi-watt MMICs. Further development of these semiconductor and packaging technologies led to the first mass-produced RF modules and components to use mainstream printed circuit board (PCB) technology and surface mount assembly techniques. This activity was followed by DARPA programs aimed at developing compound semiconductors for higher output power, higher efficiency and higher frequency operation. GaN technology became a major focus of development and investment, culminating with high frequencies (to 500 GHz), yield, uniformity and reliability.

Initiated in 2014, DARPA's Arrays at Commercial Timescale (ACT) program is designed to streamline development and manufacturing cycles for next-generation radar, electronic warfare (EW) and communications systems by leveraging best practices established in the commercial domain. It aims to achieve a digitally-interconnected phased array building block, from which larger systems can be built without a full redesign for each new application. This approach to radar system implementation is anticipated to shorten time-to-market and reduce costs, both necessary for AESAs to achieve mainstream adoption for civil and commercial applications.

SLAT VS. TILE

The cost and mainstream viability of AESAs correlate to the cost of the electronic components that comprise them and the way they are architected in the array. From the transmit/receive (T/R) module to the RF boards and cabling, there are many considerations to weigh that impact final system cost.

Approximately half the cost of the phased array portion of the radar is attributable to the T/R module, the cost of which is determined by the types of MMICs, housing and substrates used in the module. Conventional T/R modules for radar applications employ ceramic-based materials for the substrates and are manufactured using chip-and-wire assembly processes, during which MMIC die and other ICs require additional touch labor. These add considerable expense compared to plastic encapsulated MMICs used in commercial systems. The multi-layer RF boards and cables employed in the phased array design account for almost all the rest of the cost (assembly and test processes and the structure represent approximately 10 percent of the total cost). As with the T/R modules, the underlying architecture of the array design can add considerable cost.

This is exemplified via the conventional approach to constructing large phased arrays, commonly known as the slat array architecture, which has a series of slats arranged perpendicularly to the face of the array (see ***Figure 2***). The slat approach has a couple of advantages:

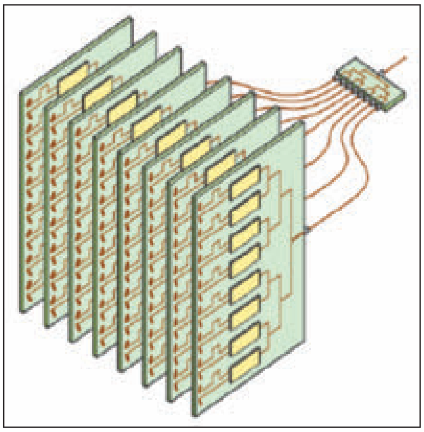


Fig. 2 Slat array.

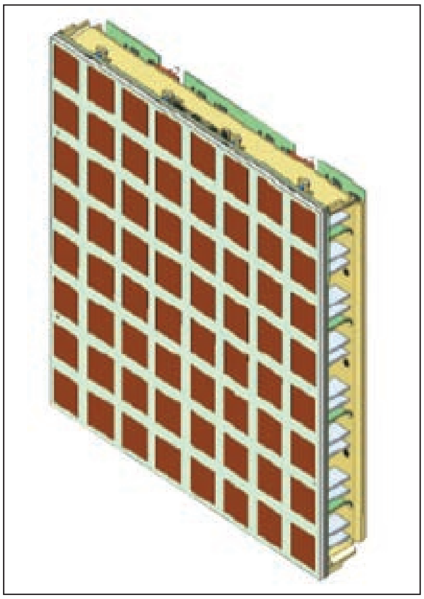


Fig. 3 Tile array.

it provides a large surface area on which the T/R modules and supporting components can be attached. Also, the thermal load from the high power amplifiers can be distributed across a large volume, factoring in the depth of the slat and the aperture area. The downside is that a large number of RF boards and copious cabling are required to channel the RF, DC and control signals on and off the slats. This adds considerable cost to the design.

An alternative approach—the tile array—overcomes these disadvantages through a more streamlined architecture, where the array is constructed of layers that are oriented parallel to the face (see ***Figure 3***). Antenna elements and RF beamformers are integrated in a single, multilayer RF board, with the T/R modules mounted on the back of the board. This approach significantly reduces the area of the RF boards and dramatically reduces the number of cables and connectors. Costs can be further reduced through the use of T/R modules designed to leverage volume-scale commercial packaging and manufacturing techniques. With this approach, the T/R module MMICs are assembled in industry standard, quad flat, no-lead (QFN) packages that are directly soldered onto an inexpensive PCB that is soldered to the back of the tile. Simple metal pads lining the edge of the PCB serve as the RF and DC interconnects between the T/R module and the back of the tile.

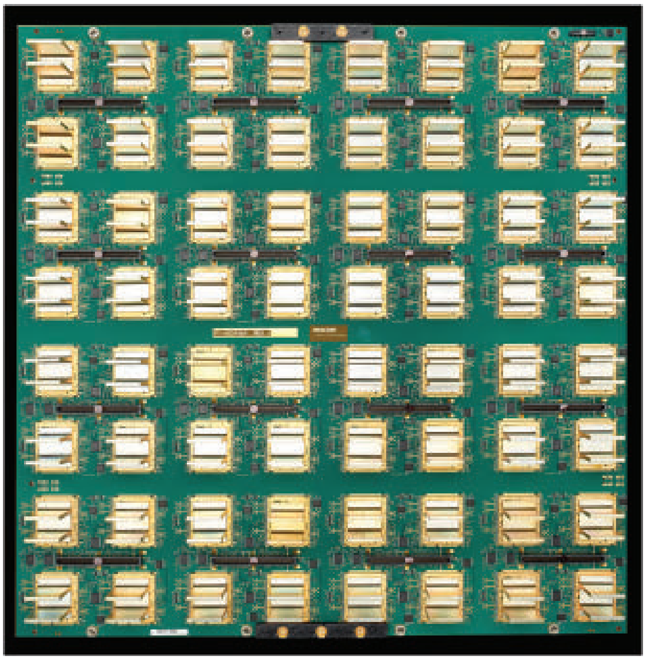
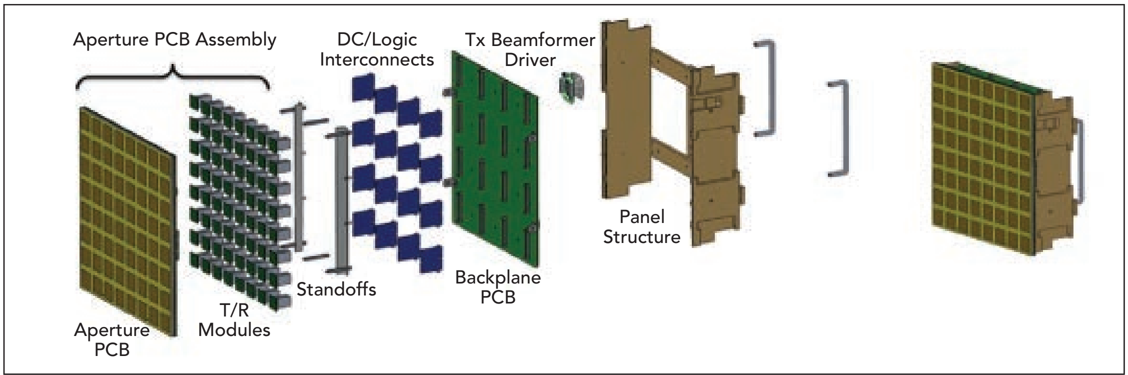


Fig. 4 SPAR™ Tile prototype developed by MACOM and MIT Lincoln Laboratory.

Comparing the relative transmit power per unit area versus the cost per unit area for the slat and tile array architectures, a greater than 5x cost reduction can be achieved with the tile array at both high power and low power outputs.[1]

MULTIFUNCTION RADAR

Working together, MACOM and the Massachusetts Institute of Technology (MIT) Lincoln Laboratory have optimized the tile array architecture, demonstrating the cost efficiencies that can be achieved using commercial manufacturing processes. Sponsored by the Federal Aviation Administration (FAA) and



▲ **Fig. 5** SPAR Tile construction.

National Oceanic and Atmospheric Administration (NOAA), the MACOM/Lincoln Laboratory Multifunction Phased Array Radar (MPAR) is designed to be the next-generation civil radar, integrating eight separate legacy radar functions into a single multifunction platform. The first-generation MPAR (see ***Figure 4***) uses an array of Scalable Planar Array (SPAR) Tiles to detect and track weather systems, aircraft and airborne objects.

While most legacy radar systems mechanically rotate and tilt the radar dish to scan different sectors of the airspace, the SPAR™ Tile-enabled radar comprises hundreds to thousands of T/R elements in a stationary flat panel array that electronically scans the airspace. As shown in ***Figure 5***, the MPAR SPAR Tile consists of a front aperture printed circuit board (APCB) containing the radiating elements, transmit and receive beamforming networks, power and logic distribution. The T/R modules are surface-mounted to the back of the APCB using standard industry manufacturing processes. A second PCB, the backplane, contains the DC power supplies, general purpose processors and high level logic. It is combined with the APCB to form the SPAR Tile. The two PCBs are connected with low cost, high performance interconnects, and a simple mechanical structure holds the two PCBs together and forms the structure for the assembly of the full array.

The first deployed MPAR prototype is being validated for weather observation by the National Severe Storms Laboratory (NSSL) in Oklahoma. It also provides a baseline platform for the development of back-end architecture and AESA data-driven weather modeling algorithms. When fully implemented, this system will help increase forecast accuracy for severe weather events such as tornadoes, enabling earlier major storm warning and other benefits.

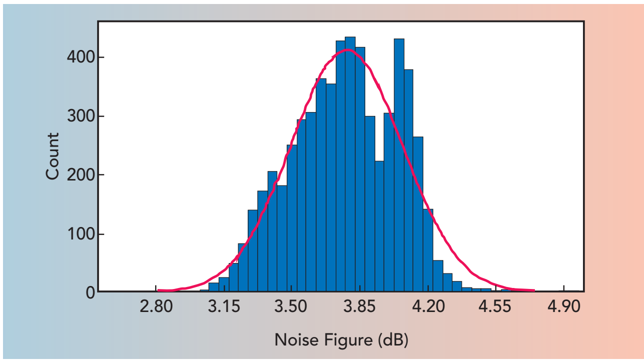


Fig. 6 Noise figure distribution of the ATD T/R modules. The histogram approximates a normal distribution with a mean noise figure of 3.7 dB.

For the FAA, MPAR systems can dramatically improve air traffic awareness and homeland defense surveillance.

MACOM has been maturing the SPAR Tile technology for almost a decade. From concept demonstration to the deployment of the first prototype system in a realistic end-use environment, the Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) of the SPAR Tiles have advanced. Based upon the success of the first prototype system, MACOM has begun the first phase of scaled manufacturing of SPAR Tiles, with over 90 tiles for the FAA/NOAA Advanced Technology Demonstrator (ATD) being delivered for a full system demonstration. This has allowed, for the first time, meaningful statistics to be gathered on the performance distribution from the end-to-end manufacturing process. Over 6,000 T/R modules have been built and tested, yielding data such as shown in ***Figure 6***.

TILE-BASED AESA OPPORTUNITIES

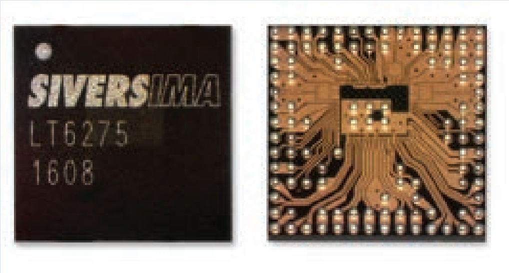
With legacy civil radar infrastructure for air traffic control and weather surveillance approaching the end of life and government-mandated spending reductions impacting key defense programs, there is a unique opportunity to develop a new and more cost-effective approach to radar system production, an approach combining an innovative RF system architecture with commercial manufacturing processes.

Tile-based AESAs create the foundation for such a new generation of high performance, agile radar systems that can be built quickly and cost effectively and flexibly tailored and scaled for deployment across defense, civil and commercial applications. The design and assembly techniques used for the tile array MPAR address both communications and sensing applications, enabling active antenna capability at a cost point that makes this technology viable for a wide range of commercial use cases: internet in the sky, 5G, sense-and-avoid for airborne drones and radar for autonomous vehicles.■

Reference

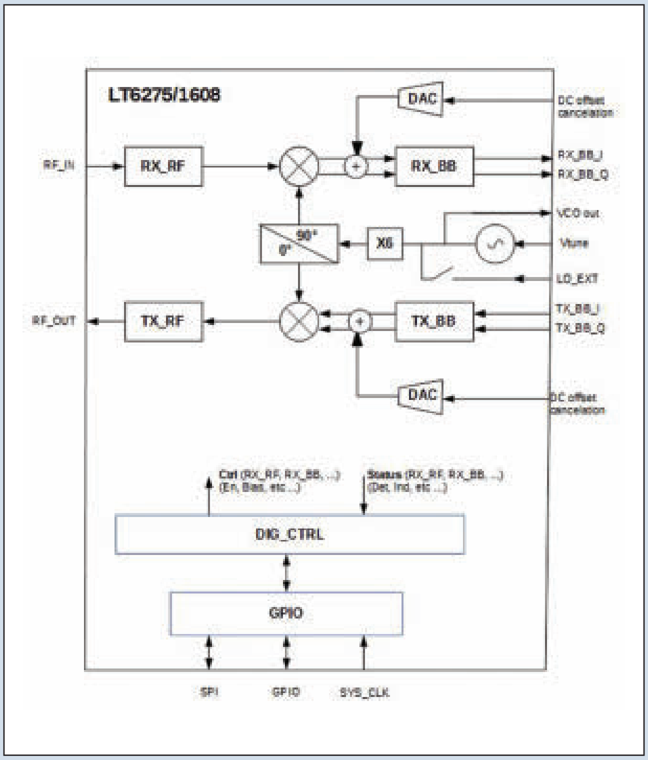
1. Jeffrey S. Herd and M. David Conway, "The Evolution to Modern Phased Array Architectures," *Proceedings of the IEEE, 2016*, Vol. 104, Issue 3, pp. 519–529.

Most Valuable Product



V-Band Transceiver Chip for Point-to-Point Backhaul

Sivers IMA AB
Kista, Sweden



▲ ***Fig. 1** The TRX 1608-LT6275 circuit includes a complete millimeter wave transceiver, digital control, signal source and a complete analog baseband.*

The seemingly ceaseless demand for data is pushing microwave backhaul to its limits as there is not enough available bandwidth for microwave links to backhaul all the data from the base stations/access points (BTS/AP). Traditional microwave bands are, due to regulatory reasons, often limited to bandwidth of 56 to 112 MHz for each channel available for a point-to-point backhaul link. Hence, microwave links offer typically up to 1 Gbps backhaul using very high modulation schemes like 4096-QAM. Even if the modulation in the next generation microwave links were increased to 8192 QAM, the capacity would only rise by 8 percent.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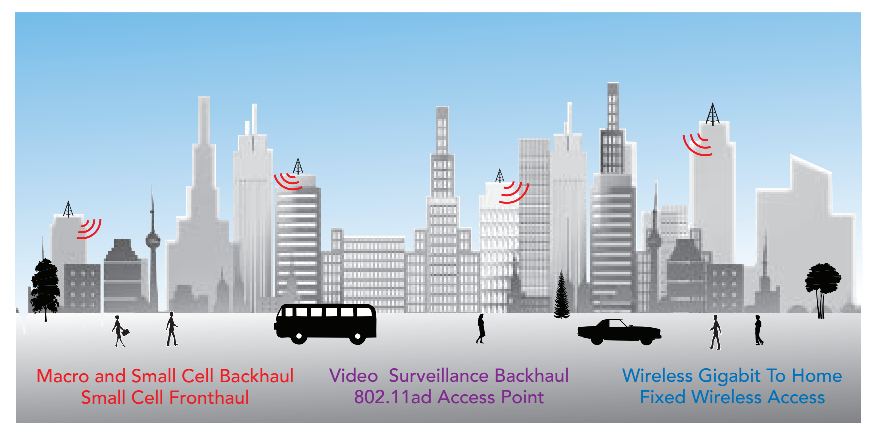

Fig. 2 Examples of point-to-point use cases for the TRX 1608-LT6275.

It is increasingly being recognized that millimeter wave-based communication is a possible solution, as it can support 5 to 10× larger throughput than microwave links. In the U.S., the Federal Communications Commission (FCC) recently added a 7 GHz license to the license free V-Band, which now includes a 14 GHz band ranging from 57 to 71 GHz. By using only 1 GHz bandwidth and 64 QAM modulation, at least 4 to 5 Gbps can be achieved.

To address this market Sivers IMA has introduced the highly integrated TRX 1608-LT6275 transceiver for millimeter wave applications that is claimed to offer a price-performance ratio, which should be of interest to all data and telecom point-to-point radio link vendors. It also has the potential to cut their time to market for a V-Band link by at least 18 months compared to making their own transceiver chip.

The circuit, shown in ***Figure 1***, includes a complete millimeter wave transceiver, digital control, signal source and a complete analog baseband. This third party millimeter wave transceiver fully supports for the market leading 85100 millimeter wave baseband/modem from MaxLinear (formerly Broadcom). By having fully integrated analog baseband (BBTx and BBRx) support, a better total cost of ownership for the wireless backhaul is available.

There are various point-to-point use cases where the TRX 1608-LT6275 can be utilized. As illustrated in ***Figure 2,*** these include a broad portfolio such as: macro cell backhaul, small cell backhaul, Remote Radio Head (RRH) fronthaul for C-RAN, Fixed Wireless Access (FWA), Wireless Gigabit to Home (GBTH) and video surveillance backhaul applications.

Thanks to advanced Silicon Germanium (SiGe) technology and a very high fmax of 300 GHz, high output power and low noise figure can be achieved. The packaged chip includes all building blocks such as millimeter wave 57 to 71 GHz up and down-converters, Power Amplifier (PA), Low Noise Amplifier (LNA), x6 LO Switch, Programmable Gain Amplifier, Voltage Controlled Oscillator (VCO) and analog baseband (BB Tx and BB Rx).

The front-end millimeter wave technology is silicon proven and qualified in Sivers IMA's second generation converter modules. The integrated VCO provides excellent phase noise to support up to 64 QAM modulation. Optionally, an external LO can be injected, enabling user selectable LO and even higher modulation.

Significantly, the SiGe transceiver chip has been integrated into a 7 mm × 7 mm embedded Wafer Level Ball Grid Array (eWLB) packaged device, which offers excellent millimeter wave performance at 57 to 71 GHz together with production friendly packaging technology—for easy surface mounting on printed circuit boards. All process steps on the eWLB package are performed on the wafer, which results in a small and flat package with excellent electrical and thermal properties.

Additionally, this millimeter wave solution also offers the possibility to develop smaller antennas with decreased cost as well as the size of the final product, which are very important aspects for all telecommunication infrastructure.

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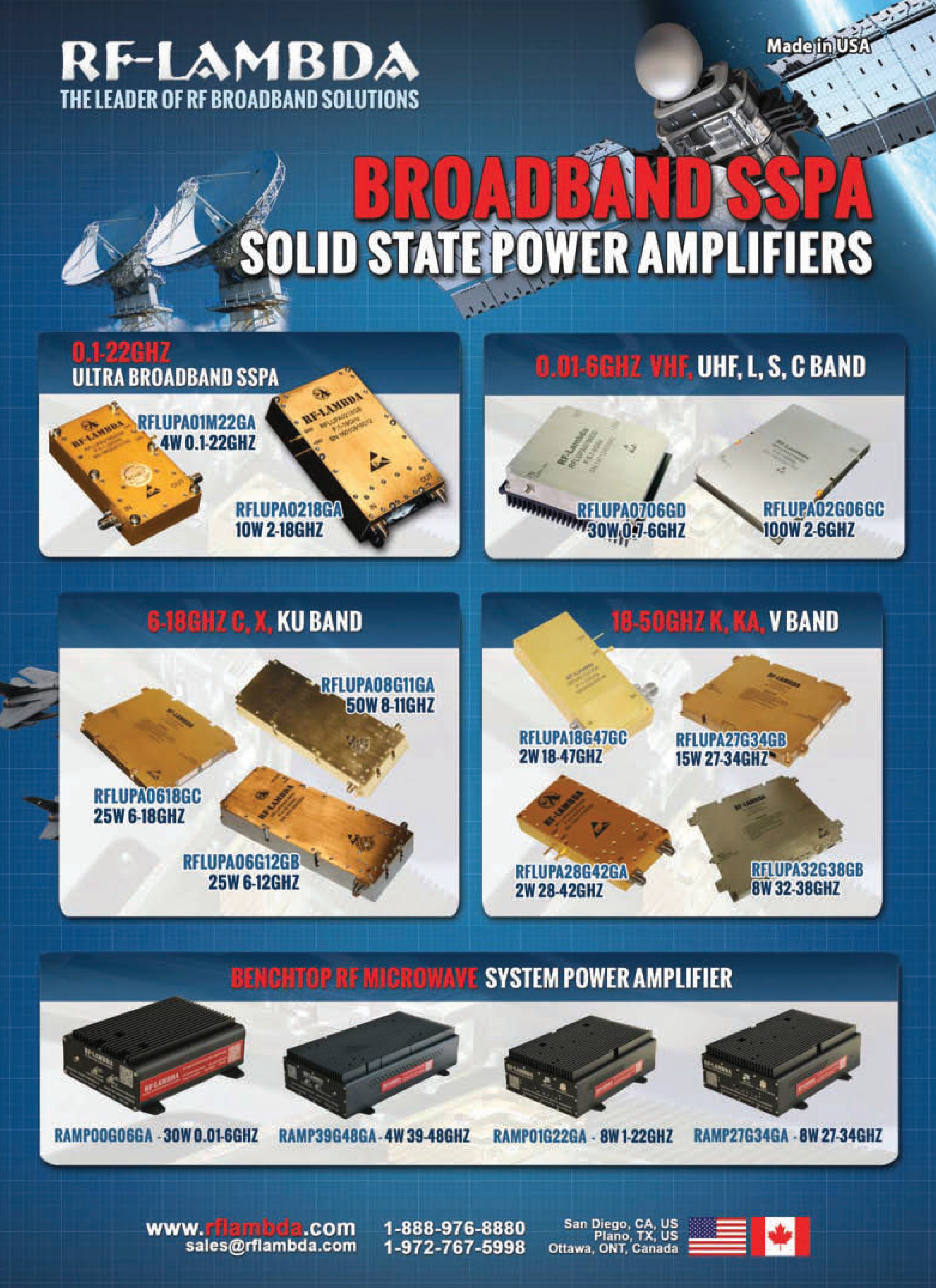
Kista, Sweden
www.siversima.com



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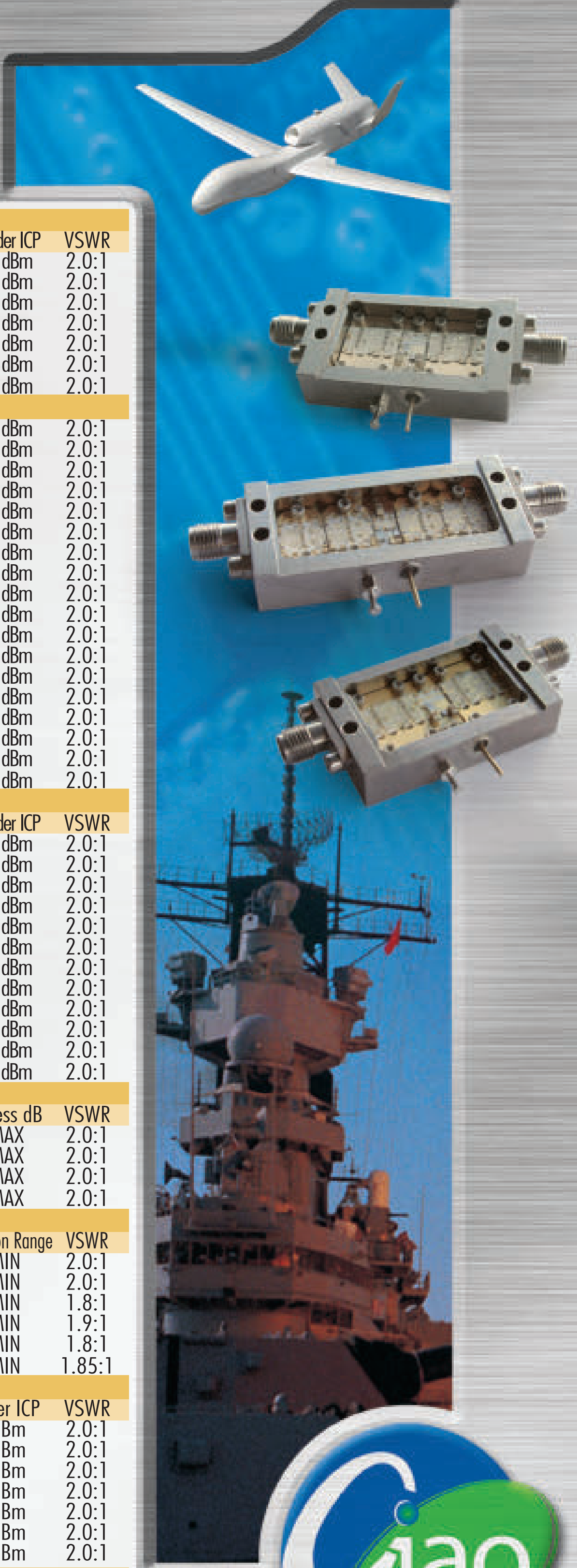

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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TRS-4D AESA Radars for Freedom Variant LCS

Airbus Defense and Space Inc. is under contract with its affiliate, Airbus DS Electronics and Border Security GmbH, to provide TRS-4D naval radars for the U.S. Navy's Littoral Combat Ship (LCS) program through Freedom-variant LCS prime contractor, Lockheed Martin. A factory acceptance test was recently completed for the radar planned to go aboard LCS 21. This follows the already planned installations of TRS-4D aboard LCS 17 and LCS 19.

The TRS-4D radar for LCS is a rotating version of the Active Electronically Scanned Array (AESA) fixed panel TRS-4D radar currently going aboard the German F-125 class frigates. It combines mechanical and electronic azimuth scanning to achieve fast generation of target tracks. Airbus Defense and Space radars have been aboard LCS since the program's inception, with the TRS-4D's predecessor, the AN/SPS-75 radar, going aboard each Freedom Variant LCS from LCS 1 through LCS 15.

System characteristics of the TRS-4D are an excellent match for the environment faced by LCS and its evolution to a frigate. The radar's AESA technology delivers increased sensitivity to detect smaller targets with greater accuracy, as well as faster track generation to give LCS more time to react to advanced threats and support enhanced weapons systems.

This software-defined radar is programmable, enabling the customer to define changes to radar characteristics to match future threats that evolve over the life of the ship. The ability to customize the characteristics of the TRS-4D helps enable LCS to evolve through its service life and adapt to evolving required operational capabilities and projected operational environments in an affordable manner.

Combining multiple capabilities within a single radar is one way that TRS-4D contributes to the affordability of LCS. Employing state of the art AESA technology, the TRS-4D is a three-dimensional, multi-mode naval radar for surveillance, target acquisition, self-defense, gunfire support and aircraft control. It automatically detects and tracks all types of air and sea targets, alleviating crew workload requirements. LCS affordability is further enhanced by the reliability of the TRS-4D's solid state system design, keeping maintenance costs low and further contributing to lower LCS life cycle costs.

Littoral combat ships are fast, agile surface combatants optimized for operating in the highly trafficked near-shore regions of the world. Through its innovative modular design, LCS can be reconfigured for surface warfare, anti-submarine warfare, and mine countermeasures in the near term, and adapt its capabilities for changing threats and scenarios that will occur over its service life.

Source: Airbus Defense and Space Inc.

Operational Testing Of Highly Autonomous Unmanned Surface Vessel

Leidos, a global science and technology solutions company, recently announced that it is beginning operational testing of the technology demonstration vessel it is developing for the Defense Advanced Research Projects Agency (DARPA) Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) program. Testing will occur off the coast of San Diego, Calif., and follows the successful completion of performance trials from the summer.

The 132-foot trimaran, christened Sea Hunter at a ceremony in April 2016, has commenced at-sea testing of sensors, mission control hardware and software, and the autonomy system. In initial testing of Sea Hunter's autonomy capability, the ship successfully executed a multi-waypoint mission with no person directing course or speed changes. Leidos also completed a test of the Remote Supervisory Control Station (RSCS), which allows remote supervisory control of the vessel and enables new mission tasking from a remote location, either afloat or ashore. The completion of the RSCS test was the final test before beginning more extensive autonomous operations. Testing of the Sea Hunter autonomy system in a variety of mission scenarios is scheduled to continue through fall 2017 as part of a two-year test program jointly funded by DARPA and the Office of Naval Research (ONR).

"Sea Hunter is at the forefront of new autonomy technologies for the U.S. military," said Mike Chagnon,

DARPA Photo

For More Information Visit mwjournal.com for more defense news president of the Leidos Advanced Solutions Group. "The operational testing is designed to showcase the unprecedented capabilities that this type of unmanned vessel could offer our military forces."

Electronically Scanned Array Market $8.43B by 2021

The electronically scanned arrays market is projected to grow from $6.24 billion in 2016 to $8.43 billion by 2021, at a CAGR of 6.2 percent during the forecast period. The base year considered for the study is 2015, and the forecast period is from 2016 to 2021. Factors such as replacement of traditional electronically scanned array systems and integration of active electronically scanned arrays with traditional radar system components are expected to drive growth.

Based on type, the active segment of the electronically scanned array market is expected to grow at the highest CAGR during the forecast period. Active electronically scanned arrays (AESA) are equipped with transmitters and receivers composed of numerous small solid-state transmitter/receiver modules. These radars are considered to be highly effective for radar resource management. Active electronically scanned arrays are capable of spreading emissions across a wide range of frequencies, and thus, are widely utilized for land and sea surveillance.

Based on platform, the naval segment is projected to grow at the highest CAGR. Naval radars are used for detection and tracking of naval activities. Detection of warships, submarine, offshore patrol vessels (OPV), and other naval vessels is their prime function. These systems are also utilized for the detection of anti-ship missiles and other ammunitions.

Based on range, the medium range segment is expected to grow at the highest CAGR. Medium-range electronically scanned arrays operate at frequencies between 8 and 40 GHz and are used to detect targets typically between 50 and 150 km range. These radars are employed in air traffic management, maritime activities, warships and naval activities.

Based on location, the Asia-Pacific market is anticipated to grow at the highest CAGR, owing to increasing terror threats in this region, which have propelled the demand for upgrading surveillance capabilities. Territorial disputes among countries in the Asia-Pacific region have grown considerably over the past decade. This has further led to rise in military budgets to enhance anti-missile capabilities.

Key players in this market include Lockheed Martin Corp., Northrop Grumman Corp. and Raytheon Co. (U.S.); Saab AB (Sweden) and Thales Group (France).

BAE Systems Opens Aerospace Skills and Training Academy in UK

The £15.6 million Academy for Skills & Knowledge (ASK) training academy that has been opened by BAE Systems will train all the apprentices and graduates in the company's military aircraft business as well as provide life-long learning and skills development activities for 13,000 employees for at least the next four decades.

The 7,400 m^2 ASK, which is situated on the Samlesbury Aerospace Enterprise Zone in Lancashire, UK, alongside BAE Systems' military aircraft advanced manufacturing centre will also act as a collaborative skills-hub for the North West of England's engineering and manufacturing sector and offer an exciting learning education centre for school children from five to 14 years old.

With 26 modern, light and airy classroom facilities, the ASK has been designed and built from scratch over three years. It mirrors the latest advanced manufacturing technologies and factory layouts used at BAE Systems including robotics, 3D printers, a virtual reality 'cave', a composites clean room, electronics and welding facilities.

Northern Powerhouse Minister Andrew Percy said, "Our Enterprise Zones across the North have already attracted nearly 9,000 skilled workers and today BAE Systems has become the latest world-class company to get on board with our plans to build a Northern Powerhouse. Northern businesses have established themselves in the top flight of the aerospace industry and the new flagship Academy for Skills and Knowledge will offer excellent opportunities to our young people from the area."

Chris Boardman, managing director of BAE Systems Military Air & Information, added, "The Academy for Skills & Knowledge is the single biggest investment in skills in the aerospace industry and offers an unrivaled modern engineering and manufacturing environment in which BAE Systems can deliver the highest quality training. We are committed to playing our part in developing skills for the future, for our business, those in our supply chain and in education."

Courtesy BAE Systems

Open Source Projects Use oneM2M Standards

OneM2M, the global standards partnership for Machine-to-Machine (M2M) communications and the Internet of Things (IoT), revealed its standards are being used by a number of independent open source foundations and projects, in addition to commercial deployments. Several open source foundations and projects have been actively using oneM2M standards in various applications and services since the organization released its first set of specifications in January 2015. oneM2M's Release 2, was published early in 2016.

Among the foundations using the standards is the open alliance for IoT standard OCEAN, which was established in January 2015 by the Korean government and research institute KETI. It has now attracted 214 members and develops code for the oneM2M-based IoT server platform project Mobius and IoT device platform &Cube.

Also, recognizing the importance of low-cost and power-efficient IoT clients to support applications like smart cities and wearables, ATIS has started developing an open source support for light weight oneM2M compatible client frameworks with a focus on constrained hardware.

"The open source community has become extremely important for a number of industries as technology continues to evolve and the IoT is no different," said Dr. Omar Elloumi, Technical Plenary Chair, oneM2M, and member of Nokia Bell Labs and CTO group. "Use of the oneM2M standards by these groups is an extremely positive step forward for the IoT industry. It is projects like these that are contributing to our ultimate aim of making IoT applications and products interoperable so that they can achieve the goal of truly enhancing users' daily lives."

European Ministers Support 'United Space in Europe'

At a two-day Council meeting at ministerial level in Lucerne, Switzerland in December 2016, European Ministers in charge of space matters from the European Space Agency's (ESA) 22 member states plus Slovenia and Canada allocated €10.3 billion for space activities and programmes based on the vision of a United Space in Europe in the era of Space 4.0. The high level of subscriptions demonstrates that ESA's Member States consider space as a strategic and attractive investment with a particularly high socioeconomic value.

It also underlines that ESA is the European Space

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Agency capable of channeling their investment to respond effectively to regional, national and European needs by covering all elements of space: science, human spaceflight, exploration, launchers, telecommunications, navigation, Earth observation, applications (combining space, airborne and terrestrial technology), operations and technologies; as well as responding to the needs and challenges of Europe and the Member States by bringing together all stakeholders.

Ministers confirmed the confidence that ESA can conceptualize, shape and organize the change in the European space sector and in ESA itself, while also acting as a global player, broker and mediator at the centre of international cooperation in space activities.

Huawei Launches Integrated Fronthaul/ Backhaul 5G Network Solution

At the ITU-T 2020 FG Workshop and Demo Day Wireline Technology Enablers for 5G Conference in Geneva, Switzerland, in December 2016, Huawei released X-Ethernet technology for 5G bearer networks. The company also proposed X-Ethernet for integrated fronthaul/backhaul networks, with deterministic low-latency and end-to-end network slicing capability.

In the 4G and 4.5G era, Ethernet is the dominant data bearer technology due to its simple, effective and low-cost characteristics. In the coming 5G era, three key scenarios—MBB, mMTC and uRLLC—will set stringent requirements for bearer networks. Operators will need to satisfy 5G requirements such as fronthaul/backhaul convergence, service isolation and low-latency in Ethernet while maintaining its existing advantages. That will pose a new challenge to the mobile bearer network domain.

The Network 5.0 Team at Huawei's Network Technology Laboratory, part of the company's 'Laboratory 2012' proposed the innovative X-Ethernet technology, which fundamentally solves the problem brought by the high bandwidth, determinacy, low-latency, hard isolation and low-cost requirements of 5G. X-Ethernet holds many innovative features such as a Layer 1.5 Switch, Hybrid Multiplex and Ethernet E2E Flexible Hard Pipe.

Huawei, as a member of the IMT-2020 Focus Group, participates in research on 5G bearer network technology. The company is open to collaboration with global partners, exploring Ethernet bearer network architecture and technologies to meet 5G requirements and develop new services.

500 Million 5G Subscribers Will Bring $200B in Revenue by 2026

While mobile network operators and vendors meet current market demands with LTE-A and LTE-A Pro, pre-standard 5G millimeter wave (mmWave) deployments are imminent. ABI Research forecasts that 5G in the cm and mmWave bands will reach nearly $200 billion in cumulative service revenues by 2026 while LTE, LTE-A and LTE-A Pro exceed five billion subscriptions.

"While the global LTE subscriber base will continue to grow in the immediate future as operators evolve to LTE-A Pro networks, it will likely soften in developed markets when 5G deployments take off," says Khin Sandi Lynn, industry analyst at ABI Research. "In 2026, the LTE portfolio will remain the dominant mobile technology, representing more than 50 percent of worldwide mobile subscriptions, while the 5G subscriber base will grow to account for close to 5 percent of the market's total."

> "... the 5G subscriber base will grow to account for close to 5% of the market's total."

Developed markets in North America and Asia-Pacific will lead the way for 5G services. U.S. mobile operators AT&T and Verizon completed field and lab testing of 5G technology and aim for pre-standard deployments in 2017, while operators in Japan and the Republic of Korea amp up their own 5G services in preparation for their upcoming Olympics. The 5G Open Trial Specification Alliance—formed by KT, NTT DOCOMO, SK Telecom and Verizon—will also develop 5G trial activities.

Other stakeholders working toward 5G include Qualcomm. The company recently announced that its Snapdragon X50 5G modem will deliver 5 Gbps device downloads in the 28 GHz band. Meanwhile, leading infrastructure vendors Ericsson, Huawei, Nokia and ZTE are unleashing a flurry of 5G technology agreements, demos, trials and roadmaps to increase momentum for 5G.

Short-Range Wireless Connectivity to Thrive in Emerging IoT Applications

The market for short-range wireless connectivity—including Bluetooth, Wi-Fi, 802.15.4 and NFC—continues to evolve and expand its use cases in order to meet new IoT market requirements. Technical enhancements, new specifications, emerging protocols, collaborations and partnerships, as well as multi-protocol ICs, will all help propel the wireless connectivity market to more than 10 billion IC shipments by 2021.

"Collaborations, cooperation and multi-protocol connectivity ICs are trends that will become increasingly important for future wireless connectivity market growth," says Andrew Zignani, industry analyst at ABI Research. "However, each technology has its own unique strengths that suppliers and OEMs must maximize in order to take advantage of the enormous opportunities that the IoT promises."

While Thread was initially seen as a challenger to ZigBee for 802.15.4-based solutions, the recent ZigBee Alliance and the Thread Group collaboration shows that both technologies will help each other grow. Many ZigBee devices will have the ability to upgrade to Thread, and while one major limitation of ZigBee 3.0 is that IP is not supported, collaboration means that this can be circumvented by utilizing the ZigBee 3.0 application profiles above the Thread networking protocol. A complete solution with an end-to-end certification is expected before the end of 2016, which will provide the market with an IP-based 802.15.4 radio solution that takes advantage of the strength of both organizations.

"Further collaborations between ZigBee and other organizations, such as the EnOcean Alliance, will help drive self-powered energy harvesting IoT devices in areas such as home and building automation," continues Zignani." This will enable 802.15.4 to become the leading home automation and smart lighting technology by 2021, followed closely by Bluetooth, further enhanced by Bluetooth 5 and imminent mesh networking standardizations."

Wi-Fi is also branching out into low-power IoT applications through HaLow. Though it has a number of advantages versus competing technologies, it will not be an easy task for the technology to carve out significant market share due to its late arrival, strong competition, and challenges it faces in building a Sub-1 GHz Wi-Fi ecosystem. However, Wi-Fi will continue to evolve in other areas, with 802.11ad (WiGig) expected to hit the mainstream in 2017, and other protocols like 802.11ax set for rapid growth upon its arrival in 2019.

"Qualcomm is in a prime position to take advantage of the wireless connectivity market's new trends," concludes Zignani. "Its leading expertise in cellular and Wi-Fi technologies, as well as recent acquisitions of CSR for Bluetooth, and more recently, the potential acquisition of NXP for NFC and 802.15.4-based technologies, will all help fill gaps in the company's portfolio, better target automotive applications, and make it a leading provider of connectivity solutions for almost all IoT connectivity technologies. Similar acquisitions of Broadcom's IoT connectivity assets by Cypress, and Qorvo's acquisition of 802.15.4 supplier GreenPeak, both highlight the growing importance of these wireless connectivity technologies in the IoT space."

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Car OEMs Target 2021 for Rollout of SAE Levels 4 and 5 of Autonomous Driving

VIEW VIDEO

New OEM smart mobility divisions, growing safety concerns relating to semi-autonomous driving, and recognition by national governments of the environmental and societal advantages of driverless vehicles will accelerate the deployment of more autonomous forms of driving. Semi-autonomous systems will continue to dominate the market over the next decade, with SAE level 2 (driver aid) and 3 (limited autonomy) systems accounting for 86 percent of autonomous vehicles shipping in 2026. Higher levels of autonomy will gain traction quickly, representing just under one-third of autonomous vehicles shipping in 2030.

"Driverless cars will transform the way mobility is consumed, bringing environmental, societal and convenience advantages to the end user," says James Hodgson, industry analyst at ABI Research. "It also represents a fundamental disruption to the business model that dominated the automotive market for almost one century. OEMs have much to gain in pursuing semi-autonomous operation, maintaining the importance of the driving experience. However, recent announcements from BMW, Ford, Renault-Nissan and Tesla signal that OEMs are not only looking to introduce higher levels of autonomy by 2021, but are also actively planning to transition from vehicle sellers to mobility providers."

> "Driverless cars will transform the way mobility is consumed, bringing environmental, societal and convenience advantages..."

Both Ford and Renault-Nissan launched smart mobility divisions to build on the existing trend of OEM/rideshare partnerships and investments. The divisions also provide a platform for these brands to research and implement autonomous and connected technologies.

Meanwhile, Tesla Network's decision to withdraw the level 2 Autopilot system in favor of Enhanced Autopilot, and eventually deep learning-based autonomous functionality, consistent with SAE level 4 (full autonomy in limited environments), or even level 5 (full autonomy, anywhere under any conditions), is the most concrete example of the shift in industry attitudes toward low level semi-autonomous driving.

"The spread of low-speed traffic jam assist systems to more of the mass market, in tandem with the increasing combination of longitudinal and lateral assistance on highways, will see semi-autonomous vehicles retaining their dominant market share for some years," concludes Hodgson.


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AN/ALQ-187 USAF, F-16
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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

MACOM Technology Solutions Holdings Inc. has entered into a definitive agreement to acquire **AppliedMicro Circuits Corp.** The acquisition, valued at approximately $770 million, allows MACOM to strengthen its portfolio for the data center market, adding OTN framers, MACsec Ethernet networking components and a single-lambda PAM4 platform. MACOM expects the deal to close in the first calendar quarter of 2017. MACOM is paying approximately $8.36 per share for AppliedMicro, consisting of $3.25 in cash and 0.1089 share of MACOM per share of AppliedMicro.

Analog Devices Inc. announced the acquisition of a solid-state laser beam steering technology from **Vescent Photonics Inc.**, a privately held company based in Golden, Colo. Vescent's innovative non-mechanical beam steering technology enables more robust integrated LIDAR1 systems that overcome many of the major drawbacks associated with today's bulky mechanical offerings such as reliability, size, and cost. This acquisition strengthens ADI's position as a major automotive safety system technology partner for next generation ADAS and autonomous driving applications and builds on ADI's 20-year history in advancing automotive safety.

Mercury Systems has acquired mission computing company **CES Creative Electronic Systems S.A.,** (CES). The acquisition was completed on November 4, 2016. The addition of CES adds important and complementary capabilities in mission computing, safety-critical avionics and platform management that are in demand from Mercury's customers. These new capabilities will also substantially expand Mercury's addressable market into commercial aerospace, defense platform management, C4I and mission computing—markets that are aligned to Mercury's existing market focus. Like Mercury, CES has exceptional technology, solid engineering talent and strong leadership, providing an excellent fit strategically, culturally and operationally between this business and Mercury.

COLLABORATIONS

Keysight Technologies Inc. and **ASELSAN A.S.**, Turkey, announced the signing of a memorandum of understanding (MOU) to establish a strategic partnership on research and development of 5G communication technologies. Both parties are committed to working together on 5G enabling technologies—especially on active antenna systems and remote radio heads, as well as prototype verification platform integration and characterization capabilities, with a goal of enhancing future 5G wireless communication innovations.

Modelithics and **KEMET** announced that the companies have partnered to provide highly accurate measurement based simulation models for the entire KEMET CBR RF capacitor series. KEMET and Modelithics recently collaborated to develop highly accurate measurement based equivalent circuit models for the KEMET CBR RF capacitor series, including EIA case sizes 0201, 0402, 0603, 0805 and 0505. These models are now available in industry leading simulation tools including Keysight ADS, Keysight Genesys, NI AWR Design Environment, ANSYS HFSS and Sonnet Suites.

MoSys, a leader in semiconductor solutions that enable fast, intelligent data access for Cloud, network, and communications systems, and **Integrated Device Technology Inc.**, announced interoperability between MoSys' new LineSpeed™ Flex 28G 2:1 MUXIC (MSH420) and IDT's 24-Port, 48-Lane, 600 Gbps, 10xN RapidIO® Switch (RXS2448). The IDT® Switch delivers ultra-low latency and high-bandwidth in both wireless and wireline 100G, 400G, and terabit network infrastructure applications, such as mobile edge computing, high-performance computing, and data analytics. The MoSys® LineSpeed Flex 28G MUX and retimer protocol independent devices are compatible with the 10G or 12.5G RapidIO interfaces and enable a reduction in backplane traces or QSFP cable counts for high density RapidIO systems.

Anokiwave Inc., an innovative company providing highly integrated IC solutions for mmWave markets and active antenna based solutions, announced a collaboration with **GLOBALFOUNDRIES** to deliver the world's most advanced Silicon Core IC solutions for the emerging mmWave active antenna markets. Active antennas have been used in military phase-array radar systems for many years and are now being deployed in record numbers in a wide range of commercial applications.

Sivers IMA announced that **CAE S.p.A.**, a state-of-the-art system supplier of environmental monitoring systems, has selected Sivers IMA as their radar module partner for their Level Probing Radar (LPR) Hydrometer product. Under this partnership Sivers IMA will deliver FMCW radar technology allowing CAE to provide a state-of-the-art LPR Hydrometer solution. LPR prototype has been finally approved in 2015 and the sensor has received the ETSI and the FCC certifications during 2016. Following the beginning of the industrial production, Sivers IMA has recently received a first relevant order of radar front ends for the LPR units.

NEW STARTS

Integrated Microwave Technologies, a business unit of **xG Technology Inc.**, and a leader in advanced digital microwave systems serving the law enforcement, broadcast, sports and entertainment markets, announced the launch of its new company website. The new design for www.imt-solutions.com delivers a more streamlined experience that is easier to navigate and

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provides improved functionality for its current and potential customers. The new website builds on IMT's customer support portal, which was deployed earlier this year. The new pages are organized by application, allowing users to find products that fit their specific needs and highlight full turnkey solutions.

Intelliconnect (Europe) Ltd. has launched a completely new website offering visitors easier navigation and search facilities and a new quote basket facility allowing customers to automatically request a quotation for selected products. A brochure detailing all the company's products can be downloaded from the homepage at www.intelliconnect.co.uk. Key features include the launch of the Taurus Range of RF connectors as well as the new cable selector that enables customers to build a custom cable assembly online then request a quote.

ACHIEVEMENTS

Qorvo®, a provider of innovative RF solutions that connect the world, has been awarded Huawei's Best Collaboration Partner Award and Core Partner Award. The awards were accepted by Bob Bruggeworth, president and CEO of Qorvo, during a formal ceremony at Huawei's headquarters in Shenzhen, recognizing Qorvo's contribution as an outstanding supplier of RF solutions to Huawei. The awards highlight Qorvo's competitive strengths in supply chain execution and technology collaboration, along with outstanding local service and support. Qorvo supplies Huawei with multiple innovative RF solutions, including RF Fusion™, RF Flex™, highly integrated power amplifiers, antenna tuners, premium filters, and mobile Wi-Fi solutions, across Huawei's most popular flagship and mid-tier smartphones.

Harris Corp. has received Type-1 National Security Agency (NSA) certification for its Harris Falcon III® AN/PRC-117G Multiband Networking Manpack Radio to run the Mobile User Objective System (MUOS) waveform. The NSA Type-1 certification allows secure voice and data communications on the AN/PRC-117G using the MUOS waveform. MUOS is the next-generation U.S. Department of Defense (DoD) military communications system for delivering mobile satellite connectivity through tactical radios. Harris has already successfully conducted satellite transmissions using the MUOS waveform.

The **European Space Agency** (ESA) has launched four additional Galileo satellites, accelerating deployment of the new satellite navigation system. Galileo is the global navigation satellite system (GNSS) that is currently being created by the European Union (EU) through the European Space Agency (ESA) and the European GNSS Agency (GSA). The Ariane 5 rocket, operated by Arianespace, lifted off from Europe's Spaceport in Kourou, French Guiana carried the Galileo satellites 15 - 18. This mission brings the Galileo system satellite count to 18 satellites.

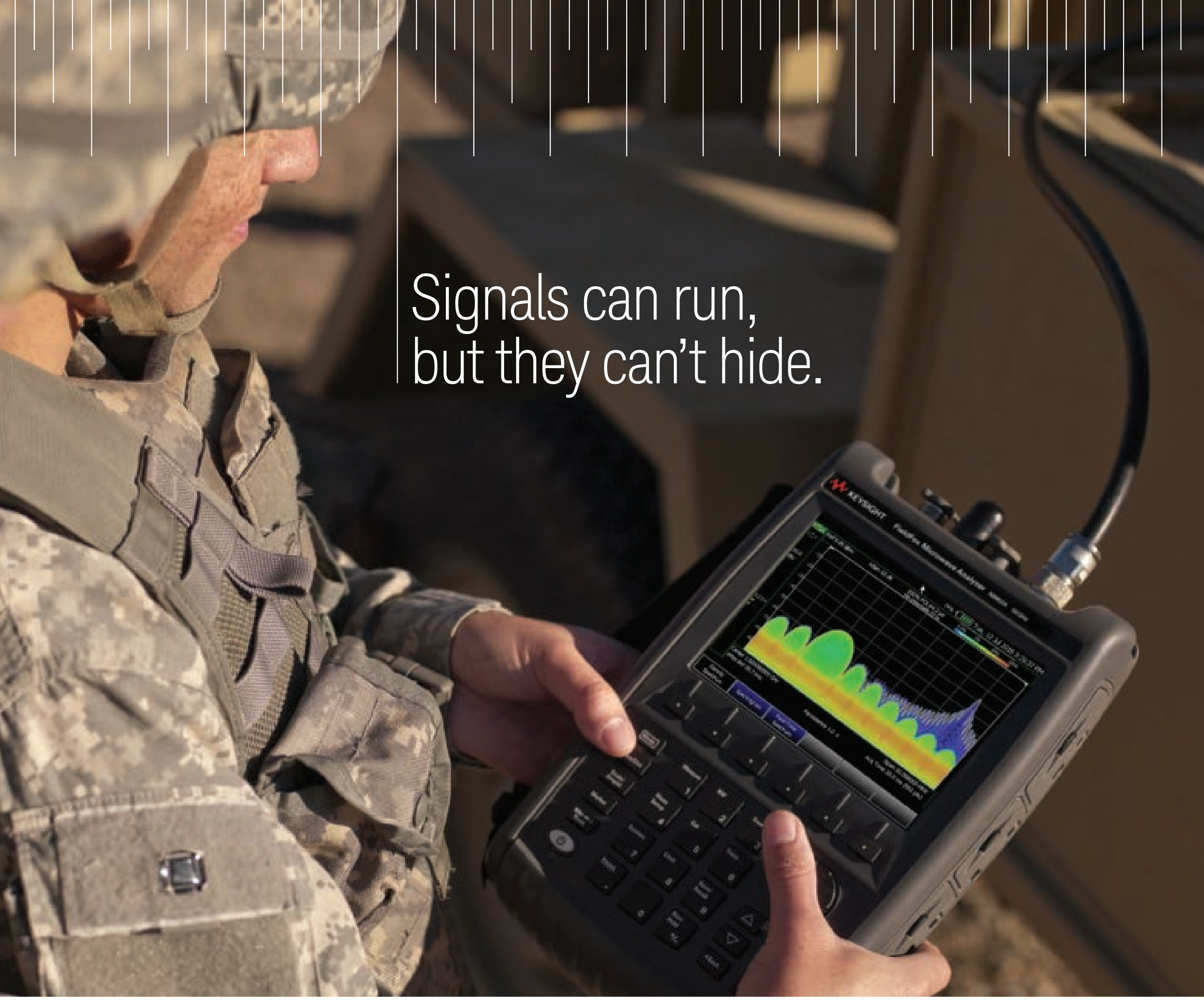
General Atomics Aeronautical Systems Inc. (GA-ASI), a manufacturer of remotely piloted aircraft (RPA) systems, radars and electro-optic and related mission systems solutions, announced that its Type-Certifiable Predator® B (TCPB) variant completed its first flight test at the company's Gray Butte Flight Operations Facility near Palmdale, Calif. Qualification testing for type certification will continue over the next two years, with deliveries to the UK Royal Air Force, expected to begin in late 2018. To facilitate qualification testing, GA-ASI is building three company-owned aircraft, along with two airframes designed specifically for full-scale fatigue and static testing.

CONTRACTS

Lockheed Martin was awarded a $1.2 billion contract to upgrade 134 F-16 aircraft for the **Republic of Korea Air Force** (ROKAF). The upgrades are based on the advanced F-16V configuration. Among the enhancements are an Active Electronically Scanned Array (AESA) radar, a modern commercial off-the-shelf (COTS)-based avionics subsystem, a large-format, high-resolution center pedestal display and a high-volume and high-speed data bus. The contract for the ROKAF upgrade is a foreign military sales contract issued by the U.S. Air Force. As Original Equipment Manufacturer (OEM) and design authority of the F-16, Lockheed Martin is uniquely qualified to design, engineer, develop, integrate and sustain a complete F-16 weapons system solution tailored to customer requirements.

Jacobs Engineering Group Inc. has received a single-award contract from the **U.S. Army Corps of Engineers New England District** (USACE NAE) to provide environmental remediation and restoration, technical support and facility maintenance at the New Bedford Harbor Superfund Site (NBHSS) in New Bedford, Mass. Jacobs has supported NAE in this capacity at the site since early 2004. New Bedford Harbor, home to a large commercial fishing fleet, is one of the oldest recreational and commercial navigation harbors along the East Coast of the United States. The USACE was requested by the U.S. Environmental Protection Agency (EPA) to clean up PCB-contaminated sediments from the harbor.

Technica Corp. announced it was awarded a $224 million NETCENTS – 2 Network Operations Small Business task order by the **U.S. Air Force**. Technica will manage all communications networks and information technology services for the Air Force's 844th Communications Group and National Military Command Center (NMCC), which serve senior leaders across the National Capital Region (NCR) and Department of Defense (DoD) agencies worldwide. Technica will support the Air Force District of Washington's no-fail mission in support of the Office of the Secretary of Defense, Joint Chiefs of Staff, Headquarters Air Force, the Pentagon, Joint Base Andrews, Joint Base Anacostia-Bolling, and other U.S. Air Force sites within a 300 mile radius, plus Ottawa, Canada.


Signals can run,
but they can't hide.

Around the **Circuit**

BAE Systems has received an indefinite delivery/indefinite quantity contract from the **U.S. Navy** for post-construction work aboard the guided missile destroyers USS Zumwalt (DDG 1000) and USS Michael Monsoor (DDG 1001). The contract has an initial award of $10.3 million and a maximum value of $192.7 million for work through September 2021. USS Zumwalt and Michael Monsoor are the first two ships of the Navy's new class of surface combatants. The ships are 610 feet long, displace about 15,700 tons and are comprised of steel hulls and composite structure deckhouses.

CACI International Inc. has been awarded a prime position on a multiple-award, indefinite delivery/indefinite quantity contract with a ceiling value of $192 million, to provide training and curriculum development to the **Naval Education and Training Command** (NETC). The six-year contract represents new work for CACI in its logistics and material readiness market area. NETC is the largest shore command in the U.S. Navy, and is responsible for the training and development of Navy personnel to ensure fleet readiness. Under the contract, CACI will support Navy training and distance learning objectives by developing and delivering instructor-based learning and modular, scalable, interactive solutions for mobile and stationary devices.

Rheinmetall's Simulation and Training unit has won another important order in the Middle East-North Africa region. A customer country has contracted with the Düsseldorf-based high-tech group to modernize and expand an existing live training facility. The order is worth just under €10 million, already included in the group's recently presented nine-month figures. Rheinmetall will supply state-of-the-art hardware and software components for expanding and updating the country's Mobile Combat Training Centre. In addition, the order encompasses the supply of new laser engagement simulators that will enable inclusion of various combat vehicles and the latest weapon systems in the tactical training process.

The Communications & Medical Products Division of **Communications & Power Industries** (CPI) has been awarded an €8.7 million, or approximately $9.5 million, contract by **Airbus Defence and Space** to support a new generation of satellites that is expected to provide global advanced meteorological data from 2021 until after 2040. The Meteorological Operational Satellite – Second Generation (MetOp-SG) program is a collaboration between the European Space Agency (ESA) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and consists of two series of satellites carrying complementary instruments. Under the contract, CPI will develop several engineering and flight models of 5.355 GHz Extended Interaction Klystrons (EIKs).

Maryville-based **Vanquish Worldwide LLC**, a Service-Disabled Veteran-Owned Small Business (SDVOSB)

Around the **Circuit**

providing global support services to the U.S. Government and the commercial market sector, announced its award of three new, multi-million dollar federal contracts to provide **U.S. Army Logistics Readiness Center** support at five locations. Contracts include work as a sub-contractor to SENTEL Corporation at Fort Bragg, N.C., and as a prime contractor at both Fort Stewart and Hunter Army Airfield, Ga., as well as Joint Base Fort Rucker, Ala. and Eglin Air Force Base, Fla.

Ducommun Inc. has received a contract from **Airbus Defence and Space** to design and manufacture high-rel switch matrices used in space. Ducommun will produce the switch matrices at its Carson, Calif., operations center through July 2018. A switch matrix is a system of electronic components that route RF signals between multiple inputs and outputs. Airbus will use the high-rel switch matrices on satellites that provide mobile communications for both military and commercial customers in remote areas. Ducommun has designed and manufactured a variety of RF components and subsystems such as high-rel switch matrices for military, space and industrial programs for nearly three decades.

Leonardo-Finmeccanica has been awarded a contract by **China's National Instruments Import and Export Corp.** (Instrimpex) to supply four new radar systems for air traffic control (ATC) in the country. The new contract strengthens the company's position as one of the premier suppliers of ATC radar systems to China, building on over 30 years of experience of providing such systems to the country. Over 60 ATC systems installed in Chinese territory provide radar coverage across nearly all of the main routes in the central and eastern regions. The four ATCR-33S NG primary radars will be employed during flight departure and landing phases as well as for extended terminal area surveillance (ETA). Part of a new generation of radar systems, they make use of the latest technology available to the communication, navigation and surveillance market.

PEOPLE

AR RF/Microwave has appointed **John Kim** vice president of corporate operations. In this position, Kim will manage operations of two AR divisions, AR Europe and AR Modular RF. He will also manage and expand Am-Rep, under which products made by third party manufacturers are branded and marketed by AR. Kim's international duties for AR will utilize the varied skills he has acquired in an impressive sales and marketing career that includes building business units, developing new markets, and dramatically increasing sales for a number of industry-leading companies. His international background includes living in Korea, Vietnam, Thailand, Canada, Austria, England and the U.S.

San-tron Inc., a leading manufacturer of RF and microwave coaxial connectors and cable assemblies, announced the appointment of a new Northeast regional

sales manager. With 20 years experience in the RF/microwave Industry, **Betsey Kenyon** joins San-tron as their Northeast regional sales manager. Previous to this role, Kenyon had managed the New England territory as well as target markets throughout the United States. Kenyon's track record of positive annual growth, her ability to develop new business relationships while strengthening existing ones and her advanced knowledge of RF and microwave products make her a valuable addition to the San-tron team.

REP APPOINTMENTS

W. L. Gore & Associates Inc. announced that **Pansystem** (Rome, Italy) has been named an authorized distributor of Gore high data rate cables for aircraft and land vehicles in Italy, Portugal and Spain. Pansystem is a leading distributor of wire, cable and interconnects to the military and defense market. Headquartered in Rome, Italy, Pansystem covers the Southern European region.

Richardson Electronics Ltd. announced a new distribution agreement with **United Silicon Carbide Inc.** (USCi), a leading manufacturer for SiC devices located in Monmouth Junction, N.J. This global agreement supports the expansion of USCi's products to new customers. USCi is a semiconductor company specializing in the development of high efficiency silicon carbide (SiC) devices and customized products with process expertise in Schottky barrier diodes and SiC switches. USCi technology and products enable affordable power efficiency in key markets that will drive the new and greener economy.

PLACES

TechPlus Microwave Inc. a technology leader in the design and manufacture of RF/microwave filters recently completed a move to larger facilities at 4231 Pacific Street, Suite 3 & 4, Rocklin, CA 95677. Rocklin Business Park, Rocklin, CA is approximately 22 miles (35 km) northeast of Sacramento. The new location will provide much needed additional space for increased productivity and expansion into other product lines.

Earlier this year **TMD Technologies Ltd.** (TMD), a West London based RF/microwave manufacturer, received a major tube production contract that necessitated the construction of a brand new purpose-built area for assembly, dress and test. Planning for this significant project began in May 2016 and the first tube completed its testing in October.

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INVITED PAPER

Editor's Note: This is the second of two articles in this month's radar and antennas issue that discusses architectural changes accelerating the evolution to the next-generation of phased array radar.

Digital Beamforming Accelerates the Evolution to Next-Generation Radar

Peter Delos
Analog Devices, Inc., Norwood, Mass.

Digital beamforming in phased arrays has proliferated in recent years, spawned by both military and commercial applications and advancements in RF component integration. Although massive MIMO and automotive radar are the subjects of much discussion, most of the recent radar development and beamforming R&D that has been in the defense industry (see ***Figure 1***), is now being adapted for commercial applications. While phased arrays with digital beamforming moved from R&D to reality in the 2000s, a new wave of defense systems are being developed, enabled by semiconductor technology that was previously cost prohibitive.

▲ **Fig. 1** AN/APG-81 AESA radar, which flies on the F-35. Source: Northrop Grumman.

ANALOG VS. DIGITAL BEAMFORMING

The block diagram of a generic phased array with analog and digital beamforming is shown in ***Figure 2***. The number of elements in the array is chosen based on aperture size, power and antenna pattern requirements. Front-end or transmit/receive (T/R) modules are located behind each antenna element, and an analog beamforming layer is behind the front-end modules. In historic phased arrays, the analog beamforming subsystem combines all the elements to centralized receiver channels. In many systems today, some level of analog beamforming is common. In a system with only digital beamforming, waveform generators and receivers are behind every front-end module, and the analog beamforming layer is eliminated. The waveform generator and receiver channels serve to convert digital data to the operating band RF frequencies. Digital beamforming is accomplished by first equalizing the channels, then applying phase shifts and amplitude weights to the analog-to-digital (A/D) data, followed by a summation of the A/D data across the array. Many beams can be formed simultaneously, limited only by the digital processing capability.

The objective of a digital beamforming phased array is the simultaneous generation of many antenna patterns for a single set of

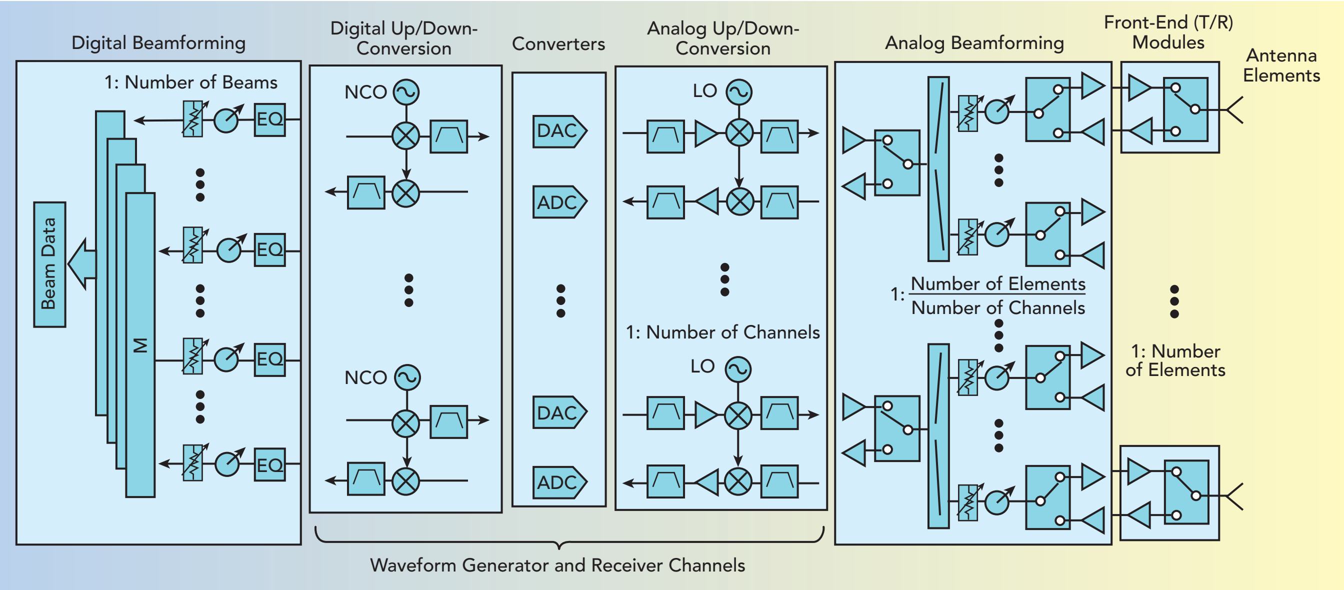

Fig. 2 Generic AESA block diagram, showing analog and digital beamforming functions.

receiver data. ***Figure 3*** shows the antenna patterns for a single element, the combined elements in a subarray and the digitally formed beams. The primary obstacle of the subarray approach is that the digitally formed beams must be within the pattern of the subarray. With a single subarray, simultaneous patterns cannot be generated at widely different angles.

It is desirable to eliminate the analog beamformer and produce an every-element digital beamforming

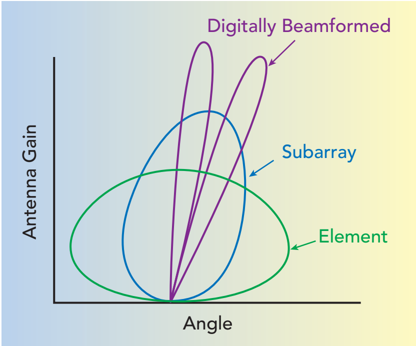

Fig. 3 Example antenna pattern created with digital beamforming.

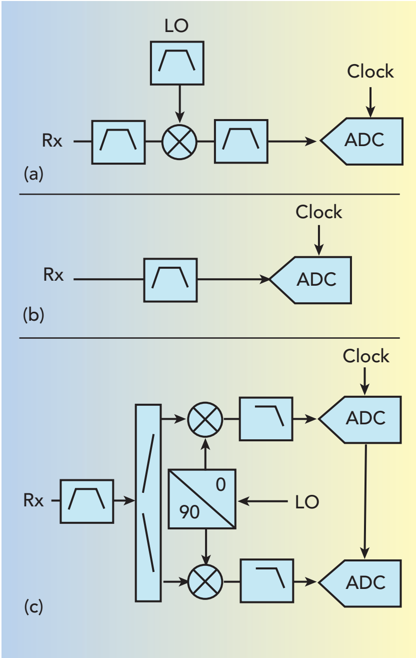

Fig. 4 Common receiver architectures: superheterodyne (a) direct sampling (b) and direct conversion (c).

system. With today's technology, this is possible at L- and S-Band. At higher frequencies, size and power constraints often necessitate some analog beamforming. However, the quest remains to approach every-element digital beamforming, which places significant demands on the waveform generator and receivers. These demands are conflicting, i.e., to reduce size and power while increasing bandwidth for most applications, as increased bandwidth typically requires additional current and circuit complexity. Digital beamforming relies on the coherent addition of the distributed waveform generator and receiver channels, placing additional challenges on the synchronization of the many channels and system allocations of noise contributions.

RF SIGNAL CHAIN

Three receiver architectures— superheterodyne, direct sampling and direct conversion—are the most commonly used in phased arrays (see ***Figure 4***). Although only the receiver is shown, the topologies also apply to the waveform generator signal chains in the transmit path.

The superheterodyne approach, which has been around for 100 years, is proven and provides exceptional performance. Unfortunately, it is also the most complicated. It typically requires the most power and the largest physical footprint relative to the available bandwidth, and frequency planning can be quite challenging at large fractional bandwidths. The direct sampling approach has long been sought after, the obstacles being operating the converters at speeds commensurate with direct RF sampling and achieving large input bandwidth. Today, converters are available for direct sampling in higher Nyquist bands at both L- and S-Band. The technology is advancing, with C-Band sampling soon to be practical and X-Band to follow. Direct conversion provides the most efficient use of the data converter bandwidth. The data converters operate in the first Nyquist band, where performance is optimum and lowpass filtering is easier. The two data converters work together sampling I/Q signals, thus increasing the user bandwidth without the challenges of interleaving. The dominant challenge that has plagued the direct conversion architecture has been maintaining I/Q balance for acceptable levels of image rejection, LO leakage and DC offsets. In recent years, the advanced integration of the entire direct conversion signal chain, combined with digital calibration, has overcome these challenges, and the direct conversion architecture very practical in many systems. ***Table 1*** summarizes the features of the three receiver architectures.

The industry is continually advancing the technology for all these signal chain options. The future will bring increased bandwidth and lower power, while maintaining high levels of performance, and integrated signal chains in system on chip (SoC) or system in package (SiP) solutions. Data converter analog performance will continue to im-

Why AR Solid State Pulsed Amplifiers Should Be On Your Radar

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TABLE 1

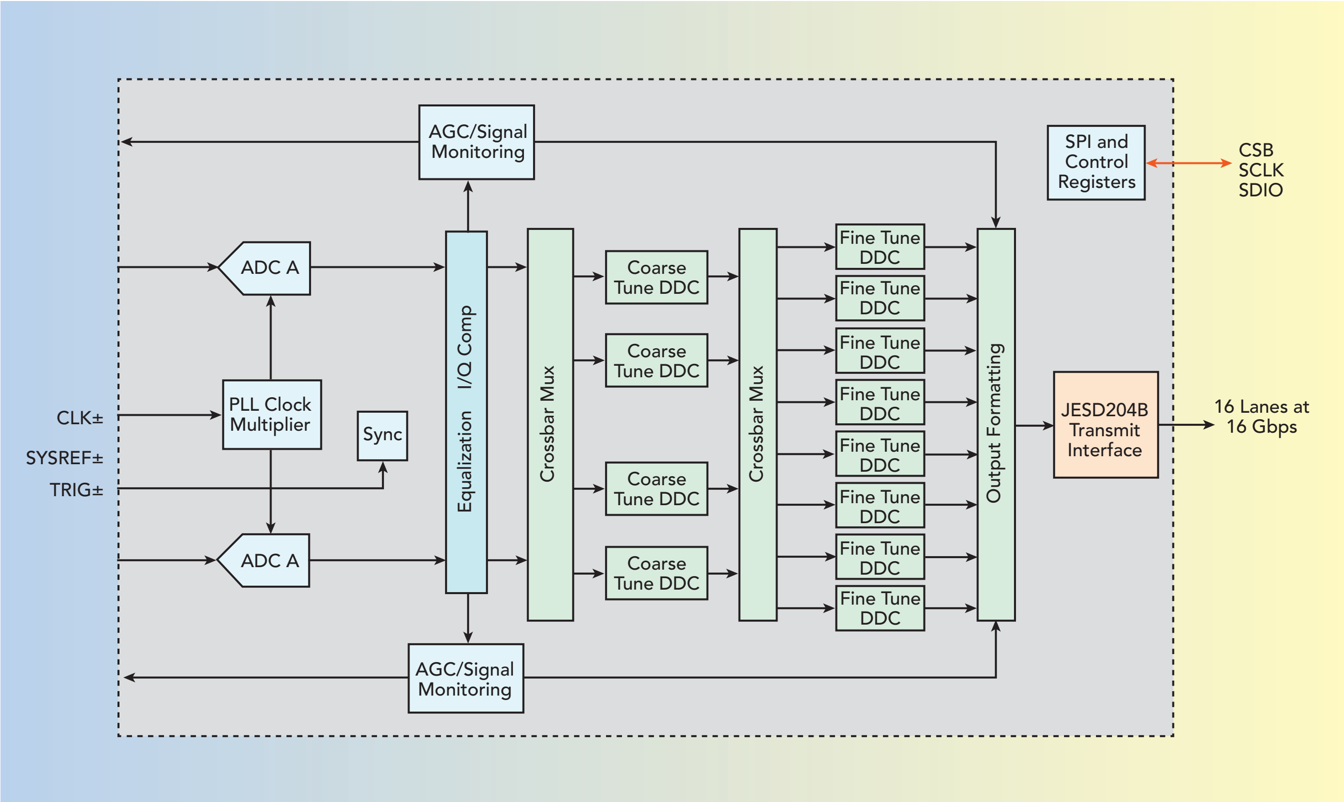
COMMON RECEIVER ARCHITECTURES

Configuration	Benefits	Challenges
Superheterodyne	• Proven/Trusted • High Performance • Optimum Spurious • High Dynamic Range • EMI Immunity	• SWAP • Many Filters
Direct Sampling	• No Mixing • Practical at L/S-Band	• A/D Input BW • Gain Not Distributed Across Frequency
Direct Conversion	• Maximum A/D BW • Simplest WB Option	• Image Rejection (I/Q Balance) • In-Band IF Harmonics • LO Radiation • EMI Immunity (IP2) • DC and 1/f Noise

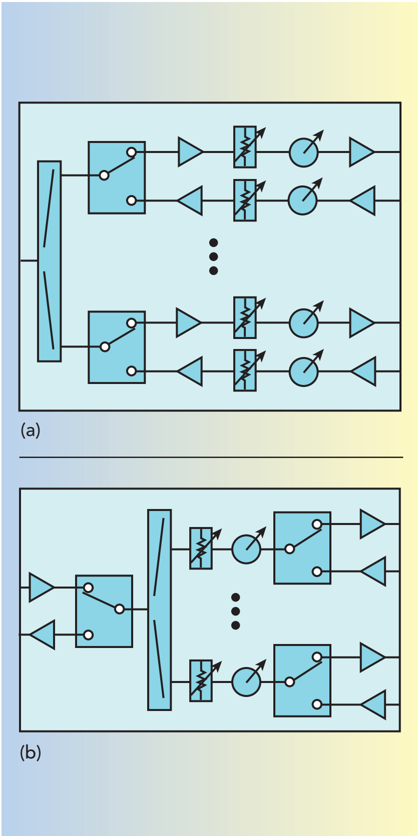
prove, and these improvements will include increased sampling rates for wider bandwidth, increased channel count and maintaining the key performance metrics of noise density and linearity. These benefits will drive all of the RF signal chain solutions, enabling new phased array solutions. An area of increased importance at the system level is the recent addition of many digital functions that can offload FPGA processing and improve system capability (see ***Figure 5***). Recently released data converters include digital down-conversion and filtering, potentially reducing the data rate to the FPGA, system power and FPGA processing requirements. Data converters will continue to add functionality, such as equalization and processing features at the front-end of digital beamforming.

HYBRID BEAMFORMING

At high frequencies or for low power systems, every-element digital beamforming is challenged by size and power requirements. The use of analog beamforming reduces the number of waveform generator and receiver channels required to be digitized. Analog beamforming is accomplished by adjusting the phase and amplitude of the signal at the individual antenna element to steer the direction of the radiation pattern. ***Figure 6a*** shows analog beamforming where independent phase shifters and attenuators are located in both transmit and receive signal paths, and the elements are combined in a single output. ***Figure 6b*** shows a functionally equivalent approach, where the phase shifter and attenuator are common, toggled between the transmit and receive paths at the antenna element. This latter topology reduces the num-



▲ Fig. 5 Embedded digital features can offload the FPGA.

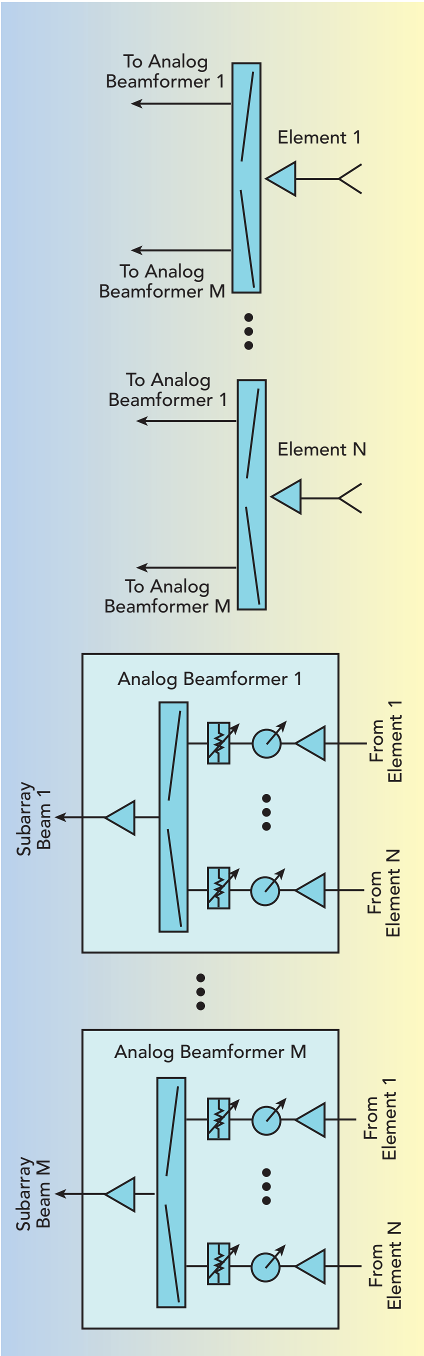


▲ Fig. 6 Approaches to analog beamforming: individual transmit and receive phase and amplitude control (a) and shared phase and amplitude control (b) for each element.

ber of phase shifters and attenuators but may require more frequent command updates to control the devices. To overcome the constraints of a single subarray, multiple subarrays can be used, with a topology as shown in ***Figure 7***. In this approach, the outputs of the low noise amplifiers (LNA) at each element are split to feed many analog beamformers, where N elements produce M analog subarray beams. Each analog beamformer is programmed for a different antenna pattern. By repeating this topology across an array, digitally beamformed patterns can be created at widely disparate angles. This is one type of hybrid architecture that can provide the benefits of an every-element digital system with a reduced waveform generator and receiver count. The trade-off is the complexity of the analog beamformer.

FRONT-END MODULES

Traditional analog beamformers have required a single-function GaAs phase shifter and single-function GaAs attenuator for each antenna element. More advanced approaches integrate the phase shifter and attenuator into a single GaAs MMIC that may include the power amplifier (PA), LNA and switch. SiGe BiCMOS technology can also real-



▲ **Fig. 7** Hybrid array architecture using M subarrays with analog beamforming to create N antenna beams.

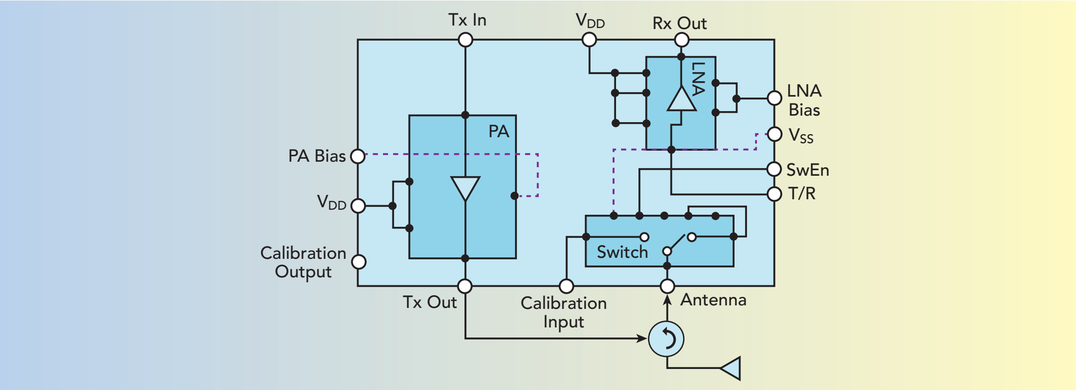


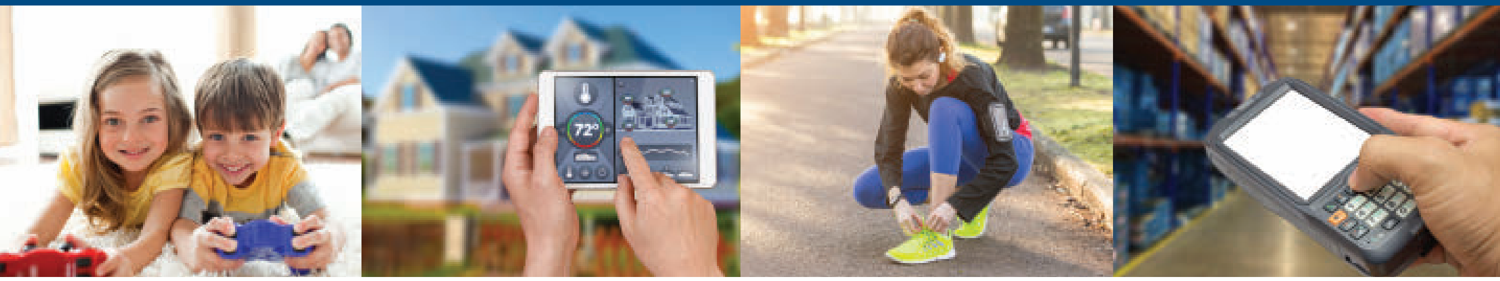
Fig. 8 T/R module integrating the PA, LNA and switch.

ize the analog beamformer, even integrating four channels into a single IC, with the benefit of reduced footprint and lower power dissipation.

As the front-end or T/R modules provide the interface to the antenna element, the transmit power and efficiency and receive noise figure are critical requirements, set by the PA and LNA. Many systems also require provisions for calibration or additional filters. A functional block diagram of a front-end module containing the PA, LNA, and switch is shown in ***Figure 8***. Many single function components are available that can be integrated into a single module. Custom ICs in various technologies support optimization and integration to meet the needs of the required application. Advances in GaN technology have created more efficient PAs with increased power density in the transmitter. GaN also enhances the receiver by providing LNAs with higher survivability to input power, eliminating the need for a discrete limiter. Higher levels of integration in both the beamformer and T/R module allow for flat-panel or tile arrays that are smaller and more cost effective to manufacture than other solutions, such as traditional plank or slat arrays or travelling wave tube (TWT) solutions.

CONCLUSION

Digital beamforming phased arrays are becoming increasingly common, with rapid development expected to cover a wide range of applications and frequencies from L- through W-Band. The semiconductor industry is enabling new system developments with high speed converters, SiGe beamformers, microwave frequency conversion and front-end modules.■



INVITED PAPER

The Challenges of SSRFE Design: Residential and Industrial Cooking Applications

Klaus Werner, Executive Director
RF Energy Alliance

Solid-state (i.e., semiconductor based) generated radio frequency (RF) used to power processes and applications has taken hold in the last couple of years in a number of markets and has given rise to the notion of RF Energy applications.[1-4] Most noteworthy, are all kinds of industrial heating, drying, curing, sintering or similar processes that are currently being developed with solid-state RF rather than the legacy magnetron as the driving source.

One of the major drivers for the adoption of this technology is the possibility to run consumer microwave ovens from solid-state power amplifiers. The large number of ovens being built with the magnetron every year (in excess of 70 million devices), makes it a very attractive business proposition—provided the system cost, which would seem to rise with current power amplifier cost levels, can be kept in check. Also, customer satisfaction or a great user experience should go without saying with a precision cooking device versus a legacy, reheating unit, which is based on a magnetron.

The system cost is being dealt with within the RF Energy Alliance (RFEA), while how to create a great user experience with microwaves as the energy source is the topic of research within white goods companies—probably more than ever before. With the legacy 'frequency hopping' magnetron the systems tried to do their best to deliver energy 'on average' to heat things up. Employing a turn table or mode stirrer attempted to improve the performance and increase homogeneity with varying success.

Through solid-state technology, the systems are suddenly 'controlled'. This means that rather than relying on a 'randomly' operating source (the magnetron) in conjunction with an averaging device (the turntable), the system controller needs to 'know' and 'predict' what kind of frequencies, power levels and phase differences the RF signals from various channels need to be in order to achieve the optimal results. To do nothing here (not changing the RF vectors) is not an option! It will make the cooking results worse. Hence, the new technology comes with great promise, but also a lot of work to actually understand how to 'instill' into the solid-state cookers the appropriate algorithms (i.e., smartness) to achieve excellent results.

I have discussed the technical challenges associated with the RF generation for solid-state RF heating systems in *Microwave Journal* before.[5] This article discusses basic

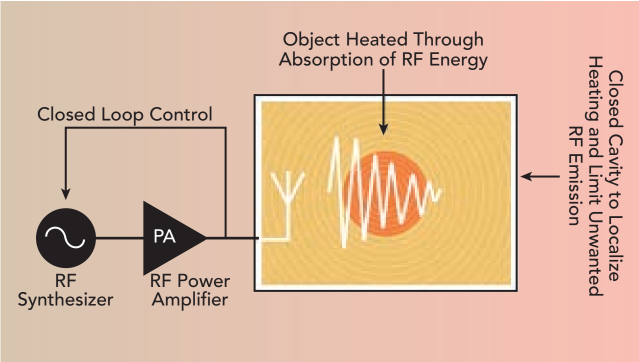


Fig. 1 Solid-state powered RF energy application.

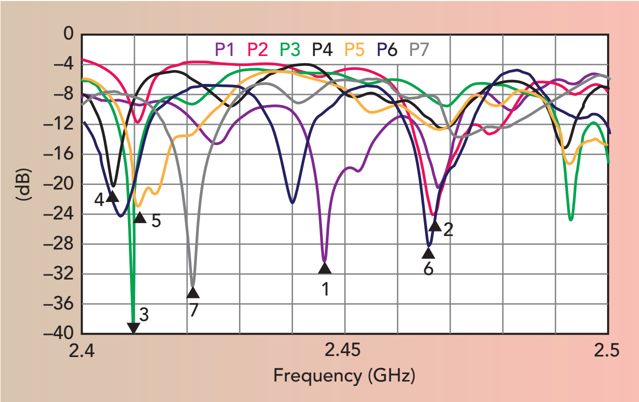


Fig. 2 S_{11} response vs. physical position of the load on a ground plane inside a cavity.

concepts of applying microwaves to food processing for both industrial and consumer use. The 'new kid on the block', solid-state generated and amplified RF is not a new concept but it needs to be rethought in order to make the best of the new possibilities—predominantly control—that comes with solid-state RF generation. In the following paragraphs, a number of the characteristics of the new technology are presented.

RF energy applications typically make use of an RF-tight cavity, which contains the load to be processed and into which the RF is irradiated by means of antennae (see ***Figure 1***). The application controller is able to determine the exact cavity/load conditions during the process via feedback (VSWR) provided, and can react accordingly.

Solid-state systems are 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. Together with the multimode cavity (high Q structure), this offers system designers a choice to actively control the electromagnetic field distribution inside, which is the core ingredient to a great cooking result provided the controller knows 'what to do'.

We clearly need to separate the industrial and consumer oriented system designs: the industrial user can typically rely on a constant or slowly varying load, mostly in continuous flow processes (e.g., along a belt) with high to very high power levels (10 to > 100 kW) in a single system. Controlling the RF power under such circumstances is relatively simple and can safely rely on a very limited number of strategies to achieve adequate energy delivery. Machines typically run a single process such as pasteurization, sintering, ceramic and pharmaceutical drying, etc.

The consumer oriented cooking 'processes' need more sophisticated strategies: defrosting, baking, broiling, simmering, sous-vide, reheating, simultaneous multi-food items, etc. plus the fact that those processes are run in batches rather than as a flow and the drive towards minimized user input (who still knows how to cook?), make it much more difficult to cater for all circumstances. Indeed, the shear fact that the position inside the cavity is 'free' already makes a big difference. The electromagnetic conditions can be totally different by just varying the position of load items inside a cavity (see ***Figure 2*** for an example).

COOKING GOAL

Cutting a lot of corners, cooking is about dosing the right amount of

energy over time at intended locations outside, and possibly, inside of foodstuff. In the end, this energy delivery gives rise to temperature increase and/or chemical and physical changes of the foodstuff such that we can later enjoy tasty and healthy meals. There are multiple physical processes involved including energy absorption in or at the surface, thermal conduction and convection to transport heat inside foodstuff, heat loss at the surface via radiation and evaporation of liquids, and changes of parameters governing those processes in the course of the cooking (illustrated in ***Figure 3***). Regardless of how the energy for the cooking process is provided, the expectation is that all cooked foodstuff has received the intended energy dose everywhere.

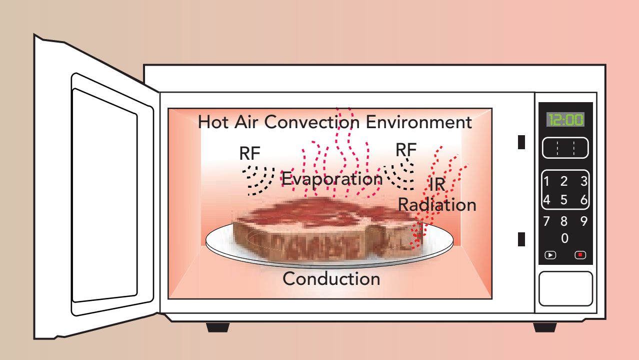


Fig. 3 Heat transport mechanisms cooking food.

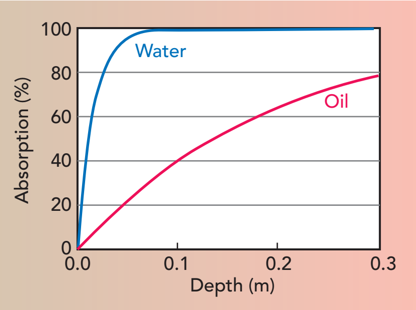


Fig. 4 Absorption depth of microwave radiation in water and oil.

PHYSICS

Conventional ways to cook usually provide the cooking energy through immersion of the foodstuff into a heated medium (water, oil and hot air) or radiation (infrared). Heating via microwaves belongs to the latter group, but in contrast to the generally limited penetration depths of infrared (IR) radiation (< 5 mm for near IR frequencies > 780 nm in tissue),[6] microwaves can penetrate deep (up to cms) into the foodstuff. In the following paragraphs, the relationships governing the energy delivery via microwaves into dielectric loads will be briefly presented.

The equation (which 'powers' all microwave heating processes):

$$P_V = 2\cdot\pi\cdot f\cdot\varepsilon_0\cdot\varepsilon''\cdot E^2 \qquad (1)$$

describes the power delivered into a volume element inside matter with a dielectric loss factor ε'', caused by microwave radiation with an average E-field magnitude E, the frequency f and the vacuum dielectric constant ε_0.

A wave traveling inside foodstuff will hence deliver energy according to this equation and gets attenuated along the way. Depending on ε'', this happens more or less quickly and it is helpful to define a 'penetration depth' l_d, which denotes the distance into the solid when the incoming field strength has diminished by 1/e times the value at the surface. For $\varepsilon''/\varepsilon' << 1$, this ld can be approximated by:[7]

$$l_d = \frac{\lambda\cdot\sqrt{\varepsilon'}}{\pi\cdot\varepsilon''} \qquad (2)$$

This allows the calculation of the absorption of the field and hence the energy delivered after some distance x into the medium:[7]

$$\alpha(\chi) = 1 - e^{-\frac{2\chi}{ld}} \qquad (3)$$

Figure 4[8] depicts the absorption depth of 2.45 GHz radiation in water and oil. Clearly, the microwaves penetrate oil much deeper than water.

Knowing the specific heat capacity of the material, the expected temperature rise of the specimen for the regions absorbing the electromagnetic energy can be calculated. Interestingly, in this example, the temperature for both water and oil will rise by roughly the same

amount due to the lower specific heat of oil, but the oil will heat up more homogeneously throughout the sample, whereas the water will heat up in a relatively smaller absorption region (neglecting conductive and convective heat transfer inside the material).

So far in the discussion, we have assumed that the dielectric constant ε' and loss factor ε" are constants with respect to frequency and temperature, which is not the case. For a rigorous treatment of the subject, this dependence needs to be taken into account. For example, ε" of clean water becomes smaller with temperature. The water will absorb microwaves less well at higher temperatures. Salty water exhibits opposite behavior: the loss increases with temperature (qualitatively depicted in ***Figure 5***).[9] In real food, this gives rise to 'thermal runaway'—relatively hot spots inside food will keep increasing in temperature faster than their environment, which leads to pronounced inhomogeneity.

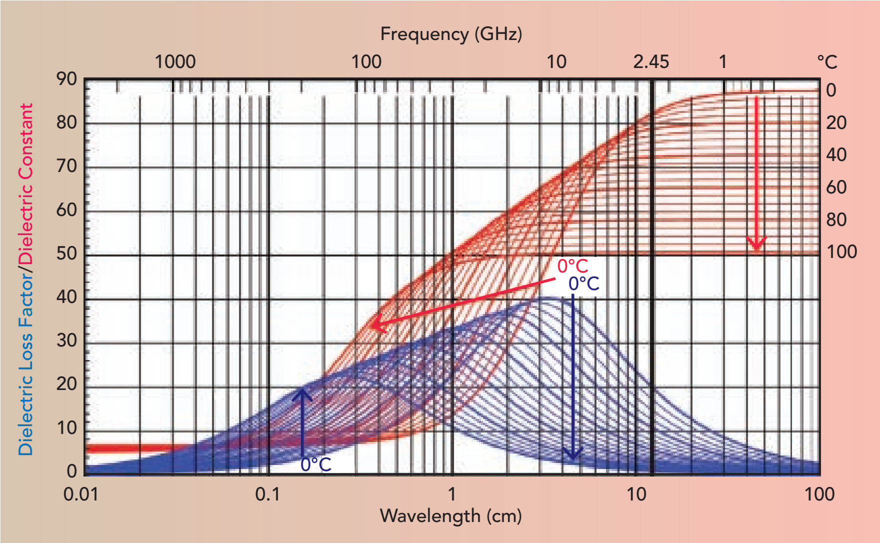


Fig. 5 Dielectric constant and dielectric loss factor of a dilute salt solution vs. temperature.

Electromagnetic waves experience reflection and diffraction at interfaces from air to matter and vice versa—exactly similar to these effects in optics, following the same equations. For water and oil interfaces with air, the result can be seen in ***Figure 6***.[8] The dielectric constant ε' of water gives rise to high reflectivity at the air to water interface of about 60 percent for basically all angles of incidence. Interestingly, at the water to air interface (leaving the specimen) the wave will experience total reflection for all angles of incidence but the smallest: microwaves are practically trapped inside water.

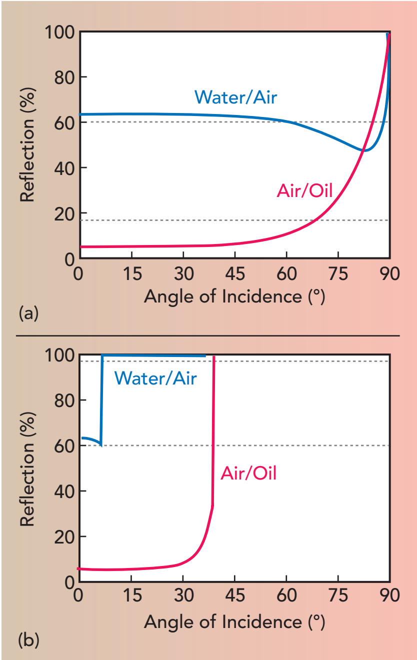


Fig. 6 Reflection vs. angle of incidence for unpolarized, 2.45 GHz radiation entering (a) and exiting (b) air/oil and air/water interfaces.

MODES

For domestic as well as industrial heating, resonating multi-modal cavities are typically used to apply the electromagnetic field to the load. These resonators together with the permittivity of the load applied 'allow' only certain frequencies inside to propagate, which create particular electromagnetic energy distributions, the 'modes.' The localized energy distribution associated with a particular mode will only deliver energy to dissipative loads at those spots.

It is clear that in order to have the load absorb the offered energy evenly, a number of complementary modes need to be created inside the cavity, e.g., via frequency variation of the incoming wave. Refer to ***Figure 7*** for an impression on the electrical field distributions of several modes excited by different feeds in an empty rectangular cavity.[10,11]

The clear discernibility of modes or resonances is a typical feature of a more or less empty cavity (Q still 'high'). With increasing dissipative load, it becomes part of the electrical length of the cavity and the resonance conditions change. In the extreme case of a fully loaded cavity, no mode spectrum exists and the homogeneity becomes a function of penetration depth into the load.

In addition to the modes of the

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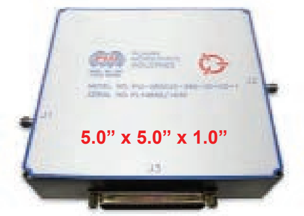
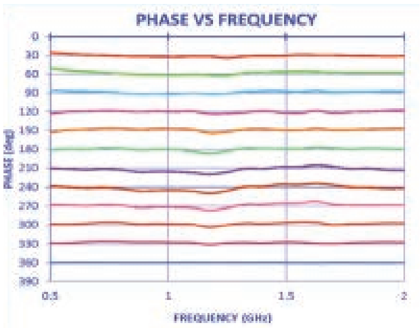
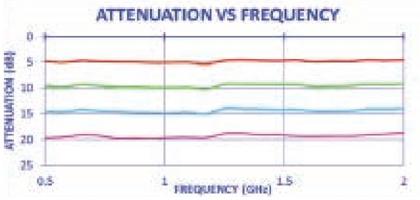


RF Connectors: SMA (F)
Switching Speed: 500 ns Max
DC Voltage:
+15 VDC @ 87 mA
-15 VDC @ 24 mA



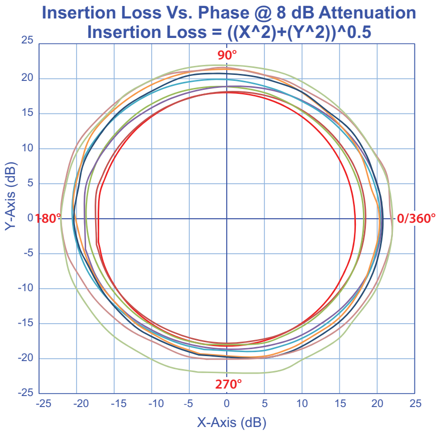
Frequency	0.5 to 2.0 GHz
Dynamic Range	20 dB & 360°
RF Input Power	+5 dBm CW, 1.0 Watt Max
Insertion Loss	11.0 dB Max - Measured 10.54 dB
VSWR	2.2:1 Max - Measured 1.59:1
Attenuation vs Frequency	±1.5 dB Typ - Measured ±1.3 dB
Phase vs Frequency	±10.0° Typ - Measured ±3.5°
Digital Control	2 x 12 Bit Monotonic TTL
Temperature	-10 °C to +60 °C Operating



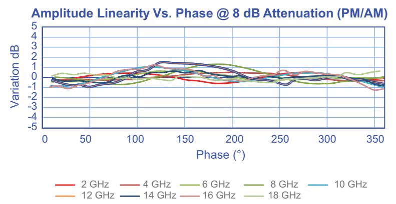
Model: PIQ-2G18G-360-16-CD-1 (2 to 18 GHz)

http://www.pmi-rf.com/Products/iq_vector_modulator/PIQ-2G18G-360-16-CD-1.htm

RF Connectors: SMA (F)
Switching Speed: 500 ns Max
DC Voltage:
+15 VDC @ 65 mA
-15 VDC @ 76 mA



Frequency	2.0 to 18.0 GHz
Dynamic Range	16 dB & 360°
RF Input Power	+10 dBm CW, 1.0 Watt Max
Insertion Loss	16.0 dB Max - Measured 14.74 dB
VSWR	2.2:1 Max - Measured 1.86:1
Attenuation vs Frequency	±3.5 dB Typ Measured ±1.19 dB @ 0 dB Attenuation ±1.41 dB @ 8 dB Attenuation ±2.91 dB @ 16 dB Attenuation
Phase vs Frequency	±20.0° Typ Measured ±9.66° @ 0 dB Attenuation ±12.35° @ 8 dB Attenuation ±18.23° @ 16 dB Attenuation
Digital Control	2 x 12 Bit Monotonic TTL
Temperature	-10 °C to +60 °C Operating



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East Coast Operation:
7311-F Grove Road
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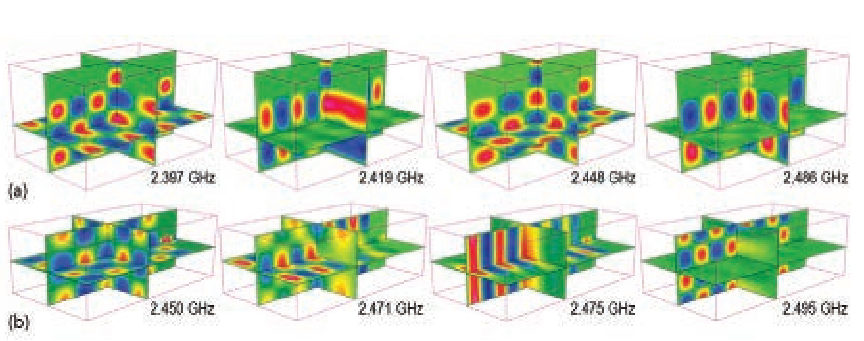


Fig. 7 Instantaneous electric fields in the coordinate planes excited by horizontal (a) and vertical (b) feeds in a two-feed empty rectangular cavity.

cavity, the shape and dielectric permittivity of loads also play an important role with respect to homogeneous energy deposition in the load. The load geometry, together with internal and external reflection, will create a dielectric resonator with a particular field distribution inside the load, which in turn depends on the outside field distribution. Simulated distributions of dissipated power for various resonant frequencies (at which the loads have much better energy coupling) excited by two different feeds in a particular rectangular cavity are shown in ***Figure 8***.[11] The patterns are highly non-uniform, and some of them dominate over others; this is explained by the depths of corresponding resonance: the deeper the resonance, the higher the energy coupling and the values of dissipated power in the pattern.

To summarize, microwave heating overcomes the thermal diffusion limited energy delivery through the surface to any kind of load through the possibility to penetrate the load and hence directly heat up the volume elements away from the surface. Unfortunately, it is not as straightforward as that, but a number of effects counteract homogeneous energy distribution inside the load:

- Inhomogeneous load/inhomogeneous dielectric (absorption) properties
- Low thermal conductivity of load
- Heat capacity of load
- Loss factor depending on temperature of the load that may change grossly during the process (thawing/defrosting)
- Pronounced edge heating and corner heating
- Energy hotspots due to modes in applicator
- Resonances inside the load
- Evaporation (heat loss) from the surface.

STRATEGIES

As a reminder, the goal of the cooking process was to supply the right amount of energy to any volume element of the load in order to achieve the intended temperature change and temperature setpoint over time.

Going further, three different load scenarios will be identified:[12]

1. Load is basically transparent to microwave radiation; weak absorption
2. Absorption depth ≈ load geometry/2
3. Absorption depth < load geometry/2

Case 1 is great for homogeneity, but may take high field strengths for effective heating (see Equation 1). 915 MHz radiation is very likely a good choice here above 2.45 GHz. Of course, the frequency can be chosen (if regulatory possible) such that the absorption depth fits better with the sample geometry (see Case 2). Given the low absorption, special care needs to be taken for the RF power measurements (forward power, reflected power). Usually the difference (reflected—forward) would be associated with the 'delivered' or 'absorbed' power. However, the walls of the apparatus or other elements of the machine may actually absorb power as well

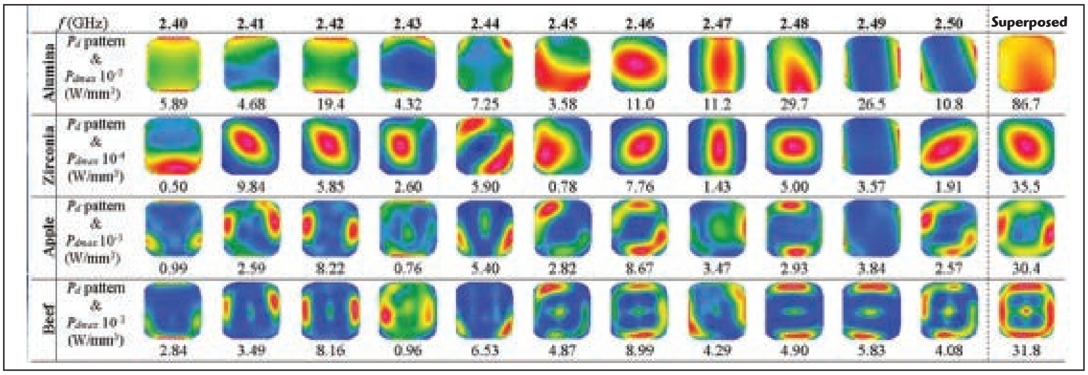


Fig. 8 Energy deposition vs. frequency within various 50 mm × 50 mm × 10 mm loads within the same cavity.

and hence the measurement needs to be carefully calibrated to identify other 'consumers'. Also, under these conditions, some RF power will be reflected back into the generators; special care needs to be taken to stay within the VSWR budget for the amplifiers.

Case 2 appears ideal for microwave based heating processes: the irradiated microwave energy is used efficiently (all the irradiated energy is being absorbed on the first 'pass' through the load; access to the load from all sides for the microwave radiation is assumed. Also, for homogeneity, this case does not need to rely on thermal diffusion (see Case 3). To promote homogeneity, several modes with different field distributions should be used. Depending on the exact parameters, edge heating may become an issue. If so, appropriate modes should be used to minimize the artifacts.

Case 3 is probably the most difficult one to get right in terms of homogeneity and process result: All microwave power is absorbed in a relatively (to the total extent of the load) small sub-surface depth. Edge heating is very likely and proper countermeasures need to be taken—the same goes for homogeneity along the surfaces at large. Also, the bulk of the load needs to be heated via the heat flux along the temperature gradient from the surface towards the bulk. If the thermal conductivity is low, the overall process will be slow and the use of microwaves may not actually be the optimal choice to heat the load. It could well be that the surface becomes too hot (thermal diffusion is slow), and/or dries out when water present is evaporated.

INDUSTRIAL VS. RESIDENTIAL APPLICATIONS

It appears that the realization of a perfect cooking/processing apparatus is less tricky from a process perspective in the industrial field. Typically, the loads presented to the systems are well known with respect to geometry, physical and chemical properties, are reproducible, uniform (at least on average) and do not change rapidly with time. Also, additional sensors for temperature, humidity, weight and such are likely to be present and their data used by the process controller. Under such circumstances, a system can be fully optimized for any of the three load scenarios discussed earlier.

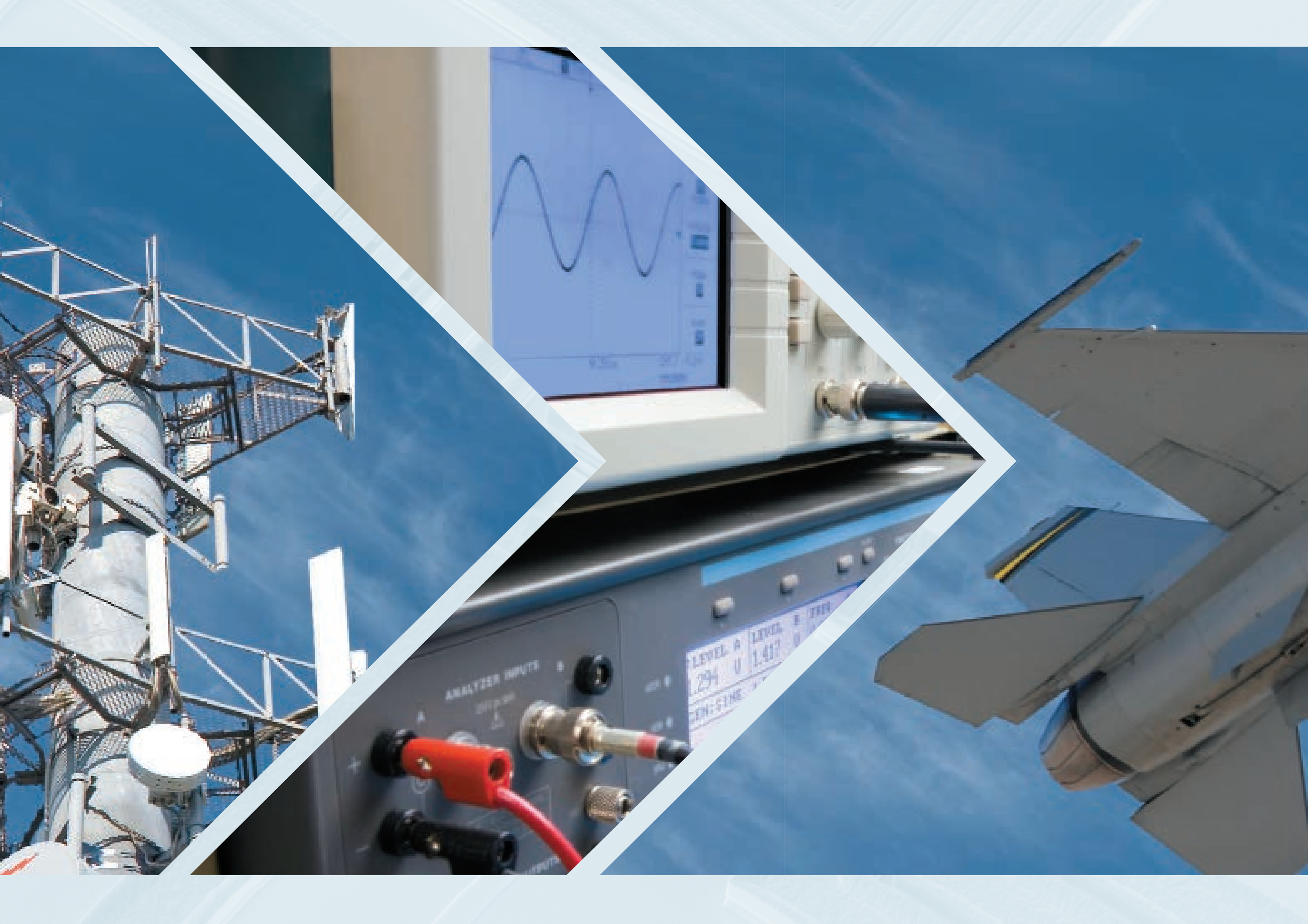
The frequency to use (915 MHz or 2.45 GHz) can be chosen based on absorption properties in connection with thermal diffusion speeds, regional spectrum, the power needed, efficiency requirements, etc. The RF control would seek to create as many complementary modes as possible, keep track of the delivered energy to realize intended temperature increases and monitor safety critical parameters. With solid-state generators, the system designer now also has a choice to move away from a limited number of high power microwave sources and to implement a more distributed RF power delivery (e.g., along a conveyor belt), which provides additional redundancy and fine-tuning capabilities to achieve a better process result (higher yield) than with less granular magnetron based systems.

On the other hand, it appears that the realization of a perfectly processing residential cooking system is a much more daunting task. Although the operating frequency is more or less fixed within the 2.45 GHz band (the 915 MHz ISM band is not available throughout the world), there are still plenty of RF system-level choices that can be made: The degrees of freedom here relates to the power level, number of RF channels and the electromagnetic design of the cavity with antenna port locations and overall geometry. One basic problem for residential systems is that the possible loads are basically endless: from hardly any load (or accidental misuse) to large absorptive 'meals' with all kinds of compositions (varying permittivity), geometries and weights.

Additional complexity arises with the introduction of additional heat sources like hot air convection, steam or broiling elements, whose respective contribution needs to be taken into account.

CONCLUSION

With all control and reproducibility, the designer has over the parameters of the RF signal, which is used to heat up a food load, comes the responsibility to 'know what to do'—in former times the magnetron with its stochastic and ageing behavior has taken those decisions. However, 'knowing what to do best' is not an easy task and depends strongly on the nature of

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the heating process, the volumes, shapes, temperature gradients, physical phases, etc. of the foodstuff. One could even argue that things have become more difficult than ever before to get the process right and produce the intended user experience. The industrial world seems to present a comparatively simpler task with well-known, generally homogeneous and uniform loads.

The realization of the perfect cooker for residential applications appears much more complicated in view of the multitude of conceivable loads and load conditions and hence the co-existence of load cases discussed in this article. However, it is clear that with the high degree of control, which is available through solid state RF, this kind of appliance has come within closer reach than ever before.■

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INVITED PAPER

Opportunities for High Frequency Materials in 5G and the IoT

Art Aguayo
Rogers Corp., Chandler, Ariz.

Not a day goes by that we don't encounter the terms 5G and IoT (Internet of Things). Indeed, the future is about super-connectivity and the promise it gives us, once everything is "talking" with each other. Connected appliances to connected cars, making life easier as we prepare for smart homes, smart cities and smart everything. It is difficult to imagine this future—yet so was imagining 2015 when looking through the view of the internet in the year 2000.

There appear to be as many definitions of 5G and IoT as forecasts and opinions when discussing the potential benefits and relevant business cases of these technologies. The International Telecommunication Union (ITU) has been working on defining what 5G IMT-2020 will be from a technical perspective, or at least how it will differ in performance from 4G (IMT-Advanced). The term 5G IMT-2020 was coined in 2012 by the ITU Radiocommunication sector and means "international mobile telecommunication system," with a target date of 2020. Within that definition, we see how IoT will benefit. Parameters like peak data rates, mobility, latency and spectrum efficiency are important, as they help define what the user experience will be, key to enhanced mobile broadband (eMBB) and ultra-reli-

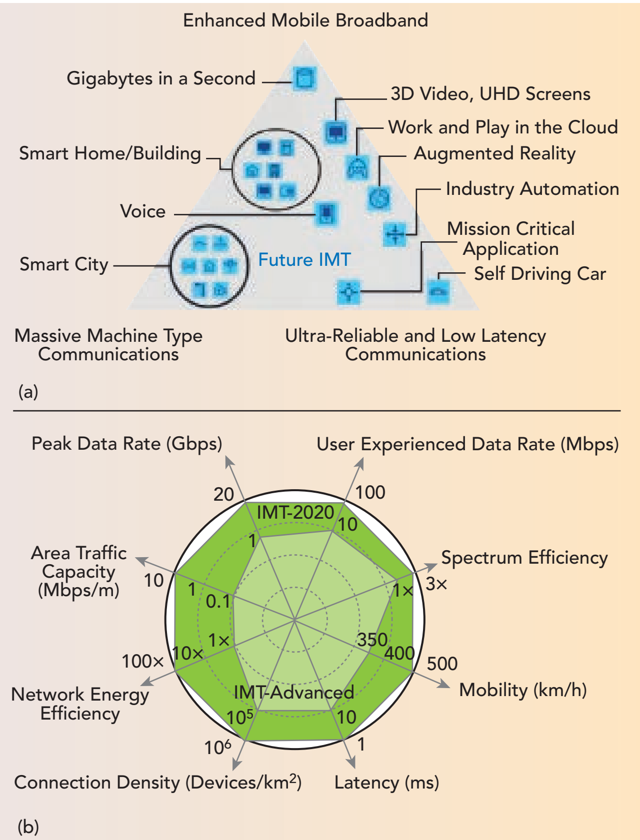
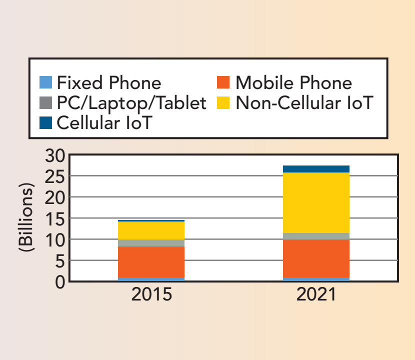


Fig. 1 ITU vision for IMT-2020, including usage scenarios (a) and enhancement of capabilities from IMT-Advanced (b).

TABLE 1

IoT APPLICATIONS

IoT Category	Example Applications
Massive IoT	Smart Building, Transport Logistics, Fleet Management, Smart Meters, Agriculture
Critical IoT	Traffic Safety, Autonomous Vehicles, Industrial Applications, Remote Manufacturing, Healthcare (including Remote Surgery)



▲ **Fig. 2** Connected devices forecast, from 2016 Ericsson Mobility Report.

able and low latency communications (URLCC). ***Figure 1*** shows how the ITU envisions 5G.

IoT, on the other hand, will need different parameters to operate in a way that needs minimal to no user action on a day-to-day basis, after the initial setup. Today, we are seeing the beginning of the IoT market, an expansion of the M2M market that already exists and accounts for 600 million devices as of 2015.[1] The IoT can be divided into two segments.[2] The first represents massive IoT connections with high connection volume, low cost, low energy consumption and small data traffic. The second comprises critical IoT connections that require ultra-reliability and availability with very low latency. ***Table 1*** shows applications for each of the two classifications. ***Figure 2*** shows a forecast for the connected devices market, based on Ericsson's mobility report.[3] The traditional connected-device market of fixed, mobile phones and computer/tablets will increase slightly, while the overall number of devices associated with IoT, both cellular and non-cellular, will grow greater than 20 percent annually. The IoT space can also be viewed by how connectivity is achieved, particularly using low power technology. Various low power standards are summarized in ***Table 2***.

Frequency band allocations for 5G focus heavily on available bandwidth, and they seem to center around three groups: sub 6 GHz, 15 to 40 GHz and greater than 60 GHz. Because much of 5G will be data intensive, the frequencies around 28, 39 and 77 GHz are gaining momentum because of the availability of spectrum within those bands. As many IoT applications are expected to be low data rate, most of the IoT activity is centering on the sub-6 GHz spectrum. An exception will be IoT for surveillance, where trans-

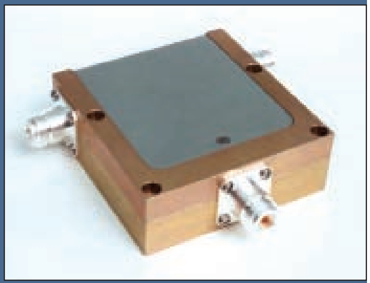
TABLE 2

LOW POWER IoT STANDARDS[4]

	Bluetooth, Wi-fi, RFID, ZigBee, Z-Wave	NB-IoT	EC-GPRS	SigFox	LoRa
Range	10 cm to 200 m	< 11 km	< 11 km	< 9 km	< 7 km
Maximum Coupling Loss (dB)	< 100	164	164	160	157
Spectrum, Bandwidth	Unlicensed 2.4 GHz	Licensed IMT, 200 kHz Shared	Licensed 800 to 900 MHz, Shared	Unlicensed 868 MHz, 600 Hz	Unlicensed 868 MHz, 125 kHz
Data Rate	< 100 Mbps	< 62 kbps UL < 26 kbps DL	<70 kbps	<1 kbps	< 50 kbps

HIGH POWER

100 MHz to 20 GHz



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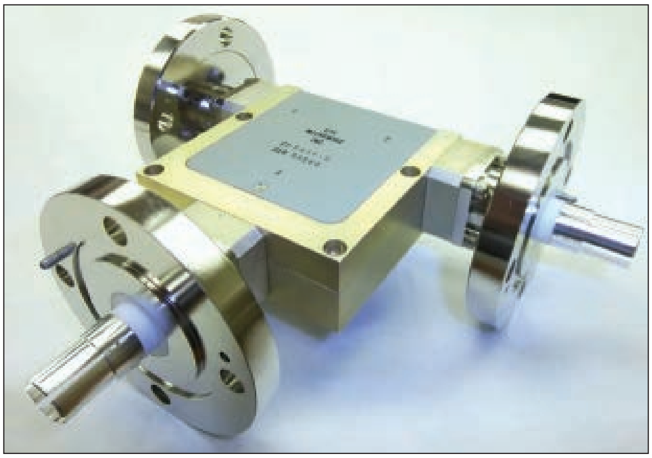

Model CT-1864-S is rated at 60kW peak and 600W average power at 325 MHz. The unit provides 20 dB minimum isolation, 0.2 dB insertion loss and 1.20:1 maximum VSWR. Its extremely compact design has flange to flange insertion length of only 6-3/4" and a height of 5-1/4". For use in radar applications, it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

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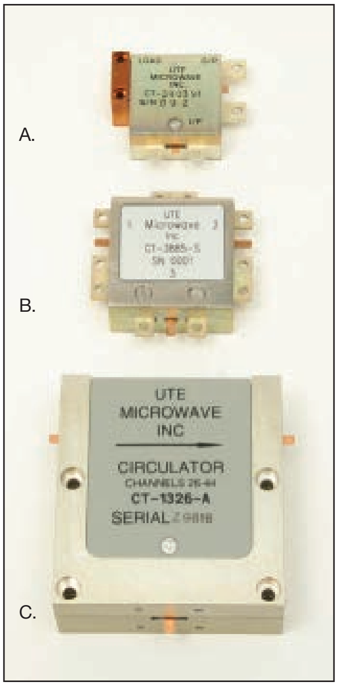
- A) 2.7–3.1 GHZ 1 kW pk, 100 W av
- B) 1.2–1.4 GHZ 3 kW pk, 300 W av
- C) UHF TV Band 5 kW pk, 500 W av



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Model No.	Power	Connectors	Freq. Range
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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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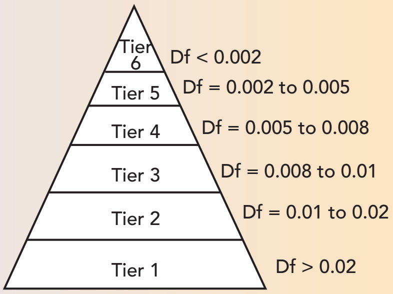


▲ **Fig. 3** **PCB material classification by loss tangent (Df).**

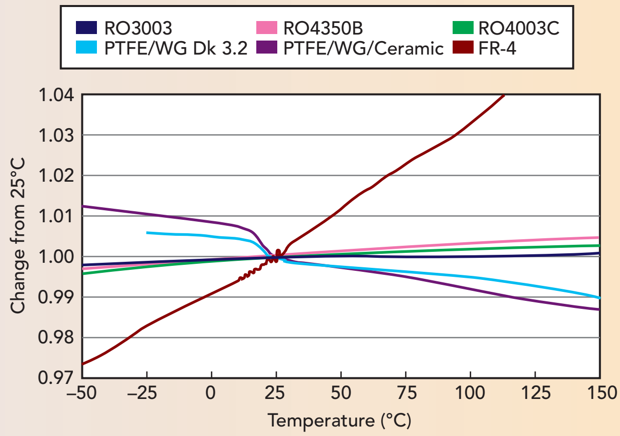
mitting high definition video from remote areas may require the bandwidth found in the millimeter wave spectrum.

MATERIALS PERSPECTIVE

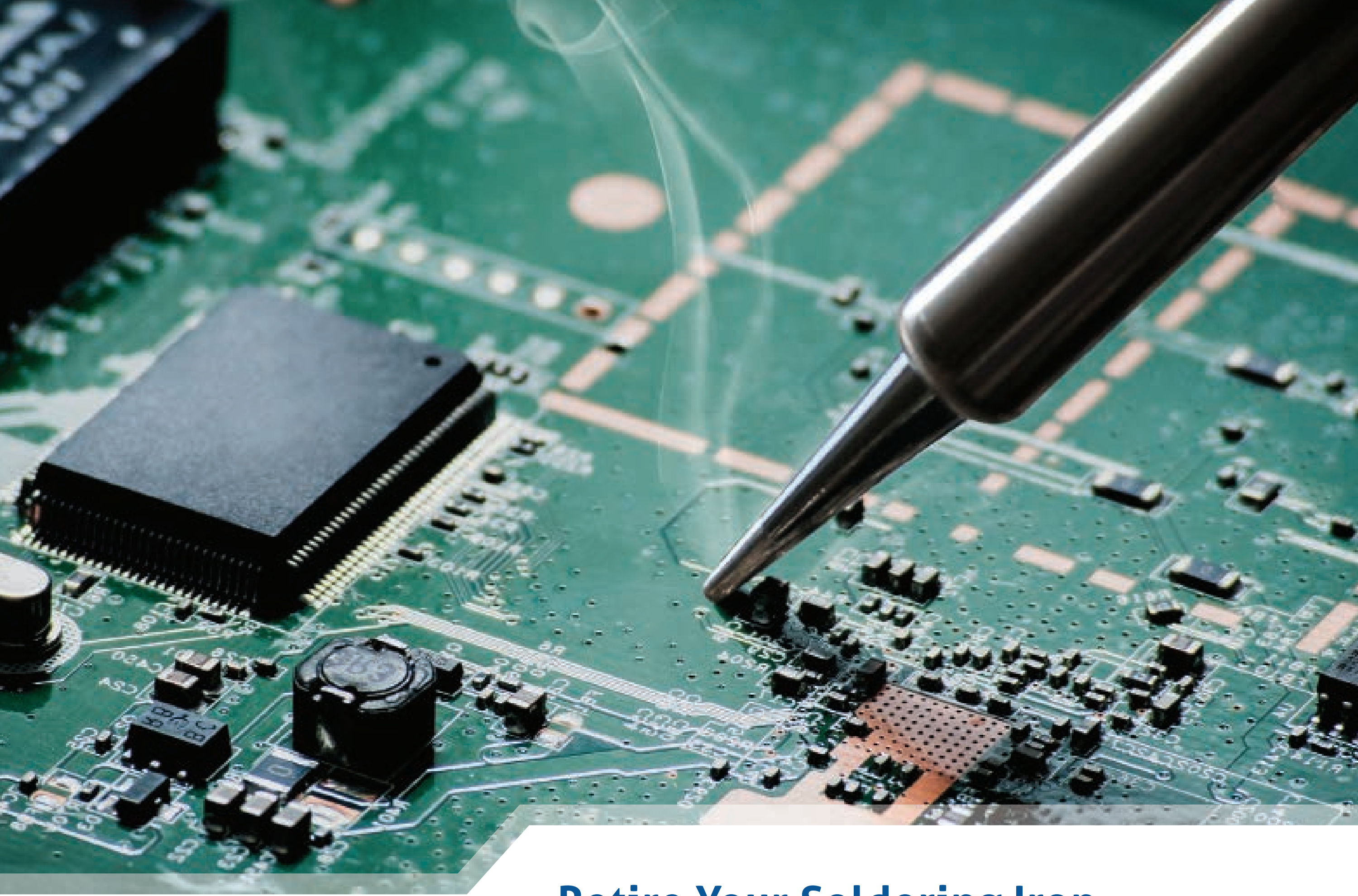
Printed circuit boards (PCB) are a building block in any electronic system. The choice of PCB material for RF applications depends on frequency, power level, circuit size and function. Designers have choices from basic epoxy/glass materials (FR-4), mid-loss materials and, ultimately, high end microwave/millimeter wave materials. The most common PCB material is FR-4, mainly developed for the mechanical properties key to multilayer circuit boards. Variations of these materials exist, offering dissipation factor (Df) or loss tangent values ranging from 0.01 to beyond 0.02 (see the tier 1 and 2 materials in ***Figure 3***). The focus of these materials has been low cost and ease of manufacturing for complex multilayer boards, with no real attention on repeatability of electrical properties, since the applications where these are used don't require that level of performance. The second set of materials use specialty resins, sometimes blended with epoxy, and achieve some improvement in loss. These materials have mainly been used in high speed digital applications up to 10 Gbps. The last group is defined as high frequency material (found in tiers 5 and 6), where the Df is less than 0.005.

Various parameters are considered in the selection process when deciding which type of PCB material to use: loss, dielectric constant, thickness, thermal conductivity and, let's not forget, cost. In the end, it is about selecting the appropriate material at the right cost. Much of the IoT market today is using traditional FR-4 in the transceiver or antenna portions of the radio. However, there is a subset of this market that requires a higher level of reliability, including industrial, medical, traffic control, automotive and smart meters. This subset is taking advantage of the higher performance materials and the increased focus on reliability that tier 5 and 6 materials can provide.

So what are the benefits of se-



▲ **Fig. 4** **Normalized dielectric constant vs. temperature.**

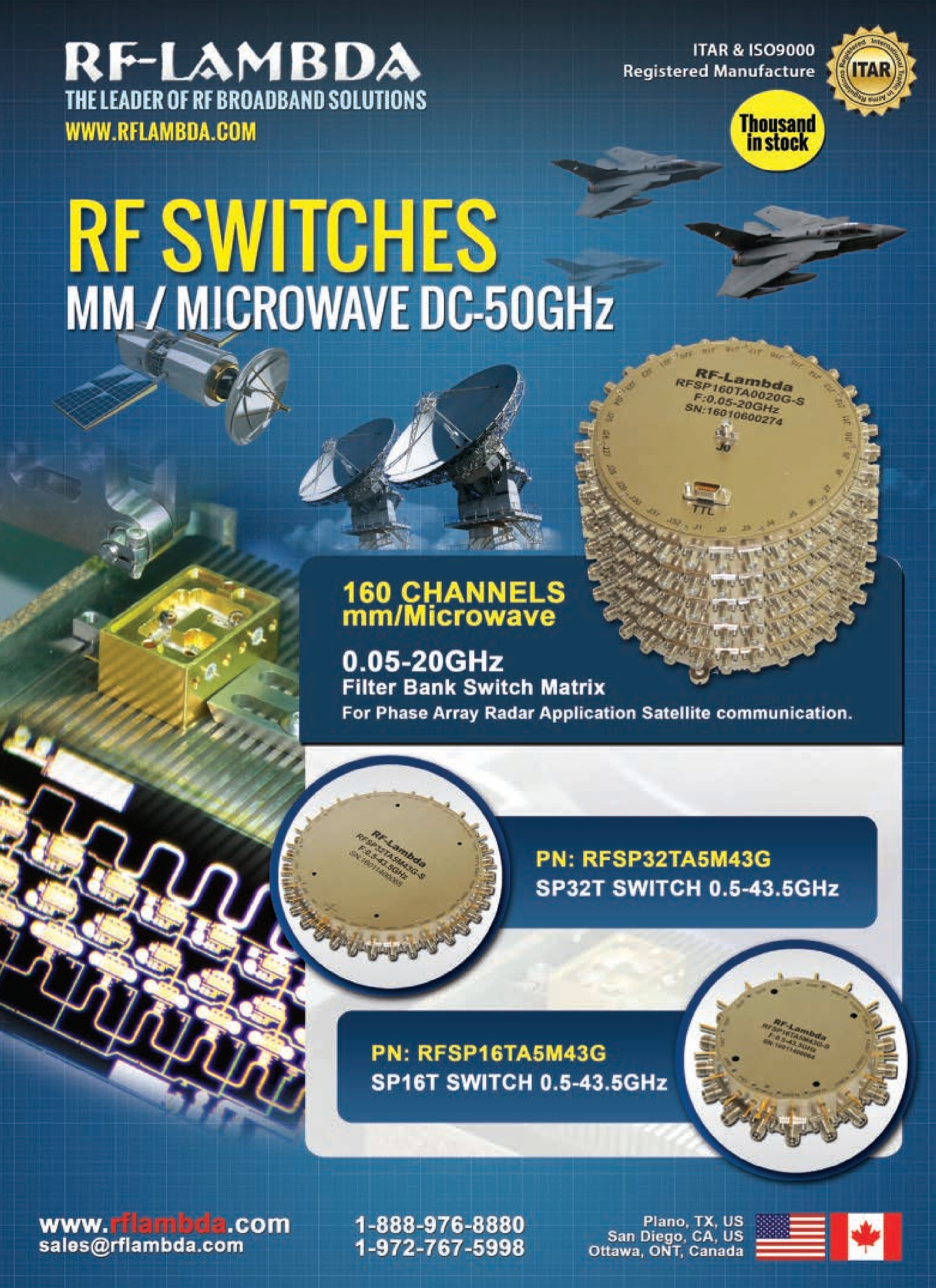


lecting a high performance material instead of FR-4? The first benefit a designer will notice is the impact loss tangent has on the loss of the circuit. Many times, this is the primary consideration. This difference can be almost an order of magnitude greater with some materials. To keep it simple — and not include in the analysis the impact dielectric constant has as Dk of FR-4 is 4.4 and many high frequency materials options are lower — consider the simulated insertion loss for a 50 Ω transmission line on FR-4, with Dk = 4.4 and a dielectric thickness of 0.020". The 50 Ω width is calculated to be 0.038".[5] Comparing the change in insertion loss when Df varies from 0.02 to 0.004 at 2.4 GHz for this line width, the insertion loss is 0.24 dB/inch for a Df of 0.02; for a Df of 0.004 the insertion loss will only be 0.01 dB/inch. The benefit here is that if the circuit is an antenna, the lower loss improves the sensitivity and will extend the range of the antenna.

In some cases, it is not the loss of the material that is the main driver for selecting a high performance material; sometimes it is the variability of the dielectric constant. Most high performance materials have a tolerance of less than ±2 percent, even less for materials with low dielectric constant, while FR-4 materials can be greater than ±5 percent. The increased variability of the FR-4 may require the circuits to be tuned to ensure they operate within the frequency specified, while materials with tighter tolerance will not need such optimization.

Environmental changes can affect the dielectric constant of FR-4, yet have minimal impact on high performance materials. FR-4 has significantly higher moisture absorption than high performance materials. This leads to an increase in Dk (also Df). If the circuit needs to operate in a high moisture environment—tropical areas such as Malaysia—FR-4 materials have been known to drift, due to the change in dielectric constant. In comparison, moisture has minimal impact on the dielectric constant of the high frequency laminates. Changes in the temperature can also have a significant impact on the operation of a circuit: with FR-4, notably, dielectric constant changes with temperature (see ***Figure 4***). The change with FR-4 is close to an order-of-magnitude higher than with the more stable materials in the figure. FR-4 can change as much as 400 ppm/°C. With materials like RO3003™ and RO4350B™ laminate, the short-term change is close to 40 ppm/°C. Considering all these factors (i.e., tolerance, moisture absorption and temperature variation), selecting a high frequency material over FR-4 may be the best choice when a more consistent design is needed in the field.

In many cases, the IoT will be about having connectivity with a circuit as small as possible, due to limited space. In these cases, reducing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the size of the antenna or circuit will be desired. By selecting materials with a dielectric constant of 6, 10 or higher, designs using FR-4 with a Dk of 4.4 can be reduced in size. Using a PCB with a Dk of 4.4, the wavelength at 1 GHz for 0.020" microstrip is about 7", while a material with a Dk of 10.2 (e.g., Rogers RO3010™ laminate), the wavelength is 4.4", close to a 40 percent reduction in size.[5] Higher dielectric constant materials allow designers to shrink the size of the circuit board, saving area compared to FR-4.

There will also be IoT applications that operate at higher frequencies, potentially in the 28 to 40 GHz range, and not necessarily on low power networks where the use of high frequency materials is a must. Managing losses is extremely important, so using materials with low dissipation factors is critical, as well as selecting copper foils that are smooth, to reduce the conductor impact on insertion loss. In the case of materials based on PTFE resin, this is often addressed by using rolled copper foil instead of traditional electrodeposited copper foil. However, for materials that use low loss thermoset resins, using smooth foil impacts copper peel strength, in many cases lowering the value to the limit specified by the industry. To address this, Rogers introduced LoPro® copper foil to go with Rogers RO4000® materials, allowing designers to reduce insertion loss while maintaining copper foil peel strength to the level of standard copper.

CONCLUSION

5G and IoT have moved from if they happen to when they happen. It is likely that the applications that will revolutionize our lives may not yet have been thought of. What we do know is that many segments in the market will be undergoing significant change during the next few years. Smart homes, smart cities, remote health care monitoring, industrial controls and autonomous driving are topics of much interest. Many of these may benefit by using higher performance materials, especially for applications that use millimeter wave frequency bands. Much is yet to be defined about 5G and IoT, and we will no doubt see surprising use cases emerge. When asked, "Why did we connect a particular thing to the internet," we may find ourselves saying "because we could."■

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Millimeter Wave Passive Bandpass Filters

Saurabh Chaturvedi, Mladen Božanic and Saurabh Sinha
University of Johannesburg, Johannesburg, South Africa

This article provides a comprehensive review of millimeter wave (mmWave) passive bandpass filters (BPF). A detailed discussion is provided on different topologies and architectures, performance comparisons, design challenges and process technologies. Passive BPFs offer the advantages of high operating frequency, good linearity, low noise figure (NF) and no power dissipation. Careful consideration of available process technologies is required for the implementation of high performance mmWave circuits. GaAs and InP (group III-V) processes provide high cutoff frequencies (fT), good noise performance and high quality on-chip passives. The CMOS process has the prominent advantages of low cost, a high degree of integration and high reliability, while the SiGe BiCMOS process demonstrates high fT, a high level of integration, and better noise and power performance.

The mmWave band of the electromagnetic (EM) spectrum spans from 30 to 300 GHz. The free space wavelength for this spectrum is in the mm range (1 to 10 mm). Worldwide availability of unlicensed frequency bands around 60 GHz makes the mmWave band very attractive for high speed wireless data transfer at multi-gigabits/second (Gbps).[1] The operating frequencies of wireless communication systems have increased rapidly with the continuous growth in communication technology. Owing to the development of mmWave transceivers, high speed data transfers through wireless local area networks, wireless home networks, and wireless personal area networks is possible.

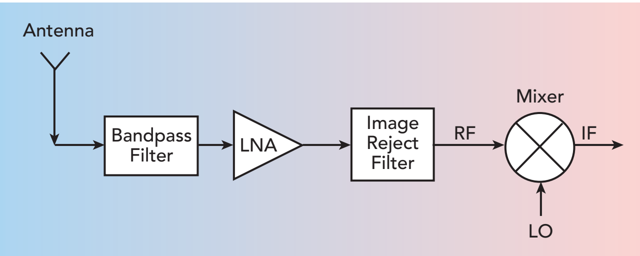


Fig. 1 A bandpass filter is typically used at the front-end of an RF receiver.

In these communication systems, filters are essential front-end components for signal selection at specific frequencies. Their electrical responses are critical for overall system performance. A BPF allows in-band signals and sufficiently rejects unwanted out-of-band signals. In a radio frequency (RF) receiver, a BPF is situated between the antenna and the low noise amplifier (LNA), as shown in ***Figure 1***.

A BPF of small size, with a high quality factor (Q-factor), low NF, low insertion loss (IL), high return loss (RL), good selectivity and high out-of-band rejection (stopband rejection) is required to improve the performance of an RF receiver. In general, systems can be divided into two categories: system-on-chip (SOC) and system-on-package (SOP). In SOC, all the functions of a complete system, including digital, analog, RF and others, are implemented in a single integrated circuit (IC). SOP, a system-level package, contains

TABLE 1 BPF CHARACTERISTICS[3]					
Filter Type	***Operating Frequency***	***Linearity***	***Noise Figure***	***Power Dissipation***	***Area***
Purely Active	Low	Poor	High	High	Small
Purely Passive	High	Good	Low	Zero	Large
Active (Active + Passive)	Medium	Poor	High	Medium	Large, But Smaller Than Passive

multiple ICs for the realization of entire system functionality. In the mmWave spectrum, monolithic ICs are preferred over hybrid ICs because of cost, size, reliability, reproducibility, design flexibility and level of integration issues. Off-chip BPFs are not suitable for modern high speed wireless transceivers because they are bulky and expensive. The elimination of off-chip components reduces the size and cost of a system; therefore, the development of new design techniques for on-chip implementation of the components previously designed off-chip is a major driving force for advanced communication systems.[2]

BPFs can be classified into three categories: purely active, purely passive and active (active + passive or semi-passive).[3] The principal advantage of purely active BPFs is small size, but their operating frequencies are low, and they also suffer from poor linearity, high NF and high power dissipation. Purely passive BPFs can be operated at high frequencies, and have good linearity, low NF and zero power dissipation, but require a large silicon (Si) area. The characteristics of active BPFs are medium operating frequencies, poor linearity, high NF, medium power dissipation and a smaller area than that of passive filters. ***Table 1*** summarizes the features of the three BPF types.

The manufacturing technologies commonly used for RF filters include MMIC, low temperature co-fired ceramic (LTCC) and printed circuit board (PCB). Various fabrication process technologies are used, including Si microelectromechanical systems (Si MEMS), GaAs, GaAs MEMS, Si benzocyclobutene (Si BCB), SiGe, integrated passive device (IPD), liquid crystal polymer (LCP) and CMOS.

GaAs and InP (III-V technologies) processes demonstrate better performance than the CMOS process because of higher breakdown voltages, higher electron mobilities, and high quality passives.[4] These processes offer high cutoff frequencies (f_T) and good noise performance. However, high cost, a low level of integration and high power dissipation are the major drawbacks of the III-V semiconductor technologies.

Low cost, a high integration density, simple fabrication steps, scaling capability and good reliability are the main advantages of the CMOS process through which digital, analog, and RF modules may be integrated in a single chip. Continuous scaling of CMOS technology has produced MOS transistors that have cutoff frequencies beyond 100 GHz. With MOSFET scaling, f_T and the maximum oscillation frequency (f_{max}) are both increased. Scaling improves the speed and noise performance of MOS transistors.

Because of the low resistivity of Si substrates (typically 10 Ω-cm) used in mmWave circuits, on-chip passive components exhibit low Q-factors and suffer from high losses in the CMOS process. Substrate and metal losses are severe issues, as well. In addition, polysilicon is used as the gate material in CMOS devices. The sheet resistance of polysilicon (approximately 10 Ω/sq) is much higher than that of metal, which consequently increases the MOSFET gate resistance. The high gate resistance can decrease MOSFET power gain

and increase noise. Noise is a severe problem in CMOS RF circuit design. By using layout techniques, the effects of the polysilicon gate can be reduced.[4] All the factors mentioned above cause degraded BPF performance in areas such as IL, RL and out-of-band rejection.

Similar to the CMOS process, the SiGe bipolar CMOS (BiCMOS) process also provides high f_T and f_{max}. In addition, SiGe heterojunction bipolar transistors (HBT) display superior noise performance and better transconductance. The SiGe BiCMOS process is the most suitable contender for low noise, low power, high density and low cost RF circuit design.

TRANSMISSION LINES AND LUMPED ELEMENTS

The size of a mmWave passive filter is smaller than that of a filter at microwave frequencies. This supports the integration of mmWave passive filters with other circuits on a single chip and helps in developing miniaturized systems at lower cost.[5]

The Q-factor of a monolithic transmission line (TL) is directly proportional to the square root of its operating frequency. Thus, with increasing frequency, the Q-factor of a TL is enhanced. Consequently, TLs are broadly used and preferred as resonators for mmWave passive filter design.[6] Below 30 GHz, passive filters based on lumped circuit elements are more compact than filters realized with TLs. Above 30 GHz, lumped elements filter implementations demand exact models and manufacturing techniques with high precision. Around and above 60 GHz, TL based implementations are more suitable for monolithic passive filter design.[7]

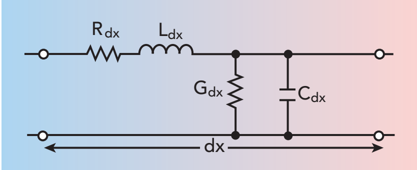
At mmWave frequencies, reactive elements required for matching networks and resonators become very small. Quasi-transverse electromagnetic (quasi-TEM) TLs are easily scalable in length and can realize small reactances. In addition, the modeling of TL based interconnects is simple. Another advantage is that their well-defined ground return path reduces electric and magnetic field coupling to adjoining structures.[4] ***Figure 2*** shows the distributed circuit model for the quasi-TEM TL. This TL can be characterized by using Equations 1-4.

$$Z_0 = \sqrt{\frac{L}{C}} \tag{1}$$

$$\lambda = \frac{2\pi}{\omega_0 \sqrt{LC}} \tag{2}$$

$$Q_L = \frac{\omega_0 L}{R} \tag{3}$$

$$Q_L = \frac{\omega_0 C}{G} \tag{4}$$

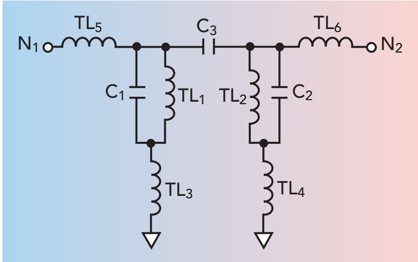


▲ **Fig. 2 Distributed quasi-TEM transmission line model.**[4]

Where R, L, G and C are the resistance, inductance, conductance and capacitance per unit length, respectively; Z_0 and λ are the characteristic impedance and signal wavelength for a lossless (R = G = 0) TL; ω_0 is the resonant angular frequency; Q_L is the inductive quality factor and Q_C is the capacitive quality factor. TLs on conductive Si substrate have low values of Q_C because of the effect of substrate coupling, while Q_L is the most crucial parameter for determining T_L loss.

In recent years, many efforts have been made to implement mmWave lumped passive filters. A number of integrated miniature mmWave lumped BPFs are available in literature. BPFs with spiral inductors and metal-insulator-metal (MIM) capacitors are realized by Dehlink et al.,[8] and Lu et al.[9] BPF design using interdigital capacitors is reported by Vanukuru et al.[10] For the realization of very small capacitance values, interdigital capacitors are preferred. Compared to interdigital capacitors, MIM capacitors have lower Q-factors owing to high dielectric

TABLE 2		
MIM AND INTERDIGITAL CAPACITOR CHARACTERISTICS		
Feature	**MIM Capacitor**	**Interdigital Capacitor**
Q-Factor	Low	High
Process Steps	More	Less
Cost	High	Low
Area	Small	Large



▲ **Fig. 3** Miniaturized CMOS passive BPF with a planar π-filter configuration BPF.[9]

losses at mmWave frequencies. Since filters with interdigital capacitors do not involve MIM processing, process cost can be significantly reduced. Nonetheless, the area of a MIM capacitor is much smaller. Because of the larger size of an interdigital capacitor, associated parasitic inductances are increased, which affect device performance.[10] ***Table 2*** summarizes the comparison between MIM and interdigital capacitors.

PASSIVE BPF TOPOLOGIES

The topologies of mmWave passive BPFs reported in the literature include coupled-line,[2,11] ring resonator[12,13] and stepped impedance resonator.[14,15] The planar π-filter configuration has shown the advantage of bandwidth (BW) insensitivity to layout and substrate thickness variations for different processes, such as PCB,[16] GaAs substrate,[17] and Si substrate.[18] This configuration, therefore, displays a larger design margin. However, there are two drawbacks to the planar π-filter structure: a relatively large area and difficulty in SOC integration. These disadvantages can be avoided by using compact microstrip line (MSL) inductors.[9] ***Figure 3*** shows the schematic of a CMOS passive BPF with a planar π-filter configuration. Miniature on-chip MIM capacitors and MSL inductors are used for realizing the miniaturized BPF.

The performance parameters of previously published passive BPFs are compared by several authors.[2, 6,

TABLE 3					
mmWAVE BPF PERFORMANCE COMPARISON					
Reference	**Process Technology**	**f_c (GHz)**	**3 dB BW (%)**	**IL (dB)**	**Chip Area (mm^2)**
22	Si MEMS	60	8	1.5	22.8
22	Si MEMS	60	2.7	2.8	22.0
22	Si MEMS	60	4.3	3.4	26.0
23	Si BCB	50	5	4.6	12.2
23	Si BCB	94	5	7.0	3.9
24	LTCC	60	3.5	4.0	6.3
25	LTCC	60	4.1	2.8	4.0
8	SiGe	77	15.5	6.4	0.01
2	0.18 μm CMOS	60	10	9.3	0.14
2	0.18 μm CMOS	77	10	9.3	0.11
12	0.18 μm CMOS	64	18.75	4.9	1.71
9	0.13 μm CMOS	60	18.28	2.55	0.085
14	0.18 μm CMOS	66	18.05	3.1	0.074
14	0.18 μm CMOS	61	18.03	3.5	0.074
26	GaAs	58	15	3.4	4.0
27	IPD	62	19.35	2.3	0.49
28	IPD	77	8.3	2.46	3.36
29	LCP	65	12.3	3.0	4.88

[9, 10, 19-21] *Table 3* summarizes the performance of various mmWave passive BPFs, where f_c is the center frequency. The 3 dB BW is also known as the 3 dB fractional bandwidth (FBW) as defined in Equation 5.

$$3\,\text{dB BW}(\%) = \frac{BW}{f_c} \times 100 \qquad (5)$$

Passive filters have a significant drawback of high loss. The Q-factor of a passive resonator is degraded owing to ohmic (metal), dielectric and radiation losses. The bulky structure of passive waveguide filters increases the size of the fully integrated transceiver module. Passive planar filters are small in size but suffer from losses.

Other critical drawbacks associated with passive filters include incompatibility with tunable elements and the trade-off between BW and IL. Various limitations and design challenges of mmWave passive BPFs in CMOS process are analyzed and explained by Mouthaan et al.[21] In the literature, no CMOS passive filter has been reported with 3 dB FBW below 10 percent or above 65 percent. Filters with FBWs below 20 percent experience high losses. Therefore, the realization of narrowband passive BPFs with low IL is a crucial design challenge. Another design challenge is the implementation of passive filters with high out-of-band rejection levels.

CONCLUSION

This review discusses the merits, demerits, design techniques, topologies and design challenges of mmWave passive BPFs. The salient shortcomings of on-chip passive BPFs include high loss and a trade-off between BW and IL. Various process technologies for the implementation of mmWave filters are also discussed and compared in detail. This review should help researchers to identify the gaps and provide motivation for future development in the area of mmWave filter design.■

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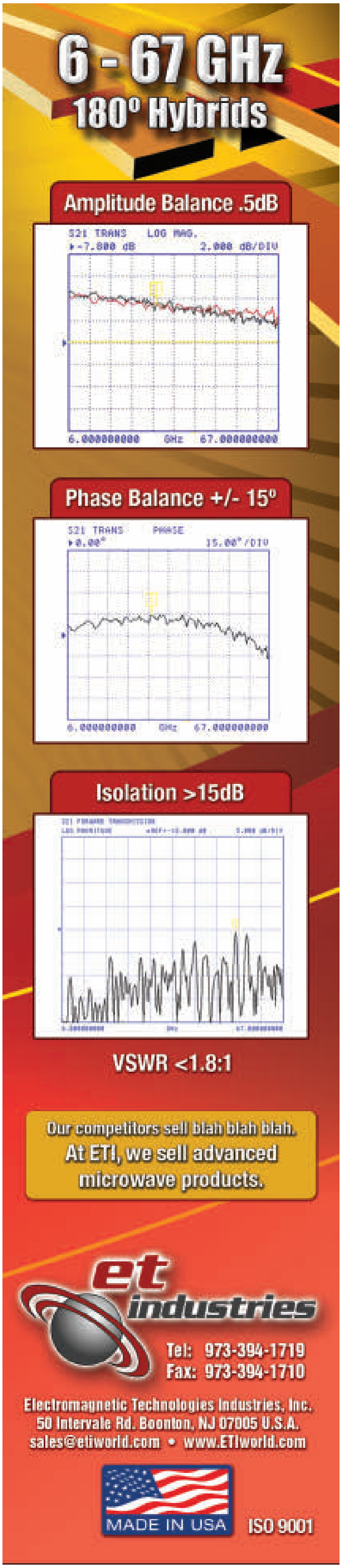

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Saurabh Chaturvedi *(MIEEE) completed his B.Tech. in Electronics and Communication Engineering (ECE) at the Jaypee Institute of Information Technology (JIIT), NOIDA, India (2001-2005). He obtained the M.Tech. degree in VLSI Design from the Centre for Development of Advanced Computing (CDAC), NOIDA (2006-2008). He then worked with the SPB R&D group of Cadence Design Systems, NOIDA (2008-2009). In July 2009, Saurabh became a faculty member in the ECE Department of JIIT and taught at undergraduate and postgraduate levels. He joined the University of Johannesburg (UJ), South Africa in May 2015, and is currently working towards his Ph.D. degree in electrical and electronic engineering. His current research is focused on mmWave IC design.*

Mladen Božanic *(SMIEEE) obtained his B.Eng. and Ph.D. degrees in electronic engineering from the University of Pretoria (UP), South Africa. In 2008, he joined Azoteq, a fabless IC design company originating in South Africa where he has been responsible for the silicon-level design, simulation and characterization of various analogue, RF, digital and mixed-mode circuits. He is also playing the role of a design for testability (DFT) engineer. He is currently with the University of Johannesburg (UJ), serving as a senior research fellow, where his areas of interest include RF, microwave and mmWaves. He is an author or co-author of over 10 peer-reviewed journal and conference articles, one book and one book chapter.*

Saurabh Sinha *(SMIEEE, FSAIEE, FSAAE) obtained his B.Eng., M.Eng. and Ph.D. degrees in electronic engineering from the University of Pretoria (UP), South Africa. Prof. Sinha served the UP for over a decade, with his most recent service as director of the Carl and Emily Fuchs Institute for Microelectronics, Department of Electrical, Electronic and Computer Engineering. On 1 October 2013, Prof. Sinha was appointed as executive dean of the faculty of engineering and the built environment (FEBE) at the University of Johannesburg (UJ). As a published researcher, he has authored or co-authored over 75 publications in peer-reviewed journals and at international conferences, and is the managing editor of the South African Institute of Electrical Engineers (SAIEE) Africa Research Journal.*

INVITED PAPER

Addressing The Challenges Facing IoT Adoption

Kailash Narayanan
Keysight Technologies, Santa Rosa, Calif.

The Internet of Things (IoT) phenomenon—ubiquitous connected things providing key physical data and further processing of that data in the cloud to deliver business insights—presents a huge opportunity for many players in electronics and software, including chipset vendors, device developers, OEMs, manufacturers, equipment vendors, network operators and end-to-end solutions providers. Many companies are organizing themselves to focus on IoT and the connectivity of their future products.

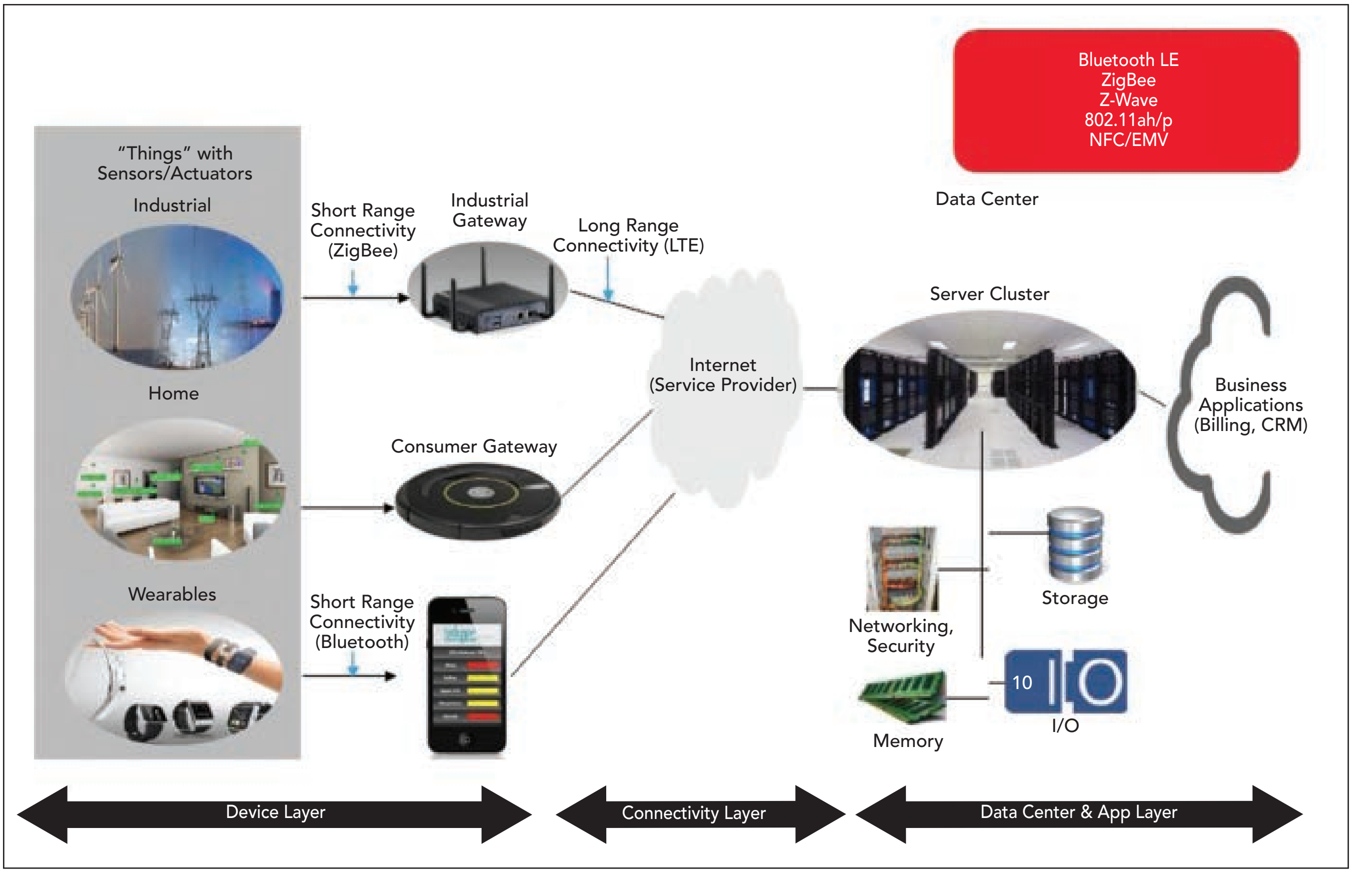
CHALLENGES

For the IoT industry to thrive, three items are crucial: a viable business model, a robust connectivity topology and reliable devices. This article discusses these, focusing on the design challenges that must be overcome to make reliable devices. Challenges vary depending on the IoT application. While cost is a major factor in consumer applications (e.g., wearables and home automation), industrial IoT applications (e.g., smart grids, connected cars and transportation) require unfailing reliability, longevity, security and the ability to operate devices with little or no human intervention.

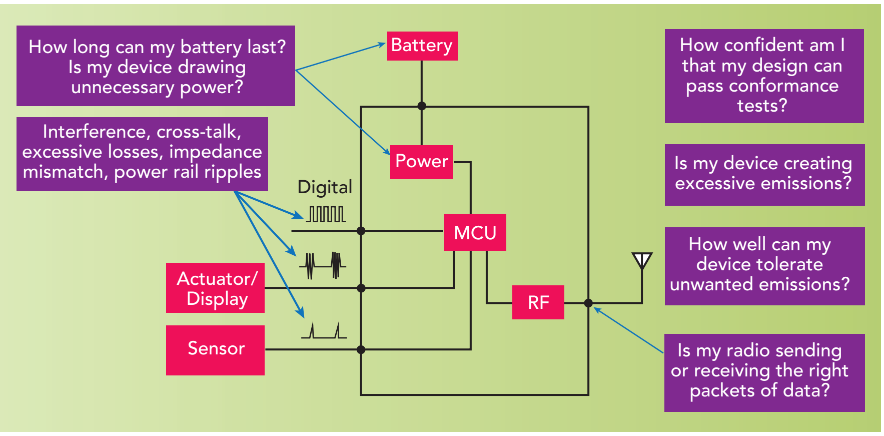
The Business Model

End-to-end solution providers operating in vertical industries and delivering services using cloud analytics will be the most successful at monetizing a large portion of the value in IoT. Low power, wide area (LPWA) IoT technologies open up possibilities for service providers. Knowing the location of pets and vehicles, tracking valuable personal belongings, monitoring utility usage, obtaining real-time data on the health of crops and livestock, employee fatigue and machine status are useful for individuals and businesses.

A typical smartphone contract delivers roughly five cents per MB of data. Assuming an IoT application uses 100 KB per month, and a user is willing to pay a modest 10 cents per month for these new IoT applications, that's already better business for



▲ **Fig. 1** Simplified IoT topology.



▲ **Fig. 2** Device challenges reflect performance and power consumption.

an operator. Delivering $1 per MB is 20x more revenue than a typical smartphone contract for the same amount of data consumption. While many IoT applications may attract modest revenue, some can attract more than $10 per month. For little burden on the existing communication infrastructure, operators have the potential to open up a significant source of new revenue using LPWA technologies. Clearly, it is important to understand the value chain and business model for the IoT application.

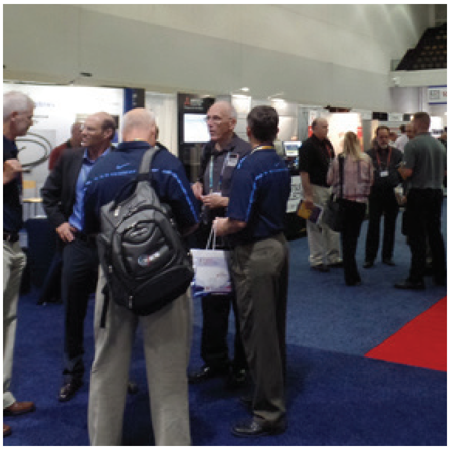
Connectivity Topology

Figure 1 shows a simple IoT network model, consisting of a device layer containing "things" with sensors and actuators that capture or initiate physical events. These connect to gateway devices using short-range wireless links, and the gateways communicate to the cloud via wide-area networks, such as LTE.

Across a variety of vertical industries, the realization of IoT networks will involve a heterogeneous mix of wireless technologies, including NB-IoT, Cat-M, Z-Wave, ZigBee, SIGFOX, LoRa, ANT, Thread, Wi-SUN, Bluetooth and Wi-Fi. Individually and collectively, these pose special challenges such as power dissipation, transmission range, data rates, seamless connectivity, handshake protocols, security and radio compliance. This diversity in deployed technologies presents a significant opportunity and challenge for the entire IoT industry. Modern microcontrollers make it possible for machine learning to run on even the lowest power devices at the edge of the network, to respond to sensor data and send triggers when actionable events take place. Connectivity topology becomes more interesting with distributed machine learning, analytics and intelligence in gateways and end nodes making more efficient use of bandwidth.

Reliable Devices and Design Challenges

IoT devices present many design challenges, some similar and many



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different than with smartphones. Developers must overcome constraints from battery drain, power, signal integrity and the complexities of the RF chain. LPWA technologies such as NB-IoT are governed by 3GPP, which requires RF conformance testing before being deployed on networks. Interference and coexistence must also be verified.

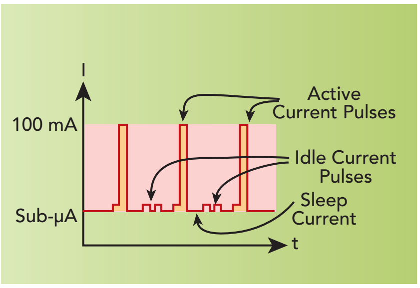
The following sections dive deeper into each of these design challenges to producing reliable devices (see ***Figure 2***).

BATTERY DRAIN

Optimizing and guaranteeing power consumption is a requirement for many IoT devices. In some installations, multiple years of battery life may be committed through a service level agreement (SLA) contract. A software update could use months of battery capacity, and too many "over the air" updates to resolve defects and security issues could compromise battery life. Network settings and handshake protocols between the device and the network can also reduce battery life significantly. What happens if the network is down? Does the device search repeatedly for the network and drain the battery?

For IoT devices, the active state —when the device is transmitting or receiving data—is very short compared to idle and standby states. Measuring the current consumption is key to understanding and optimizing the power consumption. ***Figure 3*** illustrates the different device operating states and the resulting current drain, likely a ratio of 1:1,000,000, from sub-µA to 100 mA. For example, in transmit, Bluetooth low energy transmitters use tens of mA compared to a few A for GSM transmitters. The majority of the time, devices are in idle mode, drawing from tens to hundreds of nA up to hundreds of µA.

Because IoT devices have very low duty cycles, a common way to lower the total current drain is to design the system so the device has a very short active state followed by periods of relatively low activity or no activity. The challenge in verifying the likely battery life is to accurately measure the dynamic current drain across the different operating modes over a period of time and with a single view that provides a complete and detailed analysis.



▲ **Fig. 3 Device current consumption varies with operating mode.**

RADIO FORMATS

With many types of devices deployed in consumer and industrial applications (e.g., smart grid, smart energy, smart factories and smart homes), many IoT formats are being deployed and many operate in the same spectrum (e.g., Wi-Fi, Bluetooth and ZigBee). These environments will affect multi-radio interference (co-channel or adjacent channel), transmission range and speed, and interoperability. All must be considered.

NB-IoT, Cat-M and other LPWA technologies use narrow bandwidths to connect to IoT/M2M devices, resulting in lower data rates and low power. Thread is a secure wireless mesh network for home and connected products; based on the 802.15.4 physical and MAC layers it enables the gateway to easily control connection to the cloud. Bluetooth has been the most commonly used format for consumer electronics and is often used around the smartphone and near field communication (NFC) for payments. Wi-Fi is a foundational technology that is used wherever possible. LPWA formats like LoRa and SIGFOX are opening up new applications. Many other technologies such as ZigBee, ANT and Z-Wave are being used for home automation.

With all these technologies, the radio design has to be optimized for data rates and sensitivity. Good RF transceiver and antenna design are needed to achieve deep in-building coverage, as making a receiver work hard to decode a weak signal further reduces battery life.

POWER AND SIGNAL INTEGRITY

The increased demand for expanded functionality in a small form factor drives the need for higher density, lower power and compact circuit design. Maintaining signal integrity and power integrity becomes more challenging as traces get closer together and supply voltages are lowered.

Common signal integrity issues that can degrade overall system performance include reflections, excessive losses, crosstalk, distortion and power supply noise. Power integrity speaks to how effectively the power is converted and delivered from the power source to the load within the device. With the drive toward low power electronics, DC supply voltages and tolerances have been reduced, some from ±5 percent to ±1 percent. Ripple, noise and transients riding on the output power rails can adversely impact the clock and accuracy of digital data. Designers need a power integrity solution that can measure these low DC voltages with high accuracy.

CO-EXISTENCE AND CONFORMANCE

IoT devices may be integrated into products and gateways that include a variety of different standards operating over a range of frequencies. Each radio and device type will need to meet a specific set of downstream acceptance tests. Cellular devices need to pass certification tests from standards bodies, and many operators have their own acceptance test plans. All devices must pass regulatory testing that depends on frequency band and region. Many system integrators run their own acceptance tests to select modules in their systems. So designers need to ensure that interference and intermodulation effects are anticipated, understood and tested.

SECURITY

IoT devices at the edge of the network increase the security vul-

nerability of networks. Yet devices don't have the needed resources to host sophisticated security protocols. The capability for remote software updates needs to be designed into the device to allow for security updates, which has implications on battery life. Authentication and cyber security features need to be tested and upgradeable. The most secure development approaches available today are likely to be compromised in the coming years, so security patches should be anticipated. In the future, security will likely be built into these devices.

CONCLUSION

IoT is likely to be a significant enabler of many disruptive business models and market efficiencies. Recall how the internet and players like Amazon, eBay and Uber have and are transforming markets. Peer-to-peer banking, personalized car insurance, personalized health insurance and crowd-sourced businesses are emerging. IoT devices for ordering convenience will lead to more services on top of products. These new business models and services rely on networks of sensors and actuators, linked by radio and connected to the cloud for data analytics. For these big connected sensor systems to work well, even the smallest of components must be secure, stable and reliable.■

Kailash Narayanan *is vice president and general manager at Keysight Technologies, where he leads the wireless device business and is responsible for product and solution development, marketing and delivery to the wireless device ecosystem. His current focus is 5G and IoT. He received a master's in electrical engineering from the University of Illinois, Chicago and an MBA from Walden University.*

Accurate 40 GHz RMS Power Detector

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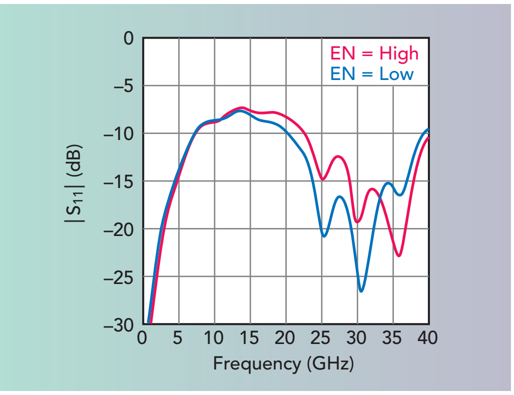

▲ **Fig. 1** Input return loss vs. frequency.

- 50 Ω impedance, without any external matching components (see ***Figure 1***).
- 35 dB linear-in-dB dynamic range, with ±1 dB accuracy over the industrial (I) case temperature range from -40° to +105°C. The high temperature limit can be extended to +125°C with the H-grade version.
- High output, capable of driving 50 Ω loads.
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- ESD ratings of 3.5 kV human-body model (HBM) and 1.5 kV charged-device model (CDM), easing handling in manufacturing environments.

By their nature, root mean square (RMS) power detectors are well-suited to accurately measure the average power of arbitrary waveforms. This is because such devices precisely implement the definition formula for average power, i.e., proportional to the average of the squared signal. Other types millitech

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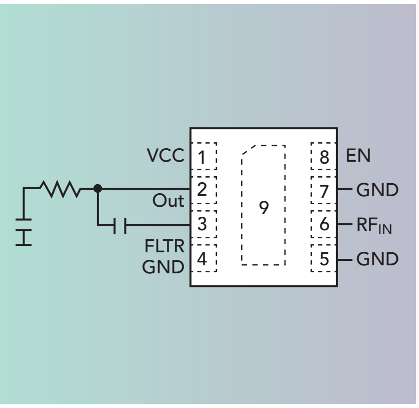
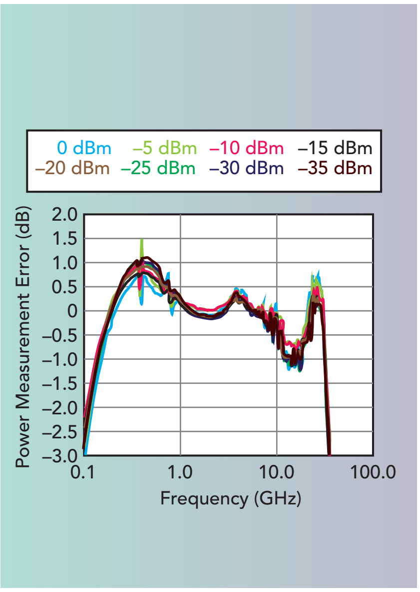
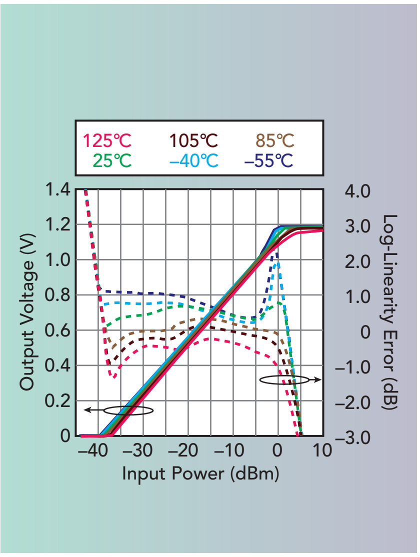


▲ **Fig. 2 LTC5596 pinout and interface connections.**



▲ **Fig. 3 Detector response vs. frequency and input power, relative to 5.8 GHz.**



▲ **Fig. 4 Output voltage vs. input power and temperature at 30 GHz, with linearity error relative to an ideal transfer curve at 25°C.**

of power detectors, such as Schottky diode detectors or demodulating logarithmic amplifiers, implement slightly different operation that often involve the signal envelope. Their response changes whenever the input waveform—but not the average power level—is changed. Modern communication systems use complex modulation (e.g., OFDM, WCDMA), with high PAPR signals. These systems adaptively adjust the modulation and coding based on the quality of the radio link, resulting in literally thousands of different waveforms with greatly varying PAPRs. In such an environment, achieving the required power measurement accuracy (typically ±1 dB) with a non-RMS power detector can usually only be achieved with extensive and laborious calibration and a prior knowledge of the type of waveform received. With the LTC5596 RMS power detector, such calibration is typically no longer necessary for signals up to Ka-Band.

The ground-signal-ground configuration of the RF input (see ***Figure 2***) is designed to interface seamlessly with a coplanar grounded waveguide on a 5-mil thick RO3003 or similar substrate, without needing any external matching components. The response of the LTC5596 hardly changes over a wide input frequency range. This minimizes the need for calibration of the response at different frequencies. As shown in ***Figure 3***, the measurement error due to the frequency response relative to 5.8 GHz is less than ±1 dB from 200 MHz to 30 GHz.

In many applications, the power levels of RF signals are typically specified on a dB scale. One motivation for this is that transmission path loss is approximately linear in dB vs. distance. The LTC5596 generates a (DC) output voltage proportional to the average power level (i.e., the RMS signal level) in dBm at its input port. The response is also very stable over a wide operating temperature range, with typically less than ±1 dB error over the full operating temperature range (see ***Figure 4***).

At any point within the LTC5596's dynamic range from -37 to -2 dBm, a 1 dB change in input power results in a 29 mV change of the output voltage. Diode-type detectors or linear-in-volt power detectors, for example, produce a much smaller output signal change for a 1 dB power step at low input power levels vs. high power levels. This makes it very difficult to achieve accurate power measurements over the full dynamic range. By connecting an analog-to-digital converter (ADC) to the LTC5596 output, a digital representation with constant and high resolution across the entire dynamic range of the measured power can be obtained.

The LTC5596 also provides a simple means to apply additional filtering to the output signal, which is useful to reduce residual high frequency ripple and noise. The bandwidth of the output driver amplifier inside the device can easily be reduced with a single capacitor connected between OUT and FLTR (see Figure 2), without compromising the current drive capability. A few tens of pF capacitance is typically sufficient. Alternatively, a filter can be connected to the OUT interface of the device. The high output capability of the LTC5596 drives a wide range of impedance levels without changing power measurement accuracy. The LTC5596 is well suited for low duty-cycle applications, where the device is active only for a small fraction of the time. The output interface becomes a high impedance during shut down, which minimizes the discharge of large capacitors in an output filter and ensures fast settling once the device is enabled again.

The LTC5596 is offered in a small 2×2 DFN-8 package in I-grade (-40° to +105°C case temperature) and H-grade (-40° to 125°C case temperature). The H-grade also has tighter limits guaranteed for the logarithmic slope and intercept parameters, which simplifies or even eliminates the need for factory calibration.

VENDORVIEW

Linear Technology Corp.
Milpitas, Calif.
www.linear.com

Small, RF Monitoring and Detection Receivers

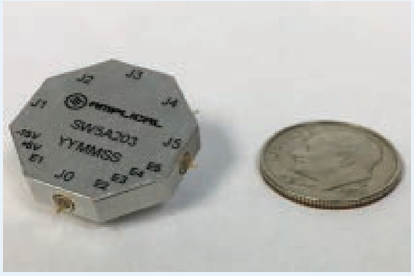
DRS Technologies, Inc. has introduced a new family of small, high performance RF monitoring and detection receivers for U.S. military, intelligence agency and commercial spectrum monitoring. Providing a significant advancement in RF performance with a modular, open system architecture, the Vesper family can be configured with up to 10 RF channels—either receive or transmit—in a single slot, 1" pitch, 6U VPX module. The modular design is an advantage compared to proprietary solutions that hinder upgrades over the system's lifecycle.

The current instantiation of Vesper accepts nine blind-mate antenna inputs, each feeding a receiver channel covering 2 MHz to 6 GHz. Each receive channel down-converts the incoming RF signal to IF, with up to 100 MHz bandwidth. The raw output data from the analog-to-digital converter feeds a field-programmable gate array for time stamping, digital down-conversion, filtering, decimation and packetization. Data is formatted per the VITA 49 VRT standard for transport using the Aurora protocol. Other transport protocols, including 10GigE, and PCIe Gen 2/3, will be available.

The current product instantiation also includes one exciter channel, covering 2 MHz to 6 GHz with 100 MHz of instantaneous bandwidth. Input data should be formatted using the Aurora data transport protocol. Additional Vesper configurations are available.

The Vesper synthesizers have low phase noise with fast tuning and rapid phase settling. To extend application possibilities, the channels within a VPX card or between multiple VPX cards can be operated independently or, when tuned to the same frequency, will be phase coherent.

DRS Technologies, Inc.
Germantown, Md.
www.drs.com/Vesper



Drop-In, 2 to 18 GHz, SP5T PIN Diode Switch

Amplical Corp.'s family of competitively priced, high performance, broadband PIN diode switches feature low insertion loss, low VSWR, high isolation and fast switching speed. The SW5A203 is an absorptive, SP5T switch that covers 2 to 18 GHz. All five RF ports are terminated in 50 Ω when switched to the off state, and all include DC blocks.

Maximum insertion loss is 3.7 dB, maximum VSWR is 2:1 and the minimum isolation is 60 dB below the insertion loss. OIP3 is 45 dBm minimum, with an OIP2 of 75 dBm minimum. Switching speed is 75 ns maximum for turning on (from the 50 percent point on the TTL signal to the 90 percent point on the RF signal) and 45 ns for turning off (from the 50 percent point on the TTL signal to the 10 percent point on the RF signal). RF rise time is 25 ns maximum (from 10 to 90 percent), and the fall time is 15 ns maximum (from 90 to 10 percent).

An on-board driver provides a TTL-compatible interface for logic control. The SW5A203 operates from +5 and –12 to –20 V DC. The switch is packaged in a compact octagonal form factor measuring 0.8" across and 0.17" high, designed for drop-in microstrip or stripline applications. Four #0-80 x 0.10" threaded holes are provided for chassis mounting.

Additional frequency ranges, configurations and features are available, including SPST through SP4T and hi-rel screening.

Amplical Corp.
Whippany, N.J.
www.amplical.com
(973) 386-1119

CatalogUpdate

Test & Measurement Catalog

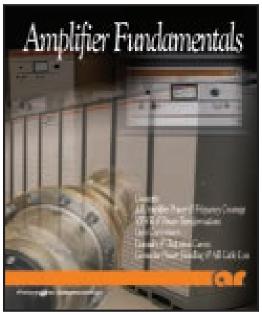
VENDORVIEW

Aaronia AG released a new 12-page short form catalog. The catalog features Aaronia's full lines of test & measurement products like the real-time spectrum analyzers (1 Hz to 20 GHz with up to 1.4 GHz real-time bandwidth), EMC and direction finding antennas (1 Hz to 40 GHz), RF drone detection systems (counter-UAV) and portable signal generators up to 6 GHz. Made in Germany, Aaronia products are known worldwide for their affordability and high quality. Visit Aaronia's website at www.aaronia.com for a free download and more information.

Aaronia AG
www.aaronia.com

Amplifier Fundamentals Poster

VENDORVIEW

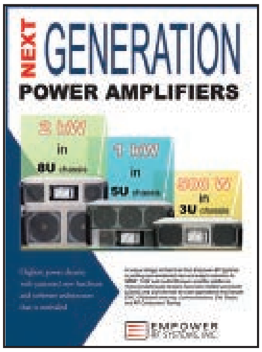


Request your free copy of AR's new Amplifier Fundamentals poster. This reference poster includes all you need to know about linearity & distortion curves, gain conversions, VSWR & power transformations, modulation and more. Download an electronic version or contact AR for a hard copy. Most AR RF/Microwave Instrumentation products support radiated and conducted immunity testing including IEC, automotive, aviation and military susceptibility specifications as well as medical test requirements.

AR RF/Microwave Instrumentation
http://bit.ly/amplifierfundamentals

Next Generation Power Amplifiers

VENDORVIEW

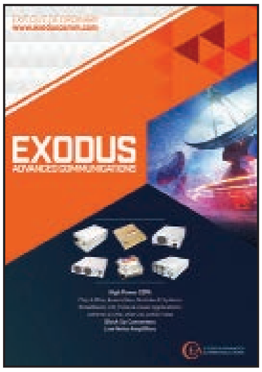


The most technologically advanced COTS RF amplifier is available from Empower RF featuring user selectable RMS, peak and pulse detection on both the input and output enabling automatic gain control (AGC) and automatic level control operation. Download Empower RF's Next Generation brochure to read more about this future proof architecture at www.empowerrf.com/download/. These breakthrough designs have been fielded using both LDMOS and GaN devices for user applications that include EMC/radiated immunity, communications, EW, radar and RF component testing.

Empower RF Systems Inc.
www.empowerrf.com

Solid-State Amplifiers

VENDORVIEW



Exodus Advanced Communications announced the release of a new catalog featuring the company's newest solid-state amplifiers developed with the latest in LDMOS, GaN and GaAs FET discrete devices and hybrid chip and wire on ceramic substrate technologies. Exodus' capabilities include frequency ranges from 10 KHz to 47 GHz and power levels exceeding 1 kW for modules and 10 kW for systems. New amplifiers are constantly being introduced between catalog releases. Visit www.exodus-comm.com to see the latest.

Exodus Advanced Communications
www.exoduscomm.com

Antenna Catalogue

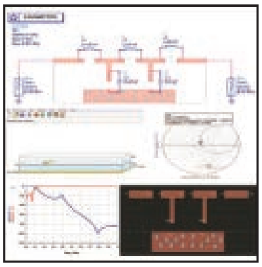
VENDORVIEW

Huber + Suhner's new antenna catalogue provides a complete list of their antenna portfolio. The first few pages provide a summary of the various antenna ranges. This overview also acts as a table of contents and makes the catalogue easy to use. The main technical parameters of the antennas are visible at a glance. Detailed information about the various antennas is available in datasheet form. Directional diagrams are also available on the company website at www.hubersuhner.com.

Huber + Suhner AG
www.hubersuhner.com

ADS Example Book

VENDORVIEW



This collection of demonstration guides for Keysight's Advanced Design System (ADS) provides step-by-step screenshots that help users get started using Keysight ADS without assuming any prior experience. After completing these demos, you will be able to: build your own electromagnetic simulation (EM), use the ADS built-in Smith Chart for impedance matching and learn how to work with the ADS 3D substrate viewer to construct your substrate layers. Download a free PDF at www.keysight.com/find/eesof-ads-rfmw-examples.

Keysight Technologies Inc.
www.keysight.com


DELTA
Electronics Mfg. Corp.
Interconnect Solutions
Create
Collaborate
Connect
ARROW | Aerospace & Defense
A.E. Petsche Co.
SMP & SMPM
High Performance
Connectors to 65 GHz
"Fully customizable cost effective solutions"
Distributed by A.E. Petsche Co.
A Delta Channel Partner
contactAEP@aepetsche.com
www.aepetsche.com
(844) AEP-7600
(844) 237-7600

CatalogUpdate

Hot New Products

VENDORVIEW

This new 24-page product guide provides a complete survey of the hottest Mini-Circuits product releases from the second quarter of 2016. Highlights include everything from ultra-wideband MMIC splitter/combiners, MMIC mixers and MMIC multipliers to their revolutionary reflectionless filters, ultra-sharp cavity bandpass filters, high-power stripline couplers and new portable USB/Ethernet test and measurement devices. Mini-Circuits is continuously innovating new products to meet your needs, and this informative product guide will help you stay up-to-date with their latest model releases.

Mini-Circuits
www.minicircuits.com

RF Product Guide

VENDORVIEW

Pasternack released their new 2017 RF Product Guide containing thousands of in-stock products including greatly expanded portfolios of RF amplifiers, PIN diode and electromechanical switches, waveguide components, as well as the industry's largest selection of passive, active, interconnect and test & measurement components, all available for same-day shipping worldwide. The new catalog also features newly designed product selection guides as well as other useful charts and resources, making this a very helpful desk-reference tool. Visit www.pasternack.com to request your copy today.

Pasternack
www.pasternack.com

Rotating Solutions

VENDORVIEW

SPINNER is one of the world's leading producers of high-performance rotary joints. Fiber optic rotary joints (FORJ) in particular call for extreme exacting assembly of all optical and mechanical components in clean room environments. And SPINNER provides both from a single source. SPINNER supplies combinations of fiber optic rotary joints with RF rotary joints, contactless power transmission modules, slip rings, multimedia joints and contactless data transmission. The company's specialties also include integrated data and power transmission solutions with a small form factor.

SPINNER GmbH
www.spinner-group.com

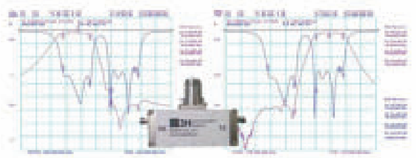
NEW PRODUCTS

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

COMPONENTS/DEVICES

Miniature LTE Duplexers

VENDORVIEW



3H's new miniature LTE duplexers and filters offer low insertion loss and high selectivity with >50 dB co-channel isolation. The miniature LTE duplexers and filters are power rated for 10 W CW with other power levels available. Package sizes vary with LTE frequency bands. Contact 3H Communication Systems at (949) 529-1583 or email sales@3hcomm.com.

3H Communication Systems
www.3Hcommunicationsystems.com

Failsafe SPDT Switch

Guerrilla RF Inc. introduced the GRF6011, the first member of the company's growing list of failsafe switch and amplifier devices. Failsafe refers to the characteristic whereby one switch path defaults to a low loss state, when all power is removed. A key application for this single-pole, double-throw (SPDT) switch is at the low noise amplifier (LNA) in a tower mounted amplifier (TMA), where this failsafe functionality is typically implemented using expensive mechanical relays or cumbersome Schottky diode switches external to a traditional LNA device.

Guerrilla RF
www.guerrilla-rf.com

Notch Filter

K&L Microwave, part of the Microwave Products Group, has developed a new Band 5 wireless notch filter to protect the 800 MHz public safety band from LTE Band 27 interference and emissions. The high Q design of part WSN-00418 provides minimal insertion loss in the two passbands (0.5 dB max. from 817 to 824 MHz, 1.25 dB max. from 862 to 863 MHz, and 0.6 dB max. from 863 to 869 MHz) and features steep roll-off to reject unwanted frequencies.

K&L Microwave
www.klmicrowave.com

Dual Directional Coupler

VENDORVIEW

MECA announced its latest addition to their extensive line of stripline couplers with the 785-dB-9.700, covering 7 to 12.4 GHz. Available in 10 and 20 dB models with SMA female connectors, optimized for excellent performance with industry leading specifications offering typical VSWRs ranging from 1.30:1, isolation of 20 dB typical. Made in the U.S. and 36-month warranty.

MECA Electronics Inc.
www.e-MECA.com

YIG-Tuned Band Reject Filters

Micro Lambda Wireless Inc. announced the production release of YIG-tuned band reject filters with 50 dB notch depths at 500 MHz and 60 dB notch depths starting at 2 GHz. Standard models cover 500 MHz to 2 GHz, 2 to 6 GHz, 6 to 18 GHz and 2 to 18 GHz. The standard model operates over the 0 to +65°C temperature range, but Military versions covering -40° to +85°C are available on special order.

Micro Lambda Wireless Inc.
www.microlambdawireless.com

SP4T Switch

VENDORVIEW

Mini-Circuits' MSP4TA-18-12D+ is an ultra-reliable, rugged-duty absorptive fail-safe SP4T switch designed in break-before-make configuration. Its patented switch design is comprised of very few frictionless moving parts which enable repeatable and optimum performance. Powered by +12 VDC, the device has a typical switching speed of 20 milliseconds, insertion loss of 0.2 dB and high isolation of 90 dB. The MSP4TA-18-12D+ is suitable for use across a wide range of applications, including switching for automated test equipment and redundancy switching.

Mini-Circuits
www.minicircuits.com

Multilayer Ceramic Series Capacitors

VENDORVIEW

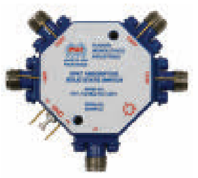
PPI is now offering traditional NP0, Hi-Q/low ESR 0505C, 1111C, 2225C and 3838C multilayer ceramic series capacitors with an increased temperature and life test performance. They are now qualified to 200°C, under 2× WVDC, for 2000 hours. The 6040C, 7676C and the new 1313C (UHF/RF Hi-Q) ceramic capacitors are now qualified to 175°C. These parts exhibit low ESR/ESL, low noise, high power, high self-resonance, as well as ultra-stable performance over temperature.

Passive Plus Inc.
www.passiveplus.com

Four Throw Switch

VENDORVIEW

PMI Model No. P4T-1G18G-70-T-SFF is an absorptive, high speed, single pole four throw switch capable of switching within 100 ns maximum. The frequency range is 1 to 18 GHz and the impedance is 50 Ω. This switch has > 70 dB isolation. Features include SMA female connectors. Unit size is 1.25" × 1.25" × 0.4" with painted blue finish.



Planar Monolithics Industries Inc.
www.pmi-rf.com

Directional Coupler

Pulsar Microwave's wideband directional coupler CS20-24-436-20 covers a frequency range of 0.5 to 27 GHz with 20 ±1 dB coupling. Insertion loss is 1.8 dB, with frequency sensitivity of ±1.4 dB and 12 dB directivity. Power handling forward and reverse is 20 W with VSWR 1.6:1. Housing dimensions are 4.4"×0.7"×0.4" and connectors are 2.92 mm female.

Pulsar Microwave Corp.
www.pulsarmicrowave.com


HAPPY
NEW
YEAR
2017

Coaxial Isolator

For test and measurement applications, REC has designed an octave band isolator covering 500 to 1000 MHz in a simple package with less than 1.20 dB loss and minimum 13 dB isolation.
Renaissance Electronics
www.rec-usa.com

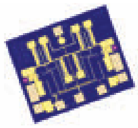
Reflective 2 to 4 GHz Coaxial SP2T Switch

RF-Lambda's part number RFSP2TR0204GH reflective 2 to 4 GHz coaxial SP2T switch features wide band operation, an included

TTL compatible driver, fast switching speed, low insertion loss and high isolation. The temperature range is 45° to +85°C. Customization is available upon request. Hermetically sealed packages up to 60,000 ft are available upon request.
RF-Lambda USA LLC
www.rflambda.com

Voltage Variable Attenuator

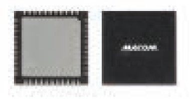
VENDORVIEW



RFMW Ltd. announced design and sales support for a voltage variable attenuator (VVA) for instrumentation, radar, communications and EW platforms in the 2 to 25 GHz frequency range. The Qorvo TGL2767 features a 20 dB attenuation range with < 2 dB of insertion loss. I/O return loss is >12 dB. The TGL2767 is available in DIE form and packaged (TGL2767-SM).
RFMW Ltd.
www.rfmw.com

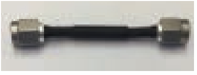
20 W, X-Band, SPDT Switch

VENDORVIEW



Richardson RFPD Inc. announced the availability and full design support capabilities for a new 20 W SPDT switch from MACOM Technology Solutions Inc. The MASW-011071 is a terminated silicon PIN diode SPDT switch designed for X-Band high-power, high-performance applications. The switch is assembled in a lead-free 7 mm, 44-lead PQFN plastic package and handles greater than 20 W of continuous wave (CW) power at +70°C over 8 to 10.5 GHz.
Richardson RFPD Inc.
www.richardsonrfpd.com

Cable Filters



RLC Electronics' cable filters can be designed as either lowpass, highpass or bandpass constructions, covering frequency ranges up to 50 GHz. These filters are available in conformable (FCLPF Series) and semi-rigid cable styles (CLPF Series) that are built to your cut-off, rejection and mechanical specifications, including cable length, bend position and angle. Computer designed and advanced coaxial techniques ensure optimal performance in a minimum amount of space.
RLC Electronics Inc.
www.rlcelectronics.com

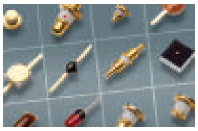
E-Band, Subharmonically Pumped Mixer

VENDORVIEW

Model SFS-12-N2 is an E-Band subharmonically pumped mixer. The mixer is designed with high performance GaAs Schottky diodes and accepts an LO frequency at half the RF frequency to cover 60 to 90 GHz. With a low LO frequency range of 30 to 45 GHz, this mixer is well suited for low cost E-Band system solutions. The mixer provides 14 dB conversion loss, 15 dB RF to LO isolation and 30 dB LO to IF isolation.
SAGE Millimeter
www.sagemillimeter.com

Step Recovery Diodes

VENDORVIEW



SemiGen Inc. has added step recovery diodes (SRD) to its expanding product line. These SRDs utilize controlled grown junction epitaxial silicon combined with a silicon dioxide passivation to ensure greater stability and reliability. SemiGen's SRDs offer low snap time through voltages ranging from 8 VDC to 120 VDC. Capacitances at 6 VDC range from 0.2 to 3 pF. Discontinued by many suppliers, SemiGen has opted to offer these devices for customers servicing legacy RF and microwave systems.
SemiGen Inc.
www.semigen.net

Power Metal Strip Resistor

Vishay Intertechnology Inc. announced a new surface-mount Power Metal Strip® current sense resistor that combines a high power rating up to 6 W, TCR down to ±70 ppm/°C, and extremely low resistance values down to 0.0003 Ω in the 2512 case size. Providing a power density of 192 W/in^2, the Vishay Dale WSLF2512 allows designers to save board space in high-power circuits by utilizing the smallest resistor possible.
Vishay Intertechnology Inc.
www.vishay.com

CABLES & CONNECTORS

Right-Angle Waveguide to Coax Adapters

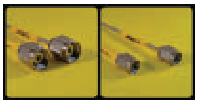
Fairview Microwave Inc. released a new line of 1.85 mm, 2.4 mm and 2.92 mm waveguide to coax adapters with operating ranges up to 65 GHz. These waveguide adapters are ideal for numerous applications requiring a transition from coax to waveguide or vice versa, including SATCOM, wireless communications, industrial, test and measurement and defense systems. Fairview's 10 new waveguide to coax adapters extend the company's large portfolio to include millimeter wave frequency ranges with models in the K-Band (18 to 26.5 GHz) up to the V-Band (50 to 65 GHz).
Fairview Microwave Inc.
www.fairviewmicrowave.com

MMBX Connectors and Adapters

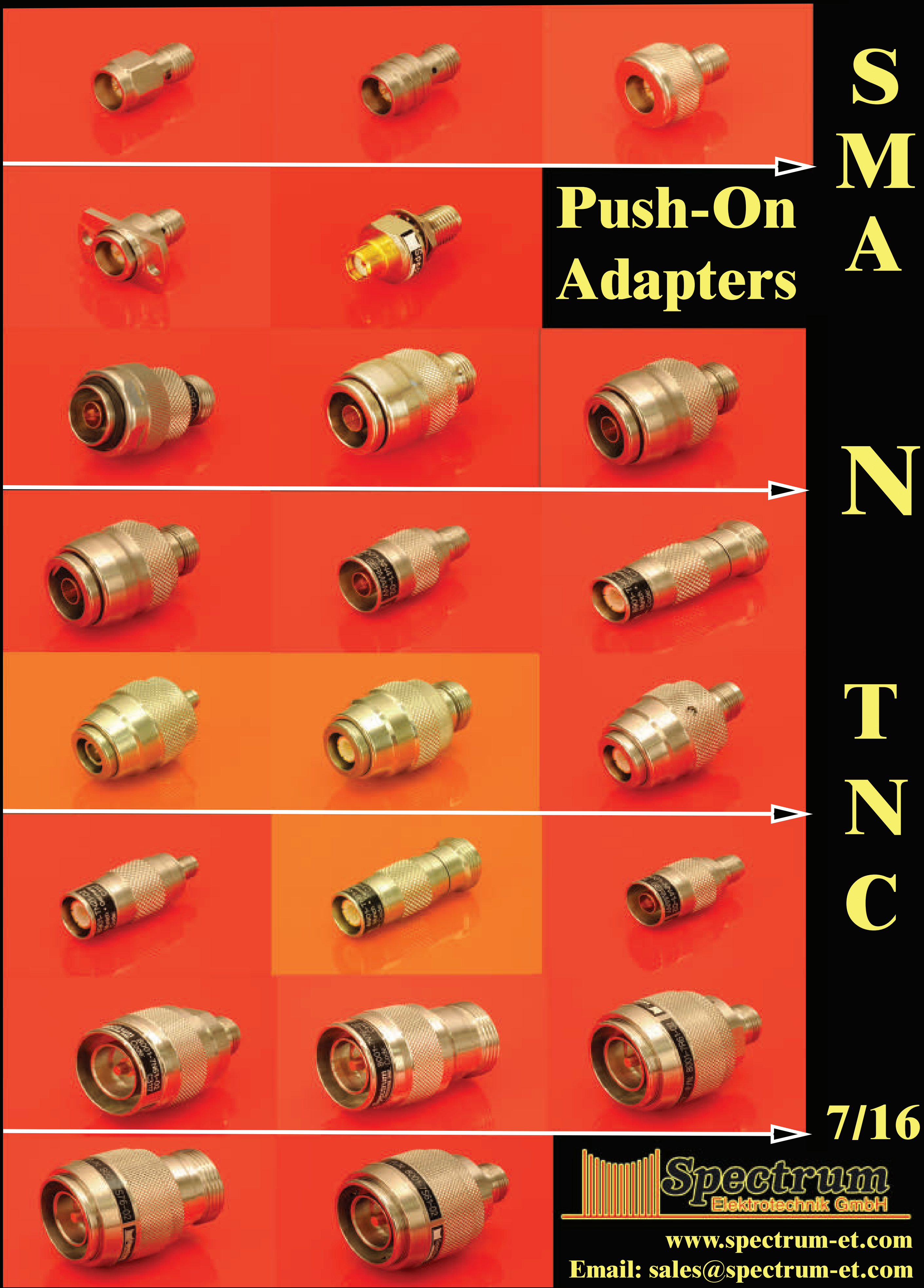
VENDORVIEW

Pasternack now offers small form factor MMBX connectors and adapters most commonly used on circuit boards and their associated input/output connections for industrial, telecom and consumer product applications. MMBX style connectors and adapters were developed to provide a versatile and easy PCB-to-PCB connection as well as coax-to-PCB connections. Due to their mechanical design, they also work well in backplane applications. These MMBX adapters and connectors offer a maximum operating frequency of 12.4 GHz.
Pasternack
www.pasternack.com

One-Step Cable Connectors



SGMC Microwave's new one-step connectors have captivated center contacts offering excellent performance up to 65 GHz (usable up to 67 GHz). With no loose parts to handle, assembly is as simple as trimming the cable and then inserting it into the body for soldering. Features include: DC to 65 GHz, VSWR: 1.25:1 max per connector, captivated center contact (beryllium copper, gold plated) and body components (corrosion resistant type 303 stainless steel, passivated). Quality, performance and reliability you can count on.
SGMC Microwave
www.sgmcmicrowave.com


Push-On
Adapters
SMA
N
TNC
7/16
Spectrum
Elektrotechnik GmbH
www.spectrum-et.com
Email: sales@spectrum-et.com

NewProducts

AMPLIFIERS

Liquid Cooled Amplifiers

VENDORVIEW

AR can now supply chillers for any of its standard liquid-to-liquid cooled amplifiers. This capability ensures amplifier performance in any operating condition, reduces the risk of inappropriately sized equipment and eases the procurement process by working with only one vendor. Each chiller is sized for the amplifier model, taking into consideration the user's operating requirements and environment. AR can also supply chillers for custom amplifiers designed to user specifications—providing a true turnkey solution.

AR RF/Microwave Instrumentation
http://bit.ly/CoolAR

Solid-State Power Amplifier Module

Comtech PST's new high power density solid-state RF module is available in today's marketplace. Comtech's latest development continues to expand on its proven innovative integrated RF GaN power amplifier designs by further increasing the RF power density. Consistent with its planned technology development roadmap, Comtech proudly introduced the latest in GaN-based 6 to 18 GHz RF amplifiers. This highly integrated design is ideal for use in communication, electronic warfare and radar transmitter systems where space, cooling and power are limited.

Comtech PST
www.comtechpst.com

10 kW L-Band Transmitter HPA

VENDORVIEW

Empower RF announced availability of their field proven model 2185 pulsed amplifier operating from 960 to 1215 MHz at 10 kW peak and duty cycles from 0.1 to 5%. This compact and versatile DME, IFF, TACAN and JTIDS transmitting amplifier, with flexible operating modes, also makes an ideal fit for radar component testing, advanced research and system development. Because of its superior SWaP, it is also well suited for mobile EW and threat simulator applications.

Empower RF
www.empowerrf.com

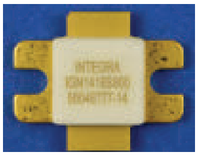
VHF/UHF Amplifier

VENDORVIEW

VHF/UHF amplifier model AMP1136 is a new 20 to 1000 MHz, 200 W min CW LDMOS module. It features instantaneous bandwidth with 3 dB peak to peak flatness and 24A max consumption operating from a 32 VDC source. This unit is suitable for all single channel modulations standards and has built in protection circuits. Other notable characteristics are its small form factor, high power density, high reliability and ruggedness. For EW, EMI/RFI and any other application requiring high power in the VHF/UHF frequency range.

Exodus Advanced Communications
www.exoduscomm.com

GaN/SiC Transistor



Integra Technologies' 800 W, 1450 to 1550 MHz, GaN/SiC transistor is designed for L-Band radar applications. This high-power GaN-on-SiC HEMT transistor supplies 800 W of peak pulsed output power at 50 V drain bias, with 14 dB of gain and 60% of efficiency at 8 µs, 1% pulse conditions.

Integra Technologies
www.integratech.com

SOURCES

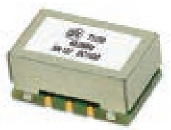
OEM Signal Generator Platform

VENDORVIEW

Berkeley Nucleonics released a customizeable OEM signal generator platform for RF/microwave systems requiring brand singularity or system integration. The platform leverages proven designs at 20 and 26.5 GHz frequencies. Industry leading specifications in low phase noise, phase coherence, robust modulation features and fast frequency switching speeds ensure a broad range of applications can be addressed. The fast switching (FS) option allows for extremely fast digital sweeps at a minimum rate of 10 µs.

Berkeley Nucleonics
www.berkeleynucleonics.com

10 to 50 MHz TCXO



Greenray Industries Inc. announced the availability of the T1250 series TCXO. The new T1250 temperature compensated crystal oscillator is available from 10 to 50 MHz, with CMOS or clipped sinewave output. The T1250 features very tight temperature stability down to ±30 ppB over -40° to +85°C, with long term aging down to 3 ppM over 20 years. Acceleration sensitivity is available down to < 7 × 10^{-10}/g to maintain performance during shock and vibration.

Greenray Industries Inc.
www.greenrayindustries.com

Low Phase Noise VCO

The DCRO200280-10 is a low phase noise, voltage-controlled oscillator designed for low S-Band applications. It covers the frequency range of 2000 to 2800 MHz with tuning voltage of 0.5 to 24 V. This VCO offers superb phase noise of -103 dBc/Hz at 10 kHz offset from a planar resonator structure and is housed in a 0.5"×0.5"×0.18" RoHS package.

Synergy Microwave Corp.
www.synergymwave.com

YIG-Based Synthesizer

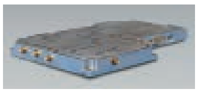
VENDORVIEW

Teledyne Microwave Solutions' YIG-based synthesizer yields a fully functional synthesizer that delivers superior performance and ROI to the standard industry alternative, voltage-controlled oscillators (VCO). It offers a 6 to 13 GHz frequency range, produces power output of +10 dBm minimum and +16 dBm maximum. TMS has other frequency bands available that operate down to 2 GHz.

Teledyne Microwave Solutions
www.teledynemicrowave.com

X-Band Synthesizer and Up-Converter

VENDORVIEW



Smiths Microwave Subsystems announced that TRAK Microwave has added an X-Band direct synthesizer/up-converter to its wide range of product offerings. The SYN152 features four ×2, ×3, ×4 and ×17 multiplied output ports with various powers in either the L-, S- or X-Bands as well as an X-Band BIT detector. With UHF input power at -6 dBm, this synthesizer can output 0 dBm in the S-Band, 2 dBm in the X3 L-Band, 4 dBm in the X2 L-Band, and 10 dBm in the X-Band.

TRAK Microwave Corp.
www.trak.com

Low Jitter VCSO

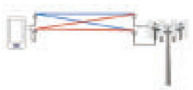
VENDORVIEW

The VS-800 is the latest addition to Vectron's high frequency voltage controlled SAW oscillator (VCSO) family, packaged in a 5 mm × 3.2 mm × 1.8 mm^3 making it the smallest ultra low-jitter VCSO available on the market. This VCSO is capable of achieving 6 fs rms jitter performance over the offset bandwidth of 12 kHz to 20 MHz. This product is ideal for emerging optical transport networks, supporting high speed converters that demand a low jitter high frequency reference clock.

Vectron International
www.vectron.com

SOFTWARE

Wireless InSite MIMO



Remcom announced the release of Wireless InSite® MIMO, a new version of its site-specific radio propagation software that simulates the detailed multipath of large numbers of MIMO (multiple-input-multiple-output) channels while overcoming the increased level of computations required for traditional ray tracing methods. With a tremendous increase in

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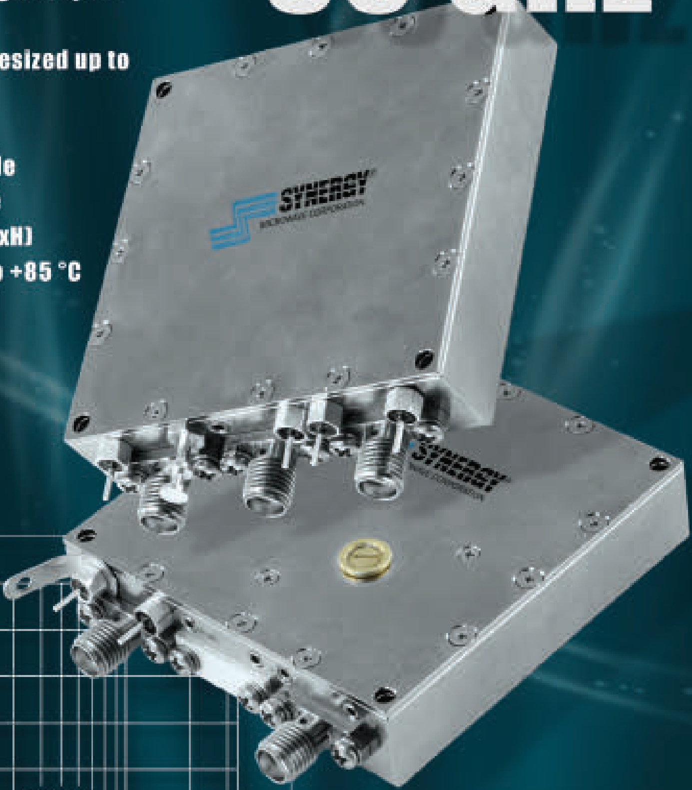

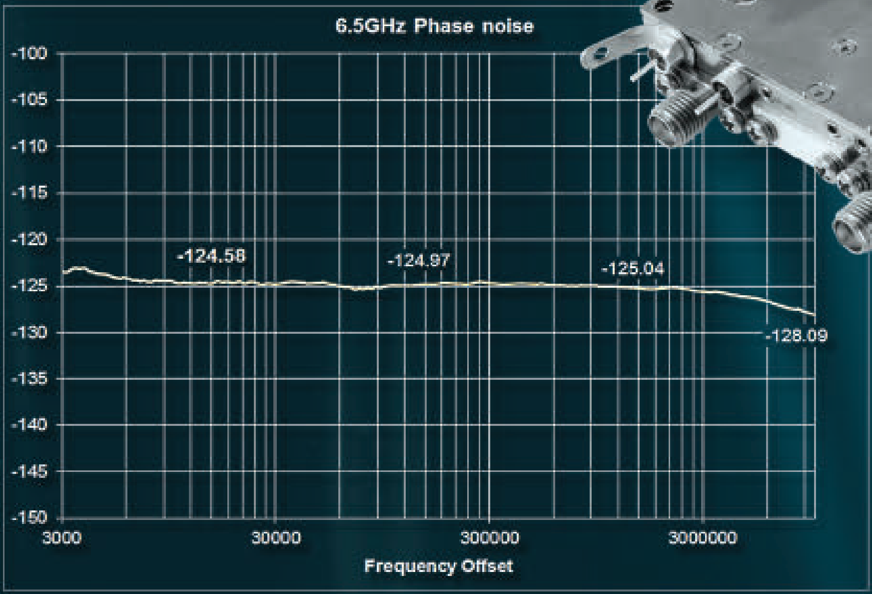

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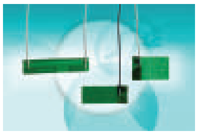
New**Products**

the number of connected devices and mobile data demand predicted over the next decade, the wireless communications industry is exploring new technologies to accommodate 5G wireless data systems, including MIMO-based solutions.

Remcom
www.remcom.com

ANTENNAS

Wireless PCB Antennas



Pulse Electronics introduced three, ready-to-use, standard, wireless printed circuit board antennas for laptops, tablets, mobile devices and devices that operate in a similar environment. The SH0319D/E/W family of antennas provides wireless signal reception ranging from dual bands to multi-bands covering GPS, Glonass, WLAN/dual-band Wi-Fi and GSM900/1800. The antennas are design-ready and can be directly integrated into various electronic devices as an evaluation antenna for use or performance evaluation.

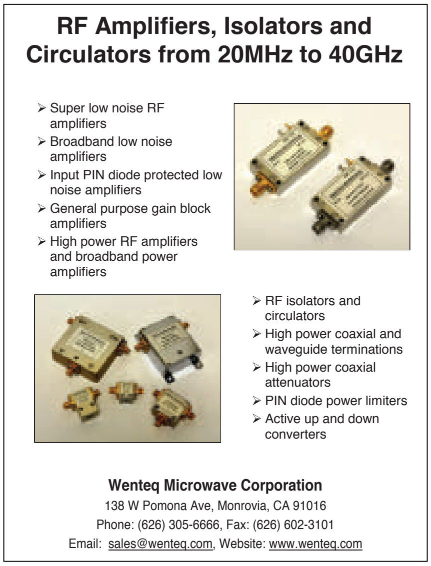
Pulse Electronics
www.pulseelectronics.com

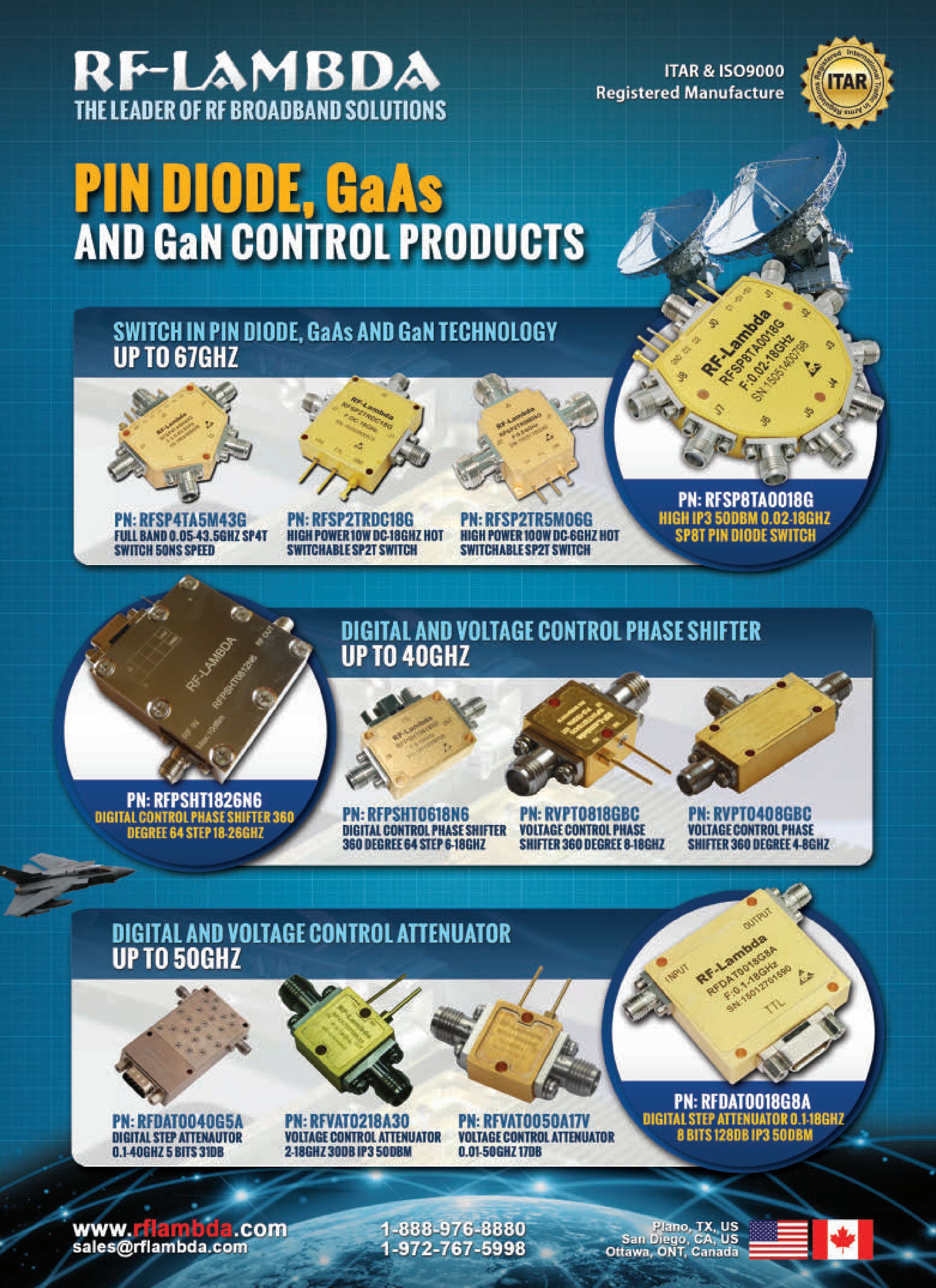
MIMO Sector Antennas

VENDORVIEW

Three new MIMO sector antennas from Southwest Antennas are available in 1.4 to 1.7 GHz or 1.7 to 2.5 GHz for international applications, U.S. Federal Law Enforcement, or license-free ISM Band use, and are compatible with a wide variety of multi-port MIMO radio systems currently on the market. The focused sectorial radiation pattern is ideal for directional communication. Slant left/right and vertical polarization provide superior MIMO polarization and spatial diversity for crowded RF environments.

Southwest Antennas
www.southwestantennas.com

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Erratum

Metamaterial Advances for Radar and Communications

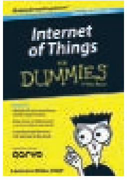
Our cover feature in the November 2016 issue, "Metamaterial Advances for Radar and Communications," contained several errors about Kymeta's metamaterial antenna. The following summary corrects these and clarifies Kymeta's antenna technology:

The Kymeta antenna uses metamaterial resonators; however, they do not operate as phase shifters. Phase shifting is not required. Rather, the beam is formed by tuning some of the elements in the array while leaving others detuned. Using many elements at less than λ/2 spacing, an accurate hologram with cells at the right phase and amplitude can be achieved. The antenna resonators are considered metamaterials because they are sub-wavelength structures designed—not found in a natural material—for a specific and controlled electromagnetic response. The data rates supported by a system using a Kymeta antenna depend upon various factors, including antenna size and frequency.

While both Ku- and Ka-Band antennas have been demonstrated, Kymeta is presently commercializing a Ku-Band design. The antenna has completed successful demonstrations without incurring adjacent satellite interference; should interference occur, Kymeta can implement a feedback technique to reduce sidelobes.

In 2013, Kymeta worked with O3b Networks on an R&D project to develop an antenna; however, that effort did not lead to a contract to supply antennas for the O3b system. Kymeta has not disclosed the cost goal for the antenna. The antenna shown in Figure 2 was an early concept; a current photo of a Kymeta antenna is shown below.

Microwave Journal regrets these errors.



Internet of Things for Dummies and Internet of Things Applications for Dummies

Lawrence Miller

The "for Dummies" books are well known for providing understandable introductions to often deep and arcane topics, like "Anatomy and Physiology for Dummies" or "Philosophy for Dummies." They are also helpful explaining popular yet confusing buzzwords, separating the hype from the underlying realism. Such is the objective with two short books produced by Qorvo that explain the Internet of Things (IoT).

The first, "Internet of Things for Dummies," explains what makes the IoT the IoT (physical, smart and connected), IoT use cases and how businesses can incorporate the IoT into their products and services. The discussion then delves deeper into the communication standards that enable the IoT and how to handle the massive amount of small data packets that will traverse the network, from data analytics to security. The first volume concludes with eight takeaways that will make you sound like you know more about the IoT than you probably do.

The second "for Dummies" book covers IoT applications, beginning with the "smart" home. That means automating the basic functions in a home (e.g., thermostats, lighting and all the devices that have frustrating remote controls). Connecting everything to everything and to the cloud will lead to smart home "lifestyle systems" and the Smart Home as a Service (SHaaS), yet another way for the cable company — or perhaps Alexa — to tap into your wallet. Seriously, such systems may allow the elderly to maintain their independence and quality of life safely. This book covers more than the smart home, touching on "smart" applications in agriculture, transportation, health and medicine, retail, supply chain management and cities. By the end of this volume, you should be an evangelist for the IoT.

The author, Lawrence Miller, is a certified information systems security professional (CISSP) and must also have a certified sense of humor. The two volumes are fun and easy to read — and free, thanks to Qorvo.

Published by John Wiley and Sons Inc.

www.wiley.com

Internet of Things for Dummies,
22 pages
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Internet of Things Applications for Dummies
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SPINNER – Looking to the Next Generation

When Dr. Georg Spinner started his 'engineering' company in a very small office in central Munich in 1946, he likely did not imagine that 70 years later the third generation of the Spinner family would be overseeing a global company that now has over 1,100 employees worldwide, with subsidiaries and representatives in over 40 countries.

Dr. Spinner was an engineer by trade but an inventor at heart who had the ability to identify problems and use his knowledge and expertise to come up with solutions. His inventive problem solving approach has become the DNA of the company, where the ethos is to utilize the expertise and knowledge gained by its workforce throughout its operation.

From its humble original workshop, the company's success soon forced a move to larger premises, which, luckily, were found 'just around the corner.' Initially housing the whole operation from plating to production, the facility's footprint expanded as the company took up extra buildings on the site.

Eventually, growth could not be maintained on the site and, in 1966, production and R&D were moved to Feldkirchen-Westerham, with the Munich facility dedicated to operations including sales and marketing. Further market expansion has subsequently seen SPINNER open production facilities in Saxonia, Germany; Hungary and China.

A major focus of production for the company is the mobile communications market, with the high-end products emanating from its largest production facility in Feldkirchen-Westerham, which houses 500 people. As part of the complete supply chain, quality control plays a vital role. At SPINNER, testing is total, as the teams are highly skilled and highly educated — so much so that at Feldkirchen-Westerham, the engineers built their own test environment, which has been upgraded and improved over the years. The experience and knowledge that has been acquired is also being utilized in other areas of product qualification.

The second production facility in Germany — SPINNER Lauenstein GmbH, near Dresden in Saxonia, which was established in 1991 — specializes in producing jumpers for mobile base stations. From the beginning, jumper production was highly automated, with a high level of testing and the ability to immediately satisfy customer demand at short notice. SPINNER is synonymous with connectors, and these have been produced at the company's factory in Szekszárd, Hungary since it opened in 1995.

The company's commitment to global expansion continued with the establishment of SPINNER Telecommunication Devices (Shanghai) Co., Ltd. in 2000, which strives to be close to its customers, both geographically and professionally, in order to listen to their needs and respond quickly. The Shanghai facility fulfills all functions, including R&D. Its focus is on mobile communication, and it has the flexibility to adapt designs and products for a variety of markets.

Over seven decades one creative Munich engineer's vision and philosophy has been nurtured, developed and expanded to serve the industry through dedicated facilities that address customer requirements globally.

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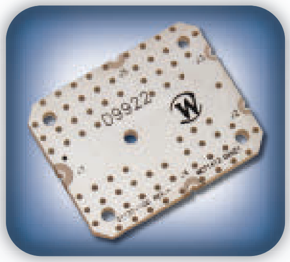
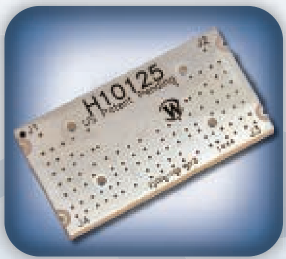


90° Hybrid Couplers

180° Combiners



Directional Couplers

Model	Type	Frequency (MHz)	Power (W CW)	Coupling (dB)	Insertion Loss (dB)	VSWR (ML)	Mounting Style	Size (Inches)
C8740	Dual	20-512	200	40	0.3	1.15:1	Tabs	1.5 x 0.95 x 0.55
C9655	Dual	20-1000	100	30	0.7	1.25:1	Tabs	1.5 x 0.95 x 0.55
C8631	Dual	20-1000	150	40	0.35	1.25:1	Tabs	1.5 x 0.95 x 0.55
C10561	Dual	20-1000	250	50	0.1	1.25:1	SMT	1.35 x 1 x 0.15
C7962	Bi	450-2500	100	30	0.2	1.20:1	SMT	1.15 x 0.7 x 0.07
C8025	Bi	500-3500	125	30	0.3	1.25:1	Drop-In	1.3 x 1 x 0.07
C8098	Bi	800-2000	200	30	0.7	1.20:1	Drop-In	1.3 x 1 x 0.07

0° Combiners/Dividers

Model	Type	Frequency (MHz)	Power (W CW)	Insertion Loss (dB)	VSWR	Isolation (dB)	Mounting Style	Size (Inches)
D9888	2-Way	1000-3000	500	0.35	1.35:1	15	SMT	2.8 x 2.2 x 0.27
D9922	2-Way	2000-6000	200	0.35	1.40:1	15	SMT	1.4 x 1.1 x 0.14

Hybrids

Model	Type	Frequency (MHz)	Power (W CW)	Insertion Loss (dB)	VSWR	Amplitude Balance (±dB)	Mounting Style	Size (Inches)
QH10738	90°	20-1000	150	0.8	1.40:1	0.25	Tabs	3 x 2.75 x 1
QH9056	90°	30-520	400	0.8	1.30:1	1.2	Drop-In	4 x 1.7 x 0.29
QH9304	90°	60-1000	150	1.0	1.40:1	1.0	Drop-In	2 x 1 x 0.16
QH8849	90°	80-1000	250	0.65	1.40:1	1.0	Drop-In	2.9 x 2.1 x 0.31
QH8100	90°	100-512	250	0.45	1.30:1	0.5	Drop-In	3.3 x 1.52 x 0.28
QH10245	90°	100-1300	150	0.75	1.30:1	0.75	SMT	2.5 x 1.7 x 0.16
QH8922	90°	150-2000	100	0.75	1.40:1	1.0	SMT	1.47 x 1.13 x 0.16
QH7900	90°	450-2800	125	0.55	1.35:1	0.45	SMT	1.5 x 1.1 x 0.095
QH7622	90°	500-3000	150	0.55	1.35:1	0.6	Drop-In	1.65 x 1.1 x 0.09
QH10541	90°	700-6000	100	0.5	1.35:1	0.6	SMT	0.66 x 0.86 x 0.09
QH10089	90°	800-2800	200	0.35	1.30:1	0.4	SMT	1.25 x 0.55 x 0.08
QH7741	90°	800-3000	200	0.3	1.40:1	0.45	Drop-In	1.35 x 0.65 x 0.09
H10125	**180°**	**1000-3000**	**350**	**0.5**	**1.35:1**	**0.2**	**SMT**	**2.31 x 1.21 x 0.25**
QH10637	90°	1000-6500	100	0.65	1.45:1	0.6	SMT	0.86 x 0.66 x 0.09
QH8193	90°	2000-6000	100	0.25	1.30:1	0.75	SMT	0.85 x 0.33 x 0.14
QH10148	90°	2000-6000	100	0.3	1.30:1	0.5	SMT	0.75 x 0.45 x 0.08
H10126	**180°**	**2000-6000**	**100**	**0.8**	**1.35:1**	**0.4**	**SMT**	**1.15 x 0.6 x 0.14**
QH10707	90°	2500-5500	200	0.25	1.25:1	0.35	SMT	0.65 x 0.4 x 0.12
QH10651	90°	3000-3500	150	0.2	1.20:1	0.25	SMT	0.56 x 0.35 x 0.1

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