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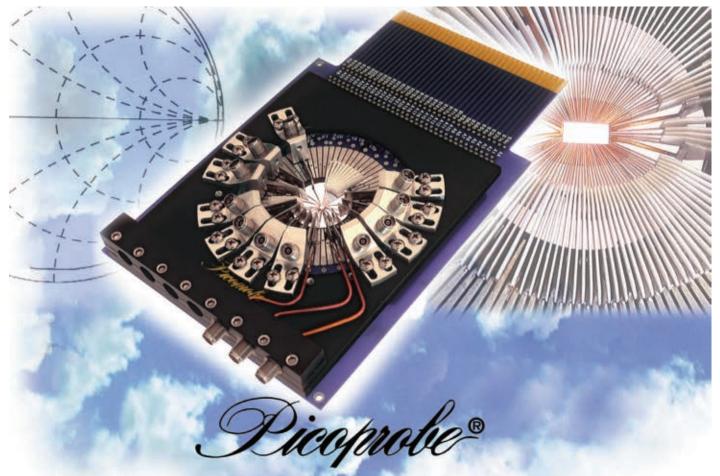












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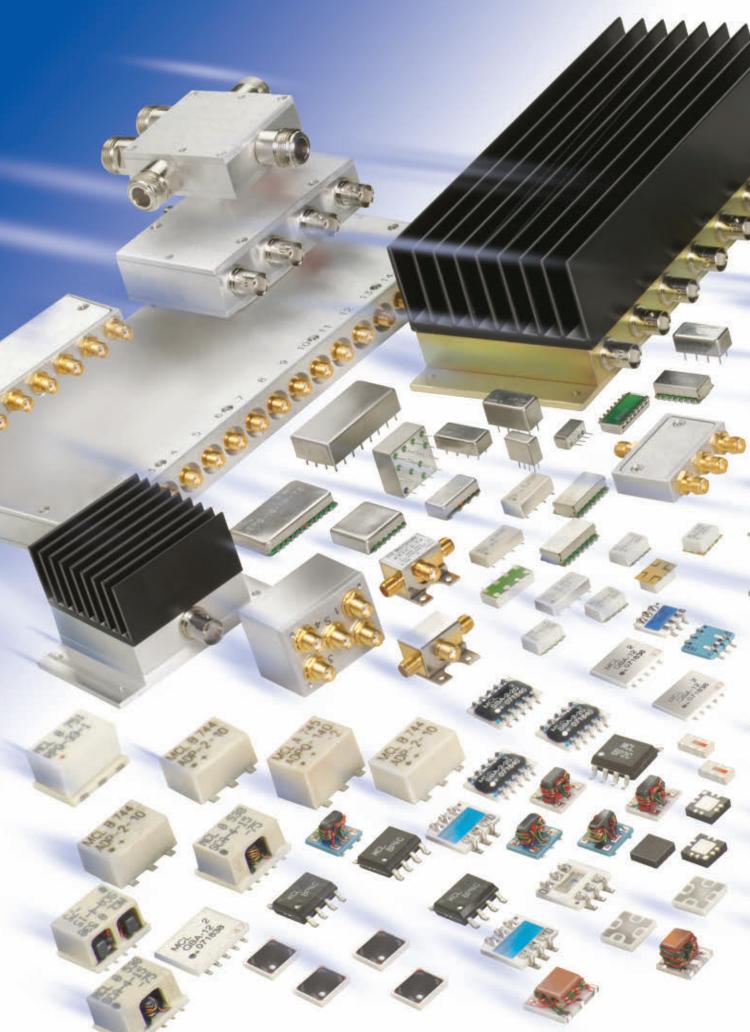
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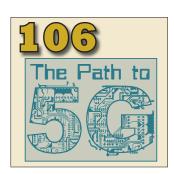


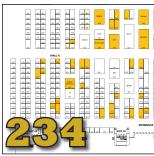
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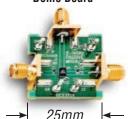


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BUFFER AMPLIFIER

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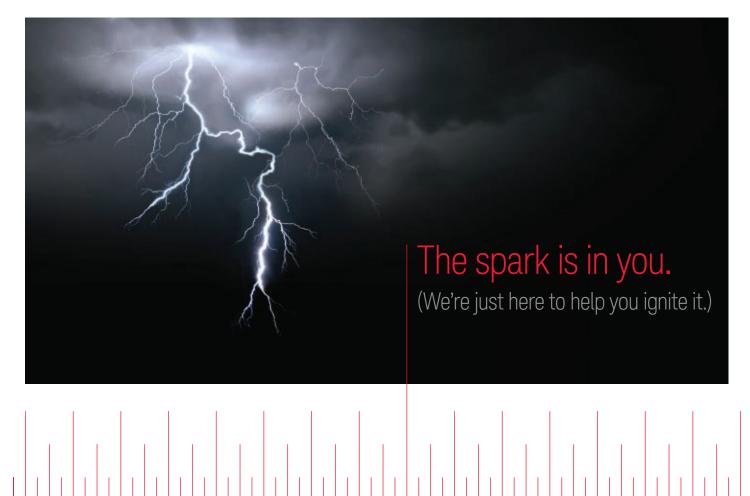
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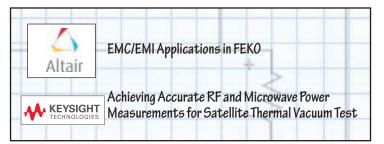
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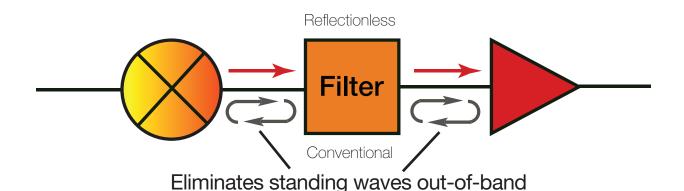
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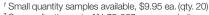
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² See application note AN-75-007 on our website

⁴ Defined to 3 dB cutoff point



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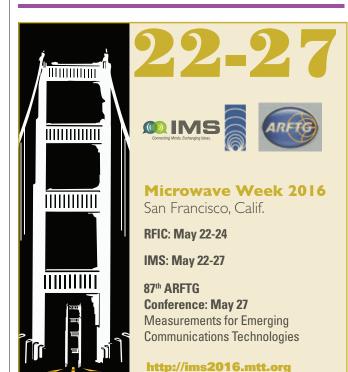
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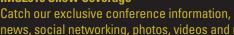


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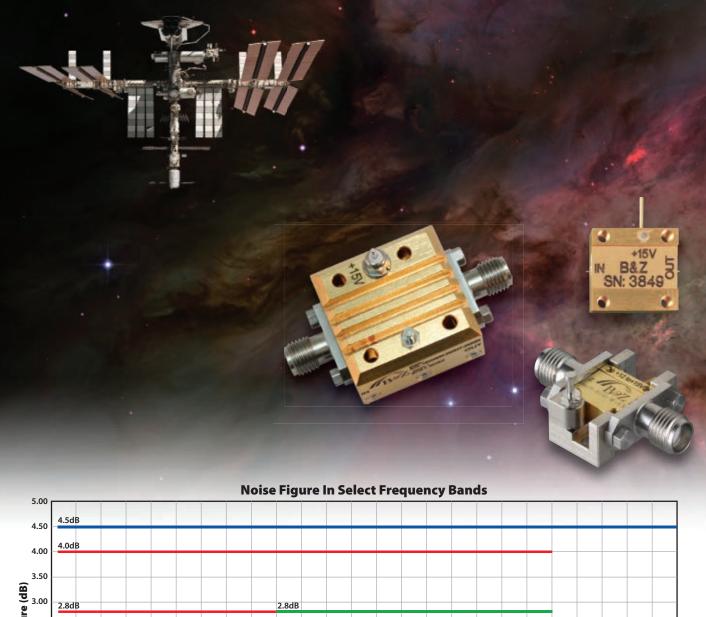




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An Insider's Perspective

Gary Lerude *Technical Editor*, Microwave Journal

CONTRIBUTIONS FROM ANALOG DEVICES AND QORVO

Te're witnessing a transition in the landscape of the RF/microwave industry, arguably a time of unprecedented change as the major players align and consolidate (see *Table 1*). The currents behind this make for an interesting list: slowing growth in the overall semiconductor market, the ascendency of Apple and Samsung as the two major smartphone manufacturers, the growing complexity of the RF block diagram in the phone, the added performance requirements for the infrastructure to deliver exabytes of data feeding consumer appetites and the

stockpiles of cash accumulated as companies recovered from the Great Recession. Responding to these currents, many companies have chosen mergers and acquisitions (M&A), in some cases to diversify, in others to add competencies or gain scale

to better compete.

Microwave Journal thought our readers would find it interesting to explore two recent transactions, so we asked Analog Devices (ADI) and Qorvo to respond to a few of our questions about their respective deals. We wanted to get the insider perspective of why these marriages made sense and the work that led up to "the big merge."

BITS TO ANTIENNA

In June 2014, ADI announced an agreement to acquire Hittite Microwave for \$2.45 billion, or \$78 per share. The price was 29 percent above the closing price of Hittite's stock on the prior trading day and just under 9× Hittite's prior four-quarter revenue. The deal closed in just over six weeks, surprisingly fast and a point of pride for ADI.

Hittite's annual revenue, \$277 million, was only a tenth of ADI's (see *Figure 1*). So why would ADI acquire Hittite and for such a premi-

January 2015
Qorvo Born
June-July 2014
ADI Acquired Hittite
February 2014
RFMD & TriQuint

Announced Merger

COVER FEATURE

0007

iPhone Launched

1991 D Formod

RFMD Formed

985

Hittite & TriQuint Formed

1970s

197

Market Growth

MERGE

3G → LTE

Smartphone Era

Great Recession

Cell Phone Adoption

Telecom Bubble Bursts

GaAs MMIC Start-Ups and Commercialization

GaAs R&D

1965 ADI Formed

MICROWAVE JOURNAL ■ APRIL 2016

RF & MICROWAVE FILTERS

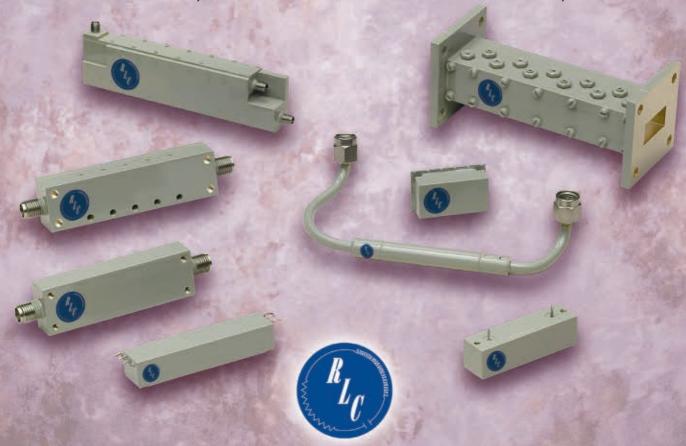
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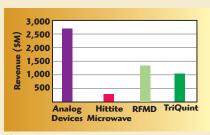
TABLE 1					
RF/MICROWAVE INDUSTRY CONSOLIDATION					
Deal	Close	Price or Value (\$)			
ADI acquires Hittite Microwave	July 2014	2.4 billion			
RFMD and TriQuint merge	January 2015	1.6 billion			
API Technologies acquires Aeroflex Inmet and Weinschel	June 2015	80 million			
Keysight Technologies acquires Anite	August 2015	606 million			
National Instruments acquires Micropross	October 2015	108 million			
JAC Capital acquires Ampleon (from NXP)	December 2015	1.8 billion			
NXP acquires Freescale	December 2015	11.8 billion			
MACOM acquires Aeroflex/Metelics	December 2015	38 million			
Avago acquires Broadcom	February 2016	37 billion			
II-VI acquires ANADIGICS	March 2016	78 million			
Qualcomm forms JV with TDK	Early 2017 (est)	3 billion			

um? Both companies were facing the dilemma of slow growth. Hittite's high margin business model (70 percent gross margin and 40 percent operating margin) had created an expectation among investors that was reflected in the company's high stock price and market capitalization. While Hittite's financial performance was the envy of the industry, it restricted the markets they could pursue, and their growth plateaued. ADI was more diversified in products and markets, yet many of their markets (e.g., industrial and automotive) were mature and growing slowly.

From the outside, the combination made sense. ADI's strength was in data converters and signal processing, and their RF products truncated above a

few gigahertz. Hittite's core was RF, extending into millimeter wave, high power and complex modules for the defense market. The two companies' product lines had little overlap, perhaps in phase-locked loops and Hittite's 2011 acquisition of an analog-todigital converter company that lacked critical mass. With approximately \$2.7 billion in annual revenue, \$4.8 billion in cash and short-term investments and little debt, ADI could afford to pay a premium. Hittite would enable ADI to address the block diagram from bits to antenna and, a selling point for the investment community, the deal would accelerate ADI's growth.

Organizationally, ADI clearly endorsed Hittite's management, appointing Hittite executives to senior



▲ Fig. 1 Analog Devices, Hittite Microwave, RFMD and TriQuint trailing annual revenue, prior to the close of their respective deals.

roles at ADI. Rick Hess, Hittite's CEO before the acquisition, now leads ADI's automotive and communications sector, and Greg Henderson manages ADI's RF and microwave segment.

ALL AROUND YOU

At Mobile World Congress in February 2014, RFMD and TriQuint announced that the two companies would merge, what they termed a "merger of equals." Unlike ADI and Hittite, the two were comparable in annual revenue—\$1.3 billion for RFMD and \$1 billion for TriQuint (see Figure 1). The merger was an allstock transaction, structured so each company's shareholders would own approximately half of the new company. RFMD stockholders received 1 share in the vet-to-be-named Qorvo, while TriQuint shareholders received 1.675 shares. The deal represented a 5.4 percent premium over the closing price of TriQuint's stock on the prior trading day. The merger didn't close





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LP2-26A	12-26	3.5	+9	+20
LP18-26A	18 - 26	3.0	+9	+19
LP1840A	18-40	4.0	+9	+19
LP1404	1-40	4.5	+9	+20
LP240A	2 - 40	4.5	+9	+20
LP2640A	26-40	4.0	+9	+19

Notes: 1. Insertion Loss and VSWR (2:1) tested at -10 dBm.

Notes: 2. Power rating derated to 20% @ +125 Deg. C.

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until the beginning of 2015, held up by the review and approval of the Chinese government's Ministry of Commerce (MOFCOM).

Both RFMD TriQuint had two business units focused on THE BIG their key markets: 1) mobile phones and tablets and 2) commercial infrastructure, defense and aerospace. Assessing the two competitors in 2013 showed RFMD stronger in mobile and TriQuint leading in defense, with each strong in separate infrastructure markets. Both companies had gaps in technology and product portfolios: RFMD lacked internal SAW and BAW filter technologies, key to integration in high-end smartphones. TriQuint lagged in Wi-Fi and CATV products for infrastructure.

Although the merger announcement was unexpected, it seemed immediately intuitive. Qorvo would have the full portfolio of technology and products needed to integrate the RF front-end in the mobile phone, better able to compete with Skyworks and Avago (now Broadcom Ltd.). The company would be a strong player in nearly all infrastructure markets, combining RFMD's position in CATV and Wi-Fi with TriQuint's in base station and optical. Qorvo would essentially dominate the U.S. defense market for compound semiconductors. Their only threats would be Cree, for GaN opportunities, and MACOM, who had reentered the military market after years of absence.

For the investment community,

RFMD and TriQuint committed to \$150 million in annual "synergies" - cost reduction — with half realized during the first year of combined operation, the remainder, the following year. The synergies MERGE would largely come eliminating stacked margins: RFMD would no longer buy SAW and BAW filters from an external supplier, and TriQuint's products would be assembled and tested in RFMD's internal operations in China.

Reflecting the spirit of RFMD and TriQuint's "merger of equals," the executive ranks of Qorvo reflect near-equal apportionment. Bob Bruggeworth, RFMD's president and CEO, plays the same role at Qorvo, while Ralph Quinsey, TriQuint's CEO, is chairman of the board. The mobile business is led by Eric Creviston, who led that same business at RFMD; James Klein, from TriQuint, leads the infrastructure and defense segment.

INSIDE VIEW

The outside view is not necessarily the same perception seen by the companies. So *Microwave Journal* asked ADI and Qorvo a series of questions to get their perspectives.

Microwave Journal. How did you decide that this business combination was a strategic fit, considering technology, products, market share, revenue, profitability and culture?

Sidebar: The Importance of Cultural Fit

On December 7, 2015, NXP completed the acquisition of Freescale Semiconductor. During the first earnings call of the combined company, in February 2016, a financial analyst asked about the cultural integration of the two companies. Daniel Durn, the chief financial officer of NXP, who held that post at Freescale, said:

"Based on my prior experience, culture is one of those key elements to successful integration. And you've got to get it right if you want to drive the value from the industrial logic that ultimately created what we're creating here. We made a decision a while ago that as soon as we close this transaction, there's no more us vs. them or us and them. It is just we ... and we've made surprisingly good progress early, early on in melding these two cultures and getting everybody focused on our customers' requirements and success in the marketplace. I couldn't be happier with the cultural integration progress we're making, but the approach we're taking really at the core of that is a philosophical belief on the importance of blending these cultures on a go-forward basis ... the importance we place on blending these cultures that we no longer have them and us, literally day one."



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Analog Devices. When we compared our strengths, we saw that Analog Devices and Hittite would support our customers better as one entity, because our solutions had great synergy in end applications. We had highly complementary market and technology leadership: ADI was the leader in high performance signal chains in the analog and mixed-signal space, with solutions up through 6 GHz; and Hittite was the leader in RF and microwave products up through

the microwave and millimeter wave range, resulting in virtually no overlap between product portfolios.

The merger has allowed us to develop more highly integrated solutions that combine the best of our respective technologies. This was a perfect fit, because our customers are moving to much higher value products that require more integrated solutions to provide significant advantages and impact in their end applications.

Qorvo. Both predecessor companies served many of the same markets and had developed some very complementary technologies. We had core strengths in system design, semiconductor processing, advanced packaging, high volume manufacturing and strategic foundry services. We also recognized that we were capable of serving both high volume commercial and defense customers. For two companies that were more or less in the same line of work, there was almost no overlap.

At the same time, we had different but complementary technologies that were well suited to a combined offering. Our combined strengths and expertise in GaN, GaAs, power amplifiers, switches, filters and tuners are at the core of many new, highly integrated products we are now introducing as Qorvo. We are using this expertise to help solve our customers' toughest RF challenges, whether in mobile, infrastructure or defense applications. We are well positioned with the core technologies necessary to help our customers accelerate their products to market.

Microwave Journal. Knowing that the investment community expects quickly accretive combinations that will increase the value of the new company, how did you assess the synergies and whether the deal made financial sense?

Qorvo. We identified certain cost synergy opportunities before we announced the proposed merger and provided those expectations in the original announcement on February 24, 2014. We expected \$150 million in annualized cost synergies — \$75 million exiting year one after the merger (completed in January 2015), and an additional \$75 million in cost synergies exiting year two. In our first full year as Qorvo, we exceeded our target for achievement of an exit run rate of \$75 million in synergies, and we are on track for the previously committed \$150 million run rate reduction by the end of calendar year 2016.

Analog Devices. A lot of recent M&A activity in the electronics sector has been fueled by the need to reduce costs or rapidly scale business. ADI and Hittite were already running profitable businesses based on a model that our value to our customers is heavily dependent on

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the strength of our technology. That's what drove our motivation to merge — with our combined strengths we can help customers break into new frontiers, such as 5G communications and autonomous driving. Our aim is to help them do this faster and more cost effectively by providing access to more highly integrated, power-efficient, high frequency and wideband solutions.

Microwave Journal. Describe the most important steps you took to ensure a smooth combination, both operationally and organizationally. How are you merging overlapping products, organizations, facilities?

Analog Devices. Because we had virtually no product overlap, we were able almost immediately to begin combining our technology strengths into something our customers could leverage to improve the performance of their systems. An

example of this is our PLL portfolio. ADI had best-in-class phase noise and switching speeds, Hittite had the lowest spurs in the industry. By merging these development teams, we are able to integrate these two technologies into a new generation of products that simultaneously achieve best-in-class performance in all three parameters.

Another area of leverage was in bringing ADI's advanced packaging technology to the Hittite product line. By leveraging the ADI technology and supply chain we are now bringing to market surface-mount, millimeter wave modules that are 10 to 50 times smaller than previous solutions. These are providing highly integrated functionality—such as a complete E-Band radio—at frequencies up to 100 GHz.

Qorvo. Fortunately, both predecessor companies had similar cultures. By benchmarking each other and also looking at best practices outside of the company, we were able to roadmap the best systems, processes, technologies, design and manufacturing resources and products, as well as design our organization that allows Qorvo to achieve our goals of innovation, product leadership, scale and speed. We created two product organizations, Mobile Products and Infrastructure and Defense Products (IDP) and are now moving ahead on a plan that optimizes our manufacturing capabilities across our global foot-

We have several major ongoing or planned capital projects that will allow us to better serve our customers while maximizing efficiency and cost savings. We're creating centers of excellence in each of our manufacturing locations that will focus on one or two primary products or technologies (see **Table 2**). All of these projects will reduce our costs and help our teams to better collaborate. They will also focus our design, manufacturing and technology/product resources where they can be most efficient and effective in achieving our long-term goals and customer commitments.

Microwave Journal. Discuss your philosophy and the process of merging the cultures of two independent and proud companies.

Qorvo. Our goal was to create one culture for Qorvo that allows us to achieve our brand prom-





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ises of innovation, product leadership, scale and speed. We compared best practices of the two predecessor companies and also looked outside of the company to identify best practices in our industry to foster the right culture for Qorvo. We try to reinforce the kind of culture we're creating through frequent and effective employee communications. We also designed our awards and recognition program around our brand attributes so that we could help nurture the culture we want to create for Qorvo. This allows us to recognize and celebrate success and continuously track our progress. Our new awards and recognition program helps define our culture by recognizing achievement of our strategic objectives, technical achievement including patents and/or invention and brand-building through Qorvo's author and speaker program.

Analog Devices. Our cultures are surprisingly similar, in that they are technology and engineering

driven and focused on solving customer design challenges through application-level innovation. The speed at which the companies came together into a highly collaborative team environment was the result of this culture and accelerated our integration to one company.

(Éditor's Note: See sidebar on page 28 for another view.)

Microwave Journal. How have you improved your value proposition with the combination? What do you offer now that wasn't possible before the transaction?

Analog Devices. Thanks to the merger, ADI is the best positioned company to cover the entire RF signal chain, from antenna to baseband, at frequencies from DC to 100 GHz. With the industry's largest portfolio and broadest array of technologies, we continue to move deeper into markets as diverse as communications infrastructure, defense electronics, instrumentation and automotive. The acquisition also exposed our collective customer base to a wider range of semiconductor processes, which include CMOS, SiGe, GaAs and GaN, as well as advanced packaging, bestin-class design support tools and a global distribution channel.

From a customer perspective, that means we provide significantly higher value RF and microwave content, both

TABLE 2



IABLE Z				
QORVO'S MANUFACTURING FOOTPRINT				
Location	Primary Focus			
Apopka, Fla.	• SAW and Temperature Compensated (TC) SAW filters			
Greensboro, N.C.	• SAW and TC-SAW filters • Existing GaAs and GaN products			
Hillsboro, Oregon	Commercial GaAs-based technologies			
Richardson, Texas	Production of BAW and GaN products Advanced microwave module assembly			
Beijing, China	Assembly/packaging hub for wafer-level fan out and thin substrate/packaging technologies			
Dezhou, China	Manufacturing of wire bond and flip-chip products			
Costa Rica	Packaging/assembly of SAW and BAW filters			





The semiconductor technology landscape for wireless infrastructure is undergoing a major transformation, particularly in the power amplifier (PA) market. The multi-decade dominance that laterally diffused metal oxide semiconductor (LDMOS) transistors have sustained in the PA domain is being challenged by Gallium Nitride (GaN), and the implications for wireless basestation performance and operating costs are profound.

The clear technology advantages that GaN provides – improved energy efficiency, greater bandwidth, higher power density, smaller form factors – position it as the natural successor to LDMOS for the next generation of basestations, particularly for cellular bands above 1.8 GHz. While GaN was once prohibitively expensive compared to LDMOS, MACOM's fourth generation GaN on Silicon technology (MACOM GaN) brings their respective cost structures into close alignment.

Here we'll take a closer look at the relative merits of LDMOS, GaN on Silicon Carbide (SiC) and MACOM GaN technologies, assessing their advantages and tradeoffs ranging from performance attributes to costs to supply chain ecosystems. As the only company in the industry to offer both GaN on Si and GaN on SiC technologies – with decades of proven experience and expertise in wireless infrastructure applications – MACOM is uniquely positioned to assess their respective suitability for commercial basestation applications.

MYTH:

GaN on Si power transistors offer negligible efficiency advantages over LDMOS, and can't match the efficiency of GaN on SiC devices.

MACOM GaN-based MAGb power transistors deliver efficiency over 70% and linear gain of 19 dB at 2.6 GHz, with the ability to achieve over 80% peak efficiency when the devices are presented with proper harmonic terminations. This power efficiency profile rivals that of best-in-class GaN on SiC devices, and represents an efficiency improvement of 10% compared to legacy LDMOS offerings.

Properly exploited, this efficiency advantage can make a profound impact on service providers' operating expenses (OPEX) through major savings in the utility bills and savings in the capital expenditures (CAPEX) through minimizing the size of the heat sink, the power supply unit (PSU) and the overall size of the remote radio head (RRH.) The utility bill savings of switching only new macro base stations deployed in a year to GaN can exceed \$100M when modeled with an average energy rate of \$0.1/KWh.

	LDMOS	MACOM GaN	GaN on SiC	Benefits
Power Amp Efficiency ">2GHz"	-	>10% Improvement	>10% Improvement	Lower Operating Expense
Higher Frequency Bands	3.6 GHz	Up to >3.8 GHz	Up to >3.8 GHz	New Spectrum Deployments
Wider Bandwidths	100 MHz	200 MHz	200 MHz	Higher Capacity per Basestation
Power Density	1-1.5 W/mm	4-6 W/mm	4-8W/mm	Smaller Antenna, Lower CapEx
Linearity	DPD Friendly	DPD Friendly	Charge Trapping	Higher Order Modulation Schemes
Supply Chain	8"	Up to 8"	4"→6"	Capacity and Surge Capability
Cost	Silicon	Silicon	sic	LDMOS Like Cost Structure

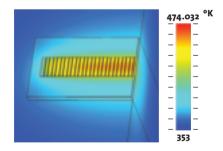


MYTH:

GaN on SiC's thermal attributes ensure better PA reliability in the field.

MACOM's **MAG**b power transistor series has demonstrated MTTF over 10⁶ hours at real-world basestation operating temperatures of 200° C. These devices are therefore proven to be every bit as robust and reliable in the field as competing GaN on SiC devices, and match the field longevity profiles of legacy LDMOS devices.

MACOM achieved this thermal performance parity with GaN on SiC devices leveraging advanced transistor and package design techniques. By optimizing the transistor die layout and using innovative heat sinking and die attachment methods, the 15% to 30% delta in thermal conductivity at the Si vs SiC substrate level is effectively negated at the device level.



MYTH:

GaN-based devices introduce linearity issues that are difficult to correct with digital pre-distortion.

Doherty amplifier implementations are popular for their attendant efficiency benefits, but they can magnify signal problems by introducing non-linearity. This can be corrected with digital pre-distortion (DPD), but DPD has proven difficult to implement with GaN on SiC devices. The charge trapping effects in SiC, believed to be caused by crystalline defects in its silicon structure, ultimately yield challenging and less linearizable PAs.

In comparison, MACOM GaN-based **MAG**b power transistors are easy to linearize and correct with DPD schemes compared to other GaN technologies. MACOM GaN doesn't exhibit the same levels of the aforementioned artifacts and is therefore a technically superior solution to both LDMOS and GaN on SiC for basestation applications.

MYTH:

Gan's power density benefits are counterbalanced by prohibitively high costs.

MACOM GaN can produce 4X to 6X more power from the same transistor die size as LDMOS. And while the wafer material costs for MACOM GaN are slightly higher than LDMOS due to GaN epitaxial deposition, MACOM's wafer processing efficiency enables a 50% reduction in the number of processing steps compared to LDMOS fabrication, yielding a negligible difference in cost per wafer. Ultimately, in volume production, MACOM GaN die size will be between 1/4 and 1/6 that of LDMOS, while supporting an inherently lower cost structure.

The high power density provided by MACOM GaN naturally enables smaller device packages. Alternatively, a designer could maintain existing PA form factors while delivering higher power and/or greater integration to accommodate massive MIMO transmit/receive antenna architectures.

MACOM's **MAG**b power transistor series exemplifies this power density advantage. Initial entries in this product series include single-ended transistors providing up to 400W peak power, dual-transistors, and single-package Doherty configurations providing up to 700W peak power in both symmetric and asymmetric power options. The physical size of these devices is equal to that of lesser performing LDMOS devices and comparably performing GaN on SiC devices.

TO272S plastic package offers earless TO272footprint solutions capable of up to 300 W peak power with improved thermal performance

MACOM GaN...Delivered

MYTH:

GaN is simply too expensive for basestation applications.

MACOM GaN is on a trajectory to yield GaN-based devices that are half the semiconductor cost per watt of comparable LDMOS products, and significantly lower cost than comparably performing but more expensive GaN on SiC wafers at volume

production levels. MACOM GaN is the clear winner on cost.

winn A fr Id no mate

4" vs. 8" Wafer

At maturity, GaN on Si stands to benefit from silicon cost structures that are 100X lower cost than today's GaN on SiC technology, owing to the 200X to 300X slower material growth of SiC boules compared to silicon, and the attendant equipment depreci-

ation and energy consumption absorbed by its fabs. GaN on SiC will therefore remain perpetually higher cost and thus prohibitive for mainstream use in commercial basestations.

In contrast, a full year's production of MACOM GaN for the entire RF and microwave industry can be serviced in a few weeks by a single 8-inch silicon factory. MACOM's industry leadership and partner collaboration on 6-inch silicon wafer production, moving to 8-inch production in 2017, enable the capacity and requisite cost structures to break the barriers to mainstream GaN adoption in the commercial basestation market.

MYTH:

GaN can't meet the basestation industry's supply chain requirements.

The high attendant costs of producing SiC dictates that it will be serviced by a small community of high mix, low volume fabs that lack the ability to service commercial scale applications, particularly at peak demand. And whereas SiC is a relatively new material with a correspondingly short history of use in commercial scale applications, silicon has benefited from more than 60 years of industrialization and development. As such, the supply chain for GaN on Si has a host of natural efficiencies aligned in its favor. The industry's ability to support volume production of GaN on Si, maintain inventories, and accommodate surges in demand is firmly established.



Taking all of these factors into account, MACOM GaN strikes the optimal balance of performance, cost effectiveness and commercial supply chain scalability, distinguishing it as the clear technology platform of choice for the next generation of macro basestations.



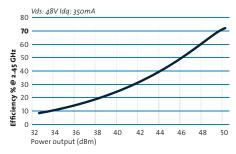
The portfolio, partnerships & people to fully leverage GaN in a wide range of industrial RF energy applications

We're shattering the final barriers to mainstream GaN adoption with an industry-leading portfolio of cost-effective RF power devices available in Si and SiC. For over 40 years, our engineers have been redefining RF power and are now applying their GaN expertise to commercial, ISM and wireless applications.

MACOM GaN delivers cost, bandwidth, power density and efficiency advantages in an array of form factors:

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- > Packages from QFN to TO-272 to ceramic

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CoverFeature

at the component and module level. An example of this value is through the development of highly integrated phased array solutions for markets such as communications, automotive radar and industrial and military sensing. Through development of integrated phased array products, our customers can achieve higher resolution, range and throughput at reduced power consumption and size compared to more traditional architectures. ADI

is enabling our customers to achieve all of these requirements, while improving time-to-market and lowering cost, by providing a complete phased array signal chain from the data converter all the way up to the antenna. Also, for customers looking for a module-based solution, we're developing monolithically integrated phased array chips that can help them reduce complexity and to improve that needed accuracy.

shrink their system footprint in order

Phased array and other high frequency applications like E-Band backhaul and emerging 5G technology are also driving customer demand for new classes of instrumentation devices and test and measurement equipment. Test equipment manufacturers turn to ADI, because they know that our technology has to be even better than theirs if we are to help them achieve the right mix of frequency ranges, resolution, speed and performance required to test their customers' most advanced communication systems.

Global satellite networks represent another rapidly evolving market, as we move closer to the day when every person on Earth is connected by high data rate communications. Customers in the communications and defense electronics markets designing low-earth-orbit satellite networks are especially sensitive to size, weight and power considerations. ADI's complete antenna-to-bits solutions, with their small form factor and low power, are helping these customers get to market more quickly and at lower cost.

Qorvo. We are already starting to see the benefits of our combination in new, highly integrated Oorvo products for Wi-Fi and LTE.

At Mobile World Congress 2016, we announced several mobile Wi-Fi design wins for our new highly integrated front-end modules (iFEMs). We developed a new RF FusionTM Wi-Fi iFEM, which delivers higher performance than discrete components while saving space and simplifying design for leading smartphone manufacturers. As Qorvo, we are uniquely positioned to design and manufacture all of the high value components in the Wi-Fi iFEM, including high-performance filters, switches and amplifiers.

To help smartphone manufacturers address the technical challenges of carrier aggregation, Qorvo developed the new QM78064 RF FusionTM multimode high band module that offers best-in-class linearity for TD-LTE and full support for TD-LTE intraband carrier aggregation for enhanced uplink performance. This new module incorporates all major transmit and receive functionality into highly integrated split-band placements. We also ramped to production new highly integrated diversity receive modules supporting 2× and 3× downlink carrier aggregation. These new modules



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deliver enhanced data rate performance in a highly compact form factor and combine our proprietary Low-DriftTM filter technology with high-performance switches and LNAs in a very compact form factor.

These are just a few examples of many new products we will be introducing that leverage the technology and product expertise we bring to mobile, infrastructure and defense markets as one Qorvo. Microwave Journal. How do you see this consolidation benefitting the industry and those who work in it?

Qorvo. The industry consolidation that started with the merger to form Qorvo is helping accelerate the pace of innovation and industry change that will positively impact RF innovation. In our case, customers benefit from Qorvo's new scale advantages in manufacturing and R&D

and a more aggressive roadmap of new products and technologies. By bringing together all of the critical RF building blocks necessary to simplify design, reduce size, conserve power and improve system performance, we help solve difficult RF challenges facing customers across mobile, infrastructure and defense markets. This helps customers by making mobile handset designs simpler and more tightly integrated, while offering higher performance. It also helps accelerate deployment of next-generation communication infrastructure, from high speed networks to the optical paths that connect them. It benefits defense customers by accelerating development of communications, radar and electronic weapon systems.

Analog Devices. Our customers are facing severe time-tomarket and cost pressures, especially with the growing demand for increased connectivity in the Internet of Things (IoT) era. By 2020, the market expects to include more than 50 billion IoT devices, many of which will require increased connectivity, higher data rates and the ability to be quickly tested and deployed. IoT networks also support multiple operating modes: from very high data rates, where a device must communicate constantly over short ranges, to very low data rates, where the device may run for months or years without communicating. That level of complexity is overmatching many in-house design teams, who are turning to ADI for wider band, higher frequency solutions and tapping our broad cross section of engineering expertise, which includes sensor, analog, digital, RF and microwave design.

Nearly two years after the acquisition, ADI's RF and microwave business is stronger than ever. We believe we are a more collaborative, application-focused design partner and our defense, industrial and automotive customers see us as a vital resource as they grow more reliant on millimeter wave technologies for new sense and radar applications. We're already working with small and large customers to develop advanced technologies for applications up to 100 GHz and we expect to play a vital role in making automobiles safer, industrial equipment more autonomous and our world a more connected place.

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OUTLOOK

Anyone who has read the Harvard Business Review or taken a course on M&A has heard that most acquisitions fail. Despite that common view, most of the recent deals in the RF/microwave industry seem to be succeeding, although the final verdict may not be known for some years.

Investor perceptions of the combinations, whatever they may be, don't jump out from ADI's and Qorvo's stock prices. Since the Hittite acquisition closed (see Figure 2), ADI's stock price has cycled from 28 percent above to 20 percent below the closing share price that first day of trading $(\$53.7\overline{5})$. On March 11, the stock closed 4.1 percent above the first day baseline. Qorvo's stock has been even more volatile (see Figure 3), appreciating 25 percent before dropping to a trough 51 percent below the closing price on the first day of trading. On

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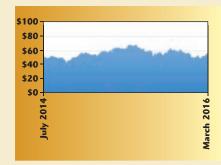


Fig. 2 Analog Devices closing stock price following the acquisition of Hittite Microwave (from July 22, 2014 through March 11, 2016).

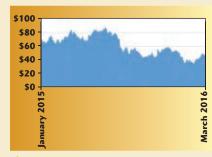


Fig. 3 Qorvo closing stock price following the merger of RFMD and TriQuint (from January 2, 2015 through March 11, 2016).

March 11, the stock closed 31 percent below the first trading day baseline. With both companies, variations in the stock price generally reflect business conditions rather than a judgment about the deals. During their earnings call last July, Qorvo disclosed a severe downturn in their China base station revenue, which triggered a significant drop in price. Recently, softness in demand from Apple has affected revenue in the mobile segment and the

outlook for many of Apple's suppliers. Ultimately, the success of ADI and Qorvo will be determined by the markets they serve. Customers in those markets will judge the performance, price, reliability and support of the products offered. ADI/Hittite and RFMD/TriQuint have now been together long enough to see new products emerging from their respective development pipelines. Qorvo made several new product and design win announcements at the recent Mobile World Congress, some reflecting the integration of the two former competitors' capabilities. This month's International Microwave Symposium is another opportunity to see what innovations the combination of technologies and manufacturing capabilities will birth.■



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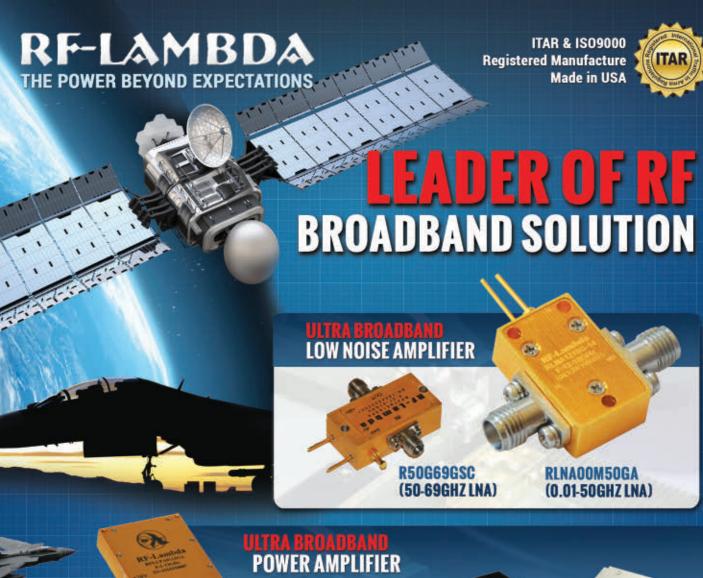
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Your Guide to IMS2016

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Patrick Hindle
Microwave Journal Editor

an Francisco is 49 square miles surrounded by reality," said Paul Kantner, co-founder of Jefferson Airplane, but come the week of May 22nd, it will be surrounded by thousands of microwave engineers. The 2016 IEEE MTT International Microwave Symposium (IMS) takes place in San Francisco, Calif., May 22-27 at the well known Moscone Convention Center. It consists of a full week of events, including technical paper presentations, workshops, special sessions.

panels and tutorials, as well as numerous social events and networking opportunities. The symposium also hosts a 600+company exhibition and is co-located with IEEE RFIC and ARFTG conferences.

The event typically draws record crowds when it takes place in San Francisco and Boston as those areas are able to draw a large local audience from a significant number of surrounding companies in the industry. While total attendance has been averaging about 8000 over the last decade, the previous decade was closer to 10,000 with a sharp downturn occurring in 2007 in Honolulu (see Figure 1). As the event heads to Honolulu in 2017, we hope the big drop off in attendance does not happen again.

San Francisco is a great place to visit with a tremendous amount of high tech industry in the area. Silicon Valley is in the southern part of the San Francisco Bay Area and home to many of the world's largest technology companies including Apple, Cisco, Google, HP, Intel and Oracle. The term came from the region's large number of silicon chip companies but now is generally referred to as the high tech area. According to the IMS2016 website, Silicon Valley continues to be the leading hub

tal investments in the United States. If you have not already visited San Francisco, try to make time to visit some of the many local attractions. View the iconic Golden Gate Bridge and visit the Golden Gate Park or take a trip to the infamous Alcatraz Island. Fisherman's Wharf offers many restaurants, shops, attractions and street performers. The area is home to many wineries with various wine tours available. Downtown there are many interesting districts like Chinatown, Japantown, Mission District and Union Square for the shoppers as well as the iconic "most crooked street in the world," Lombard Street.

for high tech innovation and development,

accounting for one third of venture capi-



IMS2016 KEYNOTES

The father of the cell phone, Dr. Martin Cooper, will speak at the plenary session about "The Birth and Death of the Cell Phone" on Monday at 17:30-19:00. Dr. Cooper believes that although the cell phone contains tremendous semiconductor and software technologies, it is still in its infancy as cell

phone connectivity has the potential to revolutionize health care and education. The closing ceremony on Thursday from 16:30-18:00 includes Dr. James Truchard, president, CEO and co-founder of National Instruments talking about "Software's Role in Next-Generation 5G, RF and Microwave Systems," and Professor Jan M. Rabaey, Donald O.

Pederson Distinguished Professor at UC Berkeley talking about "The Human Intranet: Where Swarms and Humans Meet."

CONFERENCES

Microwave Week consists of the IMS. RFIC and ARFTG technical conferences, each offering excellent opportunities for all segments of the



IMS2016 Conference Chair Dr. Amarpal Khanna

IMS2016 will feature about 470 technical papers, 31 workshops and five short courses in addition to a number of related events. Discussions will include emerging RF and wireless related growth areas such as 5G technologies, automotive radars, wear-

able electronics, Internet of Things (IoT), Internet of Space (IoS) and RF/microwave technology in life science.

Multiple focused programs to promote student and diversity participation will be held this year. The student paper contest, student design competition, Ph.D. student initiative and the IMS Connect programs are designed to increase college graduate participation at the conference. The IMS Connect program aims to encourage participation of students from under-represented minorities and specifically prepare them for careers in science and engineering. The Women in Microwaves team this year has organized a focused session, which includes paper presentations from leading professionals practicing RF and microwave technologies. Following the paper-presentation session will be a leadership-coaching panel session.

Additionally, the Science Technology Engineering and Math (STEM) program will introduce students to the field of microwave engineering and technology through a STEM-focused day-at-a-conference experience on Thursday. Students from local middle and high schools will be invited to attend exciting talks and visit selected exhibition booths and demos. This one-day event will include opportunities to showcase student-submitted science projects, interact with engineers and graduate students and provide a conference ex-

A Wireless Wonders pavilion is being organized to showcase consumer wireless technology products and services. The MicroApps forum, which will be held in the exhibition area, will include dynamic presentations by IMS exhibitors who will introduce attendees to new products and applications. A one-day RF boot camp will teach the basics to graduate students, young engineers and others interested in a fundamental understanding of RF technology. The boot camp will include demonstrations on how to use test instruments for modeling and characterization of RF components. To further enrich the IMS experience, ample opportunities to interact with peers and exhibitors will be provided throughout Microwave Week. Day-to-day programs have been created, keeping in mind the importance of networking for conference participants. We believe this will be an enriching and rewarding experience for all attendees.

I invite you to come and experience IMS2016 and the beautiful city of San Francisco. With all of what IMS2016 and the city have to offer, your time in San Francisco is sure to be fun and productive. The entire IMS2016 steering committee is looking forward to seeing you and extends a warm welcome!



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microwave community to learn about new technologies and products. The conferences include a wide variety of technical sessions, interactive

forums, panel sessions, workshops, short courses, industry showcases, application seminars, and industrial and historical exhibits.

The theme of IMS2016 is "Gateway to the Wireless Future." Several new topics added this year include 5G, autonomous vehicles, IoT, wear-



RFIC 2016 Conference Chair Albert Wang

RFIC 2016 will continue to offer a number of initiatives: The two-page industry brief format, allowing the latest state-of-the-art RF IC design results to be presented without requiring die photos and detailed schematics, will

continue in 2016. The popular Industry Showcase Session, featuring 13 poster presentations (some have demos) of the most innovative and highly-rated industrial papers (both two- and four-page), will be the highlight during the RFIC Reception Sunday evening. This year, the Industry Showcase will be held jointly with the Interactive Forum (IF) Session, featuring 11 papers during the RFIC Reception, which will offer attendees an enhanced interactive experience in a relaxed environment. To improve academic submissions, all of the RFIC student paper finalists will receive complementary RFIC registration. Students may volunteer to help with RFIC (and/or IMS) conference logistics in exchange for complementary conference registration, meals, T-shirts and other benefits. The joint RFIC/IMS Ph.D. Student Sponsorship Initiative Program will continue to involve selected first and second-year Ph.D. students to complete technical assignments during the conference in exchange for complementary conference registrations, lodging and meals.

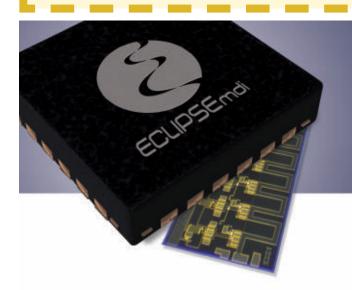
The RFIC 2016 will open on Sunday, May 22, with 11 workshops (four full-day and seven half-day), seven of which will be joint RFIC/IMS workshops. These workshops cover a wide range of topics including: "Phased Arrays for Handsets and Cellular/Integrated Circuit, System and Antenna Realization of Millimeter-wave Front-ends for 5G Radios," "Highly Efficient 5G PA Design," "How mmWave Systems Reshape the Future of Telecom and Sensing Applications," "Circuit

Techniques and System Architectures for Carrier Aggregation and Multi-Band Radios," "Calibration and Correction Techniques for CMOS Radios," "Enhanced IC Design and Waveform Control Techniques for Wireless Power Transfer, Energy Harvesting, and RFIDs," "Frequency Synthesizers of Multi-Band, Multi-Standard Radios and Internet of Things (IoT)," "RF/Analog IC Design Challenges in Advanced CMOS Technology," "High-Efficiency Broadband Multimode Multi Standards Amplifier Design, High Efficiency Transmitters," "Millimeter-Wave Electronics: From Applications to Manufacturing," and "e-Health: Implantable Systems and Communications in the Human Body."

The Plenary Session will be held Sunday evening beginning with conference highlights, followed by the presentation of the Student Paper Awards and the Industry Best Paper Award. The Plenary continues with two outstanding keynote talks by Craig Barratt, senior vice president of Google Access, discussing "Innovations for Enabling Scalable Wireless Capacity," and K. Lawrence Loh, corporate senior vice president of MediaTek Inc., discussing "RFIC Under Big Digital Semiconductor Companies: Challenges and Opportunities."

Immediately following the Plenary Session is the joint Industry Showcase Session and Interactive Session embedded in the RFIC Reception, providing a mixed experience of "hot chips" with cold drinks. You will not want to miss the RFIC Reception!

Technical papers will be presented during oral sessions throughout Monday and on Tuesday morning. Two Panel Sessions will be featured during lunchtime on both Monday and Tuesday. The two "controversial" panel topics will be "Bio-electronics: No Silicon in My Body!" and "Patents – The Good, the Bad and the Ugly." Make sure to bring your own "controversial" opinions to the panels. On behalf of the RFIC 2016, we cordially invite all of you to attend the 2016 RFIC Symposium. We are looking forward to an exciting program and hope you can join us in San Francisco!





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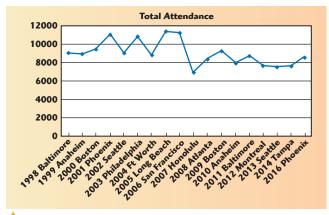


Fig. 1 IEEE IMS total attendance since 1998.

able electronics and RF/microwave technology in the life sciences. The conference starts with workshops and short courses on Sunday and Monday, then Tuesday through Thursday are conference sessions and interactive forums. Friday concludes the symposium with more workshops and short courses. There are hundreds of technical papers presented at IMS so there is something for everyone. From all types of devices and components ranging

in frequency from MHz to Terahertz, technologists from around the world present their latest research and development. Hot topics this year will surely be 5G and IoT including wearables and automotive sensing applications. IMS casts a wide net with everything from introductory

courses to the latest technologies being developed at universities and companies. They engage everyone from experienced R&D engineers to students including a STEM program for middle and high school students.

RFIC 2016

The 2016 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium will be held May 22-24. It is focused exclusively on the latest

advances in RF, microwave and millimeter wave integrated circuit technologies and designs, as well as high frequency analog/mixed-signal designs and innovations. The RFIC conference starts on Sunday with workshops and short courses, followed by two plenary talks and a reception embedded with a joint industry showcase and interactive forum. Monday and Tuesday will have presentations of contributed papers and special lunch-time panel sessions. RFIC also has short-format original industrial-only submissions.

ARFTG 2016

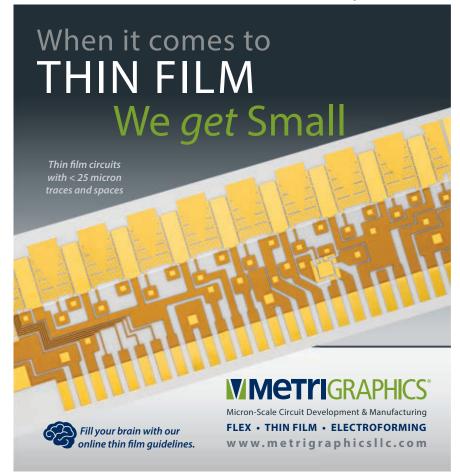
ARFTG (Automatic RF Techniques Group) will hold its 87th conference on Friday, May 27th as part of the Microwave Week activities in the Marriott Marquis Hotel. The Microwave Measurement Conference will cover electrical measurements, particularly high-frequency measurements (anything from kHz to THz), device or system modeling, and instrumentation. This includes everything from high throughput production systems to one-of-a-kind metrology measurements, complex systems or simple circuit modeling, small signal Sparameter or large-signal nonlinear measurements, phase noise or noise figure, DC or lightwave.

PANELS AND RUMP SESSIONS

There are interesting and diverse panels and rump sessions at IMS2016 including:

- "Bio-Electronics: Silicon in My Body?!" (RFIC Panel), Monday, 12:00-13:15
- "Patents: The Good, the Bad and the Ugly" (Joint RFIC/IMS Panel), Tuesday, 12:00-13:15
- "The Internet of Space: Technological and Economic Challenges for the Future Space-based Internet," Tuesday, 18:30-21:00
- "Are S-parameters Dying?," Wednesday, 12:00-13:15
- "Doing Business in China," Thursday, 12:00-13:15

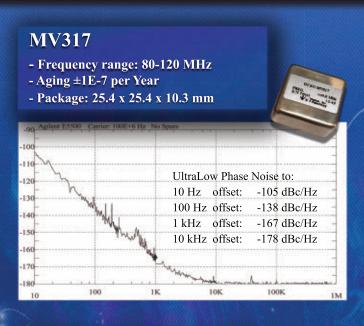
Horizon House (*Microwave Journal's* parent company) president, Ivar Bazzy, will present "Doing Business in China," sharing industry best practices from our associations in China that we have

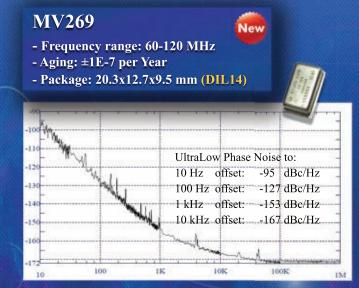


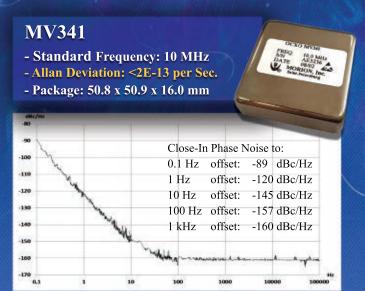


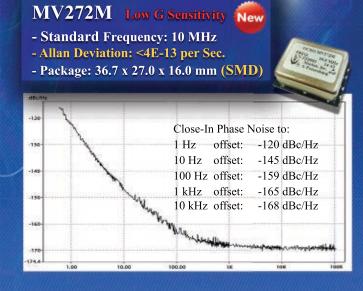
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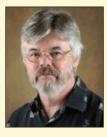
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ARFTG Conference Chair John Wood

You will find that the atmosphere at ARFTG is informal and friendly. We have technical sessions and invited speakers, an exhibition of instrument and equipment vendors, a poster session, a breakfast and awards luncheon. The oral technical sessions

at ARFTG conferences are conducted in a single-track style, with papers on topical subjects that are both theoretical and practical, address both end user and manufacturer, and cover both modeling and measurement. As well as oral presentations, authors may present their work as poster papers in the open forum that jointly runs with the vendor exhibition. The following link will give you an idea of the types of presentations given at ARFTG conferences: http://conferences.videos.arftg.org.

One of the most stimulating parts of the ARFTG experience is the opportunity to directly interact on a one-to-one basis with colleagues, experts and vendors in the RF/microwave test and measurement community. Networking is a key feature of ARFTG's conference, with ample coffee breaks to allow you to view the posters, meet the vendors and discuss their new products and measurement solutions, as well as meet up with old friends and new colleagues. Chances are you will come away with much more than you came with — maybe some new ideas to help with your current projects, some new technical contacts to use in the future and some answers to your tough questions.

The theme for this year's conference is "Measurements for

Emerging Communications Technologies." ARFTG will highlight papers on the following key topics:

- 5G, millimeter wave and THz technologies, including MIMO
- **■** High data rate optical communications
- Nanomaterials, including graphene and related materials
- Medical and biological technologies, including wearables and PANs as well as contributions in other areas of RF, microwave, and/or millimeter wave measurement techniques and technologies such as wide bandwidth measurements, nonlinear systems and power amplifier measurements and modeling, calibration techniques, deembedding and correction methods, and more.

What is ARFTG?

ARFTG is the "Automated RF Techniques Group." It is a technical organization interested in all aspects of RF and microwave test and measurement. ARFTG was originally set up in 1972 to help end-users get the most from the latest generation of test and measurement equipment; at the time, this was predominantly the vector network analyzer or VNA: a completely new instrument class. As the high frequency measurement field has continued to evolve, so has ARFTG, and it now covers the measurement space from kHz to THz, nonlinear or large signal network analyzers, signal analyzers, mixed-signal domains, signal integrity and much more. ARFTG now has more than 700 members worldwide.

ARFTG's core mission is education, and it achieves this by hosting conferences, workshops and training courses covering a wide range of topics in RF, microwave and millimeter wave measurement, and by awarding research fellowships for graduate students and sponsorships to enable students to attend.



built over the years with our *Microwave Journal China* publication and successful trade show, Electronic Design Innovation Conference (EDI CON) China.

MICROAPPS

Exhibitors get a chance to show off their technology in the MicroApps Theater that is located in the back of the exhibition hall just off center to the left. Of the more than 100 proposed topics, about 80 were selected for presentation in the MicroApps. The featured keynote/panels include:

Keynote: "Now You See Me, Now You Don't!" – A discussion on mmWave signal propagation and the implications on the design and test of next generation mobile communications systems. Mike Millhaem, 5G technical architect at Keysight is the presenter on Tuesday at 10:05.

Panel Session: "The 5G IoT Conundrum" – This panel of experts will debate possible solutions and future directions for the debate between very high speed, low latency networks, 5G networks and the opposite needs of IoT networks for

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a relatively low data rate, very low power network that can support millions of devices and sensors. This panel session is organized by *Microwave Journal* and takes place on Wednesday at 12:00.

Keynote: "Getting mmWave Products to Market and Avoiding Regulatory Issues" – Michael Marcus, founder of Marcus Spectrum Solutions LLC, presents on this topic Thursday at 09:00.

EXHIBITION

The exhibition runs from Tuesday to Thursday consisting of more than 600 companies covering the latest technologies in materials, devices, components and subsystems, as well as design and simulation software, and test & measurement equipment. The exhibition is a great place to network and see what state-of-the-art products are debuting this year. In addition to the MicroApps theater area on the exhibition floor, the Wireless Wonders Pavilion will display the latest in wearable electronics.

PRODUCT PREVIEWS

Microwave Journal reached out to some leading microwave companies and gathered the following exclusive product previews for IMS2016.

Analog Devices (ADI) (Booth 1519) will showcase a number of new products that focus on improving efficiencies in power, design time and cost to meet increasingly rigorous demands across applications in the communications, industrial, and aerospace and defense industries. ADI will feature a PLL synthesizer with integrated VCO that allows mobile network operators to improve cellular base station performance and the quality of wireless service. The new ADF4355 PLL with VCO synthesizer operates up to 6.8 GHz, a frequency band that allows significant margin to industry's current carrier frequencies. Another product is a 10 W GaN amplifier that operates between 0.01 and 1.1 GHz with ±0.5 dB gain flatness. The HMC1099 GaN amplifier is ideal for Industrial applications where GaN technology is needed to meet the

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increasing demands on battery lifetime, energy and low cost requirements while reducing the system complexity in a smaller footprint.

The HMC8100 and HMC8200 product family of intermediate frequency receiver and transmitter chips will also be featured, which offers a highly integrated compact solution for microwave radio as well as broad market RF communication applications. The T/R functionality across the broad frequency range combines the value from what were traditionally four to five separate chips into a single IC.

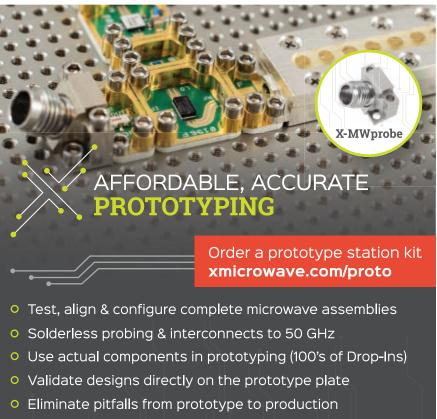
Finally, a 100 W high power microwave amplifier that covers 2 to 18 GHz will be on display. High power and small form factor are achieved using proprietary power combining GaN MMICs. Small and rugged, the solid-state high power amplifier is well suited for EW applications and the replacement of TWT amplifiers – offering long lifetime reliability, continuous 2 to 18 GHz bandwidth, and no need for a high voltage power supply.

The Ampleon (Booth 2149) name may not have appeared at IMS before but the company's expertise and technology will be familiar as this spin off from NXP Semiconductors attends the show as a uniquely focused RF power technology company for the first time. As well as highlighting its latest developments in its key traditional markets such as wireless infrastructure, broadcast and industrial, scientific and medical, the company will demonstrate the strategic growth of the A&D segment. The company's focus on the RF Energy markets will continue, enhanced by the participation of the RF Energy Alliance at the Ampleon Booth 2149.

Anritsu Co. (Booth 949) will dis-



Fig. 2 Anritsu VectorStar VNA.



Marie microwave

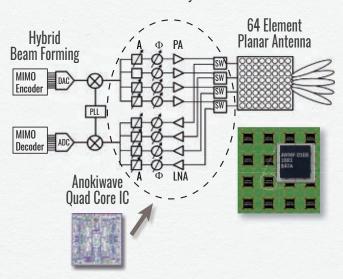


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Market	Product Family	Part Number	Description
5G Communications Antenna Arrays	Ka-Band Silicon Core IC Solutions	AWMF-0108*	Quad Core Transceiver IC
Radar and Communications AESA	X-Band Silicon Core IC and ASIC Solutions	AWS-0101 AWS-0103 AWS-0104 AWS-0105 AWMF-0106	Dual Beam Low NF Quad Core IC Dual Beam High IIP3 Quad Core IC Single Beam Low NF Quad Core IC Single Beam High IIP3 Quad Core IC Medium Power Front End ASIC
Satellite Communications AESA	K and Ka-Band Silicon Core IC Solutions	AWS-0102 AWMF-0112* AWMF-0109* AWMF-0113*	4-element Rx Quad Core IC (K-Band) 8-element Rx Quad Core IC (K-Band) 4-element Tx Quad Core IC (Ka-Band) 8-element Tx Quad Core IC (Ka-Band)

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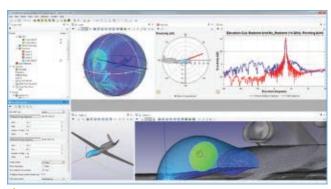


Fig. 3 ANSYS Savant.

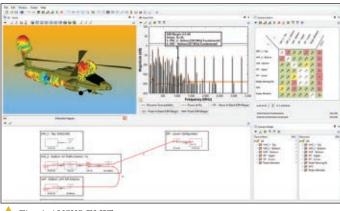


Fig. 4 ANSYS EMIT.

play the ability to make vector network analyzer (VNA) measurements of devices under test (DUT) stimulated with wideband modulated signals. Utilizing the high speed IF digitizer option in the VectorStar® VNA series (see *Figure 2*), measurements can be made with up to 200 MHz of instantaneous bandwidth in the receiver. The primary enabler of wideband VNA measurements is the Anritsu Non Linear Transmission Line (NLTL) sampler that can cap-

ture wideband modulated signals for waveform analysis. The result is the ability to perform VNA corrected modulated measurements with bandwidths up to 200 MHz and carrier frequencies up to 70 GHz with 14-bit dynamic range resolution.

Also on display will be the MS46524B 4-port Performance VNA in the Anritsu ShockLineTM VNAs. The MS46524B will be equipped with the E-Band option that makes E-Band component design and man-

ufacturing more affordable. These VNAs are also based on the Anritsu NLTL technology, which in this case enables high performance millimeter wave measurements at a lower cost than alternative technologies. In addition, the option provides a dedicated solution focused on the enhanced E-Band, allowing further cost reduction by stripping out components for unused bands.

ANSYS (Booth 1539) will feature new technology to analyze performance. installed antenna ANSYS Savant is now a part of the ANSYS HFSS design environment. Savant's industry leading Shooting and Bouncing Ray plus (SBR+) technology provides fast and accurate prediction of installed antenna patterns, near fields and antenna-toantenna coupling on electrically large platforms (see Figure 3). Savant is ideal for analyzing antennas installed on platforms and in environments that are 10s to 1000s of wavelengths in size, can compute accurate solutions with incredible speed.

ANSYS will also feature EMIT, software for predicting radio frequency interference (RFI). EMIT works hand-in-hand with ANSYS HFSS to combine RF system interference analysis with best-in-class electromagnetic simulation for modeling installed antenna-to-antenna coupling (see Figure 4). The result is a complete solution that reliably predicts the effects of RFI in multiantenna environments with multiple transmitters and receivers. EMIT's powerful analysis engine computes all-important RF interactions including nonlinear system component effects. EMIT solves radio frequency



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interference in environments ranging from large platform cosite interference to receiver desense in electronic devices.

AR (Booth 1711) has some impressive high power products that it just released (we are talking about really high powers here) — a Class A RF amplifier capable of delivering over 50,000 W with excellent harmonic performance of -40 dBc minimum. Another recent milestone is a 10,000 W linear amplifier covering the entire 80 to 1000 MHz frequency band as well as a 1 to 2.5 GHz amplifier capable of producing over 3,000 W. These products are leading the industry in energy efficiency and are capable of delivering extremely large field strengths when combined with a matched antenna. At IMS they are introducing a new series of solidstate pulse amplifier products that cover 1 to 4 GHz in various bands. These amplifiers have excellent harmonic distortion, ease of maintenance, very high MTBF and produce output powers approaching 20,000 W. Typical applications include EMC



Fig. 5 AR wideband single amplifier covering 0.7 to 6 GHz.

and radar testing.

AR is also showcasing their ultra-wideband single amplifier 0.7 to 6 GHz (see *Figure 5*), hybrid power modules and benchtop amplifiers in both Class A and Class AB designs. These single band amplifier designs incorporate the latest GaN devices, and utilize chip and wire technology, proprietary combining techniques, and are manufactured

in its recently expanded microelectronics hybrid facility. Typical applications include semiconductor testing, wireless communications, EMC, IED and EW.

CST (Booth 739) will release CST STUDIO SUITE 2016 at IMS, the latest version of the company's EM simulation software. One area that has seen particular development is antenna design and placement this has always been a crucial and fast-moving field, but with the rise of wearable electronics, V2V and the IoT, more engineers are finding that understanding the installed performance of antennas are crucial to the success of the device. In addition, technologies such as mmWave and smart antennas mean that antenna arrays now are used in numerous applications. The integration of Characteristic Mode Analysis (CMA) allows patch antenna designers to visually analyze how the geometry of the antenna and the flow of current correspond to its resonances (see Figure 6). This is particularly useful for analyzing and optimizing

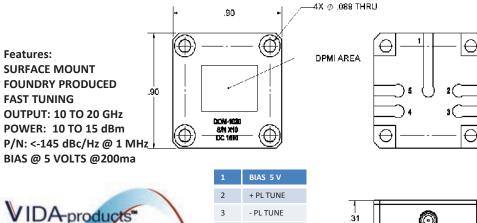
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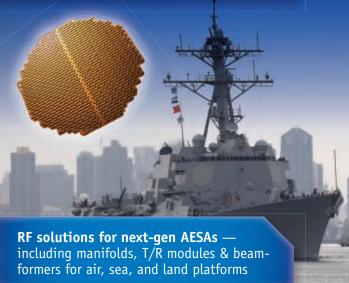
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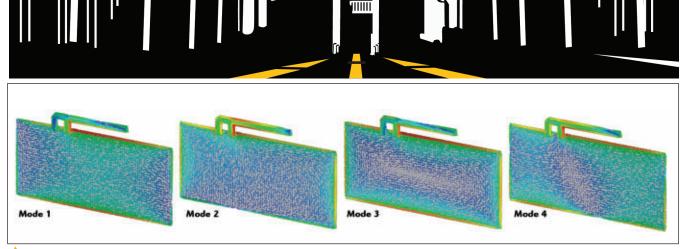
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▲ Fig. 6 CST STUDIO SUITE 2016 current flow correlation to resonances.





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integrated printed antennas, which often have to be compact and multiband to fit in a portable device.

Also, a range of new features including real ground, GPU acceleration for the ray-tracing asymptotic solver and improved workflow for hybrid antenna-platform simulations help engineers investigate the installed performance of antennas faster and more flexibly. New features in the CST array design tool also make it easier to develop antennas from creating the initial element to analyzing the installed performance of the whole device.

The Dover Microwave Products Group (Booth 1639) has developed a series of K&L Microwave® brand high power, lowpass filters for these types of requirements. Multiple design innovations reduce insertion loss, minimizing dissipated power to provide higher power handling in a relatively small package. Cutting off at frequencies as low as 460 kHz and handling up to 3.0 kW CW, the filters are remarkably compact. Two part numbers delineate the current cut-off frequency range for this series. Part number 3LL10-0.46/ XQ0.70-N/N, with 0.5 dB of insertion loss from DC to 460 kHz and 60 dB rejection at 700 kHz, was designed to handle 2.5 kW in the passband and passed qualification with 3 kW input power. Dimensions are 12.3"L $\times 3.5$ "W $\times 2.1$ "H. Part number 7LL10-100.0/XQ140-N/N



Fig. 7 K&L Microwave high power lowpass filters.



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features 0.5 dB insertion loss from DC to 100 MHz and 60 dB rejection at 140 MHz, handling 1.1 kW CW power. Size is 4.51"L \times 1.9"W \times 1.25"H. Both are quite small given frequency and power (see *Figure 7*).

The Microwave Products Group will also launch a new K&L Microwave brand Thin Film Lumped Element (TFLE) product line utilizing sputtering deposition on alumina. Inductors are realized as high im-

pedance lines, with capacitors implemented as low impedance sections or interdigitated structures. In direct coupled schemes, this approach supports fractional bandwidth beyond 60 percent of center frequency, exceeding the range of relatively narrow bandwidths typically realized with quarter-wavelength edge-coupled lines. In addition, the ability to alter the nature of the main coupled sections and to mix

1111111

inductors and capacitors allows the reduction of rejection skirt skewing effects associated with wide bandwidths. Sonnet® software and co-calibrated port capabilities facilitate optimization of performance and size during the design process.

Focus Microwaves (Booth 1349) will feature their RAPID digital tuner that is the heart of a precision, highspeed, load-pull device characterization system. The RAPID has been developed by Focus' UK subsidiary MESURO and is suitable for every phase of the design and production test cycle. This series of new digital tuner products provide performance, reliability and cutting edge features for a reasonable cost. The RAPID series is compatible with the hardware and software of existing labs, thereby allowing users to easily upgrade their existing systems.

The RAPID can be used as a standalone impedance synthesis and measurement system, or combined into a hybrid solution when paired with Focus' MPT series harmonic tuners. The passive tuners can be used to synthesize fixed harmonic impedances in a high speed fundamental active setup. With this modular configuration the user benefits from speed, increased tuning range for FO, CW, pulsed and modulated signals while reducing cost and simplifying the system (see Figure 8). The system provides full wave characterization (a1, b1, a2, b2) and DC in 20 ms per measured point. A full application programming interface (API), compatible with a large variety of commonly used compilers is available for impedance control and measurement automation. This programming library allows the user to synthesize any impedance, perform measurements from a variety of platforms.

While showcasing its wide range of RF and microwave products,

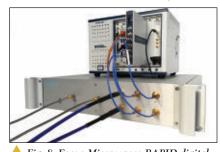
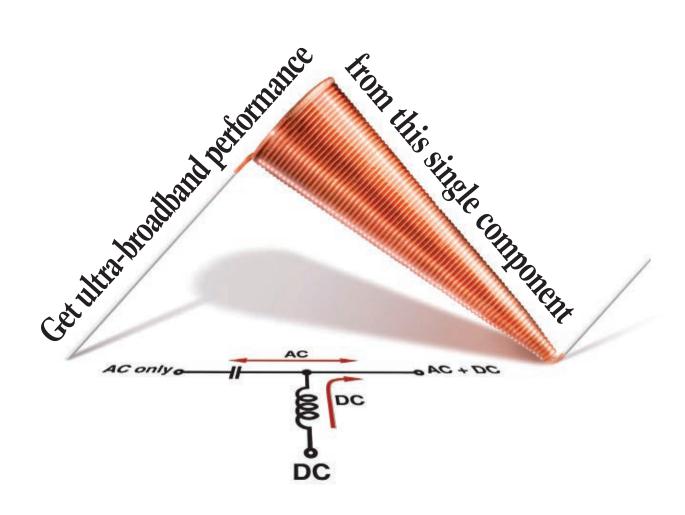


Fig. 8 Focus Microwaves RAPID digital tuner measurement system.





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HUBER + SUHNER (Booth 846) will highlight its test and measurement products together with those for space applications. An example of the company's development in the T&M sector is the SUCOFLEX®126 low loss, phase stable assembly that operates up to 26.5 GHz. This high performance microwave cable assembly offers a comprehensive connector portfolio and features optimized inner conductor construction, precise mea-

surements with high phase stability combined with low loss and excellent return loss, excellent reliability with a ruggedization that can withstand flexure and crushing reducing downtime because of increased intervals between calibrations.

For space applications, the Power Sub-Miniature (PSM) connector range combines low weight and small envelope characteristics of the SMA-connector, and the high power

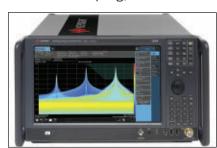


▲ Fig. 9 H+S cable assemblies, panel connectors and adaptors for space applications.

capability of the TNC-connector will be previewed before its launch in Q3/Q4. With its future proof interface, the range offers: multicarrier capability, is multipaction, corona and PIM optimized, with a multipaction threshold >1500 W in P-Band and L-Band. The offering includes cable assemblies, panel connectors and adaptors (see *Figure 9*).

Keysight Technologies (Booth 1239) will be showcasing their latest design, simulation and test solutions for wireless communications (5G, IoT, 802.11ad) and aerospace/defense (Radar, EW, Ka-Band and beyond). Visitors can meet Keysight's application experts and evaluate a range of solutions in various form factors from benchtop to modular to handheld. Keysight will be demonstrating the new X-Series signal analyzers that feature streamlined multi-touch interface, integrated 1 GHz analysis bandwidth up to 50 GHz, the widest real-time streaming up to 255 MHz bandwidth, and industry-best phase noise performance in all models (see Figure 10).

Also in the Keysight booth will be their new CX3300 Series of Device current waveform analyzers which enable the visualization of low-level current waveforms that were previously unmeasurable. The CX3300 series will be used by R&D engineers designing IoT devices and modules (i.e., ultra low power modules) and provide 150 pA minimum measureable current, 1 GHz maximum sampling, 14-bit or 16-bit



▲ Fig. 10 Keysight X-Series UXA signal analyzer.

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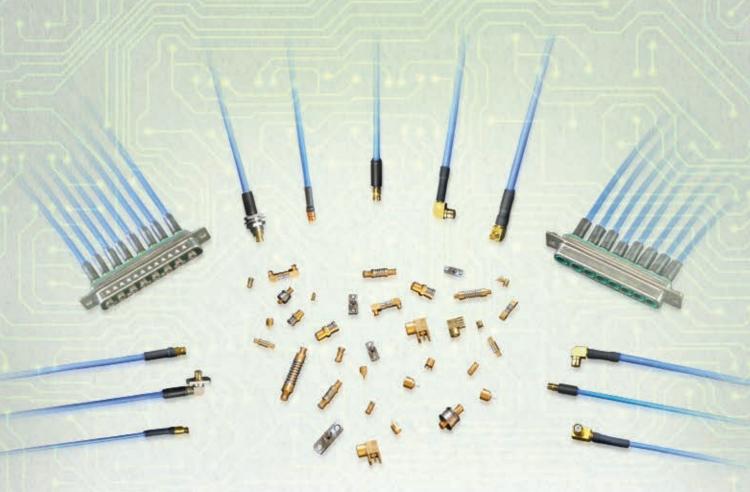
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MACOM (Booth 939) will introduce its MAGb series of GaN power transistors for use in wireless macro base stations (see *Figure* 11). Leveraging Gen4 GaN technology, MACOM's new MAGb series are the industry's first commercial base station-optimized GaN transistors to achieve performance parity with expensive and GaN on silicon

carbide-based products at a LDMOS like cost structure, with path to better than LDMOS cost. The MAGb series of power transistors target all cellular bands within the 1.8 to 3.8 GHz frequency range. Initial entries in the product series include single-ended transistors providing up to 400 W peak power in small packages, dual-transistors, and single-package Doherty configuration providing up to 700 W peak power



Fig. 11 MACOM GaN power transistors for macro base stations.

in both symmetric and asymmetric power options. This product series delivers power efficiency improvement of up to 10 percent and package size reduction greater than 15 percent over legacy LDMOS offerings.

Maury Microwave (Booth 1139) will address today's demanding commercial telecom and military communication measurement challenges, including the analysis of wider bandwidths and more complex modulation schemes. Maury's new MT2000E4-series 40 GHz multi-harmonic mixed-signal active load-pull system is unique in its ability to control up to 240 MHz of instantaneous



Fig. 12 Maury Microwave multi-harmonic mixed signal active load-pull system.



Fig. 13 Maury Microwave ColorConnect

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bandwidth for wideband modulated signals between 700 MHz and 40 GHz (see Figure 12). The MT2000E4 is ideal for LTE, WCDMA, WLAN, 802.11ac, X-, Ku-, K- and Ka-Band communication protocols.

In addition, the company will feature its ColorConnectTM line of interconnect solutions, including StabilityTM and UtilityTM microwave/RF cable assemblies, precision adapters, attenuators and

torque wrenches. ColorConnect is the industry's only comprehensive line of color-coded interconnects that enable easy identification of compatibility (see Figure 13). The benefits of using ColorConnect include the prevention of damage to equipment due to compatibility mismatch, a greater confidence in connector identification and use, and financial savings in training time and costs.

Instruments National (Booth 1529) will be featuring new products that address the entire product lifecycle - from initial design to manufacturing test. NI AWR Design Environment demonstrations will feature advances in NI AWR software automation and tool interoperability. The most recent release of the open platform supports enhanced management of design/result data and simulation control between Microwave Office and EM simulation technologies, including AXIEM and Analyst or third-party tools such as ANSYS HFSS and Sonnet EM. With its innovative EM Socket II technology, NI AWR Design Environment offers seamless uni- and bidirectional data flows between the Microwave Office circuit framework and supported EM solvers, allowing engineers to define their chip/package/ module designs, specify simulation parameters and review results all from within a single user interface. This new capability supports a number of operations ranging from a single embedded EM simulation to more robust yield/corner analyses of 3D structures. Results are automatically integrated with active devices in the circuit hierarchy for nonlinear simulations, optimization and circuit verification without users needing to manually import/export EM design data.

In addition to EDA tools, NI will be demonstrating its industry leading solutions for RFIC test — from lab-based characterization systems to high-volume manufacturing test solutions. NI's PXI-based RFIC test system combines its vector signal transceiver (VST), high-speed digitizer, and source measure unit (SMU) technology into an integrated system for WLAN, UMTS, and LTE power amplifier test. In version 2.0 of the RFIC Test Software NI has added LTE-advanced multicarrier support,



Fig. 14 NI PXI RF Vector Signal Transceiver.



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with EVM and ACP measurements on up to five component carriers. In addition, the new version natively integrates NI's SMU technology for integrated power added efficiency (PAE) measurements.

Finally, NI will be introducing the industry's first measurement solution for 802.11ax or high-efficiency Wi-Fi (HEW) devices. The system is based on NI's PXI RF vector signal transceiver (VST), which offers 200

MHz of bandwidth at frequencies of up to 6 GHz (see *Figure 14*). The new 802.11ax measurement suite supports narrower subcarrier spacing, 1024-QAM, and Orthogonal Frequency Division Multiple Access (OFDMA). The software is based on the latest draft of the 802.11ax specification revision.

NXP (Booth 1839) will feature solutions for cellular infrastructure, industrial and military markets to

help accelerate RF design. NXP RF Military adds to its high performance GaN offering by introducing five new products covering output powers from 12 to 250 W CW, which are suitable for narrowband and multi-octave amplifiers, radar, EW jammers and EMC testing up to 2.7 GHz. The four lower power transistors are in NXP's plastic OM270 package which offers excellent thermal performance. In addition, NXP RF military announces a new 1000 W LDMOS RF transistor for 1.2 to 1.4 GHz L-Band primary radar applications, and is suitable for long pulse applications with large duty cycle. For S-Band radar there is a new 60 W and > 500 W wideband 2.7 to 3.5 GHz GaN RF transistors in NXP's plastic OM270 package which offers excellent thermal performance. Finally, NXP RF Military expands its L-Band RF LDMOS transistors targeted for IFF, DME and TACAN applications. This portfolio expansion includes a 250 W, 2-stage RF plastic IC for IFF transponders, offering an ideal solution for size and weight sensitive applications such as UAVs. Also available are a 1 kW wideband 960 to 1215 MHz transistor suitable for long pulse applications with large duty cycles, and a 1.5 kW narrowband 1030/1090 MHz transistor for IFF secondary

Peregrine Semiconductor (Booth 2129) will be highlighting their UltraCMOS PE41901 and PE41902 high-frequency mixers that operate from 10 to 19 GHz. The PE41901 is an up-conversion mixer with an integrated LO coupler, and the PE41902 is a down-conversion mixer with an integrated LO combiner and RF cou-

radar.



Fig. 15 Peregrine high frequency mixers.

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pler (see *Figure 15*). These complete MMIC mixer solutions are ideal for test & measurement systems and Ku-Band earth terminals such as VSAT and point-to-point communication systems.

Another featured product includes the UltraCMOS® PE46130 and PE46140 that join the PE46120 MPAC product family in offering phase and amplitude control for Doherty power amplifier ap-

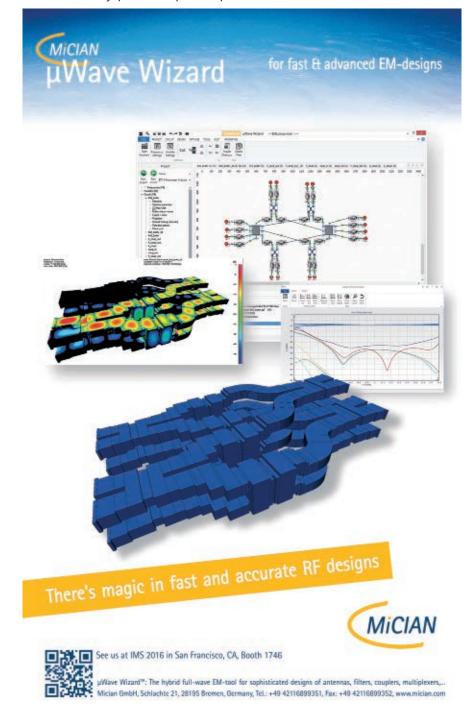
plications. The PE46130 provides excellent phase and amplitude accuracy from 2.3 to 2.7 GHz, and the PE46140 extends from 3.4 to 3.8 GHz. Each monolithic phase and amplitude controller (MPAC) integrates a 90-degree hybrid splitter, digital phase shifters, digital step attenuator and a digital SPI interface on a single die.

Rohde & Schwarz (Booth 1827) will introduce and showcase a vari-

ety of barrier breaking test and measurement instruments. For wideband communication standards such as 5G or IEEE 802.11ad, R&S will showcase new capabilities for the R&S®SMW200A vector signal generator, which is the first to offer an internal modulation bandwidth of 2 GHz with a frequency range all the way up to 40 GHz. There is also the R&S®FSW signal and spectrum analyzer which is the first offering frequency ranges up to 85 GHz, an analysis bandwidth up to 2 GHz, and a real time bandwidth of up to 512 MHz. For the automotive industry, in addition to the above mentioned 85 GHz signal and spectrum analyzer, Rohde & Schwarz has introduced the ARTS — Automotive Radar Target Simulator, that allows customers to simulate variable distance, variable speed, variable direction and variable size targets, and test their products (radar sensors) as these would operate in the real world.

Also new is the R&S®FSWP phase noise analyzer and VCO tester that now supports phase noise analysis up to 50 GHz in a single platform. It combines low noise internal sources and cross correlation technology, delivering extremely high sensitivity for phase noise measurements. As a result, it takes just seconds to measure even highly stable sources such as those found in radar applications. Other presentations include VNA's and an up-converter for terahertz applications for up to 750 GHz, a new lineup of fast and accurate USB and LAN power sensors up to 50 GHz. and new handheld spectrum analyzer and oscilloscopes that are equally capable of addressing measurement needs in the field and in the lab.

Rogers Corp. (Booth 2039) will be featuring TC350TM laminates that are for designers seeking a cost effective high thermal conductivity PTFE material. These materials are designed for applications where high power RF signals demand improved PCB thermal management. With a combination of low loss tangent (0.0020 at 10 GHz), high z-axis thermal conductivity (1.0 W/m°K), low z-axis CTE (23 ppm/°C), and excellent temperature phase stability (-9 ppm/°C), TC SeriesTM laminates enable improved performance and





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reliability in high power applications. TC Series materials are ideal for high volume applications with panel sizes available as large as 48"×54". TC Series materials are often chosen for applications such as power amplifiers and devices such as couplers, combiners and dividers.

In addition, Rogers will feature RO4700JXRTM series antenna grade laminates were designed for use in base station, RFID and oth-

er antenna designs and combine low-loss dielectric with low-profile copper foil for reduced passive intermodulation (PIM) and low insertion loss. The specially formulated RO4700JXR thermoset resin system incorporates a hollow microsphere filler resulting in a light weight, low density laminate, which is approximately 30 percent lighter weight than woven-glass PTFE materials. In addition, RO4725JXRTM

IIIIIII



Fig. 16 Skyworks BLE front-end module.

(2.55 Dk) & RO4730JXRTM (3.0 Dk) laminates provide a lower cost solution for high frequency circuit boards used in base station and other antennas. RO4700JXR laminates feature a low Z-axis coefficient of thermal expansion (CTE of <30 ppm/°C) for design flexibility. With a TCDk <40 ppm/°C, the laminates provide consistent circuit performance regardless of short term temperature variations.

Skyworks (Booth 1611) will be featuring two low-power Bluetooth® low energy (BLE) front-end modules (FEM) for connected home, wearable and industrial applications. The SKY66110-11 and SKY66111-11 FEMs (see Figure 16) operate between 2.4 to 2.485 GHz, with power consumption of only 10 mA in transmit mode. They are suitable for products operating from coin cell batteries including sensors, beacons. smart watches. thermostats. smoke and carbon dioxide detectors, wireless cameras and audio headphones, hearing aids and medical pendants. The FEMs more than double the range when compared to a stand-alone system on chip solution. The SKY66111-11 FEM features adjustable output power. Each device comes in a small footprint 3 mm \times 3 mm \times 0.8 mm, 16-pin multichip module solution. They will also introduce a step-down regulator with auto-bypass and low drop out that controls the operating voltage for multimode, multiband WDCMA or GSM/EDGE power amplifiers, delivering optimum efficiency for all operating states. Targeted for smartphones, mobile/cellular phones, wireless data cards, and portable media devices the SKY87000-13 integrates a bypass linear regulator that further improves system performance.



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Frequency: 1380 - 1420 MHz

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Power: 1 dBm (typ)

Operating Temp: -40 to 85°C Dimensions: 0.2" x 0.2" x 0.038"

RFS4300Z-LF | PLO w/ Internal Ref. for Radar

Frequency: 4300 MHz

Phase Noise: -85 dBc/Hz @ 10 kHz offset

Supply Requirements: 5 Vdc @ 60 mA

Power: 3 dBm (typ)

Operating Temp: -55 to 105°C Dimensions: 1.0" x 1.0" x 0.235"



SFS14400H-LF | PLO w/ External Ref. for Satcom



Frequency: 14400 MHz

Phase Noise: -98 dBc/Hz @ 10 kHz offset

Harmonic Suppression: -30 dBc (typ)

Reference Suppression: -65 dBc (typ)

Reference Input: 100 MHz Dimensions: 1.0" x 1.0" x 0.235"

CRO6950Z-LF | VCO for Satcom

Frequency: 6945 - 6955 MHz

Phase Noise: -104 dBc/Hz @ 10 kHz offset

Harmonic Suppression: -40 dBc (typ)

Power: 3.5 dBm (typ)

Operating Temp: -40 to 85°C

Dimensions: 0.866" x 0.63" x 0.22'





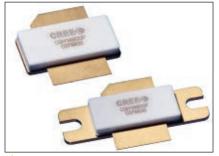
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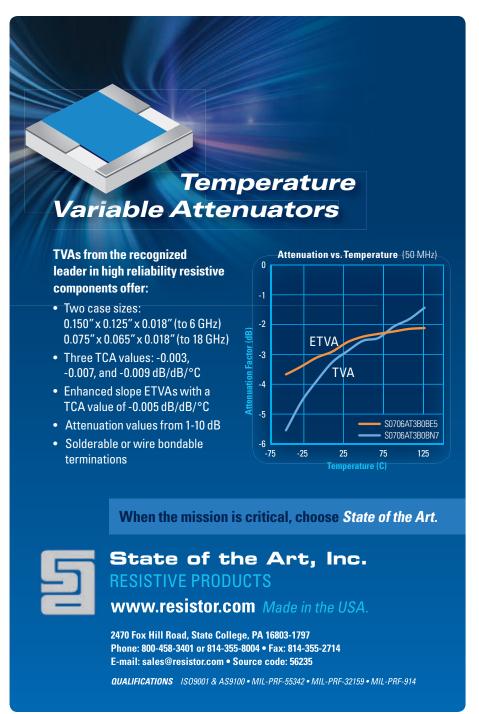




A Fig. 17 Wolfspeed 800 W GaN device.

Wolfspeed (a Cree Company, Booth 1621) will introduce a new 50 V, 800 W GaN HEMT device that provides high output power for L-Band radar applications. Live demonstrations are scheduled to take place in their booth. The CGHV14800 is an input and output matched GaN HEMT with a circuit for pulsed applications from 1.2 to 1.4 GHz. Utilizing a Class A/B circuit, the 50 V device

provides 13 dB gain, 70 percent drain efficiency and 850 W output power at pulsed PSAT, with a 3 µs pulse width and 3 percent duty cycle (see *Figure 17*). The product is available in metal-ceramic flange and pill packages. The export classification is EAR99. The part will be available for purchase, including the evaluation board, from Digi-Key and Mouser in the second half of 2016. ■







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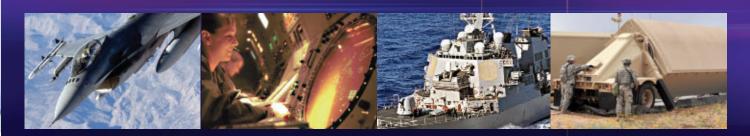
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OCTAVE DA	ND LOW N	OICE AMADI	IFIFDC			_
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power -out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
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	1.1 MAX, 0.95 TYP 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		+20 dBm	2.0:1
			MEDIÚM POV			
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 CA34-2110	2.7 - 2.9 3.7 - 4.2	29 28	0.7 MAX, 0.5 TYP 1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm +20 dBm	2.0:1 2.0:1
CA56-3110	5.4 - 5.9		1.0 MAX, 0.5 TYP	+10 MIN +10 MIN	+20 dBm	2.0.1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN +10 MIN	+20 dBm	2.0.1
CA910-3110	9.0 - 10.6	40 32 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			+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.0 MAX, 3.0 TYP 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		30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	4.5 MAX, 3.5 TYP 5.0 MAX, 4.0 TYP 4.5 MAX, 3.5 TYP 5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.U MAX, 5.5 IYP	+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
			TAVE BAND A		0 10 1 100	VCMD
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power -out @ P1-dB		VSWR
CA0102-3111 CA0106-3111	0.1-2.0 0.1-6.0	28 28	1.6 Max, 1.2 TYP 1.9 Max, 1.5 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 2.0:1
CA0108-3111	0.1-8.0	26		+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	32 36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2 0 MAY 1 5 TVP	I 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	5.0 MAX, 3.5 TYP 5.0 MAX, 3.5 TYP 5.0 MAX, 3.5 TYP 3.5 MAX, 2.8 TYP 5.0 MAX, 3.5 TYP	+10 MIN		2.0:1
CA218-4110	2.0-18.0				+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
	MPLIFIERS	nnut Dynamic Pe	ango Outnut Power	Dango Deat Dow	or Elatnoce dD	VSWR
Model No. CLA24-4001	Freq (GHz) 2.0 - 4.0	-28 to +10 dB	ange Output Power	1 dRm	/- 1 5 MAY	2.0:1
CLA24-4001	2.0 - 6.0	-28 to +10 dB -50 to +20 dB	m ±14 to ±1	8 dRm ±	/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dB	m +14 to +1	9 dBm +	/- 1 5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dB	m +14 to +1	1 dBm + 8 dBm + 9 dBm + 9 dBm +	/- 1 5 MAX	2.0:1
	WITH INTEGR		TTENUATION	, dbiii	7 1.5 1100	2.0.1
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB) Pov	ver-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 6.0-12.0	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 .2 MAX, 1.6 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A		ZJ Z.	Z MAA, 1.0 111	+10 //IIIV	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0		.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1
	ENCY AMPLIF	Gain (dB) MIN	Noico Figuro dD	Power-out @ D1 JD	3rd Order ICP	VSWR
Model No. CA001-2110	Freq (GHz) 0.01-0.10	18 18	Noise Figure dB 4.0 MAX, 2.2 TYP	Power-out@P1-dB +10 MIN	+20 dBm	2.0:1
CA001-2110	0.04-0.15	24	3.5 MAX, 2.2 TYP	+10 MIN +13 MIN	+20 dBm	2.0.1
CA001-2211	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, 2.2 TYP 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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DefenseNews Cliff Drubin, Associate Technical Editor

Cockroach-Inspired Robotics Research Opens Doors for Military and Civilian Missions



nupported by the U.S. Army Research Laboratory, researchers from the University of California, Berkeley, have developed a small, crawling robot that mimics a cockroach's ability to squeeze through confined spaces. A report on this work, written by UC Berkeley researchers Dr. Kaushik Jayaram and Dr. Robert Full, is featured in the latest edition of "Proceedings of the National Academy of Sciences," the academy's official scientific journal.

According to the publication, cockroach exoskeletons inspired UC Berkeley researchers to manufacture an origami-style, soft, legged robot that can move around rapidly in both open and confined spaces. These spaces include rubble generated by natural disasters and explosions that first responders may not be able to access in emergency situations. The robot, which is palm-sized, is known as CRAM for "compressible robot with articulated mechanisms.'

While currently a prototype, researchers see great possibilities for this insect-inspired technology, which will be tested in real-world disasters when a more robust version is developed. The research is supported by ARL's Micro Autonomous Systems and Technology, commonly referred to as MAST, Collaborative Technology Alliance, which involves researchers from the Army, industry and academia.

Dr. Brett Piekarski, cooperative-agreement manager of the MAST CTA, said its goal is to develop and explore the underpinning science to enable increased situational awareness for the dismounted soldier in complex, realworld environments by enabling increased autonomy, collaboration, and mobility of micro-aerial and ground-based autonomous systems.

"The research at UC Berkeley is exploring bio-inspired mobility and control methods that can be applied to future Army autonomous robotic systems," Piekarski said. "Over



Source: ARL

the course of the program, they have performed research in many areas from how insects can maneuver and transition over and through varying surfaces, to how lizards use their tails to maintain stability over rugged terrain or to maneuver rapidly, to bio-inspired self-righting technologies that have led to a joint project with ARL, and to the focus of the recent paper on how cockroaches maneuver through verv small cracks."

Piekarski said all of these studies are providing exciting new discoveries that will lead to new innovations in how future micro-autonomous systems will operate and rapidly maneuver through very complex 3-D terrains.

Ultra Wideband Sensor Capability to be **Provided to US Navy**

he Office of Naval Research has awarded BAE Systems an \$11 million contract to develop next-generation electronic warfare (EW) technology that will quickly detect, locate and identify emitters of radio frequency signals. Known as the Full-Spectrum Staring Receiver (FSSR), this technology will enable near-instantaneous battlespace situational awareness, emitter identification and tracking, threat warning and countermeasure, and weapon cueing. Conventional situational awareness systems are not able to deliver the high level of coverage and responsiveness that FSSR will provide.

"The Full-Spectrum Staring Receiver program integrates a complementary array of innovative technologies into a comprehensive demonstration capability that closes a widening gap for a range of Navy ships and aircraft," said Steve Hedges, FSSR principal investigator at BAE Systems. "By subjecting the FSSR demonstrator to realistic, complex electromagnetic environments, we can demonstrate how these discrete innovations combine to enable an effective EW system capability."

With FSSR, U.S. Navy ships will be constantly aware of threat emitters over a very broad span of the electromagnetic spectrum. This effort is part the ONR's Electronic Warfare Discovery & Invention Program, which seeks to develop and demonstrate a broad range of next-generation electronic warfare systems that exploit, deceive, or deny enemy use of the electromagnetic spectrum while ensuring its unfettered use by friendly forces. As the prime contractor on FSSR, BAE Systems brings its electronic warfare system domain expertise, threat characterization and identification processing, and system design and integration knowledge.

"I am particularly excited by this research effort because it integrates a number of electronic warfare technologies that have been advanced by ONR-funded efforts dating back to 2008," said Dr. Peter Craig, electronic warfare program officer for ONR. "Even more gratifying is that it brings together the talents of researchers from academia, industry and the government in a coordinated effort that will benefit not only the Navy but the entire Department

of Defense community."

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Other members of BAE Systems FSSR team include the S2 Corp., University of Colorado Boulder, Montana State University, Purdue University, HRL Laboratories and the Naval Research Laboratory.

SM-6 Shatters Engagement Distance Record

his recent test series, supported by the Cooperative Engagement Capability, validated the tactical warfighting capability of SM-6 by demonstrating both maximum down range and a maximum cross range intercepts in over-the-horizon, engage-on-remote missions.

"These tests demonstrate the full warfighting potential of SM-6 and its proven multi-mission value," said Dr. Taylor Lawrence, Raytheon Missile Systems president. "The versatility of SM-6 makes it deployable on 60 surface combatants in the fleet, providing additional layers of capability and protection."

The USS JOHN PAUL JONES (DDG 53), configured with AEGIS Baseline 9.C1, executed the series of four missions with five SM-6 missiles for follow-on operational test and evaluation, part of the final testing leading to a likely declaration of full operational capability in 2017.

The USS GRIDLEY (DDG 101) was on station to perform as the AEGIS assist ship for the engage-on-remote missions. The tests also proved the ability of SM-6 to



U.S. Navy Photo

conduct complex, multiple target scenarios.

SM-6 is a key component of the U.S. Navy's Naval Integrated Fire Control – Counter Air mission, providing U.S. Navy sailors and their vessels extended range protection against fixed and rotarywing aircraft, unmanned aerial vehicles, cruise and ballistic missiles.

The SM-6 deployed for the first time in 2013, and Raytheon has delivered more than 250 missiles. The missile's final assembly

takes place at Raytheon's state-of-the-art SM-6 and SM-3 all-up-round production facility at Redstone Arsenal in Huntsville, Ala.

SM-6 delivers a proven over-the-horizon air defense capability by leveraging the time-tested advantages of the Standard Missile's airframe and propulsion:

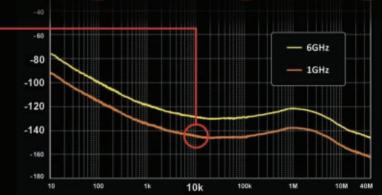
- The SM-6 uses both active and semiactive guidance modes and advanced fuzing techniques.
- It incorporates the advanced signal processing and guidance control capabilities from Raytheon's Advanced Medium-Range Air-to-Air Missile.
- SM-6 delivers multi-mission capability for long range Fleet Air Defense and Sea-Based Terminal Defense.

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Build your own solution with UMS

InternationalReport

Richard Mumford, International Editor



he RF Energy Alliance (RFEA) has released its initial solid-state RF energy (SSRFE) specification, "The RF Power Amplifier (PA) Roadmap: Residential Appliances." The document marks the first time cross-value chain representatives have collectively defined and specified current and future SSRFE PA modules. Notably, the roadmap demonstrates that PA modules can be cost competitive to current magnetron-based solutions within a decade. This establishes mass-market viability of what has been considered a cost-prohibitive and complex technology.

"...exceptional culinary experiences with remarkable energy efficiency."

A clean, highly efficient and transformative heating and power technology, SSRFE is commonly understood as an alternate power source for magnetron-powered applications (e.g., microwave furnace). Spearheaded by Ampleon, E.G.O. Group, Huber+Suhner, ITW, Rog-

ers Corp. and Whirlpool R&D, the roadmap sets parameters for five PA module generations targeting cooking applications. More than 40 characteristics are defined per module, ranging from operational lifetime requirements and environmental conditions over efficiency and size to RF output and interface standards.

"The RF Energy Alliance views this roadmap as the first agreed-upon approach to solid-state RF energy design," said Dr. Klaus Werner, executive director, RFEA. "You'll soon see elegantly designed cooking appliances delivering exceptional culinary experiences with remarkable energy efficiency. What's more exciting, though, is what comes next as RFEA continues to build on this foundation. We're at a critical turning point for many power- and heat-dependent industries as we've just begun to tap the true potential of solid-state RF energy."

"The RF PA Roadmap: Residential Appliances" is available only to Alliance members and the roadmap's companion document, "The RFEA System Architect's Guide," is slated for release in Q2 of 2016.

GSA Confirms LTE Passed One Billion Subscriptions

he Global mobile Suppliers Association (GSA) confirms that LTE continues to grow faster than any other mobile communications system technology and is now responsible for 1 in 7 mobile connections worldwide. LTE gained almost 156 million connections in Q4 2015, which is 75 percent more than 3G/HSPA systems. The number of LTE and LTE-Advanced subscriptions is

expected to pass the 3G/WCDMA-HSPA global total in 2020. GSM subscriptions fell by 141 million in the quarter.

Analyzing mobile subscriptions data provided to GSA by Ovum Ltd. for Q4 2015, GSA noted that the number of LTE and LTE-Advanced subscriptions reached 1.068 billion worldwide by 31 December 2015. A total of 552.2 million LTE subscriptions worldwide were gained during the past year, representing 107 percent annual growth.

APAC, with over 580 million LTE subscriptions, further grew its share of global LTE subscriptions to 54.3 percent. By December 2015 China had passed 386 million LTE subscriptions, adding almost 84 million in Q4 alone. North America remains the second largest LTE market with al-

most 237 million, though its share of the world market further declined to 22.2 percent of the global total. The European share remained in the mid-teens (14.8 percent).

Strong growth was recorded again in the Latin America and Caribbean ...there will be 550 commercially launched LTE networks by end 2016.

region having more than quadrupled its number of 4G/LTE subscriptions to over 54 million. More than one million LTE subscriptions were added during each month in the Middle East and the region now has 32.5 million LTE subscriptions, having achieved an annual growth of around 110 percent. Russia has over 11.7 million LTE subscriptions.

480 operators have commercially launched LTE systems in 157 countries, according to GSA data announced on January 25, 2016. GSA forecasts there will be 550 commercially launched LTE networks by end 2016.

More than 1 in 3 operators are investing in LTE-Advanced system deployments, with the commercialisation of carrier aggregation the first feature to be exploited. 116 operators, i.e. over 24 percent of all LTE operators, have commercially launched LTE-Advanced service in 57 countries.

IMT-2020 Makes Progress in Developing 5G Standard

n 26 February 2016 the International Telecommunication Union (ITU) group engaged with developing International Mobile Telecommunication (IMT) systems—ITU-R Working Party 5D—met in Beijing, China, to further develop IMT-2020, the standard for 5G mobile systems.

This was the first meeting of ITU-R Working Party 5D following the decision of the World Radiocommunication Conference 2015 (WRC-15) to identify and harmonize spectrum for operation of IMT systems in frequency bands below 6 GHz. WRC-15 also requested ITU-R to study potential use of additional spectrum above 6 GHz for IMT, and the results of those studies will be considered at the next WRC in 2019.

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ITU is continuing to work closely with administrations, network operators, equipment manufacturers and national and regional standardization organizations to include today's 5G research and development activities in the IMT-2020 global standard for mobile broadband communications.



"Following additional spectrum allocations for mobile during the World Radiocommunication Conference in late 2015, ITU is continuing to work in close collaboration with governments and the global mobile industry to make rapid progress in bringing

make rapid progress in bringing the vision of IMT-2020 to fruition," said ITU Secretary-General Houlin Zhao. "Future steps in 5G mobile technology are aimed at a new paradigm of connectivity among people and things in a smart, networked environment encompassing big data, applications, transport systems and urban centres."

"5G has already become the research and development focus of global industry," said Liu Lihua, Vice Minister, Ministry of Industry and Information Technology (MIIT) of the People's Republic of China. "The development of IMT-2020 is speeding up and the ITU-R WP5D is playing a key role in international standardization and global spectrum issues related to 5G."

TDIA of China Renews Commitment to TTCN Work

aving one comprehensive set of 3GPP conformance test cases for TD-SCDMA and TD-LTE devices has been made possible thanks to the manpower provided by the Telecommunication Development Industry Alliance (TDIA) of China, within the 3GPP Task Force 160 (TF160). In 2016, the TDIA will again provide experts to TF160 to develop TTCN-3 test cases for LTE-Advanced Pro, prioritizing NB-IoT, the new Internet of Things technology from 3GPP.

Olivier Genoud, the TF160 Leader said, "Conformance test cases specification and implementation will need to come swiftly in order to align with the IoT indus-



trial priorities. TDIA experts within TF160 are again set to play a key role in ensuring the on-time delivery of high quality conformance test cases to meet this need."

TF160 maintains a set of over 3000 conformance test cases, adding up to 200 new tests per year. These tests are in turn used by Certification Fora such as GCF and PTCRB to certify the compliance of mobile devices (e.g., smartphones) against the 3GPP standards.

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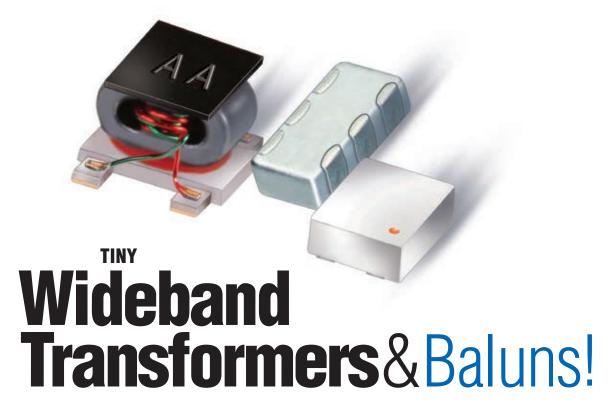




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CommercialMarket Cliff Drubin, Associate Technical Editor

IoT 2016 Predictions

ccording to the Strategy Analytics Internet of Things (IoT) Strategies latest report, IoT will be *the* defining trend of the next decade, impacting virtually every vertical industry and permeating the vast majority of business processes.

Services, security, big data analytics and connectivity, particularly low power telecoms, will all play prominent roles as IoT mainstream deployments and usage increases over the next 12 months. Merger and acquisition activity (M&A), followed by inevitable consolidation will continue brisk throughout 2016 as large, established vendors strengthen their core capabilities and expand their IoT presence.

"This will be a watershed year for IoT deployments as practical actions take precedence over hype," noted Laura DiDio, IoT Systems Research and Consulting director.

Services, security, analytics and low power connectivity drive IoT adoptions.

"Embedded security, data analytics and services enablement will be essential for organizations to realize IoT's full benefits and economies of scale," she added.

"IoT is imperative in the shift from selling products to services and, conse-

quently, a shift from Capex to Opex. In 2016, IoT will continue to ramp up as increasing numbers and diverse types of devices become connected, driving a range of 'as-a-service' business models," noted Andrew Brown, executive director of Enterprise and IoT Research, and author of the report.

Highlights:

Security will be a crucial issue for vendors, consumers and corporations. SA's IoT 2016 Security Threats and Trends Survey found that 56 percent of organizations experienced a security breach. However, only 6 percent of survey respondents were able to identify and thwart hacks in advance. In interconnected IoT systems, the risks associated with a successful hack can cause greater collateral damage

Big data analytics is *the* differentiator in IoT. Analytics software revenues are projected to reach \$40.4 billion worldwide in 2015 and double to \$81.1 billion by 2022, exclusive of service revenues.

Low power trends are hot. The standardized 3GPP path to narrow band IoT via LTE-M with Release 13 is expected to provide real competition to LPWA vendors in the market, offering reduced device costs, reduced power consumption, extended coverage and the ability to handle large numbers of devices.

Merger and acquisition activity will continue to accelerate unabated in 2016. Recent acquisitions of Altair by Sony and Jasper Technologies by Cisco have already topped \$1.6 billion and demonstrate that IoT is now table stakes. IoT M&A activity could potentially reach \$20 billion in 2016.

IoT in Smart Cities Market Worth \$147.5B by 2020

he Internet of Things (IoT) in smart cities market size is estimated to grow from \$51.9 billion in 2015 to \$147.5 billion by 2020, at an estimated compound annual growth rate (CAGR) of 23.2 percent during the forecast period, according to ASDReports. The major growth drivers of this market include increasing demand for intelligent cities globally and the rising demand for IoT devices. More than 200 smart city projects across the globe provide huge opportunities in this market for IoT vendors, service providers, platform providers and consulting companies.

The market smart city has considerably grown over the past few years and the emergence of disruptive technologies such as IoT and connected devices has further augmented the opportunity areas for IoT in smart cities. The advancement in IoT technologies, cloud-based platforms, and services are marked with increasing IoT application has led to significant investment in smart cities. The development of smart devices such as smart meters, home gateways, smart appliances and smart plugs would also act as an opportunity for the IoT in smart cities market. Government policies, privacy and security issues, inadequate financial incentives for utilities and interoperability and standard interface are the major restraints of the overall growth of this market.

The IoT in smart cities market has been segmented into

solutions, services, technologies, platforms and applications. The data management and location analytics solution sub segment is projected to grow at a high growth rate and present good market opportunity during the forecast period. System inte-

North America is expected to hold the largest market share and dominate the IoT in smart cities market...

gration services hold a major share in the IoT smart cities services segment. The increasing integration of ICT and IoT with different industries is considered as the primary driver influencing the growth of the IoT in smart cities services market.

North America is expected to hold the largest market share and dominate the IoT in smart cities market from 2015 to 2020, with the growing number of smart city projects and increasing grants from the U.S. government. Asia-Pacific, the Middle East and Africa offer potential growth opportunities due to large-scale infrastructure development and growing number of smart city projects.

The major vendors covered in the IoT in smart cities market for this study include Bosch Software Innovation, Cisco Systems Inc., Huawei Technologies, IBM Corp., Intel Corp., Schneider Electric, SAP SE, Symantec Corp., ThingWorx and Verizon Communications.

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Global Penetration of OEM Telematics in New Passenger Cars to Exceed 72 Percent by 2021



BI Research forecasts the global penetration of embedded and hybrid factory installed OEM telematics in new passenger cars to exceed 72 percent by 2021. Growth will mainly be driven by key volume car OEMs in the U.S., European Union and China markets. Brands within these markets showing accelerated growth include GM, which expects to reach 12 million OnStar subscribers globally by the end of 2016, including its Opel brand in Europe and Cadillac in China; and Ford, which claims to have already 15 million SYNC-equipped vehicles on the road worldwide.

"While lower cost hybrid approaches remain attractive to end users, a clear trend toward embedded solutions can be observed, as illustrated by Ford's recently announced SYNC Connect," says Dominique Bonte, managing director and vice president at ABI Research. "At the same time, embedded solutions are made more affordable through shared data plans, allowing customers to avoid purchasing a separate connected car data plan by adding allowing their connected cars to existing plans."

The rising embedded solutions trend is resulting in fierce competition among carriers vying to capture lucrative connected car market share in an increasingly saturated mobile environment. While in the U.S., AT&T and Verizon are pitched against each other, Vodafone, T-Mobile and Telefonica are competing in Europe. Meanwhile in China, major carriers are also actively targeting the automotive segment.

"Despite major market growth in OEM telematics, cyber security continues to remain a challenge..."

The strong expected growth of OEM connected car solutions is due to a number of factors, which include eCall mandates in the EU and Russia, increasing user awareness about safety, and improved value propositions through additional services such as UBI, preventive maintenance, and remote control capabilities via smartphones and wearables.

Additionally, ABI Research anticipates next-generation use cases, such as vehicles used as delivery locations and Car-to-Home applications, to start gaining momentum and increase the perceived value of connected car offers from car manufacturers like Volvo, Ford, BMW and Toyota.

"Despite major market growth in OEM telematics, cyber security continues to remain a challenge," concludes Bonte. "To overcome this obstacle, many car OEMs are implementing an over-the-air software capability, which in itself is expected to become a major growth driver for vehicle connectivity in the future."

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MERGERS & ACQUISITIONS

FormFactor Inc. and Cascade Microtech Inc. announced they have entered into a definitive agreement under which FormFactor will acquire all outstanding Cascade shares in a cash and stock transaction. The transaction values Cascade at \$21.13 per share, or \$352 million in equity value based on the closing price of FormFactor's stock on February 3, 2016, of \$7.85. This combination creates significant scale by combining complementary market leadership positions in semiconductor test, measurement and characterization applications. By leveraging combined global support and channel investments across a product line that spans from engineering to production test applications, the combined company is uniquely positioned to solve customers' most difficult test challenges.

Integrated Microwave Technologies (IMT), a leader in advanced digital microwave systems serving the broadcast, sports, entertainment and law enforcement markets, announced it has been acquired by **xG Technology Inc.** (xG), a leader in providing critical wireless communications for use in challenging operating environments. IMT will continue to manufacture its existing product line and will now also be able to provide a secure, rapidly-deployable mobile broadband solution to its broadcast, government, law enforcement and military customers. The acquisition will also create new markets for IMT's high-performance video transmission technology, as xG Technology will be providing IMT's market-leading products to its own customer base in the public safety, DoD and critical infrastructure sectors.

e2v has strengthened its investment in high performance electronic solutions with the acquisition of Swedish signal processing design and development company, **Signal Processing (SP) Devices**. SP Devices offers expertise in embedded error correction solutions for signal processing sub-systems and provides digitizers for demanding applications such as communications, radar and signal intelligence. With this added expertise, e2v will offer solutions in error correction services for increased performance in time-interleaved analog-to-digital converters (ADC), linearized components, system and quadrature demodulators, as well as develop plans to release ADCs with enhanced performance specifications.

iRobot Corp., a leader in delivering robotic technology-based solutions, announced that it has signed a definitive agreement to sell its Defense and Security business to **Arlington Capital Partners** for up to \$45 million in total consideration, including a contingent payment based on achieving certain milestones. This transaction enables iRobot to solidify its position as the leader in diversified home robots and focus on technologies for the connected home.

COLLABORATIONS

ViaSat Inc. and Eutelsat Communications announced an agreement to create a joint venture combining Eutelsat's current European broadband business with ViaSat's broadband technologies and consumer Internet Service Provider (ISP) business expertise. Building on a decade-long relationship, ViaSat and Eutelsat will expand Eutelsat's current wholesale broadband business and launch a new consumer retail service in Europe. The joint venture will consist of two businesses coordinating efforts to expand the European broadband market: wholesale services will be focused on providing wholesale broadband services in the European and Mediterranean regions, and retail services will be focused on building a direct-to-consumer ISP business in Europe.

Veeco Instruments Inc., a supplier of metal organic chemical vapor deposition (MOCVD) systems, has signed a joint development project (JDP) agreement with **imec**, a Belgium-based nano-electronics research center. The collaboration is expected to accelerate the development of highly-efficient, gallium nitride (GaN) based, power electronic devices using GaN Epi wafers created using Veeco's Propel® Power GaN MOCVD system. Imec has already demonstrated significant gains in GaN layer uniformity and run-to-run repeatability with Veeco's Propel system, resulting in significantly improved power device yields. The single wafer reactor incorporates Veeco's proprietary TurboDisc® technology that delivers superior film uniformity, run-to-run control and defect levels compared to batch reactors.

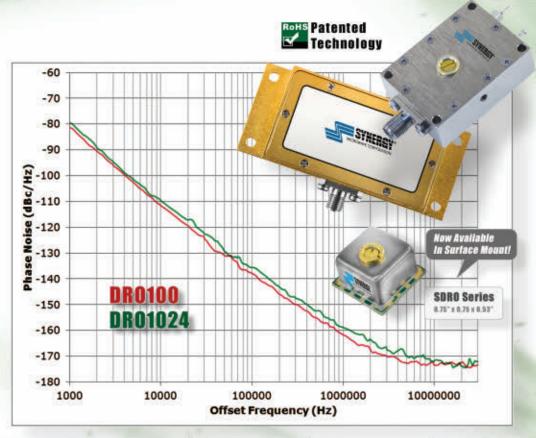
Anritsu Co. announced it is a founding member of the Open Lab Alliance (OLA), a collaboration of industry leaders with the common goal of advancing connected vehicle and autonomous vehicle technologies. The OLA was officially launched during a grand opening ceremony at the CETECOM laboratory in Milpitas, Calif. in February 2016. The OLA promotes a collaborative test environment to the automotive engineering and software development communities. It provides the real-world, in-lab test scenarios necessary for developing connected vehicle subsystems and applications. Anritsu, CETECOM and other founding members formed OLA to accelerate the development of connected vehicle and autonomous vehicle technologies used in intelligent transportation systems.

Qorvo® Inc., a provider of core technologies and RF solutions for mobile, infrastructure and defense applications, announced the company has joined **3GPP™** as a guest delegate to assist in the development of key aspects of 5G nextgeneration wireless communications standards. 3GPP is a global group of organizations responsible for developing the telecommunications standards used by wireless networks worldwide, including 3G, 4G and the forthcoming 5G specifications. The 5G standard is expected to be released in two phases. Phase 1, due for completion in 2018, will focus on frequencies below 6 GHz and define specifications for a prioritized subset of vertical markets. Phase 2, due in 2019, will focus on frequencies above 6 GHz and define specifications for an expanded list of vertical markets.

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SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-111
Connectorized Mo	odels	A .	Ÿ.	W
DRO100 10		1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10	1 - 15	+7 - 10 @ 70 mA	-109

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

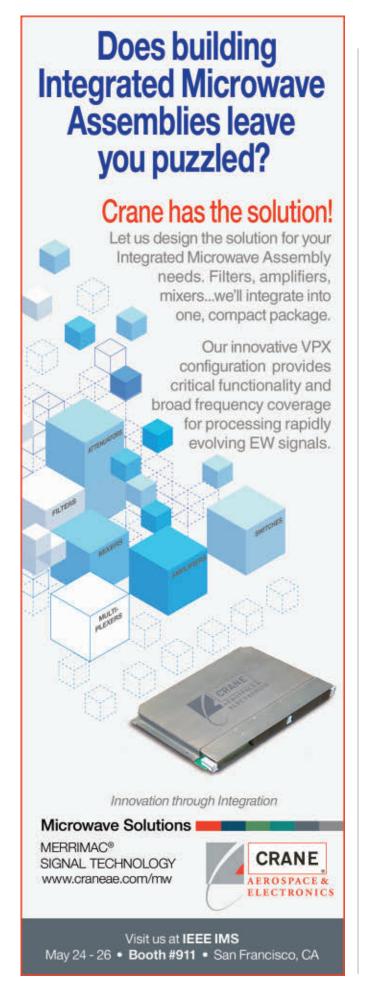
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Around the Circuit

Optimal+, a global big data analytics provider for the semiconductor industry, announced that it has collaborated with **NI**, a leading provider of platform-based test systems that enable engineers and scientists to solve the world's greatest engineering challenges. The entire suite of solutions from Optimal+ will be supported by NI's Semiconductor Test System (STS) via the Optimal+ Proxy starting in Q1 2016. Optimal+ solutions are already in full production use at leading IDMs, OSATs, and fabless companies, enabling them to optimize their manufacturing supply chain based on the industry's most complete, high integrity test data. The ability to analyze data on the open, modular architecture of the STS will reduce hardware test costs, improve throughput and increase overall quality.

After successful trials on Halcyon Unmanned Surface Vehicle (USV), **Thales** and **ASV** have strengthened their partnership. Both companies have signed an agreement to develop autonomous USV technology and capability for maritime, civil, security and military domains. Thales is a global technology leader with the capability to design and deploy equipment, systems and services to meet customer's operational requirements. ASV, an agile small and medium-sized enterprise (SME) with 60 employees spread across the UK and U.S., has specialized expertise and experience in USV design, build, operation and maintenance. This agreement, which builds on the strong existing relationship and the combined skills and expertise of the two companies, provides world leading, innovative solutions for autonomous maritime requirements.

Keysight Technologies Inc. announced a partnership with **SGS** in Taiwan for LTE-A 3DL CA conformance test cases validation for GCF and PTCRB approval. Keysight recently introduced a new test platform, the TP195, to support the evolution of LTE standards. The same test platform is able to execute RF and RRM conformance tests. Collaborating with SGS will help Keysight speed up the GCF/PTCRB approval process and make the TP195 test system available for the wireless industry users for validation of their LTE-Advanced devices. Keysight and SGS worked together to establish the LTE-Advanced 3DL CA test capability and is now ready to serve the industry's customers.

NEW STARTS

Mentor Graphics Corp. announced the launch of the Open Manufacturing Language (OML) initiative that directly addresses the longstanding need and urgent calls from the industry for a printed circuit board (PCB) assembly-specific Internet of Manufacturing solution. For the first time, IT teams, solution providers and equipment providers can easily integrate shop-floor data to create or enhance addedvalue manufacturing execution solutions based on a single, normalized, vendor-neutral communication interface. This minimizes development and support effort while ensuring optimum data accuracy, timeliness and completeness.

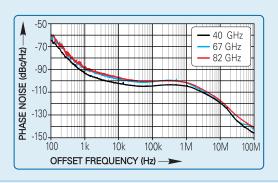
QuickSyn Synthesizers Now Extended to mmW

Low Phase Noise and Fast Switching With USB/SPI Control



We've extended our popular QuickSyn Lite frequency synthesizers to three commonly used mmW bands—27 to 40 GHz, 50 to 67 GHz, and 76 to 82 GHz—for high-speed short-range data links, WirelessHD, IEEE 802.11ad, digital radios, automotive radars, etc. QuickSyn mmW frequency synthesizer modules are ideal for demanding application environments like field trials and embedded systems where bulky benchtop solutions have been the only choice.

Feature	FSL-2740	FSL-5067	FSL-7682
Frequency (GHz)	27 to 40	50 to 67	76 to 82
Switching Speed (µs)	100	100	100
Phase Noise (at 100 kHz)	-97 dBc/Hz at 40 GHz	-101 dBc/Hz at 67 GHz	-101 dBc/Hz at 82 GHz
Power min.(dBm) +17	+16	+10
Output Connector	2.92 mm	1.85 mm	WR-12



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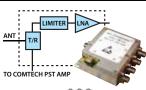
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Around the Circuit

ACHIEVEMENTS

Vaunix Technology Corp., a manufacturer of programmable wireless test equipment, announced they have registered as an ITAR Compliant manufacturer of defense articles covered under the United States Munitions List (USML) by the Office of Defense Trade Controls Compliance. This registration certifies Vaunix as a manufacturer who abides by ITAR compliance regulations. All products manufactured by Vaunix, including their USB powered, programmable lab brick digital attenuators, signal generators, switches and phase shifters can now be used as a part of any ITAR regulated or restricted project.

Anokiwave Inc. announced it has achieved ISO 9001:2008 certification after a thorough analysis of its management and organizational processes by NQA, an independent, third party registrar. ISO 9001 is the internationally recognized standard for Quality Management Systems. It provides a framework and set of principles that ensure a common-sense approach to the management of an organization to consistently satisfy customers and other stakeholders. By receiving this certification from an industry-recognized, third-party registrar, Anokiwave assures customers that they are committed to delivering world-class service and products.

CONTRACTS

The U.S. Army awarded Raytheon Co. \$31.8 million contract to produce and deliver 464 Excalibur Ib extended-range precision projectiles. In full-rate production since mid-2014, Excalibur Ib has revolutionized cannon artillery, making it possible to engage targets precisely at long ranges. Excalibur is the longest-range, most precise, cannon-fired projectile in the world. Raytheon has also funded an internal development program aimed at bringing Excalibur's unprecedented capabilities to the maritime domain. To meet the U.S. Navy's need, Raytheon is developing Excalibur N5, a 5-inch/127 mm variant that uses Excalibur Ib guidance and navigation unit and an overall re-use of 70 percent of Excalibur Ib parts and components.

Harris Corp. has been awarded a five-year, \$28 million ceiling, single-award IDIQ contract to provide repair services for the Navy's Integrated Defensive Electronic Countermeasures (IDECM) program. The contract includes a two-year base period and three one-year options. Under the contract, issued by the U.S. Naval Supply Systems Command Weapon System Support (NAVSUP WSS), Harris will repair Weapons Replaceable Assemblies (WRA) on an order-by-order basis to support IDECM fleet assets. Harris has supported the IDECM program for 18 years — continually improving the AN/ALQ-214's capabilities to address the evolving airborne electronic warfare threat landscape.

Mercury Systems Inc. announced it received a \$3 million follow-on order from a leading defense prime contractor for high performance microwave subsystems for an elec-



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VDI's Mini VNAX modules are one-quarter the volume of standard modules making them well suited for probe station and antenna measurement applications.

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VDI's VNA Extenders provide high performance frequency extension of vector network analyzers from 50GHz-1.5THz. These modules combine high test port power with exceptional dynamic range and unmatched stability.

VDI's mini-modules are reduced in size, but yield the same industry leading performance as our original designs. The compact form factor and simplified power supply make them the recommended solution for most applications. Mini-modules are currently available in standard waveguide bands for 50-330GHz with higher frequency bands coming soon.

Waveguide Band (GHz)	WR15 50-75	WR12 60-90	WR10 75-110	WR8 90-140	WR6.5 110-170	WR5.1 140-220	WR3.4 220-330	
Dynamic Range (BW=10Hz, dB, typ) (BW=10Hz, dB, min)	120 100	100 120	120 100	120 100	120 100	120 100	115 100	
Magnitude Stability	0.15	0.15	0.15	0.15	0.25	0.25	0.3	
Phase Stability (±deg)	2	2	2	2	4	4	6	
Test Port Power (dBm)	6	6	6	0	0	-4	-9	



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Around the Circuit

tronic warfare application. The order was received in the company's fiscal 2016 second quarter and is expected to be shipped over the next several quarters.

Filtronic, a designer and manufacturer of microwave electronics products for the wireless telecoms infrastructure market and adjacent markets, has received an order to develop core elements within long range, E-Band communication systems. The order from a major U.S. multinational company covers the design, development and delivery of prototype communication sub-systems to enable ultrahigh capacity transmission of telecommunications data over a 20 km range using E-Band frequencies. This technically challenging project pushes the boundaries of current technology and will be centered on Filtronic's class leading Orpheus transceiver technology. The contract is structured on incremental development milestones worth up to \$1.9 million upon successful completion.

PEOPLE

The **IEEE** recently announced its newly elevated fellows for 2016. The IEEE Grade of Fellow is conferred by the board of directors upon a person with an extraordinary record of accomplishments in any of the IEEE fields of interest. The total number selected in any one year does not exceed one-tenth of one percent of the total voting institute membership. Each new fellow receives a nicely matted and framed certificate with their name and a brief citation describing their accomplishment, a congratulatory letter from the incoming IEEE president and a gold sterling silver fellow lapel pin. Some notable recipients in our industry include Ajay Poddar of Synergy Microwave Corp., Paterson, N.J., for contributions to microwave oscillators; Terry Cisco, Raytheon (retired)/consultant, Glendale, Calif., for leadership in the development of airborne active array transmit and receive module technologies; and Jian-Guo Ma, Tianjin University, Tianjin, China for leadership in microwave electronics and RFIC applications. A complete list of the 2016 IEEE fellows can be found at: www.ieee.org/ membership_services/membership/fellows/2016_elevated_fellows.pdf.



▲ Janine Love

Janine Love joins Horizon House Publications as event director, working on EDI CON in the U.S. and China. She will also serve as contributing editor on the *Microwave Journal* staff. Previously, she was the technical program director for DesignCon and ARM TechCon at UBM, and has held numerous editorial positions for a variety of publications. Prior to UBM, Love

founded her own freelance technical writing firm, which she ran for 13 years. She began her career in this industry as an associate editor at *Microwaves & RF* magazine. Love holds a bachelor's degree from the University of Delaware and a master's from Duquesne University.



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- High RF consistency
- Broadband Performance
- Optimized for DPD systems
- Reference Designs



RADAR and Avionics Product Line

	Product	Operating	Matching		@P _{1dB}			@P _{3dB}		Pulse	V _{DD}
		Frequency (MHz)		P _{OUT} (W)	Gain (dB)	Eff (%)	P _{OUT} (W)	Gain (dB)	Eff (%)		
	PTVA030121EA	390 – 450	Unmatched	12	25.0	69	14	22.0	73	12µs, 10% DC	50V
	PTVA035002EV	390 – 450	Unmatched	400	19.5	65	500	17.5	67	12µs, 10% DC	50V
1	PTVA102001EA	1030 / 1090	I/O	200	18.0	57	230	16.0	58	128µs, 10% DC	50V
	PTVA104501EH	960 – 1215	I/O	450	17.0	57	490	15.0	55	128µs, 10% DC	50V
	PTVA101K02EV	1030 / 1090	I	920	18.0	56	1090	16.0	57	128µs, 10% DC	50V
	PTVA120251EA	500 – 1400	Unmatched	30	16.0	56	40	14.0	59	300µs, 10% DC	50V
	PTVA120501EA	1200 – 1400	1	54	16.5	55	63	14.5	57	300µs, 10% DC	50V
	PTVA123501EC/FC	1200 – 1400	I/O	375	16.0	56	415	14.0	57	300µs, 12% DC	50V
	PTVA127002EV	1200 – 1400	I/O	700	16.0	55	800	14.0	58	300µs, 10% DC	50V

ISM (2.45GHz) Product Line

	Product		Matching		@P _{1dB}			@P _{3dB}	Test Signal	V _{DD}	
		Frequency (MHz)		P _{OUT} (W)	Gain (dB)	Eff (%)	P _{out} (W)	Gain (dB)	Eff (%)		
V	PTFD252207NF	2400 – 2500	I/O	210	16.7	57	250	14.7	57.5	CW	28V

New Solutions for RADAR & ISM Applications

NEW 700W L-BAND LDMOS 200W L-BAND LDMOS 220W ISM LDMOS ■ PTVA127002CV ■ PTVA102001EA PXFD252207NF **700W** ■ 200W **220W** ■ 1200 - 1400MHz ■ 1200 - 1400MHz ■ 2400 - 2500MHz ■ 55% Efficiency ■ 59% Efficiency ■ 58% Efficiency ■ 16 dB Gain ■ 18 dB Gain ■ 17 dB Gain

New GaN Solutions for Cellular Applications

Product	Operating Frequency [MHz]	P _{1dB} Typ [W]	Gain Typ [dB]	Eff Typ [%]	Supply Voltage Typ [V]	Test Signal	Package Type
GTVA261702FA	2620 - 2690	170	18	47	48	WCDMA	H-37265J-2
GTVA262601FA	2620 -2690	260	18	40	48	WCDMA	
GTVA263202FC	2620 -2690	160 + 160	18	40	48	WCDMA	H-37248-4
GTVA220701FA	1800 - 2200	70	20	70	48	CW	H-37265J-2

General Purpose Transistors (700MHz - 2200MHz)

Product	Operating Frequency [MHz]	Matching	P _{1dB} Typ [W]	Gain Typ [dB]	Eff Typ [%]	P _{out} Avg [W]	Test Signal	Supply Voltage Typ [V]	θJC	Package Type
PTFC270051M	900 – 2700	Unmatched	7.3	20.3	60	-	CW @ 2170	28	3.84	PG-SON-10
PTFC270101M	900 – 2700	Unmatched	12	20.0	60	-	CW @ 2140	28	4.04	

LDMOS Integrated RF Power Amplifiers (700MHz – 2200MHz)

Product	Operating Frequency [MHz]	P _{1dB} Typ [W]	Gain Typ [dB]	Eff Typ [%]	P _{out} Avg [W]	Test Signal	Supply Voltage Typ [V]	θJC	Package Type
PTMA080152M	700 – 1000	20	30	34	8	GSM/EDGE	28	8.5/2.5	PG-DSO-20-63
PTMA180402M	1800 – 2200	40	30	16	5	CDMA	28	3.6/1.5	
PTMA210152M	1800 – 2200	20	28.5	33	7	WCDMA	28	3.6/1.5	THE PROPERTY OF THE PARTY OF TH
PTMA210204MD	1800 – 2200	10+10	30	19	2.5	WCDMA	28	9.7/3.1	PG-HBDSO-14

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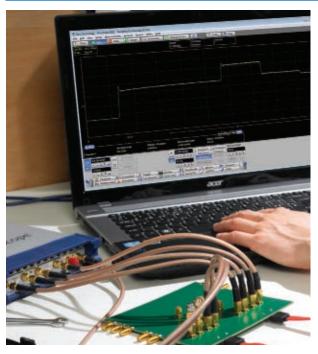




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20 GHz bandwidth, 2 channels, TDR/TDT analysis



The PicoScope 9311 and 9312 scopes include a built-in differential step generator for time domain reflectometry and time domain transmission measurements. This feature can be used to characterize transmission lines, printed circuit traces, connectors and cables with as little as 1.5 cm resolution.

The PicoScope 9312 is supplied with external tunnel diode pulse heads that generate positive and negative 200 mV pulses with 40 ps system rise time. The PicoScope 9311 generates large-amplitude differential pulses with 60 ps system rise time directly from its front panel and is suited to TDR/TDT applications where the reflected or transmitted signal is small.

20 GHz bandwidth

- ullet 17.5 ps rise time ullet 40 ps differential TDR / TDT
 - 11.3 Gb/s clock recovery
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Integral signal generator: Pulse, PRBS NRZ/RZ, 500 MHz clock, Eye diagram, eye line, histograms and mask testing

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Around the Circuit



▲ Alyssa Connell

Alyssa Connell has joined *Microwave Journal* in the role of event coordinator. She replaces Jacqui Williams and will handle logistics for the EDI CON events, MWJ trade show exhibitions and barters. Connell comes to *Microwave Journal* from a publisher of medical related journals where she held the role of advertising production coordinator.



▲ Angie Rogers

Modelithics Inc. has announced the appointment of Angie Rogers to sales manager. Rogers will be responsible for leading Modelithics' sales and customer relations as well as providing executive assistance to the president and CEO of Modelithics in the area of customer relations. Rogers has extensive knowledge in sales management, customer rela-

tions and business growth, with 20 years experience in various sales and management positions. Rogers' previous roles as senior branch sales manager and CRM instructor have already been a valuable asset in Modelithics' continued growth and customer information tracking.



▲ Eli Brookner

EDI CON USA 2016 announced **Dr. Eli Brookner's** participation as a keynote speaker and course instructor. Dr. Brookner will provide a keynote speech on the latest advancements in radar and phased array technology and teach a two-hour course on the latest phased array and MIMO radar technology. A full day track on radar technology will include the latest in semiconductor tech-

nology (GaN and CMOS control devices), device and system design, and measurement/modeling of radar components and systems. Dr. Brookner is renowned for his contributions to radar technology. He retired from Raytheon as principal engineering fellow in 2014 after a long and distinguished career spanning more than 50 years. EDI CON 2016 takes place September 20-22 in Boston, Mass. at the Hynes Convention Center.

REP APPOINTMENTS

Dynawave Cable Inc., a developer and supplier of high-performance RF/microwave coaxial connectors, cables, and cable assemblies, announced a new global distribution agreement with **Richardson Electronics Ltd.**, a supplier of high-frequency and high-power devices and components for commercial, industrial, and military/aerospace markets and applications. The agreement teams Dynawave's expertise in high quality, high performance RF/microwave connectors and coaxial cables with Richardson Electronics' impressive worldwide distribution network and commitment to the highest-quality technical support and customer service.

Empower RF Systems announced a partnership with **TEVET** to become a value added reseller of Empower's RF and microwave amplifier modules and systems. TEVET



Delivering GaN, SSPA expertise to meet your emerging ATC needs.

High efficiency, high power, and compact with proven GaN transistor technology.

CPI's VSS3617 Solid State Power Amplifiers are reliable, highly efficient and easy to maintain. The VSS3617 solid state power amplifiers are designed for use in air traffic control radar and instrumentation applications. GaN transistors provide high efficiency and excellent pulse fidelity, and require minimal cooling.

Contact the SSPA experts at CPI BMD for your ATC transmitter needs.

Features:

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Benefits:

- High efficiency
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Modulators
Magnetrons
Cross-Field Amplifiers





Around the Circuit

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PLACES

Advantech Wireless announced the opening of its new U.S. headquarters. The new office will provide customer service and support as well as sales, training and finished goods inventory for fast deliveries to Advantech Wireless' U.S. customers. It is strategically located in Buford, Ga., near several key U.S. customers and the Atlanta International Airport. The new office address is 1707 Enterprise Drive, Suite B, Buford, GA, 30518. Direct telephone number: (770) 456-5601.

VIDA Products has completed its relocation to Rohnert Park as part of its business plan to provide both component rebuilding service and YIG oscillator MMICs. The company manufactures new cutting edge YIG technologies and provides new, used and refurbished electronic test & measurement equipment — repaired, tested and calibrated. The

new address is 6167 State Farm Drive, Unit B1, Rohnert Park, CA 94928-2147. Office phone: (707) 541-7000.

Linear Technology Corp. opened the company's third semiconductor test facility in Singapore. The additional space for staff, equipment and materials will allow the company to more than double its production capacity of advanced analog circuits and μ Module® (micromodule) products. This will strengthen Linear Technology's ability to meet the growing demand for high performance analog integrated circuits worldwide. The new 87,000 sq. ft. facility is located beside Linear Technology's present 191,000 sq. ft. facility at Yishun Industrial Park A.

L-3 Electron Technologies Inc. (L-3 ETI), a global provider of high reliability space and defense solutions, announced it is opening a new office in Tokyo to expand into the Japanese marketplace. The office will act as the Asian headquarters for L-3 ETI's pursuit of international sales of its product lines, which includes traveling wave tube amplifiers. **Yoshimoto Watanabe**, an aerospace veteran, will serve as L-3 ETI's in-country representative. He will provide a vital interface with domestic and international government officials and industrial partners. He has more than 20 years of successful business development experience with satellite manufacturers and operators such as Space Systems/Loral and Thales Japan K.K.



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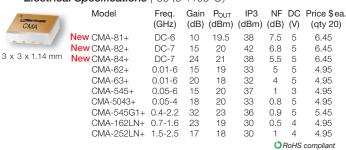
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New England in the Fall + Electronic Design Innovation: A Perfect Combination

Janine Love Contributing Editor, *Microwave Journal*

DI CON China is in its fourth year this month, and it has given rise to the new conference known as EDI CON USA, which will be held at the Hynes Convention Center in Boston, Mass., September 20-22, 2016. The growth of EDI CON has been impressive to watch, and I am happy to be part of the team that will enable it to evolve and grow to meet the needs of engineers and designers both in the U.S. and abroad.

This year's EDI CON USA will begin the celebration of both the analog and the digital realms, bringing together RF and microwave engineers with their high speed digital colleagues as we look for intersections of learning and provide opportunities for discussion and overcoming shared challenges. What I find exciting about EDI CON is that attendees come to find solutions, products and design ideas that they can put to immediate use.

The "EDI" in EDI CON stands for "electronic design innovation," and that will be on full display on the EDI CON USA exhibit floor. Focused on what's hot right now, the expo will be home to more than 100 exhibits and the Frequency Matters Theater, where all attendees can experience speed trainings, hands-on demonstrations and educational talks.

In the nearby conference rooms, speakers will be diving deep into the technical details, sharing their work, methodologies, and technology developments as well as answering questions for conference delegates in the form of technical sessions, panels, workshops and short courses.

If your work includes any of these areas, you should really plan to be at EDI CON USA: test and measurement; RF and microwave (including ultra-low power, high frequency and space-qualified ICs and subsystems); EDA for circuit, system and electromagnetic design and simulation; EMC/EMI; signal integrity for high speed design, simulation and verification; semiconductor foundry services and device manufacturing; cable/connectors; and materials and manufacturing.

Look for registration to open soon. You can use the early bird pricing to take advantage of the full complement of educational opportunities that EDI CON USA will offer, including talks by employees of Raytheon Co., BAE Systems, Keysight Tech-

nologies, National Instruments, Rohde & Schwarz, ANSYS, CST, COMSOL, MACOM, NXP, Mini-Circuits and Copper Mountain Technologies. I'm particularly looking forward to a presentation on microwave and millimeter wave power amplifier design by BAE Systems Electronic Systems' Dr. James Komiak.

Or, register for a free expo pass and explore the show floor that will be home to exhibitors serving customers in the communications, defense, electronics, aerospace and medical industries, as well as free demonstrations, poster sessions, learning, the plenary session and networking opportunities. In the Frequency Matters Theater on the show floor, we are currently planning a radio building workshop, a design contest and a HAM radio demonstration.

If you want to take a more active role, the abstracts submitted to the Call for Papers are currently in review by our Technical Advisory Committee. But, if you have a fantastic idea for a presentation, contact me today (jlove@mwjournal.com) and we'll see what we can do to get you caught up into the process. I look forward to seeing you in Boston in the fall!



The future is Ka band. Now, there's a rugged, dependable handheld designed to deliver precise, lab-grade measurements up to 50 GHz. At only 7.1 lbs., it's an all-in-one cable and antenna tester (CAT) + vector network analyzer (VNA) + spectrum analyzer and more. Which means, now you get comprehensive system performance insight at higher frequencies. Plus with easy upgrades and multiple configurations, you'll be ready to go where no handheld has gone before – today and beyond.

Keysight FieldFox Handheld Analyzers

6 new models to 50 GHz

MIL-PRF-28800F Class 2 rugged

Agrees with benchtop measurements

CAT + VNA + spectrum analyzer



Unlocking Measurement Insights





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Paving The Way For 5G Realization and mmWave Communication Systems

Mark Pierpoint Keysight Technologies, Santa Rosa, Calif. Gabriel M. Rebeiz University of California, San Diego, Calif.

oday's wireless communications industry is on the verge of a revolution. While much has already been written about the need for higher data rates and therefore, wider bandwidths, the industry is also being driven to find ways to serve more users in a given area—a concept generally referred to as "densification." This need has prompted

interest in utilizing less populated frequency spectrum in the microwave and millimeter wave (mmWave) bands, and it is shifting the industry from one in which power is transmitted over a physically broad area to one where it is transmitted in a very directive manner. In this new era of directive communication, one

or more beams of energy can be sent directly to a single user, enabling higher frequency reuse, as well as a higher quality of service and better overall experience. Directive communications is quite a technological leap at consumer price

points and if realized, promises to enable a wealth of possibilities for 5G and beyond, including a host of new terrestrial and airborne applications, with data services provided much more effectively and inexpensively to a wider population.

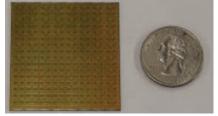
Key to enabling this "5G densification" is the antenna, which for directive communica-

tion must be physically large (typically greater than 8×) relative to the wavelength of the transmission. Keeping the antennas to a size manageable for commercial use, however, requires short wavelengths or higher frequencies—a fact that has driven great interest in the unregulated 60 GHz band. The most commonly used standard is IEEE 802.11ad (WiGig) that

provides multi-gigabit data rates up to 7 Gbps by utilizing a beam forming protocol that employs phased array transmitters and receivers to improve channel efficiency and system performance, and assist users in aligning the transmission path.

While the promise of 5G and multi-gigabit speed wire-

less communication is enticing, enabling this reality has required two key breakthroughs: development of low cost phased arrays and proof that they can actually be used in a 5G communications link. The latter part of that challenge is exactly what researchers from the University of California, San Diego (UCSD), in collaboration with Keysight Technologies, set out to address last year. What resulted represents a significant step forward in achieving those breakthroughs—successful demonstration of the world's first $64 (8 \times 8)$ and 256-element (16×16), 60 GHz silicon wafer-scale phased array transmitter with integrated high efficiency antennas for Gbps communications over several hundred meters. The demonstration not



▲ Fig. 1 UCSD's 5G 64- and 256-element, 60 GHz silicon wafer-scale phased array transmitter with beam forming capabilities.

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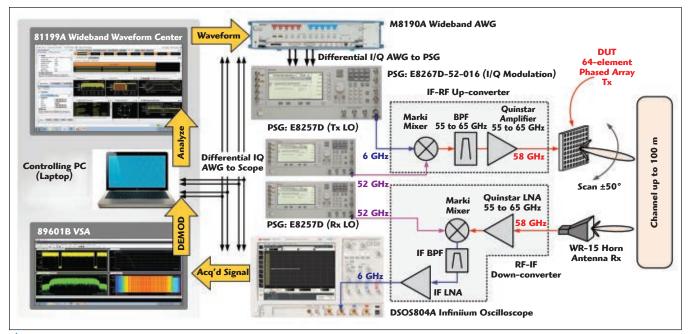


Fig. 2 Measurement setup used for the 60 GHz communication link.

only proved the viability of such a link, but that it could deliver record performance as well.

A STRONG FOUNDATION

Getting to that demonstration took a great deal of effort and hinged on two critical factors. One was the development of the industry's first 64and 256-element system-on-a-chip (SoC) phased arrays operating at 60 GHz (see Figure 1). That development sprung from an earlier effort between UCSD and TowerJazz that was sponsored by the Defense Advanced Research Projects Agency (DARPA). The resulting wafer-scale SoCs each comprised a 60 GHz source, amplifiers, distribution network, phase shifters, voltage controlled amplifiers and high efficiency on-chip antennas. This SoC is targeted for 5G advanced communications systems and aerospace/ defense applications.

The other factor was a long history of collaboration between UCSD and Keysight; one that began some 10 years earlier when Keysight began funding a MEMS (microelectromechanical systems) development effort at UCSD. In 2015, Keysight solidified its relationship with UCSD by officially signing on as an industry affiliate for its Center for Wireless Communication.

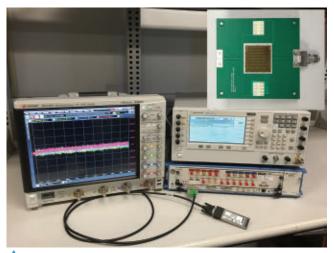
It was about this time that UCSD had just finished developing its phased array SoCs and were ready to take the

next step—proving that the chips could be used in a 5G communication link. To do that, UCSD needed a hardware and software measurement system; one that had the perfornecessary mance and accuracy, and could be operated by the small number of UCSD researchers working on the project.

MEASUREMENT SETUP

The measurement system also had to be fast. UC-SD's researchers invested a great deal of time and effort developing the antenna, roughly two and a half years. In just a matter of days, the necessary measurement setup for the 60 GHz communication link was in place, a 60 GHz link at 4m, 30m and approximately 100m link was developed, and the performance of the 64-element transmit phased array was successfully demonstrated.

To develop that link, an instrument setup was developed as shown in *Figure 2*. The instruments included a M8190A arbitrary waveform generator, E8267D PSG vector signal generator and DSOS804A Infiniium



▲ Fig. 3 Measurement setup for the 60 GHz 802.11ad and 5G link measurements with the UCSD 64-element wafer-scale phased array.

S-Series high definition oscilloscope with 10-bit ADC. For local oscillator generation, the E8257D PSG analog signal generator was used. Standard software was used to generate a 60 GHz 802.11ad waveform, apply digital predistortion and improve the error-vector-magnitude performance. The actual setup is shown in *Figure 3*.

Once the communication link was developed, the next step was to measure it at link distances of 4m, 30m and 100m. To do that, UCSD's 64-element phased array transmitter was placed on a tripod so that the scanning performance of the array could be measured with a communication waveform. A stationary horn antenna with a gain of 20 dB acted as the re-





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ceiver, and for measurement purposes was coupled to oscilloscope running demodulation software.

Constellations were then measured for different modulation schemes, center frequencies and scanning angles. For the longer distances, the transmitter was placed on the roof of a six-story building, while the receiver was situated in a parking lot, introducing additional challenges with interference from cars and trees.

In both cases, measured constellations showed that the 60 GHz communication link worked well. At the 4 m link distance (full 802.11ad channel), the 64-element phased array transmitter was able to maintain a complex communication link at all scan angles ($\pm 45^{\circ}$ in all planes) and with virtually no added distortion, achieving a 16-QAM modulation with 3.85 Gbps. Nearly the same performance was achieved at 30 m. Over the 100 m

link distance, the communication link was able to achieve a QPSK modulation with 1.54 Gbps while scanning to $\pm 45^{\circ}$ in all planes.

LOOKING TO THE FUTURE

The successful demonstration of the world's first 5G communication link based on a 64- and 256-element phased-array transmitter with beampointing capabilities, represents a significant step forward in the realization of 5G. But it is not the end of the story as phase three of the research project is already underway with UCSD researchers now focused on developing transmit/receive components, larger arrays and more efficient networked 5G systems over the next year.

Like the 5G communication link, any new developments to stem from the ongoing research hold great promise for helping the industry evolve to an era of 5G directive communication. Just as critically, it will help pave the way for future research and development of mmWave communication systems.







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Mark Pierpoint is the vice president and general manager of Internet Infrastructure Solutions at Keysight Technologies. Pierpoint leads the company's focus on network equipment, transport links and cloud, including Keysight's 5G Program. Pierpoint holds a Ph.D. in microwave engineering and a B.Sc. in electrical & electronic engineering from the University of Leeds in the UK. He serves on a number of advisory boards for electrical and computer engineering, including UCSD and the Broadband Wireless Access Center, part of NSF's I/UCRC program.

Gabriel M. Rebeiz (IEEE Fellow) is distinguished professor and wireless communications industry endowed chair at UCSD. He was elected a member of the National Academy of Engineering in 2016, and his group has won the IEEE MTT Microwave Prize twice for work on phased arrays and RF MEMS. He is considered one of the fathers of RF MEMS and tunable networks, and low cost phased arrays based on silicon RFICs. Rebeiz is an advisor to several of the large commercial and defense electronics and communication system companies in the United States.

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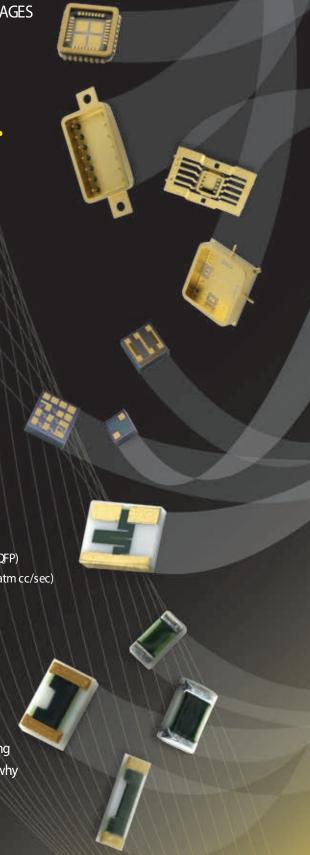
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What's Driving the IoT? It's Not Just Consumers

Eric Starkloff

NI Executive Vice President of Global Sales and Marketing

The rapid growth of the so-called Internet of Things is having a significant effect on the requirements of future wireless standards such as 5G. In particular, new types of applications requiring high reliability and low latency need wireless technology that is different from what we use today. These emerging requirements will change the way wireless systems are designed, prototyped, manufactured and tested.

Today, we are entering a third era of connectivity — and this era is changing the way we use wireless. In the first era, wired telephony and internet technology were the primary methods connecting homes and businesses. Over the last couple of decades, the second era

▲ Fig. 1 Industry-leading connectivity technology in 2000.

emerged, and the industry shifted from connecting places using wired technology to connecting people wirelessly.

One example of this shift is the demise of the desk phone. *Figure 1* is an example of devices that were once the most important things on our desks, that are now unceremoniously discarded (I took the photo with a mobile phone, of course). This picture is indicative of NI's move — and really the industry's move — to mobile and Skype connections for every employee.

Connecting things is the third era of communications, and the tipping point is happening much faster than many of us realize. Today, there are over 7 billion mobile devices globally connecting over 3.8 billion people. Tomorrow, we will exponentially connect more things than people. According to a recent estimate in the November 2015 Ericsson Mobility report, the number of machine-to-machine (M2M) connections will roughly quadruple to nearly 12 billion over the next five years. By 2030, Ericsson expects that there will be roughly 10 times the number of connected things as connected people.

mmWAVE EMERGES

In the past, consumers have largely dictated the requirements of new wireless standards. In

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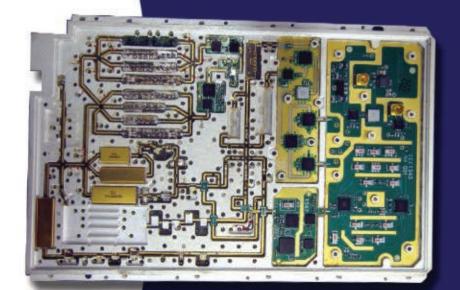
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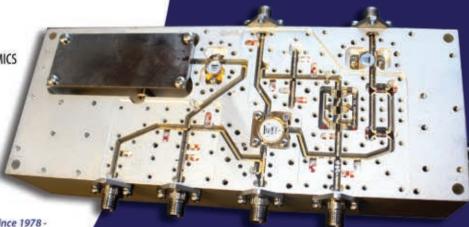
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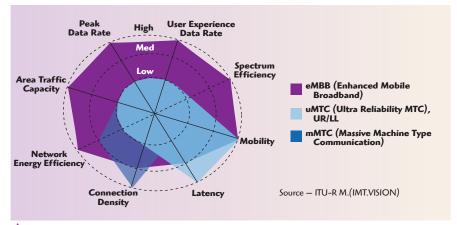
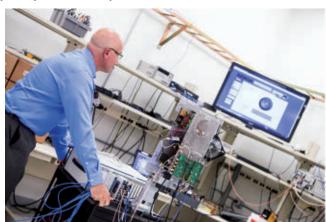


Fig. 2 5G use cases defined by the ITU Vision for 2020.

the future, however, these requirements will be driven by the need to connect machines. The differences in requirements between people and things are clearly defined in the proposed use cases for 5G. As part of its 5G vision, the International Telecommunications Union estab-(ITU) has use cases for wireless communications²



lished three distinct A Fig. 3 A working 5G at Nokia Networks in Arlington Heights, Il.

— each focused on delivering different performance in terms of latency, throughput, density and mobility (see *Figure 2*).

Enhanced Mobile Broadband Communications

The first use case is enhanced mobile broadband (eMBB). We can think of it as the natural evolution beyond LTE and LTE-Advanced. Similar to how the progression from GPRS to HSPA to LTE provided consumers with the benefit of increasingly higher data rates, a future 5G standard will continue this trend. The eMBB use case defines the technical requirements to achieve peak data rates of 10 Gbps — culminating in 10,000 times more total network traffic.

One of the most exciting outcomes of the eMBB requirements is the ultimate adoption of millimeter wave frequencies into mainstream consumer products. Achieving throughputs of 10 Gbps or more requires massively wider bandwidths — and the necessary spectrum is only available at mil-

limeter wavelengths.

Only a few years ago, the idea of using bands beyond 6 GHz for wireless communications seemed impractical and cost-prohibitive. However, today's 5G researchers are proving that millimeter wave frequencies are viable for the mass market. As an example, NI recently collaborated with Nokia Networks (see *Figure 3*) to demonstrate a 5G system capable of delivering 14.7 Gbps at Mobile World Congress 2016 in Barcelona.

Of course, 5G is not the only technology that requires higher throughput — and it is not the only technology utilizing millimeter waves. At present, we are literally months away from having 60 GHz 802.11ad chipsets in mainstream mobile devices and only a few years away from 802.11ay. In the future, these radios might augment 5G mobile networks by delivering throughput of up to 20 Gbps as the "last-mile connectivity" to IoT devices.

Machine Type Communications

The next two 5G use cases defined by the ITU are designed to solve the

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challenge of connecting things rather than people. Not surprisingly, these use cases, massive machine type communications (mMTC) and ultra-reliable machine type communication (uMTC), have very different requirements than that of massive broadband.

With the mMTC use case, key radio requirements include ultra low power consumption and ultra low cost. For these radios, the goal is for a single battery to power the radio for 10 years or more. On the other hand, uMTC is designed for mission-critical applications. Key uMTC requirements are < 1 ms latency and better than 99.999 percent reliability.

Although the requirements of 5G are an excellent example of how the IoT is shaping future standards development, it isn't the only example by far. The imminent reality that wireless must be designed to connect things more frequently than it must connect people is already influencing the development of near-term wireless LAN technologies like 802.11ah and mobile technologies like LTE-M.

A LOOK AT LTE-M

LTE for M2M communications, or LTE-M, was first outlined as a part of 3GPP Release 12 in March 2015. LTE-M defines a low cost device category (category 0) for machine-to-ma-

chine communications.³ In an effort to save power, new category 0 radios are allowed to support only the 1.4 MHz bandwidth option of LTE and are only half-duplex instead of full-duplex. LTE-M also allows for a longer discontinuous reception (DRX) cycle — enabling devices to have longer periods of inactivity to reduce power consumption further.

Of course, the efforts to evolve LTE for low power operation won't stop with 3GPP Release 12. In Release 13, we are likely to see narrowband LTE-M (NB-LTE-M). NB-LTE-M adds a 200 kHz bandwidth option which supports up to 200 kbps downlink data rates with power consumption as low as one-fifth of today's LTE radios.

ety in significant and positive ways. Although many of the industrial use cases are less obvious, however, there will ultimately be more of them.

In fact, recent forecasts predict that over the next decade, automo-



▲ Fig. 4 Manufacturing test station for e-call modules built by NI alliance partner Noffz.

APPLICATIONS FOR THE INDUSTRIAL IOT

As consumers in an increasingly connected world, it is easy for many of us to imagine how wireless technology will become more embedded in consumer electronics. These applications have the opportunity to affect soci-



Fig. 5 Wireless analog IC cost and unit volume from 2011 to 2019.8

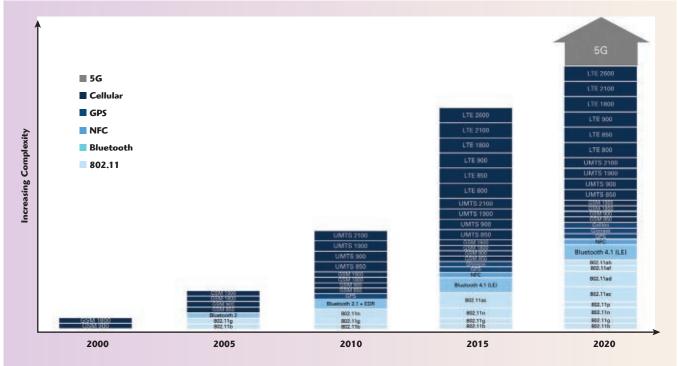


Fig. 6 Increasing radio complexity of tomorrow's smartphones.

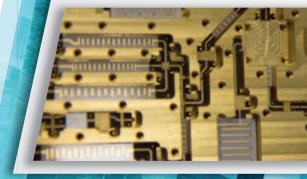
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tive and industrial IoT (IIoT) applications combined will account for nearly 50 percent of connected things. As a result, wireless will become the technology empowering coordinated traffic lights, automobiles and industrial machines – not just the smart phone. In the end, the sheer scale of the IIoT will eventually outweigh the consumer IoT in unit volume; even dictating the technologies that we as consumers have access to.

One family of applications where wireless is enabling innovation is the connected car. Those in North America may remember when General Motors introduced the first "On-Star" system on select 1997 Cadillac models. The original system utilized the AMPS⁴ (pre-CDMA and pre-GSM) mobile phone networks and allowed vehicles to contact a central call center in the event of an emergency. Today, the service uses LTE modems and can even provide Wi-Fi connectivity to passengers within a vehicle.

Although OnStar technology has been available for nearly 20 years, the adoption of cellular modems within an automobile is still relatively low. In 2015, only 20 percent of vehicles sold worldwide contained the ability to connect to a network infrastructure. In the future, this number will approach 100 percent.⁵ In fact, the European Union recently mandated that after 2018, all new vehicles be equipped with e-call technology — a European equivalent of OnStar that provides crash notifications in the event of an emergency.⁶ As a result of technologies like e-call, traditional infotainment vendors like Harman are increasing production of modules supporting both Wi-Fi and LTE. This requires investment in new test techniques in manufacturing, such as parallel test (see *Figure 4*).

Wireless technologies like cellular and automotive radar at 77 GHz have dramatic implications on automotive test methodology. The increasing complexity of the automobile has long required hardware-in-the-loop (HIL) test methods to ensure safety and reliability. As wireless becomes an increasingly mission-critical function of the automobile, engineers are increasingly required to apply the same HIL test techniques to RF systems like 802.11p radios and radar.

IMPLICATIONS OF THE IOT FOR RF DESIGN AND TEST ENGINEERS

Over nearly four decades, we have observed the price of a mobile phone go from nearly \$10,000⁷ (adjusted for inflation) to less than \$100. With today's mobile technology serving a broader purpose than human-to-human interaction, the cost expectations of the mobile radio must decline even more significantly. As an example, the price target for a NB-LTE-M radio is less than \$5.

One of the most telling indicators of the "cost of wireless" can be observed by evaluating the average selling price (ASP) of the semiconductor components themselves. In fact, a recent market forecast by DataBeans predicts that the ASP of mobile device analog ICs will decline by more than 30 percent from 2011 to 2019 (see **Figure 5**).

It should not be surprising that broader adoption of wireless technology is driving lower costs, and that the falling prices will continue in the era of the IoT. Lower costs, however, have also been associated with an increase in wireless complexity. Just over a decade ago, in 2005, Sprint announced support for world's first ever "Quad-Band" phone — the Samsung IP-A790. Designed to connect to cellular networks both in the U.S. and abroad, this phone retailed for over \$500. Today, a viable mobile phone must support nearly 20 mobile bands (see Figure 6) in addition to multiple Bluetooth, GNSS and even NFC technologies. Over the next few years, mobile devices will add millimeterwave bands from 802.11ad, 802.11ay, and 5G-with most devices continuing to support existing bands. As wireless becomes embedded in both consumer and industrial products, the industry is tasked with finding a way to design, test and deploy increasingly sophisticated wireless technology at a lower price and with a smaller footprint than ever before.

I remember working with one of the leading mobile phone providers in the early 2000s when they first added Wi-Fi to their phones. This "simple" addition effectively doubled the test time and cost of test in production, while the device sold for roughly the same amount. Today we have added a dozen or more radios, and the cost of devices has fallen. Clearly, the cost of test must continue to scale down significantly. The IoT will hasten this





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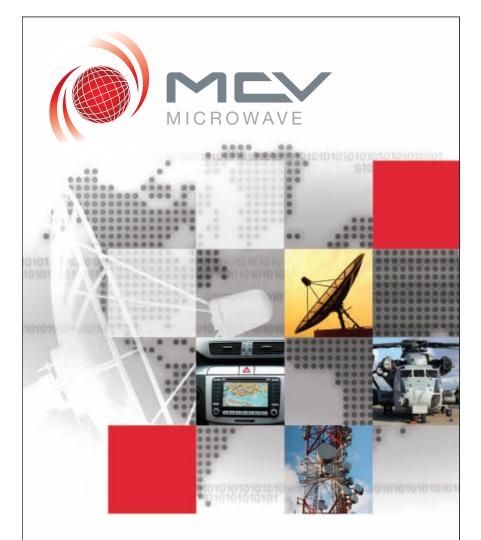
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decline, as the volume of IoT devices and subsequent economies of scale drive down the price of wireless.

WHAT DOES THIS MEAN FOR YOU?

Wireless is increasingly becoming one of the most critical technologies that will make the IoT possible. Given the importance of wireless, the success of the next generation of wireless depends on all of us. Without researchers developing the world's first prototypes using software-defined radios, 5G would not be possible; of course, 5G will not be practical if design and test engineers cannot solve the next challenge, which is to design and manufacture millimeter wave radios in a cost-effective manner.

Thirty years ago, many of us saw first-hand how the commoditization of the PC created dramatically new expectations for cost, performance and size. Today, the same thing is happening in wireless. From the PA, to the mobile phone, to the test equipment we develop at NI, all of our products must become smaller, more power efficient and less expensive. The days of \$6 mobile PAs and six-figure spectrum analyzers are long gone. It is time we embrace the future.

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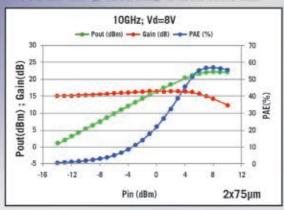




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2x75µm device @8V, 10GHz, 150 mA/mm



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Peak Gm	410 mS/mm	460 mS/mm	580 mS/mm	725 mS/mm
Vto	-1.15 V	-1.3 V	-0.7 V	-0.95 V
BVGD	20V(18V min)	16V(14V min)	9V(8V min)	10V (8V min
f _T	65 GHz	90 GHz	100 GHz	130 GHz
f _{max}	190 GHz	185 GHz	150 GHz	180 GHz
Power Density (2x75µm)	1100 mW/mm @ 8V, 10GHz	870 mW/mm @ 6V, 29GHz	580 mW/mm @ 4V, 29GHz	860 mW/mm @ 4V, 29GHz (2x50μm)

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Printed 3D Stacked Chipless RFID Tag with Spectral and Polarization Encoding

Stevan Preradovic

A fully printable 3D stacked chipless RFID tag on a 50 µm thin polyimide film consists of multi-layer cross-polarized dipole resonators that overlap. Data encoding is performed in a multiresonating circuit comprised of multiple stopband resonators. The resonators are screen printed with a silver based conductive paste. The chipless RFID tag is designed specifically for security applications suitable for mass deployment (trillions) of low cost items.

Research efforts have been devoted to developing RFID tags with no ASICs in an effort to lower the price of the RFID system. Chipless RFID tags have been designed and reported by researchers around the world. Encoding data without an IC is accomplished mainly by encoding schemes based on either time domain reflectometry (TDR) or spectral signatures. A comprehensive review of chipless tags is presented by Preradovic and Karmakar.²

To date, the only commercially available and successful TDR chipless RFID system is surface acoustic wave (SAW) based (developed by RF SAW®).³ Although operational, SAW tags are not fully printable and planar due to their piezoelectric nature and hence cannot be applied to banknotes, postage stamps or other paper or plastic items. Printable TDR based chipless tags have data capacity and size limitations due to the long delay lines required for data encoding.⁴

Printable spectral signature (frequency encoding) tags have been published in significantly higher numbers by researchers due to their compact size, multi-bit capacity and reading range compared to TDR based tags. The earliest version of a multi-bit 35-bit chipless tag was presented by Preradovic et al., ⁵ using a basic presence or absence of resonance for representing logic 0 and 1, respectively. A further increase in data capacity was introduced by Vena et al., 6 with a reduced size and a novel encoding technique based on resonance shifts within a certain frequency band representing different binary codes. Islam et al.,7 further increased data encoding by using orthogonal polarizations (polarization diversity). Polarization diversity can only apply to applications where the tag's orientation and placement is constant and/or known at all times. If the code is repeated in both polarizations, the tag is orientation insensitive; however, the data capacity is reduced by half.8 Chipless tags insensitive to

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polarization presented by Shen and Law⁹ use circularly polarized scatterers that do not have orientation restrictions.

All of these works describe tags that contain copper. The purpose of chipless RFID is to reduce the cost of the tag to a fraction of a cent. This makes copper unacceptable in a final solution. Conductive inks and pastes offer cheaper and easier ways to print tags, but performance is compromised due to their comparatively lower conductivities. So far, three types of printing techniques have been used: inkjet, screen printing and flexography. Work on ink-jet printed chipless tags with three scatterers and a total of 6 bit encoding capacity is presented by Vena et al. 10 Work on screen printed chipless tags with 3-bit data capacity using the presence and absence of resonances is presented by Nair et al.¹¹ Tags printed using flexography on paper with five resonators for encoding have been reported by Vena et al. 12

This article describes a novel chipless tag that has overlapping dipole resonators printed in multiple layers, with orthogonal polarizations, on a low cost substrate. The tag enables the use of 3D resonator placement for efficient use of space and enhances the tag's application as a security feature. The resonators are printed using screen printing. We investigate the effect of different conductive ink thicknesses on the performance of the tag, tag orientation and the isolation between overlapping orthogonally polarized resonators. This is developed mainly for security and anti-counterfeiting applications, where its multilayer aspect does not automatically identify the true nature of the layout and therefore creates ambiguity for counterfeiters. It has been patented.

OPERATING PRINCIPLE

Figure 1 is a photograph of the chipless RFID tag. This prototype operates between 1.8 and 3 GHz; if required, it can be designed to operate higher in frequency by reducing its dimensions. It contains linearly polarized, shorted dipoles printed in orthogonally polarized orientations separated by a dielectric layer. The tag has two layers but one can easily add more, depending on the application. It employs dual polarization to either encode more data or enable the tag to be orientation insensitive.

To enhance data capacity, orthogonal polarization is achieved by printing a set of dipoles with vertical polarization and a set of dipoles with horizontal polarization. In order to interrogate the tag, the RFID reader sends a signal in both polarizations when polarization diversity is employed for encoding or in a single polarization when it is not. Since isolation between orthogonally polarized signals is very high, signals with orthogonal polarizations can be transmitted at the same time to reduce reading time. Each shorted dipole has a resonance which acts as a stopband filter when the tag is placed between two reader antennas. The number of bits depends on the encoding technique. A simple presence or absence of resonance gives a maximum capacity of 8 bits with each resonator encoding 1 bit. With the encoding technique presented by Vena et al., it can be increased depending upon the reader's frequency resolution and tag resonator separation.

DESIGN

Tag Substrate and Printing

The tag is printed on a low cost polyimide thin film ($\varepsilon_r = 4.8$, h = 50 μm , tan $\delta = 0.04$). Using screen printing, conductive paste is deposited in various thicknesses. Figure 2 shows measured thicknesses of 10 and 0.8 µm using a microscope. Figure 2 indicates that the thickness of the ink can vary 15 percent from the desired thickness so it is important to measure more tags and average the results.

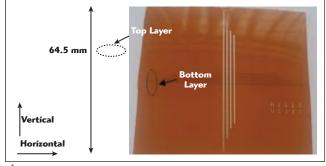
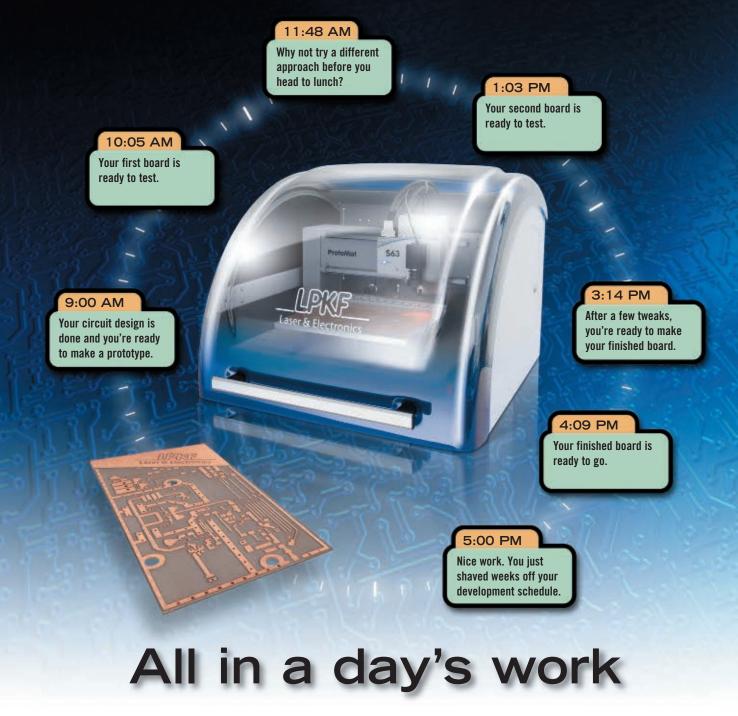


Fig. 1 Photograph of the printed chipless RFID tag.



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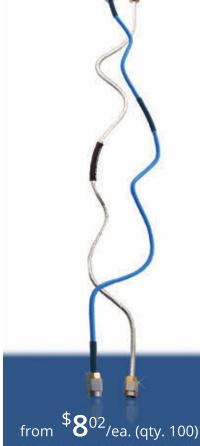
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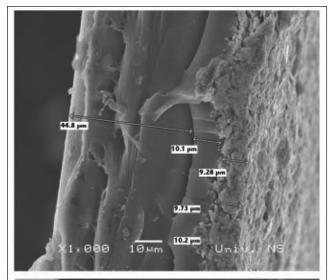
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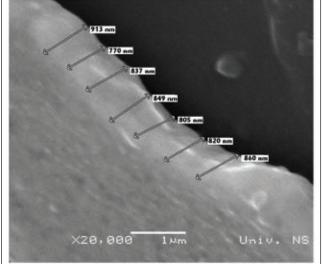


Fig. 2 Photograph of screen printed ink at 10 μm and 0.8 μm on a 50 μm polyimide film.

TABLE I CHIPLESS TAG RESONATOR LENGTHS					
Dipole Resonator Resonant Length (mm) Frequency (GHz)					
64.5	1.85				
53	2.21				
45	2.51				
41	2.8				

Tag Resonators

The tag resonators are used to encode data by resonating at different frequencies. *Table 1* shows the relationships between the lengths of the resonators used in the tag from Figure 1 and their resonant frequencies. A parametric study of physical parameters using ANSYS HFSS is used to optimize their resonant frequencies (see *Figure 3*). The resonators are

evenly spaced at ~300 MHz.

A figure of merit for another para-metric study is the attenuation created by each resonator. Better performing resonators attenuate stronger at their resonant frequencies. The tag is placed between two reader antennas at a distance of 5 cm from each antenna. The reader antennas are ultra-wideband, low gain disc monopoles. The near far field region for the monopole antennas is calculated to be at ~2 cm.

After setting the length of the resonators, we investigate the effect of printed conductive ink thickness. We calculate that the conductivity of the ink is approximately 3×10^6 S/m. The resonator is set to a length of 64.5 mm resonating at 1.85 GHz. **Figure 4** shows the variation of resonator attenuation with

ink thickness. As expected, the thicker the deposition of the conductive ink, the greater the attenuation. Below 4 μ m the attenuation of the resonator drops below 10 dB. Below 1.5 μ m the attenuation starts dropping faster due to the skin effect. The recommended ink thickness is above 6 μ m based on the results shown in Figure 4.

The relationship between dipole resonator separation and width is presented in *Figures 5* and *6*. We set the printed conductive ink thickness to 10 µm. Placing the resonators next to each other causes them to couple. It is first required to understand the minimum separation between resonators before coupling starts affecting performance. Figure 5 shows that the minimum required separation is 1000 µm. Figure 6 shows the response of the resonators for different

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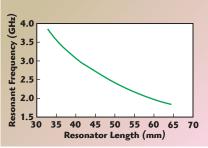
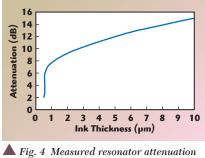


Fig. 3 Simulated dipole resonant frequency vs. resonator length.



vs. ink thickness.

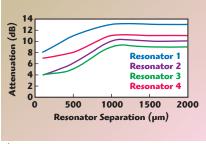


Fig. 5 Measured resonator attenuation vs. resonator separation.

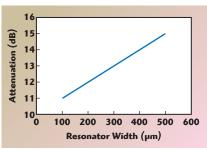


Fig. 6 Measured resonator attenuation vs. resonator width.

widths. With the width of the resonator varied from 100 to 500 µm, a linear relationship between attenuation and width is

observed.

MEASUREMENT Setup

The experimental setup block diagram and photograph are shown in Figures 7 and respectively. The reader antennas are linearly polarized Vivaldis. Vivaldi antennas exhibit wide bandwidths, directional and high gain. The tag is placed 10

cm away from each reader antenna. An Anritsu vector network analyzer, transmitting -10 dBm power, is the reading instrument. S_{21} is measured with and without the tag placed between the reader antennas. The value of S_{21} when the tag is not present is used to calibrate and normalize the tag received signal.

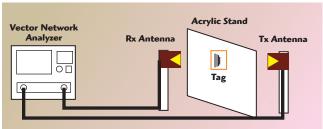
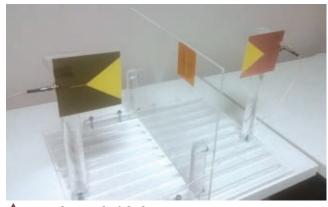


Fig. 7 Chipless RFID tag measurement setup.



radiation patterns 🛦 Fig. 8 Photograph of chipless RFID tag measurement setup.

Cross-Polarization Encoding

In this mode, the chipless RFID tag uses polarization encoding to enhance the number of resonances used to encode data and therefore enhance its data capacity. The application of the tag in this case is orientation sensitive and must be known to align reader antenna polarization.







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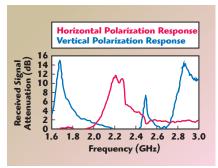
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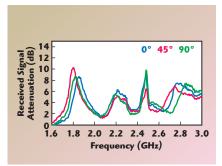
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▲ Fig. 9 Measured received signal from tag 10110100 at 10 cm.

Figure 9 shows the tag's normalized received signal. It encodes the data using three resonances in the vertical polarization and one resonance in the horizontal. Resonances are removed simply by not printing the dipole resonator. As shown in Figure 9, resonators with orthogonal polarizations do not appear in the response. We can conclude that polarization isolation is high and that it is possible to have good isolation with the resonators overlapping and separated by a thin $50~\mu m$ dielectric.



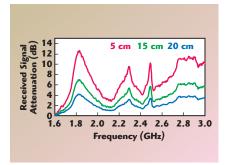
▲ Fig. 10 Tag 1111 measured code at 10 cm for different rotations.

Orientation Insensitive Encoding

If the application requires an unknown tag orientation, or one that is not fixed, then the dual polarization behavior can be made polarization insensitive by encoding the same code in both polarization planes. *Figure 10* shows the response of the tag at angles of 0, 45 and 90 degrees, respectively. In all three orientations the tag response remains reasonably constant and uniform.

Distance

Figure 11 shows the chipless RFID tag response at different dis-



▲ Fig. 11 Tag 1111 measured code at various distances from reader antennas.

tances from the reader antennas. A chipless tag with four printed resonators is used. A comprehensive study has been reported by Nair et al., ¹¹ on conductive ink printed tags for reading ranges up to 100 cm. In this work, we go out to 20 cm, which should be acceptable for anti-counterfeiting applications such as banknote authentication. From Figure 11, it is apparent that no resonant frequency shifts occur with the change of distance; as expected all that changes are the amplitudes.

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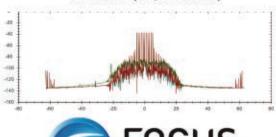
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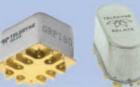
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CONCLUSION

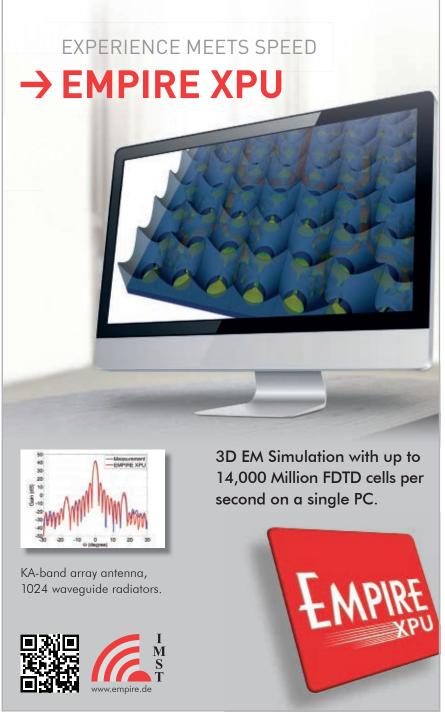
A novel chipless RFID tag with 3D stacked dipole resonators printed on a thin 50 µm polyimide film is the first tag with overlapping multilayer resonators to be successfully developed and tested. A parametric study of the tag's performance with varying resonator length, width, conductive ink thickness, orientation changes, polarization and reading range is presented. The tag operates between 1.8 and 3 GHz and can produce four or eight

resonances for data encoding depending upon the application. For higher data capacity and orientation sensitivity the tag uses polarization diversity to encode the data. For orientation insensitive applications the tag encodes the same data in both orthogonal polarizations in order to be readable in any orientation. The tag is printed using a low cost screen printing technique, on low cost polyimide film with a lossy conductive ink with 3 \times 10^6 S/m conductivity, almost 20 times

lower than copper. We have demonstrated that the tag is fully operational and has the potential to enhance anticounterfeiting of banknotes and other paper/plastic items.

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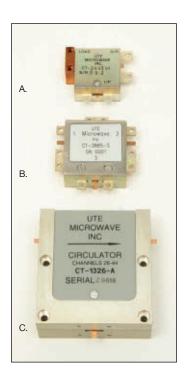
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University of Electronic Science and Technology of China, Chengdu, China¹ University of Wisconsin-Madison, USA²

A small planar flexible monopole antenna with a parylene-c coating is designed for wireless local area network and the ultra-wideband system applications. It is fabricated on a polyimide film and consists of a folded and meandered radiating strip fed by a microstrip line. A parallel plate capacitor loads the open end of the radiating strip to reduce its size. The antenna operates from 2.4 to 2.484 GHz and from 3.8 to 10.6 GHz. Far field radiation patterns under bent conditions are also presented.

Plexible electronics are low profile, light-weight and have the capability to conform to curved surfaces. The previous decade has seen a great deal of research in flexible electronics for applications in areas such as health care, mobile communications, flexible displays, wearable individual communication devices and biomedical telemetry devices. 2–3

Much effort has gone into the design of light-weight multiband antennas in order to combine communication standards such as wireless local area network (WLAN) and ultra-wideband (UWB) technology in a single portable device. 4-6 WLAN covers frequency bands of 2.4 to 2.484 GHz, 5.15 to 5.35 GHz and 5.725 GHz to 5.825 GHz in accordance with the IEEE 802.11 WLAN standards. In 2002, the frequency band 3.1 to 10.6 GHz was officially allocated to unlicensed UWB communication applications by the Federal Communication Commission.

Monopole antennas have been extensively used in communication systems because they have uncomplicated structures and thin profiles, are lightweight and exhibit wideband characteristics. Diverse structures such as arc-shapes,⁷ half-elliptical-edges⁸ and u-shapes⁹ have been utilized. To further shrink antenna size and to improve input matching, several loading techniques including capacitive loading,¹⁰ inductive loading¹¹ and multiresonator-loading⁹ have been proposed; however, most antennas incorporating loading techniques are not fabricated on a thin and flexible substrate.

This work describes a flexible capacitively-loaded monopole antenna that operates in both the WLAN and upper UWB frequency bands. The antenna, with a thickness of just 127µm, is coated with 10 µm of conformal parylene-c to for protection from corrosive agents. Input return loss, amplitude radiation patterns and gain under flat and flexed conditions show that the antenna may be bent or formed with minimal performance degradation. With the conformal parylene-c coating, it also has the capability to function normally in harsh environments.

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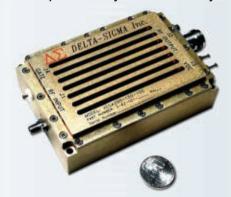
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ANTENNA CONFIGURATION AND DESIGN

The geometry and dimensions of the antenna are shown in *Figure 1*. *Figure 2* is a photograph of the fabricated antenna (including a subminiature SMA connector), clearly demonstrating its flexibility. It is fabricated on a 127 µm thick Dupont Kapton HN polyimide film with a dielectric constant of 3.5 and a loss tangent of 0.0008. The overall dimensions are 28 mm × 18 mm.

The antenna has a double sided layout that includes a 50 Ω microstrip feed, a two stage impedance transformer, an open strip, a radiating meandered strip and a circular-plate loading capacitor. Two rectangular metal grounded strips on the top side are connected to the ground plane on the bottom side of the polyimide film with six metallized vias.

The two metal symmetrical grounded strips on the top side of the substrate are designed for the convenience of connecting an SMA end-launch connector for measurement. A two-stage impedance transformer

is connected to the 50 Ω transmission line feed in order to improve wideband input impedance matching. A 7.5 mm length of open strip further optimizes the input return loss over the operating bands. The center frequency of the antenna is slightly tunable with strip length alteration.

The parallel-plate capacitor can be easily realized because the thickness of the polyimide substrate is only $127 \, \mu m$. The circular patch on the bottom side of the substrate and the open end of the strip on the top side with a width of $2.3 \, mm$ together determine the loading capacitance. The capacitance of the loading capacitor with area S and the thickness d can be approximated by:

$$C = \varepsilon_0 \varepsilon_r \frac{S}{d} \tag{1}$$

where ϵ_r is the permittivity $(\epsilon_r$ =3.5) of the polyimide substrate, ϵ_0 is the electric constant $(\epsilon_0$ =8.85 \times 10⁻¹²) and the area of the capacitor is about 3.01 \times 10⁻⁶ m². The calculated capacitance is about 0.7 pF.

Parylene-c is a commercially available product that is lightweight, un-

stressed, optically transparent and chemically/biologically inert. This makes it an excellent barrier material. Furthermore, it has a low dielectric constant ($\varepsilon_{\rm r}$ =2.95) and low loss (tan8 \approx 0.002 at 6 GHz). ¹² In this design, parylene-c coating with the thickness of 10 µm is used to enhance reliability in harsh environments.

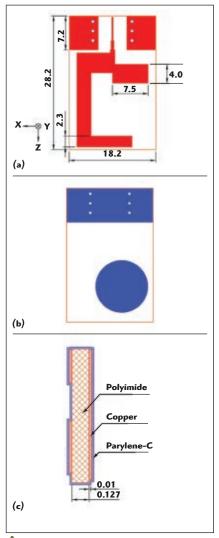


Fig. 1 Monopole antenna geometry (dimensions in mm); top layer (a) bottom layer (b) cross section (c).



Fig. 2 Photograph of the fabricated



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ANTENNA FABRICATION

Fabrication of the monopole antenna took place in the Wisconsin Center for Applied Microelectronics at the University of Wisconsin-Madison. The process is summarized in Figure 3. A 127 µm thick polyimide film (Dupont Kapton HN) is first cut using an ultraviolet laser for accurate via hole and rectangular device formation. The pre-cut film is laminated on top of a polydimethylsiloxane (PDMS) coated glass substrate, which is a conventional micro-fabrication process. A 1 µm thick copper layer is uniformly sputtered on the top side of the film and in the via holes, followed by photolithography-based copper etch-back process to form the circular patch and ground metal. The film is then flip transferred to another PDMS coated glass substrate for antenna patterning. With additional repetitive copper sputtering and etch-back, the antenna fabrication is complete. In the last stage, the fabricated antenna is de-laminated from the handling glass substrate.

An SMA end launch jack connector from Amphenol Connex is soldered to

the microstrip feed line. Because the polyimide substrate is very thin, the soldering iron temperature is kept as low as possible (about 200°) during assembly to avoid melting.

The antenna with its SMA connector is then moved into the parylene coating chamber. A 10 µm conformal parylene-c coating is formed on the surface. First the solid parylene-c dimer is heated to about 150°C in the vaporizer and undergoes pyrolysis. Then the gas parylene-c dimer is transformed into a monomer gas in a furnace. Finally, the monomers enter the vacuum deposition chamber at room temperature, becoming a thin film on the antenna polyimide substrate.

MEASURED RESULTS

Antenna input return loss, radiation patterns and gain are measured with a Satimo spherical near field measurement system. *Figure 4* compares simulated and measured antenna return loss, showing good agreement. The fabricated antenna has a -10 dB impedance bandwidth in the frequency ranges of 2.4 to 2.484 GHz and 3.8

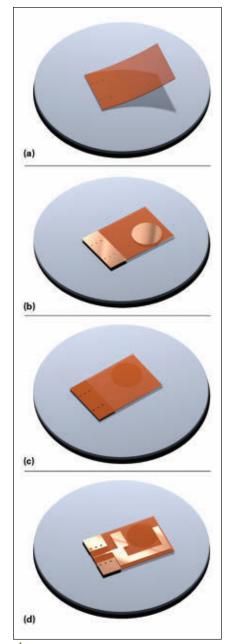


Fig. 3 Fabrication process; laminate polyimide film on temporary substrate (a) deposit and etch back copper (b) delaminate and flip transfer onto different temporary substrate (c) deposit and etch back copper (d).

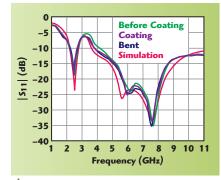


Fig. 4 Simulated and measured antenna return loss.



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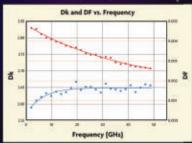
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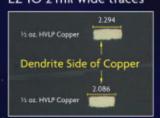
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to 10.6 GHz. These correspond to WLAN and upper UWB communication frequencies bands, respectively.

Return loss with and without parylene-c coating is shown in Figure 4, as well, demonstrating that the 10 μm of parylene-c has no significant effect. This is because the dielectric constant of the parylene-c coating material is close that of the substrate material and is only 10 μm thick as compared to the substrate's 127 μm thickness.

The results shown in *Figure 5* are the measured radiation patterns of the flat antenna in the anechoic chamber at 2.44 GHz, 5.8 GHz and 10.6 GHz. The peak gain of the antenna is about -3.8 dBi, 1.1 dBi and 2.8 dBi for 2.44 GHz, 5.2 GHz and 10.6 GHz, respectively.

Return loss of the antenna bent over polystyrene foam ($\varepsilon_{\rm r}=1.06$) with a radius of 40 mm, is shown in *Figure* 6. As seen in Figure 4, there is little difference between the return loss of the flat and bent antenna. Radiation patterns under the flat and bent conditions at 2.44 GHz and 5.8 GHz are compared in *Figure* 7. It is apparent that the antenna retains its omnidirec-

tional radiation pattern despite being bent over the foam mandrel.

CONCLUSION

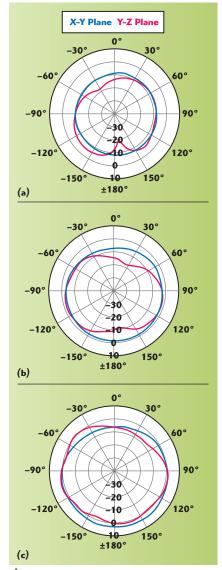
A flexible monopole antenna for WLAN and upper UWB applications is described. It is fabricated on a Dupont Kapton HN polyimide film and is coated with a parylene-c conformal coating that has excellent mechanical and electrical properties. The antenna is measured under bent conditions, exhibiting minimal degradation in return loss and radiation performance. Flexibility, simplicity of fabrication, good radiation characteristics and high reliability demonstrate the antenna's suitability for use in flexible/conformable wireless applications.

ACKNOWLEDGMENTS

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 \blacktriangle Fig. 5 Measured radiation patterns at f = 2.44 GHz (a) f = 5.8 GHz (b) and f = 10.6 GHz (c).



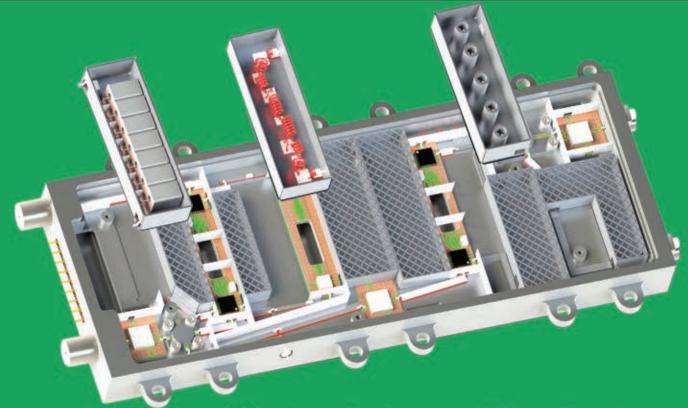
Fig. 6 Antenna bent around a polystyrene foam mandrel.



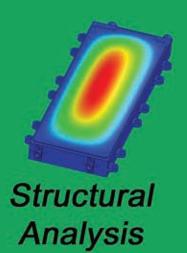


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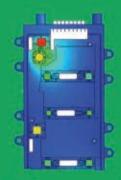


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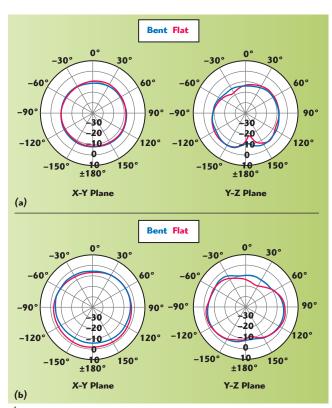


Fig. 7 Antenna radiation patterns under flat and flexed (bent) conditions at f = 2.44 GHz (a) and f = 5.8 GHz (b).

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Broadband CPW-Fed Wearable Antenna for WLAN and WiMAX Applications

Qingshuang Liu^{1,2}; Yilong Lu¹; Jie Jin² Nanyang Technological University, Singapore¹ Tianjin University, Tianjin, China²

A broadband T-shaped patch textile antenna with a coplanar waveguide (CPW) feed has a 10 dB return loss bandwidth from 1.8 to 3.8 GHz and good radiation patterns across the entire band with a maximum gain of 1.94 dBi. Return loss and radiation pattern differences are small when placed on a human body vs. free space, making it a promising candidate for WLAN and WiMAX wearable applications.

ith an increasing interest in smart clothing and wearable wireless communication systems, a wide range of devices may be integrated into human clothing which can be useful for various wireless applications such as fire fighting, GPS, healthcare and personal satellite communication.^{1,2} In these applications, the antenna plays a vital role

in system performance. Textile antennas, as a new antenna concept, are becoming more and more attractive for smart clothing due to their light weight and easy integration into everyday wear.³

Some recently proposed wearable antennas⁴⁻⁶ are either complicated or only able to cover a very limited bandwidth. Due to its inherently narrow bandwidth, bending of a conventional patch antenna in wearable applications can cause its resonant frequency to shift

reducing power transmission efficiency. A coplanar waveguide (CPW)-fed antenna, on the other hand, has wider impedance bandwidth and consists only of a single conducting layer that is more convenient for wearable textile antenna fabrication and applications. This article will introduce a cost effective, high performance wearable CPW-fed textile antenna with ordinary fabric as the substrate. The antenna has a 10 dB return loss bandwidth from 1.8 to 3.8 GHz covering both WLAN and WiMAX bands, and a higher tolerance to twisting conditions on human clothing.

ANTENNA STRUCTURE AND DESIGN

To minimize performance degradation from deformation and fabrication tolerances, a microstrip patch antenna with a CPW feed structure is chosen (see $Figure\ 1$). It consists of two layers. The top layer is a conductive fabric and the bottom layer is a denim substrate with a relative permittivity of 1.6, loss tangent of 0.02 and thickness of 1 mm. Ordinary denim fabric is chosen as the substrate because it is

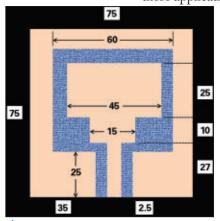


Fig. 1 Textile antenna geometry with dimensions in mm.



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flexible, lightweight, easy to integrate into clothing, stackable for different thicknesses, and most importantly it is a popular clothing material. Both materials are flexible and conformable. They can also be easily cut without special tooling. The textile antenna prototype is handcrafted by cutting the conductive fabric to the prescribed antenna geometry and then adhering it to the denim.

The resonant frequency of the an-

tenna can be estimated by Equation 1 which is a modification of an ordinary patch antenna design⁷

$$f \approx \frac{c}{\sqrt{\epsilon_{\rm r,e}} \left(L + W \right)} \tag{1}$$

$$\varepsilon_{\rm r,e} = \frac{2\varepsilon_{\rm r}}{1+\varepsilon_{\rm r}} \tag{2}$$

where c is the speed of light in air, ε_{re}

is the effective dielectric constant, L and W are the inner length and width of the slot, respectively. The initial size of the antenna can be approximated by Equation 1. The gap between the feed line and the ground is chosen to create 50 Ω CPW, and the length and width of the T-shaped patch is used to tune the antenna's resonant frequency and directivity. Parameters of the antenna geometry are optimized and a good return loss bandwidth is achieved using commercial field simulation software.8 Optimized dimensions to achieve an impedence match over a frequency range of 1.4 to 3.8 GHz are shown in Figure 1.

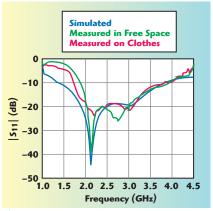
SIMULATED AND MEASURED **RESULTS**

When an antenna is attached to clothing it is not expected to be flat. Therefore, the return loss of the textile antenna on clothing is measured and compared with free space results. For on-body measurements, the textile antenna is placed on left upper arm, which is one of the most common wearable positions (see Figure 2).

Figure 3 compares measured with simulated return loss. The simu-



📤 Fig. 2 Arm-mounted wearable antenna.



A Fig. 3 Wearable antenna simulated and measured return loss.



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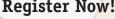
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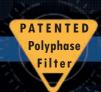


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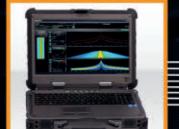
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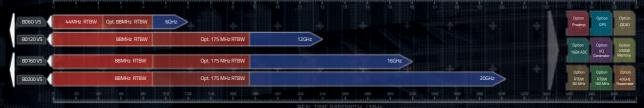
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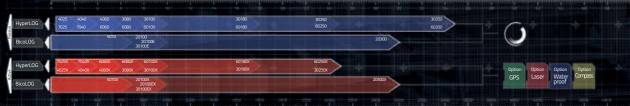
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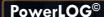
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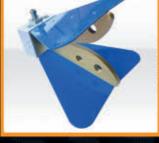
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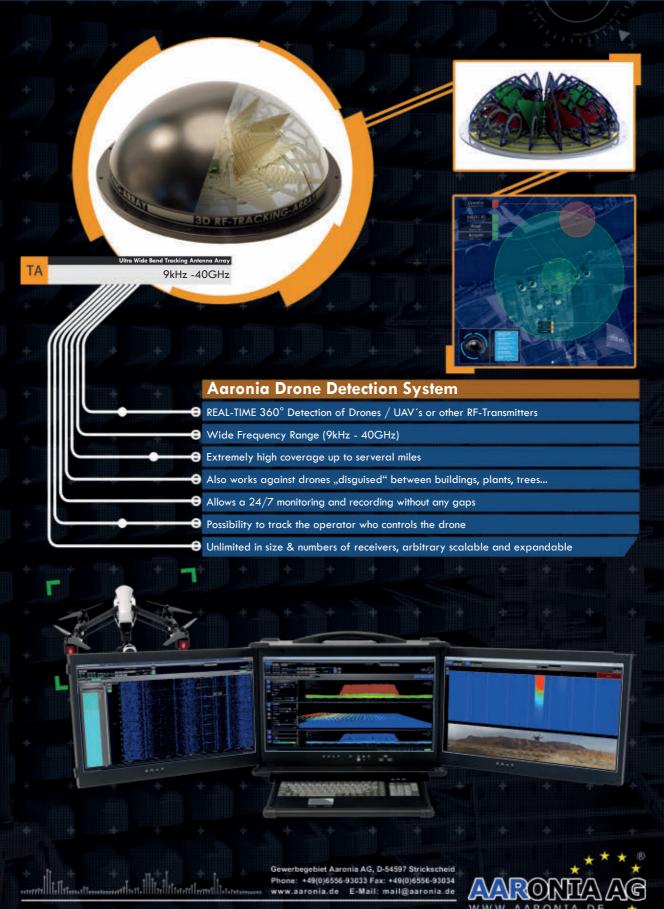


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lated 10 dB return loss bandwidth is 2.4 GHz (from 1.4 to 3.8 GHz with a fractional bandwidth of about 92 percent). The measured bandwidths are 2.1 GHz (from 1.8 to 3.9 GHz) in free space and 2.05 GHz (from 1.75 to 3.8 GHz) on-body, respectively. Good agreement is observed. Small discrepancies between the simulated and measured return loss curves that may be due to measurement error and fabrication tolerances.

Measured radiation patterns in free space and on-body at three points across the frequency band are compared in *Figure 4*. There are some differences likely due to the fact that the body's tissues influence substrate permittivity, changing the antenna currents. Nevertheless, there is little change in maximum gain with a value of around 1.9 dBi. The results show that performance of the textile antenna when placed

on-body is comparable to that of free space.

CONCLUSION

The design and performance of a wearable broadband CPW-fed textile antenna are presented. The antenna's simple structure, wide impedance bandwidth and denim fabric substrate distinguishes it from previous wearable antennas. Return loss is greater than 10 dB across a 2 GHz bandwidth from 2 GHz from 1.8 to 3.8 GHz. Radiation patterns are comparable to those measured in free space. ■

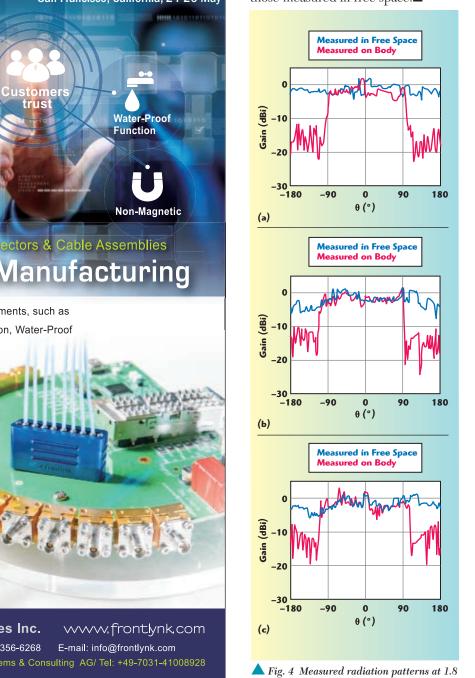
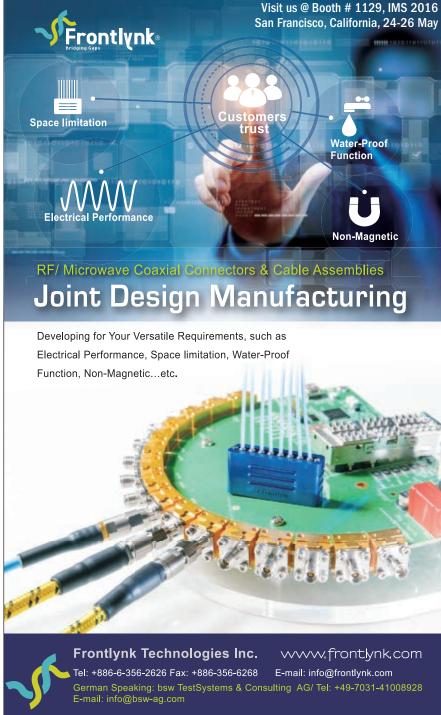


Fig. 4 Measured radiation patterns at 1.8 GHz (a) 2.5 GHz (b) and 3.8 GHz (c).



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ACKNOWLEDGMENT

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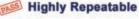
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ⁱ See datasheet for suggested application circuit.



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A Compact Balanced-to-Unbalanced Diplexer Using Interdigital Line Resonators

Jianzhong Chen, Jie Shen, Ni Gao and Anxue Zhang Xi'an Jiaotong University, Xi'an, Shaanxi, China

A balanced-to-unbalanced diplexer using interdigital line resonators (ILR) reduces circuit size and realizes high common mode rejection. By converting a symmetric four-port balanced bandpass filter (BPF) to a three-port device, a balun BPF with high selectivity and compact size is accomplished using ILRs. Then, a balanced-to-unbalanced diplexer is constructed by combining two balun filters with two 50 Ω matching lines. The balanced-to-unbalanced diplexer with operating frequencies at 1.8 GHz and 2.45 GHz exhibits excellent in-band performance, high selectivity and good isolation.

n modern communication systems, multifunction devices are desirable because they enable smaller and lower cost circuits. The balun diplexer is such a device, featuring both a diplexer filtering function and a balancedto-unbalanced conversion function. Several three-port balun bandpass filters (BPF) that integrate BPFs and balun functions have been reported.¹⁻³ Relatively little research has been done on balun diplexers, however. Bao et al.,4 and Wu et al.,⁵ report on unbalanced-to-balanced diplexer designs with one single-ended port and two balanced ports. These examples, however, are unbalanced-to-balanced diplexers that can only connect a single-ended antenna with differential receiver/transmitters. To function as an interface between a differential antenna and single-ended receiver/transmitter,

a balanced-to-unbalanced diplexer is needed.

This article describes a new balanced-to-unbalanced diplexer with compact size, high isolation and good common-mode suppression through the use of ILRs. The design process includes three steps. First, the ILR is analyzed for its application in balanced BPFs. Second, a balun BPF with specific performance is realized by conversion from a four-port balanced BPF. Finally, two balun BPFs are combined with a 50 Ω tee to implement a balanced-to-unbalanced diplexer.

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The ILR layout is shown in *Figure 1a*. Since it is symmetric along the dashed line, the odd-even mode approach is used to analyze its resonant behavior. The odd-mode and even-mode equivalent circuits are illustrated

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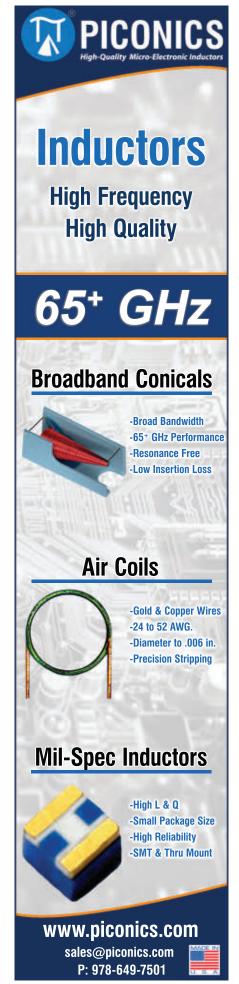
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in *Figures 1b* and 1c. The odd-mode circuit is treated as a hybrid resonator, resonating at f_{dd} . Compared to

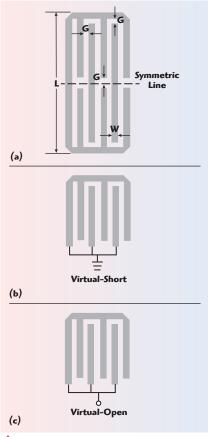
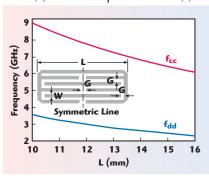


Fig. 1 ILR layout (a) odd-mode equivalent circuit (b) even-mode equivalent circuit (c).



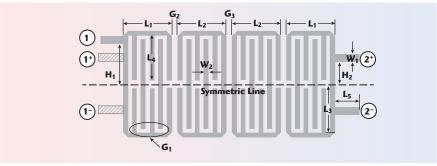
▲ Fig. 2 ILR simulated CM and DM resonant frequencies with different values of L, where W=0.5 mm and G=0.2 mm.

conventional quarter- and half-wave resonators, the ILR can operate at a lower resonant frequency, providing a size reduction benefit. On the other hand, the even-mode circuit can be considered a multi-open stub loaded resonator, resonating at $f_{\rm cc}$.

Because f_{cc} is much higher than f_{dd} high CM suppression can be achieved. To verify this, an ILR is simulated on RT/Duroid 5880 substrate (h = 0.508 mm, ϵ_r = 2.2 and tan σ = 0.001), the same material used throughout the remainder of the development. The resonant frequencies simulated using Mentor Graphics' IE3D are shown in *Figure* 2.

BALUN FILTER DESIGN UTILIZING ILRS

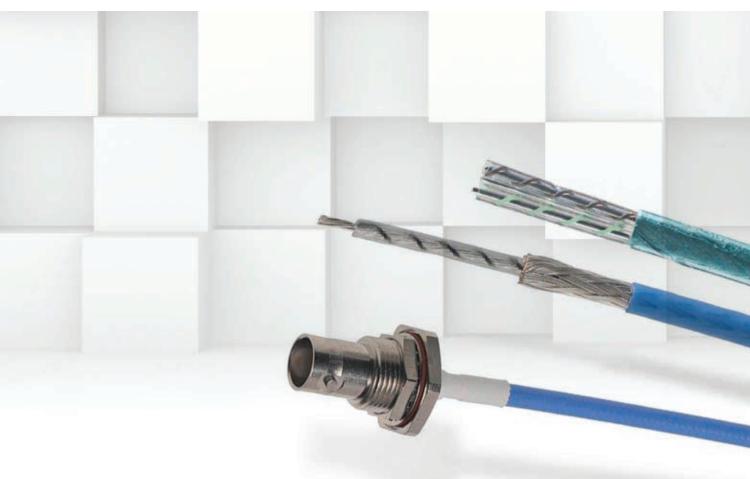
It has been shown that a three-port balun filter can be implemented from a symmetric four-port balanced filter with one of the ports being open.^{6,7} The four-pole balun BPF, composed of four compact ILRs, is shown in $\begin{tabular}{ll} \textbf{Figure} & \bf 3 & (\hat{W}_1 = 1.5, & W_2 = 0.5, & L_1 = 4, \\ \end{tabular}$ L_2 =4.1, L_3 =7.2, L_4 =6.75, L_5 =11.5, G_1 =0.2, G_2 =0.2, G_3 =0.8, H_1 =1.74 and $H_2=3.25$. Unit: mm). Port 1 on the left side is the unbalanced port, and port 2 on the right side is the balanced port. The structure is symmetrical to the symmetry line, except for the unbalanced port. The balanced ports 1+,1-(diagonal filling portion) on the left side are used to show what a balanced filter should be and illustrates the relationship between a balanced filter and a balun filter. Since the balun filter is transformed from a balanced bandpass filter, the first step in the design of the balun filter is to design a balanced filter. For the DM response, a fourth-order Chebyshev filter is employed with a fractional bandwidth of 5 percent and a center frequency of 2.45 GHz. The ideal DM external quality factor and coupling coefficients are



▲ Fig. 3 Balun filter structure using symmetric ILRs.

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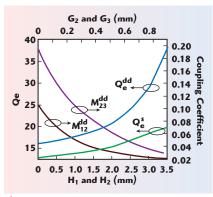












▲ Fig. 4 Extracted differential Q_e and the Mij with respect to corresponding balun BPF physical parameters.

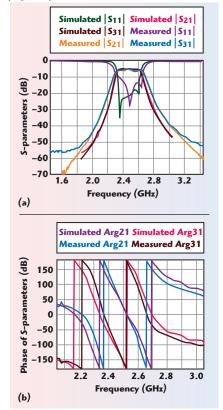


Fig. 5 Balun BPF simulated and measured responses; amplitude (a) phase (b).

$$\begin{array}{l} Q_{\rm e}^{\rm dd} = 18.66, M_{12}^{\rm dd} = M_{34}^{\rm dd} = 0.0455, \ \ (1) \\ M_{23}^{\rm dd} = 0.035 \end{array}$$

In the DM excitation, the symmetric plane is a virtual short. The center frequency of the DM passband is determined by Figure 2. The tap positions and gaps affect the $Q_{\rm e}$ and coupling coefficients, respectively. The DM coupling coefficient and $Q_{\rm e}$ are extracted, and their values with respect to structure parameters are shown in *Figure 4*. In the balanced filter design, simulation is accomplished with the IE3D full-wave simulator as well.

After obtaining the respective parameters using Equation 1, and Figure 4, the DM response is simulated and optimized. Under CM excitation, the symmetric plane is a virtual open. The resonant frequency is decided by Figure 2. The CM resonant frequency is much higher than the DM frequency; therefore, the CM response is strongly suppressed near the DM passband.

To transform the balanced filter into a balun filter, one side of the balun filter should be an unbalanced port, and the other side should be a pair of balanced ports. For the balun filter to have almost the same response as that of the balanced filter, the tap position of the balanced port should not be changed. However, for the unbalanced port, the tap position should be tuned to meet the external quality factor requirement

$$Q_e^s = Q_e^{dd} = 18.66$$
 (2)

where $Q_{\rm e}^{\rm s}$ is the external quality factor at the unbalanced port.

In this balun filter design, the extract-

ed Q_e^s with respect to the tap position is extracted in Figure 4 as well. With the tap position set to be 3.25 mm, a good balun filter response is obtained. Simulated and measured results are shown in **Figure 5**. Good agreement and high performance are observed.

BALANCED-TO-UNBALANCED DIPLEXER

Based on the above approach, a second four-pole balun filter with 7 percent fractional bandwidth and a 1.8 GHz center frequency is designed. Then, the balanced to unbalanced diplexer is constructed. **Figure 6** shows the configuration of the balanced-to-unbalanced diplexer, where the common Port 1 is balanced and Ports 2 and 3 are single-ended. To achieve high isolation and low return loss, the reflection coefficients $\Gamma_2^{\rm dd}$ and $\Gamma_3^{\rm dd}$ in Figure 6 should satisfy

$$\begin{split} &\left|\Gamma_{2}^{\mathrm{dd}}\left(f_{\mathrm{CH1}}\right)\right| \approx 0, \left|\Gamma_{2}^{\mathrm{dd}}\left(f_{\mathrm{CH2}}\right)\right| \approx 1, \\ &\left|\Gamma_{3}^{\mathrm{dd}}\left(f_{\mathrm{CH2}}\right)\right| \approx 0 \text{ and } \left|\Gamma_{2}^{\mathrm{dd}}\left(f_{\mathrm{CH1}}\right)\right| \approx 1 \, (3) \end{split}$$

These requirements are easily realized by tuning the reflection group delay to make the common port group delay values equal to the individually synthesized values at the center frequency of both channels. After several optimizations, final dimensions are obtained (L_1 =4, L_2 =4.1, L_3 =9.66, $L_4=9.16$, $L_5=12.5$, $\bar{L}_6=3.5$, $L_7=2$, $L_8=4$, $L_9=4.1$, $L_{10}=4.1$, $L_{11}=4.0$, L_{12} =6.55, L_{13} =7.55, $G_1 = 0.23$, $G_2=0.97$, $G_3=0.23$, $G_4=0.31$, $G_5=1.16$, $G_6 = 0.37$, $G_7 = 0.2$, $W_1 = 1.5$, $W_2 = 0.5$, $\dot{H}_1 = 3.76$, $\dot{H}_2 = 4.03$, $\dot{H}_3 = 1.8$ and $H_4 = 3.01$. Unit: mm).

EXPERIMENTAL RESULTS

Good agreement between mea-

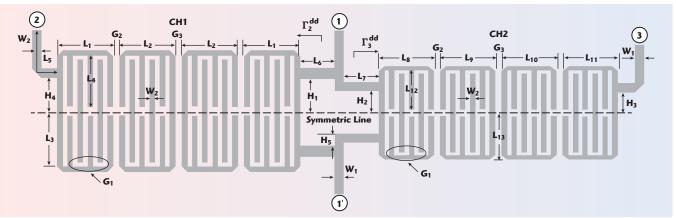


Fig. 6 Balanced-to-unbalanced diplexer structure.



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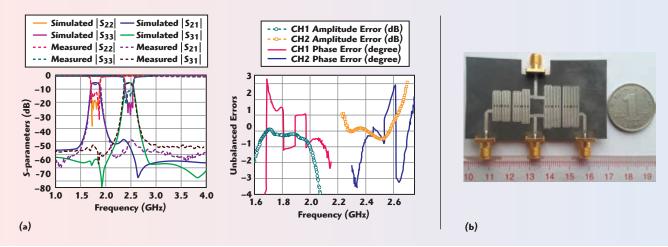
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▲ Fig. 7 Diplexer simulated and measured responses (a) balanced performance (b) photograph (c).

sured and simulated responses of the balanced-to-unbalanced diplexer is shown in *Figure 7*. The passbands are located at 1.8 GHz and 2.45 GHz with 3 dB bandwidths of 7.2 percent and 5.3 percent, respectively (see *Figure 7a*). The minimum insertion loss for each of the two channels, including SMA connectors, is 2.1 dB and 2.4 dB. Balanced performance is shown in *Figure 7b*. The maximum amplitude error is 0.5 dB and the maximum phase error is 2° in the two operating bands. A photograph of the balanced-

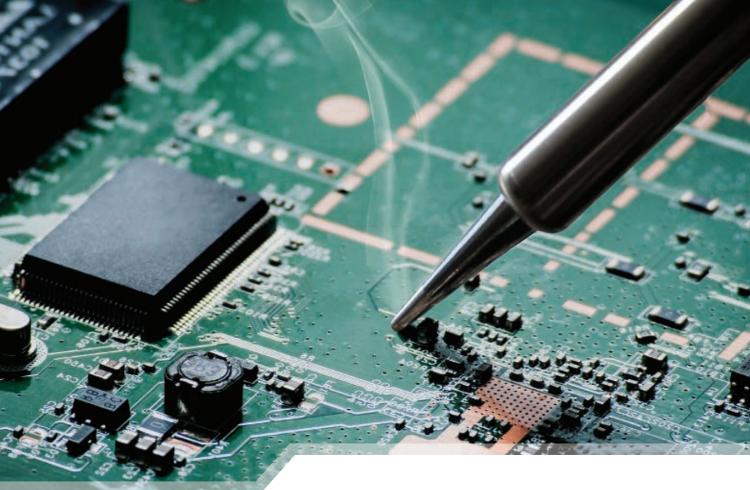
to-unbalanced diplexer is shown in **Figure 7c**. It is very compact at 34 mm \times 9 mm $(0.28\lambda_g\times0.40\lambda_g),$ where λ_g is the guided wavelength at 1.8 GHz.

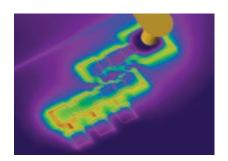
CONCLUSION

A novel ILR is used to design a balanced-to-unbalanced diplexer. The resonator is compact and enables a large frequency separation of the DM and CM passbands. A balanced-to-unbalanced diplexer with operating frequencies at 1.8 GHz and 2.45 GHz is designed, fabricated and mea-



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ACKNOWLEDGMENTS

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Design of a Compact Four MIMO Handset Antenna Structure

Hyunsoo Kim and Sungtek Kahng University of Incheon, Incheon, Korea

A compact communication platform employing four antennas is designed for LTE MIMO applications. It includes one pair of small MIMO antennas with a zeroth-order resonator (ZOR) in-phase electric field distribution and another pair of MIMO chip antennas. The radiators are $9.0 \text{ mm} \times 5.5 \text{ mm}$ and $12 \text{ mm} \times 3.0 \text{ mm}$, respectively, and are placed on the top and bottom edges of a realistic handheld device. The design operates in the 2.4 GHz LTE band. Antenna gain is greater than 1.3 dBi, and isolation is greater than 10 dB for all antennas.

ultiple input multiple output (MIMO) antennas offer higher qualtity mobile communication by providing RF isolation in diverse signal environments. Designers have been challenged to reduce antenna size while increasing isolation between the multiple antennas. 1-14 Mak et al., 1 introduced a set of antennas with a structure that traps the near field from one antenna to the other based upon a local current loop disconnecting a fictitious enlarged loop in order to increase isolation. The antennas have acceptable radiation patterns and isolation, but are large; the radiators and the trap occupy the top edge and two sides of a handset. Payandehjoo et al.,² adopted an EBG geometry to increase diversity gain by preventing coupling between antennas. Its size, however, exceeds the industrial standard and its working frequency is not within the WiMAX band. Wang et al.,³ introduced two microstrip-fed antennas whose layered radiating parts stand perpendicular to the handset stratified ground with a folded and periodically meandered decoupling structure

for improved isolation. Although this provides greater than 12 dB isolation, it has a microstripfed monopole-type decoupling geometry and three-dimensionally folded radiators that occupy a large area.

Simple meandered quarter-wave radiators are separated with a split ground by Sharawi et al.,⁴ and a hybrid coupler by Bhatti et al.⁵ Although, in the latter case, the radiators are connected with an LC-based branch coupler for reduced coupling, three-dimensionally folded monopoles share a shorted loop for better decoupling in the design by Han and Choi.⁶ Taking a different approach, a very compact radiator using a double-layered CRLH loop is adopted for miniature symmetrically-shaped MIMO antennas by Yoo et al.¹⁴ The total size of the structure occupies two-thirds of the top edge of a handset device, gain is greater than 0 dBi and isolation is greater than 12 dB.

In this work, four MIMO antennas are demonstrated, having a compact size suitable for use in a mobile handset. In contrast with the dual antenna approaches, 1-13 two pairs of an-

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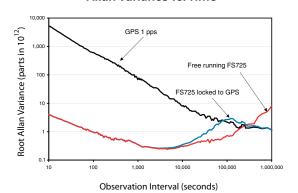
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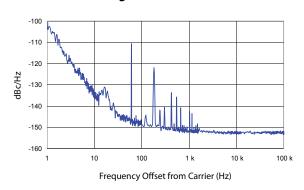
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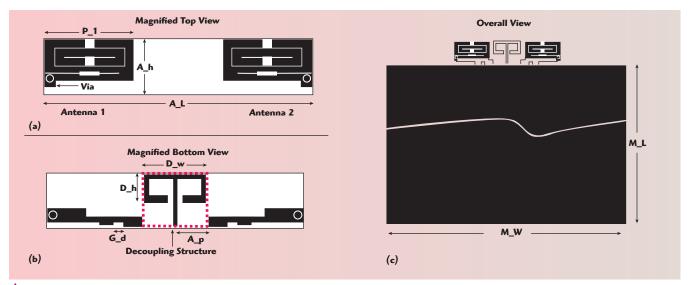


Fig. 1 The two MIMO antennas placed on the top edge of the hand held device; top-view (a) bottom view (b) the two antennas installed on the top edge (c).

tennas form a densely populated antenna structure within a 54 mm \times 80 mm area. One pair consists of two small radiators and a decoupling device between them, similar to that of Yoo et al. ¹⁴ Each radiator is designed to resonate with the in-phase electric field distribution of the coupling rings in a 9 mm \times 5.5 mm footprint, and radiate with the peak-gain over 1 dBi. These ZOR radiators are placed close to each other, but the decoupling structure provides isola-

tion greater than 10 dB. The other pair employs modified monopoles, each smaller than 12 mm \times 3 mm. The first pair of antennas sits on the top edge of the platform, and the second pair is placed on the bottom edge.

CRLH ZOR ANTENNA DESIGN

The specifications are $f_0 = 2.4$ GHz, return loss $|S_{11}| \ge 10$ dB, antenna gain ≥ 1 dBi, efficiency ≥ 50 percent and





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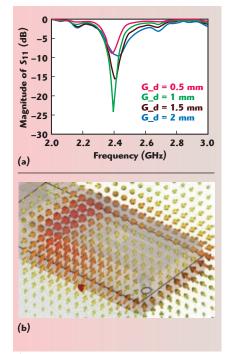
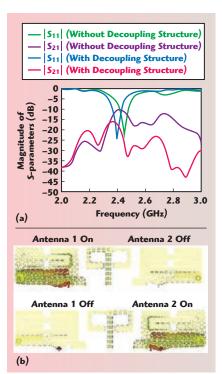


Fig. 2 Parametric sweep and field at the ZOR; return loss of the CRLH MIMO antenna as a function of G_d (a) ZOR electric field (b).

isolation $|S_{ij}| \geq 10$ dB. The antenna elements are similar to split ring resonators (SRR) in the sense that their inner open-gap rings are surrounded by their outer rings. Different from an ordinary SRR, however, is that one corner of the outer ring is connected to an upper transmission line (UTL) coupled through the electric field while the other end is connected to a lower transmission line (LTL) attached to ground, resulting in composite right and left-handed (CRLH) properties.

The antenna elements' SRRs and the UTL are located on the top surface of a 2 mm thick FR4 substrate whose bottom surface contains the feed points to the handset ground, the planar mushroom (decoupling structure) and the LTL as shown in Figure 1. Since a conventional SRR has a right-handed resonance, it seems unsuitable, at first sight, for effective size reduction. Therefore, each of the antennas uses the SRR as the series capacitance (C_L) and part of the series inductance (L_R) in implementing the CRLH zeroth-order resonance. Simultaneously, the electric field coupling and current flowing between the upper and lower transmission lines determine part of the shunt capacitance (C_R) and the shunt inductance

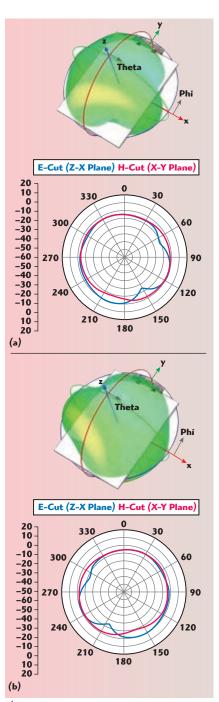


▲ Fig. 3 Predicted isolation (S₂₁) before and after adding the planar mushroom; S-parameters (a) surface currents on the top two MIMO antennas.

 (L_L) , respectively. In addition, the LTL influences L_R and C_R . These factors are adjusted to make the SRR smaller. For this, a parametric study (see *Figure 2*) is conducted.

Because G_w and G_d affect impedance matching and C_B, return loss $(|S_{11}|)$ is investigated when G_d is varied. G_d ranges from 0.5 to 2.0 mm and four samples are taken. With a 10 dB criterion, G_d values of 2 mm and above are acceptable as shown in Figure 2a. This implies that a certain collective shunt capacitance of C_R is required, maintaining G_d. Figure **2b** shows that the in-phase variation phenomenon with one-direction electric field vectors (all directed upward) is generated at the ZOR frequency. When the ZOR condition and resonance conditions are met, the following values are obtained for the geometrical parameters: A_h=5.5 mm, $A_L = 27$ mm, $P_1 = 9$ mm, G_d = 1 mm, $A_p = 3.2$ mm, $D_w = 6.5$ mm, $D_h = 3$ mm, $M_L = 80$ mm, and $M_W = 60 \text{ mm}$ with 2 mm-thick substrate of $\varepsilon_r = 4.3$ and loss tangent $(\tan \delta) = 0.025.$

To achieve isolation greater than 10 dB, the planar modified mushroom decoupling structure of Figure 1 is used. Typically, a mushroom is a 3D



▲ Fig. 4 Simulated radiation patterns of the top two MIMO antennas; Antenna 1 (a) Antenna 2 (b).

structure made up of a surface patch with a shorted via, and plays the role of bandstop filter that can be broadened in the form of arrays. For this application the mushroom is modified to fit into a planar structure. The arms are made longer and bent twice to make branch loops, increasing the shunt capacitance due to the narrowed gap between the ends of the arms and ground. The capacitance of the mushroom resonates with the

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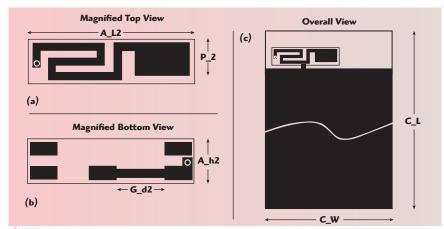
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▲ Fig. 5 Structure of the chip antenna; top surface (a) bottom surface (b) antenna at an edge of the platform (c).

higher inductance of the loop in the arm, when the magnetic field from one radiator passes the loop. This acts as a bandstop filter.

As shown in **Figure 3a**, with the planar mushroom as the decoupling structure, isolation is increased from 9 to 16 dB. The surface current densities are plotted in **Figure 3b** to visualize how the increased isolation is obtained. The decoupling structure draws surface current due to the near

field from one excited antenna and plays the role of a trap; consequently, isolation between the element antennas is enhanced.

Figure 4 shows the radiation patterns of the top two MIMO antennas. The two antennas exhibit similar omni-directional far field patterns, appropriate for mobile communication. Also, full-wave simulated results yield a radiation efficiency of 55 percent and a peak gain of 1.2 dB.

CHIP ANTENNA DESIGN

A new compact chip antenna with a 2 mm-thick FR-4 substrate is the element for each of the bottom two antennas of the platform. The specification is the same as the previously proposed CRLH MIMO antennas. The antenna structure shown in *Figure 5* is smaller than a $\lambda/4$ planar inverted F antenna (PIFA). The patch is attached at the end of meander line to augment the decreased radiation resistance caused by miniaturization. Its reactance is tuned to adjust the resonant frequency.

Figure 6a shows its frequency-response versus patch length, which is adjusted to change reactance for the best return loss. At resonance, the antenna exhibits 87 percent radiation efficiency and 1.6 dB of peak gain. Its geometrical values are A_h2 = 3 mm, A_L2 = 12 mm, P_2 = 2.5 mm, G_d2 = 3.5 mm, C_L = 50 mm and C_W = 21 mm. **Figure 6b** shows its predicted radiation patterns.

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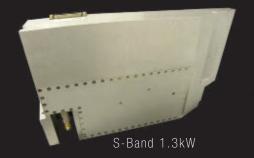
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	DM-HPS-35-101	2.2	2.5	20	40	35%	CW	28	4.0 x 4.00 x 1.00
5	DM-HPC-60-101	5.5	8.5	50	50	25%	CW	28	2.5 x 2.75 x 0.45
ATCOM	DM-HPX-100-105	9.75	10.25	50	100	30%	CW	28	7.4 x 4.30 x 1.65
ATC	DM-HPKU-40-105	13.75	14.5	45	50	20%	CW	24	4.5 x 4.00 x 0.78
S	DM-HPKU-40-101	14.4	15.5	45	30	15%	CW	28	2.5 x 2.75 x 0.45
	DM-HPKA-10-102	29	31	50	12	15%	CW	20	3.1 x 3.00 x 0.78
	DM-HPKA-20-102	29	31	50	20	15%	CW	20	3.5 x 4.50 x 0.78
	DM-HPL-1K-101	1.2	1.4	50	1000	40%	100 µs, 10% d.c.	50	6.0 x 6.00 x 1.50
	DM-HPS-1K-102	2.9	3.1	45	1300	35%	100 μs, 10% d.c.	32	14.0 x 8.00 x 1.75
	DM-HPS-1K-103	2.9	3.3	45	1500	35%	100 μs, 10% d.c.	50	9.5 x 9.50 x 1.50
	DM-HPS-1K-104	3.1	3.5	45	1300	35%	100 μs, 10% d.c.	50	9.5 x 9.50 x 1.50
	DM-HPC-50-105	5.2	5.8	50	50	35%	100 μs, 10% d.c.	32	3.0 x 3.00 x 0.60
E E	DM-HPC-200-101	5.2	5.9	50	200	40%	100 μs, 10% d.c.	50	4.5 x 4.50 x 0.78
RADAR	DM-HPX-140-101	7.8	9.6	50	140	40%	100 μs, 10% d.c.	40	3.6 x 3.40 x 0.67
æ	DM-HPX-400-102	8.8	9.8	50	450	35%	100 μs, 10% d.c.	50	7.0 x 4.50 x 1.65
	DM-HPX-800-102	8.8	9.8	50	900	35%	100 μs, 10% d.c.	50	9.0 x 6.00 x 1.65
	DM-HPX-250-101	9.4	10.1	50	250	40%	100 μs, 10% d.c.	50	3.6 x 3.40 x 0.67
	DM-HPX-800-101	9.4	10.1	50	900	35%	100 μs, 10% d.c.	50	9.0 x 6.00 x 1.65
	DM-HPX-20-101	9.9	10.7	46	20	30%	100 μs, 10% d.c.	32	3.6 x 3.40 x 0.67
	DM-HPX-50-101	9.9	10.7	50	50	30%	100 μs, 10% d.c.	40	3.6 x 3.40 x 0.67
	DM-HPMB-10-103	0.1	6	55	10	20%	CW	28	2.5 x 2.75 x 0.45
끭	DM-HPLS-50-101	1	3	50	50	30%	CW	45	4.3 x 3.50 x 0.45
ECTRONIC WARFARE	DM-HPLS-160-101	1	3	16	160	25%	CW	45	6.3 x 6.00 x 0.78
/AR	DM-HPSC-50-101	2	6	50	50	30%	CW	28	2.5 x 2.75 x 0.45
S	DM-HPSC-80-101	2	6	50	80	25%	CW	28	4.5 x 4.00 x 0.78
Ž	DM-HPSC-150-101	2	6	60	150	25%	CW	28	6.5 x 6.50 x 0.78
E C	DM-HPMB-10-101	2	18	45	10	15%	CW	32	2.5 x 2.75 x 0.45
ြူ	DM-HPMB-40-101	6	18	50	30	15%	CW	28	2.5 x 2.75 x 0.45
H	DM-HPX-25-101	8	11	45	25	30%	CW	28	2.5 x 2.75 x 0.45
	DM-HPX-50-102	8	11	50	50	30%	CW	28	2.5 x 2.75 x 0.45

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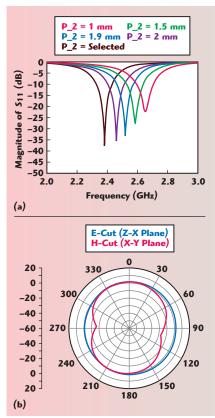


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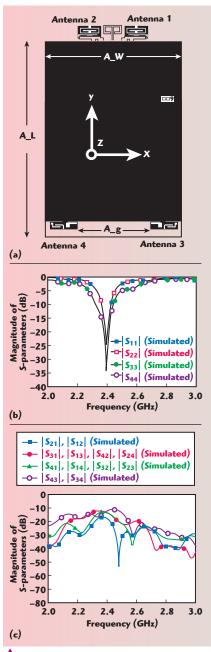


▲ Fig. 6 Parametric sweep of the small chip antenna (a) simulated radiation pattern (b).

data transmission and enhanced channel capacity compared to the conventional MIMO architectures that use only two antennas. **Figure 7** shows the four-antenna structure with the following dimensions: A_W= 60 mm, A_L= 80 mm, and A_g= 32 mm on the 2 mm-thick substrate of $\epsilon_{\rm r}=4.3,$ loss tangent tan $\delta=0.025.$

The two ZOR antennas (1 and 2) are placed in the center of the top edge of the handheld platform in *Figure 7a*. The two chip antennas (3 and 4) are located near the corners of the bottom edge. Their positions are optimal with A_W, A_L, and A_g equal to 60 mm, 80 mm and 32 mm, respectively; with the other geometrical parameters unchanged from the previous design stages. *Figure 7b* is the simulated return loss for the four antennas showing that they all resonate at 2.4 GHz. Isolation (see *Figure 7c*) is greater than 10 dB.

Simulated antenna radiation patterns are omni-directional as shown in *Figure 8*. Radiation efficiency is 47 percent and peak gain is 1.5 dB at the resonant frequency of antennas 1 and 2, which indicates that the radiation efficiency is lower by about 10 per-



▲ Fig. 7 Finalized structure, and simulated frequency responses of the four MIMO antennas; geometry (a) return loss (b) isolation (c).

cent when compared to their separate designs. Radiation efficiency and peak gain of antennas 3 and 4 are 57 percent and 1.7 dB, respectively. They are acceptable considering the specifications.

MEASUREMENTS

The fabricated antennas are connected to SMA connectors for RF evaluation as shown in *Figure 9a*. Measured return loss of the individual antennas is slightly shifted from that of the simulation, but the four antennas demonstrate greater than 10 dB

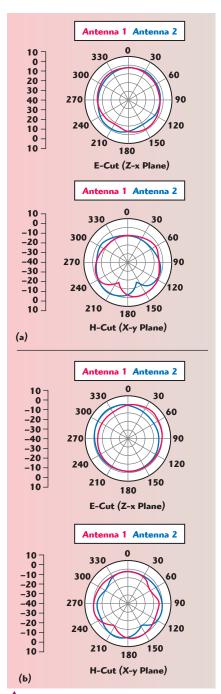


Fig. 8 Simulated radiation patterns of the four MIMO Antennas; E- and H-plane cuts of Antennas 1 and 2 (a) E- and H-plane cuts of Antennas 3 and 4 (b).

return loss at 2.4 GHz (see *Figure 9b*). The isolation among all the antennas is greater than 10 dB, as well. *Figure 9c* is the far field pattern of antenna 1 (and antenna 2 by symmetry), and *Figure 9d* is the far field pattern of antenna 3 (and antenna 2 by symmetry). The peak gains for the four antennas, greater than 1.3 dBi, over almost the omni-directional far field distribution, are suitable for mobile MIMO applications.



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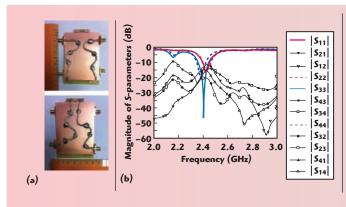
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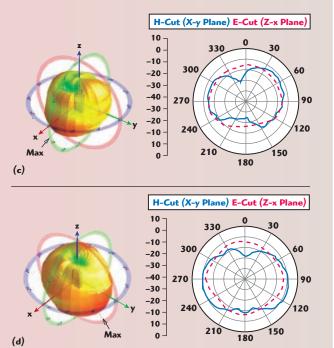
▲ Fig. 9 Measured results for the fabricated four MIMO antennas; Photo of the fabricated antennas (a) return loss and interference (b) Eand H-plane beam-patterns for Antennas 1 and 2 (c) E- and H-cut beampatterns for Antennas 3 and 4 (d).

CONCLUSION

A compact communication platform with four multiple antennas is designed for LTE MIMO applications. For a higher antenna population in the handset, one pair of small MIMO antennas with a ZOR in-phase electric field distribution is used along with a pair of modified monopole type chip MIMO antennas. The radiator areas are 9 mm \times 5.5 mm and 12 mm \times 3 mm, respectively. The small size of the radiators plays a critical role in their placement on the top and bottom edges of a realistic handheld device to obtain a

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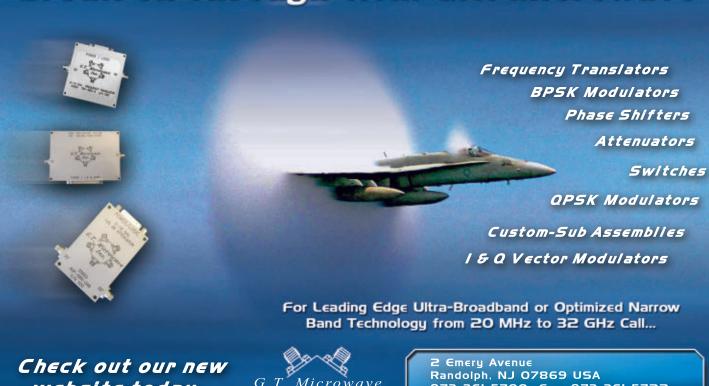
low correlation coefficient. It is designed for the 2.4 GHz LTE band, and has useful MIMO performance with the antenna gains greater than 1.3 dBi, and isolation between antennas greater than 10 dB.■

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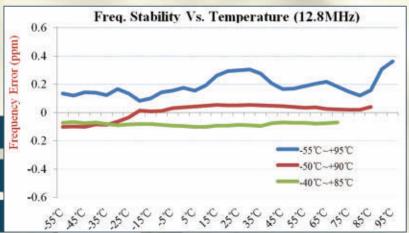
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Computing Thermal Resistance of PCB-Mounted MMIC Devices

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emperature has a direct impact on the operating performance and reliability of semiconductor devices. Devices that operate at high junction temperatures for long periods of time can sustain permanent damage sooner, compromising reliability and shortening operating lifetime. For thermally related failures, the life of a MMIC component is directly related to the temperature at the hot spot of the semiconductor die in the device which is mounted on a printed circuit board (PCB). It is therefore critical that designers understand the thermal properties of a PCB design for a given MMIC device in order to minimize thermal resistance and temperature rise.

This article discusses a simple method for computing thermal resistance between a MMIC amplifier and the ambient environment. The temperature rise from the PCB to case is calculated based on the thermal resistance of the PCB layout and compared with measured temperatures using thermal photography to validate the accuracy of the calculation method.

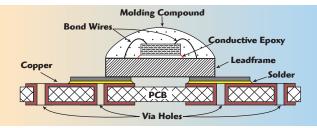


Fig. 1 Cross section of a MMIC component.

CALCULATION

A packaged MMIC component consists of a semiconductor die mounted on a lead frame as shown in *Figure 1*. The die is attached to the lead frame using conductive epoxy and electrical connections from the die to the lead frame are made using wire bonding. The die is covered with a plastic molding compound to protect it from environmental damage and contamination.

Thermal resistance is defined as the ratio of temperature rise to the power dissipation and is expressed in °C/W. The thermal resistance from the hot spot on the die to external ambient consists of a series of thermal resistances:

- Hotspot on the die to bottom of die (θ_{die})
- Conductive epoxy (θ_{ce})
- Lead frame $(\hat{\theta}_{lf})$
- Solder on PCB (θ_{sl})
- Top of PCB to bottom surface (θ_{PCB})
- PCB to ambient (θ_{PCB-A})

The sum of thermal resistances of the die, conductive epoxy and lead frame is usually called θ_{jc} or thermal resistance from junction to case:

$$\theta_{ic} = \theta_{die} + \theta_{ce} + \theta_{PCB} \tag{1}$$

This is typically provided by component manufacturers. An example is the Mini Circuits PHA-1+ amplifier for which θ_{ic} is 60°C/W.

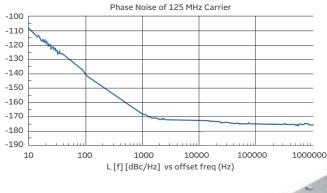
The contribution of solder on the PCB (θ_{sl}) is small and not discussed in this article. What remains to be determined is the thermal resis-



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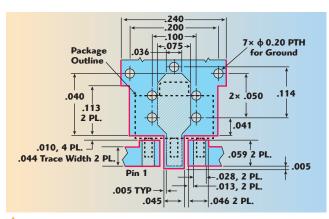


Fig. 2 Suggested MMIC amplifier PCB layout. tance of the PCB which is dependent on PCB design. A thermal design using the PHA-1+ as an example is described.

The amplifier operates on a single +5V power supply and is housed in an industry standard SOT-89 package. The suggested PCB layout is shown in Figure 2. The layout must accommodate both the electrical requirements of the device (such as proper line impedance, DC bias, grounding, bypassing, etc.) and the thermal require-

ments. Via holes in the PCB play an important role in providing good electrical and thermal paths to ground. The recommended PCB layout consists of 7 via holes under and around the amplifier unit.

Where:

sistance (θ) of a single via hole can be calculated using Equation 2:

$$\theta = \frac{1}{k * A} \tag{2}$$

Where:

l = Length of the via hole (m) A = Area of via hole cross section (m²)k= Thermal conductivity (W/m-K) =

385W/m-K (for copper) For an unfilled via:

$$A = \frac{\pi \left(d_o^2 - d_i^2\right)}{4} \tag{3}$$

The thermal re-

Each of the 7 via holes in the suggested PCB layout of Figure 2 has a 0.02" outer diameter (d_o) with a copper thickness of 0.0014", resulting in an inner diameter (d_i) of 0.0172". PCB thickness is 0.020". Also, given a 0.0014" copper thickness on the top and bottom of the PCB, the length of the via (l) is 0.0228".

 d_o = Outer diameter of the via (m)

d_i = Inner diameter of the via (m)

 d_0 and d_i is the copper thickness.

gle copper via is expressed as:

 $\theta = \frac{4 * l}{k * \pi \left(d_o^2 - d_i^2\right)}$

decreases

Note that the difference between

Substituting Equation 3 into Equa-

Equation 4 implies that θ decreas-

Length of the via or PCB thickness

Via diameter (d_0) increases

 $(d_0 - d_i)$ increases

Copper thickness in the

(4)

tion 2, the thermal resistance of a sin-

Substituting these parameters into Equation 4, the thermal resistance of a 20-mil diameter unfilled via hole is determined to be 29°C/W. For 7 via holes, we assume the thermal resistance is calculated as if they were in parallel to simplify the calculation; therefore, the thermal resistance for 7 vias in parallel is 4.1°C/W. This method does not take into account the spatial distribution of the vias, but it provides a good first order approximation.

Given that thermal resistance is the ratio of temperature rise to power dissipated, the value for thermal resistance allows us to predict the temperature rise as:

$$\Delta T = \theta_{PCB} * P_{d} \tag{5}$$

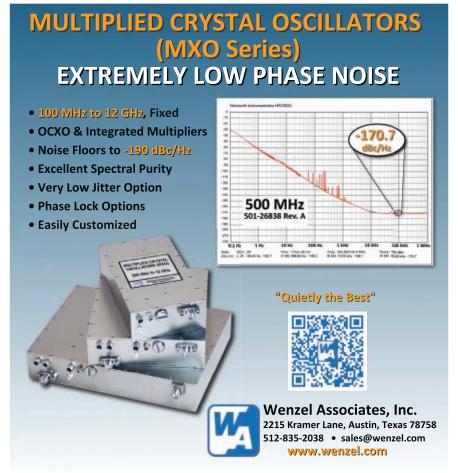
Where P_d is power dissipation defined as the product of device voltage and current. For a PHA-1+ amplifier, the device voltage is +5V and current is 0.165A, so power dissipation is 0.825 W. The temperature rise is therefore:

$$\Delta T = 4.1^{\circ} C / W * 0.825W = 3.4^{\circ} C$$
 (6)

This is a first order approximation temperature rise from the device case to the ground lug.

MEASUREMENTS

To validate the accuracy of these calculations, a +5V supply is applied





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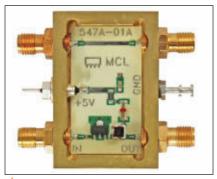


Fig. 3 MMIC amplifier test board.

		TABLE 1		
	COMPUTED	VS. MEASURED TEM	PERATURE RISE	
Computed (°C)	Meas	ured (°C)	Gnd-Case (°C)	Computed- Measured (° C)
$\Theta_{PCB} \times P_d$	Case	Gnd	Rise	Measured (°C)
3.4	32.7	36.1	3.4	0.0

to the DC terminal of the test circuit shown in Figure 3, with measured DC current of 0.165A. After temperature stabilization, a thermal photo-

graph is taken of the case, PCB, ground lug and amplifier body (see Figure 4). Table 1 compares measurement results with the calculations.

The measured (mean) temperature of the case (assuming it is the same as the bottom of the PCB) is 32.7° C: the measured (mean) temperature the ground lug is 36.1°C. Therefore the measured temperature rise from case to ground lug is 3.4°C, which is the same as the computed value. The method for calculating thermal resistance shown in this article therefore allows designers to predict temperature rise without the need for sophisticated thermal analysis tools and software. This is a useful tool in designing a PCB to minimize thermal resistance.

The calculation allows accurate prediction of thermal resistance from PCB to case. Often, thermal resistance from junction to ambient is needed. For the case of the PHA-1+, given an ambient temperature of 24°C and measured case temperature of 32.7°C, the difference between case and ambient temperature is ΔT_{PCB-A} = 8.7°C. The thermal resistance from case

(or bottom of PCB) to ambient is:

$$\theta_{PCB-A} = \frac{\Delta T_{PCB-A}}{P_{d}}$$
= 8.7° C / (5V * 0.165A) = 10.5° C/W

Therefore total thermal resistance from junction to ambient (θ_{iA}) is:

$$\theta_{jA} = \theta_{jc} + \theta_{PCB} + \theta_{PCB-A}$$
 (8)
= -60° C/W + 4.1° C/W + 10.5° C/W

 $= 74.6^{\circ} \text{C/W}$

From this result, junction temperature can be calculated as:

$$T_{j} = \theta_{jA} * P_{d} + T_{A}$$
= 74.6°C/W * 0.825 + 24°C
= 86.6°C (9)

CONCLUSION

The procedure demonstrated in this article can be used to compute thermal resistance of the PCB and junction temperature in PCB design. In general, the thermal resistance of vias can be minimized by increasing number of vias, via outer diameter and/or copper thickness. It can also be decreased by decreasing via length or PCB thickness.



Fig. 4 Thermal image to determine case, PCB, ground lug and MMIC body temperature.



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Adaptive Gate Bias Module Ensures Amplifier Performance

Donna Vigneri NXP RF Group, Tempe, Ariz.

This compact circuit for solid-state RF power amplifiers provides the temperature compensation required to ensure optimum performance under varying temperature conditions as well as providing an optional windowed gate voltage for switching applications.

emperature compensation is required to ensure that the quiescent current of an RF power amplifier remains nearly constant regardless of temperature variations caused by transistor self-heating. Without it, third-order intercept point (IP3), efficiency, and other characteristics are unpredictable and less than optimum. The effects of device heating and the necessity for providing temperature compensation to RF power transistors to ensure stable performance is widely documented¹ as are the causes of changes in

quiescent current by the transistor's variations in performance.² Consequently, temperature compensation has become an essential component in virtually all RF power amplifiers regardless of what type of device technologies are employed.

The adaptive bias circuit described in this article compensates for fluctuations in temperature and automatically adjusts the transistor's gate voltage under varying temperature conditions. It can also provide a windowed gate voltage for switching applications. The circuit is compact, adds little to

amplifier size and uses inexpensive devices. Although Freescale's MRFE6VP5150N LDMOS transistor is used as an example, the circuit can be used with a broad range of LDMOS transistors and devices based on other technologies.

GENERAL CONSIDERATIONS

The active bias module described in this article (see *Figure 1*) provides this capability for an LDMOS RF power transistor. The level of compensation required varies with device technology and its class of operation, and is measured in mV/°C. To apply the proper compensation slope, either the device's required gate-voltage compensation rate is found on its datasheet (see *Figure 2*) or its quiescent current drift is measured before designing a temperature-compensating circuit.

There are several techniques used to create temperature-compensating circuits, some of which employ temperature-sensing components such as thermistors, diodes or transistors. Other approaches employ microcontroller-based "lookup" systems³ in which stored values are used to vary gate voltages at measured drift rates.

When sensing temperature, the sensing component must be placed as close as possible to the transistor case.⁴ If applied externally it will be far from the transistor die, introducing a

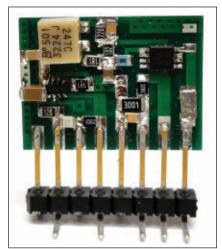


Fig. 1 Active bias module.



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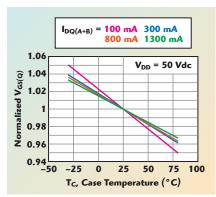
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▲ Fig. 2 MRFE6VP5150N LDMOS transistor gate-voltage compensation rate as shown on its datasheet.

thermal time constant proportional to the change of case temperature (T_c) to junction temperature (T_j) . The use of a microcontroller, while seemingly more sophisticated, requires as much if not more initial measurement effort with little additional benefit.

Production variation must also be considered as it can be as great as 200 mV. Even when operating in the less-demanding Class AB, a variation of 1 mV translates to a change of 1 mA; so, when using a lookup table, an encoded equation to adjust the value of starting gate voltage may not be useful.

When using external thermalsensing components, accurate and repeatable measurements and calibration are essential before the circuit is finalized, as uncontrolled ambient temperature can cause fluctuations in voltage until a steady state is reached. This is even more important when the desired quiescent current is set very high, i.e., 2 to 3 A or more, because of the increased change in current vs. gate voltage during a 1 to 2 percent drift.

CIRCUIT DESIGN

The equivalent schematic for the adaptive bias module with test points is shown in *Figure 3*. The temperature-compensation circuit consists of a temperature sensing NPN bipolar junction transistor (BJT) U2 (in this case a BCW72LT1G from ON Semiconductor), its biasing network and voltage regulation. The voltage regulator U1 supplies +5 VDC and a reference voltage at Pin 4.

Pin 4 of U1 is normally a ground pin, but in this circuit the BJT base and collector are connected at Pin 4 to activate the tracking. If the pin were grounded, U1 would act as regulator as described on its datasheet. The supplied voltage is chosen to ensure that the BJT operates in its active-linear mode and that its base and collector currents scale to ensure predictable behavior.

Active Linear Region:

$$\begin{aligned} V_{BE} &= V_{\gamma} (\text{forward bias voltage}); \quad \ (1) \\ I_{B} &> 0; V_{CE} > V_{\gamma} \end{aligned}$$

Regardless of the chosen sensing transistor, the BJT datasheet will show a characteristic curve of temperature coefficient (θ_{BE}) vs. collector current (I_C). From this curve the compensation slope in mV/°C is set to match that of the LDMOS transistor to ensure that the gate voltage correction results in the least possible deviation in circuit performance.

The BJT temperature coefficient curve shows only a small range of correction slopes may be achievable, which is complicated by the fact that the circuit may not be the same one that the manufacturer used to conduct the test. In addition, as the manufacturer's test circuit and printed circuit board material differ from those used in the adaptive bias module, a new graph must be created.

The resistor divider consisting of resistors R6 and R7 is used to bias the BJT within its active-linear region. The resultant values for base and collector current are then predicted using a combination of measured and calculated values.

$$I_{C} = \beta * I_{B}; I_{B} = IR6 - IR7$$
 (2)

Where IR6=(VC-VB)/R6 and IR7=VB/R7

This assumes room temperature operation of 25°C. Note that β is equal to 310 at 25°C for the example values

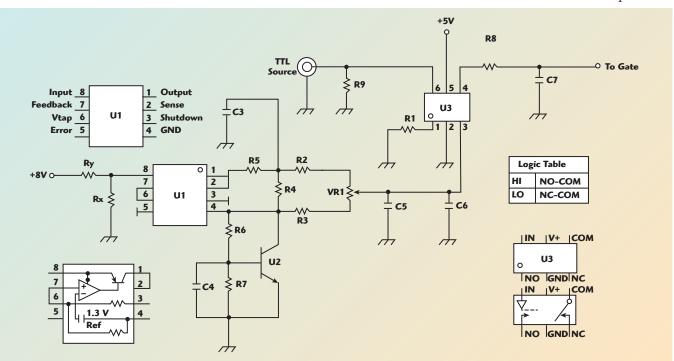


Fig. 3 Adaptive bias module schematic.

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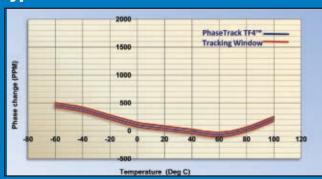


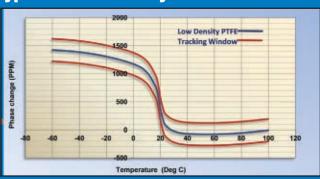
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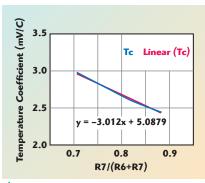


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 \blacktriangle Fig. 4 Graph used to determine the value of R7 when R6 is fixed at 1200 Ω.

TABLE 1			
QUIESCENT CURRENT VS. TEMPERATURE			
I _{DQ} (mA)	Slope (mV/°C)		
100	-2.466		
300	-2.058		
800	-2.015		
1300	-1.877		

of R6=1200 ohms and R7=9090 ohms. The value of β will vary with the values chosen for R6 and R7, and will also vary slightly with temperature. Before accepting the temperature coefficient values in a BJT datasheet, it is important to determine that the slope θ_{BE} is valid for the given values of $I_{C}.$ For the module described in this article, the curve was created using empirical measurements. The graph in Figure 4 can be used to determine the value of R7 when the value of R6 is 1200 ohms.

The plot in Figure 2 shows varying gate voltage versus normalized quiescent current as a function of temperature for the MRFE6VP5150N RF power transistor. The resulting slope vs. temperature for each class of operation is listed in *Table 1*.

The value of R7 for the sensing BJT must be chosen to achieve a compensation slope θ_{BE} that matches the quiescent current drift of the LDMOS transistor for the desired class of operation (in this case, 100 mA). If the drift slope of the transistor is not already known, Equation 3 can be used. Its delta variables are measured values.

Slope (mV/C) =
$$\Delta V_G/\Delta T$$
 (3)

The compensation rate of the sensing BJT should track the apparent drift of the LDMOS transistor's gate voltage vs. temperature:

	TABLE 2					
	BILL OF MATERIALS					
Part	Description	Manufacturer				
C1	Optional capacitor					
C2, C4, C5	1 nF 0805 chip capacitor	TDK				
С3	1 μF 0805 chip capacitor	Murata				
С6	10 nF 0805 chip capacitor	Murata				
C7	33 pF chip capacitor	AXTC				
R1	5.1 ohm chip resistor	Vishay Dale				
R2	510 ohm 0805 chip resistor	Susumu				
R3	22 ohm 0805 chip resistor	Susumu				
R4	4.7 Kohm 0805 chip resistor	Susumu				
R5	10 ohm 0805 chip resistor	KOA Speer				
R6	1 Kohm 0805 chip resistor 1/8 W	Vishay Dale				
R7	2.49 Kohm 1206 chip resistor 1/4 W					
R8	12 ohm 0805 chip resistor	Vishay Dale				
R9	10 Kohm 0805 chip resistor	Vishay Dale				
VR1	500 ohm potentiometer, 11 turn	Bourns				
U1	Micro8 5V voltage regulator	ON Semiconductor (PN LP2951ACDMR2G)				
U2*	Bipolar transistor, NPN, 45 V	ON Semiconductor (PN BCW72LT1G)				
U3	1.865 to 5.5 V SPDT analog switch SOT-23	Texas Instruments (TS5A3159)				
PCB	S1000-2, 20-mil, 1 oz. E _r = 4.8	MTL				

^{*} External

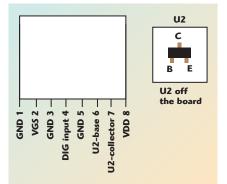


Fig. 5 Active bias module pin-outs.

Slope (mV/C) =
$$\Delta V_G/\Delta T$$
 = $\Delta V_{GS}/\Delta T$ (4)

Values for $V_{\rm GS}$ and $V_{\rm C}$ are in millivolts and the change in temperature is in ${}^{\circ}{\rm C}.$

PHYSICAL CONFIGURATION

The bill of materials for the active bias module is shown in *Table 2*. Circuit board dimensions are 0.85"×

0.56". The module is attached to the amplifier board through an 8-pin breakaway header. The board is intended to be mounted vertically but either straight-pin or 90° pin headers may be used to accommodate the application. Standoffs cannot be mechanically attached to the board in its current configuration.

Because all input and output connections are located on one side of the board, the module can also be adapted to differing circuit topologies with jumper wires. The active bias module includes all parts but the BJT and U2 which should be placed as close as possible to the desired temperature-sensing point. Tuning of the compensation slope may require a value of resistor R7 (and possibly R6, depending on the class of operation) to be changed.

The supply voltage to the module is +8 VDC. Other input voltages require a resistor to ground to ensure that about +8 VDC is applied to the in-



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put pin of U1. Varying the input voltage too widely may keep the sensing BJT from operating in its active linear mode, eliminating the advantage of its predictable behavior.

The pin-out diagram for the module is shown in *Figure 5*. Pins 1, 3 and 5 are ground pins connected through drill-plated via holes to the ground plane of the module. Pin 2 is the gate voltage output to the LDMOS transistor gate lead. Pin 4 is for an optional input signal from a pulse generator or equivalent power amplifier circuitry for the gate windowing. This is useful when optimizing performance in pulsed-amplifier applications.

Pins 6 and 7 are DC feed lines to the BJT sensing transistor's base and collector located on a separate application board. The module should be placed close to the BJT so it can be connected using jumper wires, which should be as short as possible to minimize inductive effects. The emitter of the BJT should be placed as close to the LDMOS transistor as possible to minimize the thermal time constant.

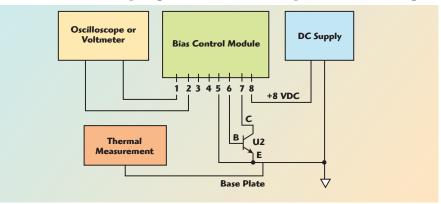
Pin 8, the voltage input to U1, is set at +8 VDC. Although input volt-

age may vary, it should be maintained at about +8 VDC using a resistor divider, for which space is provided on the module. The pin-out diagrams for the analog switch and voltage regulator are shown in Figure 3.

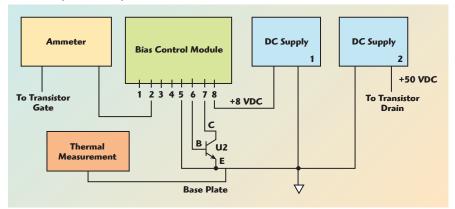
TEST SETUP AND MEASUREMENTS

The basic test setup for recording delta values of voltage and temperature required to calculate the module compensation slope is shown in Figure 6. Minimum equipment includes a source of heat and cold, a DC power supply, a multimeter and the device to be tested. The accuracy of the voltmeter should be at least 1 mV. The same test setup may also be used to measure the transistor's drift with the exception that quiescent current is measured in milliamperes rather than millivolts. Modification of the setup for transistor temperature coefficient measurement is shown in *Figure 7*.

Each test begins at a temperature of 25°C to record the normalized value. Sufficient time must lapse before a measurement is recorded to ensure that leveling has occurred. The plot-



▲ Fig. 6 Test setup for recording delta values of voltage and temperature to calculate the module compensation slope.



▲ Fig. 7 Setup for transistor temperature coefficient measurements.

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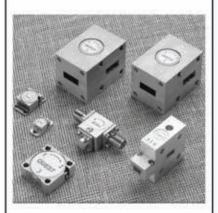
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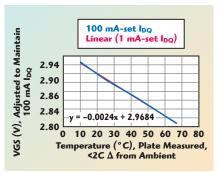
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▲ Fig. 8 Measured MRFE6VP5150N transistor gate drift.

ted measurements should be linear in relation to each other. The wider the range of measured temperatures, the more accurate the reading.

At a setting of 100 mA quiescent current, the gate voltage drift of the MRFE6VP5150N was measured at 2.421 mV/C (see *Figure 8*), confirming within a few microamperes the value on its datasheet. Figure 8 also shows the change in voltage versus temperature needed to maintain the required 100 mA quiescent current.

The module was measured with three different ratio values to create the result shown in Figure 4. When R7 is 9090 ohms, the temperature coefficient is closest to the gate voltage drift exhibited by the MRFE6VP5150N transistor at a 100 mA bias setting. While not exactly the same, it is close enough to be used for test.

Table 3 shows the change in quiescent current vs. temperature using the adaptive bias module for compensation. The change from -10° to

 70°C is 2 percent or less. Based on the normal drift rate measured of -2.421 mV/C of the power transistor, the quiescent current drift might be 50 percent or more over this range at a starting I_{DQ} of 100 mA without the benefit of the module. Although the drift rate is not zero, the gate voltage is compensated well enough so that the RF output of the transistor is minimally affected.

OPERATION

At first turn-on, the potentiometer VR1 (see Figure 3) should be turned completely clockwise (off) to ensure that the gate voltage supplied to the transistor during initial biasing is low enough to prevent transistor damage. The module's output voltage can then be adjusted by turning the potentiometer adjustment screw counterclockwise until the desired nominal quiescent current level and gate voltage are reached. In most applications, it is best to bias the transistor by first applying the drain voltage. Most RF transistor datasheets provide I-V curves that can be used to determine the gate voltage required for any class of operation.

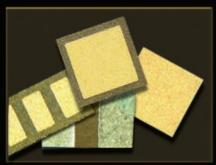
The duty cycle, pulse width and period vary by application. Whenever a pulsed gate voltage is required it is usually because the power amplifier's performance goals cannot be met with a pulsed RF signal alone. The active bias module will receive a TTL signal from a separate pulse generator circuit or instrument that the module then uses to supply voltage to the transistor gate via output Pin 2.

	TABLE 3				
CHANGE IN QUIESCENT CUI	ANGE IN QUIESCENT CURRENT VS. TEMPERATURE USING ADAPTIVE BIAS MODULE				
Temp. (°C)	Ina (mA)	Delta Ing (mA)			

Temp. (°C)	I _{DQ} (mA)	Delta I _{DQ} (mA)
-10	101	1
2	101	1
3	101	1
5	100	0
25	100	0
40	100	0
45	100	0
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55	101	1
60	101	1
65	102	2
70	102	2



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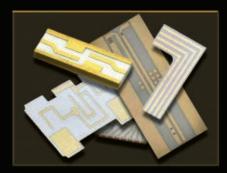
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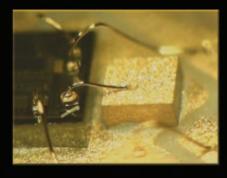
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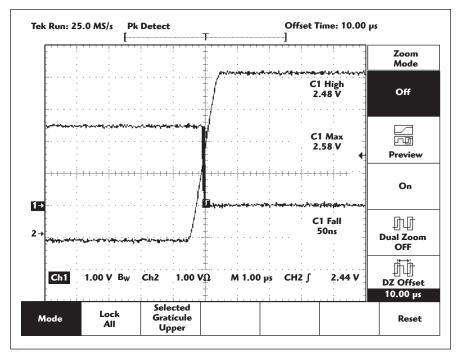
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A Fig. 9 Typical gate-voltage waveform with gate-voltage pulse width of about 100 μs at a duty cycle of 12.5 percent.

Synchronizing components are not provided by this module when RF power and gate voltage are windowed together. This can be achieved through external monitoring and manipulation. The inset of Figure 3 shows the binary states of analog switch U3. In a logic HI (+1.65 to +5.5 VDC), the input signal is on and the output voltage at module Pin 2 is windowed off. In logic LO, the input signal is off and the output gate voltage is constant, allowing the module to be used in either a windowed or constant-gate-voltage configuration. To turn the gate voltage off, the DC supply to Pin 8 of the module is removed or a digital input of constant HI (100 percent DC) is provided so that the gate voltage is turned off via the digital control.

Switching rise and fall times are affected by the $C_{\rm gs}$ value of the LDMOS RF power transistor, onstate resistance, and other factors, which can be compensated for by tuning the module for specific applications. Space is provided on the module to attach additional 0805 chip capacitors for decoupling.

A typical gate voltage output waveform is shown in *Figure 9*. The gate voltage pulse width is about 100 µs at a duty cycle of 12.5 percent. The

waveform input is the opposite duty cycle because of the logic state reversal of the analog switch.

CONCLUSION

The adaptive bias module described in this article automatically adjusts the gate voltage of an LDMOS RF power transistor under varying temperature conditions and provides an optional windowed gate voltage for switching applications. It can compensate for fluctuations in temperature that would otherwise cause the RF power transistor to have unpredictable performance.

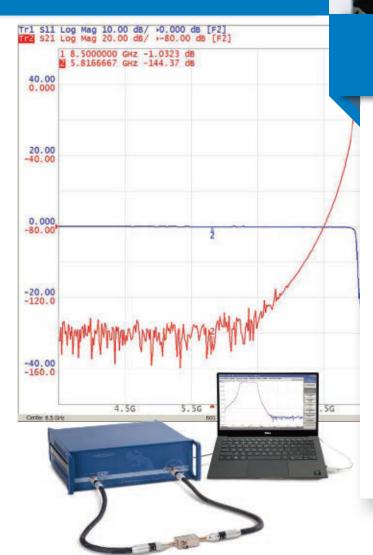
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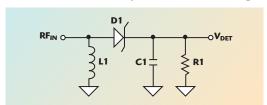


IC RF Power Detectors Simplify Wireless System Design

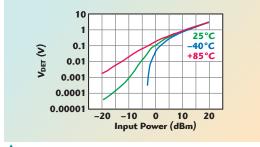
Eamon Nash Analog Devices, Norwood, Mass.

Because of their fundamental rectifying characteristic, diodes have been used to generate DC voltages that are proportional to AC and RF signal levels for as long as there have been diodes. This article compares the performance of diodebased RF/microwave detectors with integrated circuit alternatives. Topics include transfer function linearity, temperature stability and interfacing with analog-to-digital converters.

popular diode RF detection circuit (see *Figure 1*) can be thought of as a simple half-wave rectifier with output filtering. The positive half cycles of the input signal forward bias the Schottky diode, which charges



▲ Fig. 1 Schottky diode RF detector.



▲ Fig. 2 Transfer function of a Schottky diode RF detector.

the capacitor. On the negative half cycle, the diode is reverse biased, causing the voltage on the capacitor to be held at a DC output that is proportional to the input signal. To allow this voltage to drop when the input signal decreases or is turned off, a resistor in parallel with the capacitor provides a discharge path. *Figure 2* shows the transfer function of this circuit. The input power is scaled in dB, and the output voltage is plotted on a logarithmic scale.

The 25°C transfer function has two distinct operating regions on the curve. The so-called linear region extends from the top of the input range (approximately +20 dBm) down to around 0 dBm. This linear region derives its name because the output voltage is roughly proportional to the input voltage. Below 0 dBm, the so-called square law region begins, where the output voltage is roughly proportional to the square of the input voltage. The transfer function has a greater slope, as seen in the figure. Figure 2 also shows the output voltage vs. input power transfer functions when the temperature is between -40° and +85°C. These show significant deviations at power

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ApplicationNote

levels below 0 dBm, which renders the device unusable in applications where the temperature varies by any significant amount. Techniques can be used to mitigate this temperature drift somewhat. They involve introducing a second, reference diode that is either part of the circuit or a standalone circuit with its own output. The temperature drift of the reference diode matches that of the primary diode, so by a process of subtraction (either analog or digital, based on the circuit), some amount of drift can be cancelled.

Figure 3 shows the transfer function at 25 GHz of an integrated Schotky diode detector that has several novel features. As part of the signal processing, the input passes through a circuit which performs a "square rooting" function on signals below a certain power level. The transition point is set to equal the power level where the diode transitions from the square law to the linear region. As a result, the square law effect of the diode is

-30 -20 -10

0.01

0.001

20

10

0

▲ Fig. 3 Improved performance of an integrated Schottky diode detector, measured at 25 GHz.

P_{IN} (dBm)

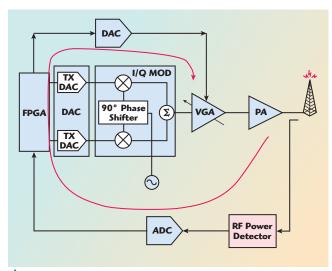


Fig. 4 Typical digital RF power control loop.

cancelled, and there is no sign of the two-region transfer function that is so apparent in Figure 1. Figure 3 also shows the transfer function at various temperatures from -55° to +125°C, as well as the variation in the transfer function vs. temperature. Using linear regression of the 25°C transfer function as a reference, the error in dB is plotted at each temperature. With integrated temperature compensation and the square law elimination circuit, errors due to linearity and temperature drift are reduced to approximately ±0.5 dB over the majority of the input range.

ADC INTERFACING

While RF/microwave detectors are sometimes used in analog power control loops, it is more common to build a digital power control loop (see *Figure 4*). In this configuration, the output of the power detector is digitized by an analog-to-digital converter (ADC). In the digital domain, the power level is calculated using the

code from the ADC. Once the power level is known, the system will respond by adjusting the transmitted power if necessary. While the response time of this loop will depend to a small extent on the response time of the detector, the sampling rate of the ADC and the speed of the power control algorithm will have a far larger impact.

The loop's ability to measure and precisely set the RF power level is impacted by several factors, including the transfer function of the RF detector and the resolution of the ADC. To illustrate, *Figure* **5** compares the responses of a diode detector and a microwave logarithmic amplifier (log amp), both at 20 GHz. The

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Model	Frequency (GHz)	Output Pow Min(dBm)
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NTWPA-0000010011000	0.00001-0.01	60
NTWPA-0000010013000	0.00001~0.01	65
NTWPA-0000010015000	0.00001~0.01	67
NTWPA-001011000	0.01~0.1	60
NTWPA-001013000	0.01-0.1	65
NTWPA-001015000	0.01~0.1	67
NTWPA-008031000	0.08-0.3	60
NTWPA-008032000	0.08~0.3	63
NTWPA-0310700	0.3~1.0	58
NTWPA-03101000	0.3~1.0	60
NTWPA-00305100	0.03-0.512	50
NTWPA-00305200	0.03~0.512	53
NTWPA-000110100	0.001-1.0	50
NTWPA-00810100	0.08~1.0	50
NTWPA-00810200	0.08-1.0	53
NTWPA-0510100	0.5~1.0	50
NTWPA-0510200	0.5~1.0	53
NTWPA-0510500	0.5~1.0	57
NTWPA-05101000	0.5~1.0	60
NTWPA-0710100	0.7~1.0	50
NTWPA-0710200	0.7~1.0	53
NTWPA-0710500	0.7~1.0	57
NTWPA-1822100	1.8-2.2	50
NTWPA-1822200	1.8-2.2	53
NTWPA-1822500	1.8~2.2	57
NTWPA-2327100	2.3-2.7	50
NTWPA-2327200	2.3~2.7	53
NTWPA-2327500	2.3-2.7	57
NTWPA-0822100	0.8~2.2	50
NTWPA-0822200	0.8-2.2	53
NTWPA-0822500	0.8~2.2	57
NTWPA-0727100	0.7~2.7	50
NTWPA-0727200	0.7~2.7	53
NTWPA-2560100	2.5-6.0	50
NTWPA-2560200	2.5~6.0	53
NTWPA-2060100	2.0-6.0	50



ApplicationNote

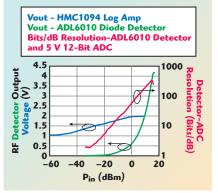


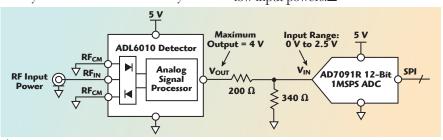
Fig. 5 Performance comparison of integrated Schottky diode detector and log amp.

log amp has a transfer function that is linear in dB, where a 1 dB change in input power always results in the same voltage change at the output (over the linear input range from approximately -50 to 0 dBm). In contrast, the diode-based detector has a transfer function which appears exponential when plotting output voltage vs. input power in dB. Because ADCs have a transfer function that is scaled in bits per volt, system resolution in dB per bit continually decreases with decreasing input power. Figure 5 also shows the bits per dB resolution that would be achieved if the diode detector were to drive a 12-bit ADC with a full-scale voltage of 5 V (the plot is on a logarithmic secondary axis for ease of viewing). At the low end of the device's power range, around -25 dBm, the incremental slope would be approximately 2 bits per dB, yielding a resolution of approximately 0.5 dB per bit. This suggests that a 12-bit ADC is adequate to accurately resolve the output of the diode detector IC over its full range. As the RF input power increases, the incremental slope in bits per dB increases steadily to a maximum of approximately 300 bits per dB at the maximum input power of +15 dBm. This is valuable in RF power control applications where accuracy is most critical when the system is at its maximum power. This is a very typical scenario in applications where RF detectors are used to measure and control the power of a high power amplifier (HPA). Where power is being controlled to prevent the HPA from overheating, high resolution power measurement at maximum power is very valuable. The transfer function of the log amp in Figure 5 has a constant slope over its linear operating range. This suggests that a lower resolution ADC (10-bit or possibly even 8-bit) would be adequate to achieve a resolution well below 1 dB.

An application circuit where the diode detector interfaces with a 12bit, 1 MSPS precision ADC is shown in Figure 6. The ADC has an internal 2.5 V reference which sets the fullscale input voltage. Because the diode detector can reach a maximum voltage of approximately 4.25 V, a simple resistive divider is used to scale this voltage so that it never exceeds 2.5 V. This scaling can be implemented without needing an op-amp buffer. The achievable resolution at the bottom of the input power range is similar to the example, i.e., approximately 0.5 dB per bit.

CONCLUSION

Integrated RF/microwave detectors offer benefits when compared to discrete implementations. Integrated temperature compensation ensures the output voltage is stable to approximately ±0.5 dB over a wide temperature range. An internal square-rooting function effectively eliminates the square law characteristic at low input power, resulting in a single linear transfer function that simplifies device calibration. The buffered output of the integrated detector can directly drive ADCs without concern that loading will affect computational accuracy. In all applications, the ADC should be chosen so adequate bits per dB resolution can be achieved at low input powers.



▲ Fig. 6 Application circuit for an integrated microwave power detector mated with a precision ADC.



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The Progressive Transformation of Spectrum Analyzer Technology

Keysight Technologies Santa Rosa, Calif.

n technology, changes that occur over a long period of time are often based on a broad range of innovations. As a result, the actual extent of the transformation is clear only in retrospect. Such is the case with the evolution of spectrum and signal analyzers. The biggest changes are in the block diagram. Through the increasing performance of high speed digitizers, digital filters and fast Fourier transform (FFT) technology, the intermediate frequency (IF) section has evolved from scalar to vector. Increasingly, this reflects the nature of the signals and systems many engineers must measure. The other important transformations are in the user interface (UI) and associated user experience. Today, the touch-enabled UI technology widely used in smartphones, tablets and PCs can be readily adapted to the large displays that are increasingly common in signal analyzers. Consequently, analyzers now provide new levels of interaction that enable intuitive connections between cause and effect during development, debugging and troubleshooting.

TECHNOLOGY TO SUIT THE USER

Over the past 20 years, changing technologies have driven departures from the familiar "swept spectrum analyzer" paradigm. The first big departure occurred in the early 1990s, with

the advent of vector signal analyzers (VSA). About 10 years later, benchtop real-time spectrum analyzers (RTSA) produced another shift. Compared to traditional spectrum analyzers, these new instruments operated differently, made different measurements and produced different displays. For some end users, the differences proved to be a substantial barrier to acceptance and adoption.

The technology in the latest Keysight X-Series signal analyzers is designed to bend those trends in ways that make virtually every measurement task simpler and faster. This has been accomplished in two ways: first, through the use of a single analyzer to cover swept, vector and real-time signal analysis. This convergence addresses the real needs of RF engineers who may need one or more of these capabilities on any given day. The second change is based on simplified measurement set-up and analyzer operation in whichever mode the engineer chooses to use. With touch capability, access to rich functionality in measurement, display and analysis no longer requires a deep, complex hardkey/softkey UI.

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to that of a tablet (a 14.1" diagonal display in the UXA, 10.6" with the others). Measurement settings and displays are easily controlled using familiar gestures, such as single or double tapping to select a parameter or expand a window, dragging and pinching to zoom and scale a display and using press-and-hold to access context-sensitive selections.

The intuitive power of the sweptanalyzer paradigm remains. A single touch of an in-display menu panel, measurement bar, annotation hotspot or drop-down window provides direct access to major parameters, whether the task is simple spectrum analysis or complex digital demodulation (see Figure 1). With any of the new X-Series analyzers, it takes no more than two touches to complete most operations. This enables rapid navigation of display capabilities and analysis functions without abandoning the natural feel of a swept analyzer when making basic spectrum measurements.

As signals and tests become increasingly complex, engineers often

nal analyzer, there are two ways to mitigate this problem: minimizing change from the familiar usage model and using the same UI, measurement applications and programming commands across multiple measurement platforms. There are five models in the X-Series: UXA, PXA, MXA, EXA and CXA. The shared internal architecture includes a measurement abstraction layer that, wherever possible, shields the front-panel user or instrument programmer from any internal hardware differences and complexities. This yields one key benefit: with consistent operation and programming across the family, learning one X-Series analyzer means knowing them all. When used in any mode — spec-

face a steep learning curve. In a sig-

When used in any mode — spectrum analyzer, RTSA or measurement application — the large touch screen and multi-trace displays make it easier for engineers to create multiple, simultaneous views of complex signals (see *Figure 2*). These views leverage the engineer's own knowledge and

help identify causeand-effect, even when signal behavior is complex and timing relationships are unknown.

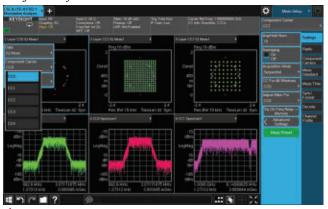
As with the UI, the five X-Series analyzers share a variety of applications that are proven, ready-to-use measurements for signal analysis. Examples range from parametmeasurements such as phase noise and noise figure to standards-specific analysis of LTE/ LTE-Advanced and W-CDMA signals. Across all five models, the use of consistent measurements. algorithms and controls prorepeatable duces results that reveal the performance of devices and designs. The X-Series fam-

ily is also compat-

ible with Keysight's



▲ Fig. 1 A single press on the menu panel provides direct access to capabilities such as Keysight's Noise Floor Extension (NFE) technology, which yields an improvement of up to 12 dB in the spectrum analysis noise floor.



▲ Fig. 2 Drop-down windows enable quick configuration of an LTE-A FDD ETC transmitter measurement, including 256-QAM demodulation.



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- P-1D dB: 34 dBm (Typ), 33 dBm (Min)



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- Gain Flatness: +/-1.0 dB acoss the band
- Noise Figure: 4.0 dB (typ)

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89600 VSA software, which provides a comprehensive set of tools for demodulation and vector signal analysis. The software also provides connections to the simulation capabilities of electronic design automation (EDA) software. such as Keysight's ADS and System-Vue platforms.

DIN CONTRACTOR OF THE PROPERTY OF THE PROPERTY

▲ Fig. 3 Combining the UXA signal analyzer and IQC5255B recorder with the X-COM Spectro-X and Keysight 89600 VSA software applications creates a comprehensive solution for RF streaming.

IMPROVING MEASUREMENT QUALITY

An enhanced UI is even more valuable if the underlying measurements have also evolved. Inside the X-Series signal analyzers, recent advances in digital technologies have made their way into the local oscillator (LO) section. Keysight designed and developed an RF-optimized digital-to-analog converter (DAC) that is the core of a direct digital synthesizer (DDS) that is used in the LO of the UXA and PXA models. Because the LO is used in all frequency conversion operations, its purity and stability are reflected in the spurious and phase noise specifications of both models. For medium and narrow frequency offsets, the DDS LO is used alone. One key benefit is elimination of the typical pedestal that appears in the phase noise floor of analyzers that rely solely on phase-locked loop (PLL) technology. For wider frequency offsets, the DDS LO is used in conjunction with a YIG-based PLL to yield additional improvements in phase noise.

To address new and emerging wideband applications, the UXA now offers a maximum analysis bandwidth of 1 GHz with automatically-applied frequency response corrections. Because this capability is integrated into the analyzer, it is more convenient than commercial or do-it-yourself systems that require multiple instruments. Those who chase after elusive and intermittent signals can configure the PXA or UXA for gap-free sampling and internal recording at analysis bandwidths up to 510 MHz. To facilitate the acquisition of dynamic signals, the RTSA mode supports frequency mask and time-qualified triggering functions that respond to userspecified signal behaviors.

A PXA or UXA can also be configured to serve as the core of a turnkey RF streaming solution (see *Figure 3*). Through a high speed PCI Express digital interface, either analyzer can stream complex-valued I/Q data at a maximum real-time rate of 255 MHz to the IQC5255B signal record-and-playback unit from X-COM Systems. The IQC5255B is available with 2 or 4 TB of onboard memory, and it also supports external RAID arrays of up to 15 TB, which can store more than three hours of gap-free data at the maximum 255 MHz bandwidth.

Within the X-Series, each model occupies a distinct place in a price/performance curve: the essential measurements of the CXA, the cost effectiveness of the EXA, the wireless focus of the MXA, the benchmark performance of the PXA and the wide open performance of the UXA. In addition, each analyzer incorporates digital technologies that provide yet another useful benefit: future upgradeability. Initially, an engineer can select the level of performance and optional capabilities needed to match specific requirements, such as frequency coverage, analysis bandwidth, phase noise and noise floor. As requirements change, additional or enhanced capabilities are easy to add. These levels of inherent flexibility and future adaptability are essential attributes of every tool an RF engineer may choose to use.

VENDORVIEW

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USB Power Sensors: Fast, Accurate Measurements at an Affordable Price

Anritsu Morgan Hill, Calif.

he old adage "time is money" has never been more pertinent to industry than it is today. As companies try to streamline processes, maximize throughputs and reduce budgets, selecting the right test equipment can be a difference maker on the path to success. To help manufacturers meet these objectives, Anritsu recently introduced the MA242x8A and MA243x0A USB power sensors, which utilize advanced processing circuitry and improved algorithms to provide measurement speeds hundreds of times faster than older generation sensors.

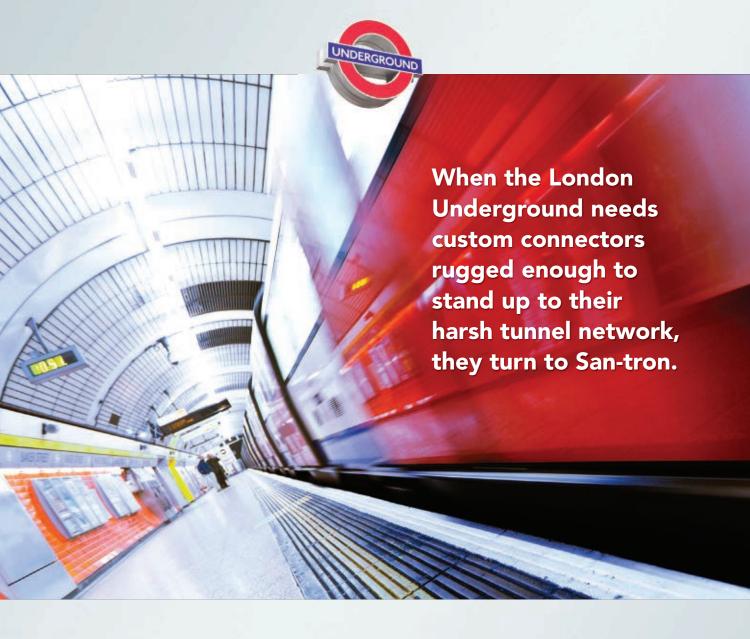
The MA24208A and MA24218A are designed with a patented three-path architecture that provides true RMS power measurements across the entire frequency range (10 MHz to 8 or 18 GHz) and dynamic range (-60 dBm to +20 dBm). True RMS measurements are modulation independent, so these sensors can be used to measure the average power of almost any signal. In addition, the MA242x8A sensors have advanced triggering capabilities that facilitate time-dependent power measurements in signals like WiMAX, GSM and LTE. The MA24330A, MA24340A and MA24350A provide fast, accurate CW measurements up to 33, 40 and 50 GHz, respectively. These sensors also have accelerated measurement speeds and triggering capabilities, which make them suited for automated test situations like manufacturing lines or calibration procedures. The MA243x0A sensors are a perfect solution for test engineers who currently use Anritsu's popular MA247xD and MA244xD traditional sensors, yet would like the advantages of the USB form factor.

IMPACT OF MEASUREMENT SPEED

The faster measurement speed of the MA242x8A and MA243x0A allows companies to reduce — even eliminate — bottlenecks in regular test processes, increasing the throughput of the system. Increasing throughput in manual or automated test systems has several positive business impacts. In cases where the system cannot keep up with demand, companies may be late on orders or have to turn down new business. Solving those problems through increased throughput will improve customer satisfaction and open the door for more orders. Increased throughput may also allow companies to decrease the number of test systems required to meet demand. That leads to both capital and operational expense savings and frees valuable floor space that could be used for new products. Finally, an improved throughput can improve time-to-market, which not only increases customer satisfaction but can make the difference when bidding against other companies for new business. The improved measurement speeds of the Anritsu USB sensors can add to the top line, while simultaneously helping control costs.

USB VS. THE TRADITIONAL METER/ SENSOR

In one small package, Anritsu's USB power sensors provide all the same quality measurement performance as a traditional power meter and sensor combination. They are portable and easy to share between test groups, which makes it possible to accomplish more testing with fewer sensors. By combining the meter





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and sensor into the same package, the need to perform reference calibration is eliminated, which removes a step from long test procedures, again increasing throughput. Rather than having a built-in user interface, USB sensors are controlled directly with a PC or by Anritsu's PowerXpert® software, which can be downloaded to any PC for free from Anritsu's website. License-free software means Anritsu sensors can be controlled by any PC in the lab, not just the one that happens to have the license installed. That saves engineers time and hassle and greatly simplifies the test process. The sensors are also fully remote programmable with standard power sensor commands, which makes them easy to integrate into any automated test system. Anritsu's USB sensors are less expensive than their traditional meter/sensor counterparts, which means buying a USB sensor will provide the same measurement quality as a traditional setup, in a smaller package, with improved performance and for a lower price. In addition, Anritsu's USB power sensors have the industry's

TABLE I ANRITSU USB POWER SENSORS			
Models	Description	Frequency Range	Dynamic Range
MA243x0A	CW USB Sensors	10 MHz to 50 GHz	-70 to +20 dBm
MA242x8A	True RMS USB Sensors	10 MHz to 18 GHz	-60 to +20 dBm
MA24105A	Inline USB Sensor	350 MHz to 4 GHz	+3 to 51.8 dBm
MA241xxA	True RMS USB Sensors	10 MHz to 26 GHz	-40 to +20 dBm

highest levels of protection from accidental over powering, helping defend the budget from unplanned repair or replacement costs.

Beyond the MA242x8A and MA243x0A, Anritsu offers several other USB sensors for different needs (see *Table 1*). The MA24105A inline USB sensor can be placed directly in line with a transmission system to measure both forward and reverse power. It can be used for constant monitoring of active systems, like wireless base stations, without interrupting transmission. The built-in coupler reduces the number of external elements in the system, which decreases mismatch uncertainty and protects signal integ-

rity. The forward power detector has high video bandwidth to capture both average and peak power. Anritsu also has a budget line of three-path, true RMS USB sensors. For those who don't need the higher measurement speeds or wide dynamic range of the newer USB sensors, the MA241xxA sensors are a suitable alternative that provide quality measurements at a budget saving price.

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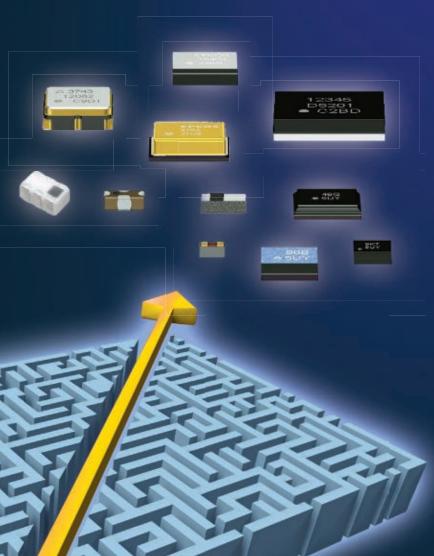
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Aaronia AG Strickscheid, Germany

The new Spectran V5 Series is claimed to be the world's first real-time handheld spectrum analyzer, so with such claims what does it have to offer? Featuring 12 new patents it aims to provide innovation and the best performance achievable by a handheld instrument. And weighing just 850 g it is truly 'handheld' as it fits comfortably in one hand.

With a frequency range from 1 Hz to 20 GHz and a sensitivity of -170 dBm/Hz this real-time spectrum analyzer enables continuous analysis and real-time data streaming, for example USB to hard disk. The real-time bandwidth of the V5 can provide unlimited recording/streaming up to 175 MHz, which together with a Probability of Intercept (POI) below 1 µs demonstrates its lab performance and puts it on par with more expensive benchtop units. A significant feature is the use of poly-phase-filters, which are even used overlapped and shifted.

DIRECT DIGITAL SYNTHESIS

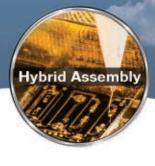
The Spectran V5 also offers a 'classical' spectrum analyzer mode by means of an ultrafast Direct Digital Synthesis (DDS) sweep: In addition to LO-modulation the V5 has a DDS- synthesizer with up to 800 MSPS I/Q for extremely fast frequency hops of the local oscillator. This technology allows sophisticated measuring programs over the full frequency range up to 20 GHz and offers a pulse detection of 10 ns.

The signal processing is realized by a Field-Programmable Gate Array (FPGA), which also includes a vector processor for statistical analysis and demodulation. Together with the powerful Dual Core Blackfin DSP-CPU and the 800×480 pixel high-resolution color display and touch screen, the possibilities for analysis of even the most complex signals are claimed to be limitless.

Within the analog process, the signal is sampled by a real 14 Bit A/D converter with up to 500 MSPS (250 MSPS I/Q) data rate. This process always ensures a dynamic range of 80 dB and a high quality of analysis. The internal 200 GB memory offers a gapless recording of two hours or more, while the modular construction allows a fast extension and customization of the front-end, to fit nearly every end-users requirement.

The Spectran V5 series is available in different versions, each specially equipped for its spe-

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Design Services



ProductFeature



Fig. 1 The Spectran V5 does not require power from a connected laptop/PC.

cific application. Besides the handheld version there is the USB (X and OEM) series, remote-control analyzers (19" RSA and outdoor box), military grade counter-surveillance receivers (XFR V5 PRO) and a portable triple screen command center (real-time RF Drone and Radar Detection System).

POWER CONSUMPTION

Only a USB 2.0 output (not a 3.0 output) is required to connect the analyzer to the PC and the instrument comes with a USB-slave port to connect and control external USB devices. The Spectran V5 also comes equipped with an integrated 8000

mAh lithium polymer (LiPo) battery, which offers an operation time of two hours. It doesn't need power from a connected laptop/PC and an optional 20,000 mAh external power pack will provide an additional four hours of runtime.

SOFTWARE

Figure 1 shows the Spectran V5 operating with a laptop. Aaronia's operating and monitoring system is 100 percent coded in Germany and the included RTSA PC analysis software suite transforms the V5 into a fully-featured benchtop spectrum analyzer. This powerful software is available for MAC OS. Linux and Windows and comes with lifelong free upgrades. Real-time remote control software is also included to run the Spectran V5 directly over the desktop. An application programming interface (API) offers custom system integration, while more advanced software-evaluation and analysis-options are currently under development and will be available for retrofit when requested.

HARDWARE REQUIREMENTS

Thanks to the FPGA pre-processing and optimized software code the standard V5 RTSA suite software runs on an Intel Atom processor. Intel i5 is recommended for full feature availability. This offers the possibility for low-power and low-cost OEM system integrations. The software further uses GPUs from graphic cards for optimized signal processing.

The company also offers many options and accessories for the Spectran V5 to help achieve the best performance available for specific customer measurements, such as a 6 GHz IQ vector signal generator, a 40 GHz oscilloscope/peak power meter, an OXCO time base or a GPS Logger including compass, gyro, tilt and barometer. The high quality CNC cut aluminum housing of the Spectran V5 turns this first-class measurement instrument into an optical highlight.

VENDORVIEW

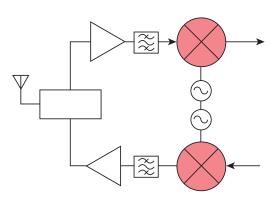
Aaronia AG Strickscheid, Germany www.aaronia.com





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2 to 14 GHz Matched Microwave Mixer Solves Difficult Design Challenges

Linear Technology *Milpitas*, *Calif.*

new very wideband mixer with integrated LO buffer and frequency doubler solves several challenging problems for microwave designers. The LTC5548 mixer eases design with the following key features:

- IF port, extending from DC to 6 GHz, eases wideband IF sampling
- On-chip LO limiting amplifier eliminates external LO buffer stage, reducing cost and minimizing total solution size compared to hybrid module solutions
- 0 dBm LO drive reduces total radiation leakage, reducing external filter and shielding requirements
- Ultra-wideband RF (2 to 14 GHz) and LO (1 to 12 GHz) ports are continuously matched.
 The device has a wideband differential IF

port that works from DC to 6 GHz. Its low frequency capability makes for more flexible frequency planning. The LTC5548 is ideal for receiving wideband signals, especially with bandwidths of 500 MHz to 1 GHz or higher.

Unlike most microwave mixers, which typically require a "hefty" +13 dBm or higher LO drive, the LTC5548 has an integrated LO buffer and only requires 0 dBm drive. Since the device starts with a 0 dBm signal, rather than the +13 dBm or higher typical with alternative devices, the LO leakage present at other ports is 13 dB lower. This results in much simpler filtering requirements, especially with the low IF frequencies the LTC5548 can support. The on-chip LO buffer significantly improves the RF to LO port isolation, which helps reduce any issues with frequency pulling of the syn-

the sizer source due to a parasitic RF signal at the LO input.

The LTC5548 is designed for wideband operation and can be used bidirectionally, either as an up-conversion or down-conversion mixer. Its RF port can be the input in a down-converting receiver or the output in an up-converting transmitter. Its RF port has an on-chip balun, enabling it to operate single-ended. The balun transformer is matched to 50 Ω continuously from 2 to 13.6 GHz, with better than 10 dB return loss.

To make the part truly useful for wideband applications, its LO port is also single-ended and is matched to 50 Ω continuously from 1 to 12 GHz. The 50 Ω impedance termination is constant, regardless of whether the LTC5548 is enabled or disabled, so switching the mixer on and off produces no disturbance that could unlock the phased-locked loop in the LO source. The 50 Ω ports greatly ease design for the microwave system designer. First, this makes for simpler filtering and interfacing to other parts of a 50 Ω system. Secondly, the extremely broadband match is far more forgiving to the circuit's sensitivity to external matching component value variations, producing very consistent performance with system production variations.

The LTC5548's LO port can be driven directly with a signal source to 12 GHz for best noise figure and spur performance. Alternatively, the port can be configured to use the internal frequency doubler; when selected via a digital select pin, up to a 6 GHz LO signal



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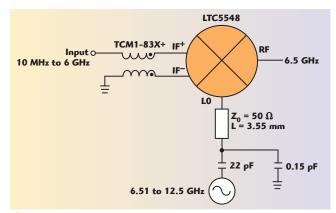
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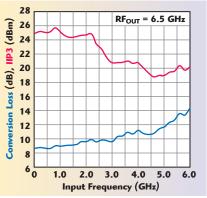
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ProductFeature



▲ Fig. 1 Up-converter design for converting a wideband, 10 MHz to 6 GHz IF to a constant 6.5 GHz RF output.

will be doubled internally to operate up to 12 GHz. This option facilitates the use of a lower cost, low frequency PLL/ synthesizer. The trade-off is slightly higher noise figure and more spur components at the mixer's input and output because the frequency generates not only



the fredoubler LO doubler off. $T_c = 25^{\circ}\text{C}$.

the harmonics of the desired LO frequency but also the harmonics of the half LO input frequency. The result is an extremely small size solution.

An example of a wideband transmitter application is shown in *Figure 1*. This circuit up-converts a 10 MHz to 6 GHz input signal, using a swept LO frequency of 6.51 to 12.5 GHz, to create a fixed 6.5 GHz RF output. To achieve such wideband input performance, a Mini-Circuits model TCM1-83X+ balun transformer is used to convert the single-ended input to the differential IF port of the mixer. With high-side LO injection, the mixer exhibits a relatively flat conversion loss from near DC to 3 GHz, as shown in Figure 2. Within any 1 GHz of input bandwidth below 5 GHz, the gain flatness is better than 1 dB. Once the input is pushed above 5 GHz, the conversion loss begins to change more rapidly. The input IP3 (IIP3) remains greater than 23 dBm from near DC to 2.5 GHz and is better than 19 dBm to 6 GHz. This example illustrates an extremely compact solution with minimal external components that requires only 0 dBm LO drive. The total solution cost is attractive, and an otherwise complex microwave circuit becomes much simpler and more manufacturable.

Housed in a tiny 2 mm \times 3 mm plastic QFN package, the LTC5548 mixer is built on an advanced SiGe BiCMOS process with very consistent performance.

VENDORVIEW

Linear Technology Milpitas, Calif. www.linear.com

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GaN Improves Efficiency of Rugged, Compact 100 W Ka-Band SSPA

Teledyne Paradise Datacom *State College, Pa.*

eledyne Paradise Datacom has developed a 100 W solid-state power amplifier (SSPA) packaged in a rugged, compact outdoor enclosure. The Compact Outdoor family of SSPAs has a long legacy of providing high reliability in extreme environmental conditions. With an MTBF greater than 100,000 hours, this new Ka-Band SSPA joins that family of products.

The 100 W Ka-Band SSPA is available with several options that include: wideband coverage (27 to 31 GHz) as well as operation over any 1 GHz sub-band in that range when used with an integral L-Band block up-converter (BUC). This HPAA2100 series utilizes the latest GaN technology to achieve 100 W of saturated power at the output flange of the amplifier. The linear output power is one half of the saturated output power, or 50 W, to maintain -26 dBc third-order intermodulation products. Alternately, 50 W linear output power is achieved with a single QPSK or OQPSK signal while maintaining -30 dBc spectral regrowth at 1× the symbol rate. The outstanding linear output power is made possible by embedded analog linearization circuitry.

The gain of the amplifier is 75 dB and is adjustable down to 55 dB in 0.1 dB increments. Gain is temperature compensated so that it does not vary from the set level as the ambient temperature of the amplifier changes; typical gain variation is ± 0.5 dB from -30° to ± 50 °C. The operational temperature range of the amplifier is from -40° to ± 60 °C. The amplifier is protected from high VSWR by an integral microwave isolator. An RF sample port provides a -40 dBc sample of the RF output power via a 2.92 mm female connector.

The efficiency of the GaN devices is seen in the overall amplifier efficiency. At its linear output power setting, the amplifier consumes less than 1000 W of AC prime power. The integral AC to DC switch-mode power supply is power factor corrected and operates over an AC input voltage range of 180 to 260 VAC.

The latest 3D electromagnetic (EM) modeling techniques were used to design and optimize spatial waveguide combining networks to achieve the lowest possible insertion loss. This allows efficient combining of multiple, discrete, lower power GaN devices to achieve the higher output power levels. The amplifier



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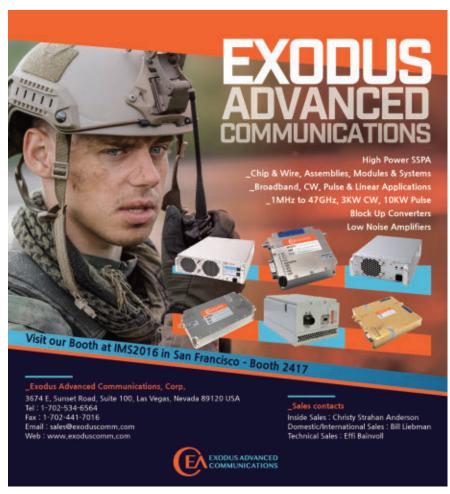
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ProductFeature

chassis has a unique thermal design that uses forced air convection cooling. A removable fan tray on the bottom of the amplifier is easily removed to clean out excessive dirt and debris from the internal heat sink. No special tools are required to remove the fan tray, making maintenance easy to perform in the field.

The L-Band BUC is a popular option that allows operation directly from an L-Band frequency source, up-converting a signal input in the 1000 to 2000 MHz range to Ka-Band. The BUC has a low phase noise local oscillator that can be supplied with a high stability reference oscillator. With the reference oscillator, the converter can automatically detect and switch to an externally supplied 10 or 50 MHz reference frequency. The low noise phase-locked local oscillator can be set to allow the unit to operate over the 28 to 29 GHz, 29 to 30 GHz or 30 to 31 GHz output frequency bands.

The HPAA2100 series amplifier has the same monitor and control functionality as the other members of the Compact Outdoor amplifier family. The standard interfaces include RS485/422/232, discrete IO and Ethernet. The Ethernet interface can be integrated into higher level monitor and control systems using SNMP or UDP. For simplicity, a built-in web browser enables easy setup from any computer. Built-in redundancy control is a standard feature on all Compact Outdoor SSPAs. This provides control over an external redundancy switch without needing a separate controller. A Windows-based monitor and control program is available for free download from the Teledyne Paradise Datacom website.

Along with its CE label, the HPAA2100 has been tested to stringent MIL-STD-461 EMI standards and MIL-STD-810 environmental standards. Weighing less than 50 lbs. (22.6 kg), this product represents a new standard in power density for KaBand SSPAs. This flagship product is the first of a series of Ka-Band SSPAs that will provide up to 500 W of saturated output for the most demanding requirements.

Teledyne Paradise Datacom State College, Pa. www.paradisedata.com



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New Passive Component Line Extends Bandwidth to mmWave

ECA released a new family of millimeter wave power dividers, couplers, isolators, attenuators and terminations covering C- to V-Bands. The family was designed for 5G, satellite communications and backhaul applications. Offering broadband performance and rugged construction, the products enable systems to migrate to higher frequencies to support 5G and other high frequency communications systems without increasing component count.

The power dividers are available in two- and four-way splits and optimized to achieve industry-leading performance, including excellent amplitude and phase balance. Typical VSWR is 1.5:1 to 1.7:1, and isolation

is 14 to 15 dB. The power dividers are available with either SMA connectors that cover 6 to 26.5 GHz or 2.92 mm connectors, which extends the frequency range to 40 GHz. For splitting applications where isolation is not required, resistive two-way splitters are available with 2.92 mm connectors that cover DC to 26.5 GHz.

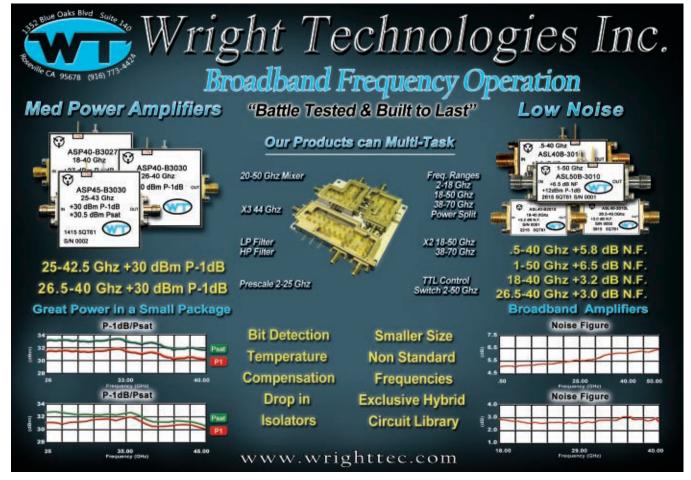
Couplers in MECA's family comprise 10 and 20 dB models optimized for low insertion loss and low frequency sensitivity from 6 to 40 GHz (using 2.92 mm connectors). VSWR is typically 1.8:1 to 1.9:1, with directivity a minimum of 12 dB across the entire band. The isolators are available in several bands, covering 18 to 26.5 GHz, 27 to 31 GHz and 26.5 to

40 GHz (with 2.92 mm connectors). For the terminations and attenuators, the frequency range extends to 40 GHz, while the bias tees span either 500 MHz to 26.5 GHz or 100 MHz to 40 GHz.

Since 1961, MECA (Microwave Equipment & Components of America) Electronics has served the RF/microwave industry with equipment and passive components covering Hz to 40 GHz. Privately held, MECA manufactures their products in the U.S. and is ISO9001:2008 certified.

VENDORVIEW

MECA Electronics Inc. Denville, N.J. www.e-MECA.com



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TechBrief



he EDPLO-4000 series phase-locked dielectric resonator oscillator (PLDRO) from Exodus Dynamics externally locks to a 10 MHz reference to achieve crystal stability up to millimeter wave frequencies. Frequency coverage is from 30 MHz to 50 GHz, and the low profile and rugged construction of the RoHS-compliant design provides excellent durability against harsh environments due to shock, vibration, temperature and humidity.

The EDPLO-4000 series oscillator comprises an ultra-low noise amplifier with series feedback at the source and a dielectric resonator at the gate. High gain, low noise GaAs FETs or silicon BJTs are matched and biased precisely to ensure minimum phase noise

Phase-Locked DRO Achieves Crystal Stability to 50 GHz

and compensated to achieve the optimum negative resistance and maximum temperature stability. Cascaded low noise driver and power amplifiers buffer the oscillator stage to minimize load-pulling and provide output power up to +25 dBm. The PLDRO includes internal voltage regulation to protect from voltage transients and reverse bias, as well as reducing bias modulation and frequency pushing.

The active devices and all chip components are directly attached to gold-plated Kovar carriers to minimize shear and maximize heat transfer from the active devices. The Kovar carriers are mounted to the chassis to provide an efficient thermal junction and a stable structure that reduces microphonics. To ensure oscillator stability over the -55° to +105°C operating temperature range, the tuning elements are precisely designed and positioned to compensate for temperature variation — reducing drift by 3×. The EDPLO-4000 series incorporates a proprietary phase-locked loop (PLL), which is assembled with the internal multiplier using surface-mount technology. The construction of the PLL sub-assembly is unique, providing excellent temperature stability and minimizing solder joints for maximum reliability.

VENDORVIEW

Exodus Dynamics Poway, Calif. www.exodusdynamics.com









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TechBrief



Small Receivers Cover 27 GHz with 100 MHz Instantaneous BW

Berkeley Nucleonics' wideband receivers enable users to operate across multiple frequency bands without spending large amounts of money on down-converters or investing time on integration. Devices in the RTSA7500 series weigh only 6 lbs. (2.7 kg) and have a footprint smaller than a standard sheet of paper, which increases deployment flexibility and the number of use cases — providing a solution for both benchtop and field applications. A rechargeable battery option further increases the portability and versatility of BNC's high performance wideband receivers.

Disrupting the highly competitive signal analysis market was no

simple task. Nevertheless, the extremely broad frequency range and large instantaneous bandwidth of the RTSA 7500 series did just that. From 100 kHz to 27 GHz, the wideband receivers provide a real-time instantaneous bandwidth of up to 100 MHz with a 100 percent probability of intercept (POI) of only 1 μs. With a spurious free dynamic range (SFDR) of 100 dBc, large and small signals are easily captured by these instruments. For applications that require refined control of resolution bandwidth (RBW) and enhanced scanning functionality, the RTSA 7500 wideband receivers are capable of a sweep speed of 200 GHz/s and RBWs as fine as $0.62\ \mathrm{Hz}.$

The interface for the wideband receivers is an easy-to-use and intuitive GUI. For optimum utility and integration, APIs are available for Lab-VIEW, MATLAB®, SCPI, C/C++ and Python-based platforms. With these tools, users can create real-time plots of spectrum, spectrogram and persistence spectrum, as well as I/Q plots interpreted through a user-defined display.

VENDORVIEW

Berkeley Nucleonics Corp. San Rafael, Calif. www.berkeleynucleonics.com





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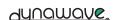






















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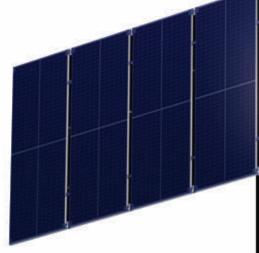
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SPACE QUALIFIED PRODUCTS:

- Connectors
- Cable Assemblies
- · Attenuators / Terminations

CAPABILITIES:

- · High Power / Low PIM
- Wedge dielectric interfaces to prevent multiplication
- · Real Time X-Ray Machine
- Clean Room Assembly
- Only DLA approved source for M3933/30 attenuators

CERTIFICATIONS:

- MIL: J-STD-001, Class 3
- IPC WHMA-A-620





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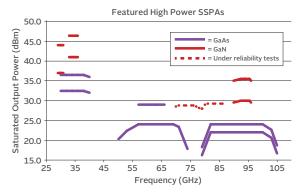
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- Pulse or CW
- Standard Waveguide Interfaces



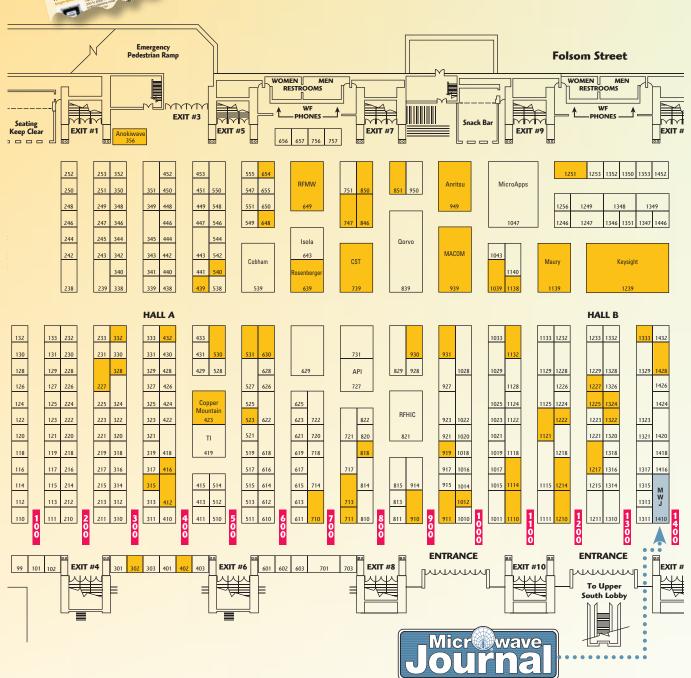


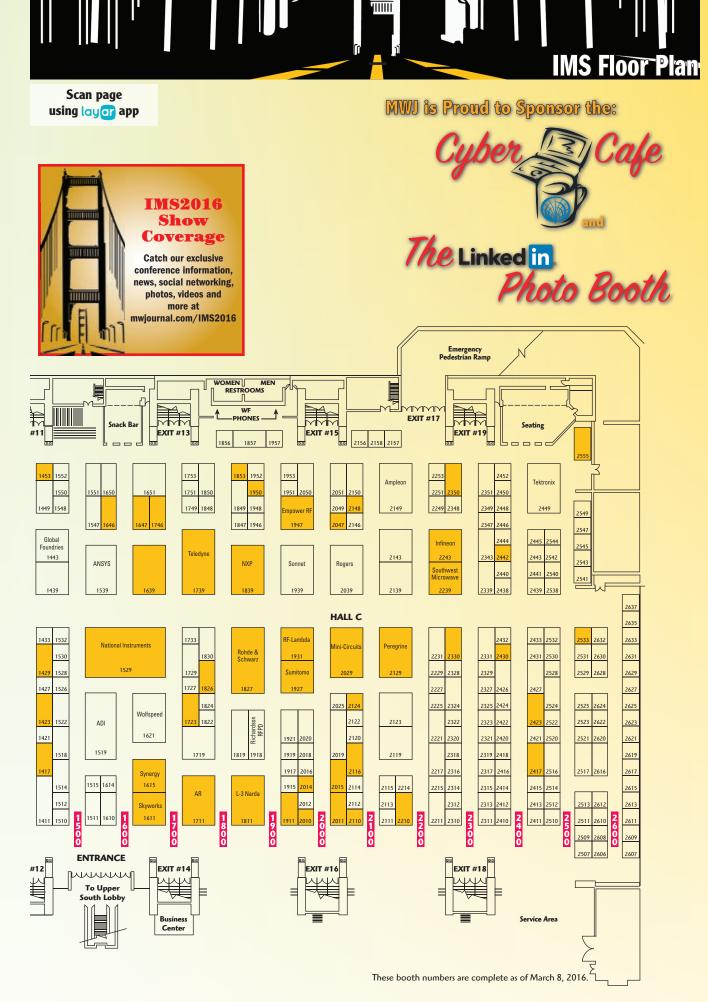




Your Product Guide to The Show Floor

Shaded exhibitors have a product featured in the IMS Product Showcase pages to follow. Look for these products at this year's IMS2016.





The following booth numbers are complete as of March 8, 2016

Komax Wire

Booth 227

Modular Wire Cut and Strip Machine



Komax Wire will feature the new Kappa 331 UX modular wire cut and strip machine at

IMS2016. The Kappa 331 UX is capable of processing coaxial and triaxial cables with cross sections ranging from AWG 24 to AWG 2. The Kappa 331 UX can be changed over quickly to increase efficiency and production rates. For more information, please contact your local Komax Wire sales representative or visit Booth 227 at the show.

www.komaxgroup.com

Sage Millimeter Inc.

Booth 302

VENDORVIEW

W-Band Mechanically Tuned Gunn Oscillator

Model SOM-94308315-10-M1 is a W-Band mechanically tuned Gunn oscillator utilizing a high performance InP Gunn diode and



proprietary cavity design to deliver +15 dBm typical power directly with a frequency range of 90 to 98 GHz. Product

delivers low AM/FM noise and harmonic emissions in the wide mechanical tuning range. The Gunn oscillator is equipped with a micrometer tuner for quick frequency tuning and setting as benchtop equipment.

www.sagemillimeter.com

Polyphase Microwave

Booth 315

Single-Sideband Mixer



The SSB0260A is a 200 to 6000 MHz single-sideband mixer that is ideal for applications requiring exceptional carrier leakage and sideband suppression

performance. The carrier leakage can be nulled by the device automatically to < -60 dBm via USB. Onboard, non-volatile memory provides 200 null settings that can be saved and recalled for different carrier frequencies, all while maintaining typical sideband suppression performance of < -40 dBc. This unit is also sold as an I/Q modulator for high performance wireless applications.

www.polyphasemicrowave.com

Wenteq Microwave

Booth 328

Wideband Coaxial Circulator

Model F2548-0079-46S is a wideband SMA connectorized circulator covering 610



to 970 MHz. It features 0.5 dB maximum insertion loss, 15 dB minimum reverse isolation, and 1.40:1 maximum VSWR, and

can handle 50 W of CW power. The package size is 2.362" \times 2.472" \times 1.180".

www.wenteq.com

Accel-RF

Booth 332

Accelerated Life-Test/Burn-In Test Systems



Accel-RF specializes in the development, design and production of accelerated life-test/burn-in test systems for GaN and other RF compound semiconductor devices. The automated multi-chan-

nel RF-biased burn-in test system is the only integrated instrument that can demonstrate compliance with aerospace, government and commercial RF semiconductor life test standards (GaAs, SiGe, GaN, SiC, InP and RFIC). Accel-RF solutions decrease product development time, ensure exceptional reliability and accelerate income opportunities.

www.accelrf.com

Anokiwave

Booth 356

Silicon Quad Core AESA ASICS VENDORVIEW



Anokiwave offers a family of silicon quad core AESA ASICs at X and K/Ka-Bands for commercial radar, 5G, SATCOM, and A&D markets. The company's product portfolio of si core ICs

and system-in-package solutions allows its customers the fastest time-to-market possible, with expert systems engineering and optimal technology solutions.

www.anokiwave.com

Agile Microwave Technology Inc.

Booth 402

Broadband 15 W Power Amplifier



Agile MwT's new broadband 15 W power amplifier operates from 2 to 18 GHz and is offered in

a benchtop box or in a compact module configuration. AMT-A0350 provides Psat of 15 W with flat small signal gain of 42 dB typical, ±1 dB typical gain flatness with VSWR of 1.8:1 typical. The family of these PAs are competitively priced and ship from stock or short lead time. Agile MwT offers great value with most innovative designs in the industry.

www.agilemwt.com

SignalCore Inc.

Booth 412

High Performance 20 GHz Signal Source



SignalCore's high performance 20 GHz VCO-based synthesized signal source is cost effective, compact and designed for seamless integration. With frequency spanning 100 MHz to 20 GHz (1 Hz resolution), low phase noise of -1.15 dBc/Hz at 10 kHz offset at 10 GHz carrier, and amplitude step resolution of 0.01 dB over a -30 to +10 dBm output range, this product is ideal for R&D, academic, military and commercial applications. Full implementation instructions and GUI included. Available in USB, SPI, RS-232 and PXIe.

www.signalcore.com

MCV Microwave

Booth 416

Ceramic Filters



MCV ceramic filters feature high Q, low loss filters, small size and rugged SMT design using discrete resonators and

monoblock ceramic covering 300 MHz to 10 GHz. MCV's ceramic filter line includes bandpass filter, band reject filter, lowpass filter, highpass filter, duplexer and multiplexer. High power ceramic filters (20 to 30 W continuous power) are suitable for small cell base station applications such as 4G LTE, public safety and wireless communication in 700 MHz up to 5 GHz.

www.mcv-microwave.com

Copper Mountain Technologies

Booth 423

High Performance VNA



Experience an exceptionally accurate VNA while utilizing the latest PC advances. Copper Mountain Technologies' Cobalt

C1220 offers lab-quality S-parameter measurements between 100 kHz and 20 GHz. This compact, high performance VNA takes advantage of manufacturing innovations to deliver the speed and metrological accuracy you need. C1220 offers a typical dynamic range of 145 dB, up to 500,001 measurement points per sweep, and can reach a measurement speed of 10 microseconds per point.

www.coppermountaintech.com

CTT Inc.

Booth 432

2 to 6 GHz, 80 W Power Amplifier



This new GaN-based solid-state power amplifier, model AGM/060-4960, covers 2 to 6 GHz with CW output power

ranging from to 80 W, with a 150 W version coming soon. This compact amplifier is designed for commercial, industrial and military EW applications. Specifications: gain, 60 dB; gain flatness, ± 3.0 dB; noise figure, 6 dB; Psat, +49 dBm (+48 dBm at band edge); Vdc +30 V; DC current, 15 A. The amplifier measures 6.32" \times 4.50" \times 0.80".

www.cttinc.com



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0 to 120 dB $\,$ 0.25 dB Step* 1 to 8000 MHz † $\,$ from $^{\$}395$

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Model RCDAT-3000-63W2+ specified step size 1 dB Model RCDAT-3000-63W2+ specified from 50 – 3000 MHz; 120 dB models specified from 1 – 4000 MHz

IMS PRODUCT SHOWCASE AISLES 400-600

IIIIIII

Besser Associates Inc.

Booth 439

RF and Wireless Training

Besser Associates is a worldwide leader in RF and wireless training. Their instruction combines theory with hands-on practice, the latest tools and technology, and the most appropriate training media (online and traditional classroom) for individualized, meaningful participant experiences. Besser chooses their instructors from the best and brightest in their fields around the world; they carry an average of 20 years of field and applied teaching experience. Courses can be presented on-site and customized to meet the specific needs of the client.

www.besserassociates.com

Vaunix

Booth 523

Programmable Attenuator VENDORVIEW



The LDA-203 offers excellent frequency coverage of 0.1 to 20 GHz and has an attenuation range of 0 to 63 dB. It features a programmable step size

resolution of 0.5 dB, insertion loss from 10 to 15 GHz of -16 dB max., and a response time of 100 nsec. It is programmable for fixed attenuation or swept attenuation ramps directly from the included graphical user interface (GUI) software and is powered and controlled by connection to a PC or self-powered USB hub.

www.vaunix.com

Spectrum Elektrotechnik GmbH E

Booths 530/531

Phase Shifters



Phase shifters or phase adjusters of Spectrum Elektro-technik GmbH are passive devices, being used to change the phase of an RF signal. Key parameters include

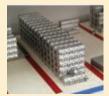
consistent amplitude across all phase states and low insertion loss. The units are used in phased array antennas, phase modulators, frequency converters, testing and instrumentation. Frequency ranges start always at DC, with operation to 2, 12, 18, 26, 40, 50 and 63 GHz. New are the mini phase adjusters.

www.spectrum-et.com

Quest Microwave

Booths 530/531

Ferrite Devices



Quest Microwave provides a broad range of ferrite devices for the global microwave electronics marketplace. Standard and custom designs are available

for both commercial and military applica-

tions. With over 60 years of combined experience, the company's engineering staff can design and develop ferrite devices for virtually any application. They are there to provide you with world class microwave components solutions.

www.questmw.com

Norden Millimeter

Booth 540

Block Frequency Converters VENDORVIEW



Norden Millimeter produces a variety of block frequency converters converting 18 to 26.5 GHz, 26.5 to 40 GHz, 40 to 60 GHz, and 60 to 70 GHz bands into the 2

to 18 GHz band. These converters are usable to extend the frequency range of existing systems with 18 GHz capability. Norden makes both down and up-converter versions for each of these bands. These converters can have variable gain, 0.03 to 18 GHz bypass paths, and common IF input/output. Pictured is a four channel 26 to 40 GHz down-converter presently in production.

www.nordengroup.com

Mercury Systems

Booth 630

Surface-Mount Isolators and Circulators



Mercury Systems introduces surface-mount isolators and circulators operating from 2 to 36 GHz in varying bandwidths. These components offer ideal solutions to grounding issues

associated with drop-in style devices and don't require a pocket to be machined into the final board layout. The devices are temperature stable and can handle solder reflow temperatures associated with SN62 (or lower temperature) solder. Specific board materials can be accommodated based on customer requirements. Electrical performance is typically commensurate with comparable connectorized devices.

www.mrcy.com

Rosenberger

Booth 639

Multifunctional Site Analyzer



For efficient on-site test and measurement, Rosenberger introduces its new CPRI and RF PIM multifunctional Site Analyzer α , the world's first analyzer

for mobile network infrastructure – with copper or fiber interface and exchangeable filter units. This unique portable equipment is ultra-broadband and presents various options for test and measurement functionality: CPRI PIM, RF PIM, RF return

loss/VSWR, isolation and the most accurate distance to fault on the market. www.rosenberger.com/pia

Wenzel Associates Inc.

Booth 648

1 GHz Golden-Q Frequency Source



The 1 GHz Golden-Q frequency source is one of Wenzel's lowest phase noise crystal oscillators with exceptional noise floors below -176 dBc/Hz. The oscillator has an integrated

phase jitter performance of 3.380 fs RMS from 12 kHz to 20 MHz, critical to high bandwidth systems. Part of the company's MXO line of multiplied oscillators, which are available to 16 GHz, are easily customized with no NRE and can come with internal PLLs, multiple outputs and a precision 10 MHz OCXO suitable for the system clock.

www.wenzel.com

RFMW Ltd.

Booth 649

Power Transistor VENDORVIEW



Ampleon's BLF10M6200 is a 200 W LDMOS power transistor targeted for 700 to 1000 MHz ISM applications. The BLF10M6200 offers 28.5 percent typical

drain efficiency and is internally matched for ease of use. Ampleon designers integrate internal ESD protection for enhanced reliability. The BLF10M6200 offers ruggedness in class-AB operation and is capable of withstanding a load mismatch of 10:1 through all phases. With 20 dB of gain, this transistor draws 1400 mA of current from a 28 V supply.

www.rfmw.com

R&D Interconnect Solutions Booth 654 Invisipin



Invisipin is the world's first solderable, individual pin conductive elastomer contactor. Invisipin offers unparalleled performance with 20 m Ω resistance (typical), high

compliance range, 1 dB bandwidth > 50 GHz, and up to 4 amps current capacity. Invisipin also offers flexibility with standard pin configurations of 0.23 mm to 0.64 mm diameter supporting pitches from 0.4 mm to >1 mm. Available in tape and reel (machine placeable) or fully integrated into custom products, Invisipin is infinitely configurable and individually replaceable.

www.rdis.com



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IMS PRODUCT SHOWCASE AISLES 700-900

B&Z Technologies

Booth 710

Ultra Low 2.5 dB Noise Figure Amplifier



B&Z Technologies now offers an ultra low 2.5 dB noise figure amplifier in the 26 to 40 GHz Ka-Band. Ideal for use in sensitive signal

detection in SATCOM and microwave communication applications, this amplifier offers >35 dB gain with more than +10 dBm power and a typical gain flatness of \pm 2 dB. Packaged in a small form factor housing (30 mm \times 19 mm \times 7.5 mm), it is powered by a single supply voltage as low as +8 V and consumes less than 1.2 W. It also has an excellent resilience to ESD.

www.bnztech.com

Z-Communications Inc.

Booth 711

Phase-Locked Oscillator





The RFS4300Z-LF is a fixed phase-locked oscillator with an integrated reference oscillator that provides a very stable signal at 4.3 GHz. Requiring just a single

+5 Vcc at 60 mA, it delivers a nominal +3 dBm of power and spectral purity of -85 dBc/Hz at the 1 kHz and 10 kHz offsets. The robustness of the RFS4300Z-LF makes it even more appealing. It is designed for extreme environments by operating over the -55° to 105°C temperature range.

www.zcomm.com

Eclipse Microwave Products Booth 713

Low Noise Amplifier



Eclipse Microdevices EMD1715 is a GaAs MMIC PHEMT distributed general purpose low noise amplifier. This LNA has a small signal

gain of 14 dB with noise figure less than 1.8 dB at 6 GHz. This device is ideal for applications that require a typical P1dB output power of +20 dBm up to 12 GHz, while requiring only 103 mA from a +5 V supply. The EMD1715 comes in a small RoHS compliant 4 mm QFN leadless package which has excellent RF and thermal properties.

www.eclipsemicrowave.com

CST STUDIO SUITE





CST STUDIO SUITE is CST's flagship electromagnetic simulation tool, and is used in industries as diverse as

Booth 739

telecommunications, defense, automotive, electronics and healthcare to design, simulate and optimize products. The 2016 release lets you delve deeper into your designs than ever before. From individual components such as antennas and filters through to full assembled systems, devices can be simulated quickly and accurately thanks to the array of new modeling and simulation features.

www.cst.com

Cernex Inc.

Booth 747

Benchtop Amplifiers



Cernex's benchtop amplifiers are designed for use in a wide range of general purpose applications such as laboratory

test equipment, instrumentation and other applications. Reliable operation is achieved using rugged stripline circuit construction with selected GaAs FETs, PHEMTs and MMICs.

www.cernex.com

MECA Electronics Inc.

Booth 818

4G/5G Ready ProductsVENDOR**VIEW**



MECA announces its new family of 4.3/10.0, 4G/5G ready products, from low PIM attenuators, terminations and splitters to resistive

terminations and power dividers. Ideal for 4G, 5G and backhaul upgrade applications. Features include low PIM terminations 10, 50 and 100 W models, low PIM attenuators 50 and 100 W models, low PIM splitters 2- and 3-way, and resistive loads in 1, 2, 5 and 10 W models. All models are weatherproof IP67 rated, made in the U.S. and carry MECA's industry leading 36-month manufacturing warranty.

www.e-meca.com

Huber+Suhner Inc. Booth 846

MXP - Multicoax Test Solution



In a world where performance, speed and density matter, Huber + Suhner's MXP multicoax

solution is the perfect fit. The small form factor and outstanding electrical characteristics combined with reliable mating and ease of use make the MXP an excellent solution for benchtop and system testing with a large selection of bandwidths. MXP50 (50 GHz), MXP40 (40 GHz) and MXP18 (18 GHz) cover current data rate requirements. The entire MXP family comes with the highly flexible and ultra-stable MULTIFLEX cable as a standard.

www.hubersuhner.com

Integra Technologies Inc.

Booth 850

1200 W GaN Transistor



With the highest RF power in the industry, Integra Technologies introduces IGN1011L1200 on GaN/SiC, exhibiting

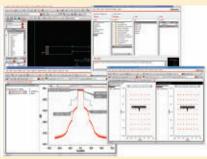
17 dB gain and 75 percent efficiency at 1030 to 1090 MHz, 50 V for IFF at ELM conditions. Devices are 100 percent tested. Please visit Integra's website for UHF, L, S, C-Band transistors and pallets. Serving the avionics, radar and communication global markets for the last 20 years.

www.integratech.com

Cadence

Booth 851

RFIC Simulator



The Cadence® Spectre® RF Option is a production-proven, accurate and high performance RFIC simulator. Its patented time domain engine is the golden reference for VCO phase noise simulation, while its frequency domain engine delivers a unique, comprehensive set of analyses for fast, accurate RFIC verification. The latest version adds Bluetooth LE/HS and 802.11b to the rich set of supported standards. Spectre RF Option is integrated into the Virtuoso® Analog Design Environment, allowing designers access to advanced analytical tools for more complete design validation. www.cadence.com

SV Microwave

Booth 910

Connectors,

Cable Assemblies and Adapters



Looking for a subminiature blindmate connector, cable assembly or adapter for your high

density, high performance application? Check out SV Microwave's complete line of SMP, SMPM and SMPS product lines. SMP series connectors are recommended for applications up to 40 GHz; SMPM series up to 65 GHz; and the SMPS series to 100 GHz. SV has COTS versions available immediately through distribution or direct.

www.svmicrowave.com



Micro Lambda's Bench Test Boxes... Simple and Easy to Use!

MLBS-Synthesizer Test Box – 600 MHz to 20 GHz Standard models cover the 0.6 to 2.5 GHz, 2 to 8 GHz, 8 to 20 GHz and 2 to 20 GHz frequency bands. All versions of the MLSP synthesizer product family can be easily inserted into the test box. Tuning consists of a control knob, key pad, USB and Ethernet connections. Units provide +10 dBm to +13 dBm output power levels and are specified over the lab environment of +15°C to +55°C and are CE certified.

Units are provided with a power cord, USB cable, Ethernet cable, CD incorporating a users manual, quick start guide and PC interface software.

MLBF-Filter Test Box - 500 MHz to 50 GHz

Standard models utilize any Bandpass or Bandreject filter manufactured by Micro Lambda today. Bandpass filter models cover 500 MHz to 50 GHz and are available in 4, 6 and 7 stage configurations. Bandreject (notch) filter models cover 500 MHz to 20 GHz and are available in 10, 12, 14 and 16 stage configurations. Units are specified to operate over the lab environment of +15°C to +55°C and are CE certified.

Units are provided with a power cord, USB cable, Ethernet cable, CD incorporating a users manual, quick start guide and PC interface software.

See our complete line of wideband, low noise components



MLSP-series Synthesizers 600 MHz to 20 GHZ 600 MHz to 16 GHz



MLSW-series Synthesizers



MLTO-series TO-8 Oscillators 2 to 16 GHz



MLSMO-series Surface Mount Oscillators 2 to 16 GHz

www.microlambdawireless.com



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IMS PRODUCT SHOWCASE AISLES 900-1100

Crane Aerospace & Electronics Microwave Solutions Booth 911

K-Band 2-Way Device





Crane Aerospace & Electronics announces a new K-Band 2-way device, expanding its iso-divider product line for space applications. The new-

est K-Band 2-way iso-divider features similar outstanding performance as previously introduced Ku-Band 2-, 4- and 8-way products, including exceptionally low insertion loss and optimum band flatness performance. Other features include small size, low weight and high reliability, crucial for space applications.

www.craneae.com

JQL Electronics Inc.

Booth 919

X-Band Surface-Mount Solution





JQL Electronics Inc., a manufacturer of RF/ microwave isolators and circulators releases its new X-Band surface-mount solution. Like many of JQL's high perfor-

mance circulators, the new X-Band solution has robust design and high performance in a small package. The new X-Band circulator offers very low loss and high isolation. The surface-mount package makes it an excellent solution for PCB mounting. For more information, please contact the company at sales@jqlelectronics.com. www.jqlelectronics.com

Millitech Inc.

Booth 930

E-Band Linear-to-Circular Polarizer



Millitech Inc. announces its high performance E-Band linear-to-circular polarizer. Offering a low axial ratio of <0.6 dB, a low insertion loss of <0.5 dB, and

a typical VSWR of 1.25:1 within the high and low unlicensed communication bands (71 to 86 GHz), the polarizer can be optimized for any frequency you require from 18 to 110 GHz and above. Key benefits are ultra-wide bandwidth, exceptional axial ratio and low loss.

www.millitech.com

Trak Microwave Corp.

Booth 931

Compact C-Band TransceiverVENDOR**VIEW**

TRAK model T001291 C-Band transceiver integrates GaN technology into this compact (4"×4.6"×0.8") module that provides 4 W min Tx output power and <3 dB Rx noise figure. The device is designed for airborne



environments offering 100 kHz step size frequency agility, <30 W DC power consumption (Tx mode), integrated

filters that provide interference rejection in Rx mode and harmonics attenuation in Tx mode. The unit incorporates all-SMT construction and moisture resistance packaging to withstand harsh military environments.

www.trak.com

MACOM

Booth 939

GaN TransistorsVENDOR**VIEW**

Leveraging MACOM's GaN technology, the new MAGb series is the industry's first commercial base station-optimized family of GaN transistors to achieve leadership



efficiency, bandwidth and power gain with a linearity and cost structure like LDMOS, and a path to better than LDMOS cost. The MAGB-101822-

120BOS is the first in this family covering 500 MHz of RF bandwidth between 1.7 and 2.2 GHz, delivering over 160 W of peak power and peak efficiency of 74 percent with fundamental tuning only and linear gain over 19 dB.

www.macom.com/wirelessinfra

Anritsu

Booth 949

VectorStar VNAs VENDORVIEW



For applications ranging from microwave component testing to on-wafer device characterization, the VectorStar™ vector network

analyzer family uses nonlinear transmission line (NLTL) technology to provide best-inclass performance — and it's only from Anritsu. Get the confidence you need in every VNA measurement. Visit Anritsu's Booth 949 at IMS to see the latest features and functionality of the full VectorStar product line.

www.anritsu.com

Metrigraphics

Booth 1012

Flexible Circuits VENDORVIEW



Micron-scale flexible circuits from Metrigraphics can be produced in multilayers and with circuit lines as narrow as 3 microns. They're flexible enough to

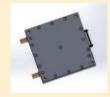
wrap around small objects and are durable enough for harsh MILCOM environments. Circuits are achieved via high resolution photolithography, as well as sputtered

thin-film and plated metal deposition techniques. Multilayer flexible circuits are constructed of several independently stacked, aligned and interconnected layers composed of very thin sputtered metal on polyimide substrates. Typical applications include sensors, electrodes, coils, resistors, inductors, conductors and bridges.

www.metrigraphicsllc.com

Micro Lambda Wireless Inc. Booth 1110

Miniature Low Noise Frequency Synthesizers



All units provide 1 kHz step size (programmable) with power levels of +10 to +13 dBm depending on frequency. Units are available with internal

crystal reference, external crystal reference or both. Interface is 5 wire SPI or standard USB control. Temperature range of 0 to +65°C is standard, but -40° to +85°C temperature range is available under special or order. Size is 2.5"× 2.5" × either 0.65" or 0.5", which is a perfect fit for a single slot PXI chassis.

www.microlambdawireless.com

Remcom

Booth 1114

XFdtd's Circuit Element Optimizer



XFdtd's Circuit Element Optimizer uses a new technology that combines full-wave 3D EM simulation with circuit optimization to solve an age-old RF

problem: determining which component values provide the desired match for a given matching network layout. Visit Remcom's booth to see a demonstration of how this new tool simplifies antenna design engineers' workflow by eliminating the step of soldering components in and out of a prototype.

www.remcom.com

Kratos General Microwave Corp.

Booth 1121

Indirect Synthesizer with Frequency Modulation



Kratos General Microwave enhanced its family of indirect synthesizers with the addition of the model SM6218 with frequency modulation

capability. It can provide a frequency deviation of 1 GHz at up to a 10 MHz rate and can be controlled with either analog or digital inputs. Of special significance — the synthesizer output frequency remains fully locked even while in the FM mode. Its small size and high reliability makes it ideal for use in demanding airborne environmental conditions as well as test systems.

www.kratosmed.com









V, E, W Fullband Medium Power Amplifiers

Model No.	Frequency Range (GHz)	Output Power (min)	Gain (min)	Gain Flatness (typ)	DC Supply	Waveguide In/ Out
QAM-50751420-X0	50-75	14 dBm	20 dB	±3 dB	5v to 12v	WR-15
QAM-60901520-X0	60-90	15 dBm	20 dB	±2 dB	5v to 12v	WR-12
QAM-75B01520-X0	75-110	15 dBm	20 dB	±2.5 dB	5v to 12v	WR-10

V, E, W-Band x8 Multipliers

Model No.	Output Frequency (GHz)	Input Frequency (GHz)	Input Power	Output Power (min)	DC Supply	Input / Output
QMM-632513080	50-75	6.25-9.37	5 dBm	13 dBm	5v to 12v	SMA / WR-15
QMM-753014080	60-90	7.5-11.25	5 dBm	14 dBm	5v to 12v	SMA / WR-15
QMM-902020080	80-100	10-12.5	5 dBm	20 dBm	5v to 12v	SMA / WR-15

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S PRODUCT SHOWCASE

Ciao Wireless Inc.

RF and Microwave Amplifiers/Assemblies



Ciao Wireless specializes in the design/manufacture of RF and microwave amplifiers/assemblies for both the

Booth 1132

defense and commercial industries, from 30 KHz to 44 GHz, including the various narrow and ultra-broadband frequencies in between. Ciao offers a complete catalog product line

and custom designs to meet all of your exact microwave amplifier and subsystem needs.

IIIIIII

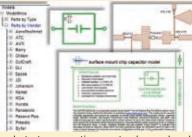
www.ciaowireless.com

Modelithics

Booth 1138

Modelithics CLR Library for Sonnet

Modelithics Inc. is once again expanding the availability of the powerful Modelithics®CLR Library of Microwave Global ModelsTM for capacitors, inductors and resistors. The advanced simulation models offer scalability



of substrate properties, part value and pad dimensions, and accurately predicts parasitic effects based on these inputs. Modelithics has supported Keysight Technologies' ADS and Genesys, and NI/ AWR Design Environment™ for years. Support for ANSYS®HFSSTM was introduced in 2015. This year, support for Sonnet® SuitesTM was announced and is now available to designers using Sonnet. www.modelithics.com/mvp/Sonnet

Maury Microwave

Booth 1139

Measurement and Modeling Solutions



Maury Microwave will be demonstrating state-of-the-art measurement and modeling solutions including: a patentpending noise parameter system, a

pulsed IV/RF and compact modeling solution, a hybrid-active load-pull solution based on the PNA-X, a patented mixed-signal active load-pull system capable of up to 1000 impedance/power measurements per minute and 240 MHz of instantaneous impedance control, and Maury's patent-pending LXITM-certified automated impedance tuners. Visit Maury for demos at IMS.

www.maurymw.com

American Technical **Ceramics**

Booth 1210

Q-Bridge Thermal Conductor



ATC's new Q-Bridge thermal conductor is manufactured with the highest quality materials for reliable and repeatable performance, providing a cost effective thermal

management solution. These devices are constructed with aluminum nitride (AIN) or beryllium oxide (BeO) and are available in 0302, 0402, 0603 and 0805 case sizes. With inherently low capacitance, Q-Bridge is virtually transparent at RF/microwave frequencies, and will not affect RF performance. Q-Bridge is manufactured using one-piece construction, and provides a RoHS compliant SMT package that can be used in a wide range of applications.

www.atceramics.com





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to 40 GHz

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to 40 GHz



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RF & Microwave

Power Meter

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Double Arrow 3 dB 180°

Hybrid Couplers to 26.5 GHz





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Broadband Limiters Pin-Pin Diode Booth #1429 Pin-Schottky Diode to 18 GHz

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IMS PRODUCT SHOWCASE AISLES 1200-1300

JFW Industries

Booth 1214

Improved Software for USB Programmable Attenuator



JFW announces the release of brand new control software and graphical user interface (GUI) for its family of USB programmable attenuators. Multiple attenuators can be individually controlled

or scripted together for complex test scenarios. JFW can also provide their easy-to-use .NET library for custom application development.

www.jfwindustries.com

Barry Industries

Booth 1217

HTCC Quad-Flat-No-Lead Packages





Barry Industries, an ISO9001:2008 certified, ITAR registered manufacturer, introduces their line of hermetically sealable HTCC

Quad-Flat-No-Lead (QFN) packages with air cavity for high frequency applications. These packages are available in 6 sizes from 3 mm to 8 mm with standard JEDEC MO-220 footprints. Maximum insertion loss is 0.5 dB from DC to 18 GHz, 1.5 dB from 18 to 35 GHz, and 4 dB from 35 to 40 GHz. HTCC construction provides for excellent mechanical strength. Standard plating is gold over nickel.

www.barryind.com

M.I. Cable

Booth 1222

Cable Assemblies

C25 series is super flexible for durable cable assemblies of superior mechanical and



electrical performance, well suited for applications requiring extremely limited installation space.

C25 series can be built with a wide range of connectors, such as SMA, MCX, SMP and 2.92 mm. These assemblies provide consistent performance with repeated bending and handling. Please email sales@ micable.cn for more information.

www.micable.cn

Herotek Inc.

Booth 1225

X-Band High Power Limiter



Herotek offers an 8 to 12 GHz high power limiter that can protect up to 100 W CW and 1 kW peak (1 microsecond pulse

width). Model LS0812PP100A has a very low leakage level or +13 dBm typical at 100 W CW input with a fast recovery time or 1 microsecond typical. It comes in a hermetically sealed module with built-in DC block at the input and output.

www.herotek.com

International Manufacturing

Services

Booth 1227

Thermal Management Device



The ThermaBridgeTM offers excellent thermal conductivity with electrical isolation at the

component level. The ThermaBridge is a simple and cost effective thermal management device which uses thermally conductive aluminum nitride with metalized terminals to transport heat from one location to another, thus enhancing overall board performance. IMS offers the ThermaBridge in numerous sizes and thicknesses, allowing users to choose the part which best fits their thermal management needs.

www.ims-resistors.com

Keysight Technologies

Booth 1239

X-Series Signal Analyzers VENDORVIEW



Keysight Technologies' new X-Series signal analyzers provide a streamlined multi-touch interface that enables optimization of

measurement parameters in two touches or less. The X-Series offers the first integrated 1 GHz analysis bandwidth to simplify test setup for analysis of wideband systems in radar and 5G research, the widest real-time streaming (up to 255 MHz bandwidth for enhanced analysis of intermittent and highly elusive signals), and industry-best phase noise performance in all models addresses emerging needs in radar, LTE and more. www.keysight.com/find/x-series

Q Microwave

Booth 1251

Wideband RF Converters



Q Microwave Inc., a supplier of RF filter products, is now offering frequencyagile RF converters, capable of converting RF frequencies

between 0.5 and 18 GHz, with 500 MHz of instantaneous bandwidth, for an IF range centered at 1200 MHz (950 to 1450 MHz). Uses two externally provided LO inputs, with digital control through a micro-d connector. Packaged in a small-sized rugged hermetically sealed housing.

www.gmicrowave.com

RelComm Technologies Inc. Booth 1322

RMT-Series 1P12T



RelComm Technologies Inc. complements its product line by offering a low cost high performance 1P12T relay configured with 'SMA' type

connectors providing exceptional RF performance to 18 GHz. The relay measures 2.25" square and is less than 2" tall. It is fitted with standard DA15P header for ease of installation. The relay is available in both latching and failsafe configurations with 12 and 24 V DC operation. Options include TTL control input.

RDT-18 GHz Series



Relcomm complements its product line by offering a new 18 GHz microstrip/co-planer

waveguide mount relay in a 1P2T configuration. This "pin out" device provides greater layout and packaging density measuring just 0.900" square × 0.550" high. The relay provides exceptional RF performance to 18 GHz (1.50:1 VSWR max, 0.50 IL max and 60 dB min ISOL). Typical uses include standby applications, input/output swapping and developing switch matrices. It can be configured with a failsafe or latching actuator and is available in 12 and 28 V DC operation.

www.relcommtech.com

Networks International Corp. Booth 1324

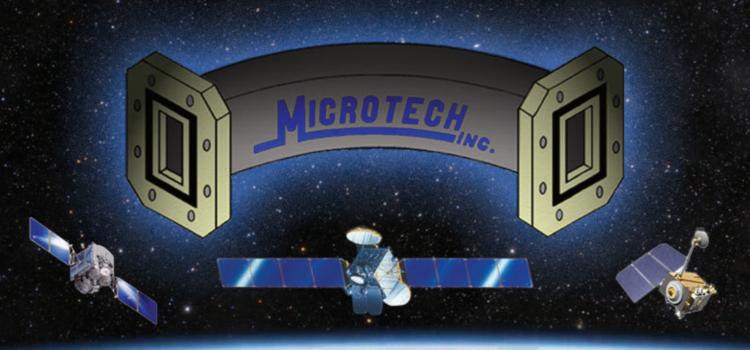
Printed Filters



NIC's engineering expertise in high reliability RF products includes a specialty in printed filters that span 1 to 20 GHz.

These low profile (0.15") filters can be customized to meet passband requirements from 1 to 100 percent as well as a wide range of environmental requirements. Whether your challenge is a small form factor, high power, or cost, NIC's unique products showcase a variety of creative solutions for all of your radar and communications needs. Please stop by Booth 1324 for additional information.

www.nickc.com



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IMS PRODUCT SHOWCASE AISLES 1300-1400

OMI Inc

Booth 1333

Down-Converter



OML introduces its first down-converter (CxxLNDC) that directly interfaces with a spectrum analyzer without the

need of an external LO source. With a typical conversion loss of 12 dB, excluding IF amplifier gain, and a compression of 0 dBm typical, this down-converter covers both V-Band (50 to 75 GHz) and E-Band (60 to 90 GHz). These two models can help to provide solutions in IEEE 80211.ad (Y-Gig), point-to-point radios and automotive radar. www.omlinc.com

Ducommun

Booth 1417

Coaxial Switching System



Ducommun's C323U5X16-01 is a bidirectional, 50 ohm blocking (one path at a time), coaxial

switching system that operates between DC to 22 GHz. This system is configured with 5 QMA (SMA/N/BNC can be substituted) input connectors and 16 QMA (SMA/N/BNC can be substituted) output connectors. Locally, the unit can be controlled via a 4-line 4×40 LCD and 16 button keypad

and remotely via Ethernet/USB/RS-232/ RS-488/GPIB using SCPI commands. www.ducommun.com

LPKF Laser & Electronics Booth 1423

Ultraviolet Laser System



The ProtoLaser U3 is an ultraviolet laser system with a 20 µm focused beam diameter for processing printed circuit boards. Winner of a SMT Vision

Award, the ProtoLaser U3 can etch circuitry, drill holes and depanel PCBs all in a single step. The ProtoLaser U3 can laser etch, drill and cut a wide variety of PCB substrates: FR4, fired ceramics, green and co-fired LTCC, flexible and rigid-flex materials, high frequency RF and microwave materials. www.lpkf.com

Delta Electronic Mfg. Corp. Booth 1428

Positive Interconnect Guidance



Is real estate a concern on your PCB's? Misalignment issues? Optimizing packaging space and positive interconnect

guidance utilizing multiple RF, microwave or millimeter wave connections are now

achievable. Delta Electronics Mfg. Corp. is the industry leader in "gang-mounting" technology. The engineers at Delta have worked closely with its customer base on significant design wins, where space and alignment issues were paramount to success. Their engineering team will work closely with you to offer a standard, or a customized version, to achieve your design goals. Email sales@deltarf.com for more information.

www.deltarf.com

Krytar

Booth 1429

Compact

Broadband Directional CouplerVENDOR**VIEW**



KRYTAR's new coupler, model 110067006, offers superior performance ratings including nominal coupling

(with respect to output) of 6 dB, ±2.5 dB, and frequency sensitivity of ±0.75 dB to 50 GHz, and ±1.50 dB to 67 GHz. The directional coupler exhibits insertion loss (including coupled power) of less than 4.40 dB, directivity of greater than 10 dB, maximum main line VSWR is 1.8. Secondary line VSWR is 1.8 at 10 to 50 GHz, and 2.3 at 50 to 67 GHz. Input power rating is 20 W average and 3 kW peak. The directional coupler comes with industry-standard 1.85 mm SMA female connectors. www.krytar.com

Piconics Inc.

Booth 1453

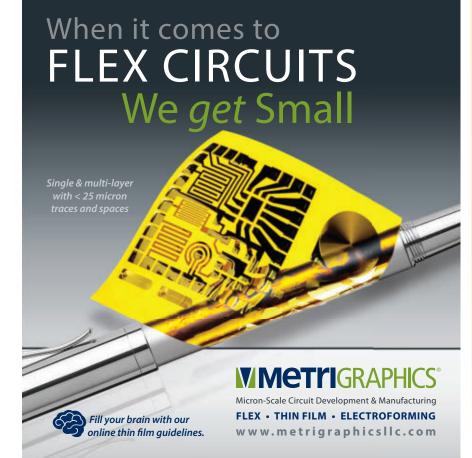
Substrate Mounted Broadband Conical Inductors



Piconics Inc. announces their new line of substrate mounted conical inductors for chip and wire applications. The Piconics CCM series

offers ultra broadband conical inductors conveniently packaged on a substrate with wire bondable contact pads. The standard CCM series features an alumina substrate with the conical mounted in shunt on a 50 ohm microstrip. All coils are held in place with epoxy and contacts are welded for enhanced reliability.

www.piconics.com





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IMS PRODUCT SHOWCASE AISLES 1500-1600

San-tron Inc.

Booth 1514

Relocated to Booth 1039

pSeries Pressurized Connectors





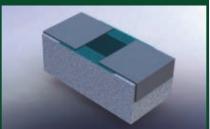
pSeries™ connectors from San-tron meet the IP68 standard via a simplified, threepiece design – body, center contact and innovative dielectric. This eliminates

troublesome internal o-rings, gaskets and silicone greases used in standard pressurized connectors. They provide low-loss performance through 30 GHz at ±65 psi and meet MIL-STD 202 Method 212, Condition D test conditions. A proprietary insulator also offers 5× more thermal stability than standard PTFE insulators. Available in 2.92 mm, 3.5 mm, SMA, TNC and type N styles. www.santron.com

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National Instruments Booth 1529

Test Solution for 802.11ax

VENDORVIEW



NI will be introducing the industry's first measurement solution for 802.11ax or High-Efficiency Wi-Fi (HEW) devices. The system is based on

NI's PXI RF Vector Signal Transceiver (VST), which offers 200 MHz of bandwidth at frequencies of up to 6 GHz. The new 802.11ax measurement suite supports narrower subcarrier spacing, 1024-QAM, and Orthogonal Frequency Division Multiple Access (OFDMA). The software is based on the latest draft of the 802.11ax specification revision.

www.ni.com

NI AWR Booth 1529

NI AWR Design Environment VENDORVIEW



The latest release of NI AWR Design Environment featuring Microwave Office,

Analog Office, AXIEM, Analyst and Visual System Simulator (VSS) features fully integrated circuit, system and EM analyses in one open platform for the development of RF/microwave products. Visit Booth 1529 to see the latest in power amplifier, filter, antenna, radar and 5G design solutions as well as third-party integration.

www.ni.com/awr

NI Microwave Components Booth 1529

QuickSyn Synthesizers





QuickSyn synthesizers are now extended to mmWave. NI Microwave Component's new QuickSyn mmWave synthesizer modules use the

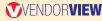
same QuickSyn technology that allows fast switching, low phase noise and compact size. These CW sources cover popular frequency bands, 27 to 40 GHz, 50 to 67 GHz, and 76 to 82 GHz for a variety of applications including a backhaul for digital radio, point-to-point and point-to-multipoint wireless HDMI, WiGig, IEEE802.11ad, wireless gigabit Ethernet, and automotive radar for collision avoidance.

www.ni.com

Skyworks

Booth 1611

FEM for BLE Range Extension Applications



Skyworks' SKY66111-11 front-end module (FEM) operates from 2.4 to 2.485 GHz, with low power consumption of 10 mA at 10 dBm Pout in transmit mode and features



adjustable output power. It more than doubles the range vs. system on chip (SoC) solutions for connected home, wearable and industrial applica-

tions. The device is suitable for products operating from coin cell batteries, including sensors, beacons, smart watches, thermostats, smoke and carbon dioxide (CO) detectors, wireless cameras, wireless audio headphones, hearing aids and medical pendants.

www.skyworksinc.com

Synergy Microwave Corp. Booth 1615

Phase-Locked Ultra-Low Noise Signal Sources

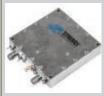
Synergy Microwave Corp. introduces a series of ultra-low phase noise, fixed-frequency, phase-locked, DRO oscillators (PLDRO). The KSFLOD1280-12-1280 is a



12.8 GHz fixed frequency source which, when locked to a low noise reference at 1200 MHz, will deliver exceptional phase noise of -96 dBc/Hz at 100 Hz offset

and -158 dBc/Hz at 10 MHz offset. This source is packaged in a 2.25" × 2.25" module housing and includes lock alarm. Options are available to 15 GHz and extendable to 30 GHz.

Phase-Locked Ultra-Low Noise Synthesizers



Synergy Microwave Corp. introduces a series of ultra-low phase noise frequency synthesizers. Model KSSL0238286-128 covers 2380 to 2860 MHz in 128

MHz step size and offers excellent phase noise of -90 dBc/Hz at 100 Hz offset and -133 dBc/Hz at 100 kHz offset. Step size and reference input options are available. These synthesizer models include SPI input programming inputs and lock alarm and are packaged in a 2.25" × 2.25" housing. Frequencies available to 30 GHz with an optional piggyback doubler.

www.synergymwave.com



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IMS PRODUCT SHOWCASE

Dow-Key Microwave

Booth 1639

Reliant Switch



Dow-Key's new product series Reliant SwitchTM offers a cost-effective design: manufactured to deliver ideal

performance for testing WLANs, WiMAX LTE/4G/5G networks in addition to a variety of other test and measurement setups. SPDT switches (SP6T coming soon) are available with guaranteed insertion loss repeatability of 0.03 dB across DC to 26.5 GHz, 10 million life cycles per switch position, latching actuator and with options of: terminated or non-terminated, control via 12 V/24 VDC supply or TTL lines. www.dowkey.com

K&L Microwave

Booth 1639

PIN Diode Switches



For more than 20 years, K&L Microwave has manufactured PIN diode switches for use in the company's high performance switched filter banks. Leveraging this

custom design expertise, K&L began offering packaged PIN diode switches in

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2015. Switches are available from single pole, double throw through single pole, eleven throw in reflective and non-reflective options for frequency ranges from DC to 20 GHz. To discuss custom PIN diode switch requirements and other Microwave Products Group offerings, visit K&L at Booth 1639. www.klmicrowave.com

CPI Beverly Microwave Division

Booth 1646

C-Band 4 kW Modular GaN



The VSC3644 is a C-Band 4 kW modular GaN, high power, solid-state power amplifier that operates from 5.2 to 5.9 GHz at 10 percent duty.

Designed to be a modular building block for 16 and 32 kW applications, this amplifier consists of four blind mated, ruggedized, SSPAs with integral air cooling and amplifier health monitoring. It's designed around proven GaN semiconductors from semiconductor manufacturer Wolfspeed. For a live demo visit CPI BMD at Booth 1646. www.cpii.com/bmd

West Bond Inc.

Booth 1647

Wire Bonders



Introducing the most flexible, complete wire bonders system available today. 7KE and 4KE series wire bonders: Bonding at 45° feed for tail control, 90° for ribbon

and deep access and ball bonding without changing heads. Wedge bonding Au, Al, Cu; ball bonding Au, Cu. automatic, semiautomatic, and manual all ESD protected. Ultrasonic, thermosonic and thermocompression wire/ribbon bonders; eutectic and epoxy die bonders, insulated wire bonders and pull testers.

www.westbond.com

AR RF/Microwave Instrumentation

Booth 1711

Solid-State Amplifier VVENDORVIEW



Model 300S1G6AB is a solid-state; 300 W class AB amplifier that instantaneously covers 0.7 to 6 GHz in one unit with an input power level of 0 dBm. This wideband output power amplifier is approximately half the size of a

traditional class A design, more efficient, and offers a more economical price. Typical uses include wireless and EW applications. www.arworld.us/post/300S1G6AB.pdf

Holzworth Instrumentation Booth 1723

RF Synthesizers VENDORVIEW



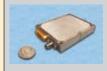
Holzworth's new HSX Series RF synthesizers are phase coherent, multichannel signal sources that offer industry leading phase noise (-142 dBc/Hz at 1 GHz, 10 kHz offset), spectral purity of better than -85 dBc (spurious), and output power dynamic range of +20 dBm to -110 dBm (0.01 dB of resolution). User defined configurations from 1 to 4 independently tunable RF outputs provide the best performance-toprice ratios in the industry. 6 GHz models are currently available with 12 GHz and 24 GHz models available by late 2016.

www.holzworth.com

Teledyne Microwave Solutions

Booth 1739

Modular, Non-ITAR GaN Amplifiers VVENDORVIEW



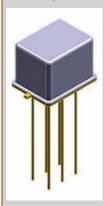
When size, weight and power (SWaP) are critical, look to Teledyne Microwave Solutions' new GaN-based amplifier

line. These wideband amplifiers establish a new baseline for small size in the 0.1 GHz to 6 GHz range. With dimensions of $2.5" \times 2" \times 0.42"$, output power ranging between 15 and 40 W, plus a calculated MTBF of 40,000+ hrs., these units are suitable for airborne applications as well as challenging land-based environments. www.teledyne.com

Teledyne Relays

Booth 1739

RF Relay



Teledyne Relays announced its new 121 relay. The RF121 is a high repeatability, SPDT, broadband, magnetic-latching RF relay with performance to 12 GHz. It is ideal for switchable RF attenuators, RF switch matrices, high frequency spectrum radios, ATE and applications that require dependable

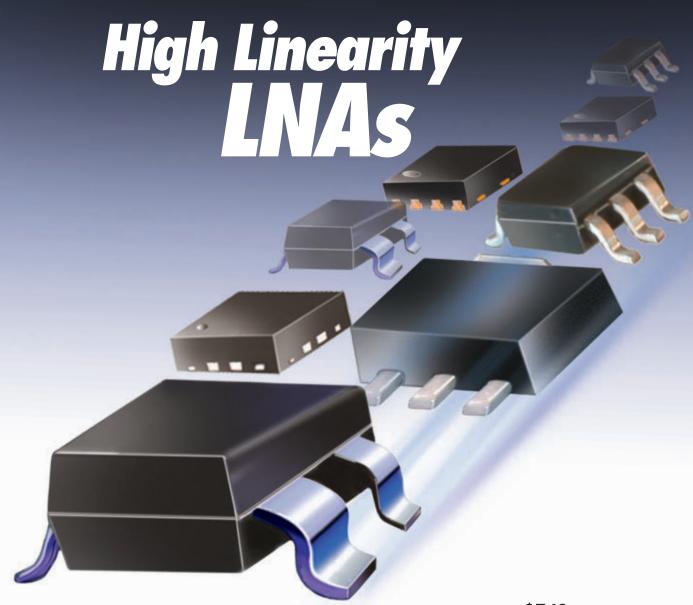
high frequency signal fidelity and performance. The RF121 is available in throughhole, surface-mount stub pin (GRF121), and J-lead configurations. The GRF121 has a frequency range of DC to 16 GHz. www.teledynerelays.com

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DC to 8 GHz · NF as low as 0.46 dB · IP3 up to 43 dBm from ea.(qty. 20)

Many combinations of performance parameters to meet your needs! With over 20 low noise, high linearity models to choose from, chances are you'll find the right combination of output power, gain, DC current and bandwidth to upgrade almost any 3 to 5V circuit – from cellular, ISM, and PMR to wireless LANs, military communications, instrumentation, satellite links, and P2P – all at prices that preserve your bottom line!

2 new ultra-wideband models with frequency range as wide as 0.5 to 8 GHz now cover applications from UHF up to C-Band in a single model with one simple matching circuit! All catalog models are in stock and ready to ship, so visit minicircuits.com for data sheets, performance curves, S-parameters, pricing and availability for reels in quantities as small as 20 pieces. Place your order today for delivery as soon as tomorrow!

Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P _{out} (dBm)	Current (mA)	Price \$ (qty. 20)	Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P _{out} (dBm)	Current (mA)	Price \$ (qty. 20)
New! PMA3-83LN+ PMA2-162LN+	500 – 8000 700-1600	21.0	1.3	35 30	23.2	80 55	11.95 2.87	New! PMA2-43LN+ PGA-103+	1100 – 4000 50-4000	19 11.0	0.46	33 43	19.9	51 60 (3V)	3.99 1.99
PMA-5452+	50-6000	14.0	0.7	34	18	40	1.49	PMA-5453+	50-6000	14.3	0.9	37	20	97 (5V) 60	1.49
PSA4-5043+	50-4000	18.4	0.75	34	19	33 (3V) 58 (5V)	2.58	PSA-5453+	50-4000	14.7	1.0	37	19	60	1.49
PMA-5455+	50-6000	14.0	8.0	33	19	40	1.49	PMA-5456+	50-6000	14.4	0.8	36	22	60	1.49
PMA-5451+	50-6000	13.7	8.0	31	17	30	1.49	PMA-545+	50-6000	14.2	0.8	36	20	80	1.49
PMA2-252LN+	1500-2500	15-19	8.0	30	17	41 (3V) 57 (4V)	2.87	PSA-545+ PMA-545G1+	50-4000 400-2200	14.9 31.3	1.0 1.0	36 34	20 22	80 158	1.49 4.95
PMA-545G3+	700-1000	31.3	0.9	34	22	158	4.95	PMA-545G2+	1100-1600	30.4	1.0	34	22	158	4.95
PMA-5454+	50-6000	13.5	0.9	28	15	20	1.49	PSA-5455+	50-4000	14.4	1.0	32	19	40	1.49
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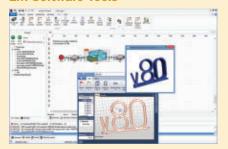


IMS PRODUCT SHOWCASE AISLES 1700-1900

Mician

Booth 1746

EM Software Tools



Mician is recognized as a leading developer of EM software tools for the design and optimization of waveguide components, feed networks and horn antennas. Version 8, the latest release of Mician's signature product µWave Wizard, now includes a modeler for user defined elements and comes with a new ribbon based graphical user interface. Speed up of GUI launch for very large projects is now up to 10 times faster. Includes a new direct and iterative solver and parallelization is possible.

L-3 Electron Devices Booth 1811 80 W Ka-Band MPM

L-3's M1292 MPM provides over 80 W of saturated power and 50 W of linear power in



Internal-LO 6GHz Mixer

A wideband mixer with integrated programmable LO perfect for downconverting!

25MHz - 6GHz LO USB & Panel Control IF up to 600MHz Input P1dB > +12dBm RF up to 6GHz Good LO leakage Low conversion loss External Ref Input

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12GHz Programmable Attenuator

A USB SCPI-controlled RF attenuator with stand-alone controls and display.

0 to 63dB Attenuation 100MHz - 12GHz Simple Windows App 0.5dB Steps Micro USB Powered Tiny 2.75" Enclosure

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Ka-Band. This amplifier is ideal for defense applications requiring high output power and high efficiency in an ultra-compact, fully airborne-qualified

package. Covering both communications and radar bands, this MPM is suitable for communications, radar and EW applications. The M1292 operates from conventional +28 VDC prime power, measures $9.75" \times 8.50" \times 1.50"$, and weighs less than eight pounds. www.L-3com.com/edd

Coilcraft Chip Inductors



Developed for use in mobile devices and cellular infrastructure equipment, Coilcraft's new 0402DF series chip inductors are available with

Booth 1826

inductance values ranging from 20 to 3300 nH, with a 5 percent tolerance for all values. They offer the lowest DCR currently available in a 0402 package and are fully optimized for use as a harmonic filter element for NFC applications. They can also be used as filter elements in bandstop and lowpass filters, a one-pole filter or RF choke in cellular bands, and for ground-to-ground isolation.

www.coilcraft.com

Rohde & Schwarz

Booth 1827

Phase Noise Analyzer and VCO Tester

VENDORVIEW



The R&S FSWP phase noise analyzer and VCO tester enables ultrasensitive and ultra-fast phase noise measurements. It

allows users to very easily measure pulsed sources and additive phase noise of RF components and signal sources such as generators, synthesizers and oscillators more quickly than with any other solution. With up to 50 GHz the extremely low phase noise of its local oscillator and cross-correlation the FSWP performs complex measurements that in the past required complex test setups with just a push of a button.

www.rohde-schwarz.com

NXP Semiconductors Booths 1839/2555

Airfast GaN Power Transistor



NXP's first Airfast second generation gallium nitride (GaN) is an asymmetric device ideal for 30 W average cellular base station applications. This GaN based

power transistor is capable of 2300 to 2690 MHz wideband operation with a power gain of 15.6 dB at 2605 MHz and 54

percent efficiency at 8 dB back-off. This product offers the mainstream cellular market with a GaN device in a small NI-780S-4L package. GaN devices, which offer higher power densities and efficiency, are key to the expanding 4G LTE deployments and emerging 5G marketplace. www.NXP.com/RF

Laser Services

Booth 1853

Laser Processed CeramicsVENDOR**VIEW**



Laser Services, an AS-9100 registered job shop, is an experienced microwave industry supplier offering advanced laser ablation, cutting, drilling, scribing,

etching and welding services. They are specialists in processing ceramic materials, frozen epoxies and a variety of PCB substrates—stocking many brand name materials such as Coorstek, Ceramtec and Kyocera for quick turn-around. A fully equipped 16,000 square foot facility features 25 low to high power lasers and a variety of other state-of-the art equipment and secondary processing tools.

www.laserservicesusa.com

Molex

Flexible Microwave Cable Assemblies



Temp-Flex®flexible microwave cable assemblies from Molex meet strong signal requirements

Booth 1911

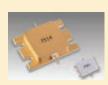
while minimizing signal loss, even in high frequency applications. Each cable assembly is constructed with proprietary techniques to maximize reliable connectivity and minimize voltage standing wave radio (VSWR) and insertion loss. By combining Molex RF connectors and Temp-Flex®coaxial cables, you get a solution tailored for your exact needs, with excellent electrical properties and proven reliability. Learn more by visiting Booth 1911.

www.molex.com

Sumitomo Electric Device Innovations

Booth 1927

X-Band Pulsed Radar Devices



Sumitomo Electric introduces new devices to its line of high power GaN products for X-Band radar applications. The F501 is a

compact two-stage hybrid module SMD with 22 dB gain, 30 W power, ideal as driver or phased array radar element. The F514 is a 300 W IMFET. These add to the existing line of 50 W, 100 W and 200 W IMFET devices. www.sel-device.com

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IMS PRODUCT SHOWCASE

AISLES_1900-2000

RF-Lambda USA LLC



Booth 1931

RF-Lambda will showcase its new filter bank switch matrix with 160 channels designed

for phase array radar systems. Model number RFSP160TA0020G features single pole 160 through, filter bank switch matrix, frequency: 0.05 to 20 GHz, isolation: 60 dB and speed: 50 ns.

Solid-State Power Amplifiers



RF-Lambda offers a variety of solidstate power amplifiers used in aerospace and military applications DC to 48 GHz

up to 5 and 150 W. Model RFLUPA08G-11GC features 100 W X-Band power amplifier, frequency of 8 to 11 GHz, high output power +50 dBm and high peak to average handle capability.

Low Noise Amplifiers



Ultra-wideband low noise amplifiers with frequencies from 0.01 GHz to 100 GHz, noise figure as low as 0.5 dB which comes in coaxial,

drop-in or waveguide packaging. Primarily used in wireless infrastructure, RF/microwave & VSAT, military & aerospace, test instrument and fiber optics. Model RLNA00M54G features frequency of 0.01 to 54 GHz, noise figure: 3.0 dB, P1dB output power: 10 dBm full band, supply voltage: +12 V at 185 mA and 50 ohm matched input/output.

www.rflambda.com Empower RF Systems

Booth 1947

Amplifier System VENDORVIEW



Model 2180, covers 1 to 2.5 GHz and delivers an unprecedented 2 kW CW of broadband output power in an 8U, air cooled chassis and is an ideal replacement

for TWT's in both CW and pulsed applications. System integration is easier with feature rich control and monitoring functions including input and output detectors (user selectable peak and RMS) and selectable output modes: automatic gain control (AGC), automatic level control (ALC) and standard manual gain. www.empowerf.com

Custom MMIC

Booth 1950

DC to 26 GHz SPDT MMIC Switch VENDORVIEW

The CMD230 offers an impressive 1.4 dB insertion loss and high isolation of



111111

40 dB at 13 GHz. It is offered in die form and operates using control voltage logic lines of 0/-5 V, and requires no bias

supply. It is a reflective design with a 3.4 ns switching speed and is pin-compatible with the obsolete Celeritek CSW0118. Over 80 high performance products are now available in Custom MMIC's design library. www.custommmic.com/CMD230_Switch/

UTE Microwave Inc.

Booth 2010

Isolators and Circulators



From milliwatts to kilowatts, UTE Microwave offers a wide line of ferrite isolators and circulators covering

the spectrum from 75 MHz to 20 GHz. These include drop-in low power units thru high power devices for radar, medical, scientific and communications. Connecting interfaces are available in coaxial, waveguide and EIA flanges. Typical of the high power circulators is model CT-1739-D operating at 128 MHz with 20 kW peak and 2 kW average power in a 9" × 9" footprint with DIN-7/16 connectors.

www.utemicrowave.com

QuinStar Technology Inc. Booth 2011

mmWave Amplifiers and Multi-Function Assemblies



QuinStar Technology offers complete product lines of mmWave amplifiers and customized

multi-function assemblies for frequencies up to 110 GHz. Amplifier products range from ultra-low noise amplifiers to full waveguide band driver amplifiers covering K through W-Band (18 to 110 GHz), to very high power amplifiers up to 100 GHz with unparalleled power output level, linearity and efficiency. CW and pulsed high power amplifiers are ideally suited for replacing tubes in radars and communication transmitters.

www.quinstar.com

Berkeley Nucleonics

Booth 2015

40 uS Frequency Switching Signal Generator VENDORVIEW



Berkeley Nucleonics releases a new fast switching signal generator model capable of 40 uS

frequency switching times. The 845-FS RF/microwave signal generator will reduce lag time in time sensitive applications while still maintaining signal purity and reliability. The new 845-FS is available with 12, 20 and 26.5 GHz frequency ranges and can be configured in benchtop and 1U rack-mount designs.

www.berkeleynucleonics.com

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RF-Lambda SP160TA0020G-S F:0.05-20GHz 16010600274

RF SWITCHES MM / MICROWAVE DC-50GHz



160 CHANNELS mm/Microwave

0.05-20GHz Filter Bank Switch Matrix

For Phase Array Radar Application Satellite communication.



PN: RFSP32TA5M43G SP32T SWITCH 0.5-43.5GHz

PN: RFSP16TA5M43G SP16T SWITCH 0.5-43.5GHz



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Mini-Circuits

VENDORVIEW

Bidirectional Coupler



Mini-Circuits' ZGBDC20-33HPD+ is a high power, wideband

Booth 2029

bidirectional coupler providing 20 dB coupling with good coupling flatness across 300 to 3000 MHz. This model is capable of handling up to 250 W RF input power and passing up to 3.0A DC current from input to output. 20 dB typical directivity allows accurate sampling of signal through the coupled port, and low mainline loss (0.15 dB typical) provides excellent transmission of signal power from input to output. The coupler comes housed in a rugged, IP67 weatherproof case measuring 5.58" × 2.50" × 1.00" with 7/16 DIN connectors.

Coaxial Bias Tee



Mini-Circuits' ZX85-40W-63+ is a coaxial bias tee providing 40 W power handling and 0.5 dB

insertion loss for applications over the 700 to 6000 MHz frequency range. It provides 33 dB typical DC-RF isolation and handles up to 1A DC current at the input. This model features rugged unibody construction with SMA connectors and provides excellent durability. The small, 0.74" × 0.75" × 0.46" case size saves space in crowded system layouts.

Coaxial Triplexer



Model ZTPL- 4620+ is a high performance $50~\Omega$ triplexer with the lowpass channel-1 at 9.8 to 10.2 MHz, bandpass

channel-2 at 852 to 1872 MHz, and highpass channel-3 at 3300 to 4620 MHz. The triplexer is a 4-port passive device used to separate the C-Band and L-Band receive signals on a common port and route them non-interactively to separate output ports. Additionally, the device routes a 10 MHz reference signal appearing on the fourth port non-interactively to the common port.

Coaxial Splitter/Combiners



Mini-Circuits' new ZN2PD-622SMP+ and ZB3PD-63SMP+ coaxial splitter/ combiners feature

ultra-thin (0.43") packages with SMP snap-on blind mate connectors for easy connection to adjacent modules in systems with tight space constraints. Both models provide wideband performance with low insertion loss, high isolation, low phase and amplitude unbalance, high power handling and DC passing.

Miniature High Power Couplers



Mini-Circuits' SCBD-series of surface-mount, high power, bidirectional couplers features 7 models covering applications from 50 to 6000 MHz with

power handling up to 100 W. These miniature couplers provide coupling values ranging from 10 to 31 dB with low mainline loss, high directivity, excellent VSWR and DC current passing up to 2A. The units are designed into open printed laminate measuring only $0.70" \times 0.32" \times 0.20"$.

MMIC Frequency Mixer



Mini-Circuits' new MDB-24H+ ultrawideband doublebalanced MMIC frequency mixer provides an RF and

LO frequency range from 5 to 21.5 GHz and an IF frequency range from DC to 5 GHz. Ultra-wideband coverage in a single device makes this mixer suitable for wideband systems such as defense communications and radar, as well as a wide variety of narrowband applications from Wi-Fi through Ku-Band and more.

Ultra-Flexible Test Cables



Mini-Circuits' new ULC-series ultra-flexible test cables provide low insertion loss and excellent

VSWR for a wide range of test applications from DC to 18 GHz. These cables are specially designed for stability of phase and amplitude versus flexure in bend radii as tight as 2" (2" minimum dynamic bend radius, 0.7" minimum static bend radius), making them ideal for demanding lab environments where frequent bending is common.

Wideband Directional Coupler



Mini-Circuits' ZADC-13-73+ is a coaxial, wideband directional coupler providing 13 dB coupling with good coupling flatness across the 2600 to 7000 MHz. This model is capable of handling up to 4 W RF input power and passing up to 1.0 A DC current from input to output. 18 dB typical directivity allows accurate sampling of signal through the coupled port, and low mainline loss (0.8 dB typical) provides excellent transmission of signal power from input to output.

High Power Splitter/Combiner



Mini-Circuits' ZN2PD-9G+ is a 2way 0° high power splitter/combiner providing up to 30 W power handling as a

splitter (0.8 W as a combiner) and 0.5 dB insertion loss across the 1700 to 9000 MHz frequency range. Its outstanding combination of high power handling and low loss minimize power dissipation and provide excellent signal power transmission from input to output. The ZN2PD-9G+ comes housed in a rugged aluminum alloy case measuring 1.8" \times 1.75" \times 0.65" with SMA connectors.

Monolithic Amplifier



Mini-Circuits'
CMA-84+ is a
wideband monolithic
amplifier providing
high dynamic range
from DC to 7 GHz. It

uses patented, Transient Protection
Darlington Configuration circuit architecture
and is fabricated using InGaP HBT technology. The amplifier is bonded to a multilayer
integrated LTCC substrate, then hermetically
sealed under a controlled Nitrogen
atmosphere with gold-plated cover, eutectic
Au-Sn solder, and Ni-Pd-Au termination
finish. CMA-series amplifiers have been
tested to meet MIL requirements for gross
leak, fine leak, thermal shock, vibration,
acceleration, mechanical shock and HTOL.

MMIC Splitter/Combiner



Mini-Circuits' EP2K1+ is a MMIC splitter/ combiner designed for wideband operation from 2 to 26.5 GHz. This model provides excellent

power ratings in a tiny device package (4 mm \times 4 mm \times 1 mm), with up to 2.5 W power handling (as a splitter) and up to 1.2A DC current passing. Manufactured using GaAs IPD technology, it provides a high level of ESD protection and excellent reliability.

www.minicircuits.com









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IMS2016 KEYNOTES

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Plenary Speaker: "The Birth and Death of the Cell Phone" Dr. Martin Cooper Father of the Cell Phone



Closing Speaker: "Software's Role in Next-Generation 5G RF and Microwave Systems" **Dr. James Truchard** President, CEO and Co-founder, National Instruments



Closing Speaker: "The Human Intranet: Where Swarms and Humans Meet" Prof. Jan M. Rabaey Donald O. Pederson Distinguished Professor, UC Berkeley

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IMS PRODUCT SHOWCASE

AISLES 2000-2100

RLC Electronics

Booth 2047

Surface-Mount Cavity Filters



RLC Electronics manufactures surface-mount cavity filters for small scale, low profile system integration. High Q

cavity filter performance is available up to 30 GHz with profile height as low as 200 mm. The surface-mount design is suitable for reflow attachment, providing savings on size, cost and weight. This type of design results in low loss, achieves rejection of 60 dBc up to 3× faster and also maintains good VSWR (14 dB min) throughout. RoHS compliant versions available upon request. www.rlcelectronics.com

Reactel

Booth 2110

VENDORVIEW Filters, Multiplexers & Multifunction Assemblies



Reactel manufactures a line of filters, multiplexers & multifunction assemblies covering up to 50 GHz. From

small, lightweight units suitable for flight, to high power units capable of handling 10 kW, connectorized or surface-mount – Reactel's talented engineers can design a unit specifically for your application. Visit Booth 2110 to learn more.

www.reactel.com

TTE Filters & Gowanda

Booth 2116

Bias Tees to 40 GHz



TTE's bias tees are now available for frequencies from 10 MHz to 40 GHz and current handling to 7A DC. They offer superior broadband performance, low

insertion loss, minimal return loss, desirable VSWR characteristics, extremely flat gain response and RoHS-compliant options. TTE's RF & microwave filters are available to 26 GHz, featuring built-to-order lead times as short as 3 to 5 days. TTE's filters, Gowanda Electronics' conicals and RF & power inductors, Communication Coil's custom magnetics and Instec's EMI/RFI filters will be on display at IMS2016, Booth 2116. All companies are affiliates of Gowanda Holdings. www.GowandaHoldings.com

Delta Microwave Inc.

Booth 2124

GaN SSPA Power Amplifier



Operating over 29 to 31 GHz, model DM-HPKA-10-102 delivers 8 to 10 watts of linear output power. SSPA offers gain of 50 dB and

excellent AM-PM ($<3^{\circ}$ /dB) in a compact size of 3.1" \times 3" \times 0.78". Product functions with a single 20 V input supply and includes

features such as fast on/off, over temperature and over current protection. Design and construction meet full military requirements for -40° to +85°C environmental conditions. www.deltamicrowave.com

Peregrine Semiconductor Booth 2129

UltraCMOS Mixers

IIIIIII

The UltraCMOS®PE41901 and PE41902 are high frequency mixers that operate from 10 to 19 GHz. The PE41901 is an up-conversion mixer with an integrated



LO coupler, and the PE41902 is a down-conversion mixer with an integrated LO combiner and RF coupler. These complete MMIC

mixer solutions are ideal for test and measurement systems and Ku-Band earth terminals such as VSAT and point-to-point communication systems. These mixers encompass the key UltraCMOS technology strengths of high isolation and high linearity, while providing a robust and reliable solution for frequency-mixing applications.

UltraCMOS MPAC - Doherty

The UltraCMOS®PE46130 and PE46140 join the PE46120 MPAC product family in offering phase and amplitude control for



Doherty power amplifier applications. The PE46130 provides excellent phase and amplitude accuracy from 2.3 to 2.7 GHz, and the PE46140 extends

from 3.4 to 3.8 GHz. Each monolithic phase and amplitude controller (MPAC) integrates a 90° hybrid splitter, digital phase shifters, digital step attenuator and a digital SPI interface on a single die. www.peregrine.com

Passive Plus

Booth 2148

VENDORVIEW

High-O/Low ESR/ESL Capacitors

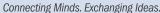


With over 30 years in the RF/microwave industry, Passive Plus Inc. (PPI) manufactures and specializes in High-Q/Low ESR/ ESL capacitors for the military, medical,

semiconductor, broadcast and telecommunications industries. Capacitor case sizes include 0505, 1111, 2225, 3838; EIA 0201, 0402, 0603, 0805, High power 6040, 7676; Broadband capacitors 01005, 0201, 0402. Known for superior customer service, fast deliveries, competitive prices and outstanding quality, PPI continues to broaden its technology portfolio in the ever-changing environment of today's electronics market.

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Planar Monolithics

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Successive Detection Log Video Amplifier

PMI Model No. SDLVA-18G40G-65-2-292FF is a successive detection log video amplifier (SDLVA) that operates between 18



and 40 GHz. It has a dynamic range of 65 dB (-63 dBm to +2 dBm), a log slope of 25 mV/dB, and a nominal video bandwidth of 32

MHz. This design uses cutting edge GaAs technology which provides stunning performance and reliability in a compact package (2.37" × 1.80" × 0.42") making it an optimum solution for high speed channelized receiver applications. Other features include SMA female connectors, VSWR 2.5:1, operating voltage of +12 V at 600 mA, -12 V at 250 mA. www.pmi-rf.com

Southwest Microwave Inc. Booth 2239

Push-on Connector

Nearly four decades ago, the RF design community was introduced to a new push-on connector that addressed the need for increased electrical performance, quicker installation and greater density in higher frequency applications. This design, commonly known as the



sub-miniature push-on (SMP) connector, was built around a blind-mate adapter, or bullet, housed between two PCB or panel-mounted receptacles. The bullet, available in

different lengths, tolerated a degree of axial and radial misalignment, or float, while still maintaining transmission integrity.

www.southwestmicrowave.com

Infineon

Booth 2243

GaN RF Power Transistors

The GTVA261701FA is a 170 W transistor that operates over the 2620 to 2690 MHz frequency band and offers 18 dB of gain and 47 percent efficiency under one carrier



WCDMA signal. In a 3-way Doherty configuration, an amplifier using the GTVA-261701FA can

achieve efficiencies of over 57 percent under the same test signal. The GTVA220701FA is a single-ended driver transistor that operates from 1800 to 2200 MHz and offers 60 W of output power and 20 dB of gain. It comes in an open cavity ceramic package. Evaluation boards are available for both devices. www.infineon.com/rfpower

SGMC Microwave

Booth 2330

Precision Coaxial Connectors



SGMC Microwave is a registered ISO 9001:2008 manufacturer of precision coaxial connectors including cable connectors, receptacles and adapters.

SGMC's product catalog along with its newly revamped website showcases its extensive line of readily available products which includes these series: 1.0 mm, 1.85 mm, 2.4 mm, 2.92 mm, 3.5 mm, SMA, N, TNC and SSMA. SGMC Microwave's hallmarks are always quality, performance, and reliability. www.sgmcmicrowave.com

Richardson Electronics

Booth 2350

Disruptive Technologies in the Think Tank

For nearly 70 years, Richardson Electronics has been an industry-leading global provider of engineered solutions, power grid and microwave tubes. With the launch of the Power & Microwave Technologies group, the company continues this legacy and complements it with new RF & microwave technologies. At Richardson Electronic's IMS Think Tank, Booth 2350, the company will feature the disruptive technologies and new prod-

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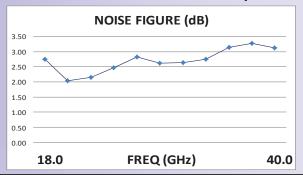
K-Band 18 to 40 GHz LNA



ACTUAL SIZE

The APT4-18004000-4008-B18 is a wideband, medium gain low noise amplifier with good Flatness across the band. It is designed mainly for wideband telecommunications, such as for Military and Space, Point-to-Point Radios and Test Equipment. The input signal can be as large as +16 dBm.

- 18.0 to 40.0 GHz Frequency Range
- 3 dB Typical N.F.
- 41 dB typical Gain
- Gain Flatness ± 3.0 dB typ
- Internal DC Regulator
- Reverse Voltage Protection
- MIL-883 construction & reliability



Cellular Band 100W HPA

- 800 MHz to 2600 MHz Frequency Range
- 50-100W Output Power
- High Power Density
- State-of-the-art GaN Technology
- 110V and 220V operation
- Heat Sinks Provided
- MIL-883 construction and reliability

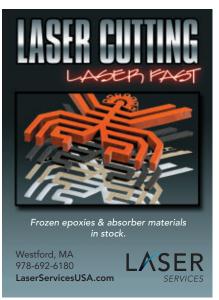


FREQUENCY (MHz)	Роит @Рім -3 dBm	Gp @PIN -3 dBm	CURRENT @PIN -3 dBm	PAE @PIN -3 dBm
800	50.51	53.52	10.12	32.30
1000	51.50	54.12	9.57	41.20
1200	50.92	53.92	8.23	45.44
1400	50.02	52.81	6.23	45.98
1600	50.60	52.89	8.32	38.23
1800	50.40	52.64	8.45	33.54
2000	50.10	52.90	9.92	32.21
2200	51.22	52.94	8.98	34.33
2400	50.21	51.76	9.52	32.41
2600	50.11	51.98	8.01	33.10

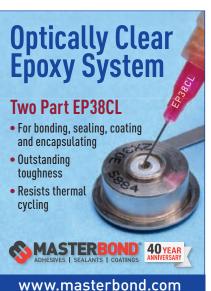
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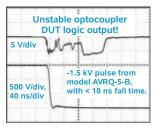


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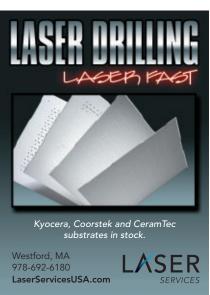


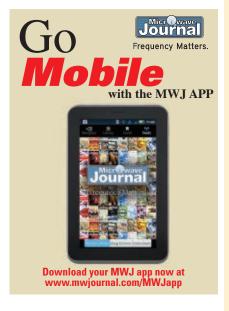
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Smart Marketing for Engineers

An Inbound Marketing Guide to Reaching Technical Audiences

Rebecca Geier

isking a generalization, most practicing scientists and engineers are more interested in technology than marketing. So Rebecca Geier wrote a book for the technical community, setting out to explain "inbound" marketing and effective strategies to use it. Inbound marketing, also called pull marketing, refers to activities that use informative content to attract people, such as a Google search that leads to a white paper on a company's website. Outbound marketing (push marketing) is what we've grown up with: advertising messages generated by a company and broadcast to a wide audience. While Geier sees roles for both in a company's marketing strategy, "Smart Marketing for Engineers" focuses on inbound marketing.

This practical handbook lays out a systematic and actionable process for

implementing an inbound marketing plan. However, before a business can develop a marketing plan, it must clearly understand its differentiation. Geier begins with this step, then moves to developing the marketing plan and creating "personas," which describe the characteristics of the "buyers" the company wishes to attract.

With this foundation, Geier discusses selecting keywords, designing a website and developing a content plan. She argues that companies should treat content as seriously as developing new products, and she suggests the type of content that the technical community finds meaningful and credible. In addition to content that develops customer loyalty, a well designed inbound marketing program generates leads and allows a company to measure market response and return-on-investment. These aspects are covered in the four chapters that conclude the book.

Rebecca Geier is the CEO and cofounder of a business-to-business (B2B) marketing company that serves technical clients. Before launching her firm, Geier gained expertise through roles at

technology companies — principally 14 years at National Instruments — where she developed an understanding of engineers and scientists and how best to communicate with them. She's lived through the adoption of email, the Internet, the World Wide Web, social media and inbound marketing and has seen the power of these tools when effectively used for marketing.

Practical and readable, "Smart Marketing for Engineers" will help the technical community better communicate our messages. It should be particularly useful for scientists and engineers who move into marketing or launch their own ventures.

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SAGE Millimeter: The Future of Millimeter Wave is Today



fter decades as an arcane, nascent technology — largely the purview of military and scientific researchers, millimeter wave has become the glamorous debutante, almost synonymous with 5G. Its coming of age reflects the abundant spectrum that will enable the 10 Gbps data rates promised by 5G, as well as an assortment of commercial applications such as WiGig.

Yonghui Shu saw this coming. Following years doing research in academia and at TRW, he decided to commercialize millimeter wave technology. He first formed WiseWave Technologies in 2001, which offered a mix of microwave and millimeter wave products. After Ducommon bought the business, Shu formed SAGE Millimeter in 2011, this time just tending to the spectrum above 18 GHz.

SAGE Millimeter offers a range of products extending to 140 GHz, beginning with antennas and including passive and active components, bolt-together subassemblies, integrated modules with sensors and test equipment. Many of the products are in the catalog and stocked. More complex subassemblies can often be developed by simply bolting together passive and active components from the catalog — a technique termed "smart designs." Using this approach, SAGE Millimeter developed an 8-channel FMCW ranging sensor operating at E-Band. However, if the smart design approach does not meet customer needs, the firm will modify an existing product or develop a new design. As an example, a Ka-Band transmitter assembly with antenna was developed for CubeSat and launched in July 2014.

While many applications remain military or scientific, SAGE Millimeter's customers reflect growing commercial interest. Facebook, Google and Qualcomm are the

most obvious signs of a market transition. The company serves a global market, although pays careful attention to ensure compliance with U.S. export regulations.

SAGE Millimeter designs and manufactures its products and performs all critical assembly and test operations internally, from an 18,000 sq. ft. facility in Torrance, Calif. Active components do use semiconductors from outside suppliers, carefully chosen to ensure performance and reliability. In the four years since its formation, SAGE Millimeter has delivered more than 30,000 products. Most are in the field, operating 24/7, and have demonstrated excellent field reliability.

In addition to focusing on the millimeter wave spectrum, SAGE Millimeter is building differentiation through the performance and quality of the company's products and by offering customers quick solutions. They achieve this time-to-market advantage through a base of catalog products, smart designs that enable standard components to be bolted together to create custom designs, and the engineering expertise to develop new custom designs to solve customer problems. The company's website contains more than 750 datasheets, and the "RFQ Cart" makes it easy to request a quote and see what's in stock.

Founder Yonghui Shu is optimistic about the future. "Technological advances — especially those improvements related to simulation and design tools, semiconductor device performance and consistency and manufacturing methods — have allowed millimeter wave technology to reach the final stage of maturity," he states. After decades of waiting, millimeter wave is moving from being the technology of the future to the technology of today.

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When working at the cutting edge of technology, you shouldn't waste your time with inferior tools. Rely on measuring instruments evolved in the spirit of innovation and based on industry-leading expertise. Instruments like the R&S®SMW200A vector signal generator and the R&S®FSW signal and spectrum analyzer. Each is at the crest of today's possibilities. As a team, they open up new horizons.

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Absorptive Filters

Low Pass

High Pass

Band Pass

Model AF9350



Werlatone Absorptive Filters are NON-Reflective!

Out-of-Band Signals are **NOT** reflected back to the source.

- Out-of-Band signals are **internally terminated.**
- Electrical Specifications are less susceptible to temperature change.
- Reduces the dependency of the system on the length of interconnecting cable between two non-perfect components.

Model AF10200



Werlatone Absorptive Filters Eliminate:

- Instability of power amplifiers at out-of-band frequencies.
- Excessive In-Band ripples due to out-of-band reflected energies.
- False trigger of power detector circuitry due to reflected harmonics.
- Potential damage to power amplifiers due to reflection of high power out-of-band energies.

Model	Frequen	cy (MHz)	Power	(W CW)	Insertion Loss(dB)	Rejection(dB)	VS	WR	Size
	Pass Band	Stop Band	Pass Band	Stop Band	Pass Band	Stop Band	Pass Band	Stop Band	(Inches)
AF10200	0-2.5	4.5-30	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10201	0-4.2	7.5-50	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10202	0-7	12.6-100	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10203	0-12	21-150	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10204	0-19	34-200	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10205	0-30	57-250	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10502	0-2.5	4.5-25	1,500	400	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10503	04.1	7.4-41	1,500	400	0.5	45	1.30:1	1.60:1	15 x 6.1 x 3.5
AF10504	0-6.7	12.1-67	1,500	400	0.5	45	1.30:1	1.60:1	15 x 6.1 x 3.5
AF10505	0-11	19.8-110	1,500	400	0.5	45	1.30:1	1.60:1	15 x 6.1 x 3.5
AF10506	0-18	32-180	1,500	400	0.5	45	1.30:1	1.60:1	15 x 6.1 x 3.5
AF10507	0-30	54-300	1,500	400	0.5	45	1.30	1.60:1	15 x 4.6 x 3.5
AF9673	1-2.7	3.9-32	1,200	150	0.4	50	1.40:1	1.40:1	15 x 4.6 x 3.5
AF9438	1-30	50-380	5,000	250	0.5	50	1.30:1	1.60:1	20 x 16.9 x 3.4
AF9349	10-150	270-1500	500	25	0.4	50	1.35:1	1.60:1	4.5 x 1.75 x 1.1
AF9187	10-490	850-3000	100	10	0.5	45	1.40:1	1.90:1	2.5 x 1.3 x 1
AF9350	10-500	750-3000	400	25	0.5	45	1.25:1	1.60:1	4.2 x 1.75 x 1.1
AF9960	10-500	750-3000	600	25	0.5	45	1.25:1	1.60:1	4.2 x 1.75 x 1.1
AF9680	10-520	1040-3000	160	10	0.6	60	1.25:1	1.60:1	4.2 x 1.75 x 1.1
AF9313	10-870	1700-4000	100	10	0.6	53	1.30:1	1.60:1	2.5 x 1.3 x 1



Field-Proven GaN Solutions from Qorvo



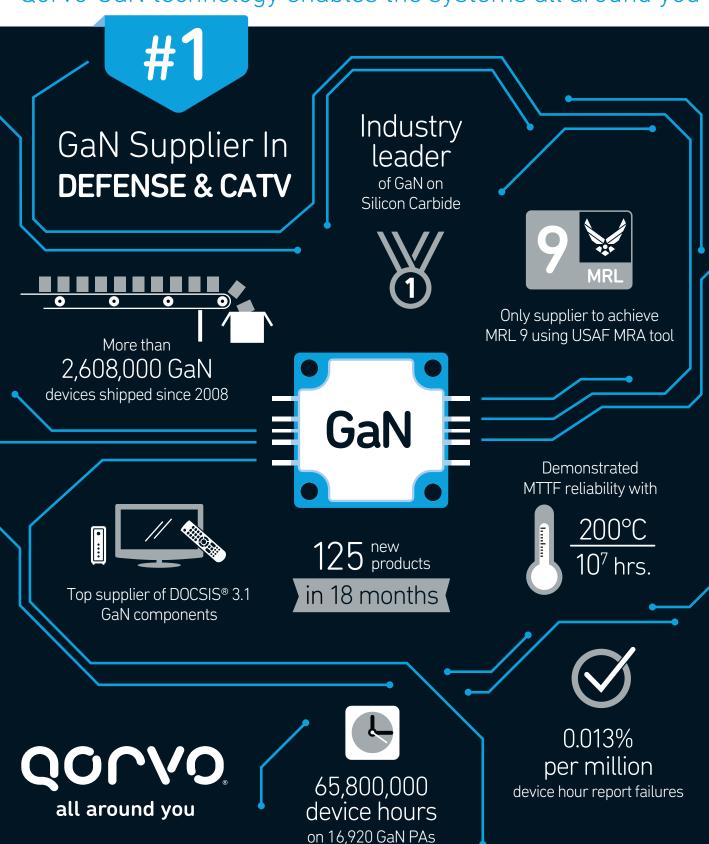






STRENGTH IN NUMBERS

Qorvo GaN technology enables the systems all around you



Gallium Nitride Innovation

Qorvo has driven innovation and development of gallium nitride (GaN) products and technologies that enable next-generation systems for over 15 years. With high-performance GaN technology supporting products from DC through Ka-band, Qorvo continues to build on a strong GaAs legacy by offering new products and strategic foundry services that strive to meet our partner's demanding system requirements. With Qorvo, not only are you getting world-class electrical performance, our partners also benefit from a 'trusted' supplier with industry-leading GaN reliability. Qorvo is also the only GaN supplier to reach manufacturing readiness level (MRL) 9. Looking for a supplier who can take your ideas from concept to production? Qorvo is expanding the possibilities.

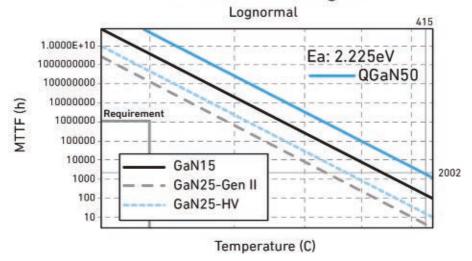
The GaN Advantage

RF power densities, made possible with GaN technology, range between five and six-times higher than gallium arsenide-based RF amplifiers. GaN technology's proven ability makes it an ideal choice for infrastructure, defense and aerospace applications such as radar, electronic warfare, communications, navigation and similar applications. This increase in performance capability offers our partners the flexibility to reduce board space and system costs while improving system performance. Only Qorvo delivers performance, quality and reliability that sets the standard for the industry.

Key Qorvo GaN attributes:

- >65 million device hours on 16,900 devices in the field, with less than 0.013% failures per million hours
- · Applications from DC through W-band
- · High power density
- Proven reliability at high junction temperatures, mean time to failure (MTTF) of greater than 10⁷ (10 million) to 10⁹ (1 billion) hours at 200 degrees (C) and greater than 10⁶ (1 million) to 10⁸ (100 million) hours at 225 degrees (C)
 - Highest power-added efficiency
 - Excellent noise figure comparable to pHEMT
- · Highly robust to ESD and RF input signals
- High RF power handling (receiver applications)
- · Very high thermal conductivity substrate

All GaN Technologies



Parametric failure is defined as a 10% degradation in Idmax*

*QGaN50 parametric failure is shown here at a
3.5% degradation in Idmax*



GaN Foundry Processes

As a DoD-accredited 'Microelectronics Trusted Source', Qorvo offers a variety of GaN custom ASIC solutions. Accreditation encompasses foundry, post-processing, packaging/assembly and test services. Support provided by our foundry services division complements Qorvo's high-frequency standard product portfolio. Qorvo services are centered upon satisfying custom requirements and can blend product and process solutions.

QGaN25:

• Technology: 0.25µm GaN on SiC

• Drain bias (Vd): up to 40V

· Operating frequencies: DC-18GHz

PAE: >60% at 10GHz

· Power density: 6W/mm at 10GHz

 Reliability: >10M hours at 200C and 40V (3-temp DC MTTF w/failure defined as 10% degradation in Idmax)

QGaN15:

• Technology: 0.15µm GaN on SiC

• Drain bias (Vd): up to 28V

· Operating frequencies: DC-40GHz

• PAE: >50% at 30GHz

Power density: 4.5W/mm at 30GHz

 Reliability: >10M hours at 200C and 28V (DC MTTF w/failure defined as 10% degradation in Idmax)

QGaN25HV:

• Technology: 0.25µm GaN on SiC

Drain bias (Vd): up to 50V

• Operating frequencies: DC-10GHz

• PAE: >78% at 3.5GHz

• Power density: 6.5W/mm at 3.5GHz

 Reliability: >10M hours at 200C and 48V (3-temp DC MTTF w/failure defined as 10% degradation in Idmax)

QGaN50:

• Technology: 0.50µm GaN on SiC

Drain bias (Vd): up to 65V

· Operating frequencies: DC-10GHz

• PAE: >80% at 3.5GHz

• Power density: 9W/mm at 3.5GHz

 Reliability: >100M hours at 200C and 65V (DC MTTF w/failure defined as 10% degradation in Idmax)

GaN Packaging Advancements

Qorvo's GaN MMICs in our unique, copper-based packages deliver superior heat transfer from the MMIC to the heat sink. These packages are much lower cost than other thermal spreaders. We also offer GaN in surface mount plastic over molded packages which provide environmental protection and ease of assembly for our customers.

GaN Standard Product Portfolio

Qorvo's proven technology leadership in high-performance gallium arsenide (GaAs) has been extended to gallium nitride (GaN). With GaN proving to be an evolutionary technology in support of next generation military and commercial applications, Qorvo is leading the way with an assortment of world class products across frequency and functionality. With a growing portfolio of GaN-based amplifiers and switches along with our expanding line of high-performance transistors, Qorvo is the premiere solution provider for your GaN needs.

Qorvo conducts extensive testing and analysis of both processes and products in order to provide the highest performance and reliability while delivering exceptional high-volume manufacturing capability. Equally important is measuring and predicting thermal behaviors. Qorvo simulates FET channel temperature using finite element analysis then verifies those models against micro-Raman measurements of the FET in order to provide accurate long term lifetime reliability data.

GaN on SiC Power Transistors

December 1999	Frequency	Linear	Psat	PAE	Voltage	Current	Package	FOON	Part
Description	(GHz)	Gain (dB)	(dBm)	(%)	(V)	(mA)	(mm)	ECCN	Number
285W, 36V, DC-2GHz	DC-2	19	54.2	54	36	576	NI-780	EAR99	T1G2028536-FL/-FS
120W, 50V, DC-3.2GHz	DC-3.2	-	51	-	50	-	Ni-360	EAR99	QPD1008/L
100W, 32V, DC-3.5GHz	DC-3.5	15	51	50	32	250	NI-360	3A001b.3.b	TGF2819-FL/-FS
100W, 28V, DC-3.5GHz	DC-3.5	15	50	55	28	260	NI-360	EAR99	TGF2929-FL/-FS
120W, 36V, DC-3.5GHz	DC-3.5	16	50.8	52	36	360	NI-360	3A001b.3.b	T1G4012036-FL/-FS
2x120W, 36V, DC-3.5GHz	DC-3.5	16	54	52	36	520	NI-650	3A001b.3.b	T1G4020036-FL/-FS
45W, 32V, DC-3.5GHz	DC-3.5	19	46.4	52	32	220	NI-360	EAR99	T1G4004532-FL/-FS
30W, 32V, DC-3.5GHz	DC-3.5	16.5	44.5	49	32	150	NI-360	EAR99	T2G4003532-FL/-FS
100W, 28V, DC-3.5GHz	DC-3.5	15	50	55	28	260	NI-360 HM	EAR99	TGF2929-HM
55W, 28V, DC-3.5GHz	DC-3.5	15	47.2	50	28	200	NI-360	EAR99	T2G4005528-FS
50V, DC-4GHz	DC-4	_	-	_	50	_	Ni-360	EAR99	QPD1015/L
5W, 32V, DC-4GHz	DC-4	19	37	68	32	25	PQFN 3x3	EAR99	TQP0102
15W, 32V, DC-4GHz	DC-4	19	43.5	64	32	70	PQFN 3x4	EAR99	TQP0103
30W, 32V, DC-4GHz	DC-4	17	44.6	64	32	60	PQFN 3x4	EAR99	TQP0104
16W, 50V, DC-4GHz	DC-4	24	42	72	50	26	PQFN 3x3	EAR99	QPD1009
8W, 50V, DC-4GHz	DC-4	25	39	70	50	18	PQFN 3x3	EAR99	QPD1010
10W, 32V, DC-6GHz	DC-6	19	40	54	32	50	QFN 5x5	EAR99	T1G6001032-SM
15W, 28V, DC-6GHz	DC-6	15.5	42.3	70	28	100	NI-200	EAR99	T2G6001528-SG
7W, 28V, DC-6GHz	DC-6	15.5	39.5	50	28	50	NI-200	EAR99	T2G6000528-Q3
18W, 28V, DC-6GHz	DC-6	15	42.5	>50	28	50	NI-200	EAR99	T2G6001528-Q3
30W, 28V, DC-6GHz	DC-6	14	45	50	28	200	NI-200	EAR99	T2G6003028-FL/-FS
12W Discrete Power	DC-12	14	41.2	54	32	50	Die	EAR99	TGF2953
27W Discrete Power	DC-12	14	44.3	54	32	100	Die	3A001b.3.b	TGF2954
40W Discrete Power	DC-12	14	46.3	54	32	150	Die	3A001b.3.b	TGF2955
55W Discrete Power	DC-12	14	47.7	54	32	200	Die	3A001b.3.b	TGF2956
70W Discrete Power	DC-12	14	48.5	52	32	250	Die	3A001b.3.b	TGF2957
5W, 32V, DC-12GHz	DC-12	13@10GHz	37	50	32	25	PQFN 3x3	EAR99	TGF2977-SM
20W, 32V, DC-12 GHz	DC-12	11@10GHz	43	50	32	100	PQFN 3x4	3A001b.3.b	TGF2978-SM
25W, 32V, DC-12GHz	DC-12	11@10GHz	44	50	32	150	PQFN 3x4	3A001b.3.b	TGF2979-SM
7W Discrete Power	DC-14	14	37.6	54	32	25	Die	EAR99	TGF2952
6W Discrete Power	DC-18	18	38	71.6	28	25-125	Die	EAR99	TGF2023-2-01
12W Discrete Power	DC-18	21	40.1	73.3	28	50-250	Die	EAR99	TGF2023-2-02
25W Discrete Power	DC-18	18	43	78.3	28	100-500	Die	3A001b.3.b	TGF2023-2-05
50W Discrete Power	DC-18	19.8	47.3	69.5	28	200-1,000	Die	3A001b.3.b	TGF2023-2-10
90W Discrete Power	DC-18	19.2	50.5	70.5	28	400-2,000	Die	3A001b.3.b	TGF2023-2-20
10W, 32V, 0.03-3GHz	0.03-3	17	39.7	51	32	50	PQFN 3x3	EAR99	TGF3015-SM
5W, 32V, 0.03-3GHz	0.03-3	17	37	50	32	30	PQFN 3x3	EAR99	TGF2965-SM
5W, 32V, 0.03-4GHz	0.03-4	17	44	55	32	65	PQFN 3x4	EAR99	TGF3021-SM
5W, 32V, 4-6GHz	0.03-4	12	44	50	32	25	PQFN 3x3	EAR99	TGF3020-SM
15W, 28V, 0.03-1.215 GHz		20	42	70	28	26	PQFN 5x6	EAR99	QPD1000
6	3.00 1.210						. 4. 11 0.00		Q. 21000

Samples/evaluation fixtures are available; call for details.

GaN & GaAs Hybrid Power Amplifier

Description	Frequency (GHz)	Gain (dB)	P5dBm	Package (mm)	ES Date	Production	ECCN	Part Number
C-Band PA	5.9-7.7	31	+40dBm	QFN 7x9	Available	Released	3A001.b.2.b.2	TGA2753-SM
C-Band PA	7.1-8.5	28	+40dBm	QFN 7x9	Available	Released	3A001.b.2.b.2	TGA2752-SM
9.5 -12GHz PA	10-11.7	30	+42dBm	QFN 8x10	Available	Q1′16	3A001.b.2.b.2	TGA2760-SM

Samples/evaluation fixtures are available; call for details.

GaN PtP Radio Power Amplifiers

Description	Frequency (GHz)	Gain (dB)	P5dBm	Package (mm)	ES Date	Production	ECCN	Part Number
Ka-Band 1W Linear PA	29-30	>25	-	6x6	Apr'16	Q4′16	_	TGA2636-SM
13/15GHz PA	12.7-15.4	>22	+40dBm at 22V	6x6	Jun'16	Q4′16	3A001.b.2.b.2	TGA2782-SM
18GHz PA	17.7-19.7	>21	+40dBm at 22V	6x6	Jul'16	Q4′16	3A001.b.2.c	TGA4548-SM
23GHz PA	21.2-23.6	>21	+40dBm at 22V	6x6	Jun'16	Q4′16	3A001.b.2.c	TGA4549-SM

Samples/evaluation fixtures are available; call for details.

GaN Power Amplifiers

	Frequency	Psat	LS Gain	PAE	Bias	Package		Part
Description	(GHz)	(dBm)	(dB)	(%)	(V/mA)	(mm)	ECCN	Number
10W Wideband PA	0.03-2.5	40	>13	55	32/360	PQFN 4x4	EAR99	QPA2237
10W Wideband PA	0.03-2.5	40	>13	55	32/360	QFN 5x5	EAR99	TGA2237-SM
10W Wideband PA	0.1-3	41	>13	>40	40/360	QFN 4x4	EAR99	TGA2976-SM
10W Wideband PA	0.1-3	41	>13	>40	40/360	QFN 5x5	EAR99	TGA2216-SM
2W Wideband Driver	2-6	32.5	14.5	>30	25/40	QFN 4x4	EAR99	TGA2597-SM
30W Wideband PA	2-6	45	22	>30	28/400	15x15 Cu Bolt Down	3A001.b.2.a	TGA2578-CP
4W Wideband PA	2-18	36	14	>15	22/600	15x15 Cu Bolt Down	3A001.b.2.c	TGA2214-CP
10W Wideband PA	2-18	40	5	25	30/500	Die	ITAR	TGA2573-2
45W Wideband PA	2.5-6	46.5	20	>36	30/1550	Flange	3A001.b.2.a	TGA2576-2-FL
12W S-Band PA	2.7-3.5	41	25	52	28/175	PQFN 5x5	EAR99	TGA2975-SM
18W S-Band PA	2.7-3.5	42.5	25	54	28/225	PQFN 5x5	EAR99	TGA2830-SM
10W S-Band PA	2.7-3.7	40.5	25	>50	25/175	QFN 5x5	EAR99	TGA2583-SM
18W S-Band PA	2.7-3.7	42.5	24.5	>50	28/225	QFN 5x5	EAR99	TGA2585-SM
30W S-Band PA	2.8-3.7	45.5	18.5	>47	28/200	PQFN 6x6	EAR99	TGA2818-SM
50W S-Band PA	2.8-3.2	47	22	58	25/200	PQFN 7x7	EAR99	QPA1000
60W S-Band PA	2.9-3.5	>48	>24	>54	28/200	PQFN 7x7	EAR99	TGA2817-SM
100W S-Band PA	3-3.6	50	23	>50	30/300	15x15 Cu Bolt Down	3A001.b.2.a	TGA2813-CP
80W S-Band PA	3.1-3.5	49.5	24.5	55	30/200	PQFN 7x7	3A001.b.2.a	TGA2814-SM
80W S-Band PA	3.1-3.6	49	22	50	30/200	15x15 Cu Bolt Down	3A001.b.2.a	TGA2814-CP
100W S-Band PA	3.1-3.6	50	24	56	30/300	PQFN 7x9	3A001.b.2.a	TGA2813-SM
50W C-Band PA	5-6	47	20	45	28/500	PQFN 6x6	3A001.b.2.b	TGA2307-SM
2W C-Band Driver	5-8	>33	>15	>34	25/50	PQFN 4x4	EAR99	TGA2599-SM
2W C/X-Band Driver	6-12	>32	20	>15	25/200	QFN 5x5	EAR99	TGA2627-SM
2W C/X-Band Driver	6-12	33	14	>25	25/100	QFN 4x4	EAR99	TGA2598-SM
30W C/X-Band PA	6-12	>45	>22	>30	20/2000	15x15 Cu Bolt Down	3A001.b.2.b	TGA2590-CP
50W X-Band PA	7.9-8.4	47	10	36	24/2240	Flange	EAR99	TGA2586-FL
50W X-Band PA	7.9-11	47	24	34	28/650	15x15 Cu Bolt Down	3A001.b.2.b	TGA2238-CP
100W X-Band PA	7.9-11	50	22	35	28/1300	15x15 Cu Bolt Down	3A001.b.2.b	TGM2635-CP
20W X-Band PA	9-10	43	25	40	28/365	QFN 7x7	3A001.b.2.b	TGA2624-SM
16W X-Band PA	9-10	>42	>27	>37	28/365	15x15 Cu Bolt Down	3A001.b.2.b	TGA2624-CP
35W X-Band PA	9-10	45.5	27.5	>42	28/290	QFN 7x7	3A001.b.2.b	TGA2622-SM
35W X-Band PA	9-10	45.5	27.5	>43	28/290	15x15 Cu Bolt Down	3A001.b.2.b	TGA2622-CP
60W X-Band HPA	9-1	48	10	38	24/2400	Flange	3A001.b.3.b	TGA2312-FL
17W X-Band PA	10-11	42.5	28	>40	28/365	15x15 Cu Bolt Down	3A001.b.2.b	TGA2625-CP
32W X-Band PA	10-11	45	27	>41	28/290	15x15 Cu Bolt Down	3A001.b.2.b	TGA2623-CP
2W Ku-Band Driver	13-18	33	20	>25	20/70	QFN 4x4	EAR99	TGA2958-SM
12W Ku-Band PA	13.4-16.5	41	23	30	28/225	QFN 5.5x4.5	3A001.b.2.c	TGA2218-SM
25W Ku-Band PA	13.4-16.5	44	28	31	28/450	15x15 Cu Bolt Down	3A001.b.2.c	TGA2219-CP
35W Ku-Band PA	13.4-15.5	45.5	25.5	>34	22/900	15x15 Cu Bolt Down	3A001.b.2.b	TGA2239-CP
20W Ku-Band HPA	14-15.35	43	19	27	25/1000	Flange	3A001.b.2.b	TGA2579-2-FL
16W Ku-Band HPA	14-16	42	18	>24	25/2000	Flange	ITAR	TGA2572-2-FL
4W Ka-Band PA	27-31	36.5	22.5	25	20/140	PQFN 7x7	3A001.b.2.c	TGA2594-HM
8W Ka-Band PA	27.5-31	39	21	>22	20/560	15x15 Cu Bolt Down	3A001.b.2.c	TGA2595-CP

Samples/evaluation fixtures are available; call for details.

GaN Low Noise Amplifiers

Description	Frequency (GHz)	Max Pin (dBm)	P1dB/IIP3 (dBm)	Gain (dB)	NF (dB)	Voltage/Current (V/mA)	Package (mm)	ECCN	Part Number
S/C-Band LNA	2-6	30	18/30	22	1	10/100	PQFN 4x4	EAR99	TGA2611-SM
Wideband LNA	2-20	40	23	15	2	8/125	QFN 4x4	EAR99	TGA2227-SM
C/X-Band LNA	6-12	33	19/28	22	2	10/100	PQFN 4x4	EAR99	TGA2612-SM

Samples/evaluation fixtures are available; call for details.

GaN Switches

Description	Frequency (GHz)	IL (dB)	ISO (dB)	P1dB (dBm)	Voltage (V)	Package (mm)	ECCN	Part Number
40W SPDT	0.5-6	<1.1	>25	46	0/-40	QFN 4x4	EAR99	TGS2354-SM
100W SPDT	0.5-6	<1.1	>40	50	0/-40	QFN 5x5	EAR99	TGS2355-SM
5W SPDT	0.5-12	<1	>30	37	0/-40	QFN 4x4	EAR99	TGS2352-2-SM
4W SPDT	0.5-18	<1.5	>25	36	0/-40	QFN 4x4	EAR99	TGS2353-2-SM

Broadband DOCSIS® 3.1 Solutions

Qorvo offers a broad family of products tailored for the next-gerneration of cable networking, DOCSIS 3.1. Qorvo's DOCSIS 3.1 family includes 1.2GHz power amplifiers as both hybrids and multi-chip modules (MCMs) that use state-of-the-art GaN HEMT process technology and offer optimal linearity and output power while providing robust reliability.

Hybrid and MCM Power Doubler Amplifiers (12-34v)

Min Freq (MHz)	Max Freq (MHz)	Power Gain	Pout (dBmV at Max Freq)	CTB (dBc)	CSO (dBc)	Vcc (V)	Current (mA)	Package (mm)	Part Number
45	1218	23	60	-80	-80	24	430	S0T-115J	RFPD2580
45	1218	23	60	-80	-80	24	430	MCM 9x8	RFCM3316
45	1218	23	67	-80	-80	24-34	540	S0T-115J	RFPD3580
45	1218	23	63	-78	-80	24	480	S0T-115J	RFPD3210
45	1218	23	63	-78	-80	24	370-470	S0T-115J	QPA3230
45	1218	23	63	-78	-80	24	470	MCM 9x8	RFCM3327
45	1218	24	65	-80	-69	28	540	MCM 9x8	QPA3590
45	1218	25	60	-75	-80	24	445	QFN 5x7	TAT9988
45	1218	25	60	-80	-80	24	430	MCM 9x8	RFCM3326
45	1218	25	60	-80	-80	24	430	S0T-115J	RFPD3190
45	1218	25	63	-78	-80	24	370-470	S0T-115J	QPA3240
45	1218	25	63	-78	-80	24	470	MCM 9x8	RFCM3328
45	1218	25	63	-78	-80	24	480	S0T-115J	RFPD3220
45	1218	28	55	-82	-80	24	420	S0T-115J	RFPD2540
45	1218	28	59	-80	-80	24	420	S0T-115J	RFPD3540

Samples/evaluation fixtures are available; call for details.

Hybrid and MCM Push Pull Amplifiers (12-24v)

Min Freq (MHz)	Max Freq (MHz)	Power Gain	Pout (dBmV at Max Freq)	CTB (dBc)	CSO (dBc)	Vcc (V)	Current (mA)	Package (mm)	Part Number
45	1218	23.5	44	-64	-70	24	230	S0T-115J	RFPP2590
45	1218	28	46	-72	-78	24	260	S0T-115J	RFPP3870
45	1218	28-32	44	-63	-75	12-24	265	S0I016W	TAT8858A1H
45	1218	28.5	46	-67	-70	12	410	MCM 11x11	RFAM3790
45	1218	28.5	46	-68	-75	24	250	MCM 11x8.5	RFCM4363
45	1218	34	46	-66	-72	24	240	S0T-115J	RFPP3180

Samples/evaluation fixtures are available; call for details.

Hybrid and MCM Reverse Amplifiers

Min Freq (MHz)	Max Freq (MHz)	Power Gain at Max Freq (dB)	NF (dB)	CTB (dBc)	CSO (dBc)	Vcc (V)	Current (mA)	Package (mm)	Part Number
5	100	38	3.8	-72	-70	24	158	S0T-115J	RFRP2920
5	100	25	3	-60	-80	5	262	SOIC8	CGR0118Z
5	200	20	2.2	-73	-70	12	355	S0T-115J	R2005200P12
5	200	24.2	1.8	-70	-70	12	355	S0T-115J	R200240P12
5	200	28.3	-70	-69	4.9	24	135	S0T-115J	R2005280L
5	200	30.3	-72	-72	4.7	24	138	S0T-115J	R2005300L
5	200	35.2	-72	-72	5	24	158	S0T-115J	R2005350L
5	200	17	4	-67	-80	5	217	SOIC8	CGR0218Z
5	220	39	3.2	-63	-60	12	205	MCM 11x11	RFCM5304
5	300	19	1.7	-70	-77	5	260	SOIC8	RFCA8830
5	300	17.5	4	-76	-80	5	215	SOIC8	RFCA1008
5	300	25	5.6	-59	-64	24	138	S0T-115J	R3005250L
5	300	30	5.3	-70	-72	24	145	S0T-115J	R3005300L
5	300	35	5.1	-70	-75	24	155	S0T-115J	RFRP3120
5	300	37	4.8	-	-	8	320	MCM 6x6	TAT3814

Samples/evaluation fixtures are available; call for details.

Optical Receivers - Hybrid and MMIC

Description	Min Freq (MHz)		Power Gain at Max Freq (dB)	EINC pA√ <i>Hz</i>		Current (mA)	Package (mm)	Part Number
Optical Receiver	45	1218	31	4.2	24	245	S0T-115J	RF0S601x (x=2,3)

Samples/evaluation fixtures are available; call for details.

MMIC Broadband Amplifiers - Push Pull (5-8V)

Description	Min Freq (MHz)		Power Gain at Max Freq (dB)	EINC pA√ <i>Hz</i>				Current (mA)	Package (mm)	Part Number
Broadband Amplifier	45	1500	17	2	-70	-72	7	220	SOIC8	RFCA8818

Samples/evaluation fixtures are available; call for details.

MMIC Broadband Amplifiers - Single Ended (5-8V)

	Description		Max Freq (MHz)	Power Gain at Max Freq (dB)						Package (mm)	Part Number
Е	Broadband PA	45	1218	22	1.5	-82	-68	5	170	SOT-89	RFCA3828

Samples/evaluation fixtures are available; call for details.

Attenuators and Switches - MMIC

Description	Min Freq (MHz)	Max Freq (MHz)	Insertion Loss (dB)	CTB (dBc)	CSO (dBc)	Vcc (V)	Attenuation Range (dB)	Package (mm)	Part Number
DSA, 0.5dB Step, Serial	5	2000	2.3	1.5	-82	5	31.5	QFN 4x4	RFSA2654
VCA	5	3000	1.5	-75	-80	5	30	QFN 3x3	RFSA3043
SPDT	5	6000	0.75	>100	>100	3	-	QFN 2x2	RFSW1012
VCA	30	3000	2.7	-65	-70	5	30	QFN 3x3	RFSA3013
VCA	30	3000	2.7	-65	-70	3.3	30	QFN 3x3	RFSA3023

Samples/evaluation fixtures are available; call for details.

