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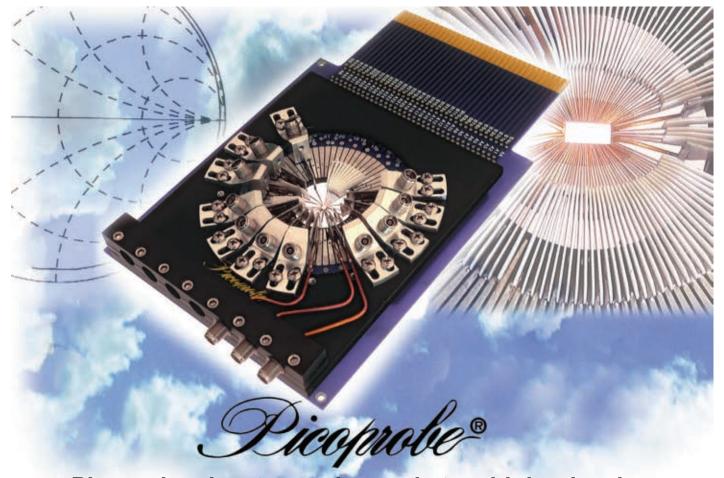
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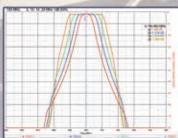
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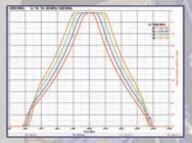
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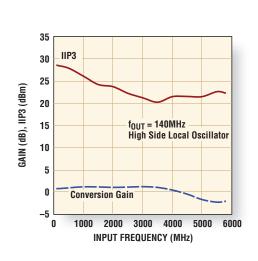
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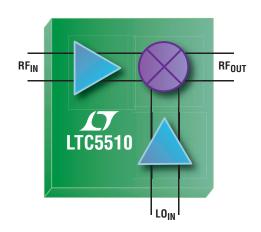
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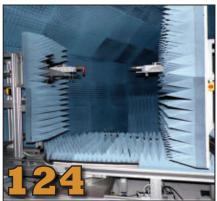
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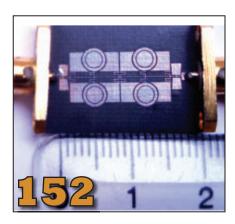
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High Frequency Performance [23 votes] (49%)

Thermal Dissipation [8 votes] (17%)

Long Term Reliability [5 votes] (11%)



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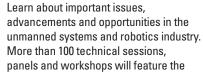




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ISPSD 2015

International Symposium on Power Semiconductor Devices and ICs

May 10–14, 2015 • Hong Kong, China www.ispsd2015.com

RFIC 2015

IEEE Radio Frequency Circuits Symposium

May 17–19, 2015 • Phoenix, Ariz. www.rfic-ieee.org

IMS 2015

IEEE MTT-S International Microwave Symposium

May 17–22, 2015 • Phoenix, Ariz. www.ims2015.org

CS ManTech 2015

May 18–21, 2015 • Scottsdale, Ariz. www.csmantech.org

Space Tech Expo 2015

May 19–21, 2015 • Long Beach, Calif. www.spacetechexpo.com

Aerospace Electrical Systems Expo 2015

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85th ARFTG Microwave Measurement Symposium

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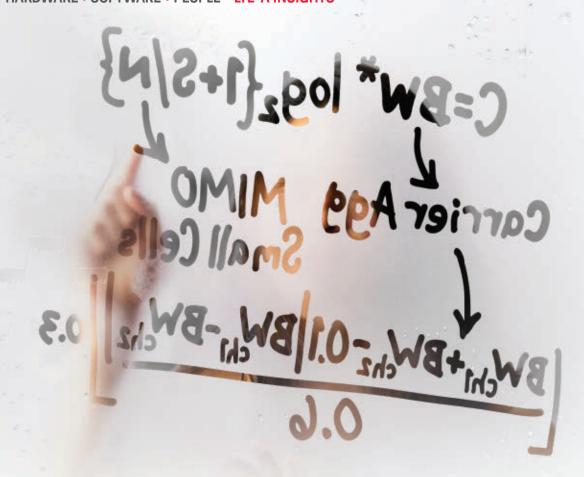
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Hay way way

Phoenix Rising



Patrick Hindle

Microwave Journal Editor

'otorola rose like the Phoenix after it moved west from Illinois to sunny Arizona in 1949. Our cover story chronicles the history of Motorola and the technology companies it has acquired and spun off over the years. An integral part of the Phoenix area, Motorola was the leading technology company and commercial employer for decades. They pioneered the first commercial radio, military radio, cathode ray TV, portable telephone, 8-bit microprocessor, cellular phone, digital cellular system (GSM) and Wi-Fi cable modem gateway. Long-time Motorola and now current Freescale employee Leonard Pelletier (aka RF Leonard), gives an insider's view of the company's culture and scientists that helped drive innovation. Read this unique view of the history of Motorola and its impact on society through the years.

Freescale Semiconductor, the most well known spin-off from Motorola, recently announced it is being acquired by NXP, as merger mania continues to dominate industry headlines. The combined RF power businesses of the companies has about 80 percent market share, so NXP plans to divest their RF power business and retain all of the businesses of Freescale. This could result in a new RF company if it is spun out from NXP or someone else could purchase it.

Everyone looks forward to IMS each year as the largest gathering of RF engineers in the industry. It is a few weeks earlier than normal this year, taking place May 17-22 in Phoenix. The opening plenary speaker, Dr. John Rogers, Professor of Materials Science & Engineer-

ing and Chemistry at the University of Illinois, Urbana-Champaign, will present his talk "Soft Assemblies of Radios, Sensors and Circuits for the Skin" on Monday from 17:30-19:00. He will discuss advanced, flexible sensors, circuits, radios and power supply systems mounted on the skin that have the potential to provide clinical-quality health monitoring capabilities. The closing ceremony speaker, Darlene J.S. Solomon, senior vice president and chief technology officer, Agilent Technologies, will discuss "The Century of Biology is Great for Engineering" on Thursday from 16:30-18:00. Many believe the 21st century will be defined as the century of biology, referring to our expanding knowledge of living systems to the point where we can develop biology-based solutions to some of the planet's largest societal challenges - healthcare, energy and the environment.

As these keynote speakers will address, radio technology and advanced packaging are enabling many future medical applications, due in large part to the expanding Internet of Things (IoT). From Smart Cities to connected appliances, IoT promises to connect the world to realize new benefits and conveniences for society. Some experts are forecasting around \$5 trillion being invested in smart cities in China by 2017. ABI research is projecting that nearly 41 billion devices will be connected to the Internet by 2020, thus advances in wireless technology will be needed to enable reduced power, increased capacity and lower latency.

These challenges promise to be addressed with 5G communication systems using technolo-

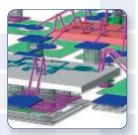
gies such as massive MIMO, software defined radios/cloud RAN, mmWave/terahertz transceivers, AESA radios, alternative modulation schemes and small cells/ HetNets. Microwave Journal is organizing a special "Path to 5G: Design and Test Challenges" panel session on Wednesday at noon in the MicroApps Theater. This special panel of industry experts will examine the challenges of device design and device/system testing for 5G technologies. Please join us on the exhibition floor and participate in the interactive discussion.

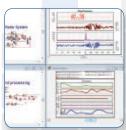
In addition to all of the regular IMS sessions, there are many interesting special sessions similar to the 5G Panel. Some of these topics include the evolution of power amplifiers, Maxwell's equations, small satellite development, energy harvesting technologies, 100 Gbps wireless technologies, THz nano electronics, mobile communications beyond 6 GHz, low noise receivers for remote sensing on small satellites, non-foster networks and adaptable front-ends for military applications. These sessions cover a wide array of new technologies and are given by experts in the field.

In this issue we also have messages from the chairs of the IMS, RFIC and ARFTG conferences who will provide an overview of each event. We also cover the exhibition with a floor map and product highlights from participating companies listed by aisle for easy reference. The exhibition floor is the best place to network and find out about the latest new products and innovations from both leading and emerging companies in our industry. See you in Phoenix!

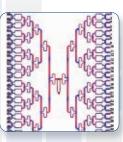


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Motorola Rises in Phoenix

Leonard Pelletier

Freescale Semiconductor, Tempe, Ariz.

n 1921, businessman Paul Galvin and his friend Edward Stewart started a storage battery factory in Marshfield, Wis. The company failed to make a profit and went out of business two years later. In 1926, Galvin and Stewart restarted their battery manufacturing company, this time in Chicago. The company built a defective product and all of the units had to be recalled, so that company went out of business too.

Galvin's third business venture started in Chicago in 1928 when, for \$750, he purchased the tools and plans for a battery eliminator at the Stewart Battery Co. bankruptcy auction. Paul and his brother Joseph incorporated Galvin Manufacturing Corp. on September 25, 1928. At the time, radio receivers for home use were all the rage and the radio sets ran on very expensive, heavy and messy batteries. The Galvins wanted to solve that, so they went to work manufacturing "battery eliminators," which

were basically AC-to-DC power supplies that enabled consumers to plug battery-operated radios into their home's AC electrical system. One of their first customers, Sears, Roebuck and Co., sold the battery eliminators to consumers through mail order catalogs.

In 1930, Galvin Manufacturing introduced the Motorola radio, one of the first

commercially successful car radios. These one-way radio receivers were used by consumers, public safety departments and municipalities. By the 1940s, Galvin Manufacturing had evolved into America's premier maker of radios for car and home use (see *Figure 1*). At the same time, the company's expertise in two-way radio systems was growing.¹

When World War II broke out, Galvin Manufacturing provided two-way radios for the military, including the 1940 U.S. Army Signal Corps' "Handie-Talkie" SCR536 AM handheld two-way radio, and, in 1943, the "Walkie-Talkie" SCR300, the world's first FM portable two-way radio (see *Figure 2*). Galvin Manufacturing also prospered through government contracts for early airplane radar detection systems.

FROM GALVIN MANUFACTURING CORP. TO MOTOROLA

Galvin Manufacturing Corp. went public in 1943 with the sale of 40,000 shares at \$8.50 per share. All the products the company sold, except military radios, carried the name "Motorola." This included automotive radios, home radios and two-way radios for public safety, fire and industrial use.

The name "Motorola" is a portmanteau of the words "Motor" for motorcar and "ola" for sound, as in Victrola. In the 1930s, "ola" was a common suffix widely used in the radio business. There were



Fig. 1 An early version of a pre-war Motorola home radio.

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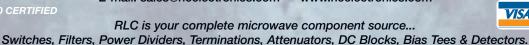


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many companies and brands that ended in 'ola. The Motorola brand was meant to imply "sound in motion." The brand was so successful that in 1947, Galvin Manufacturing changed its name to Motorola and set up a profit-sharing plan for employees. The company also began making television sets in addition to radios for both car and home use.²

GALVIN HIRES A VISIONARY

It's safe to say that Motorola would never have become as influential in the world of RF communications without hiring Dr. Daniel E. Noble (see *Figure 3*). Dr. Noble came to Galvin Manufacturing with a wealth of RF knowledge and was a true visionary. While teaching at Connecticut State College, he was the designer,

builder, operator and manager of the Connecticut State College ra-

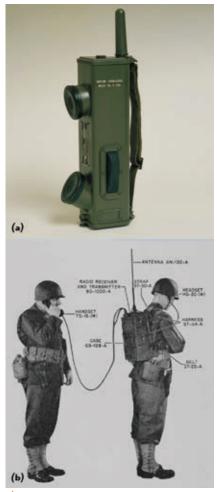


Fig. 2 The SCR536 AM portable twoway radio weighed only 5 lbs with a 1 mile broadcast range (a) and the SCR300 weighed 35 lb with a 20 mile range (b).



▲ Fig. 3 Dr. Daniel E. Noble in front of the R&D building on 56th Street in 1952. He is holding an electronic golf ball locating device.

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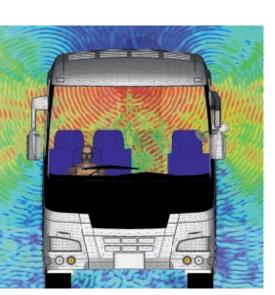
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dio broadcasting station. He later branched out, making various radio relay stations, and eventually built one of the first commercial FM broadcast stations.

In 1940, Dr. Noble created the first two-way police radio system for the entire state of Connecticut, which became the first practical mobile two-way FM radio system in the world. This breakthrough

achievement attracted the attention of Paul Galvin, who offered Noble the position of director of research at Motorola.³

DR. NOBLE TAKES MOTOROLA TO PHOENIX

Dr. Noble set into motion what was to be the beginning of Motorola's semiconductor work and would eventually lead to the es-

tablishment of the Semiconductor Products Sector (SPS) - the manufacturing arm for the semiconductor components consumed by other equipment and system manufacturing divisions of the company. After World War II, at the urging of the United States government, large corporations were encouraged to decentralize and move away from major metropolitan areas (in an attempt to reduce the potential for nuclear targets within concentrated areas). In 1949, Dr. Noble was tasked with setting up a solid-state electronics research laboratory for Motorola in Phoenix, Ariz. only two years after the first public announcement of the discovery of the transistor by Bell Labs.

Convincing Dr. Noble to move to Phoenix did not take a lot of arm twisting. He loved horseback riding and the thought of being within a few hours drive to the Grand Canyon. He also needed the drier air to help relieve his asthma. So Dr. Noble enthusiastically made the cross-country move, even though others in the company called the endeavor "Noble's folly."

Expanding into the nascent semiconductor business was a risky move for the company. There was the question if the company's internal consumption would ever be large enough to achieve semiconductor manufacturing economies of scale, so the early decision was to sell the components to other equipment manufacturers, even if they were direct competitors.⁴

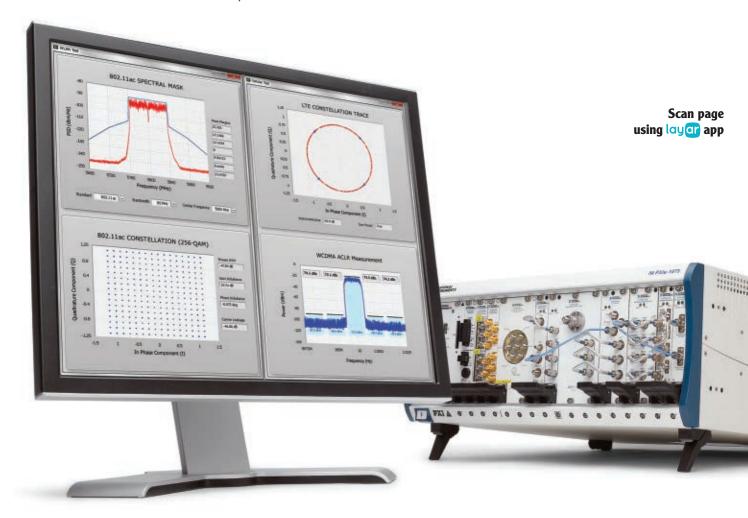
The original research lab was a rented building on Central Avenue, which was the temporary location until the headquarters building was constructed on 56th Street. Eventually, the team expanded and outgrew the 56th Street location, so a manufacturing building was constructed at the 5005 East McDowell location that is now the home of ON Semiconductor.

In 1955, Dr. Bill Taylor succeeded in developing the world's first commercially-available high power, germanium transistor for car radios, 2N176 (see



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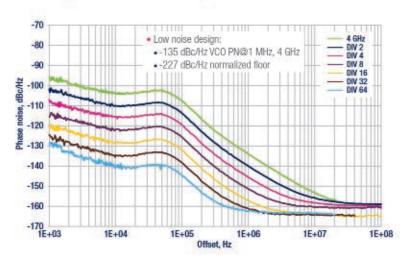
Figure 4). This was the product that launched Motorola's Semiconductor Products Sector (SPS) manufacturing in Phoenix. Large scale 2N176 transistor production began in 1956, and by January 1957 over one million of these devices had been manufactured. This represented 50 percent of the power transistors made by all of the transistor manufactur-

ing companies at that time. The initial cost for the 2N176 was \$26, but Motorola's economies of scale and manufacturing expertise lowered the cost to \$2 by 1960. The enormous success of this and other transistor products established Motorola as a major semiconductor manufacturer, and production of the 2N176 lasted well into the 1960s, until cheaper silicon tech-

nology surpassed germanium. The 2N176 used the hermetic TO-3 package style pioneered by Motorola, which helped to establish the JEDEC TO packaging standards.⁵

The external sales of components on the open market allowed SPS to grow and become a very profitable division for the company. In later years, it would be the SPS division that became a "cash cow," sometimes providing over half of the company's revenue and fueling investment in R&D in the other equipment divisions.

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In the 1960s, Motorola expanded its product lines with guided missile designs, space communications, radios for ships and aircraft, components and integrated circuits for TV sets, car ignitions



▲ Fig. 4 The 2N176 germanium transistor was rated at 6 A, 15 V, 90 W, 4 kHz, 90°C Tj max. It was the audio amplifier in a car's AM radio.



The Batwing Logo is Born!

The Motorola "emsignia" (a play on the letter M and the correct word, insignia) "batwing" logo was created in 1955, and the Motorola "signature" logo was replaced with the Motorola block font lettering logo. The "emsignia's" two triangle peaks "typified the progressive leadership-minded outlook of the company at that time." These logos still exist today, making the Motorola logos two of the longest running corporate logos in existence.9

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All of these new equipment and systems needed semiconductors for growth and technology advancement. Phoenix-based SPS was tasked with creating these components. In the 1960s, Motorola's RF power products group succeeded in creating the world's first solid-state VHF land mobile two-way radio with germanium RF power transistors. Many consider the Motorola Transistorized Advanced Communications (MOTRAC) radios to be the best

transistorized two-way radio new product introduction campaigns in history, and the radios were wildly successful (see Figure 5). The MOTRAC family was seen on "Adam-12," "Dragnet," "Emergency" and many other police shows of the era. The group's RF power transistors were also used in one of the first car telephone systems, the TLD-1100 "MJ."

Motorola demonstrated world's first portable cellular phone and system in 1973. In the 1980s, after Bob Galvin showed one to President Ronald Rea-



Fig. 5 Faceplate and microphone of the MOTRAC land mobile radio, an early version of the TLD-1100 radio telephone.



Fig. 6 Dr. Martin Cooper, who led the Motorola team that developed the cellular phone, holds a DynaTAC prototype.

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gan, the White House supported open competition for portable phones instead of an AT&T monopoly. In 1983, the FCC approved the world's first commercial cell phone, the Motorola DynaTAC (see *Figure 6*). Motorola later dominated the cell phone hardware business for years. Until the introduction of the iPhone, the Motorola RAZR was the best-selling

phone in the U.S. market, and to this day is the best-selling clamshell phone in the world. In just four years, Motorola's RAZR sold over 130 million units.

In January 2011, Motorola split into two separate companies, each still using the Batwing logo and each using the word Motorola as part of their name. Motorola Solutions is the last remaining in-

dependent division of the original Motorola and is based in Schaumburg, Ill. The company concentrates on police technologies, radios and commercial needs. The spin-off, originally based in Libertyville, Ill. and later in Chicago, was named Motorola Mobility and produced cellular phones. Motorola Mobility's core business revolved around the design of wireless handsets, and also licensed its intellectual property: cellular and wireless systems, integrated applications and Bluetooth accessories.6

In August 2011, Google announced that it would purchase Motorola Mobility for \$12.5 billion; the deal was completed by May 2012. The acquisition was a strategic move envisioned to strengthen Google's patent portfolio. At the time, Motorola had over 17,000 patents, with 7,500 additional patents pending, the most for cellular communication or handset operation. The expanded portfolio was used to defend the Android operating system, the subject of numerous patent infringement lawsuits between the various handset manufacturers. Google had tried to purchase the bankrupt remains of former cellular giant Nortel Networks Corp., for a similarly large patent portfolio, but it was rebuffed.

In October 2014, Google sold off the Motorola Mobility division to the Lenovo Group for \$2.91 billion. Google maintains ownership of the vast majority of the Motorola Mobility patent portfolio but licensed Lenovo to use this rich portfolio of patents and other intellectual property. Additionally, the Lenovo Group received over 2,000 patent assets, as well as the Motorola Mobility brand and trademark portfolio. The Beijing-based company has over 33,000 employees and approximately \$39 billion in annual sales. In 2014, it became the largest vendor of smartphones in mainland China and sold over 10 million Motorola branded smartphones in Q4 of 2014.

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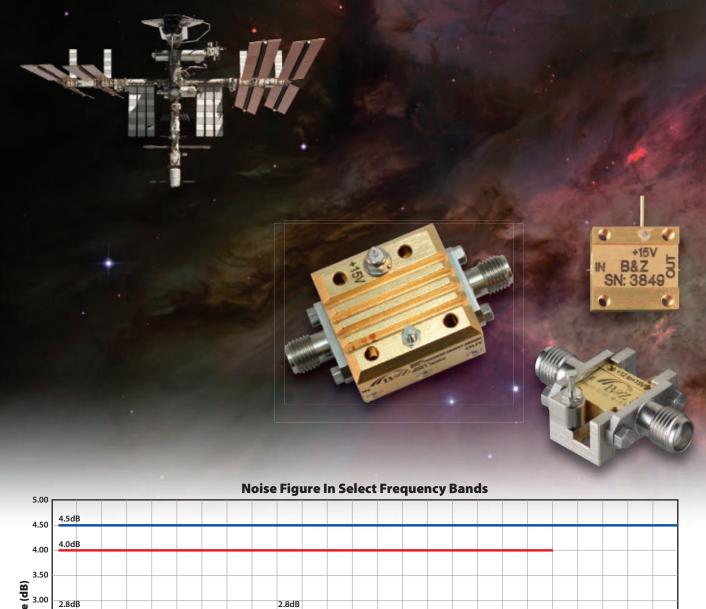
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products, analog and digital twoway radios and accompanying software and networks, and voice and data communications products based on long-term evolution (LTE). In addition, the company provides a wide variety of services and smart public safety solutions that help first responders better predict and manage events using the wide variety of informa-

tion now available from the public. The company has over 15,000 employees and approximately \$5.9 billion in annual sales.

SIX SIGMA AND MOTOROLA'S MALCOLM BALDRIGE AWARD

In the mid 1980s, President Ronald Reagan sought to strengthen the U.S. economy in the face of a world with increasing competi-

tion, especially coming from the Japanese. President Reagan, along with U.S. business leaders, felt that a renewed emphasis on worldclass quality was necessary for U.S. businesses to thrive in a world with ever increasing quantities of high technology trade goods. So Congress passed and the President signed H.R. 812, the Malcolm Baldrige National Quality Improvement Act of 1987. The act established an awards program to provide special recognition for companies demonstrating high achievement in improving the quality of their goods or services.

Motorola did not require the Malcolm Baldrige National Improvement Act of 1987 to spur them towards superior quality. The company was already well on its way. In 1986, Motorola set a goal of "Six Sigma" quality for all of its manufacturing operations. Towards this goal, they established in-house training sessions and trained blackbelt quality (and statistical) experts to assist in troubleshooting difficult manufacturing processes. Motorola was one of the inaugural winners of the Malcolm Baldrige National Quality Award in 1988 for its high ranking in quality products and for developing the Six Sigma manufacturing process. Motorola was also one of only six two-time winners when it won again in 2002. The Six Sigma quality process, statistical based manufacturing process, new employee training procedures and black-belt employee status still thrive at Motorola Solutions and in many of the various company spinoff organizations.

BUILDING A LOYAL WORKFORCE

Motorola set the standard for establishing a "respect for the employee" culture, and the nickname of their company was "Mother Moto." Once hired, an employee had a job until retirement, with regular promotions occurring every few years and a regular return on net assets (RONA) bonus at year's end, based on the company's profitability. The company had a very generous retiree health



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care plan, such that if one met "the rule of 75" (age plus years of employment), one could retire with very affordable health care coverage. There are thousands of people on this plan now and thousands of people expecting to enjoy the benefits of this plan in the future.

The company was on the cutting edge of building employee loyalty

in a host of ways. Salaries were competitive yet never exceptionally high. It was the excellent benefits, the challenging work projects and the worker camaraderie that attracted people to the company. Groundbreaking offerings included Motorola University, a policy where employees were expected to enhance their skills by taking at least 40 hours of continuing educa-

tion classes per year. It was not uncommon to have 10, 20 and even 30 year veterans working on the same team. Longevity and loyalty were strongly rewarded, and employees stuck around.

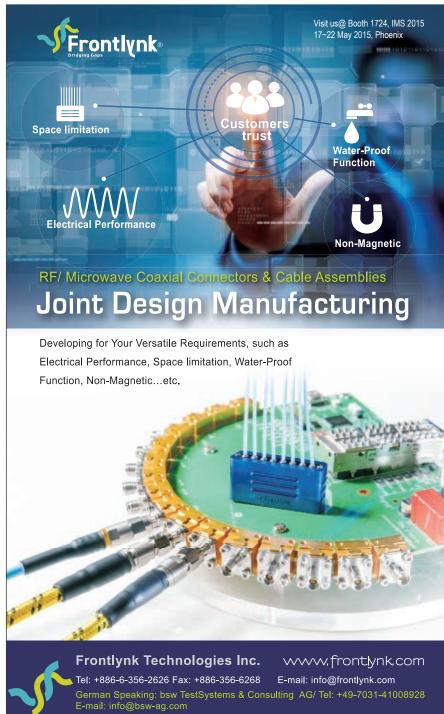
You've Been Galvinized!

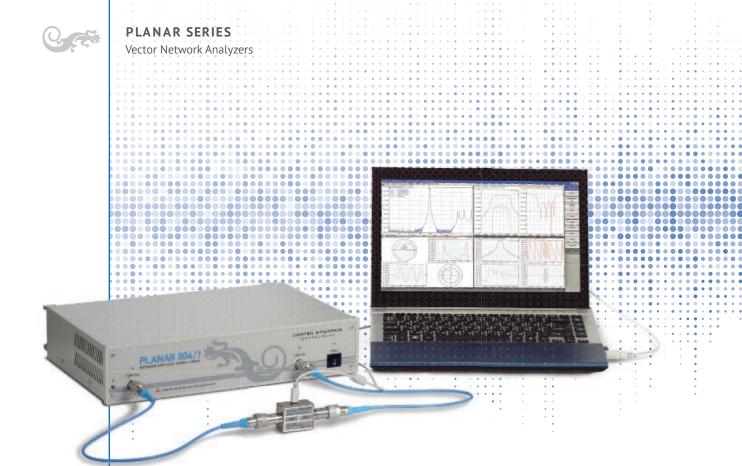
There was a term for people who passed their 10 year anniversary with the company. After ten years, the expectation was that that employee could not be fired or laid off without a direct written order by CEO Bob Galvin. These 10 year veterans were "Galvinized" and therefore could take greater risks and go after new markets without the fear of failure and firing. It is a play on the word galvanized, a protective zinc coating used on steel. The zinc coating becomes the sacrificial anode and dissolves before the underlying steel is damaged.⁷

THE SPIN-OFFS

Little did Dr. Noble know what the long-term impact of moving Motorola's semiconductor development arm on the employment footprint of Maricopa County would be. Because of his need for a drier climate and love of horseback riding, the Phoenix area is now a hot-bed of high tech development. Over the years, Motorola has created and spun off several successful companies that are still very much alive and successful in the Phoenix valley. Here we highlight some of the more significant businesses that can trace their roots to humble Motorola beginnings.

The Iridium Satellite communication concept was conceived by Bary Bertiger, Dr. Ray Leopold and Ken Peterson in late 1987. The rumor at the time was that one of these Motorola engineers was vacationing in Rocky Point, Mexico, (south of Phoenix) and was disappointed with the lack of cell coverage. The cellular telephone industry was just beginning and tower coverage was very spotty in most places outside of the core cities. The thinking was why not build a communications network based on





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satellites rather than cell towers?

The technology was created and the patents issued in 1988, but the final system was not fully operational until 1998 – at which time cell tower coverage was much better and cell phone subscription rates much cheaper. Iridium handsets were priced around \$3,000 at a time when most consumers would get a free cell phone just by

signing a three-year contract. Talk time was \$9 a minute, when cellular was offering unlimited talk, text and messaging for around \$50 a month.

Motorola spent over \$5 billion to create the system and it was sold in 1999 to Iridium Satellite for a token price of only \$25 million, including the headquarters building in Tempe, Ariz. In its

nine months of operation, there were only 50,000 subscribers and the company needed 200,000 to break even. At the time, this fiasco was named one of the biggest business disasters of the decade, and it was a significant contributor to the eventual downsizing of Motorola.

Iridium Satellite refocused its sales efforts on international companies and the U.S. military and today does a large business on machine-to-machine data transfers on remote equipment. Technically, its headquarters are in McLean, Va., but the commercial communications gateway and the engineering, marketing, and product development operations are in Tempe. The company has over 725,000 subscribers and approximately \$430 million in annual sales.

The first Motorola Semiconductor Products Sector spin off was ON Semiconductor in 1999. Motorola wanted to divest itself of the highly cyclical semiconductor business, so it split SPS into two groups, based roughly on their product technologies. Motorola held on to the more profitable business units that were working with integrated circuits (IC), microprocessors, digital signal processors and high-end logic chips. ON Semiconductor got the discrete components such as diodes, transistors, Zeners and standard TTL logic. The new company was headquartered in Phoenix at the 5005 East McDowell and 52nd Street complex, a manufacturing site that had been developed by Motorola in the early 1950s. Many long-term Motorola employees who were told their jobs were being transferred to ON Semiconductor quit on the spot and handed in their badges. Motorola kept the highly profitable RF power products division, even though most of its products were three leaded, discrete FETs and transistors. This eventual Freescale RF business unit was transferred out of the 52nd Street location and into its present home at 2100 E. Elliot, in Tempe. ON Semiconductor has



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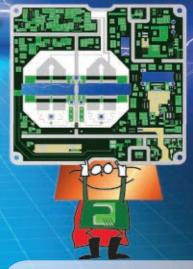
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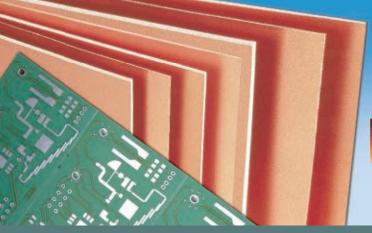
- High dielectric constant
- Low loss
- High thermal conductivity
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approximately \$2.4 billion in annual sales.

Motorola had a large business unit called the Government Electronics Group, which was located on the corner of McDowell and Hayden in Scottsdale. It specialized in producing radio communications, radar, weapons and other advanced electronics systems for government agencies and the military. At one time, the division employed over 7,500. In August 2001, after a few years of highly cyclical variations in the volume of business. Motorola agreed to sell the unit to General Dynamics for \$825 million. At the time, the division had 3,000 employees and \$850 million in sales. General Dynamics still operates the business and is now one of the largest employ-

ers in the Phoenix area. General Dynamics does not break out their sales figures by individual business units, but the company employs over 95,000 people worldwide and has approximately \$31 billion in annual sales.

Motorola announced to its employees on October 16, 2003, that it would spin-off the remaining semiconductor business with an IPO, creating a new company named Freescale Semiconductor. more long-term Motorola employees quit on the spot and handed in their badges. Motorola paid a lot of money to a marketing firm to come up with the name, the flying tiles logo called the "Momentum" mark and the corporate color pallet, which includes the standard orange and yellow colors seen today. The name Freescale is a spin on a mountain climbing term, free climbing, which means free from aid on the way up but with rope protection in place to prevent failure. The IPO was completed on July 16, 2004.

Freescale designs and produces embedded hardware and software for the automotive, networking, industrial and consumer markets. Its product portfolio includes microprocessors, microcontrollers, analog, sensors and RF power products. The company also offers software development tools to support product design and development. Freescale's current patent portfolio includes approximately 6,100 patent families. The headquarters are in Austin, Texas with design, research and development, manufacturing and sales operations in more than 75 locations in 19 countries. The company employs over 17,000 people worldwide and has approximately \$4.6 billion in annual sales. Freescale's RF, analog and sensors businesses are still based in Tempe.

Motorola has always had a very strong emphasis on radio communication and the business units here in the "valley of the sun" have always been a strong contributor in RF power transistors. The original Motorola RF power products group was the first to make the high power RF transistors that enabled the first solid-state land mobile radios.



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Dynamic Range (BW=10Hz,dB,typ)	120	120	120	120	120	120	115	115	100	100	60
Dynamic Range (BW=10Hz,dB,min)	100	100	100	100	100	100	100	100	80	80	40
Magnitude Stability	0.15	0.15	0.15	0.15	0.25	0.25	0.3	0.3	0.5	0.8	1
Phase Stability (±deg)	2	2	2	2	4	4	6	6	8	10	15
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THE TRW ACQUISITION AND EARLY CELLULAR BUSINESS

In the late 1980s, there were only about five serious RF power transistor vendors; Motorola, TRW, M/A-COM PHI, Philips (now NXP) and Acrian. Motorola had about a 35 percent market share, TRW about 15 percent and MSC about 10 percent of the overall RF power transistor market. Mo-

torola bought the TRW RF division in 1988. A recession drove several competitors out of the business, leaving Motorola with a 60 percent market share in the early 1990s. Motorola purchased TRW to gain market share, acquire talented RF engineers and access the higher frequency microwave business. Back then, Motorola dominated the market below 500 MHz in the

land mobile market and TRW dominated above 1 GHz. There were these new things called GSM cellular telephones that were taking off in Europe at 960 MHz. That initial leverage in the cellular infrastructure business was the key start for the eventual Freescale RF success. In the early 1990s, about 40 percent of the RF division's personnel were ex-TRW employees.8

CONVERSION FROM BIPOLAR TO LDMOS FETS, 1993-1999

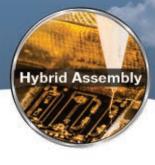
One of the key developments in enabling significant cost reduction in cellular infrastructure equipment was the development of the LDMOS FET between 1991 and 1993. The first AMPS and NAMPS base stations used Class C, common base bipolar transistors in a single channel, one amplifier per carrier design with a cavity combiner and dual stage output isolators to prevent reverse injected intermodulation distortion. They were horribly inefficient and had one amplifier per carrier, which limited capacity. AT&T developed the single stage feedforward base station with Class AB, common emitter TRW bipolar devices. However AT&T struggled with linearity as the back off IMD hump of the Class AB parts was only about -35 dBc. Motorola solved this dilemma by creating the dual stage feedforward design, but losses in the output delay lines (typically 10 meters of coax looped on the back of the frame) made the overall AC to RF conversion efficiencies 10 to 20 percent. LDMOS FETs solved this issue by having back-off IMD humps in the -45 dBc range, enabling the single loop feedforward system to meet the linearity specs. An additional benefit is that the off-state impedance of the LDMOS FETs is relatively high compared to that of the bipolar devices, enabling Doherty circuit configurations. In just a few short years, virtually all of base station power amplifiers were converted from bipolar to LDMOS. Figure 7 shows the block diagram for the feedforward design and typical performance. It shows the typical



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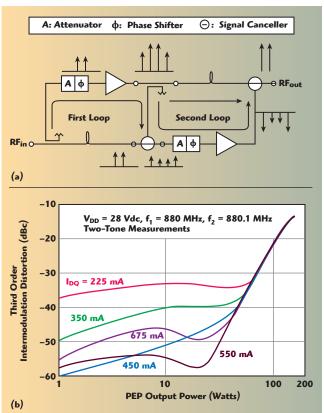
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▲ Fig. 7 Single stage, feed forward amplifier block diagram (a), and linearity performance (b).

LDMOS Class AB back-off IMD humps for various bias conditions. This part shows a -55 dB hump at $8\,\mathrm{W}$ Pout and $550\,\mathrm{mA}$ bias.

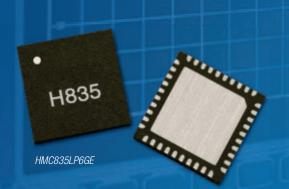
For the past 25 years and running, Motorola, and now the Freescale RF business unit, has enjoyed the number one market share position in high power RF transistors for cellular infrastructure. The business unit employs roughly 300 people at the Tempe operations site. Sales grew 57 percent in 2014 to approximately \$550 million.

CONCLUSION

Motorola has a long and glorious history of influence on many businesses in the Phoenix area. At its zenith in 1998, Motorola employed 150,000 people worldwide and over 20,000 in Arizona. In 2000, its annual sales peaked at approximately \$38 billion, and it was the largest private employer in Arizona. Many businesses that still remain in Arizona and elsewhere owe their existence to Motorola and the strong business culture. The total 2014 sales of all the spin-offs (and the whole of General Dynamics) total over \$39 billion (not adjusted for inflation), slightly larger than when they were all grouped together under the Motorola corporate umbrella. Working at Motorola was not a cult, but there were certain traditions, rules and requirements that made it a very unique place to work.

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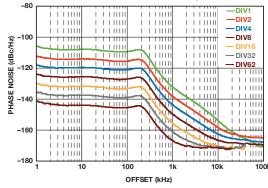
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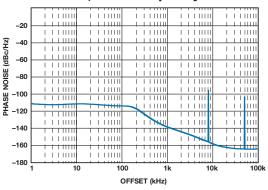
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HMC830LP6GE	25 to 3000	Wideband PLL and VCO	-114 dBc/Hz @ 2 GHz	-141 dBc/Hz @ 2 GHz	+6	159	0.114 @ 2 GHz
HMC832LP6GE	25 to 3000	Wideband RF VCO (+3.3 V)	-114 dBc/Hz @ 2 GHz	-139 dBc/Hz @ 2 GHz	+7	159	0.114 @ 2 GHz
HMC833LP6GE	25 to 6000	Wideband PLL and VCO	-114 dBc/Hz @ 2 GHz	-141 dBc/Hz @ 2 GHz	-4	159	0.11 @ 2 GHz
HMC834LP6GE	45 to 1050, 1400 to 2100, 2800 to 4200, 5600 to 8400	Wideband PLL and VCO	−108 dBc/Hz @ 4 GHz	−134 dBc/Hz @ 4 GHz	+5, +2, +2, -10	159	0.23 @ 4 GHz
HMC835LP6GE	33 to 4100	Wideband PLL and VCO	-105 dBc/Hz @ 4 GHz	-133 dBc/Hz @ 4 GHz	+7	160	0.23 @ 4 GHz





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Leonard Pelletier is a senior member of the Technical Staff and an application support manager for Freescale RF in Tempe, Ariz. and he is in charge of providing technical assistance to the amplifier design community. He is a senior member of technical staff and the marketing representative for the internal Change Action board. He is an ex-TRW employee and has been with the company since 1987 and working in his current position since 1995. Prior to his work with RF components, Pelletier held amplifier design engineering positions with the Motorola

Cellular Infrastructure Group in Arlington Heights, Ill. and the Motorola RF Products Division in Torrance, Calif., all positions involving cellular infrastructure active device communications products. Pelletier has been with the same company for 28 years, where he's been part of three company name changes, three state relocations, plus five city changes and numerous building and office location changes. Pelletier received a BSEE from Cal Poly, Pomona, Calif. in 1983 and an MBA from Pepperdine University, Malibu, Calif. in 1988. He is also a state registered professional engineer in the State of California and has been working in the high power RF arena since 1983.

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- Personal interview on 2-12-2015 with Bob Keasler, retired, 46 years as a TRW/Motorola/Freescale Manager.
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ANOTHER CHAPTER BEGINS

Editor's Note: On the eve of this year's Mobile World Congress, NXP announced that it will acquire Freescale Semiconductor, paying \$11.8 billion in stock and cash for Freescale's \$4.6 billion in 2014 revenue. Rick Clemmer, NXP's CEO and president, will remain CEO and president of the combined entity. NXP made no announcement of any role for Gregg Lowe, Freescale's CEO and president.

Freescale and NXP are the #1 and #2 players in the LDMOS RF power transistor market; combined, they would dwarf #3 Infineon. To avoid likely regulatory issues, Clemmer told investment analysts that NXP will retain Freescale's RF segment and sell their own high performance RF (HPRF) business before the Freescale acquisition closes.

Although the Freescale brand and corporate entity seem likely to disappear, the DNA of Motorola's Semiconductor Products Sector will live on at NXP.

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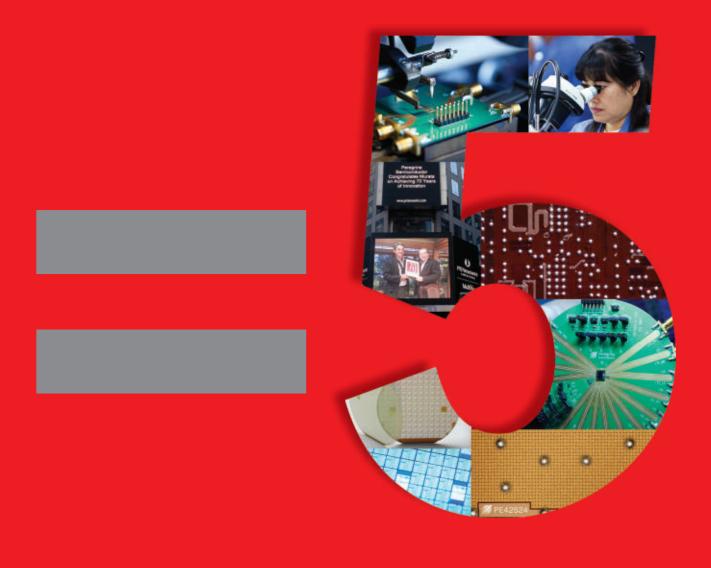
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To address today's market requirements, National Instruments is introducing a series of banded frequency synthesizer modules based on its existing industry-leading QuickSyn microwave synthesizers. Integrating QuickSyn technology with frequency multipliers and amplifiers, provides a unique solution covering the popular frequency bands (i.e., 27 to 40 GHz, 50 to 67 GHz and 76 to 82 GHz). The new QuickSyn mmWave synthesizer modules offer an unmatched combination of fast-switching speed, low phase-noise performance and medium power consumption in a compact format.

These new offerings present a very cost-effective solution for applications requiring a stable and clean CW mmWave source.

Phase Matrix (now NI Microwave Components) first introduced the revolutionary QuickSyn technology in 2010 with its full-featured QuickSyn synthesizers covering 100 MHz to 10 GHz and 200 MHz to 20 GHz (Models FSW-0010 and FSW-0020 respectively). These industry-first modules-with their variety of features and functions including AM, FM and pulse modulation, SPI and USB control interfacessatisfied a major market need and are a popular choice among RF/microwave engineers around the world. Then in 2013, NI Microwave Components introduced the "lite" version of the synthesizers, featuring fixed-power CW covering 650 MHz to 10 GHz and 650 MHz to 20 GHz (models FSL-0010 and FSL-0020 respectively). The QuickSyn Lite synthesizers, like the full-featured synthesizers, employ phase-refining technology based on fundamental VCOs up to 20 GHz. QuickSyn technology enables instrumentgrade spectral purity, 100 µs switching speed from any frequency to another frequency within the covered range, and reduced susceptibility to microphonic vibration. In addition, the use of advanced direct digital synthesis (DDS) enables a very fine frequency resolution of 0.001 Hz without the common penalty of elevated spurs.

All QuickSyn synthesizers use a highly stable internal TCXO that is factory calibrated to a GPS standard to ensure adequate accuracy and long-term stability (better than I ppm) of the synthesized signal. The synthesizer modules can also supply the same stable 10 MHz reference signal to the outside world. The internal oscillator can be locked to an external 10 MHz reference as well.



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While the full-featured Quicksyn sources offer signal modulation and power control, the QuickSyn Lite versions provide a fixed power CW signal.

The new QuickSyn mmWave synthesizer modules use a frequency multiplier module that is designed to mount on top of a standard QuickSyn Lite module, extending the frequency range to mmWave. These new modules are powered and controlled by the same +12 V supply of the base 20 GHz

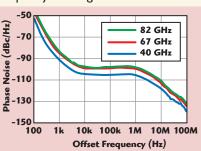
module, making integration and control simple for the user. The RF input of the frequency extender is also provided by the Quicksyn base module, and like the standard QuickSyn, these new mmWave sources include serial SPI and USB control interfaces and are immediately deployable by connecting them to a PC and a DC power source. A soft front panel allows the user to access frequency control and frequency sweep plus 32K-point LIST mode settings. Ad-

ditionally, embedded firmware enables these modules to be used as part of integrated auto test solutions.

The modules are designed to supply medium power output in the three popular bands. Care has been taken to minimize sub-harmonics and spurious. In addition to being used as local oscillators in a frequency-converter application, the QuickSyn mmWave modules can easily be used as reference-calibration frequency sources. Also, because of their fast-tuning and high-resolution capabilities, the Quick-Syn mmWave modules are ideal for characterizing antennas, semiconductor devices and other components requiring acquisition of large amounts of data in a short time.

QuickSyn Model FSL-2740 provides frequency coverage from 27 to 40 GHz with a minimum output power of +17 dBm and instrument-grade phase noise performance of -105 dBc/ Hz at 100 kHz offset and an RF frequency of 40 GHz as shown in Figure 1. The FSL-2740 module can be used for Ka-Band satellite communications applications as well as in wideband. high data rate applications between 28 to 31 GHz. With undesirable spurious products driven below 60 dBc (see Figure 2), the FSL-2740 performs well in backhaul digital radio applications, which utilize the high-end of Ka-Band. In addition, a coaxial 2.92 mm connector is used for RF output.

QuickSyn Model FSL-5067 provides frequency coverage from 50 to 67 GHz



📤 Fig. 1 Phase noise performance.

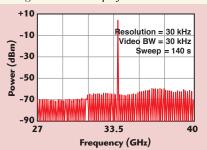


Fig. 2 FSL-2740 spectral performance.





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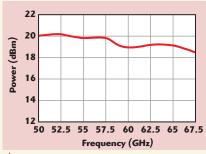


Fig. 3 Typical power vs. frequency performance.

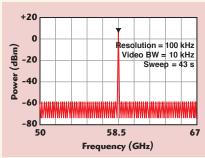


Fig. 4 FSL-5067 spectral performance. **PHASE STABLE** Semi-Rigid Cable Assemblies Are we on **your** radar? Electrical Length Change as a Function of Temperature Temperature (deg C) Phase Track® SR Excellent Stability Developed for applications where ✓ No "Teflon knee" effect typically

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with a minimum output power of +17 dBm. Figure 3 shows typical power vs. frequency performance while Figure 2 shows the FSL-5067 phase-noise performance of -101 dBc/Hz at a 100 kHz offset and an RF frequency of 67 GHz. The FSL-5067 has excellent spectral performance as shown in Figure 4, with in-band spurious products below 60 dBc at 58.5 GHz. Sub-harmonics are better than 40 dBc. The FSL-5067 is designed to support commercial applications in the license-free 57 to 64 GHz band in the U.S. as well as the 60 to 66 GHz band in Japan and Europe. Common applications within this band are in point-to-point as well as point-to-multipoint, including wireless HDMI, WiGig, IEEE802.11ad, wireless gigabit Ethernet and point-topoint high-speed data links with I to 2 km wavelength. The FSL-5067 uses a coaxial 1.85 mm connector for RF output.

The QuickSyn Model FSL-7682 covers 76 to 82 GHz with a minimum power output of +10 dBm. Figure 1 shows the FSL-7682 low phase-noise performance of -99 dBc/Hz at 100 kHz offset and an RF frequency of 82 GHz. In-band spurious and sub-harmonics are guaranteed to -60 and -40 dBc respectively. The FSL-7682 is the lowcost source for the bourgeoning field of automotive radar. Millimeter wave radars are a key part of the currently deployed narrowband, long-range radar (LRR) sensors used for collision avoidance applications. Expanding applications within the automotive field include assisted driving and driverless technology require wider bandwidths up to 81 GHz, making the FSL-7682 an attractive choice for design engineers. The FSL-7682 uses a WR I2 waveguide interface for RF output.

QuickSyn technology not only allows excellent performance, increased functionality and small size, it is inherently cost effective, greatly contributing to the product line's popularity. QuickSyn Lite synthesizers start at below \$4,000, and the new QuickSyn mmWave synthesizers are also remarkably affordable and will serve well in many mmWave applications for a variety of industries.

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The Quest for More Good Units per Hour

David Park VP of Worldwide Marketing, Optimal+, Israel

ver the past decade, the importance of RF-based systems on a chip (SoC) has grown significantly, following the exponential growth of wireless electronic devices in virtually all industry segments. Today, semiconductor companies are manufacturing billions of RF devices

that are shipped inside of consumer, industrial and military products. The performance of the RF functionality within these SoCs is now considered just as important to the success of that SoC in the marketplace as the performance of the processor cores and memories.

One of the benefits of following in

the footsteps of semiconductor processors and memories is that the RF industry can leverage the accumulated knowledge of manufacturing best practices from earlier semiconductor products. One such area is adopting a better way to measure yield and production productivity: good units per hour. Good units per hour measures the number of quality semiconductor chips produced and shipped each hour. The more shipped, the better the margins.

BIG DATA ACCESS AND ANALYSIS IS KEY

How can companies balance yield, quality and productivity to produce more good units per hour? Accessing and analyzing real time "big data" on the manufacturing floor is the key.

Each business unit in a global semiconductor company is charged with meeting specific and unique goals. For manufacturing, yield is a key metric; for product planning, the number of good die shipped to paying customers is what matters; the finance department's main goal is to minimize the cost of goods sold to maximize margins and company profitability. With each operational unit singularly focused on its individual goal, communication across units is often irregular and sometimes nonexistent. Business units are rarely housed in the same building - often they are on different continents - and meet only once a quarter to discuss business goals. The data from business units is typically siloed and not accessible to other business units.

With infrequent communication between departments and compartmentalized data, how can companies bridge this information gap to align goals and deliver more good units per hour? Analyzing manufacturing data that is tracked, validated and monitored by all the key parties in near real time is the secret to aligning goals for quality, yield and productivity. For example, analyzing test data can identify weaknesses in the test process and areas for improvement that will simultaneously increase product yield and equipment utilization. While automated test equipment delivers millions of data points each day, extracting actionable decisions from the data is difficult to accomplish without a big data solution.

Traditionally, a significant time lag – up to 60 days – separated when a chip was tested on the manufacturing floor and when the test data was avail-

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able to the product or quality engineers responsible for the device. Manufacturing problems found in the data were acted upon long after the devices left the manufacturing floor. Chips that might have been recovered to increase yield were lost, and chips of poor or unknown quality were often shipped.

Big data solutions enable the consolidation of test data from multiple facilities, whether internal or outsourced, into a single database. Yield and productivity data are easily compared, providing a check on quality. Seeing which facility is achieving the best performance motivates capacity improvement across the entire test fleet (see *Figure 1*). Adopting good die per hour as a metric aligns the entire semiconductor organization – engineering, operations and finance – and delivers higher quality to customers.

EARLY ERROR DETECTION AND INTERVENTION

Before the advent of big data solutions in test, errors (whether equipment, human or operational) were largely unresolved by manufacturing operations. The time to find manufacturing issues and the large volume of data were prohibitive. Test engineers were traditionally forced to

Tester	Product (Operation)	Total Units	Yield	First Pass Yield	Resort Utilization Impact (Time)	Run Rate (UPH)	Good Test Time (Secs)	Gross Test Time (Secs)	Actual Test Time (Hrs)	Optimized Test Time (Hrs)	Excessive Time (Hrs)
76	VA41	1,086	96.32%	94.84%	3.27%	220.83	34.699	17,704	4.918	4.918	0.000
54	VA41	30,340	97.33%	93.01%	6.35%	219.05	34.231	498,628	138.507	137.391	1.116
42	VA41	19,527	96.93%	91.41%	8.23%	218.02	34.650	322,436	89.565	88.425	1.140
52	VA41	35,509	96.60%	91.56%	8.10%	212.80	34.711	600,715	166.866	160.798	6.068
44	VA41	18,545	96.63%	95.32%	3.31%	186.44	37.348	358,090	99.469	83.979	15.490
60	VA41	14,257	97.64%	90.10%	14.71%	169.21	34.570	303,316	84.256	64.561	19.695
66	VA41	16,619	95.31%	92.35%	7.69%	104.16	36.626	574,381	159.553	75.257	84.296
									·		
	Totals	135,883							743.134	615.328	127.805
								Potential	Throughput In	provement	20.8%

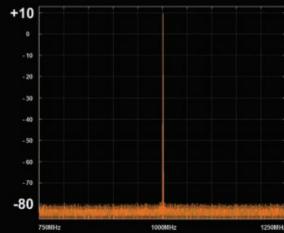
🔺 Fig. 1 If all testers of product VA41 ran as efficiently as Tester 76, throughput could be increased by over 20 percent.

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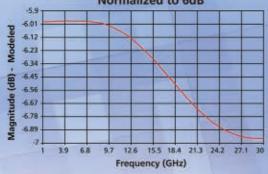


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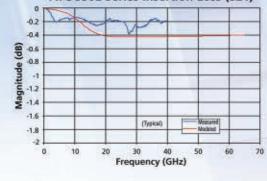
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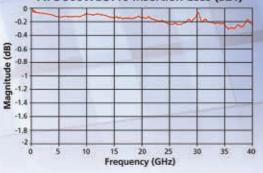
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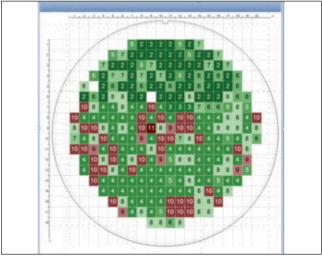


Fig. 2 Companies can monitor the number of times good die has been probed and quarantine any die that has been probed more than "n" times.

spend too many hours defining test limits and determining the correct test automation. Now, big data solutions automate and simplify manual processes through rule-based algorithms and analytic capabilities, making it possible to identify incorrect or broad test limits that are essentially meaningless. By establishing common test rules and algorithms within the data itself, operations teams can optimize the test limits for each test procedure in wafer sort or final test – dramatically increasing productivity.

Equipment failure is a daily problem. Undetected by operations, rare anomalies can occur, resulting in unreliable test results. For example, a tester instrument can "freeze", repeating the same measurement value for multiple parts, or it may skip some of the required tests. Without performing 100 percent of the tests on 100 percent of the die, chips are labeled "bad" in the sort test and have no opportunity for retesting at final test. In other cases, perfectly good chips are discarded because of incomplete or faulty test results caused by human or environmental factors. The potential for test escapes, allowing bad chips to proceed after test, is an even bigger issue: a bad die may pass because of insufficient testing, risking a future product recall.

Operational problems, such as probing too many times and ruining die integrity, can also be detected in real time (see *Figure 2*). Other benefits of rules-based big data solutions include setting tester limits so that each die is tested within the appropriate parameters and temperatures. Using relaxed limits or only optimal temperatures, bad die will pass through to assembly and final test, hurting product quality. Analyzing test data in real time can identify and quickly resolve a problem before it reduces yield, quality or productivity (see *Figure 3*).

What practices can companies use to maximize good die per hour? By analyzing high-quality, comprehensive and consistent data from all the manufacturing operations, engineers can establish rules based on proven best practices that will minimize test time and maximize results. Quick fixes include setting bin limits to realize yield



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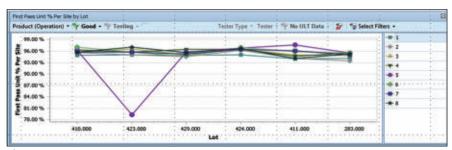


Fig. 3 Yield loss due to probe card issues is a common occurrence. Identifying the problem early allows the issue to be resolved quickly, resulting in improved yield.

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momentum. Maximizing the allocation of prober cards and testers, operations can set specific test rules and limits across the company's global manufacturing supply chain.

TRACKING GOOD DIE PER HOUR AND PREVENTING ESCAPES

Semiconductor companies use several methods and metrics to track good die. Unfortunately, the common measure of defective parts per million (DPPM) is measured after shipment. Companies have few opportunities to track die quality in test and assembly unless they can access real time data from the testers. Test escapes are a key concern, especially for companies in the automotive industry where escapes can have serious consequences. No company wants to deliver a defective chip that is used in an anti-lock braking (ABS) system.

A key benefit to leveraging big data in manufacturing is applying lean and Six Sigma principles to inline testing. By looking at outlier die and applying statistical methodologies, operations can determine if seemingly good die are imposters. Chances are, if a good die is in a bad neighborhood, the likelihood of the die being viable is slim. This is where the chip's individual DNA can be scrutinized through wafer sort, assembly and final test to determine its true quality.

The ultimate benefit of deploying big data solutions in test comes from accessing and analyzing all available data from the operations floor. This is the key to marrying the goals of yield, quality and productivity and ultimately producing more good die per hour. When all units of a business are working together and using the same data, improvements at every level provide huge dividends. Whether it's preventing escapes, reducing test time or determining the likelihood of bin recovery (see *Figure 4*), big data solutions provide real time, datadriven information that helps business units work together and consistently and predictably deliver more good units per hour.

Over the past few years, many of the world's largest semiconductor companies have deployed big data solutions in their manufacturing operations. This enabled them to pinpoint test program issues, develop



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	HB55\SB860	HB55\SB860	2B5-080300-02	0.00 %	96.56 %	1 1,	,515
	HB41\SB433	HB41\SB433	285-080300-02	0.00 %	7.83 %	1,	,480
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Fig. 4 Test analytics clearly show that the current retest plan has NO IMPACT on yield recovery, resulting in higher test time and test costs with no benefit.

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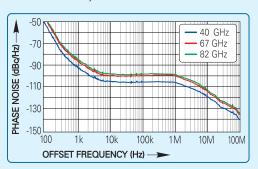
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An Invitation to Experience IMS2015







Vijay Nair IMS2015 General Chair Steve Goodnick IMS2015 Vice-Chair

t is our pleasure to invite you to experience IMS2015, May 17-22, 2015 in Phoenix, Ariz. The IMS2015 steering committee, consisting of over 75 volunteers, is very excited to host IMS for a second time in Phoenix.

Our mission is to provide a rich attendee experience by creating and fostering a forum for presenting state-of-the-art technical papers on RF and microwave related topics, exhibiting the latest products and technology solutions and networking with peers.

Microwave Week is comprised of three conferences. The International Microwave Symposium will begin on Sunday, May 17 with workshops and short courses. The RFIC Symposium begins Sunday evening, with a primary focus on RFIC design, RFIC circuits, system engineering and RF testing. The IMS technical paper presentation and industry exhibition will be held Tuesday through Thursday. For the first time at IMS2015, a one day RF

Boot Camp will teach RF basics to graduate students and young engineers as well as demonstrate the use of test instruments for modeling and characterization of RF components. Microwave Week will conclude on Friday with IMS workshops and the Automatic RF Techniques Group (ARFTG) Conference. ARFTG covers RF and microwave test and measurement techniques. Visit rfic2015.org, ims2015.org and arftg.org for more information on each respective conference.

In addition to the traditional tracks, IMS2015 will feature discussions on emerging RF and wireless related growth areas such as wearable electronics, Internet of Things (IoT), RF/microwave technology in life science and 5G. Opening plenary speaker, Professor John Rogers, University of Illinois Urbana-Champaign, will introduce wearable electronics with a talk entitled "Soft Assemblies of Radios, Sensors and Circuits for the Skin." The wearable electronics theme

is further highlighted throughout the conference with a special panel session on Tuesday and a Wearable Electronics Pavilion on the exhibition floor. Closing ceremony speaker, Dr. Darlene J.S. Solomon, senior vice president and chief technology officer for Agilent Technologies, will discuss RF and microwave technology needs in the life sciences.

In addition, 17-year-old Joseph Hudy is scheduled to give an inspirational talk. Hudy, a Phoenix high school student, amazed President Obama with his Extreme Marshmallow Cannon at the White House Science Fair in February 2012, when Hudy was only 14. Hudy has been recognized by *Business Insider* as one of the smartest kids in the world.

Seven focused programs to promote student participation and diversity will be taking place this year. The student paper contest, student design competition, Ph.D. student initiative and the



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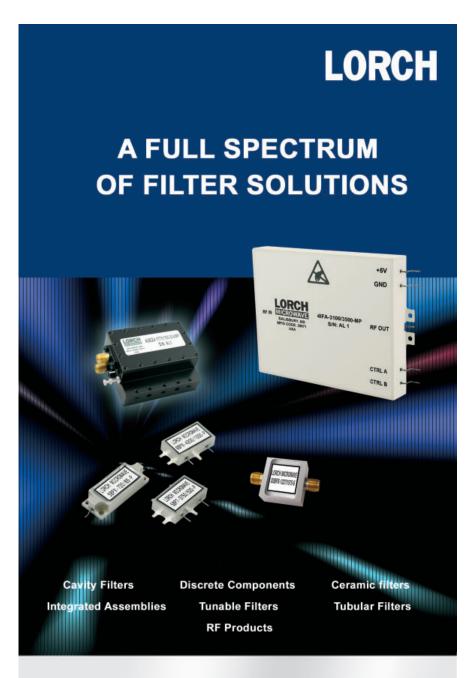




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'IMS Connect' programs are designed to increase college graduate participation at the conference. The 'IMS Connect' program aims to encourage participation of students from underrepresented minorities in the International Microwave Symposium and better prepare them for careers in science and engineering.

The IMS2015 Women in Microwave team has organized a focused session and a panel session this year. Leading professionals practicing RF and microwave technologies will be presenting papers during this session. It will be followed by a panel session discussing "Diversity in Microwaves – Let's Talk about the Demographics!"

Additionally, two more programs for middle and high school students interested in science and engineering will take place on Thursday. The IMS STEM (Science, Technology, Engineering and Math) program will introduce students to the field of microwave and technology engineering through a STEM-focused "day at a conference" experience. The second program is the High School Student Science and Engineering Invitational. The goal is to showcase the high school science and engineering talent of students in the metropolitan Phoenix area. This one-day event will include opportunities to showcase students' science fair projects, interact with engineers and graduate students and provide a conference experience.

To enrich the attendee experience further, ample opportunities to interact with peers and exhibitors are 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.

The IMS2015 steering committee has put together a superb program for you and is looking forward to your participation in making this conference a huge success!









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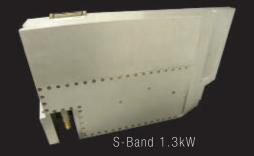
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	DM-HPS-35-101	2.2	2.5	20	40	35%	CW	28	4.0 x 4.00 x 1.00
5	DM-HPC-60-101	5.5	8.5	50	50	25%	CW	28	2.5 x 2.75 x 0.45
ATCOM	DM-HPX-100-105	9.75	10.25	50	100	30%	CW	28	7.4 x 4.30 x 1.65
AT	DM-HPKU-40-105	13.75	14.5	45	50	20%	CW	24	4.5 x 4.00 x 0.78
Ŝ	DM-HPKU-40-101	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
4	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
E.	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
쀭	DM-HPLS-50-101	1	3	50	50	30%	CW	45	4.3 x 3.50 x 0.45
FA	DM-HPLS-160-101	1	3	16	160	25%	CW	45	6.3 x 6.00 x 0.78
ECTRONIC WARFARE	DM-HPSC-50-101	2	6	50	50	30%	CW	28	2.5 x 2.75 x 0.45
٥	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 SE	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
3	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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RFIC 2015 Welcome Message







Bertan Bakkaloglu RFIC 2015 General Chair Albert Wang Technical Program Chair Kevin Kobayashi Technical Program Co-Chair

re invite you to participate in the 2015 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium in Phoenix, Ariz., May 17-19, 2015. RFIC Symposium is the premier IC design conference focused exclusively on the latest developments in RF, microwave and millimeter wave integrated circuit technology, and high frequency analog/mixed-signal design and innovation.

RFIC Symposium, the International Microwave Symposium (IMS), ARFTG and the IMS industry exhibition make up "Microwave Week," the largest worldwide RF/microwave event of the year. Come to Microwave Week to learn from the world's experts through a wide variety of technical sessions, interactive forums, panel sessions, workshops, short courses, industrial exhibits, application seminars and historical exhibits. Share your knowledge with others by presenting your latest results. Expand your network. Catch up with old friends and colleagues. Return home invigorated with new ideas and enthusiasm.

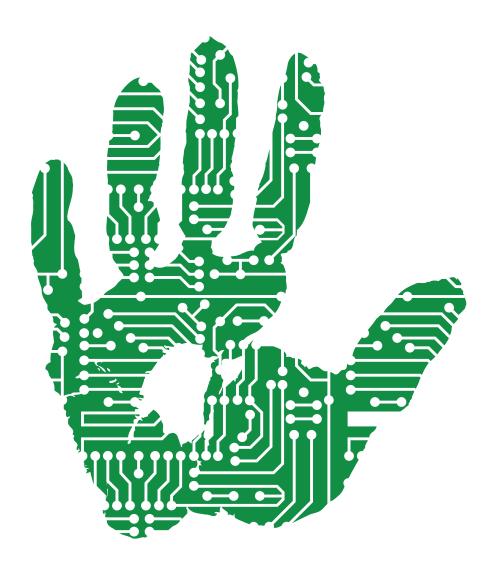
RFIC Symposium will continue to offer a number of initiatives specifically geared towards the RFIC industry. The two-page industry brief format, which was introduced in 2015, allows the latest state-of-the-art RF IC design

results to be presented, without requiring die photos and detailed schematics (as required in fulllength, four-page, submissions), and will be continued in 2015. The most innovative and highly-rated industrial papers, both two- and four-page, will be invited to present a poster (and optional demo) at a special Industry Showcase Session to be held during the popular evening RFIC Reception on Sunday, May 17. As a new initiative in 2015, there will be a Best Industry Paper Award that will be selected from the industry showcase papers and presented during the RFIC Plenary Session.

To enhance academic submission experiences, all of the RFIC student paper finalists will now receive complimentary RFIC registration. In addition, the lead authors of the top three student papers will receive a \$500 honorarium along with special recognition at the RFIC Plenary Session, where these awards will be announced. Students can also volunteer to help with RFIC (and/or IMS) conference logistics in exchange for complimentary conference registration, meals, t-shirts and other benefits. First and second-year RFIC Ph.D. students may also participate in the Ph.D. Student Sponsorship Initiative Program, joint with IMS. This program, established and sponsored by the

MTT-S administrative committee, aims to engage these Ph.D. students in the conference by having them complete technical assignments during the conference and report on them later in the week. Sponsorship includes complimentary conference registrations (RFIC and IMS), lodging and meals.

The Plenary Session will be held Sunday evening at the Phoenix Convention Center. It will begin with conference highlights, followed by the presentation of the Student Paper Awards and the inaugural Industry Best Paper Award. The Plenary continues with two outstanding keynote talks, given by two renowned leaders in the RF/microwave community. The first speaker is Prof. Siegel of Jet Propulsion Laboratories who founded and led the Submillimeter Wave Advanced Technology (SWAT) Research center for 25 years. His talk is entitled "From THz Imaging to Millimeter Wave Stimulation of Neurons: Is There a Killer Application for High Frequency RF in the Medical Community?" The second speaker is Dr. Hermann Eul, corporate vice president and general manager of the Mobile and Communications Group at Intel Corp. Dr. Eul leads a worldwide organization focused on the development of hardware, soft-



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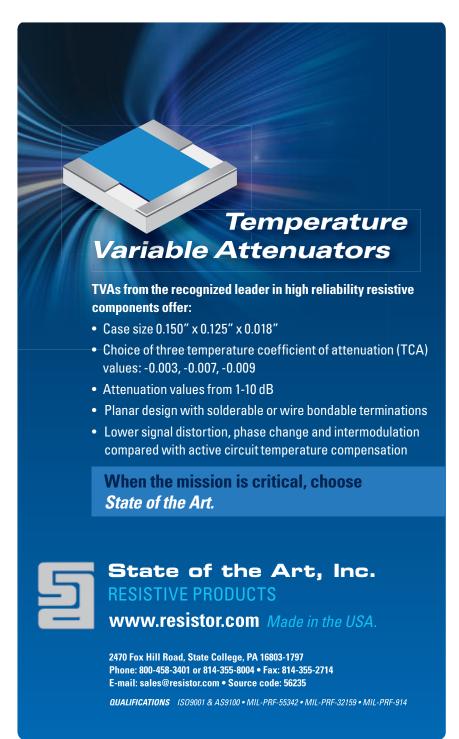
ware and connectivity ingredients for phones, tablets, UltrabookTM and other mobile devices as well as complete system solutions. The title of his talk will be "RF as the Differentiator." Be sure not to miss these engaging presentations!

Immediately following the Plenary Session is the Industry Showcase Session embedded in the RFIC Reception, providing a mix of "hot chips" and cold drinks. You won't want to miss the RFIC Reception!

The conference lineup will include one half-day workshop and 10 full-day workshops, six of which will be co-sponsored by IMS. One

tional joint RFIC/IMS workshops will be held on Monday. RFIC and RFIC/IMS joint workshops cover a wide array of topics with presentations from experts in their respective fields, and historically have been highly attended and well received. This year's workshops cover some of the hottest topics in RFIC designs. A number of workshops focus on power amplifier (PA) and high efficient transmitter design, including "Digital and Analog Techniques for Power-Efficiency Enhancement in Wireless Transmitters," "Mixed-Signal Power Amplifiers and RF-DAC," and "Application of Waveform Engineering in Design of High Power Doherty PAs." Two workshops focus on improving radio performance in the ever crowding spectrum, "RF Interference Mitigation Techniques" and "Tunable RF Filtering and Matching for Compact Antenna Interface; Technologies for Tunable and Reconfigurable RF/Microwave Filters." One workshop covers frequency generation, "Highly Efficient RF Frequency Generation in Nanometer CMOS Technologies." Topics covering next generation mmWave applications and design include "Next Generation 77 to 81 GHz Automotive Radars," "mmWave to THz, Which Applications with Which Technology," "Terahertz-Wave Wireless Communications, Enabling 5G mmWave Circuits and Systems,""Towards 5G: MIMO and Beamforming Techniques," and "Emerging and Silicon Technologies for Bio-sensing from RF to mmWave Frequencies." On the device and packaging side, topics cover "Nanopackaging: Multifunctional Nanomaterials and Devices towards 3D System Miniaturization." "Performance Metrics for mmWave Devices," and "Circuits from the Perspective of the International Technology Roadmap for Semiconductors (ITRS)." A new topic added this year, covers "Multi-Gbps Wireline Transceivers: Inching Closer to RF/mmWave IC Domain." Anoth-

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er new topic covers the increasing applications of the Internet of Things (IoT), "Micro and Nanowatt Smart RF Transceiver ICs for Internet of Things."

Technical papers will be presented during oral sessions throughout Monday and Tuesday mornings, followed by the RFIC Interactive Forum Tuesday afternoon. The Interactive Forum features papers presented in poster format, giving the attendees a chance to speak directly with the authors.

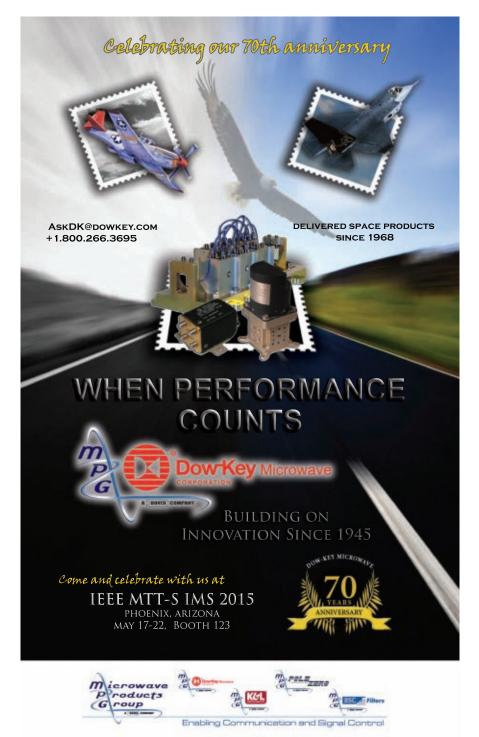
The conference will feature Panel Sessions during lunchtime on Monday and Tuesday. We have

two "sizzling" topics this year that are sure to spark lively debates among the panelists and audience. The first RFIC Panel Session is entitled "Research is Expensive, But Innovation Sells" and will debate the intricacies of how to successfully (or not!) conduct research in the industry, manage cost and resources, deal with the treacherous path from innovation to product, survive commoditization and succeed in IP protection. Directors and VPs from some of the most prestigious industry research labs in the world will share their views and opinions with the audience. The second Panel Session is entitled "Internet of Things: Hype or Boom to Come?" This panel brings together experts from across a wide range of industries, discussing the end user benefits, market opportunities, technical challenges and projected solutions for devices supporting Internet of Things (IoT). Will IoT be just an evolution of current connected devices or a real revolution? Come to the panel session to find out!

Phoenix offers a unique and exciting experience for everyone. Phoenix is America's fifth largest city in the heart of the Sonoran Desert, and is the gateway to the Grand Canyon. Phoenix offers a spectrum encompassing red-rock buttes and urban sophistication. The Heard Museum features Native American art and culture and the Phoenix Art Museum houses more than 17,000 works of classic and modern art. The artistic tapestry in Phoenix includes Native American, Hispanic, African and Asian influences. There are three mountains around Phoenix that provide the opportunity for hiking, biking and climbing. Horseback riding and water recreation are also popular.

On behalf of the entire RFIC Steering Committee, we would like to extend you all a warm welcome to the 2015 RFIC Symposium. We are looking forward to an exciting program and hope you can join us in Phoenix, Ariz.!

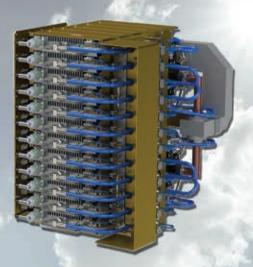
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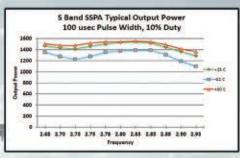
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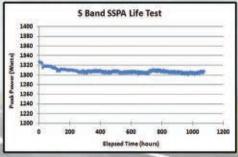
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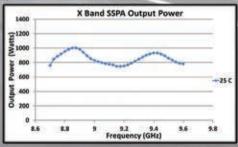
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Measurements and Techniques for 5G Applications



David Blackham 85th ARFTG General Chair

elcome to the 85th Automatic RF Techniques Group (ARFTG) Microwave Measurement Conference being held at the Phoenix Hyatt Regency Hotel on Friday, May 22, 2015. The Friday conference schedule includes two invited talks. In the morning session Kate Remley of NIST will present a talk entitled "Measurements for Millimeter Wave 5G Wireless Systems: Increased Frequency, Increased Bandwidth, Increased Calibration." In the afternoon Moray Rumney will present "5G Measurement Challenges." The program contains 14 additional talks and 16 interactive forum papers in areas of current measurement interest. The interactive forum is co-located with the vendor exhibits over extended breaks allowing much more space for interaction.

The contributed conference papers range from practical methods and techniques to cutting

edge research on measurement technology. Topics will include nonlinear measurement systems, calibration issues, 5G measurement issues, and other areas of RF and microwave measurement.

Your ARFTG conference registration also includes access to the Nonlinear Vector Network Analyzer (NVNA) Users' Forum and a one year membership in ARFTG. The NVNA Users' Forum is an informal discussion group devoted to sharing information and issues related to instrumentation utilized in vector large-signal analysis of microwave circuits and systems. This event is open to all ARFTG, IMS and RFIC attendees.

Consider also registering for the ARFTG co-sponsored workshop: "Direct Extraction of FET Circuit Models from Microwave and Baseband Large-Signal Measurements for Model-Based Microwave Power Amplifier Design." This is a full day workshop scheduled for Monday, May 18, 2015.

No better opportunity is available to interact with vendors, experts and colleagues in the RF and microwave test and measurement community. Ask questions, propose collaboration or simply learn from the experiences being discussed. ARFTG's two annual conferences are well-known for this unique opportunity and welcoming environment. Starting with breakfast and continuing through the exhibition interactive forum and luncheon, there will be ample opportunity for discussion with others facing similar challenges. Attendees find that these interactions are often the best source of ideas and information for their current and future projects.

Full details of the technical program and of the conference are available at www.arftg.org. ARFTG conference registration is available through the IMS website at www.ims2015.org. ■

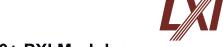
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IMS2015 MicroApps Special Panel Session

Path to 5G: Design and Test Challenges Wednesday, May 20, 12:00-1:00 p.m., MicroApps Theater

Patrick Hindle

Microwave Journal *Editor*

was the word at Mobile World Congress this year as many companies are now including demos in their booths. One interesting example was China Mobile's tile approach to 5G where they are using transceiver "tiles" (currently 2 channels but going to 8 soon) in an array that can be shaped to blend into the environment and produce massive MIMO arrays. They plan to deploy these "tiles" on the sides of buildings and other structures and can even arrange them in the shape of Chinese characters, as shown in the demo. To view the demo from this year's Mobile World Congress, visit www.mwjournal.com/ChinaMobile5G.

There is a lot of controversy in discussing the future of 5G since it is not yet defined. With planned deployment starting in 2020, most agree that the goals are up to 10 Gbps data rate to the users, 1000× the bandwidth per unit area, connection capacity for billons of devices (for IoT), 1 msec latency and a large reduction in energy use. Of course, high reliability and better coverage are also expected. But will we need

that kind of performance for every application and how practical is it to have this kind of performance?

Like last year at IMS, Microwave Journal is organizing a 5G panel session called "Path to 5G: Design and Test Challenges." This special panel session will take place Wednesday, May 20 in the MicroApps Theater (Booth 3147) from 12:00-1:00 p.m. on the exhibition floor. This panel of industry experts will examine the challenges to device design and device/system testing for 5G technologies such mmWave/TeraHertz as transceivers, massive MIMO, HetNets/small cells, CoMP, carrier aggregation, AESA radios, SDR, new modulation schemes, reduced power consumption and other technology issues related to next generation cellular communication systems.

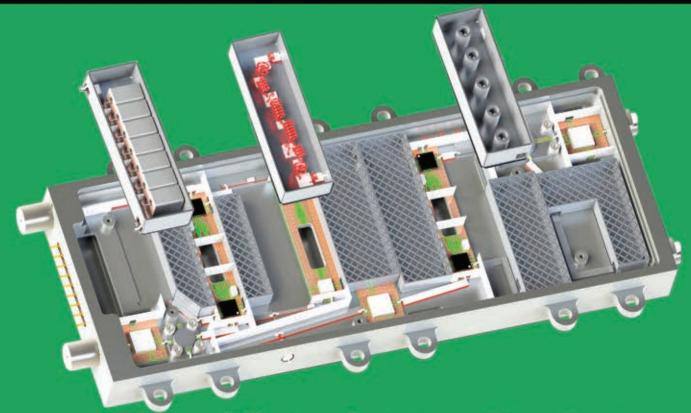
Test and measurement experts from Keysight, Rohde & Schwarz and National Instruments will address flexible testing platforms for rapid prototyping along with partnerships with research organizations evaluating 5G technologies and their

results to date. Semiconductor experts from MACOM and ADI will address the device challenges such as wideband, mmWave transceivers including the integration, performance and cost issues needed to achieve 5G goals. After opening remarks from the moderator and panelists, the audience will be able to ask questions for an extended Q&A discussion.

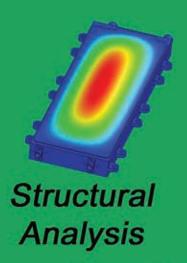
The panelists this year are Roger Nichols, 5G program manager for Keysight Technologies; James Kimery, director of marketing for RF research/SDR, National Andreas Instruments: Roessler, technology manager North America, Rohde & Schwarz; Mark Cloutier, chief scientist, Analog Devices and David Ryan, strategic marketing manager, MA-COM. Our moderator this year will be Eric Higham, Director of Advanced Semiconductor Applications, Strategy Analytics. He will introduce the panelists and direct the Q&A session. Please come by at noon on Wednesday in Booth 3147 and get the latest on 5G research and technology last year was standing room only so come early to get a seat.



Kick-Ass SubSystems BY Q MICROWAVE

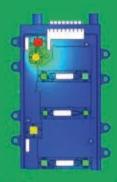


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- VLO/FLO Threats New Land Radar EW

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OCTAVE BA	ND LOW N	OISE AMPL	IFIERS			
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 1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1
			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	22-24	30	0.6 MAX, 0.45 TYP		+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1
IIITRA-RRO	ADRAND &		TAVE BAND A		TO T UDITI	2.0.1
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power -out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3 0 MAY 1 8 TYP	+22 MIN	+32 dBm	2.0:1
CA0100 4112	0.5-2.0	36	3.0 MAX, 1.8 TYP 4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	26 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	OO MAIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+30 MIN +10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1
LIMITING A		L /	J.U MAA, J.J 111	+Z4 //IIIV	+34 ubili	2.0.1
Model No.		nput Dynamic R	ange Output Power	Range Peat Pow	er Flatness dB	VSWR
CLA24-4001	2.0 - 4.0				/- 1.5 MAX	2.0:1
CLA24-4001 CLA26-8001	2.0 - 6.0	-50 to +70 dE	3m +14 to +1	I R dRm	/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-28 to +10 dE -50 to +20 dE -21 to +10 dE -50 to +20 dE	3m +14 to +1	19 dRm +	/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dE	3m +14 to +1	10 dRm	/- 1.5 MAX	2.0:1
			ATTENUATION	T UDIII T	/ 1.3 MAX	2.0.1
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB) Pov	ver-out@P1-dB Gain	Attenuation Panas	VSWR
CA001-2511A	0.025-0.150	21 5	O MAX 3 5 TVP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.023-0.130	23 2		+12 MIN +18 MIN	20 dB MIN	2.0.1
CA56-3110A	5.85-6.425	28 2		+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24 2	1.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25 2	.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
		20 2	. Z MAA, 1.0 111			
CA1518-4110A LOW FREQUE	15.0-18.0	30 3	.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1
			Noico Figuro dD	Power-out @ pa Jp	3rd Order ICP	VSWR
Model No. CA001-2110		Gain (dB) MIN 18		Power-out@P1-dB +10 MIN	+20 dBm	2.0:1
	0.01-0.10	24	4.0 MAX, 2.2 TYP	+10 MIN +13 MIN		
CA001-2211 CA001-2215	0.04-0.15	23	3.5 MAX, 2.2 TYP		+23 dBm	2.0:1
CA001-2213 CA001-3113	0.04-0.15	23 28	4.0 MAX, 2.2 TYP 4.0 MAX, 2.8 TYP	+23 MIN	+33 dBm	2.0:1
	0.01-1.0	20 27	4.0 MAX, 2.0 III	+17 MIN	+27 dBm +30 dBm	2.0:1
CA002-3114	0.01-2.0		4.0 MAX, 2.8 TYP	+20 MIN		2.0:1
CA003-3116 CA004-3112	0.01-3.0	18 32	4.0 MAX, 2.8 TYP	+25 MIN +15 MIN	+35 dBm +25 dBm	2.0:1 2.0:1
	0.01-4.0		4.0 MAX, 2.8 TYP			2.0.1
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S or

Exelis Receives \$7.6M Contract for U.S. Army On-The-Move Systems



xelis has received orders valued at \$7.6 million from ADS Inc. on behalf of the U.S. Department of Defense (DoD) through the Defense Logistics Agency (DLA) Tailored Logistics Support (TLS) program to provide mission command on-the-move systems. The systems will be used for undisclosed worldwide deployments.

Called Global Network on the Move-Active Distribution, or GNOMAD, the system provides a broadband, satellite communication (SATCOM) on-the-move (SOTM) networked command and control connectivity. With GNOMAD, Exelis delivers a combat-proven, modular, reliable communications system that fully integrates into a variety of armored combat vehicles, commercial SUVs and military platforms of all descriptions.

GNOMAD is based on an open system architecture, using low profile antennae designs, in a reduced size, weight and power profile. The system has previously supported deployed U.S. Army units and the Department of Homeland Security during critical domestic emergency response missions.

This delivery of GNOMAD systems also includes ground station satellite hubs, training and installation services and the ability to leverage commercial Ku satellite



Source: ITT Exelis

services and, once certified, X-Band satellite services on the DoD Wideband Global SAT-COM (WGS) Constellation. The SR300X is beginning WGS certification and the SR-300Ka will be available to begin WGS certification in the spring of 2015. At only 28 pounds, the SR-300 series antenna can be removed and replaced in

less than 10 minutes providing increased flexibility on the battlefield.

"GNOMAD is a proven mission essential command and control on-the-move solution ideal for the difficult communications environment that Army units operate in daily while deployed," said Nick Bobay, president of the Exelis Night Vision and Communications Solutions division. Production for this contract will be accomplished at the Exelis facility in Fort Wayne, Ind., with deliveries completed by spring 2015.

AEGIS BMD System Tracks, Simulates Engagements of Short-Range Ballistic Missiles

he Missile Defense Agency (MDA) and sailors aboard the guided-missile destroyers USS Carney (DDG 64), USS Gonzalez (DDG 66) and USS Barry (DDG 52) successfully completed a flight test involving the Aegis Ballistic Missile Defense (BMD) weapon system.

Three short-range ballistic missile targets were launched virtually simultaneously from NASA's Wallops Flight Facility in Virginia. Two Aegis BMD destroyers acquired and tracked the targets. Using this data, the Aegis BMD ships conducted simulated Standard Missile-3 Block IB guided missile engagements with the distributed weighted engagement scheme (DWES) capability enabled. The DWES provides an automated engagement coordination scheme between multiple Aegis BMD ships that determines which ship is the preferred shooter, reducing duplication of BMD engagements and missile expenditures while ensuring BMD threat coverage. Several fire control, discrimination and engagement functions were exercised. Since no SM-3 guided missiles were launched, the test did not include an attempted intercept.

This test, designated Flight Test Other (FTX)-19, was the first flight test to assess the ability of the Aegis BMD 4.0 weapon system to simulate engagements of a raid consisting of three short-range, separating ballistic missile targets. This was also the first time Aegis BMD 4.0 ships used the DWES capability with live targets.

The MDA will use test results to improve and enhance the Ballistic Missile Defense System and support the advancement of Phase 2 of the Phased Adaptive Approach for missile defense in Europe to provide protection of U.S. deployed forces, our European allies and partners. Aegis BMD is the naval component of the MDA's Ballistic Missile Defense System. The MDA and the U.S. Navy cooperatively manage Aegis BMD.



USS Gonzalez; Source: U.S. Navy

For More Information

DoD Tests Next-Generation Anti-Ship Missile



he Navy, Air Force and Defense Advanced Research Projects Agency (DARPA) recently completed a successful test of the Long-Range Anti-Ship Missile (LRASM), marking a significant step in maturing key technologies for the future operational weapon system.

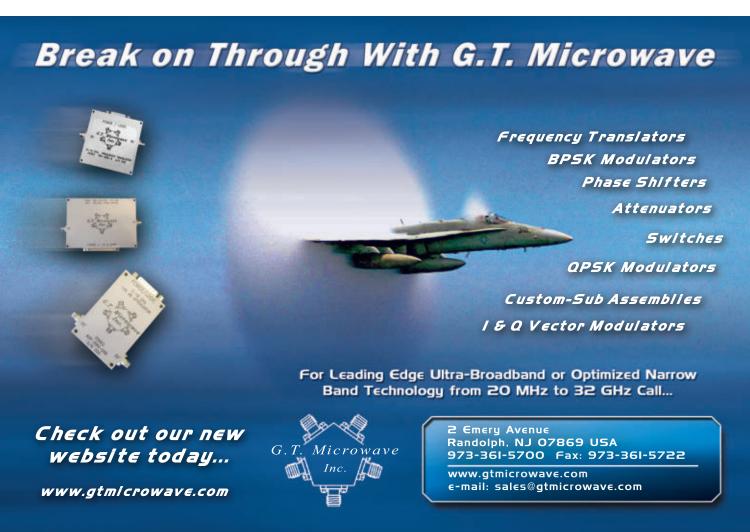
The joint-service team, known as the LRASM Deployment Office (LDO), conducted the test to evaluate LRASM's low-altitude performance and obstacle avoidance as part of the program's accelerated development effort. "We are very pleased with how LRASM performed today and we are looking forward to continuing integration efforts on the Air Force B-1, followed by our Navy F/A-18, over the next few years," said Capt. Jaime Engdahl, the LDO's Navy program manager. "We have a clear mission, to deliver game-changing capability to our warfighters in theater as quickly as possible."

During the flight from the Sea Test Range in Point Mugu, Calif., the B-1 Bomber released the LRASM, which navigated a series of pre-planned waypoints to verify aerodynamic performance. In the final portion of the flight the

missile detected, tracked and avoided an object that was deliberately placed in the flight pattern to demonstrate its obstacle avoidance algorithms.

Since completing two successful test flights in 2013, LRASM has rapidly transitioned from a DARPA demonstration to a formal, U.S. Navy program of record, with fielding set for 2018. The program reflects initiatives from DoD's Better Buying Power 3.0, which encourages rapid prototyping and other forms of innovative acquisition to keep a technological edge and achieve greater efficiency and productivity in defense spending. "We've shown that by taking advantage of the Defense Department's evolving acquisition policy, it is possible to significantly accelerate the fielding of a high-payoff technical system for the warfighter," said Artie Mabbett, LDO director.

The LDO and industry partner Lockheed Martin are developing LRASM as an air-launched offensive anti-surface warfare weapon to counter the growing maritime threats in an Anti-Access/Area Denial (A2/AD) environment. When operational, LRASM will play a significant role in ensuring military access to operate in open ocean/blue waters and the littorals due to its enhanced ability to discriminate and conduct tactical engagements from extended ranges.





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The unit generates a wideband modulated signal while locked to the reference oscillator, thus achieving perfect frequency span and center frequency. This is in a contrast to common frequency source solutions where the wideband modulation mode is done in a "free running" mode and the frequency accuracy is very limited.

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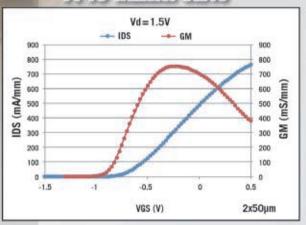




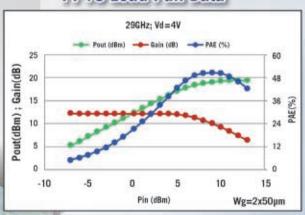
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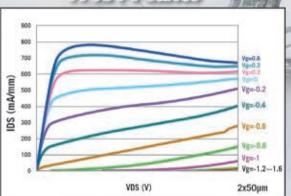
PP10 Transfer Curve



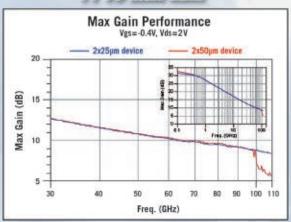
PP10 Load Pull Data



PP10 I-V Curves



PP10 Max Gain



InternationalReport

Richard Mumford, International Editor



VTT and University of Oulu Build Finland's First 5G Test Network

ogether with their industrial partners, VTT Technical Research Centre of Finland and the University of Oulu are building a 5G test network in which critical new technologies can be developed. The test



network will also enable the testing of the performance of new technologies in a realistic environment. It will consist of two parts: a restricted network on VTT's premises and a public network at the university. In the restricted network, companies can test the functionality of their technologies, while in the public network solutions such as those for the large-scale deployment of user devices can be verified.

The intention is to offer the public part of the network, based on rules yet to be defined, as an open test environment for all willing partners. In addition, the test network will be expanded to cover different parts of the city on a

"...we will build a full 5G test network environment."

more open basis. In this way, the test network can be used as a platform for developing and testing new applications.

"Within the test network, we are researching

and developing new technologies, based on which we will build a full 5G test network environment. This will enable long term co-operation between the actors involved in the wireless communication ecosystem. With the help of this research project, we can retain our leading position in the international development of 5G," stated project manager Atso Hekkala of VTT.

"5G will be the next big step in wireless communications. It will form the infrastructure of the traditionally fast-growing wireless multimedia communications, as well as massive communication between devices. While requiring significant architectural changes and the application of new technologies, 5G must also provide a seamless transition from the current system architecture and technology to the new one," commented Matti Latva-aho of the University of Oulu.

ETSI Group on Millimetre Wave Transmission Starts Work

he European Telecommunications Standards Institute's (ETSI) recently announced Industry Specification Group on millimetre-Wave Transmission (ISG mWT) held its first meeting and immediately commenced work developing a set of five specifications:

An analysis of the maturity and field proven experience of millimetre wave transmission, potential applications and use cases of millimetre wave transmission, an overview of V-Band and E-Band worldwide regulations, an analysis of V-Band street level interference and analysis of the millimetre wave semiconductor industry technology status and evolution.

Renato Lombardi of Huawei Technologies and newly elected chairman of ETSI's ISG mWT commented, "ISG

mWT was conceived as an industry wide platform to prepare for large scale usage of millimetre wave spectrum in current and future transmission networks by improving the conditions to make millimetre wave spectrum a suitable and convenient



choice for all stakeholders. The ISG aims to be a worldwide initiative with global reach to address the whole industry: national regulators, standards organizations, telecom operators, product vendors and key component vendors."

Millimetre wave spectrum, in the 30 to 300 GHz range, offers more available spectrum than in lower bands with larger channel bandwidths granting a fibre like capacity. The spectrum can be made available readily and can be reused easily, and lower licensing costs lead to lower total cost of ownership and lower cost per bit of radio systems. Participation in the ISG mWT is open to all ETSI members as well as organizations who are not members, subject to signing ISG Agreements.

EDRS Confirms Services for Copernicus in Cooperation with EC

ollowing the decision confirming the ESA/Airbus Defence and Space (Airbus DS) partnership on the European Data Relay System (EDRS), agreement has been reached with the European Commission (EC) for the provision of EDRS services to the European Union Copernicus programme.

Subsequently, ESA and Airbus DS have signed a service level agreement to provide high-speed communications to the Copernicus Sentinel-1 and Sentinel-2 dedicated missions, starting in 2015 until 2021, with an option for extension until 2028.

The agreement includes the setup of a Joint Steering Committee, ensuring high-level representation of the EC, ESA and Airbus DS, to monitor EDRS status and evolution with the objective of maintaining EDRS as an autonomous European data relay capability.

ESA and Airbus DS also signed a service contract providing data relay capacity to other ESA and ESA partner missions in the future. As a first additional user, ESA's Columbus module on the International Space Station (ISS) is planned to be provided with data relay services starting in 2018, which will support scientific experiments and enhance communication services to the astronauts on board the ISS.

For More Information

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InternationalReport

This confirms Copernicus and Columbus/ISS as initial EDRS anchor customers. It allows Airbus DS to invest in the completion and operations of EDRS. Airbus DS is expected to develop the third-party commercial market for EDRS services and to support the evolution of the system towards global coverage. These agreements allow ESA to consolidate its support to the EDRS evolution as initiated at the 2014 ESA Ministerial Council with the GlobeNet Programme.

Ukraine Joins Horizon 2020

esearchers, businesses and innovators from Ukraine will now be able to fully participate in Horizon 2020, the European Union's research and innovation funding programme, on equal terms with EU Member States and other associated countries. This is thanks to the Agreement for the Association of Ukraine to Horizon 2020, signed by Carlos Moedas, European Commissioner for Research, Science and Innovation, and Serhiy Kvit, Minister of Education and Science of Ukraine.

Commissioner Moedas said, "I am very pleased to welcome Ukraine into our EU research funding programme Horizon 2020. Ukraine has chosen to invest in its knowledge and in its people. Chosen to contribute to the common goals of the wider science and technology community.

Ukraine's great research and innovation potential offers promising partnerships for Europe. And Ukraine will now have access to the full spectrum of activities funded under Horizon 2020, helping "...both the EU and Ukraine consider research and innovation crucial..."

spur its economy. I hope Ukraine will make the most of these opportunities."

Horizon 2020 is the first EU programme in which Ukraine has chosen to participate following the beginning of provisional application of the EU-Ukraine Association Agreement. This association to Horizon 2020 highlights that both the EU and Ukraine consider research and innovation crucial for economic growth and the creation of jobs.

The agreement opens a wide range of new opportunities to Ukrainian research institutions, universities and businesses across the whole research and innovation value chain, from fundamental research up to close-to-market activities. For instance, Ukraine will now be able to host European Research Council (ERC) grants, apply for financial support to innovative SMEs, benefit from support for scientific excellence and other research policies and participate in the governance structures of the programme.





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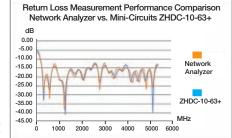
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a side-by-side comparison, our test setup using these couplers produced comparable results to those obtained using the network analyzer.* So why spend big bucks on expensive test equipment when a measurement setup with our high-directivity couplers is a fraction of the cost? Visit minicircuits.com for detailed specs.

Plot from actual test data using Mini-Circuits' ZN4PD1-63W-S+ Power Splitter



- 10 and 16 dB Models
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*Results for components with return loss rated up to 25 dB tested over frequencies from 50 to 6000 MHz.



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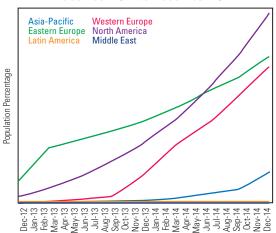
LTE-Advanced Coverage Reaches 100 Million People: 1 Billion by 2018

TE-Advanced networks have been actively deployed around the world. At the end of 2014, LTE-Advanced covered its first 100 million people worldwide, just four years since the network's inception. ABI Research predicts that the coverage will reach 1 billion by 2018.

At the end of 2014, there were 49 commercially available LTE-Advanced networks around the world. Western European operators lead the commercialization with 20 operators, followed by 13 in Asia-Pacific; however, North America still commands the largest population coverage at 7.8%. "All four major operators in the United States have either commercially deployed (AT&T and Sprint) or have been actively deploying (Verizon and T-Mobile) their LTE-Advanced networks," comments Lian Jye Su, research associate of Core Forecasting.

Globally, a number of major auctions are expected to take place in several major markets in 2015. The Telecom Regulatory Authority of India held an LTE spectrum auction in February. In France, the government recently approved the reassignment of the 700 MHz band for telecom services. The FCC in the U.S. is currently conducting an auction for AWS-3 spectrum. "As heavy subscribers' data traffic growth has exploded, ABI Research anticipates fierce competition for more spectrum, as well as an active migration to VoLTE and higher data modulation schemes such as LTE and LTE-Advanced, which has higher spectral efficiency," adds Jake Saunders, VP and practice director of Core Forecasting.

LTE-Advanced Worldwide Coverage December 2012 to December 2014



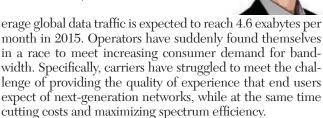
Source: ABI Research

Carrier Wi-Fi Market to be Driven by Hotspot 2.0



ore than ever before, social media, internet browsing, video streaming and applications dominate mobile phone usage. ASDReports predicts that the av**Commercial** Market

Cliff Drubin. Associate Technical Editor



Heterogeneous networks have been a salient concept in mobile networks: using a variety of access technologies in wireless networks to address density and topography. In this scope, Carrier Wi-Fi has recently emerged as a strong,

game-changing contender. This market recently saw the launch of Hotspot 2.0, an industry-wide set of technology standards that will alter the landscape of wireless network architecture. This report forecasts 5.95 million ac-

5.95 million active Hotspot 2.0 sites are projected globally by the end of 2015.

tive Hotspot 2.0 sites globally by the end of 2015.

The automation, high-performance, low-CAPEX, and unlicensed spectrum endemic to Carrier Wi-Fi amplify its value proposition to operators. The technology's success will be rooted in its unique appeal for a variety of deployment types. Not merely a tool for mobile operators, Wi-Fi 'Passpoint' deployments will become prevalent across fixed and third party carriers, such as cable operators, transport hubs and even large metropolitan areas. Demand for the technology will be rooted in dense, traffic-laden urban zones, which are growing rapidly across all world regions.

As the developed markets begin to move towards comprehensive LTE coverage, Carrier Wi-Fi grids will become an integral part of network architecture. The industry is witnessing a tremendous shift in network strategy and planning, one that revolves around a more intricate nexus of compact, high-performance elements. The Carrier Wi-Fi market will experience high double-digit growth through the forecast period. As smart device proliferation grows across Europe and Asia-Pacific, this new, automated, interoperable standard will become a necessary component of high-performance wireless networks.

Global Research Reveals the Importance of the IoT to Developing Economies

study conducted by the element14 Community has revealed high consumer interest worldwide in the Internet of Things (IoT) and a huge potential value to developing economies. The study included more than 3,500 people in North America, Europe, Asia and Australia. When asked if it would be beneficial to connect more devices and appliances to the internet, 43% agreed. However, the research highlights a notable thirst for increased internet connectivity in developing economies, hinting that IoT has the potential to continue the trend for increased

For More Information

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Commercial Market

access to the internet in developing economies that mobile

On average, 31% of consumers in Australia, France, Germany, the U.K. and the U.S. agree that the more devices in their home that connect to the internet, the better. This figure more than doubles to 71% for consumers in both China and India, newly industrialized countries with lower percentages of population having internet connectivity. More specifically:

- Respondents in China and India are more likely to agree with the statement - "The more of the world that is connected to the internet, the better" - indicating that desire for connectivity extends beyond their homes. On this statement, 73 and 86% concurred for each country respectively, compared to just a 55% average across the other countries studied.
- People in China and India are much more open to wearing a connected device such as a smartwatch or smartglasses, with 66 and 63% agreeing, compared to 26% on average in the other countries surveyed.
- Regarding privacy implications, France was most concerned with 81% agreeing this was an issue. The average number was only marginally lower (77%).
- Aside from India and China (59 and 63% respectively), Brits and Germans are the most gadget-obsessed nations, with 50% of each agreeing that they cannot live without their gadgets and technology.

- In the U.S.:
- 19% of respondents, or nearly 1 in 5, say they would allow a chip to be implanted in their body if it made life easier. Among those 18-24, the number jumps to 33%. And 37% say they would allow a chip to be implanted in their body if it came with great medical benefits. Among those 18-24, the number jumps to 44%.
- 80% of people (4 in 5) are concerned about the privacy implications of having more elements of their work and life connected to the Internet. Only 5% are not concerned.
- 64% are concerned with being inundated with alerts/ notifications/messages from their home's increasingly connected devices, which goes to show that these types of technologies will need to be fully automated.

Dr. John Barrett, head of Academic Studies at the Nimbus Centre for Embedded Systems Research at Cork Institute of Technology (CIT) commented, "The IoT has immense potential, but individuals and companies also have very valid concerns about security and privacy in an interconnected IoT world.

Dianne Kibbey, element14's community head added, "IoT offers so many opportunities for new functionality and capabilities outside of existing products, and many companies and product designers are being forced to rethink their traditional businesses. While some are struggling to realize and understand IoT's significance, this study shows key geographies and applications where IoT has strong potential."







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MERGERS & ACQUISITIONS

NXP Semiconductors N.V. and **Freescale Semiconductor Ltd.** announced that they have entered into a definitive agreement under which NXP will merge with Freescale in a transaction which values the combined enterprise at just over \$40 billion. The merger creates a high performance mixed signal semiconductor industry leader, with combined revenue of greater than \$10 billion. NXP has also announced that it has completed its acquisition of **Quintic's** Bluetooth Low Energy (BTLE) and Wearable businesses. With this transaction, NXP adds BTLE to an existing portfolio of ultra-low power RF-connectivity solutions key to the Internet of Things.

Avago Technologies Ltd. and Emulex Corp. announced that they have entered into a definitive agreement under which Avago will acquire Emulex, a leader in network connectivity, monitoring and management, in an all-cash transaction valued at approximately \$606 million, or \$609 million net of cash and debt acquired. Under the terms of the agreement, approved by the boards of directors of both companies, a subsidiary of Avago will commence a tender offer for all of the outstanding shares of Emulex common stock for \$8 per share in cash. Avago expects to fund the transaction with cash available on its balance sheet.

Maury Microwave Corp. and Anteverta-mw announced that Maury Microwave has completed the acquisition of Anteverta-mw. This strategic move is expected to further strengthen Maury Microwave in the nonlinear measurement and modeling device characterization market and accelerate innovation for the betterment of markets served by both parties.

COLLABORATIONS

RFMW Ltd. and **API Technologies Corp.** recently announced a worldwide distribution agreement. Under the agreement, RFMW will be an authorized distributor of a full range of standard, customizable and fully custom RF, microwave and microelectronics products. Featured products include antennas, RF and microwave amplifiers, high performance filters, thin film chip resistors, mixers, and passive components such as rotary joints, wireline and phase shifters. The partnership will introduce API's standard and configurable RF and microwave products to RFMW's diverse, worldwide sales channel and enable customers to receive rapid delivery of these quick-turn product solutions.

Cascade Microtech Inc., a supplier of solutions that enable precision measurements of integrated circuits at the wafer level, announced its latest MeasureOne solutions partner - **Lake Shore Cryotronics**, an innovator in solutions for measurement under variable temperature and magnetic field conditions. This formal collaboration prom-

ises to substantially accelerate the time to first device measurement for a collective customer base where early stage research typically requires testing in extreme cold and magnetic flux. Validated measurement solutions from both companies will deliver the highest levels of confidence in performance and reliability.

Peregrine Semiconductor Corp., founder of RF SOI (silicon on insulator) and pioneer of advanced RF solutions, teams with Murata to announce the 2015 UltraCMOS® Global 1 Initiative. The campaign launched with the UltraCMOS Global 1 PE56500 product demo at Mobile World Congress 2015. This new initiative seamlessly integrates the PE56500 all-CMOS RF front-end solution and Murata filters. UltraCMOS Global 1 technology makes a single, global SKU possible – saving 4G LTE mobile-device manufacturers significant time and money.

Thales and Ultra Electronics TCS have established a partnership to provide the next generation of high-capacity communications systems for use in theatre of operations. Based on the expertise of the two leading companies in High-Capacity Line-of-Sight (HCLOS) communications, this initiative resulted in the new TN 4100 product family. The TN 4100 provides a suite of capabilities that significantly enhances operational flexibility and allows users to respond to the demands of today's operations and beyond. The new TN 4100 line-of-sight radio enhances the Thales NEXIUM Theatre tactical networking solution by enabling the flexibility to support high-capacity transmission, regardless of the mission.

NEC Corp. has signed a global framework agreement with the **Axiata Group**, one of Asia's largest telecom operators, regarding the provision, installation and related maintenance services for NEC's iPASOLINK series of ultra-compact microwave communication systems. The global framework agreement covers the Axiata Group telecom operators in Malaysia, Indonesia, Sri Lanka, Cambodia and Bangladesh. Previously, NEC provided the iPASOLINK series under individual arrangements to XL Axiata (Indonesia) and Dialog (Sri Lanka) in the Axiata Group. With the new cooperation NEC will be able to conduct marketing efforts towards additional Axiata Group companies.

NEW STARTS

Keysight Technologies Inc. announced that effective June 1, 2015 it will resume direct sales of high performance products to all customers in North America. This includes Keysight's broad portfolio of high performance network analyzers, spectrum analyzers, signal sources, power products, oscilloscopes and modular solutions. Electro Rent has been responsible for selling and supporting these products at specific accounts in North America. On June 1, responsibility for selling Keysight products and solutions to these customers will revert to Keysight's direct sales force.

In-Phase Technologies completely redesigned their website, revising the look and feel of the site to ease user access.

For More Information

For up-to-date news briefs, visit mwjournal.com

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POWER DIVIDERS



Model #	Frequency (MHz)	Insertion Loss (dB) [Typ:/Max.] 0	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbelance (Deg.) [Typ:/Max.]	Isolation (dB) [Typ.Min.]	VSWR (Typ.)	input Power (Watts) [Max.] =	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05/0.4	0.8/3.0	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5/0.8	0.05/0.4	1/2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5/0.8	0.25 / 0.5	1/4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6/1.1	0.05/0.2	1/2	28 / 22	1.2:1	2	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05/0.2	1/2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3/0.4	0.1/0.3	1/3	20 / 18	1,3:1	100	220
P2D180900L	1800 - 9000	0.4/0.8	0.05/0.2	1/2	27 / 23	1,2:1	2	331
DSK180900	1800 - 9000	0.4/0.8	0.05/0.2	1/2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2/0.35	0.3/0.6	2/3	22/16	1,3:1	5	316
4-WAY				1200			10.	
CSDK31008	30 + 1000	0.771.1	0.0510.2	0.3/2.0	28/20	1,15:1	5	1695
With matched oper	rating conditions	- the state of the	A10.000		7.00.00			

HYBRIDS 🚰



Model #	Frequency (MHz)	Insertion Loss (dB) [Typ://Max.] 0	Amplitude Unbalance (dB) [Typ:/Max.]	Phase Unbelance (Deg.) [Typ./Max.]	isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8/1.2	173	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5/0.8	0,670,9	1/3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1/1.5	4/6	23/18	1.40:1	5	102SLF
DQS-118-174	118 - 174	0.3 / 0.6	0.4/1	1/3	23/18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.210.4	0.5/0.8	2/5	20/18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.270.4	0.5/0.8	2/5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1/1.6	1/4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8/1.6	1/1.6	1/4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2/0.3	0.2/0.4	2/3	22 / 18	1.20:1	50	226
180° (4-PORTS)							
DJS-345	30 - 450	0.75/1.2	0.3 / 0.8	2.5/4	23 / 18	1.25:1	5	301LF-1

COUPLERS ROHS



Model #	Frequency (MHz)	(dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ:/Min.]	Input Power (Watts) [Max.] •	Package
KFK-10-1200	10 - 1200	40 ±1.0	±1.5	0.4/0.5	22 / 14	150	376
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2/0.28	23 / 15	50	255 *
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6/0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1,0	±0.5	0.2/0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6/0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2/0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38/30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2/18	8/5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2/1.8	8/5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.771.0	14/5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14/5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12/5	25	321
KDK100800-20	1000 - 7800	20.5±2.0	±2.0	0.45/0.75	14/5	25	322
KEK-1317	13000 - 17000	30 ±1.0	±0.5	0.4/0.6	30 / 15	30	387

^{*} Add suffix - LF to the part number for RoHS compliant version.

Unless noted, products are RoHS compliant.



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Around the Circuit

The site navigation is changed to a much easier-to-navigate design with product categories that can be accessed from the home page. The home page also features highlights of the markets served by In-Phase Technologies: defense electronics, satellite, medical electronics, and microwave and fiber optic components. A series of case studies are also available, including a fast switch matrix test system, a medical device test system, a microwave vector test system and a power supply test system.

ACHIEVEMENTS

e2v announced the official MIL-PRF-30535 Class V (QMLV) certification of its facilities based in Grenoble, France – the highest standard of quality and reliability for aerospace-grade microelectronics and integrated circuits. The QMLV certification is a United States military performance-based specification document that defines the general requirements, as well as the quality assurance and reliability requirements, for the manufacturers of microelectronic or integrated circuits used in military applications and high reliability microcircuit application programs.

Guerrilla RF Inc., a provider of high performance microchips for wireless network infrastructure, announced the closing of a \$500,000 funding round led by Charlotte Angel Fund. Also participating were Piedmont Angel Network and a growing list of individual angel investors. According to Research and Markets, the overall wireless network infrastructure market will see tremendous growth over the coming years. Growing at a compound annual growth rate of over five percent, the market will account for over \$104 billion in annual spending by the end of 2020.

Tronser Inc. who proudly serves the needs of its United States based defense industry customers, announced recently that the company, located in Cazenovia, N.Y. has received their International Traffic in Arms regulations (ITAR) registration from the United States Department of State. To qualify for ITAR registration, Tronser Inc. met strict requirements for company structure, security, record keeping and procedures for the handling of sensitive military and intelligence applications.

CONTRACTS

U.S. Navy aviation experts are ordering one advanced E-2D maritime patrol and air control aircraft from its manufacturer, Northrop Grumman Corp., under terms of a \$148.3 million contract. Officials of the Naval Air Systems Command at Patuxent River Naval Air Station, Md., are asking the Northrop Grumman Aerospace Systems segment in Melbourne, Fla., to provide one E-2D full rate production advanced Hawkeye radar surveillance aircraft. According to Northrop Grumman, Advanced Hawkeye is the cornerstone of theater air and missile defense architecture in the littorals, overland and open sea.

LPKF has received an order worth €2.5 million from a Chinese electronic manufacturer for Laser Direct Structuring (LDS) systems. This is the first phase of a large-scale



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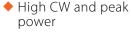




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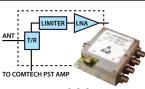








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Around the Circuit

order. With LPKF's laser direct structuring systems, circuit pathways can be imprinted directly onto three-dimensional plastic components. This saves on space and weight, making it particularly suited to the manufacture of components for small mobile end devices such as smartphones.

Exelis, a global leader in providing critical network solutions, has been selected to provide its airfield monitoring solutions to Los Angeles International Airport (LAX), Calif., for enhanced airport safety and efficiency. The Exelis suite of vehicle tracking and surveillance solutions is expected to bring an additional level of safety during regular and irregular operations, such as construction and weather events, and in critical situations, such as aircraft emergencies. The Exelis solutions provide a common airfield operating picture for air traffic controllers and key airfield operations staff for increased situational awareness and collaborative decision-making.

PEOPLE

Dr. Ulrich Rohde, of Brandenburgische Technische Universitat, is this year's recipient of the 2015 IFCS I.I. Rabi Award. The citation reads, "For intellectual





and measurement of resonator structures for implementation in high performance frequency sources, essential to the determination of atomic

resonance." Dr. Ajay

leadership, selection

K. Poddar of Synergy Microwave Corp. is this year's recipient of the 2015 IFCS W.G. Cady Award. The citation reads, "For the analysis, design and development of a host of frequency control products exhibiting state-of-the-art performance, including the development of extremely low noise crystal oscillator circuitry." Both awards were presented at IFCS-EFTF 2015 held in Denver, Colo. Drs. Rohde and Poddar are regular contributors to Microwave Journal. Their recent three part series on Möbius Strips has been well received by our readers.



Zentech Manufacturing Inc. announced that CEO and president, Matt Turpin, was appointed to the IPC Relations Government Steering Committee at the IPC Annual Meeting (APEX) in San Diego, Calif. The IPC Relations Government Steering Committee works to further IPC members' interests by advocating for policies that foster economic growth and job

▲ Matt Turpin

creation and to enhance the international competitiveness of the electronic interconnection industry. The committee addresses the range of issues that affect IPC member companies, such as: technology policy supporting electronic interconnection research and development, environmental initiatives that support science-based environmental protection, smart regulatory reform and other issues as determined by committee members.

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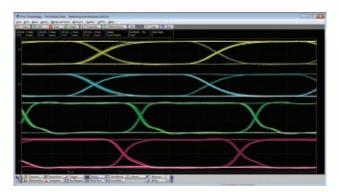
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Around the Circuit

Johanson Manufacturing, a supplier of trimmer capacitors and microwave tuning elements, announced the appointment of Walt Shelmet as director of sales and marketing. In this role, Shelmet will be responsible for developing and executing Johanson's market development, sales and new business plans. Shelmet will supervise the sales and marketing teams to identify market opportunities, fulfill market needs, ensure delivery of quality solutions, and meet short- and long-term business goals.





▲ Jung Jin-Young

hired two new engineering managers, Carmen Salvatore and (James) Jung Jin-Young. Salvatore will provide leadership and direction to the engineering team at the company's Business Park Drive

Indium Corp. has

facility in Utica, N.Y. Jung will oversee the engineering and quality teams at the company's facility in Cheongju, Korea. In addition to team oversight, Salvatore and Jung will provide support for process optimization, management of technology transfers, product quality, capital projects and review of facility designs.

API Technologies Corp. announced that Robert Tavares has been named president and chief executive officer effective immediately. Tavares will also become a member of API's board of directors. Bel Lazar. API's current



president and chief executive officer, is leaving the company. Tavares joins API with 30 years of experience in microelectronics and semiconductors for both commercial and defense applications. From March 2012 until joining API, Tavares served as president of Crane Electronics Inc., which serves the defense, commercial aerospace and medical markets with microelectronic-

based solutions for power and microwave applications.

GigOptix Inc., a supplier of advanced high speed semiconductor components for use in long-haul, metro, cloud connectivity, data centers, consumer electronics links and interactive applications, through optical and wireless communications networks, announced the opening of its GigOptix-Japan office, located in Tokyo, and the immediate appointment of Yoshi Koizumi to the position of Asia Pacific (APAC) sales director. Prior to joining GigOptix, Koizumi managed the sales operations of TriQuint Semiconductor in Japan. Koizumi's experience includes participation in both 40 and 100 Gbps optical driver design-in as well as point-to-point MMIC design-in with major Japanese telecommunications corporations.

Qorvo Inc., a leading provider of RF solutions for mobile, infrastructure and aerospace/defense applications, announced that **Dean Priddy**, the company's executive vice





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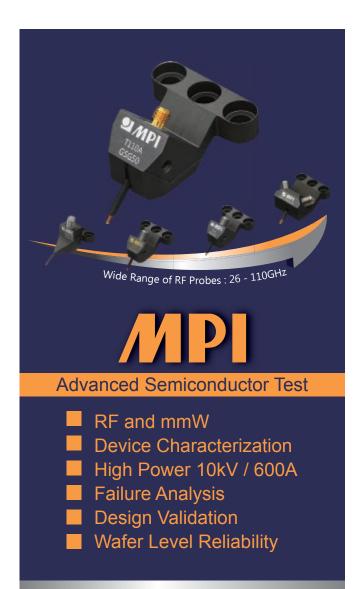
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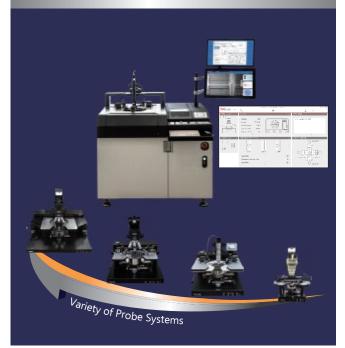
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president of administration, plans to retire at the end of the current fiscal year. Priddy's accomplished career in technology began at Analog Devices and includes 23 years at RF Micro Devices and Qorvo. Prior to his role as EVP of administration of Qorvo, Priddy was CFO of RF Micro Devices, a position he had held since 1997.

IN MEMORIAM



Dr. Lawrence Gould passed away on Feb. 13, 2015 from a long-standing illness. Dr. Gould was born in Boston, Mass. on Nov. 28, 1930 and received his B.S. degree in physics from M.I.T. in 1950, and his Ph.D. degree in physics from M.I.T. in January 1954. In September 1953, he joined **Microwave Associates Inc.** as a research physicist. As of July 1962, Dr.

Gould served as executive vice president and chief operating officer succeeding to the position of president of the corporation in May 1969, to chief executive officer in February 1975, and to chairman of the board in February 1978. Gould also served M/A-COM, Inc. as chairman of the board and chief executive officer until July 1982.

REP APPOINTMENT

ARC Technologies announced a new sales distributor partnership with **Component Distributors Inc. (CDI)**. CDI is a value added distributor of electronic components providing AC and DC power, RF and microwave, sensors, measurement and control products for simple to complex system applications. Based in Denver, Colo., CDI will represent ARC Technologies in the Americas (North, Central and South America). Having CDI as a franchised stocking distributor will open countless opportunities for growth of ARC sales. CDI has been a distributor since 1970 and currently represents over 100 different manufacturers.

PLACES



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Innovation Center is a showplace for the company's advanced embedded and high performance capabilities across the sensor processing chain, industry-leading thermal cooling solutions, and a wide range of state-of-the-art technologies and subsystems that are relied upon by leading defense prime contractors. The first Mercury Innovation Center opened in April 2014, at the company's Advanced Microelectronics Center (AMC) in Hudson, N.H.

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Understanding the Relevance of Harmonic Impedance Matching in Amplifier Design

Steve Dudkiewicz, Marc Schulze Tenberge and Giampiero Esposito Maury Microwave Corp., Ontario, Calif.
Travis Barbieri
Freescale Semiconductor, Phoenix, Ariz.

Today's modern commercial and military communication systems are demanding better performance with regards to power, efficiency, linearity and operating bandwidth. As such, extra considerations must be placed on designing the internal components of the systems, including the low-noise and power amplifiers, to maximize performance.

In order to reach higher efficiencies, significant research has been performed on designing high efficiency amplifiers by matching one or more harmonic impedances. An equally large effort has gone into designing commercial test systems which aid in the systematic identification of ideal matching impedances at the fundamental and harmonic frequencies, referred to as harmonic load-pull, in order to maximize performance.

Before venturing into a design project, it is important to ask several questions: Does the application require an amplifier with harmonic matching? If so, which test system is best suited to reach the design goals? This paper explores various types of amplifiers in order to identify which can or cannot take advantage of harmonic matching, and to compare and contrast various harmonic load-pull methodologies as they relate to amplifier design.

HARMONIC IMPEDANCE MATCHING AND ITS RELEVANCE IN AMPLIFIER DESIGN

Amplifiers are designed for various applications ranging from highly linear LNAs and PAs operating in Class A condition, to highly nonlinear PAs operating in advanced classes (E, F, G, J and their inverses). Some are designed using unmatched transistors while others are designed using partially (pre-matched

or harmonically-terminated) - or fully-matched components. The design objective and the type of transistor used will dictate the need for harmonic impedance matching.

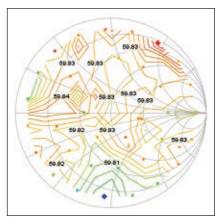
Amplifiers operating under linear (small-signal) conditions do not produce power at harmonic frequencies, and the output power of a device under test is linearly proportional to its input power. Because no power exists at harmonic frequencies, terminating the harmonic impedances should have no effect on the performance of a stable device under test (DUT). Several mathematical methods using S-parameters, including unilateral design and conjugate match, exist for determining the ideal input and output matches for maximum power and gain.^{1,2} Alternatively, fundamental-frequency load-pull can be used to identify ideal matching impedances for a given figure of merit

Modern commercial and military systems may be required to operate over several octaves or over a decade in order to meet the frequency spectrum requirements of the application. As such, wideband amplifiers play a critical role in the overall performance of the radio or radar system, often dictating output power or gain flatness over the bandwidth. When designing an amplifier, the match at the fundamental frequency strongly influences the power and gain performance parameters. When dealing with wideband amplifiers, the ideal impedance match must be determined for subsets of the overall frequency range, and the matching network synthesized to achieve the desired wideband response. In this case, it is entirely possible that the harmonic frequencies (2fo, 3fo...) of the lower frequency band overlap a fundamental frequency in the middle or upper por-



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ightharpoonup Fig. 1 Drain efficiency load-pull contours at f_0 on a harmonically-terminated transistor.

tion of the frequency band. When this happens, the ability to independently match the harmonic impedances at each fundamental frequency is drastically reduced or even eliminated.^{3,4} Consider a design example of a wideband amplifier operating between 3.1 and 10.6 GHz. For a fundamental frequency of 3.1 GHz, a theoretical Class-F amplifier would require a short at the second harmonic of 6.2 GHz and an open at the third harmonic of 9.3

GHz. However, 6.2 and 9.3 GHz are required fundamental frequencies of the wideband amplifier, and the short/open terminations could yield low performance at those frequencies.

Commercial packaged transistors are available from multiple vendors with varying degrees of integrated matching, varying from completely unmatched to partially matched and fully matched. Completely unmatched transistors can be tuned for maximum performance at a given frequency, power and bias by determining ideal loading conditions at the fundamental and harmonic frequencies, if harmonic power exists. Partially-matched and fully-matched transistors offer less flexibility as the internal matching structure within the packaged component limits the ability to significantly alter the match presented to the internal transistor. Partially- and fully-matched packaged transistors are commonly offered with optimum harmonic terminations already implemented for specific applications such as the design of commercial wireless base stations and handsets; therefore the advantages of

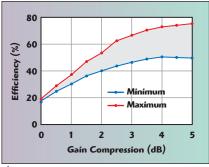


Fig. 2 Drain efficiency as a function of compression, with harmonic termination.

presenting additional harmonic terminations outside of the DUT package are practically eliminated.

Figure 1 shows the results of harmonic load-pull performed on a harmonically-terminated Freescale LDMOS Class-F transistor with integrated harmonic matching operating at 960 MHz with $V_{\rm dd}$ = 28 V, $I_{\rm dq}$ = 300 mA and 35 W output power at 1 dB gain compression. No improvement or trend can be seen when varying the harmonic terminations across the Smith Chart.

Harmonic impedance matching becomes critical in designing highly efficient amplifiers operating under compression or saturation for specific bands of operation. Under these conditions transistors will exhibit deep nonlinearities and put out power at one or more harmonic frequencies. It is under these nonlinear operating conditions that advanced classes of operation (E, F, G, J and their inverses) are achievable by terminating the harmonic impedances to ideal values.

In general, when power exists at the harmonic frequencies due to compression, power-added efficiency (PAE) can be improved by reflecting the energy back towards the device under test. This generally occurs as the magnitude of reflection $|\Gamma_L|$ approaches 1 at a specific phase angle (dependent on the reference plane of the measurement), with lower PAEs as the magnitude of reflection decreases.⁵⁻⁸

Figure 2 shows the change in drain efficiency at 2.5 GHz for a 10 W GaN transistor with varying levels of gain compression, from 0 dB (nearly small signal linear operating condition) to 5 dB (highly compressed approaching saturation) for the harmonic terminations which result in minimum (blue) and maximum (red) efficiency. The level at which termi-



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nating the harmonic impedances has an effect increases with the amount of harmonic power output by the device under test.

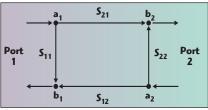
MODERN HARMONIC LOAD-PULL TECHNIQUES

Harmonic load-pull techniques have existed for decades, since the invention of the earliest closed-loop and open-loop active load-pull techniques between 1979 and 1990.9,10 While state-of-the-art at their time, these systems had inherent stability and processing issues that limited their commercial applications. Throughout the '90s and '00s, passive mechanical tuners were configured for harmonic load-pull using multiplexers to combine tuners in parallel 11 and advanced mathematics to internally/externally cascade tuners in-line. 12 As with all passive systems, achievable magnitude of reflection at the DUT was limited by the tuning range of the tuning network and the losses of the components used to connect to the device.

Modern open-loop active loadpull systems were introduced in the

'00s and '10s in order to overcome the weaknesses of the earliest active systems as well as the limitations of purely passive systems.¹³ Each system, passive harmonic, open-loop active harmonic, hybrid active harmonic and mixed-signal active harmonic has its own strengths and weaknesses, each of which should be clearly understood. The key topics that differentiate the load-pull techniques are measurement method, available magnitude of reflection at the DUT reference, methodology of harmonic control, tuning accuracy and speed, and system cost.

Load-pull systems can be based on scalar or vector measurements of power waves. Scalar-based systems use power meters or spectrum analyzers to measure scalar values at a specified marker or the entire signal, which are then de-embedded to the device reference plane. Vector-based systems use a vector analyzer, calibrated at the DUT reference plane, to directly measure vector a- and b-waves (more accurately, without de-embedding) from which performance parameters



▲ Fig. 3 Two-port network defined by S-parameters and a- and b-waves.

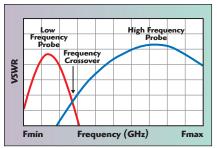


Fig. 4 Typical wideband probe response of a passive impedance tuner.

are calculated. A two-port network defined by S-parameters and a- and b-waves is shown in *Figure 3*. While passive load-pull methodologies can be either scalar- or vector-based, active load-pull methodologies require a vector-receiver to measure the a- and b-waves and determine the terminations presented to the DUT.

Passive impedance tuners are wideband in nature, which means the tuning element (probe/slug) inside the tuner creates a continuum of reflection vectors over a large bandwidth, possibly affecting multiple harmonics, as shown in Figure 4. With a single element, it is possible to control the impedance at one frequency of interest; however, the tuner will present uncontrolled wideband impedances at higher frequencies, including the harmonics. With n tuning elements internally cascaded in a single box or externally cascaded using multiple single-element tuners, it is possible to control the impedance presented at n frequencies. Therefore, a twoelement tuner configuration can present controlled impedances at two frequencies, and so on. 12

In a traditional scalar harmonic load-pull system comprised of cascaded tuning elements, the maximum magnitude of reflection achievable at any frequency is the summation of the reflections of the elements, minus the losses of the interconnection between the tuners and DUT such that $R_L(DUT) = R_L$ (tuner) + R_L (interconnection). In a typical setup using



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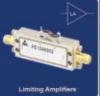


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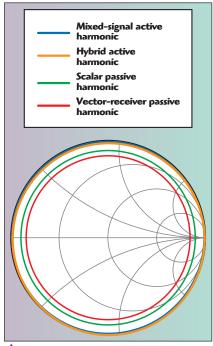


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 \blacktriangle Fig. 5 Maximum reflection of various loadpull methods at the second harmonic (2 f_0).

a 50 ohm test fixture at 2.5 GHz, a realistic $|\Gamma_L|$ =0.93 is achievable at the fundamental frequency while $|\Gamma_L|$ =0.9 is achievable at the second harmonic.

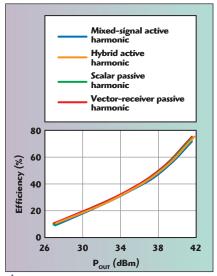
In a modern vector-receiver passive harmonic load-pull system, low-loss couplers are added between the tuner and DUT, thereby increasing the losses (R_L interconnection term) and decreasing achievable magnitude of reflection to 0.91 at the fundamental frequency and 0.85 at the second harmonic.

Open-loop active load-pull replaces the passive mechanical tuner with an active tuning chain consisting of a magnitude and phase controllable signal source. Instead of using a passive tuner to reflect energy back to the DUT, the signal source creates a new signal which is injected into the output of the DUT, satisfying $\Gamma_L = a2/b2$.

In a hybrid active load-pull system using a passive tuner for fundamental impedance control and active tuning chains at the harmonics, realistic $|\Gamma_L|$ =0.86 to 0.91 is achievable at the fundamental frequency while $|\Gamma_L|$ >1 (limited only by injection power) is achievable at the second harmonic.

A purely active load-pull system would have no limits on achievable magnitude of reflection at any frequency so long as the active tuning chain can produce sufficient power to satisfy $\Gamma_{\rm L}=a2/b2$.

It is important to note that as



▲ Fig. 6 Drain efficiency vs. output power using harmonic load-pull methods with identical loads.

frequency increases, the insertion losses of the interconnections generally increase and the tuning range of passive tuning systems decrease. *Figure 5* compares the typical magnitudes of reflection achievable at the harmonic frequencies for the various harmonic load-pull methodologies at fo=2.5 GHz.

Active load-pull systems often make use of commercial VNAs which act as both vector-receiver and active tuning chains, depending on the quantity of available signal sources within the instrument. The VNA measures the a- and b-waves presented by the DUT, software calculates the resulting injection signal required to achieve $\Gamma_{\rm I} = a2/b2$ at the DUT reference plane and commands the source to create that signal, and the VNA measures the resulting wave at the DUT reference plane for accuracy. An iterative software algorithm adjusts the active injection signal magnitude and phase until the desired reflection is achieved within a predefined convergence limit. The process is repeated for each desired impedance and power.

A unique form of active load-pull is referred to as mixed-signal active load-pull (MSALP) and utilizes wide-band arbitrary waveform generation with up-conversion, and wideband data analysis with down-conversion, instead of classic active load-pull single frequency generation and analysis methodology. Because of its wideband nature, MSALP uses a time-slotting approach to present many impedanc-





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es, near-simultaneously, to the DUT, resulting in a much faster tuning and measurement time. 13

Regardless of the method used, the same impedances presented at the same frequencies should yield the same measurement results. *Figure 6* demonstrates a comparison of measurement results between scalar passive, vector-receiver passive, hybrid active and mixed-signal active harmonic load-pull systems for the same fo, 2fo and 3fo load impedances.

An investigation into the performance of drain efficiency shows that maximum efficiency improvement normally occurs at maximum magnitude of reflection of the harmonic load impedance. In order to yield the highest possible efficiency, a $|\Gamma_L| = 1$ should be presented at the harmonic frequencies.

Figure 7 shows the change in drain efficiency at 2.5 GHz for a 10 W GaN transistor with varying magnitudes of reflection at a fixed phase of reflection with fixed gain compression and bias. The impact of harmonic tuning increases with its magnitude: presenting a second harmonic termination at $|\Gamma_L| = 0.85$ (typical of a vector-receiver passive load-pull system) results in a drain efficiency of ~75 percent whereas $|\Gamma_L| = 0.99$ (possible with active load-pull) results in a drain efficiency of ~80 percent.

While each technique has different reflection limitations, each technique also has its own characterization, calibration and measurement advantages and disadvantages. In general, using a passive mechanical tuner requires a tuner characterization process, in which S-parameters of a tuning element are mapped into a database for various motor positions. Using n elements results in a time increase by a factor of n. Modern tuners equipped with an LXI™ interface used in conjunction with a modern VNA can be characterized in ~11 minutes per element for 700 to 1000 states, while two single-element tuners or a single two-element tuner requires ~22 minutes for characterization.

System calibration varies between scalar and vector systems. Scalar calibration involves a "power calibration" in which the losses through the input chain are calculated based on deembedding power meter readings, a process which takes several minutes. Vector-based load-pull calibration is two-fold or three-fold, and involves a vector calibration, an absolute power calibration, and an optional phase calibration for nonlinear VNA measurements. The two-step process takes ~5 minutes while the three-step process takes ~7 minutes.

Tuning time varies between passive and active load-pull methodologies, and the measurement instrument used. Scalar-based, passive load-pull relies on the movement of multiple tuning elements and a slow acquisition with averaging from a power meter. Vector-receiver passive load-pull relies on the same movement of multiple tuning elements; however, the measurement is faster as it uses a vector-receiver in place of the power meter. Traditional open-loop active load-pull measurements can be

TABLE 1	
COMPARISON OF LOAD-PULL MEASUREMENT TIME (MINUTES UNLESS STATED)	

		System Cal	Step 1	Step 2	Step 3
Setup	Tuner Cal		f ₀ Load-Pull, Fixed 2f ₀ at 50 ohms (35 Loads, 16 Powers)	2f ₀ Load-Pull, fixed f ₀ at Optimized Value (20 Loads, 16 Powers)	f ₀ Load-Pull, fixed 2f ₀ at Optimized Value (35 Loads, 16 Powers)
Scalar Harmonic (2 tuning elements)	22	3	11.1	6.4	11.1
Vector-Receiver Harmonic (2 tuning elements)	22	5	5.3	3.1	5.3
Hybrid-Active Harmonic (1 tuning element)	11	5	4.2	7.3	7.5
Mixed-Signal Active (0 tuning elements)	No Tuner	5	15 seconds	35 seconds	50 seconds



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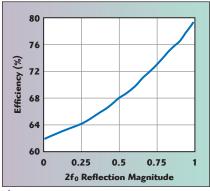


Fig. 7 Drain efficiency as a function of 2f₀ reflection magnitude at a constant phase.

faster or slower than a passive tuner, depending on the accuracy of the desired tuning and the resulting number of iterations required to converge on the desired impedance (~30 dB tuning accuracy results in faster measurements while ~50 dB tuning accuracy may result in slower measurements). Because mixed-signal active load-pull uses a time-slotting approach with wideband signal generation and analysis, it can present many impedances, near-simultaneously, to the DUT, resulting in a much faster tuning and measurement time.

Table 1 shows the time associated with tuner characterization (if applicable), system calibration, fundamental impedance load-pull with power sweeps for a fixed second harmonic impedance, and second harmonic impedance load-pull with power sweeps for a fixed fundamental impedance. For this comparison, commercial load-pull systems from Maury Microwave were used. The tuners were MT982ML01 LXI[™]-certified harmonic tuners; the vector-receiver used was N5242A PNA-X; the active tuning chain consisted of N5242A PNA-X second internal source with an external amplifier; the software used was the MT930-series IVCAD measurement and modeling device characterization suite; the mixed-signal active load-pull system was Maury Microwave's MT2000.14

CONCLUSION

It is essential to plan ahead and understand the design objectives and limitations before launching into an extensive and time-consuming design process. With regards to amplifier design, it is important to determine whether the objective is a small-signal linear amplifier, a narrowband highly efficient amplifier or a wideband amplifier, and whether it will use unmatched, partially-matched or fullymatched packaged transistors. Only when the objectives have been defined will it be possible to determine whether the design can or cannot make use of harmonic impedance terminations. If it has been determined that harmonic tuning is required, additional thought must be given to the ideal methodology and technique, evaluating the desired magnitudes of reflection, the equipment that will be dedicated to the load-pull station, and the time allocated to the test and measurement process.

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Antenna Characterization and Channel Measurements in the mmWave and Sub-mmWave Region

Mohammed Salhi, Thomas Kleine-Ostmann and Thorsten Schrader *Physikalisch-Technische Bundesanstalt (PTB)*, *Germany*

We employ a new antenna scanning system to measure the radiation pattern of mmWave and sub-mmWave antennas in the far field and describe broadband channel measurements in distinct indoor communication scenarios for frequencies up to 220 GHz. A motorized system is used to angularly scan propagation paths in a typical office and living room. As future indoor THz communication systems rely on electronically steerable antennas, a patch antenna array with a waveguide-to-microstrip transition is designed as a representative antenna under test (AUT).

The need for higher transmission data rates is increasing daily. To cope with . this demand, the use of higher frequencies up to the THz region for short range and indoor communications over the next few years seems inevitable.1 Conventional RF and microwave antenna systems are becoming less appropriate with increasing frequency. The remarkable advantage of using millimeter and sub-millimeter systems is the small size of components and hence the potential for miniaturization. As a consequence, test and measurement instrumentation needed for this frequency range is also miniaturized and often more advanced.² Much improvement is necessary to make these test and measurement systems generally available to stakeholders.

Characterization of mmWave antennas is a significant issue when designing a radar or a communication system. Frequencies between

30 and 300 GHz correspond to wavelengths ranging from 10 to 1 mm. Antennas of this size can easily be characterized directly in the far field, in contrast to components at RF and microwave frequencies that are typically characterized mathematically from near field measurements.

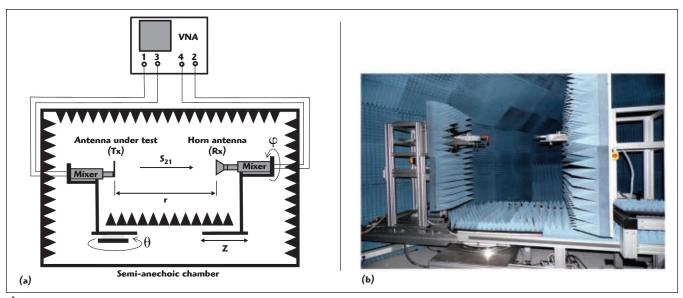
While the concept of ultra-broadband mmWave and sub-mmWave communications is established,³ antenna and propagation measurements for channel modeling of anticipated future communication systems are hardly available. Channel characterization requires measurements of line-of-sight (LOS) and nonline-of-sight (NLOS) propagation paths⁴ along with reliable knowledge of antenna gains and radiation patterns. Furthermore, it includes investigation of the influence of walls and objects on propagation. This includes scattering,⁵ diffraction⁶ and shadowing effects.



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📤 Fig. 1 Measurement setup based on an antenna scanner constructed inside a semi-anechoic chamber (a). Photograph of the measurement setup (b).

FAR FIELD ANTENNA SCANNER

An antenna scanner was built at PTB for measuring the antenna radiation pattern in the far field region within a distance of up to three meters. The scanning system is able to record measurements with high accuracy at an angular resolution as small

as 0.1°. The far field antenna scanner, which is sketched in *Figure 1*, has a rotor arm (Tx) and a rail arm (Rx). The AUT is placed on the rotor arm Tx, and the known measuring antenna is placed on the rail arm Rx. The rail arm is fixed on a track movable up to three meters from the vertical axis of the

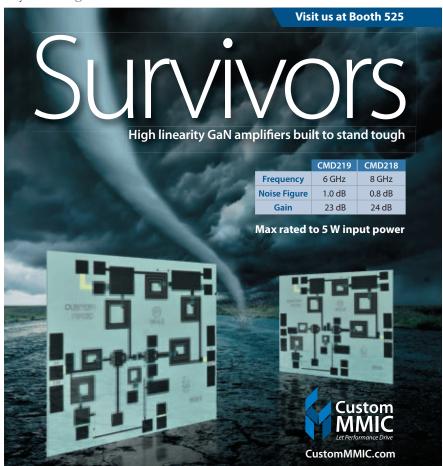
rotor arm. The rotor arm is rotatable within an angle Q from -90° to +90° around the vertical axis. Moreover, antenna fixtures on both arms are rotatable with an angle w from zero to 360° around the horizontal axis. This allows antenna measurements with any possible polarization.

The scanner is installed in a semianechoic chamber equipped with absorbers to minimize unwanted reflections and block external signals. Since the frequency converter modules themselves are built in metallic boxes, additional absorbers are placed behind the antennas as well.

Transmission measurements based on vector network analysis are used to determine antenna characteristics (i.e., gain and radiation patterns) and propagation. For measurements using the antenna scanner, a Rohde & Schwarz ZVA-50 VNA with a ZVA-Z110 frequency extender is used to cover W-Band (75 to 110 GHz). The VNA supplies the mixers in the frequency extension modules with the necessary LO and RF signals. The measurement ports are WR-10 rectangular waveguide flanges. One port is connected to the antenna array, while the other flange is fitted with a

INSTRUMENTATION FOR TRANSMISSION MEASUREMENTS 20 dB standard gain horn antenna. **ANTENNA DESIGN**

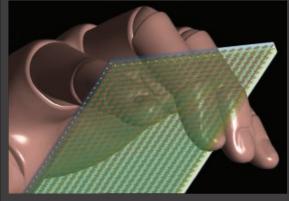
The antenna array is designed and optimized using CST Microwave Stu-





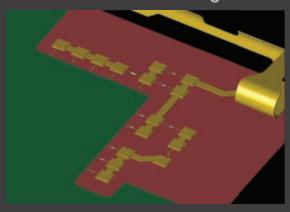
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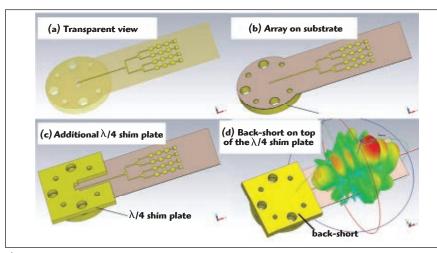


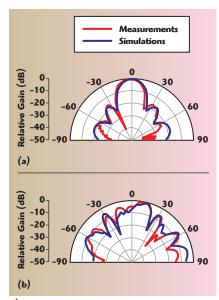
Fig. 2 Transparent view (a), array on substrate (b), additional quarter-wave shim plate (c), backshort on top of the quarter-wave shim plate (d).

dio⁷ based on the finite integration technique (FIT). Figure 2 shows the antenna array structure fabricated on an Ro3003TM substrate (dielectric constant ≈ 3). For signal distribution, a two-stage Wilkinson divider/combiner matches the patch to the junction line impedance.

Although the transition from rectangular to planar structures is already an established topic, it is still being improved, especially along with the development of new millimeter wave techniques.⁸⁻¹⁰ Designing a waveguide transition depends on frequency range, bandwidth and, of course, the substrate. The advantage of the transition used here is the absence of an impedance transformer and the optimized function using a back-short. Similar transitions have been presented and analyzed earlier by Leong and Shih. 11,12







▲ Fig. 3 77 GHz antenna array radiation patterns: H-plane (a) and E-plane (b).

The output signal from the frequency extension module is coupled from the flange through a hole in the ground layer at the backside of the substrate. There, a rectangle of 2.54×1.27 mm² is etched in the ground layer (see Figures 2a and b) to allow for wave propagation from the rectangular waveguide of the flange through the substrate and then to the microstrip line. On top of the antenna, a quarter wavelength shim plate (see *Figure 2c*) and a termination backshort (see Figure 2d) are placed. A slit is milled from the waveguide along the microstrip line to avoid contact between the feed line and the shim plate, allowing undistorted propagation to the antenna patches. The shim plate thickness and the feed line cavity width are optimized by including them in the antenna simulation. The shim plate combined with the back-short minimizes back-reflected radiation into the rectangular waveguide. In the substrate, the shim plate and the back-short, precision placement holes are drilled to allow for accurate positioning of the antenna on the flange of the frequency converter through locating pins. In addition to the four precision holes, another three holes are drilled for screws to tighten the substrate to the flange. The shim plate and back-short are fabricated with a high-precision CNC machine to minimize mechanical displacement.

RADIATION PATTERNS FROM THE FAR FIELD ANTENNA SCANNER

The array is placed on the converter of the rotor arm for measuring radiation



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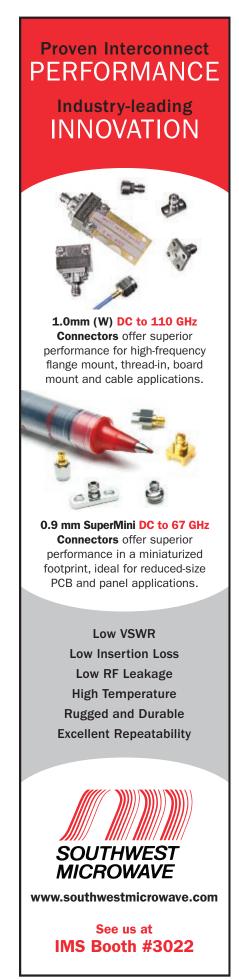












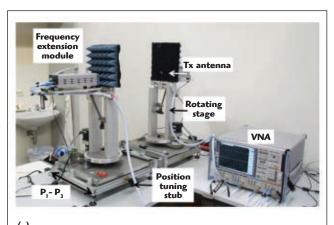
patterns with the antenna scanner. A W-Band standard gain horn antenna with 20 dB gain is attached to the other frequency converter on the rail arm. Assuming D is the linear aperture of the antenna, which is the distance from the first to the last patch of the array, then the far field lies at a distance $d \ge 2D^2/\lambda$, ¹³ which exceeds 4 cm for the 77 GHz array.

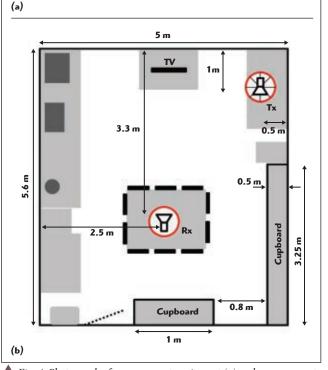
The antenna array is scanned at a distance of 50 cm with 1° resolution from -90° to $+90^{\circ}$ in the horizontal plane. Figure 3 compares time-domain the simulations to measured radiation pattern of the 77 GHz array as measured in the H-plane (a) and E-plane (b) using the far field scanner. In agreement with the simulation, the main lobe in the H-plane has a half-power beamwidth (HPBW) of 23.2°, and the side lobe level is -10 dB less than the main room schematic (b). lobe. In the E-plane,

several side and minor lobes are observed whereas the main lobe lies at about 13° from the perpendicular projection (imperfect broadside) and has a HPBW of 15°. A further design optimization could improve the directivity of the antenna. Measurements with the far field scanner, especially at the main and sidelobes, agree well with simulation.

BROADBAND PROPAGATION MEASUREMENTS

For modeling and design of communication systems in the lower THz frequency range propagation conditions need to be known. In the following we explain the procedure of ultrabroadband channel measurements for frequencies between 50 and 325





igwedge Fig. 4 Photograph of measurement equipment (a) and measurement room schematic (b).

GHz in an indoor download scenario related to a living room environment. The measurements shown here include frequencies between 140 and 220 GHz.

Measurement Setup

These measurements use the VNA and the frequency converters introduced earlier. A pair of the frequency converters (Rohde & Schwarz ZVA-Z220) with output couplers based on WR-5 rectangular waveguides are generating and detecting the signals. Standard gain horn antennas, each with 20 dB gain, are attached to the waveguide flanges of the frequency converters. The typical output power of the converters is about -14 dBm and the dynamic range is better than



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M10004A	20-1000	50	10	Α	28 Vdc
M10022A	300-500	40	1000 Pk	AB	50 Vdc
M10015A	700-1000	40	50	AB	48 Vdc
M10016A	1800-2100	30	50	AB	48 Vdc
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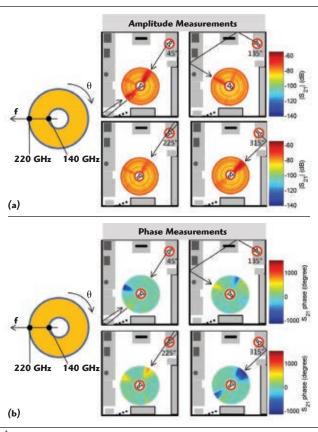
90 dB over the entire frequency band. The frequency converters are placed on mounts that are rotated by stepper motors as shown in *Figure 4a*. A computer program written in LabVIEWTM controls the stepper motors and records the measurements.

Living Room Download Scenario

One of the most relevant scenarios for future mmWave and sub-mmWave indoor communications is the transmission link within a home environment, as in the case for the wireless local area network (WLAN). This implies that both transmitter and receiver estab-

lish a directed path for transmission with high data rates over a short propagation distance. To mimic this download scenario, a room equipped with appropriate furniture is prepared. The room (see *Figure 4b*) contains tables, chairs, cupboards for books and dinnerware, and a flat screen TV. The transmitter (Tx) and receiver (Rx) are both mounted on rotational units at a distance of 3.1 m from each other. The heights of the Tx and Rx are 1.9 and 0.72 m, respectively. In the room, most of the existing components, except the cupboards, are lower than the antennas. The Tx is placed at selected angles of 45° , 135° , 225° and 315° as shown in Figure 5. The transmitter is at the upper right corner and the receiver is at a table at the middle of the lower part. The receiver is rotated 360° with 1° resolution.

To better depict the propagation paths, the results are represented in polar coordinates as illustrated in Figure 5. The radial coordinate represents frequency and the angular coordinate represents the angle of rotation. The value of magnitude and



▲ Fig. 5 Data legend and measurements. Amplitude (a) and phase (b).

unwrapped phase is presented according to the color bars. The radius of the circle starts with 140 GHz at the inner radius and increases with frequency to reach 220 GHz at the outer radius.

The upper part of Figure 5 shows the magnitude of the propagating signal and the lower part of the figure shows the measured phase. The measured result is depicted at the position of measurement where the receiver is placed on a table surrounded by several chairs (not shown here). The red color indicates a stronger signal where LOS and NLOS paths are identified. For example, when Tx is at 45°, the direct LOS path and multi-reflection paths are also observed. Scattering at the Rx holder also leads to additional multipath propagation.

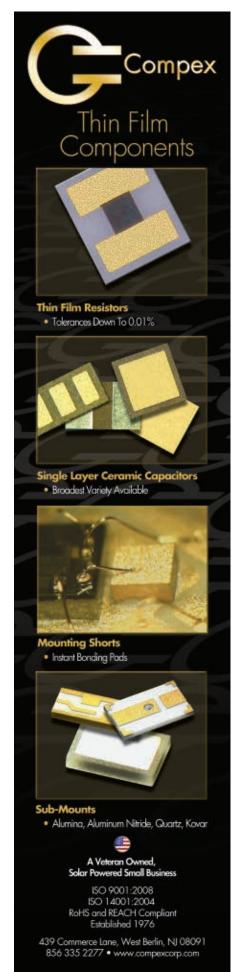
Looking at the phase measurements, some propagation paths are more detectable and some are less depending on the received phase of the signal. Ray-tracing simulations could reveal more information about individual propagation paths, but that is beyond the scope of this article.





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CONCLUSION

In this article we introduced measurement techniques to characterize antennas and propagation paths in typical indoor environments for future communication systems operating in the lower THz frequency range. We introduced an antenna scanning system that measured the antenna diagram with 0.1° of angular precision. A 4×4 patch array antenna was designed with a waveguide-to-microstrip transition and tested with this system. We also reported the broadband propagation measurements at frequencies up to 220 GHz. These measurements of magnitude and phase detected the main propagation paths – LOS and NLOS.

ACKNOWLEDGMENTS

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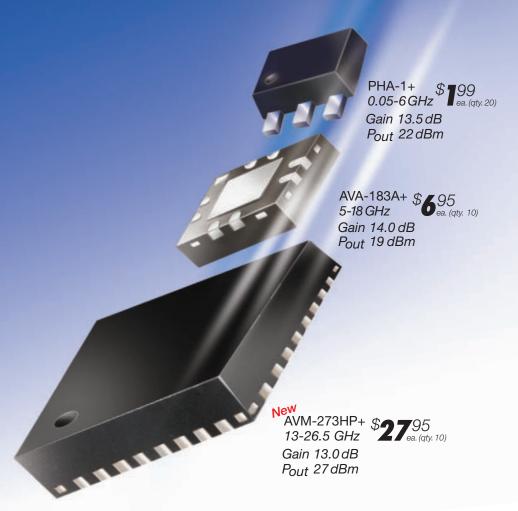
Mohammed Salhi received his Ph.D. degree in electrical engineering from the Technische Universität Braunschweig, Germany, in 2009. Since then he has been working as a researcher engineer in the Electromagnetic Fields and Antenna Measuring Techniques Group at the German National Metrology Institute (PTB) in Braunschweig, Germany. His main topics of interest are in the field of millimeter waves and terahertz technology.

Thomas Kleine-Ostmann received his M.Sc. in electrical engineering from Virginia Polytechnic Institute and State University, Blacksburg, Va. in 1999, and both the Dipl.-Ing. degree in radio frequency engineering and the Dr.-Ing. degree from Technical University Braunschweig, Germany, in 2001 and 2005, respectively. Since 2006, he has been working as a permanent scientist with the Electromagnetic Fields Group at the Physikalisch-Technische Bundesanstalt. He is currently working on realization and transfer of the electromagnetic field strength, electromagnetic compatibility, and THz metrology. He became head of the Electromagnetic Fields Group in 2007, and head of the Electromagnetic Fields and Antenna Measuring Techniques Group in 2012. He received the Kaiser-Friedrich Research Award in 2003 for his work on a continuous-wave THz imaging system.

Thorsten Schrader received the Dipl.-Ing. and the Dr.-Ing. degrees in electrical engineering from the Technische Universität Braunschweig, Germany, in 1992 and 1997, respectively. In 1998 he worked for EMC Test Systems LP, in Austin, Texas (now ETS-Lindgren, Čedar Park, Texas). In 1999 he joined the working group High Frequency Measurement Techniques of Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany. During 2000 he was a member of the Presidential Staff Office at PTB. In 2004, he became the head of the working group Electromagnetic Fields and Électromagnetic Compatibility.Schrader has been the head of the department of High Frequency and Fields since 2005 and the working group Antenna Measuring Techniques from 2006 to 2011. His current interest is the metrology for RF quantities in the mmWave and sub-mmWave range.

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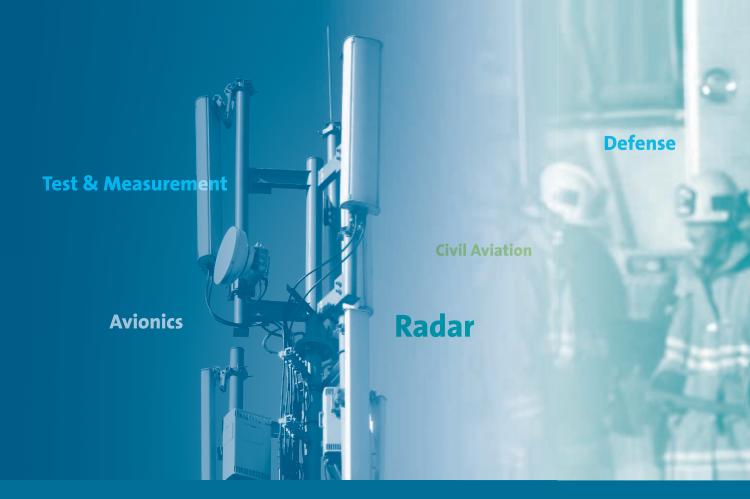
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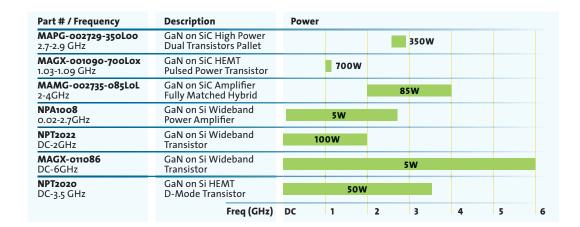
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Fully-Differential Amplifiers and Benefits When Driving ADCs

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This article reviews the basics of fully-differential amplifiers (FDA), important specifications and what they mean, and how to interface to the signal chain using an FDA for balun-type functionality with additional performance.

In today's world, most high-speed analog-to-digital converters (ADC) have differential inputs. These ADCs are used in a wide variety of applications ranging from, but not limited to, communications wireless infrastructure and backhaul to test and measurement oscilloscopes and spectrum analyzers. To support this input architecture, engineers must design the signal chain to interface to the ADC differentially.

It is easy to assume that one must use a balun in the signal chain for best performance, despite coupling issues in some applications. This is not always the case, however, especially in test and measurements where the DC component is needed. Fully differential amplifiers (FDA) are versatile tools to use in place of (or along with) baluns and offer a variety of benefits. Fully differential signal processing provided by FDAs gives the circuit design increased immunity to external noise, twice the dynamic range and reduced even-order harmonics versus traditional amplifiers with single-ended outputs.

WHAT IS AN FDA?

Imagine not having the luxury of an FDA integrated circuit (IC) to drive a differential ADC. One approach, other than a balun, is to create a differential signal using two operational amplifiers, one providing the positive $(V_{in}+)$ and the other providing the negative $(V_{in}-)$ input signal. To establish the proper external gain, eight resistors are needed.

With half the resistor count and only one IC, an FDA can provide both a single-ended-to-differential-interface and a differential-to-differential interface to the ADC. This also eliminates the need for a balun and allows DC components to pass; a balun provides DC isolation. This is important in many applications that need a superior response at low frequencies down to DC. An FDA is two amplifiers in one, a main differential amplifier (from $V_{\rm int}$) composed of multiple feedback paths and the $V_{\rm ocm}$ error amplifier (better known as the common-mode output amplifier).

The V_{ocm} amplifier samples the differential voltage (V_{out} + and V_{out} -) internally and com-

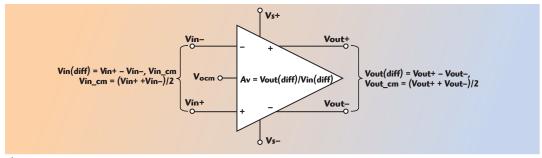
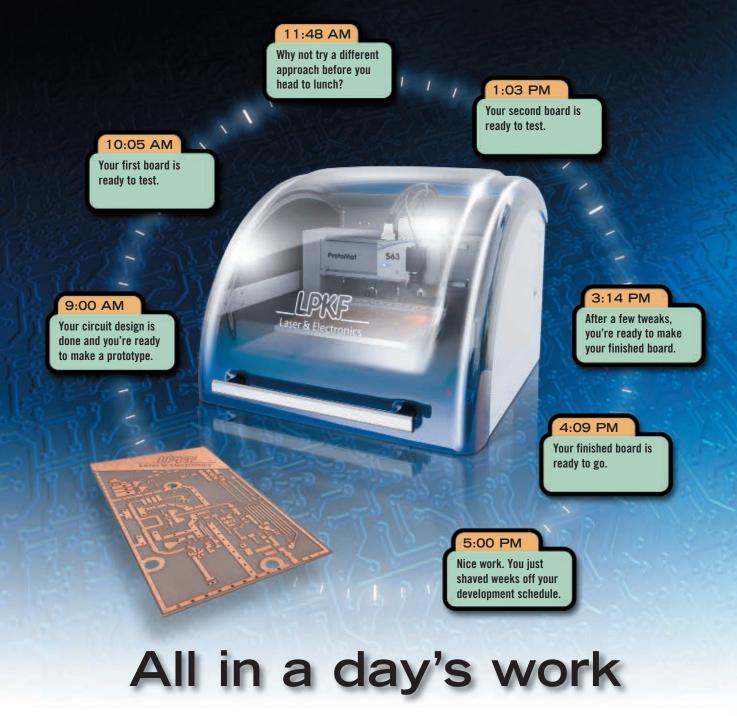


Fig. 1 Diagram of a typical fully-differential amplifier.



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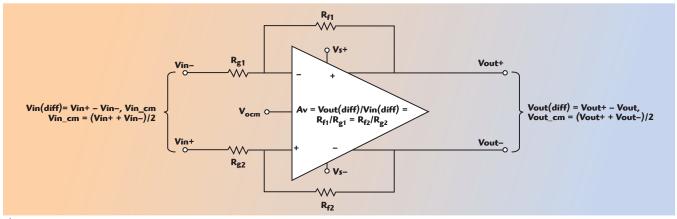


Fig. 2 Basic FDA gain configuration, differential input-to-differential output.

pares it to the voltage applied to the $V_{\rm ocm}$ pin. Through an internal feedback loop, the $V_{\rm ocm}$ amplifier is used to drive the "error" voltage of the $V_{\rm ocm}$ error amplifier (the voltage between the input pins) to zero, so that $V_{\rm out_cm} = V_{\rm ocm}$ (see **Figure 1**). If the $V_{\rm ocm}$ pin is left floating, the bias point usually defaults to $V_{\rm cc}/2$ (midway between supplies) through an internal voltage divider. This $V_{\rm ocm}$ setting on the $(V_{\rm ocm})$ pin can impact the overall output swing (as discussed later).

This is different than in a traditional op amp with a single-ended output, where the output common-mode voltage and single-ended output are inherently the same signal, impacting the dynamic range.

In addition to the $V_{\rm ocm}$ error amplifier, the main differential amplifier in the FDA has both a $V_{\rm out+}$ and $V_{\rm out-}$ output and multiple feedback paths. When analyzing this amplifier it is best to think of it as including two inverting feedback paths. One consists of an in-

verting input to non-inverting output, and the other is a non-inverting input to an inverting output (see Figure 1). For the FDA to function properly, both paths must be closed. To maintain balance, the feedback paths are best kept equal. Analysis of these two paths can become very complicated. The analysis is simplified in this discussion to introduce FDA basics and illustrate how they can assist design. FDA input and output voltages are defined in Figure 1.

In **Figure 2** external resistors are added to the basic FDA diagram to set the gain. For this simplified analysis, we define $\beta 1$ and $\beta 2$ as the feedback terms.

$$\beta 1 = \frac{Rg1}{Rf1 + Rg1} \tag{1}$$

$$\beta 2 = \frac{Rg2}{Rf2 + Rg2} \tag{2}$$

The full $\rm V_{out}$ (diff) equation in terms of feedback, $\rm V_{in} \hbox{+}, \rm V_{in}\hbox{-}$ and $\rm V_{ocm}$ is

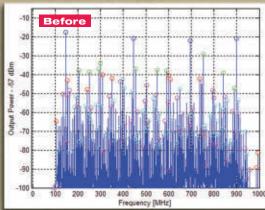
$$\begin{split} &V_{out} (diff) = \left(2 + (\beta 1 + \beta 2)\right) * \\ &\left(\left(V_{ocm} (\beta 1 + \beta 2) + \left((V_{in} +)(1 - \beta 1)\right) - \right. \\ &\left.\left(\left(V_{in} - \right)(1 - \beta 2)\right)\right) / \left(1 + \left(\frac{2}{\beta 1 + \beta 2}\right)\right) (3) \end{split}$$

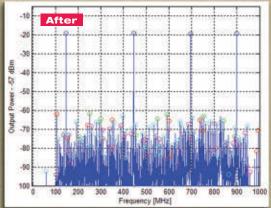
Equation 3 shows that if the feedback terms are not equal, the differential output voltage depends on $V_{\rm ocm}$. This is important, because the feedback terms should be equal or as close to each other as possible, because the $V_{\rm ocm}$ term introduces both an offset and noise. With $V_{\rm ocm}$ = 0, the gain becomes

$$\begin{aligned} & \operatorname{Gain}(\operatorname{Av}) = \\ & \frac{\operatorname{V}_{\operatorname{out}}\left(\operatorname{diff}\right)}{\operatorname{V}_{\operatorname{in}}\left(\operatorname{diff}\right)} = \frac{\operatorname{Rf}1}{\operatorname{Rg}1} = \frac{\operatorname{Rf}2}{\operatorname{Rg}2} \end{aligned} \tag{4}$$



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FDA BENEFITS

Inherent in its differential architecture, the FDA improves noise immunity and system dynamic range. System noise can accumulate and impact dynamic range when signals travel across a printed circuit board (PCB), cables and wiring, and through signal and ground paths. The FDA enables coupled noise to be rejected at the inputs. This includes noise from power supplies and signals that appear as a common-mode in a typical op amp. Single-ended components cannot reject ground noise as each part has a different reference point. Despite diligent design efforts to control highfrequency ground currents, issues may arise where differential signaling can improve performance. Noise accumulation in a typical op amp may degrade signal-to-noise ratio (SNR), compromising system design.

Along with greater noise immunity due to common-mode rejection by the FDA, the phase difference between the outputs enables the output voltage swing to be twice that (6 dB) of a single-ended output (see *Figure*

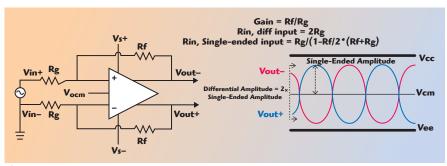
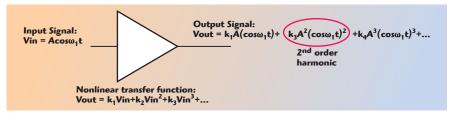


Fig. 3 Dynamic range increase in FDAs.



📤 Fig. 4 Fully differential amplifier configuration.

3). This increases the amplifier's headroom using the same power supply or allows the use of a lower voltage power supply, with lower dissipation, for the same signal swing.

A further advantage of FDAs and differential signal chains is inherent cancellation of even-order harmonics. Using a power series expansion, given a sine wave input and ignoring the DC component, *Figure 4* illustrates second-order harmonic cancellation in nonlinear differential devices such as amplifiers (FDA). While full cancellation cannot be achieved in real devices, these products see a benefit from a balanced design over a single-ended configuration (see *Figure 5*).

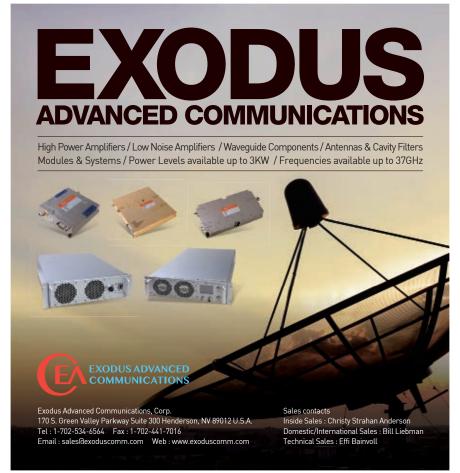
FDAs also provide excellent output balance critical to driving differential ADCs. Phase and amplitude components of the signal into the ADC are ideally matched for best performance. When there is unbalance in either or both the amplitude and phase, this is seen as a common-mode component on the output, producing SNR degradation. An ideal FDA can provide precisely 180° phase difference between the \dot{V}_{out}^+ and \dot{V}_{out}^- signals. Since the internal common-mode feedback circuitry forces the output common mode to equal the applied common mode at the V_{oem} , the balance error, Equation 5, is minimal.

Balance Error (out)=

$$20\log\left(\frac{\Delta Vout(diff)}{\Delta Vout(cm)}\right)$$
 (5)

SPECIFICATIONS

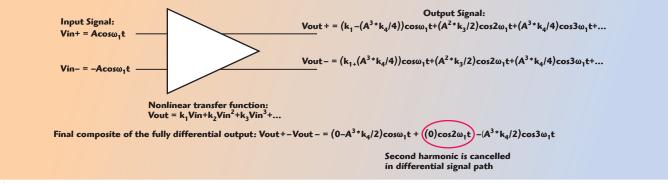
Of the specifications that may be of particular interest in high-speed system designs, linearity should be well understood; items that may need to be reviewed are common-mode voltage, noise and stability.





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▲ Fig. 5 Single-ended amplifier configuration.

Common-Mode Voltage Range

It may seem obvious how specifying the common mode voltage range impacts performance; however, a review of this topic is helpful since this is what makes the FDA so powerful. When choosing an FDA to drive a device such as an ADC, it is important to consider the differential ADC's common mode voltage and how this aligns with the FDA's common mode voltage range as well as $V_{\rm out}$ peak-to-peak (Vpp $(_{\rm out})$) capability. For AC-coupled signals, $V_{\rm ocm}$ alignment with the ADC is not much of a concern as long as the input and

output range are within specifications and are supplied as needed. Usually, one can default to mid supply of the amplifier to achieve best performance. An important consideration is Vpp (out) to meet maximum signal swing of the ADC. For an optimal system design, including margin to accommodate loss in the anti-aliasing filter is good design practice. For example, if the full scale ADC input is 1.2 Vpp and there is a 2 dB anti-aliasing filter loss, ideally 1.5 Vpp or higher should be available at the amplifier output to provide the needed margin.

In a DC-coupled design, knowing both the required $V_{\rm ocm}$ and voltage swing is paramount. Use Equations 6 and 7 to check that the amplifier can meet the desired output swing around $V_{\rm ocm}$.

$$V_{\text{out}_{\text{min}}} = V_{\text{ocm}} - \left(\frac{\text{Vpp(out)}}{4}\right)$$
 (6)

$$V_{\text{out}_{\text{max}}} = V_{\text{ocm}} + \left(\frac{\text{Vpp(out)}}{4}\right)$$
 (7)

With a DC-coupled signal, the performance and common-mode specifications at the desired $V_{\rm ocm}$ must be verified. Typically in an FDA datasheet, $V_{\rm icm}$ and $V_{\rm ocm}$ specifications are noted with minimum and maximum values. Additionally, graphs are provided to show the linearity impact and optimal range for the FDA common-mode voltage.

Depending upon the FDA, power supplies may sometimes be aligned to maintain a $V_{\rm ocm}$ just outside an optimal range for alignment with the ADC. Consider, for example, an FDA with ideal performance specified at mid-supply with ± 0.5 V of range and an ADC at 1.5 V $V_{\rm ocm}$. The supply to be used is a split supply, such that the amplifier is at $V_{\rm s}(+) = +4$ V and $V_{\rm s}(-) = -1$ V. Once verified that the required swing can be accommodated and that these supplies meet datasheet specifications, there should be no issue in using them to satisfy output common mode voltage needs.

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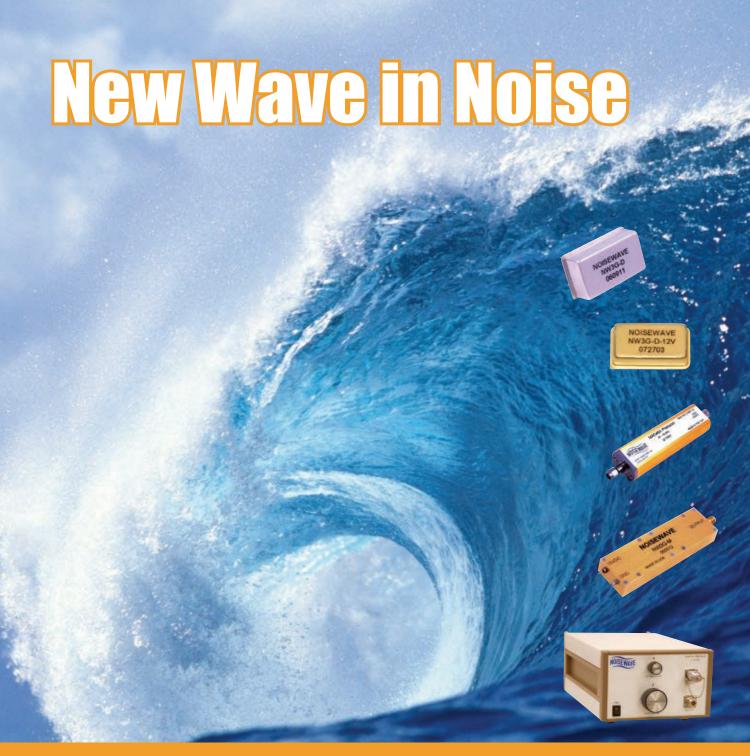
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Noise and Stability

Noise gain (NG) is essential to determining output noise and stability. Different from signal gain, noise gain is the reciprocal of the attenuation from the output of an amplifier (or any feedback loop) to the input and is equal to

$$NG = (Rin + Rf) / Rin$$
 (8)



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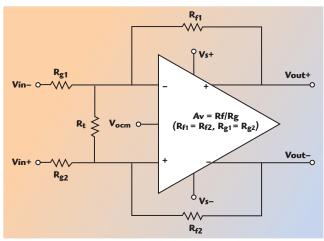
Assuming Rf1 = Rf2 and Rg1 = Rg2 in Figure 2, the noise gain is $1/\beta 1$ or $1/\beta 2$. Keep in mind that sometimes gain bandwidth products (GBP) are specified for FDAs. This is also dependent on NG as GBP (Hz) is equal to bandwidth in Hz times NG.

For simplicity, we assume purely resistive feedback. Capacitors added to the feedback and input can impact stability and NG, making the NG expression with complex impedance equal to

$$NG = (Zin + Zf) / Zin$$
(9)

Note the difference in the noise gain, Equation 8, and the signal gain, Equation 4. Their independence allows noise gain to be manipulated with signal gain held constant. For simplicity, only resistive feedback is considered in the following example. In Figure 6, a signal gain of 2 is desired in the FDA, but this FDA is stable only for NG \geq 3. For stability at this lower gain value, a 'dummy' resistor is added at the input (Rt in the differential configuration). The parallel combination of Rs and Rt is used to manipulate the amplifier's noise gain, while Rg and Rf are the signal gain-setting resistors. Adding Rt adjusts the noise gain for stability. By manipulating the noise gain with Rt, the amplifier is stabilized without impacting the signal gain or signal bandwidth. With increased NG, however, the system should be evaluated to determine if its impact on SNR and increased sensitivity to input offset voltage can be tolerated.

What is its impact on noise? To determine that, it helps to review the steps for evaluating the use of an FDA as a differ-



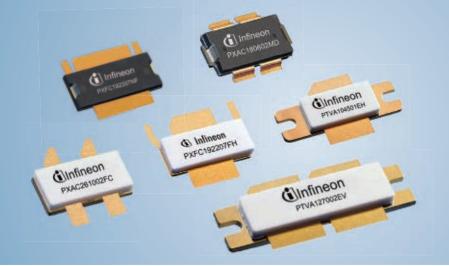
📤 Fig. 6 FDA with additional Rt to adjust noise gain.

ential ADC driver. The SNR of an n-bit ADC is quantified in Equation 10. For simplicity, assume that the ADC's SNR is the same as the reciprocal of total harmonic distortion (SINAD) and noise of the ADC. Given this, we can use the effective number of bits (ENOB) to calculate if the output noise of our FDA is sufficient to drive our ADC.

$$SNR_{ADC}(dB) = 6.02n + 1.76dB$$
 (10)

To calculate the FDA output noise, first reduce the circuit under evaluation to its simplest form (see *Figure 7*). Assume that the resistors are balanced and match as close as possible







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PTVA030121EA	390 – 450	No	12	25.0	69	14	22.0	73	12μs, 10% DC	13:1
PTVA035002EV	390 – 450	No	400	19.5	65	500	17.5	67	12μs, 10% DC	13:1
PTVA104501EH	960 – 1215	I/O	450	17.0	57	490	15.0	55	128μs, 10% DC	10:1
PTVA101K02EV	1030 / 1090	I	920	18.0	56	1090	16.0	57	128μs, 10% DC	10:1
PTVA120251EA	500 – 1400	No	30	16.0	56	40	14.0	59	300μs, 10% DC	10:1
PTVA120501EA	1200 – 1400	I	54	16.5	55	63	14.5	57	300μs, 10% DC	10:1
PTVA123501EC/FC	1200 – 1400	I/O	375	16.0	56	415	14.0	57	300μs, 12% DC	10:1
PTVA127002EV	1200 – 1400	I/O	700	16.0	55	800	14.0	58	300μs, 10% DC	10:1

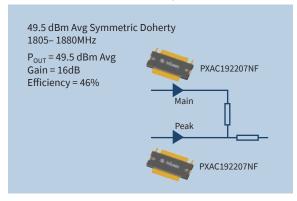
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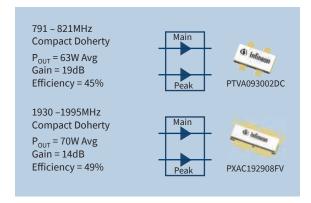
Product	Operating	Matching		@P _{1dB}			@P _{3dB}		Test Signal	VSWR
	Frequency (MHz)		P _{OUT} (W)	Gain (dB)	Eff (%)	P _{OUT} (W)	Gain (dB)	Eff (%)		
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	PXAC180602MD	Yes	1800 – 2000	21+28	18.0	50.0	28	PG-HB1DSO-4-1
EW	PXAC192908FV	Yes	1930 – 1995	110+120	14.0	49.0	28	H-37275G-6/2
EW	PXAC203302FV	Yes	1880 - 2025	140+220	16.5	46.0	28	H-37275-4
EW	PXAC243502FV	Yes	2300 – 2400	150+200	15.5	44.0	28	
EW	PXAC260622SC	Yes	2496 – 2690	25+50	17.0	45.0	28	H-37248H-4

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NEW	PTFC270051M	900 – 2700	Unmatched	7.3	20.3	60	-	CW @ 2170	28	3.84	PG-SON-10	,
NEW	PTFC270101M	900 – 2700	Unmatched	12	20.0	60	-	CW @ 2140	28	4.04	m	

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PTMA080152M	700 – 1000	Ţ	20	30	34	8	GSM/EDGE	28	8.5/2.5	PG-DSO-20-63
PTMA080302M	700 – 1000	I	32	31	36	15	GSM/EDGE	28	6.7/1.7	The state of the s
PTMA180402M	1800 – 2200	Ţ	40	30	16	5	CDMA	28	3.6/1.5	latinar 1
PTMA210152M	1800 – 2200	I	20	28.5	33	7	WCDMA	28	10.7/2.9	THE PROPERTY OF THE PARTY OF TH

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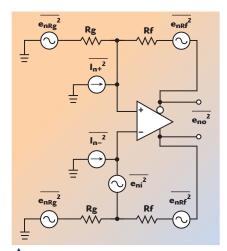


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▲ Fig. 7 FDA noise analysis simplified.

on each side. This ensures the balance of the FDA and match for the maximum HD2, IMD2 performance. Also assume that the total differential noise is the root sum of the squares (RSS) of the individual contributors (see Equation 11).

$$e_{no} = \frac{(11)}{\sqrt{\left(e_{ni}NG\right)^2 + 2\left(i_nRf\right)^2 + 2\left(4kTRfNG\right)}}$$
 Where:

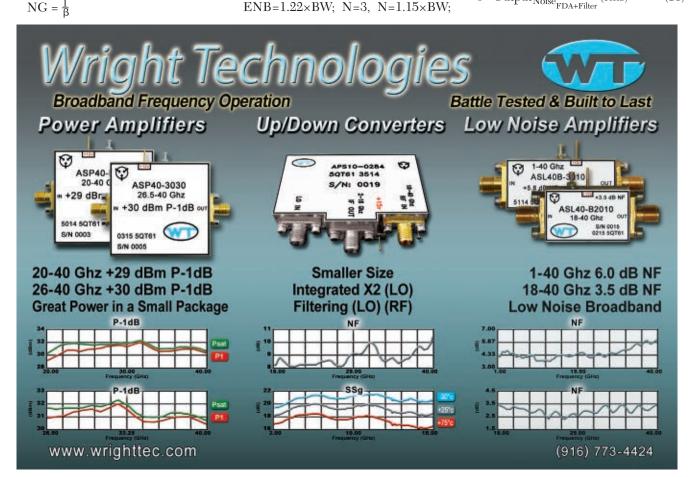
▲ Fig. 8 DC-coupled, single-ended input, differential output.

 $\begin{array}{l} e_{ni} = input \ voltage \ noise \\ (specified in \ datasheet \ of \ FDA) \\ i_n = input \ current \ noise \\ (specified in \ datasheet \ of \ FDA) \\ k = Boltzman's \ constant \\ (1.38 \times 10\text{-}23j/°K) \end{array}$

T = absolute temperature (273°K) Having determined the output noise, will this work in the system? For the anti-aliasing filter, we use a third order lowpass filter (N=1, ENB=1.57×BW; N=2, ENB=1.22×BW; N=3, N=1.15×BW; and so on). This means that the system noise bandwidth is 1.15×BW (signal). From here we use Equations 12-14 to check compatibility:

$$\begin{aligned} & \text{Output}_{\text{Noise}_{\text{FDA+Filter}}} (\text{rms}) = \\ & \sqrt{\text{System}_{\text{Noise}_{\text{BW}}} * e_{\text{no}}} \end{aligned} \tag{12}$$

$$Output_{Noise_{FDA+Filter}}(pp) = 6*Output_{Noise_{FDA+Filter}}(rms)$$
 (13)



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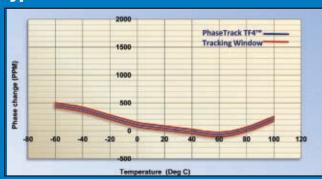


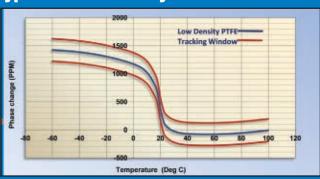
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One LSB =
$$FSpp / 2^n$$
 (14)

Finally, compare the one LSB value, which is in Vpp, to the output noise of the filter+FDA Vpp. If this is comparable, it is time to build an evaluation board to verify the calculation and assumptions. Note that the number '6' used in Equation 13 is based on the assumption of a Gaussian noise distribution.

SINGLE-ENDED INPUT APPLICATIONS

What if you have a single-ended input and need to convert for a differential ADC? Most would say this is exactly what baluns were made to do. However, these devices cannot provide a power gain, are susceptible to coupling by design, over temperature specifications are typically not well maintained, can be very big and costly if wideband signals are needed, and do not preserve the DC component. In a high speed system such as a communications receiver chain used in a test and measurement spectrum ana-

lyzer or oscilloscope, preserving the DC component while enabling GHz frequency capability may be necessary. In this case, an FDA can be a very useful tool.

If the design is DC-coupled, ensure both sides of the input circuit are configured to retain balance. The non-signal input side typically has an Rg component biased to the midrange of the expected source. This mid-scale reference point should give a balanced differential swing around $V_{\rm ocm}$ at the output. This is generally grounded if the source swings around ground. Configuring the FDA gain with external resistors provides design flexibility. Selected feedback resistors should be equal. Additionally, the impedances on each side from the summing junctions back to both the signal source and ground (or bias voltage, non-signal side) should be equal. Solve for Rt, Rg1 and Rg2; for detailed analysis refer to the LMH5401 datasheet.¹

Figure 8 shows a final schematic of the high-speed FDA using a 50 Ω source impedance (Rs) and G = 4 V/V. The NG in this example is established by NG1=1+Rf1/Rg2, or just over

three, which is unconditionally stable for this FDA.

CONCLUSION

While this article covers only the basics of fully differential amplifiers, hopefully the information will help influence your choice of amplifier by informing you of options. Before reaching for the balun, ask yourself if an FDA is more appropriate.

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Carissa Sipp is the RF systems applications engineer for TI's high speed group. She received her bachelor's degree from The Ohio State University in Columbus, Ohio. Carissa can be reached at ti_csipp@list.ti.com.



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Compact Microstrip Lowpass Filter With Ultra-Wide Stopband Using a Modified Circular Resonator

Mohsen Hayati Razi University, Kermanshah, Iran Parisa Karami Moghadam Islamic Azad University, Kermanshah, Iran

A compact microstrip lowpass filter (LPF) employing modified circular resonant patches and folded lines has a sharp rolloff, an ultra-wide stopband from 4.5 to 32 GHz with 26.2 dB attenuation and insertion loss of less than 0.12 dB.

icrostrip lowpass filters (LPF) are important for the suppression of undesired signals in microwave communication systems. A sharp transition band, a wide stopband and low passband insertion loss are key performance characteristics. Conventional LPF design methods are not normally used due to inherent deficiencies such as slow roll-off, poor frequency response in the passband and a narrow stopband. ¹

Ma and Yeo describe an ultra-wide stopband LPF using transformed radial stubs,² however its passband insertion loss and return loss are poor and the structure is complex. A compact LPF with a wide stopband using a steppedimpedance compact microstrip resonator cell (SICMRC) has been proposed by Hayati and Abbasi.³ It has adequate insertion loss and return loss in the passband but exhibits a gradual roll-off in the transition band. The use of a G-shaped defected microstrip structure provides a sharp roll-off with negligible radiation loss, but the return loss and passband insertion loss

are inadequate.⁴ The structure is large in size as well. Another approach using a front-coupled tapered compact microstrip resonator cell (CMRC), has been employed in an attempt to achieve compact size; however, the filter has a gradual roll-off and a narrow stopband.⁵

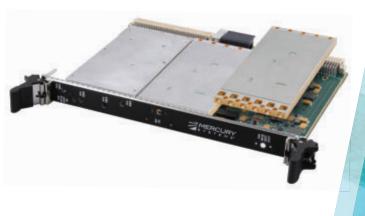
In recent years, defected ground structures (DGS) have been used in a variety of different ways for LPF applications.^{6,8,9,10} Although they have improved stopbands, the etched ground of the DGS causes radiation problems. Passband insertion loss is generally poor, and total size is large. Al-Omair et al., introduce designs of compact LPFs and bandpass filters based on a DGS using two complementary split ring resonators (CSRR) that are etched in the ground plane.9 The return loss and the insertion loss in the passband are inadequate, however, the filter is large in size with a narrow stopband. A patterned ground and its equivalent lumped circuit model are analyzed in depth by Shao and Li,11 however, the LPF is also large size with a narrow stopband. Chen

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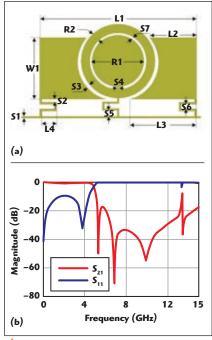


Fig. 1 Resonator layout (a) and frequency response (b).

et al., ¹² describe a compact wide stopband koch-shaped electromagnetic bandgap microstrip LPF. By forming the low impedance segments with fractal shapes, ¹³ the passband performance of a stepped-impedance LPF can be modified, but this structure has gradual roll-off in the transition band.

This article introduces a compact microstrip LPF with an ultra-wide stopband, sharp roll-off, high return loss and low passband insertion loss. This is achieved with modified circular resonant patches and folded lines.

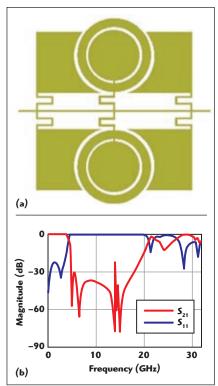


Fig. 2 Modified resonator layout (a) and frequency response (b).

LPF DESIGN

The LPF design starts with a resonator that achieves a sharp roll-off. Its performance is improved by mirroring, to form a modified resonator. Suppressing cells are added to eliminate harmonics, resulting in a two-cell filter. A four-cell filter uses the two-cell filter in a cascaded form.

Resonator Design. The layout and dimensions of the resonator are

shown in Figure 1a. Using high-impedance folded transmission lines instead of straight ones not only reduces the circuit size but also improves the transition band. The frequency response of the resonator is shown in **Figure 1b**. It has a wide stopband with three transmission zeros at approximately 5.32, 6.82 and 9.87 GHz with attenuation levels of 51.14, 70.91 and 54.79 dB, respectively. The dimensions of the resonator are optimized using Keysight's Advanced Design System (ADS) electromagnetic simulator. After optimization, the dimensions of the proposed resonator are L1 = 7 mm. L2 = 2.1 mm. L3 = 3mm, L4 = 0.68 mm, W1 = 2.75 mm, R1 = 1.15 mm, R2 = 0.4 mm, S1 = S2= S4 = S7 = 0.1 mm, S3 = 0.14 mm, S5= 0.23 mm and S6 = 0.2 mm.

Mirroring. The modified resonator is shown in *Figure 2a*. It is apparent from Figures 1b and 2b, that the location of the first transmission zero is reduced from 5.32 to 5 GHz, resulting in a sharper roll-off; insertion loss and return loss in the passband are improved and the width of the stopband is extended to 14.6 GHz.

Suppressing Cell Design and Integration. The layout of the suppressing cell is shown in *Figure 3*. Its dimensions are L5 = 0.65 mm, L6 = 0.8 mm, n1 = 0.1 mm, n2 = 0.15 mm, Rt = 1.6 mm, Wt = 1.1 mm and θ = 10 degrees. To extend the width of the stopband and increase attenuation levels, four high-impedance lines loaded



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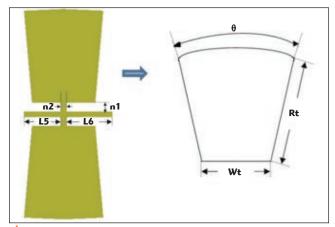
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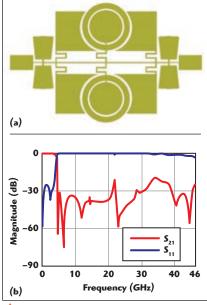
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A Fig. 3 Suppressing cell layout.



▲ Fig. 4 Two-cell LPF layout (a) and frequency response (b).

with radial stubs are added to the modified resonator. The layout and frequency response of a two-cell LPF are shown in Figures 4a and 4b, respectively. As shown Figure 4b, the two-cell LPF has a stopband rejection better than 20 dB from 4.65 to 46 GHz, insertion loss of less than 0.06 dB and return loss greater than 25 dB in the passband.

Four-cell filter design. The layout and frequency response of the

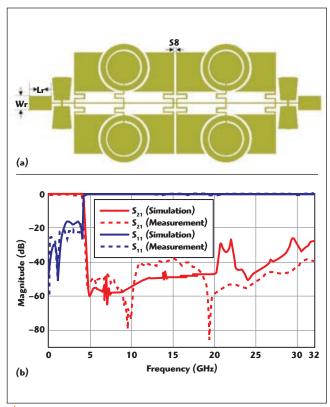


Fig. 5 Four-cell LPF layout (a) and frequency response (b).

four-cell filter are shown in **Figures 5a** and **5b**, respectively. As shown in Figure 5a, the distance between the modified resonators in cascaded form is S8 = 0.15 mm and dimensions of the matching ports are Wf = 1 mm and Lf = 1.6 mm. In Figure 5b, the four-cell LPF has a stopband rejection better than 26 dB from 4.5 to 32 GHz, with an insertion loss of less than 0.12 dB and return loss of more than 16.4 dB in the passband. The frequency response is sharp with the transition band equal to 0.24 GHz from 4.26 to 4.5 GHz and corresponding attenuation levels of -3 and -20 dB, respectively.



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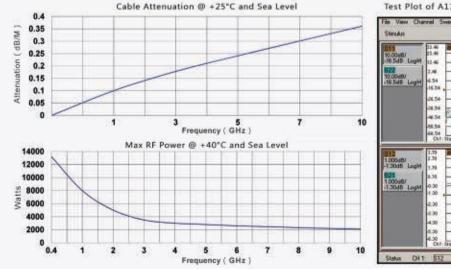


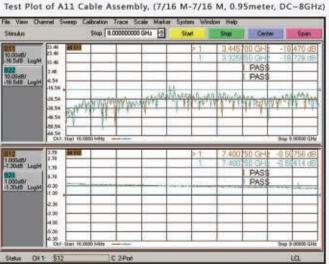
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	TABLE I PERFORMANCE COMPARISON												
Ref.	Ref. ξ Max IL Min RL RSB SF Size (dB) (dB)												
2	34.0	1.5	12	1.46	2.1	203							
6-a	13.1	1.0	22	1.29	1.0	155							
6-b	24.3	1.0	18	1.48	1.6	284							
7	28.3	1.2	10	1.35	1.0	460							
8	16.2	0.1	16	1.33	2.0	360							
10	36.2	0.5	22	1.27	2.2	150							
11	42.5	0.5	16	0.74	3.5	800							
Two-cell LPF	40.5	0.05	25	1.63	2.0	84							
Four-cell LPF	70.8	0.12	16	1.51	2.62	143							

SIMULATED AND MEASURED RESULTS

A photograph of the fabricated LPF is shown in *Figure 6*. The four-cell LPF is fabricated on an RT/Duroid 5880 substrate with relative dielectric constant $\epsilon_r = 2.2$, thickness h = 0.508 mm and loss tangent tan δ = 0.0009. The LPF is simulated using the method of moments in ADS, and the Keysight N5230A network analyzer is used for measurement.

LPF performance is compared with other works in **Table 1**, where the rolloff rate (ξ) , relative stopband bandwidth (RSB), and suppression factor (SF) are defined as:

$$\xi = \frac{\alpha_{\text{max}} - \alpha_{\text{min}}}{f_s - f_c} (dB / GHz)$$
 (1)

where α_{max} is the -20 dB attenuation point, α_{min} is the 3 dB attenuation point, f_s is the 20 dB stopband frequency and f_c is the 3 dB cut-off frequency.

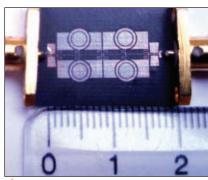


Fig. 6 Photograph of the four-cell LPF.

$$RSB = \frac{\text{stopband} (20 \, dB)}{\text{stopband center frequency}}$$
 (2)

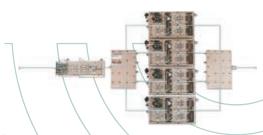
$$SF = \frac{\text{suppression level}}{10}$$
 (3)

CONCLUSION

This compact LPF exhibits a sharp roll-off, an ultra-wide stopband, compact size, high return loss and low insertion loss in the passband – features needed for modern microwave communication systems. Good agreement between simulated and measured results is demonstrated.

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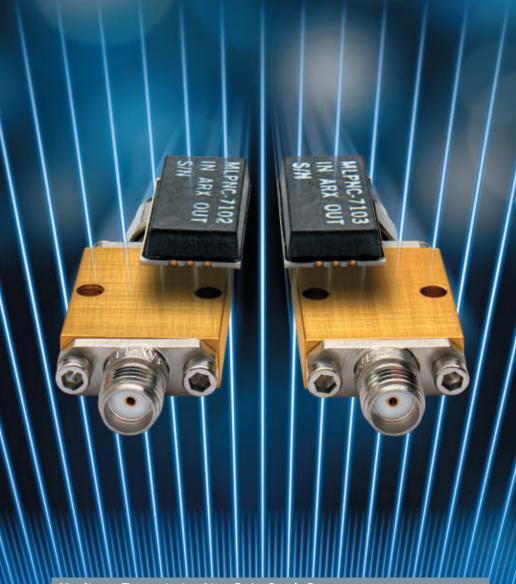


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MLPNC-7102-SMA800	21 @ 400 MHz	23 @ 600 MHz	> -8 @ 4 GHz	> -16 @ 12 GHz	> -20 @ 20 GHz			
MLPNC-7102-SMT680	21 @ 400 MHz	23 @ 600 MHz	> -8 @ 4 GHz	> -16 @ 12 GHz	> -20 @ 20 GHz			
MLPNC-7103-SMA800	21 @ 800 MHz	23 @ 1.3 GHz	> -5 @ 6 GHz	> -15 @ 18 GHz	> -20 @ 30 GHz			
MLPNC-7103-SMT680	21 @ 800 MHz	23 @ 1.3 GHz	> -5 @ 6 GHz	> -15 @ 18 GHz	> -20 @ 30 GHz			

^{*} Contact the factory for additional information or for products not covered in the table.

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Mohsen Hayati received his B.E. degree in electronics and communication engineering from Nagarjuna University, India, in 1985 and his M.E. and Ph.D. degrees in electronics engineering from Delhi University, Delhi, India, in 1987 and 1992, respectively. He joined the electrical engineering department at Razi University, Kermanshah, Iran as an assistant professor in 1993. He is currently an associate

professor in the same department. Hayati's research interests include microstrip filter design for communication systems, application of computational intelligence, artificial neural networks, fuzzy systems, neuro-fuzzy systems and electronics circuit synthesis, modeling and simulation.



Parisa Karami Moghadam received her B.Sc. degree in electrical engineering from Razi University, Kermanshah, Iran and her M.Sc. degree in electrical engineering from Kermanshah Science and Research Branch, Islamic Azad University, Kermanshah, Iran. Her research interests include the analysis and design of microstrip filters and antennas.

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Low-Profile Direction Finding System in Ku-Band Using SIW Horn Antennas

Marc Esquius-Morote, Jean-François Zürcher and Juan R. Mosig Laboratoire d'Electromagnétisme et d'Acoustique (LEMA), Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland Benjamin Fuchs IETR/University of Rennes I, France

complete Ku-Band direction finding (DF) system using a circular array of eight substrate integrated waveguide (SIW) horns is used to provide full 360° coverage of the azimuthal plane. The antennas are interconnected with commercial monolithic microwave integrated circuits (MMIC) for beam-switching to estimate direction of arrival (DoA). The entire structure is low-profile, lightweight and low cost – suitable for integration in airborne or terrestrial vehicles.

Interest in mmWave components and systems is increasing as new mmWave wireless applications are introduced. To be commercially viable, however, suitable low cost integration technologies are needed for mass production. A very promising technology for high performance, reliability and low cost is substrate integrated waveguide-like structure fabricated by creating rows of metallized vias in a dielectric substrate that are electrically connected to two parallel metalized surfaces.

Its most significant advantage is the potential to integrate several types of components on the same substrate, including passive components (e.g., filters and couplers), active elements (e.g., oscillators and amplifiers), as well as antennas.¹⁻⁷ SIW technology also enables high density component inte-

gration while having a low-profile and light weight. These features make it attractive for vehicle flush-mounted antenna systems that must minimally affect aerodynamics and aesthetic profiles.

In the case of systems working in the azimuthal plane (e.g., for inter-vehicle communication or DF applications), end-fire radiating elements are needed. Depending on the signal polarization, different types of SIW antennas have been proposed: tapered slots or quasi Yagi–Uda antennas for horizontal polarization,⁴ and H-plane apertures or horn antennas for vertical polarization.⁵⁻⁷ The latter are of particular interest for applications working near the ground, because horizontally polarized signals are greatly attenuated in these environments. An illustrative example of how to mimic a conventional H-plane horn antenna with SIW technology is shown in *Figure 1*.

A complete Ku-Band low-profile DF system using SIW horn antennas is motivated by the advantages of this technology. A circular array of eight SIW horns provides full 360° coverage of the azimuthal plane. The antennas are interconnected with commercial MMIC for beam-switching and estimating DoA. The entire structure is low-profile, lightweight and low cost, i.e., suitable to be integrated in air-



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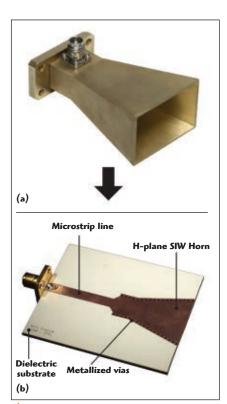
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▲ Fig. 1 Conventional H-plane horn antenna (a) and its equivalent using SIW technology (b).

borne or terrestrial vehicles.

SIW HORN ANTENNA

The SIW horn antenna is a widely used topology for radiating end-fire in system-on-substrates designs.^{4,5} Its main drawback, however, is the degradation of radiation and matching performance when the substrate thickness, h, is much smaller than the free space wavelength λ_0 .6 Usually, for $h < \lambda_0/6$, there is a strong impedance mismatch between the antenna aperture and free space, which results in unwanted back radiation. This is common at frequencies lower than 20 GHz with commercial substrate thicknesses typically lower than 2.5 mm, and why SIW horn antennas are usually not considered for applications in Ku-Band or below.

To overcome this limitation, Esquius-Morote et al., 6,7 introduced a novel SIW horn design incorporating an etched transition after the horn aperture to reduce the mismatch between the aperture and free space (see **Figure 2**). Excellent impedance matching and radiation performance over a wide frequency range is achieved with the antenna thickness, h, thinner than $\lambda_0/10$. The authors provide simple de-



Fig. 2 Etched transition reduces the mismatch between the aperture and free space.

sign rules and examples. In addition, the horns are tapered following an elliptical shape to obtain a more compact design for a given directivity by combining several TE modes.

In this article, these compact and thin SIW horn antennas are used as basic elements in a low-profile beamswitching antenna array for DF applications. Since electronic components are required to implement this functionality, the interconnection between the antennas and commercial MMICs is described.

SIW HORN ANTENNA-TO-MMIC INTERCONNECTION

Planar transmission lines, such as microstrip lines (MSL) and coplanar waveguides are commonly used for microwave system integration, and MSLs are the most viable when encapsulated MMICs are used. For this reason, a transition from SIW to MSL is needed.

The system is designed to work at Ku-Band, specifically at a center frequency $f_0 = 15$ GHz. The SIW horn antenna described by Esquius-Morote et al.,⁷ requires a low permittivity substrate. A good option is 1.91 mm Rogers TMM3 substrate $\varepsilon_r = 3.39$).8 On the other hand, thin, high permittivity substrates are preferred for MMIC placement since attachment is more convenient and a higher degree of integration is possible. Moreover, if they are encapsulated in QFN packages, usually a 50 Ω input pin of width 0.3 to 0.4 mm is available. Thus, a 0.38 mm Rogers TMM10 $\varepsilon_r = 9.56$) is chosen on which a 50 Ω MSL has a width $M_W = 0.34 \text{ mm}.$

Due to the large difference between the thicknesses of both substrates, a vertical transition is used to meet both electromagnetic and mechanical constraints. Several SIW-



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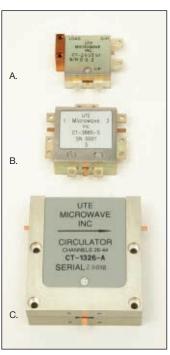
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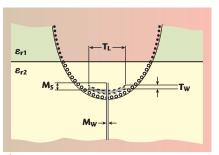
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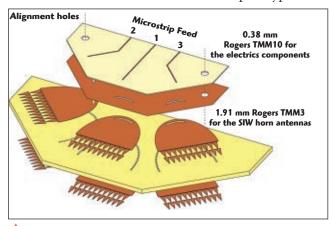
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▲ Fig. 3 Slot in the common metal plane between the MSL and SIW for coupling between the two structures.



▲ Fig. 4 Layered view of three element SIW horn antenna array.

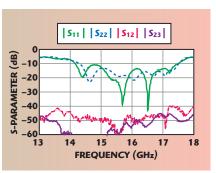


Fig. 5 Measured S-parameters of antenna array elements.

MSL vertical transitions offering similar performances are proposed, based mainly on probe feeding and slot coupling. 9,10 Because the slot coupling transition eases the assembly process and is more robust with respect to tolerances, a slot in the common metal plane between the MSL and SIW is opened for the energy to couple between these two structures (see **Figure 3**). TW defines the slot width, T_L the slot length and MS the microstrip stub length.

In a slot coupled transition, the forward and backward travelling waves of the electric field excited by the slot are in opposite direction, therefore, the slot must be opened as close as possible to the shortest end of the SIW for a maximum power transfer.¹⁰ Despite large differences in permittivity and thickness, this transition offers a good wideband behavior.

THREE ELEMENT SIW HORN ARRAY

A three element SIW horn antenna array is used to test antenna performance when fed by the multilayer transition. Measurements from this prototype are subsequently used in

the design of a complete circular array of eight elements. In practice, one element of the complete array exhibits the same behavior as the central one in this three element prototype since its performance is mainly affected by the adjacent horns.

Each SIW horn has the same dimensions as the one described by Esquius-Morote et al.,⁷

and after an optimization process, the SIW-MSL transition dimensions are determined to be $T_W = 0.6$, $T_L = 8.1$ and $M_S = 1.7$ mm. In order to obtain an overlap between adjacent beams of approximately -3 dB, the horns are placed on a circle of 52 mm radius with a 45° separation. The layered view of the prototype is shown in **Figure 4**. In this case, instead of MMICs, three SMA connectors are placed after the MSLs to measure antenna performance.

Measured S-parameters are plotted in *Figure 5*. All three horns have reflection coefficients below -10 dB over a 20 percent bandwidth (between 14.2 and 17.5 GHz). Due to the nearly enclosed structure of the SIW horn antenna and good design of the multilayer transition, mutual coupling between horns is practically negligible. In fact, measured values of $|S_{12}|$ are below -40 dB over the entire frequency range.

Measured H-plane radiation patterns of the three SIW horns at f_0 are superimposed in *Figure 6*. Despite their low-profiles, the horns provide considerable focusing of the energy

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frontwards achieving a front-to-back ratio above 15 dB. The -3 dB beam overlap required for beam-switching applications is also apparent. The efficiency of the central horn is 85 percent with a realized gain of 5.6 dBi. Moreover, a cross-polarization level below -20 dB is also measured.

SYSTEM DESIGN

A beam-switching antenna is an antenna array that can form a set of

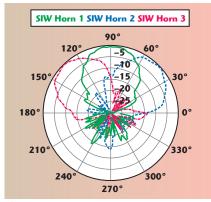


Fig. 6 Measured H-plane radiation patterns of the three SIW horns.

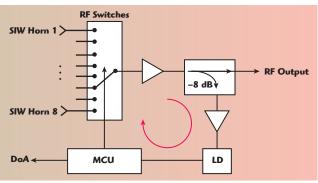
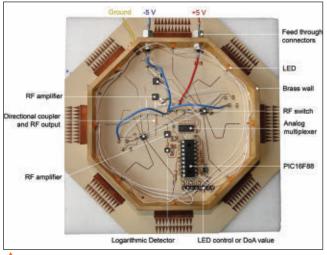


Fig. 7 Block diagram of the DF system.



📤 Fig. 8 Complete eight element DF system.

predefined beams. Once a beam is selected using switches, its received signal is downconverted and processed. Although this type of system is not as flexible as an adaptive array, its main advantage is simplicity and, therefore, low cost. All processing is done in the RF domain so that only one signal must be downconverted: this represents a significant price advantage since the circuits for downconversion are among the most expensive in today's wireless systems (this is particularly true when working at mmWave frequencies). Moreover, it is important to mention that the performance offered by a beam-switching system is usually sufficient for many common applications.11

A block diagram of the DF electronic system is shown in *Figure 7*. First, a MicroController Unit (MCU) selects the signal coming from the desired antenna using RF switches. This signal is then split with a directional coupler between the RF output and the control loop. The RF output is the port from where the information carried by the received signal is read.

The control loop signal is converted to a proportional DC voltage by means of a Logarithmic Detector (LD) and sent back to the MCU. Finally, after sampling and processing the different antenna signals, the MCU computes the DoA. Amplifiers are also used after the switches and the coupler to compensate for losses.

All RF electronics are supplied by Hittite Microwave Corp.¹² Three HM-C641LC4 SP4T switches, two HM-C383LC4 amplifiers and one HM-C948LP3E logarithmic detector provide good performance within the frequency range. All are QFN GaAs MMICs largely capable of handling

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typical power levels in a receiving antenna system. It is also important to mention that absorbent material $(ECCOSORB\ GDS-U)^{13}$ is needed to suppress amplifier oscillation.

A simple and low-cost peripheral interface controller (PIC), the PIC16F88, is used as the MCU. An internal 10-bit analog-to-digital converter is already included in this PIC which, in this case, is employed to convert the analog output of the

logarithmic detector. The control signals for the switches, however, cannot be directly generated by the PIC. As does any common microprocessor, this PIC works with a 5/0 V logic while the SP4T switches work with 0/-5 V logic. A standard multiplexer (MC14053BD) is used to convert the logic level. The PIC is programmed to sample the eight different signals, compare them and compute the DoA. The system functionality is assessed

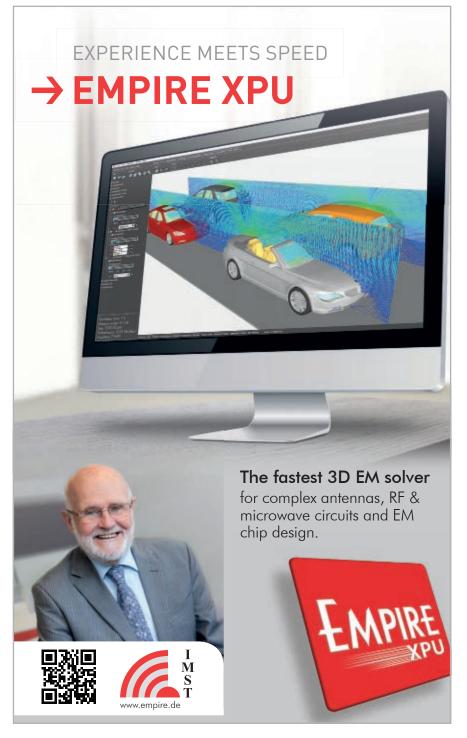
by means of a simple amplitude comparison algorithm based on the measured radiation patterns of Figure 6.

SYSTEM EVALUATION

The complete system is shown in Figure 8. The dimensions and materials used for the SIW horn antennas and the transitions are the same as in the prototype of Figure 4, but the radius of the antenna array is increased to 90 mm in order to accommodate all the required RF and DC components. A shield structure composed of a brass wall and a copper cover is also added to protect the electronics. It is extremely important to protect all the RF components since incoming high frequency signals can easily couple to the transmission/feed lines causing malfunctions, or even damage to sensitive components. For the same reason, the two DC feed lines (+5 and -5 V) are brought inside the shield using feedthrough connectors. Absorbent material (ECCOSORB MCS-U) is also glued onto the interior part of the top cover to dampen any potential cavity resonance. 14,15 For demonstration purposes, LED diodes are placed at the brass wall, one in front of each antenna, in order to indicate which antenna is receiving the strongest signal. The output pins of the PIC are used to drive these LEDs (see Figure 8).

Although the MSLs coming from each antenna have the same length (i.e. the same losses), the insertion losses of the SP4T switches are slightly different for each port. To account for this difference, the signal strength received by each antenna under the same conditions is measured at the RF output and the difference compensated later by post-processing in the PIC.

The system was tested in the facilities of the Laboratory of Electromagnetics and Acoustics (LEMA) at the EPFL. The sensitivity of the system is limited mainly by the sensitivity of the logarithmic detector. For a reliable DoA estimation, a signal strength of -65 dBm is required at the antenna. By using the amplitude comparison algorithm, the maximum DoA error is determined to be ±3° between 14.5 and 15.5 GHz. The system consumes around 300 mA (largely due to the amplifiers and the logarithmic detector) and its total weight is 220g (including the shielding structure).





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CONCLUSION

A fully operational direction finding system based on SIW horn antennas has been developed and experimentally verified. Due to the use of SIW technology, the antenna array and thus the whole system is low-profile, lightweight and low cost when compared to similar solutions at the Ku-Band. A simple way to efficiently interconnect these SIW antennas with

commercial MMICs is also presented and tested.

This system demonstrates the suitability of SIW technology for high performance commercial applications; and in particular, for flush-mounted configurations in airborne or terrestrial vehicles. Although demonstrated for a simple receiving direction finding application, the concept may be applied to more ambitious applications requiring high data rate transmission.

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BCP160T	33.2	10.4	480	63	DC - 26	8
BCP240T	34.8	10.2	720	58	DC - 26	8
DRIVER MESFET	P _{1dB} (dBm)	GAIN (dB)	I _{dss} (mA)	NF (dB)	FREQ. (GHz)	V _{ds} (V)
BCF020T	20.0	13.5	60	1.1	DC - 26	8
BCF030T	21.5	13.5	90	1.45	DC - 26	8
BCF040T	23.0	13.0	120	1.65	DC - 26	8
BCF060T	25.0	12.5	170	1.85	DC - 26	8
POWER MESFET	P _{1dB} (dBm)	GAIN (dB)	I _{dss} (mA)	PAE (%)	FREQ. (GHz)	V _{ds} (V)
BCF080T	26.0	11.2	240	27	DC - 26	8
BCF120T	28.0	11.2	340	31	DC - 26	8
BCF240T	30.4	9.8	720	26.7	DC - 26	8
LNA PHEMT	NF (dB)	G _a (dB	FREQ. (GHz)	P _{1dB} (dBm)	GATE (μm)	V _{ds}
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Harmonic Analysis for **Low Conversion Loss** Quadrupler at W-Band

Yong Fang, Baoqing Zeng, Ye Yuan, Peng Gao and Xubo Wei University of Electronic Science and Technology of China Tiguo Gan 10th Institute of China Electronic Technology Group Corp. Hai Zhang Nanchang Institute of Technology

A new W-Band balanced quadrupler using a 0.1 µm GaAs PHEMT process is designed and tested. Measured results show the output power is approximately 3 to 8 dBm from 80 to 95 GHz. The low conversion loss (CL) balanced quadrupler uses a pair of antiparallel Schottky diodes and a pair of input/output amplifiers. Open stubs are employed to match the diode impedance for low CL and a detailed harmonic analysis is given to describe the stub-loading mechanism. The input/output amplifiers are used to reduce the influence of the quadrupler's external impedance.

-Band signal sources are of interest for various applications such as radiometer, automotive radar, foreign object debris (FOD) detection and test instrumentation. Frequency multiplication is the popular approach for generating these signals in the microwave and millimeter wave bands, and Schottky diodes are commonly used. Compared with high frequency oscillators, this is a good approach for realizing a stable, low noise frequency source;1 however, it is not easy to achieve high-efficiency multiplication, especially with an increasing working frequency.

There has been much research applied to improving the multiplier's performance. Yongshik Lee et al.,2 designed high-efficiency W-Band GaAs monolithic frequency multipliers based on low loss finite ground coplanar lines. Seng-Woon Chen et al.,3 analyzed and designed a high-performance MMIC doubler. A shorted stub was used to short the second harmonic frequency at the input and an open stub was used to short the fundamental frequency at the output, but there was no detailed explanation of how the open and shorted stubs' impacted CL. Thomas et al.,4 later analyzed the effects of harmonic terminating impedances on CL. Thomas and Branner⁵ and Johnson et al.,⁶ used similar design approaches in their active multiplier designs.

It is difficult to directly apply these methods, since the multiplier in this article is not single-ended, but a balanced multiplier that includes a pair of anti-parallel diodes and a balun. Since CL is a strong function the of the multiplication factor, it is more appropriate to use harmonic analysis for the low CL quadrupler design – an approach that has rarely been reported. In this work, a W-Band low CL MMIC quadrupler is designed using harmonic analysis and electronic design automation (EDA) technology. Prototype measurements agree closely with design predictions.







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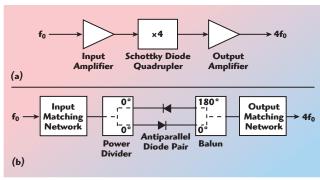
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📤 Fig. 1 Block diagram of the multiplier (a). Balanced Schottky diode quadrupler (b).

Balanced Schottky Diode Quadrupler 8,9

Schottky diode nonlinear characteristics are depicted by

ky diode quadrupler

to work more stably

because it is not eas-

ily affected by other

(input and output)

circuits. Figure 1b

shows a block dia-

gram of the balanced

Schottky diode qua-

drupler using an an-

ti-parallel diode pair.

Here, only the even harmonic frequen-

cies can be obtained

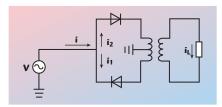
at the output.

$$i = i_s \left(e^{\alpha V} - 1 \right) \tag{1}$$

where i_c is the reverse saturation current, V is the diode external voltage, and $\boldsymbol{\alpha}$ is the diode slope parameter $(\alpha \approx 38 \text{ V}^{-1} \text{ for typical high-quality})$ gallium arsenide Schottky barrier diodes). Figure 2 shows the quadrupler schematic.

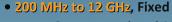
W-BAND QUADRUPLER DESIGN

Figure 1a shows a block diagram of the multiplier. It consists of three parts: input amplifier, Schottky diode quadrupler and output amplifier. Input and output amplifiers allow the Schott-



📤 Fig. 2 Quadrupler schematic.

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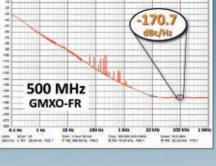
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In the multiplier mode, the fourth harmonic is generated by multiplication of the reflected second harmonic.

When V = $V_{f0}cos\omega_{f0}t$, i_L can be expressed as

$$i_{L} = -i_{s} + i_{s}I_{0}(\alpha V_{f0}) +$$

$$2 i_s \sum_{k=0}^{\infty} I_{2k} \left(\alpha V_{f0} \right) cos \left(2 k \omega_{f0} t \right) \tag{2} \label{eq:2}$$

where $I_{2k}(\alpha V_{f0})$ is the modified Bessel function of the second kind, and k is an integer. The load current i_L contains a DC term and even harmonics. With an increasing value of k, the even harmonic coefficient gradually decreases. The fourth harmonic is obtained from equation 2 when k=2.

In the mixer mode, the mixing products of reflected even harmonics and the fundamental contain the fourth harmonic. In Figure 2, the total conductance of the anti-parallel diode pair multiplier is expressed as

$$\begin{split} g &= g_1 + g_2 = \alpha i_s e^{\alpha V} + \alpha i_s e^{-\alpha V} = \\ 2\alpha i_s \cosh \alpha V \end{split} \tag{3}$$

In microwave and millimeter wave circuits, short or open circuit stubs can be used to reflect harmonics. The fundamental can be viewed as the local oscillator signal (LO), and reflected even harmonics can be considered radio frequency signals (RF) with magnitudes much lower than LO.

In the mixer model with open stubs (MMOS), the voltage of the even harmonic open circuit (OC) transmission line is

$$V = 2V^{+} \cos \omega_{s} t \tag{4}$$

where V+ is the voltage amplitude of electromagnetic wave propagating along the positive direction, ω_s is even harmonic angular velocity, and t is propagation time. The fundamental can be seen as the LO, and reflected even harmonics can be considered RF defined as

$$V_{LO} = V_{f0} \cos \omega_{f0} t \tag{5}$$

$$V_{RF} = 2V^{+}\cos\omega_{fs}t = V_{fs}\cos\omega_{fs}t \quad (6)$$

Since the RF amplitude is much smaller than the LO, the total conductance of the diodes can be expressed as the conductance of the diodes modulated only by the LO. Substituting equation 5 into equation 3 yields

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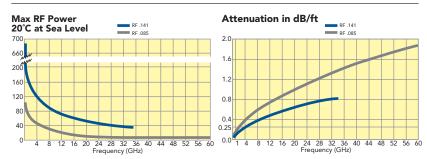
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$$g = 2\alpha i_{s}$$

$$\begin{bmatrix} I_{0}(\alpha V_{f0}) + \\ 2\sum_{k=0}^{\infty} I_{2k}(\alpha V_{f0})\cos(2k\omega_{f0}t) \end{bmatrix}$$
(7)

According to Ohm's law, the output current of the diodes is

$$\begin{split} &i_L = \\ &g \big(V_{LO} + V_{RF} \big) \\ &= g \big(V_{f0} \cos \omega_{f0} t + V_{fs} \cos \omega_{fs} t \big) \\ &= \alpha_0 \cos \omega_{f0} t + \alpha_1 \cos \omega_{fs} t + \\ &\alpha_2 \cos 3\omega_{f0} t + \alpha_3 \cos 5\omega_{f0} t + \\ &\alpha_4 \cos \big(2\omega_{f0} + \omega_{fs} \big) t + \\ &\alpha_5 \cos \big(2\omega_{f0} - \omega_{fs} \big) t + \\ &\alpha_6 \cos \big(4\omega_{f0} + \omega_{fs} \big) t + \\ &\alpha_7 \cos \big(4\omega_{f0} - \omega_{fs} \big) t + \cdots \end{split}$$

This implies that the total current of the anti-parallel diode pair contains only the frequencies $(m\omega_{f0} + n\omega_{fs})$ where (m+n) is an odd integer. When $f_s = 2f_0$, the total current of the antiparallel diode pair contains only

frequencies for which (m+2n) is an odd integer; when $f_s=6f_0$, the total current of the antiparallel diode pair contains only frequencies for which (m+6n) is an odd integer...and so on. The diodes again generate the fourth harmonic, increasing fourth harmonic output power.

In the mixer model with shorted stubs (MMSS), the voltage of the even harmonic short circuited (SC) transmission line is

$$V = 2jV^{+}\sin\omega_{s}t \tag{9}$$

Similarly,

$$V_{RF} = 2jV^{+} \sin \omega_{s} t = jV_{fs} \sin \omega_{fs} t \qquad (10)$$

And the output current is

$$\begin{split} &i_L = g \big(V_{LO} + V_{RF} \big) = \\ &g \big(V_{f0} \cos \omega_{f0} t + j V_{fs} \sin \omega_{fs} t \big) \\ &= \alpha_0 \cos \omega_{f0} t + j \alpha_1 \sin \omega_{fs} t + \\ &\alpha_2 \cos 3\omega_{f0} t + \alpha_3 \cos 5\omega_{f0} t + \\ &j \alpha_4 \sin \big(2\omega_{f0} + \omega_{fs} \big) t + \\ &j \alpha_5 \sin \big(2\omega_{f0} - \omega_{fs} \big) t + \\ &j \alpha_6 \sin \big(4\omega_{f0} + \omega_{fs} \big) t + \\ &j \alpha_7 \sin \big(4\omega_{f0} - \omega_{fs} \big) t + \cdots \end{split} \tag{11}$$

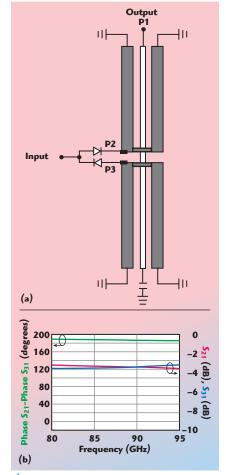


Fig. 3 Balun structure (a). Simulated phase and insertion loss (b).

Equations 8 and 11 show that the phase of the fourth harmonic produced by the multiplier mode is the same as the fourth harmonic produced by MMOS, but is 90-degrees different than the fourth harmonic produced by MMSS. Consequently, open stubs increase fourth harmonic output power, whereas shorted stubs reduce it. Open stubs are therefore used in the design of the low conversion loss balanced quadrupler.

À miniaturized planar balun¹¹ is used in the Schottky diode balanced quadrupler (CSDBQ) structure. The simulated performance of the Marchand balun on GaAs substrate is shown in Figure 3. Only even order harmonics appear at the output port of the balanced multiplier. The input power, fundamental and important harmonics (second, fourth and sixth harmonics) of the CSDBQ are considered. The input and output reflector networks include a 50 $\overline{\Omega}$ matching circuit (50), SC and OC. Some conclusions can be reached from **Table 1**:

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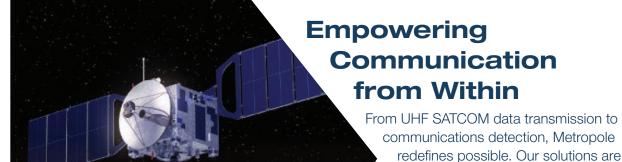
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TABLE 1 SIMULATION OF CONVERSION LOSS (CL) AND OUTPUT POWER (POUT)													
	Output Network												
Input Network		OC @ 2f ₀	50 @ 4f ₀	SC @ 6f ₀	OC @ 2f ₀	50 @ 4f ₀	OC @ 6f ₀	SC @ 2f ₀	50 @ 4f ₀	SC @ 6f ₀	SC @ 2f ₀	50 @ 4f ₀	OC @ 6f ₀
	P _{in} (dBm)	11	13	15	11	13	15	11	13	15	11	13	15
50 @ f ₀ OC @ 2f ₀	P _{out} (dBm)	-0.2	3.1	4.8	0.1	3.4	5.0	-0.9	2.2	4.1	-0.6	2.4	4.3
SC @ 4f ₀	CL (dB)	11.2	9.9	10.2	10.9	9.6	10.0	11.9	10.8	10.9	11.6	10.6	10.7
50 @ f ₀	P _{out} (dBm)	-0.1	3.2	4.9	0.2	3.5	5.1	-0.8	2.3	4.1	-0.5	2.5	4.4
OC @ 2f ₀ OC @ 4f ₀	CL (dB)	11.1	9.8	10.1	10.8	9.5	9.9	11.8	10.7	10.9	11.5	10.5	10.6
50 @ f ₀	P _{out} (dBm)	-0.2	3.1	4.8	0.1	3.4	5.0	-0.9	2.2	4.1	-0.6	2.4	4.3
SC @ 2f ₀ SC @ 4f ₀	CL (dB)	11.2	9.9	10.2	10.9	9.6	10.0	11.9	10.8	10.9	11.6	10.6	10.7
50 @ f ₀	P _{out} (dBm)	-0.1	3.2	4.9	0.2	3.5	5.1	-0.8	2.3	4.1	-0.5	2.5	4.4
SC @ 2f ₀ OC @ 4f ₀	CL (dB)	11.1	9.8	10.1	10.8	9.5	9.9	11.8	10.7	10.9	11.5	10.5	10.6

	TABLE 2										
IMP =	OPTIMIZED MULTIPLIER PARAMETERS IMP = microstrip characteristic impedance, L = microstrip length, ANG = radial stub angle										
	Value (Idealized) Value (Simulated with ADS)										
	$\operatorname{IMP}(\Omega)$ $\operatorname{L(deg)}$ $\operatorname{ANG(deg)}$ $\operatorname{IMP}(\Omega)$ $\operatorname{L(deg)}$ AN					ANG(deg)					
L1	50 @ f ₀			50 @ f ₀							
L2				38.5 @ f ₀	28 @ f ₀						
L3				74 @ f ₀	28 @ f ₀						
L4		90 @ 4f ₀	40		66 @ 4f ₀	40					
L5	50 @ 2f ₀	90 @ 2f ₀		50 @ 2f ₀	82 @ 2f ₀						
L6	50 @ 2f ₀	90 @ 2f ₀		50 @ 2f ₀	97 @ 2f ₀						
L7	50 @ 6f ₀	90 @ 6f ₀		50 @ 6f ₀	85 @ 6f ₀						
L8	50 @ 2f ₀			50 @ 2f ₀							

- 1. The input port harmonic reflector network has little effect on CL.
- 2. Suitable input fundamental power can reduce CL by about 1 dB.
- 3. A second harmonic OC at the output port reduces CL by about 1 dB.
- 4. A sixth harmonic OC at the output port reduces CL by only about 0.2 to 0.4 dB.

Applying the results from analysis and simulation yields the optimized multiplier structure shown in *Figure 4a*. ADS-optimized element values are listed in *Table 2*. Performance is summarized in *Figure 4b*. Maximum P_{out} (~ 5 dBm) and minimum CL (~ 13 dB) occur near 87 GHz when input power is around 18 dBm.



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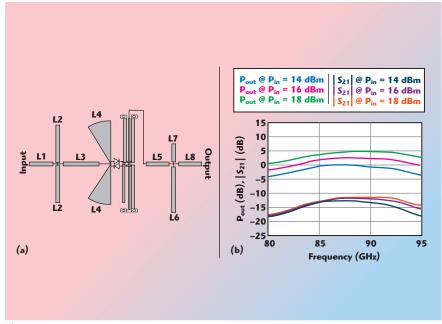
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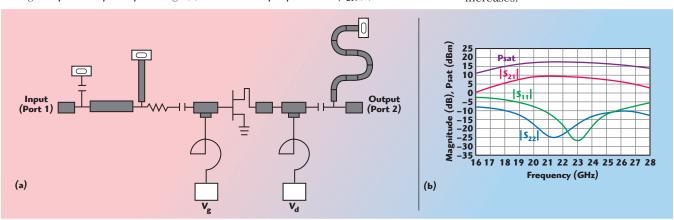
igtriangleq Fig. 4 Optimized quadrupler design (a). Simulated output power and $|\mathrm{S}_{2I}|$ (b).

Input/Output Amplifier

To reduce the variation of the input/output impedance of the Schottky diode quadrupler. A $4\times50~\mu m$ transistor die is used in the design of the input amplifier and a $2\times50~\mu m$ die is used in the design of the output amplifier. Schematic diagrams and simulated performance are shown in **Figures 5** and **6**.

QUADRUPLER SIMULATION AND MEASUREMENT

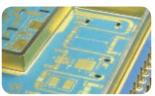
Simulation (see Figure 7), predicts P_{out} of approximately +4 to 11 dBm from 80 to 95 GHz, and CL of approximately 0 to 7 dB. Output power is maximum when the input power is 14 dBm. When the input power is 8 dBm, CL is a minimum. This is because input amplifier gain compression increases as input power increases.



▲ Fig. 5 Input amplifier design (a). Simulated performance (b).

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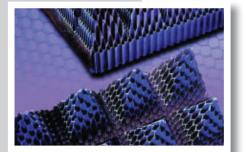
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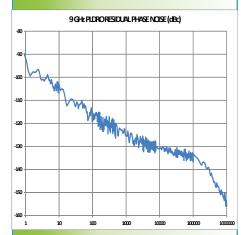
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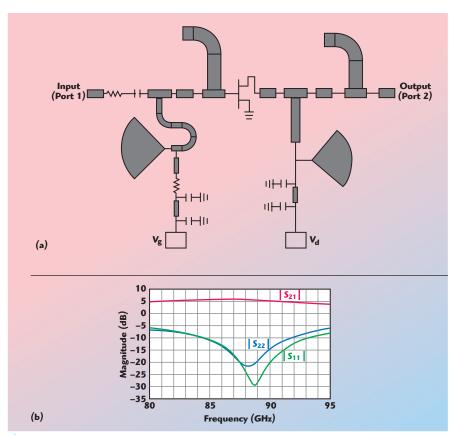
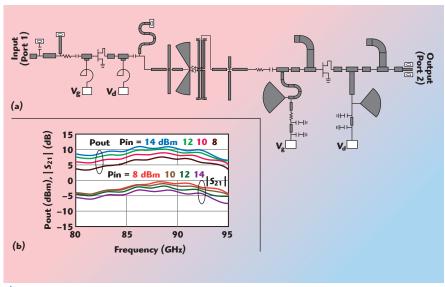


Fig. 6 Output amplifier design (a). Simulated performance (b).



 \triangle Fig. 7 Full quadrupler design (a). Simulated output power and S $_{21}$ performance (b).

The quadrupler is fabricated with a 0.1 µm gate-length GaAs PHEMT process. The assembled quadrupler chip (see *Figure 8a*) is 1 × 3.4 mm. It is tested on-wafer using a Cascade probe station (Cascade M150), WBand GSG probe (Cascade ACP110-S), and W-Band power probe (Keysight W8486A).

Measured curves are shown in *Figure 8b*, while *Figure 8c* compares simulated and measured data. Figure 8c shows a slight shift in output characteristics between simulation and measurement. This is mainly due to the difficulty in obtaining an accurate Schottky diode model at W-Band and the more pronounced impact of di-



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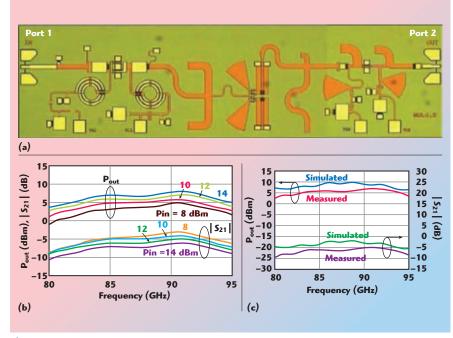
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ightharpoonup Fig. 8 Fabricated quadrupler (a). Measured output power and S_{21} (b). Comparison of simulated and measured performance with 12 dBm input (c).

electric loss and fabrication accuracy with increasing frequency.

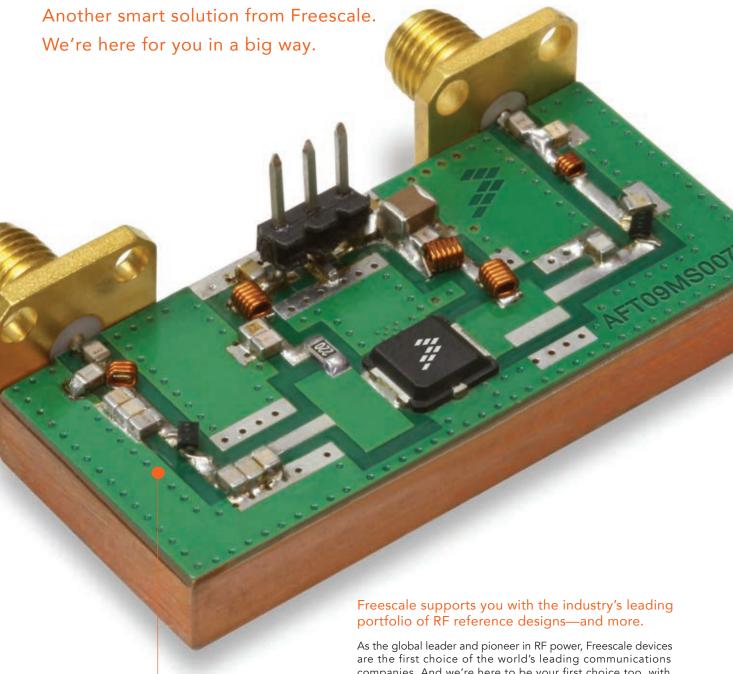
CONCLUSION

A W-Band balanced quadrupler is analyzed, designed and tested. Harmonic analysis and EDA technology are used to optimize the circuit and reduce CL. Open stubs are employed to match the diode impedance for low CL. In order to reduce the influence of the multiplier's external impedance, amplifiers are placed at the input and output. Finally, a small sized MMIC quadrupler is manufactured with using a 0.1 µm gate-length GaAs PHEMT process. Its output power is approximately 3 to 8 dBm from 80 to 95 GHz. ■

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Optimization of EVM Performance in I/Q Modulators

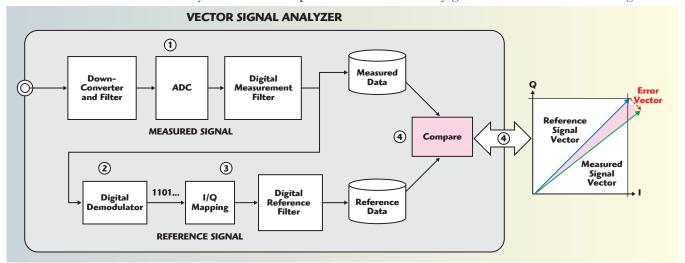
Bruce Hemp and Peter Stroet Linear Technology Corp., Milpitas, Calif.

Fror vector magnitude (EVM) is a scalar measurement of digital modulation accuracy and an important figure of merit for any source of digital modulation. Achieving low EVM in the transmitter modulator is important because the EVM of a signal degrades through each component of the transmit/receive chain. The transmitter up-converter, filters, power amplifiers, the receiver – even the communications channel – all impair the signal.

No single industry standard exists for EVM measurement and calculation. Rather, individual systems (e.g., Bluetooth, 802.11, DVB, PHS) specify the measurement for that standard. However this approach creates uncertainties, such as how to normalize the EVM for each symbol and which parameters in the

measurement to correct (e.g., frequency error, I/Q offset, quadrature phase error, gain imbalance). EVM measurements will vary when using vector signal analyzers (VSA) from different manufacturers – even different models from the same manufacturer.

Using a VSA to measure modulation accuracy is illustrated in *Figure 1*. The VSA down-converts and digitizes the input signal at a given center frequency and bandwidth, with the modulation scheme, symbol rate, measurement filter and other signal parameters specified by the user. This data represents the measured signal, which the VSA digitally demodulates to recover the source digital data stream. Using the recovered source data, modulation scheme and other factors, the VSA mathematically generates the ideal reference signal. The



▲ Fig. 1 The VSA compares a measured input signal to an ideally regenerated reference signal to determine the EVM.

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ApplicationNote

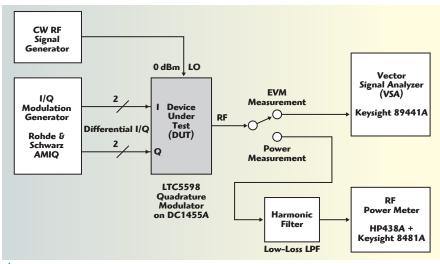


Fig. 2 Test setup for EVM measurements.

TABLE 1

EVM TEST PARAMETERS

Baseline EVM with 450 MHz LO at 0 dBm (see Figure 3)

Baseband Modulation

- 16-QAM (four bits per symbol, peak-to-average ratio = 5.4 dB)
- 1 MSPS symbol rate
- PN9
- Root raised cosine (RRC) filtering, $\alpha = 0.35$

Baseband Drive

- $V_{\rm EMF}$ = 0.8 V differential, as indicated by the Rohde & Schwarz AMIQ software; $V_{\rm EMF}$ = 1.15 $V_{\rm P-P}$ differential, as measured
- Bias Voltage = 0.5 V

VSA Measurement Filter

• RRC, $\alpha = 0.35$

VSA Reference Filter

• Root cosine (RC)

EVM vs. I/Q Drive (see Figure 4)

- 16-QAM
- 1 MSPS symbol rate
- RRC, raised cosine, $\alpha = 0.35$ (peak-to-average ratio = 5.4 dB)
- Bias Voltage = 0.5 V DC
- LO Drive = 0 dBm

EVM vs. LO Frequency (see Figure 5)

- LO Drive = 0 dBm
- 16-QAM
- 1 MSPS symbol rate
- RRC, $\alpha = 0.35$ (peak-to-average ratio = 5.4 dB)
- $V_{\rm EMF}$ = 0.8 V differential as indicated by the Rohde & Schwarz AMIQ software; $V_{\rm EMF}$ = 1.15 $V_{\rm P-P}$ differential, as measured
- Bias Voltage = 0.5 V

VSA then calculates error vectors – the difference between the measured and reference data vectors normalized to the peak signal level. The root mean square (rms) and peak EVM scalar values are extracted from the error vectors.

CHARACTERIZING EVM PERFORMANCE

This article shows how a VSA characterizes the EVM performance of I/Q modulators, using Linear Technology's LTC5598 as an example. This device is a direct quadrature modulator that covers 5 to 1600 MHz. 16-QAM is a relatively common type of digital modulation and a good vehicle to demonstrate the accuracy of the modulator. 16-QAM is the basis for many wireless systems, including LTE/LTE-Advanced, HSDPA, EDGE Evo,

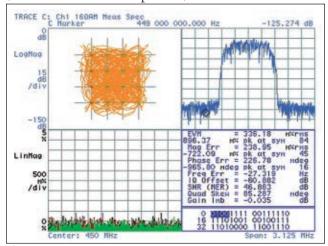
CDMA2000 EV-DO, Cognitive Radio IEEE 802.22 (TV white space), PHS and TETRA. $^{\rm 1}$

The test setup for evaluating the I/Q modulator is shown in *Figure 2* and the test conditions for each of the following measurements are summarized in *Table 1*. Mounted on a standard demonstration board, the typical EVM performance² of the LTC5598 with a 450 MHz LO signal at 0 dBm drive is 0.34 percent rms and 0.9 percent peak (see *Figure 3*). The measured output power, following the harmonic filter, is 0.4 dBm. Using the same setup, a lab-grade signal generator with the same amplitude, frequency and digital modulation measures 0.28 percent rms and 0.8 percent peak. Comparing the results indicates that the modulation accuracy of the LTC5598 is nearly as good as the test equipment used to measure it.

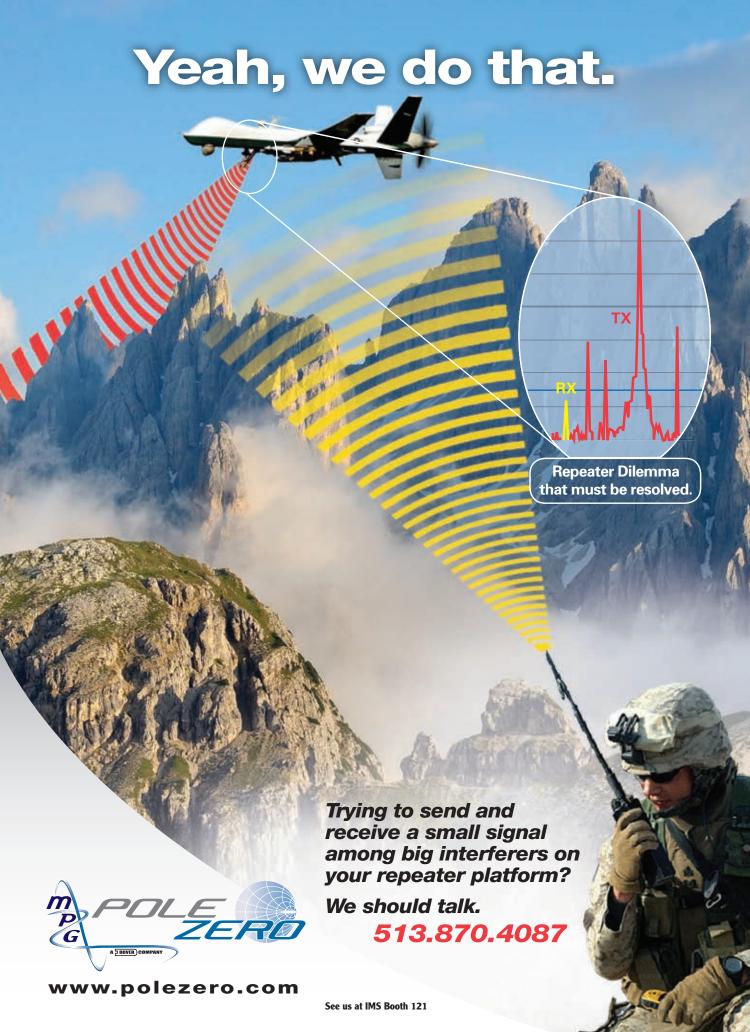
EVM increases rapidly when the baseband input level drives the peak modulator into compression (see *Figure 4*). The maximum rms output power can be estimated as

+8.4 dBm LTC5598 Output P_{1dB} Typ. at f_{RF} = 450 MHz -5.4 dB Crest Factor of 16-QAM Test Waveform

= +3.0 dBm Average Output Power (1) (Peaks will be at 1 dB compression)



▲ Fig. 3 EVM at 450 MHz LO.



ApplicationNote

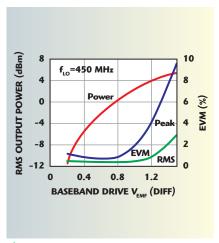


Fig. 4 EVM vs. modulator output power.

With the output level at 1 dB compression, the EVM may be too high for the application, which will reduce the usable average output power available from the modulator. For systems that employ a modulation with higher peak-to-average ratio (crest factor), the usable output power will be further reduced.

EVM varies with LO frequency and, not surprisingly, is lowest at the

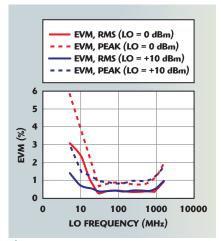


Fig. 5 EVM vs. LO frequency.

middle of the band (see *Figure 5*). At LO frequencies below 30 MHz, EVM can be reduced by increasing the LO drive. At both band edges, the main contributor to the LTC5598 EVM is I/Q quadrature phase error (see *Table 2*). Some I/Q gain imbalance is also present, although it is not much of a contributor to overall EVM. Sideband suppression is the aggregate effect of both phase and gain imbalance.

Where necessary, these error terms can be corrected open loop in baseband or, in some transmit chains, as part of the power amplifier's closed loop digital predistortion (DPD) system. While the subject of DPD correction is beyond the scope of this article, the DPD loop will have its own receiver that can measure transmit EVM and make adaptive corrections to the baseband waveforms to minimize error. DPD does not know or care where the error originates – the modulator, PA or both.

OPTIMIZING EVM PERFORMANCE

To obtain the best EVM performance from the I/Q modulator, the I/Q baseband should be "clean." This means the I/Q digital-to-analog converter (DAC) clock should have low phase noise and jitter, the DAC reconstruction filter should not encroach on the baseband bandwidth and the baseband I/Q signal paths should have flat frequency response. The LO signal source should also be clean. LO phase noise adds random phase error

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ApplicationNote

TABLE 2 LTC5598 QUADRATURE PHASE ERROR, GAIN IMBALANCE AND SIDEBAND SUPPRESSION

LO Frequency (MHz)	I/Q Quadrature Phase Error (Deg.)	I/Q Gain Imbalance (dB)	Sideband Suppression (dB)			
5	4.3	0.14	28			
10	3.6	0.01	30			
20	1.2	0.02	40			
40	-0.3	0.03	50			
1600	-1.2	0.05	39			

that cannot be removed downstream, which increases the EVM. LO harmonics will cause quadrature phase error, so the choice of LO should adhere to the modulator data sheet recommendations.

Commercial I/Q modulators, such as the LTC5598, provide excellent digital modulation accuracy across the common VHF and UHF communications bands. The performance may be comparable to that of a lab-grade signal generator. If required, EVM can be improved through baseband correction of quadrature phase error or gain imbalance.

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Bruce Hemp graduated in 1980 from California State University, Fullerton with his B.S. degree in engineering. He has held various systems, board-level and applications engineering positions. Since 2012, Hemp has been a senior applications engineer with Linear Technology.



Peter Stroet received his M.S. degree in electrical engineering from the University of Twente, the Netherlands, in 1994 and subsequently completed a two-year design program at the same university. He joined Philips Semiconductors in 1997 as a design engineer for wireless ASICs. Since 2001 he has been with Linear Technology designing ICs for RF applications.

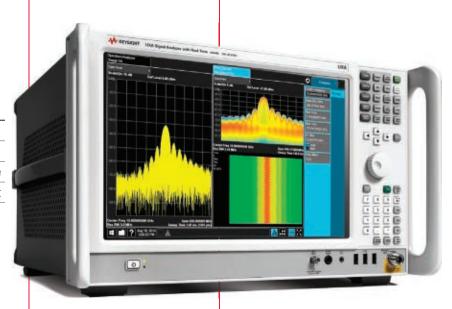


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Easier Cable Field Testing with FieldFox

Keysight Technologies Inc. *Santa Rosa, Calif.*

ngineers and technicians typically experience multiple cable testing challenges in the field. Meeting these challenges head on, Keysight Technologies recently introduced two innovative measurement options that make their FieldFox handheld analyzers the industry's most comprehensive and effective cable test solutions in the industry.

CABLE TEST CHALLENGES

Cables (e.g., waveguide, coaxial and twistedpair) are by far the most widely used components in modern RF and microwave systems such as wireless and data communications, satellite communications and radar. They are also the leading cause of failure in these types of systems. That's why proper maintenance and using the right tool for testing in the field is so critical.

The typical cable test process starts by determining whether or not a cable is faulty or performing outside its desired specification. If so, the fault's physical location along the cable must be found. Once the location is determined, the next step is to understand the nature of the error and repair it. During troubleshooting and maintenance, engineers and technicians can identify a fault's location with return loss (RL) and distance-to-fault (DTF) methods, but they are unable to determine the cause or type of fault. This makes it difficult to repair. In many cases, the failures (e.g., loose or damaged connectors, water ingress or broken solder joints) can't be seen by just looking at the cable.

Another problem is that measuring cable performance has traditionally required engineers and technicians to transport a cable and antenna analyzer, network analyzer, signal generator and power meter into the field. That process is all the more complicated when the cables are used in systems located in hard to

reach or even potentially hazardous environments. Once in place, the instruments must be correctly set up for testing. While effective, the process is error prone and leaves the instruments subject to accidental damage.

Further complicating matters, traditional vector network analyzers (VNA) have difficulty making precise and repeatable high-loss measurements for in-situ microwave cables where test ports are long distances apart.

NEW CABLE MEASUREMENTS OPTIONS

FieldFox's new Time Domain Reflectometry (TDR) cable measurement option (Option 215) complements the analyzer's current RL and DTF measurements. The RL measurement capability exposes cable connection mismatch, while the DTF capability indicates the location of any faults or poor connections along the cable. The new TDR option provides engineers with new insight to help measure the impedance changes along the cable and identify the cause (type) of specific faults, such as short, open or water ingress. To date, FieldFox is the only handheld analyzer that can perform RL, DTF and TDR measurements with the same instrument in a single sweep.

FieldFox's TDR, or step measurement, captures data using the same process as DTF. However, unlike DTF, the measurement is used to characterize the type of fault, including inductive or capacitive discontinuities. It does so by observing reflected waveforms from a step propagating through a cable. By analyzing the duration, magnitude and shape of the reflections, the nature of the impedance variation in the cable can be determined.

FieldFox's TDR measurement mode is only useful for cables that operate down to DC (e.g., two-conductor transmission lines). When

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measuring waveguide, FieldFox utilizes a bandpass time-domain transform technique. This is necessary because of the waveguide's narrowband response, which restricts the type of time-domain measurements that can be made. The bandpass measurement is ideal for frequency limited DUTs; however, it provides only the location of the fault. Determining the type of discontinuity, such as inductive or capacitive is not possible.

Another new FieldFox option, Extended Range Transmission Analysis (ERTA, Option 209), helps overcome the challenges of measuring long microwave cables in the field. This portable solution measures scalar insertion loss of long in-situ microwave cables and makes it possible to access both ends of the cable or waveguide simultaneously. Traditionally, using a scalar analyzer as the signal source with a broadband detector or power sensor to measure cable loss is a slow process. It is also prone to external interference and does not offer high levels of dynamic range. Deploying a benchtop solution in the field is also not ideal due to its large size and cost.

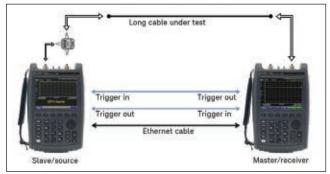
With ERTA, two FieldFox analyzers are deployed at each end of the measured cable. One analyzer acts as a source, while the other acts as a receiver. Both instruments are step synchronized with hardware triggers. By taking advantage of Keysight's proprietary InstAlign spectrum analysis technology, engineers and technicians can use this configuration to make very accurate cable loss measurements without calibration and warm up (see *Figure 1*). It offers the industry's best dynamic range for long, lossy cable measurement. This

option can also be configured with frequency-offset to measure devices such as mixers and frequency converters.

COMPREHENSIVE HANDHELD TEST SUITE

In addition to FieldFox's new TDR and ERTA options, the analyzer provides a number of other measurements; all of which give FieldFox the most comprehensive test suite in a single handheld instrument (see *Figure 2*). These additional measurements include:

- RL, VSWR, and DTF for broadband and bandpass cable subsystems
- S-parameter, group delay, phase, Smith chart and timedomain analysis
- Frequency converter conversion gain/loss
- Mixed-mode, 1-port S-parameter, time-domain analysis



▲ Fig. 1 FieldFox can be easily upgraded with the new ERTA option to make highly accurate cable loss measurements.



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REAL WORLD EXAMPLES

To better understand how FieldFox's time-domain measurement techniques help identify the locations and causes of cable faults, consider the example of two short 50-ohm coaxial cables connected together with a coaxial adapter. The shorter cable is connected to Port 1 on FieldFox, while the second cable is terminated in a 50-ohm load. As shown in *Figure 3*, a DTF measurement of the cables is very helpful in locating any discontinuities.

Notice that markers are placed at the three peaks in the measured DTF response. The peaks represent the magnitude of single reflections from a discontinuity. Marker 1, which represents the interface between the calibrated FieldFox and the first coaxial cable, reports a distance of 0 meters. Marker 2, located at the adapter between the two cables, reports a distance of 4 meters. It also indicates that the length of the first cable is 4 meters. Marker 3, located at the 50-ohm load, reports a distance of 13.8 meters. With this measurement, the length of the second cable can be calculated (e.g., 13.8 m - 4 m = 9.8 m). The noticeable drop in measured amplitude to the right of the 50-ohm load signifies the end of the cable. As this reflection measurement represents two-way signal paths, FieldFox properly adjusts the marker values and x-axis formatting to the appropriate one-way lengths.

Now, consider a coaxial cable that has been damaged in two areas (see *Figure 4a*). Fault A is a bend in the cable that exceeds the manufacturer's specification for a minimum bend radius of 1-inch. The bend at Fault A is well below this radius, creating an undesired reflection from this part of the cable. Fault B is a cut through the outer conductor of the cable. The

braided shield has been partially removed, exposing the inner dielectric of the coax. Both faults can be examined using FieldFox's DTF and TDR modes; however, only the TDR measurement will characterize this fault type.

Figure shows the measurement of the damaged cable with FieldFox in TDR mode. seen in the TDR response, the cable impedance is generally 50 ohms across the timedomain response until a discontinuity is encountered. 50-ohm load. Discontinuities oc-



Fig. 2 FieldFox provides the industry's most comprehensive handheld cable test solution that is precise enough for the lab and rugged enough for the field.

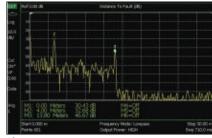


Fig. 3 A FieldFox DTF measurement of two connected coaxial cables terminated in a 50-ohm load.

cur at the input connector, the bend at fault A, the cut at fault B, and the 50-ohm termination at the end.

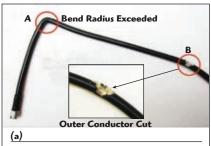
Of all discontinuities on the cable, the cut at fault B causes

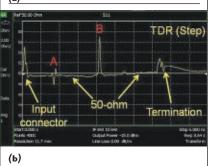




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📤 Fig. 4 Damaged coaxial cable (a). TDR measurement of the damaged cable using the FieldFox TDR option (b).

the largest mismatch, as observed by the magnitude of the associated peak. The cut on the TDR response has a single peak in the positive direction, indicating an inductive mismatch. This is typical for cuts in the outer conductor of a

coaxial cable. Generally speaking, if the cable is terminated in a load with a resistance smaller than the characteristic impedance, the TDR response will show a step in the negative direction. If the load resistance is larger than the characteristic impedance, the TDR response will show a step in the positive direction.

AN IDEAL SOLUTION

Cable measurement in the field can be tricky. Determining that a cable is faulty is just the first step in the process. Engineers and technicians then need to identify the fault's physical location and its cause. This is accomplished using various time-domain techniques. FieldFox's comprehensive suite of cable test measurements, including the new TDR and ERTA options provide the ideal solution. FieldFox's DTF and TDR timedomain measurements identify fault locations and causes in coaxial cables, while its bandpass measurement locates the physical location of faults in a waveguide. Using FieldFox, today's engineers and technicians now have a faster, easier way to test cable systems and waveguide in the field.

For more information on transmission line theory and time-domain measurement techniques, check out Keysight's on-demand cable test webcast (www.kevsight.com/find/fieldfoxwebcasts) and the FieldFox testing (Application Note (www.keysight. com/find/fieldfoxapps).



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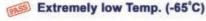
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Source 2

Source 2

Source 2

Source 2

Source 2

Spectrum Analyzer

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Harmonics
Spurs

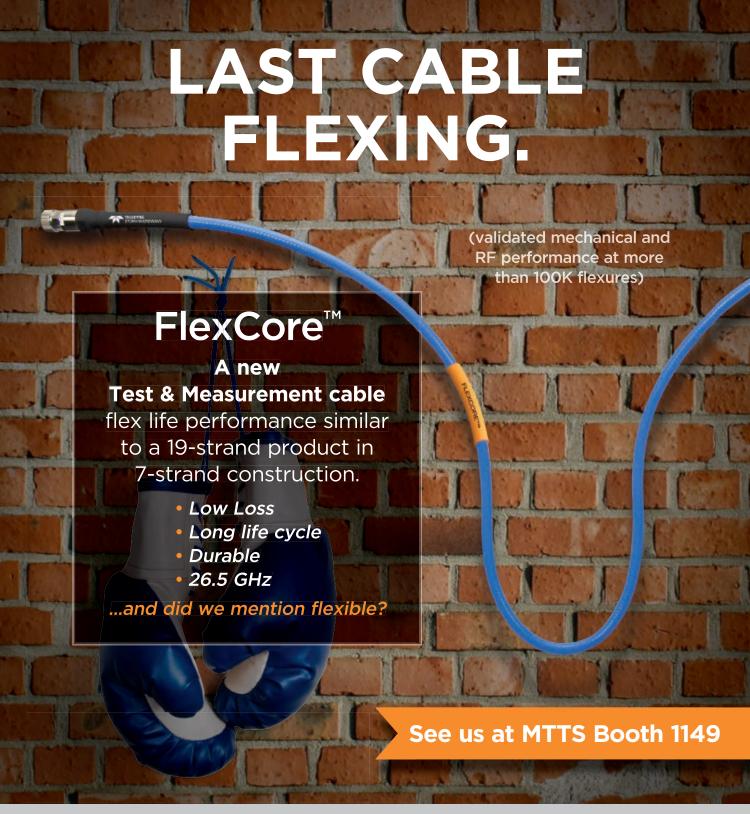
Power Meter

Absolute Power

▲ Fig. 1 The traditional setup for amplifier testing requires multiple instruments.

harmonic and second order distortion products since IP3 products are located in-band and cannot be easily filtered. The third order intercept point (TOI or OIP3) of power amplifiers is important to quickly identify the intermodulation characteristics of the active device.

During the design process, engineers often need to create accurate models of the device for simulation purposes. Accurate IMD data, including higher order products up to IM9, are used to generate accurate models and are critical to the success of amplifier design. An important aspect of accurate IMD measurements is the IP3 performance of the VNA receiver. The VectorStar receiver architecture, utilizing patented non-linear transmission line (NLTL) technology, provides industry-leading receiver IP3 performance for accurate IMD measurements. The wide range of important IMD measurements has traditionally been difficult to set up — requiring multiple test instruments combined with multiple components. The introduction of $IMDView^{TM}$ and internal combiner options in VectorStar not only simplifies the setup procedure but also offers flexible hardware configurations for accurate and



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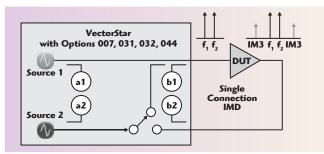


Fig. 2 Hardware and software options enable VectorStar to replace the spectrum analyzer and power meter to measure S-parameters, power and IMD.

efficient IMD measurements over the widest range of frequencies available in a single system.

SETTING UP IMD MEASUREMENTS

Traditionally, measuring active devices required a VNA, spectrum analyzer and power meter in order to measure performance parameters such as gain, harmonics, compression and IMD characteristics (see *Figure 1*). A calibrated VNA can perform these measurements when configured with the proper options. For example, inclusion of independent frequency control of the sources and receivers provides the ability to measure different frequency points of interest when stimulating the device under test (DUT). Thus, measurements of harmonics and spurs as well as IMD products can be performed with the frequency offset option. An internal dual source option (Dual Source Op-

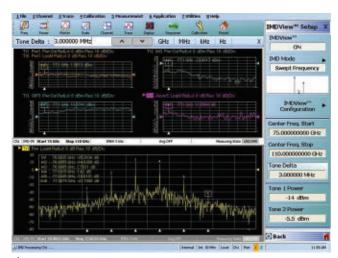


Fig. 3 IMDView software controls all measurement parameters, enabling IMD analysis.

tion 031) provides the two tones needed for intermodulation measurements, eliminates the need for locating external sources, minimizes external cabling requirements and reduces setup time.

The two recently introduced VectorStar options for IMD measurements further extend the wide range of measurement possibilities. The internal combiner option (see **Figure 2**) provides the ability to automatically switch the path of the second source to the Port 1 side of the VNA. Thus, during S-parameter measurements the switch will



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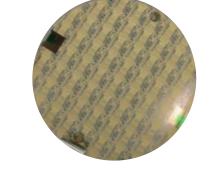
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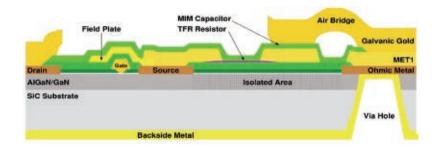
GH25 GaN MMIC TECHNOLOGY

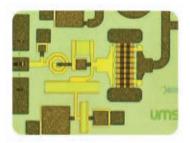
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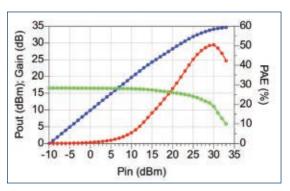


VDS	V t	lds+	Gm	Vbds	Ft	MIM Density	Metallic Resistors
(V)	(V)	(A/mm)	(mS/mm)	(V)	(GHz)	(pF/mm2)	(Ω/sq)
30	-3.5	1	290	>100	25	255	



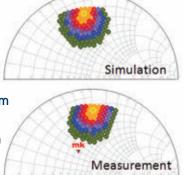


Power performance of 8x75µm transistor @ 10GHz Bias: Vds=30V. lds=100mmA/mm



PAE Simulated/ Measured output contour lines of $8x75\mu m$ transistor @ 10GHz

Bias: 30V@100mA/mm



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be in the normal path through Port 2 to perform standard S-parameter, gain and compression tests of the active device. When a two tone IMD measurement is needed, the IMD software will control the switch and combine the two internal sources for a two tone input to the DUT. With the new VectorStar combiner option, IMD measurements can be made with a single connection without the need for re-cabling the measurement

setup. This is a useful tool for reducing setup and measurement time and improving overall accuracy by reducing concatenation errors of multiple calibrations and system setups.

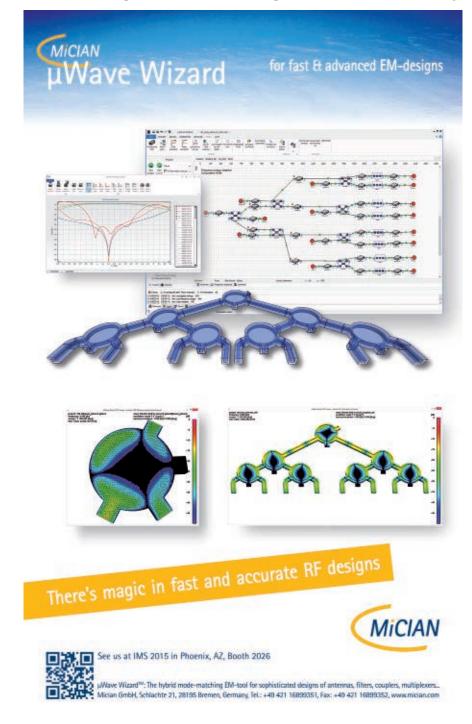
IMDView is the software that provides the graphical user interface (GUI) for setting up the IMD measurement. The software simplifies measurement complexity and controls the VectorStar hardware for the wide range of available measurements. *Fig*-

ures 3 and 4 provide a brief summary of some of the capabilities available. The measurement shown in Figure 3 is configured as a two channel layout. The top channel is sweeping the intermodulation tones and displaying parameters such as the relative power of the IM3 product and absolute power level of the main tones. In addition, OIP3 is calculated for the given power level and displayed as power over frequency. The bottom channel provides a spectrum analyzer-like display of the two tones and the products for a CW stimulus. This display is useful for validation of the measurement setup and confirming that the DUT is not oscillating in the current configuration.

IMPROVED DEVICE MODELING

Linearity, low noise and IP3 performance of the receiver are critical in acquiring accurate IMD analysis. The VectorStar NLTL-based receiver provides exceptional linearity while maintaining very low noise floors even at millimeter wave (mmWave) frequencies. Typical VNAs provide IP3 in the +25 dBm range and performance is reduced at narrow tone deltas, in some cases IP3 performance is reduced as much as 20 dB. VectorStar provides receiver IP3 performance in the 35 dBm range and continues to provide excellent performance even at narrow tone deltas. In fact, in combining the NLTL-based receiver with the source control capabilities of the VectorStar VNA, there is minimal difference in IP3 performance when measuring under wide or narrow tone deltas. Since the design engineer needs to stimulate the DUT under real-world modulation conditions for best accuracy, providing fewer restrictions during the IMD measurement process is a real advantage. Benefits of the NLTL receiver architecture also carry over into the mmWave bands providing industry-leading IP3 performance up to 145 GHz.

Measuring higher order products is important for tracking optimum spectral performance. IMDView provides easy configuration for tracking higher order products (up to IM9) and includes advance tracking capabilities such as asymmetry plotting. Trace 4 of Figure 3 is configured to plot the asymmetrical properties of the fifth order tones. This unique feature available in VectorStar provides the design



engineer the ability to track the asymmetrical properties of the IM products for advanced analysis capabilities such as memory effects of active devices. The result is more accurate models of the device for improved circuit simulation and improved chance of first-turn design success.

USEFUL AND EXTENSIVE GRAPHICAL INTERFACE

The IMDView option provides a wide range of tools to help configure the IMD measurement. In addition to setting up the trace responses, the software provides extensive trace and channel management for easy display optimization. The software also tracks the frequency bands of interest as well as the power levels required of the two tones. During power calibration the software automatically switches the paths to reflect the required configuration for the power calibrations. The result is calibrated tone power at the input of the DUT and corrected for the loss paths through the combiner.

Improvements in trace and channel management also provide easy optimization of complex measurements. For example, setting VectorStar in the active channel only mode will update the display of the active channel and provide best measurement speed for the channel. If multiple response changes need to be monitored as the device is being tuned or while a parameter is being edited, then the feature can be quickly toggled for an all channel update.

mmWAVE IMD MEASUREMENTS TO 145 GHz

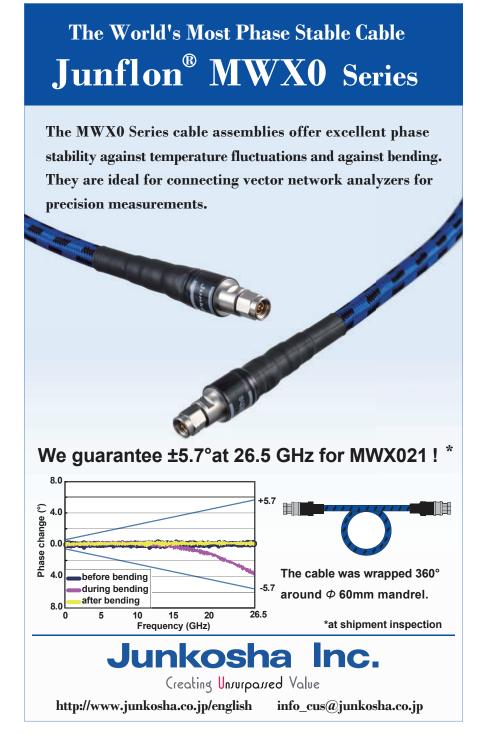
The VectorStar series platform offers the widest range of frequencies available in a VNA. Beginning with a start frequency of 70 kHz (operational to 40 kHz) the low end provides the ability to characterize amplifiers down to the actual operating condition of the DUT. Note that if the DUT operates to 10 MHz and the lower main tone is set for 10 MHz, then lower order products will be less than 10 MHz. Thus, a VNA capable of measuring signals below 10 MHz becomes even more important during IMD measurements.

At the upper end, the VectorStar series offers stop frequencies at 20, 40, 50 and 70 GHz for the baseband units. For single sweeps beyond 70 GHz, the broadband versions operate

to 110, 125 and 145 GHz in coax. The Anritsu mmWave modules for IMD measurements are used as the source tones starting at 54 GHz and go up to the 110/125/145 GHz limit.

The IMDView configuration panel automatically monitors the system configuration and provides graphical setup solutions depending on whether the system is configured for baseband operation or mmWave operation. The GUI also tracks setup requirements

for different version configurations such as when the combiner or dual source option is not included and external sources are preferred. Figure 4 shows the graphical configuration for measuring a W-Band 75 to 110 GHz DUT and provides all the parameter controls required. *Figure 5* is an example of a typical VectorStar on-wafer mmWave IMD measurement. The high performance, compact modules offer excellent IMD performance for



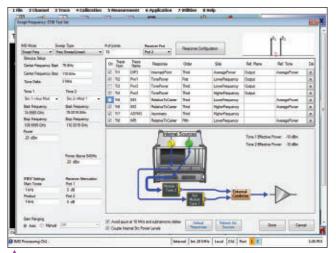


Fig. 4 Setting up IMD measurement is simplified using the IMD-View configuration panel.

on-wafer measurements at mmWave frequencies in a configuration that is easy to install using smaller, low cost platens and positioners.

IMDView software, together with an optional internal second source, provides the ability to evaluate intermodulation distortion performance of amplifiers during the design stage and in production. The VectorStar graphical user interface reduces test time by providing engineers the abil-

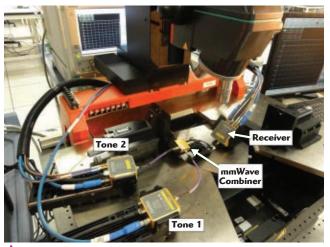
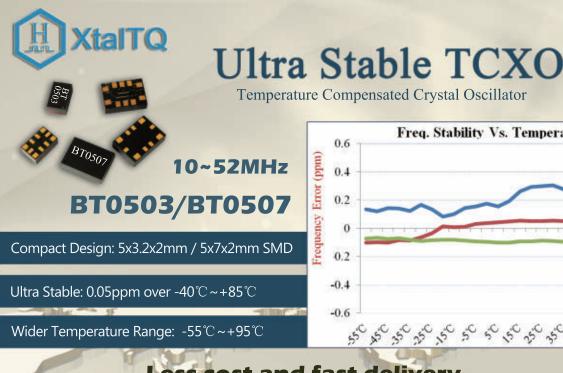


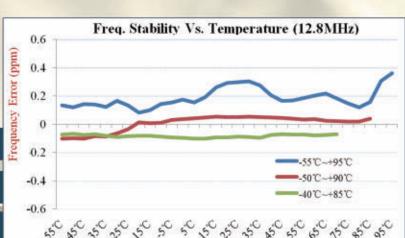
Fig. 5 IMDView supports IMD measurements of mmWave devices.

ity to modify parameters and observe the results immediately without needing to switch screen displays.

VENDORVIEW

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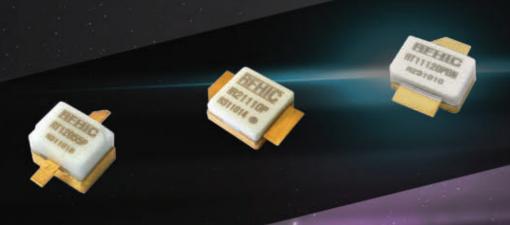


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IE27165W	2496 ~ 2690	16.9	46.0	52.2	53	76	48
IE36085W	3400 ~ 3600	17.3	42.7	49.3	53	71	48
IE36110W	3400 ~ 3600	17.1	43.0	50.4	53	68	48

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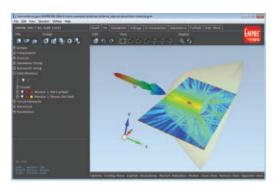
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EMPIRE XPU 7.10: XPU 3D EM Solver

IMST GmbH Kamp-Lintfort, Germany

MPIRE XPU is a 3D EM modeling tool based on finite difference time domain (FDTD) for antennas, microwave circuits, EM chip design and more. Due to increasing complexity, higher package density and the need to take environmental considerations into account the simulation effort is steadily rising. Therefore, simulation acceleration techniques are becoming increasingly important.

Solutions based on graphic cards (GPU) are expensive and limited in usable memory because only the on-board memory of the GPU may be used. With its new release the 3D EM solver EMPIRE XPU 7.1 has been further optimized for new CPU architectures to increase the simulation performance to approximately 8 GCells/s. The XPU technology is a smart implementation of the FDTD algorithm on modern CPU architectures. It can drastically reduce simulation times while maintaining full access to the available RAM.

XPU ACCELERATION METHOD

The well known FDTD method keeps samples of three electric fields and three magnetic field components per unit cell in the computer memory. The fields are calculated independently of time, overwriting the complete Efield and H-field with new samples in one step. A conventional code implementation requires reading and writing the complete E-field and H-field to the RAM each time step. On a state-of-the-art PC (Intel Core i7, 8 cores, 3 GHz clock speed and DDR4 RAM) the memory bandwidth is 68 GByte/s which yields a maximum FDTD performance of about 900 million cells per second (MCells/s).

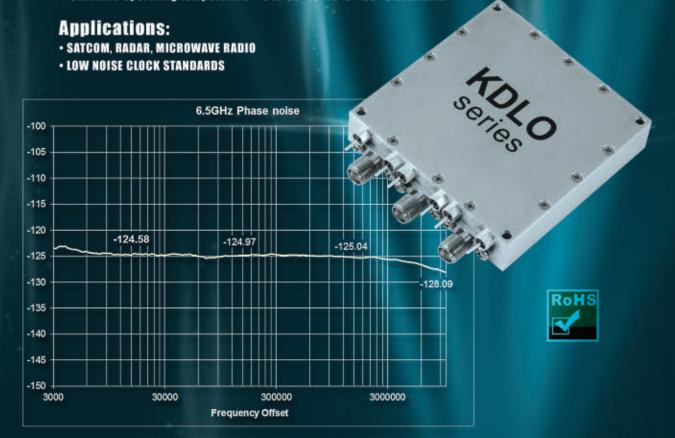
The performance on the CPU itself is about 8 times higher, indicating that the memory access time is the bottleneck. Conversely, the memory bandwidth of the last level caches is 768 GB/s which is much higher than the RAM access time. EMPIRE features a smart algorithm which can exploit the high computation speed of the CPU by executing multiple time steps in a certain number of planes within the L3 cache before exchanging the data with the RAM. The optimum number of planes and strategy is determined, during the initial simulation phase in EMPIRE.

On multi-CPU machines special care has to be taken if data has to be written into memory

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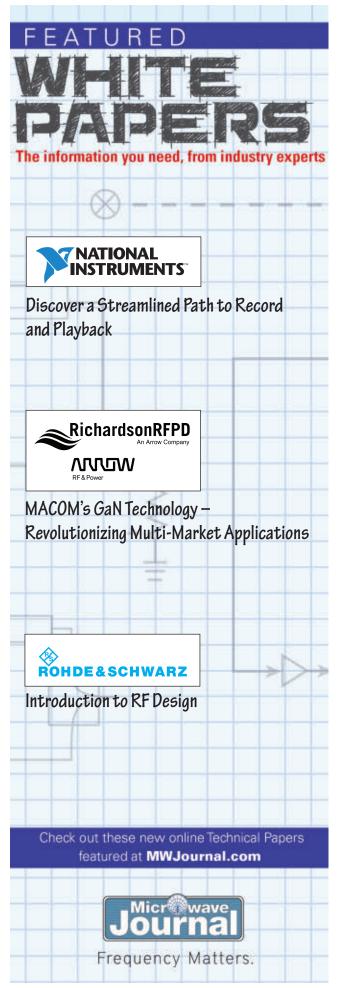
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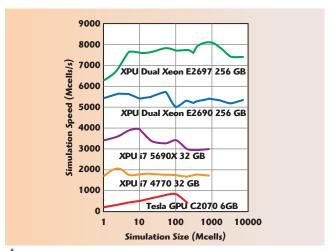


Fig. 1 Performance vs. simulation size on different processors.

modules which are associated to other CPUs. By enabling the Non-Uniform Memory Architecture (NUMA) and code optimization the simulation performance is further increased by EMPIRE XPU 7.1.

Figure 1 shows the simulation speed versus simulation size on different processors. As a reference, the red line shows the performance of a Tesla GPU card. Here the performance varies with simulation size and the simulation size is limited due to available memory. Other curves show the EMPIRE performance on consumer PCs (Intel core i7) and workstations (e.g., Intel dual Xeon, E5-2697 V3). A high performance is obtained for all simulation sizes and larger simulation problems can be solved due to access to the complete RAM (approximately 6 billion cells compared to 200 million cells on GPU).

BENCHMARK: ANTENNAS WITH RADOMES

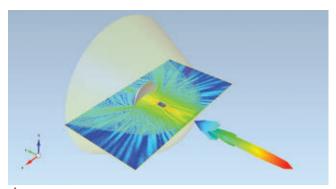
In order to obtain an accurate prediction of antenna characteristics, the antenna environment has to be included in state-of-the-art EM simulations. The presence of a radome can change the antenna gain and beamwidth as well as increase sidelobes. For example, in **Figure 2** a parabolic reflector is fed by a waveguide horn and enclosed by a radome (permittivity = 5, thickness = 7 mm). The operating frequency is 15 to 25 GHz and the simulation area is about $75 \times 75 \times 40$ cm. Using a maximum resolution of 15 cells per minimum wavelength yields a mesh with 5 billion cells. EMPIRE XPU 7.1 uses smart caching of simulation coefficients to minimize the memory effort. The required memory exceeds 114 GByte which would not be possible using GPU cards.

In this example, the simulation performance of 3.6 GCells/s is obtained on a Dual Xeon E5-2690 workstation and the 30 dB energy decay limit is obtained after 11,000 time steps in 4 hours 20 minutes. Near and far fields at 25 GHz in Figure 2 show that the radome has substantial influence on both near field and far field patterns and must be taken into account for proper EM design.

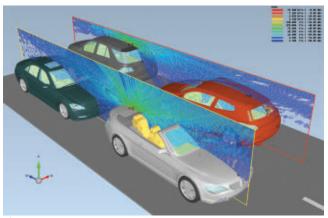
CAR-TO-CAR COMMUNICATION

The car-to-car (C2C) communication project is a European initiative for the development of data exchange between vehicles with the aim to increase safety or to optimize the traffic flow. The operating frequency chosen is

ProductFeature



▲ Fig. 2 Near and far fields of a reflector antenna with radome at 25 GHz.



▲ Fig. 3 Electric field of a car-to-car communication link at 5.6 GHz.

5.6 GHz. With EMPIRE XPU 7.1 simulations an accurate prediction of the propagation channel is possible. In *Figure 3* a scenario is depicted where two cars are transmitting while others are receiving the signals.

All details relating to the car such as the body, screen, interior or wheels were taken into account. This simulation requires about 4 billion cells and a memory usage of 96 GB RAM, including near and far field recordings. The simulation is carried out in about 5 hours on an Intel dual Xeon workstation E5-2697 V3 with a performance of 5 GCells/s, calculating 25,000 time steps to reach 30 dB energy decay.

The acceleration technique utilized by EMPIRE XPU 7.1 enables fast and efficient FDTD simulations on modern CPUs. A smart time stepping algorithm facilitates the calculation of multiple FDTD time steps in the cache memory of the CPU. This increases the simulation speed drastically as the simulation speed is no longer limited by the main memory interface. The whole RAM memory of the PC is quickly accessible for the EM simulation.

The examples given above illustrate when EMPIRE XPU 7.1 is applied to simulations of a 25 GHz reflector antenna with radome and a car-to-car communication link. Such applications requiring a large amount of RAM memory can be easily simulated with the XPU technique on conventional workstations, while a calculation on a GPU card would fail due to limited available memory.

IMST GmbH Kamp-Lintfort, Germany www.empire.de See IMST at IMS Booth 2522.



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MVG WaveStudioTM Software Solution for Over-the-Air Testing

Microwave Vision Group (MVG) Paris, France

or many years, the wireless device sector has demanded an improved software solution for over-the-air testing, data management and analysis. To meet these demands MVG has developed its latest software innovation – MVG WaveStudioTM – to deliver faster and more flexible measurements for wireless devices.



Fig. 1 The test setup interface-call is established.



Fig. 2 Results in parallel plots.

USING MVG WAVESTUDIO™

MVG WaveStudioTM has many automated features, making it user, time and cost friendly. Through its automated test method, the software suite takes full control of all equipment in the system once a testing session is underway. This allows engineers to program tests to run in batches, or repeat tests without any intervention. $Figure\ 1$ shows a test setup interface with the connection established.

MVG WaveStudio™ is provided as a two part package: a licensed version of the software and a free pre-test/post-test module. Flexibility is derived from the free module, with which users can set up batches of tests in advance of a measurement and save to execute later, as well as review measurement results using any PC.

To understand how device performance changes as hardware/software modifications are made or to understand how performance varies across different devices, re-testing is also an important step in the process. With MVG WaveStudio $^{\text{TM}}$, the measurement results are automatically stored and easily recalled with the plots viewable in parallel windows for immediate comparisons. *Figure 2* shows results in parallel plots.

To complete a measurement, the full licensed version of MVG WaveStudio[™] is required. This version allows for the comprehensive data acquisition of automated OTA measurements. It also comprises post processing capabilities and report generation that meets the requirements of standards bodies such as CTIA (The Wireless Association). *Figure 3* shows the multi-probe system interface.

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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	23-27	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

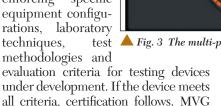


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TESTING COMPLIANCE

To ensure that high quality standards are main-tained across the industry, the CTIA has established the CTIA Test Plan enforcing specific equipment configurations, laboratory techniques, methodologies and





test A Fig. 3 The multi-probe system interface.



📤 Fig. 4 A left-hand polarization test.

REDUCED TESTING TIME

WaveStudioTM meets the software requirements of the CTIA Test Plan.

The tests ensure that any interference from cellular communication across the band does not degrade the performance of the wireless device. With MVG WaveStudioTM, a comprehensive set of measurements can be performed including the characterization of antenna radiation patterns in transmit mode: total radiated power (TRP), power sweep, conducted power and in receive mode: total isotropic sensitivity (TIS), receive signal strength (RSS) pattern, RSS linearization, intermediate channel sensitivity (ICS), sensitivity sweep and conducted power. Figure 4 illustrates a left hand polarization test.

Several factors can affect both TIS and TRP. It's important that these factors are understood and addressed during the design stage of any wireless device. It's necessary to know which part of a cellular phone design affects TIS and TRP.

Effective isotropic radiated power and effective isotropic sensitivity (EIRP and EIS) measurements reveal antenna patterns with lobes of high antenna gain and nulls, affecting the TRP and TIS values respectively.

The estimated time for TRP measurements (one channel with sampling every 15°) previously took at least 3 minutes. With MVG WaveStudioTM, this time is dramatically reduced, taking as little as 1 minute for GSM/ GPRS/EDGE for Tx average power sensitivity. For TIS (three channels with sampling every 30°), measurement time is reduced to as little as 20 minutes from RSSI pattern algorithms.

FEATURES AND CAPABILITIES

In addition to MVG WaveStudio's capability to provide fully automated OTA measurements of wireless devices, it also gives users: the ability to prepare test batches in advance, batch cloning capabilities, offset measurement capabilities, the possibility to view results from any PC, multiple test results in parallel, measurements which comply to the CTIA OTA test plan and an intuitive user interface.

SUPPORTED PROTOCOLS

MVG WaveStudioTM supports many protocols including LTE TDD/FDD, LTE-CA (available soon), GSM, GPRS, EDGE, Wi-Fi 802.11 a/b/g/n, Bluetooth 802.15.1.2 (available soon), CDMA2000, CDMA 1xRTT, CDMA 1xEVDO, WCDMA, HSDPA, HSPA, HSPA+, TD-SCDMA (available soon) and TD-HSDPA.

With MVG multi-probe technology and MVG WaveStudioTM OTA automation software, approved and certifiable by CTIA, tests can be performed quickly and effectively, optimizing test lab operations, increasing test throughput and ultimately gaining overall time to market of mobile devices.

Microwave Vision Group Paris, France www.satimo.com/content/ products/ota-measurement-suite See MVG at IMS Booth 937.



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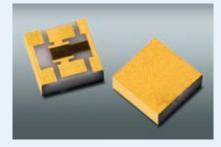
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TechBrief



emiGen fixed attenuator pads feature precise resistor films and superior metallization to provide consistent performance and reliability. The use of advanced thin film technology enables the parts to have full side wraps for surface-mount or onboard installation. Gold bondable topside contacts for the input and output make the pads suitable for standard RF/microwave assembly techniques.

The fixed attenuators comprise devices with nominal attenuation values of 0 to 30 dB (in 1 dB steps). The attenuators contain wraps that connect the topside ground to the backside metallization of each die. The devices with nominal attenuation values of 1 dB or greater are fabricated using thin film resistors deposited on alu-

Fixed Attenuator Pads

mina. The circuit topology is a simple T structure that consists of two series resistors and a shunt resistance, which is realized as a pair of shunt resistors connected to the node between the two series resistors.

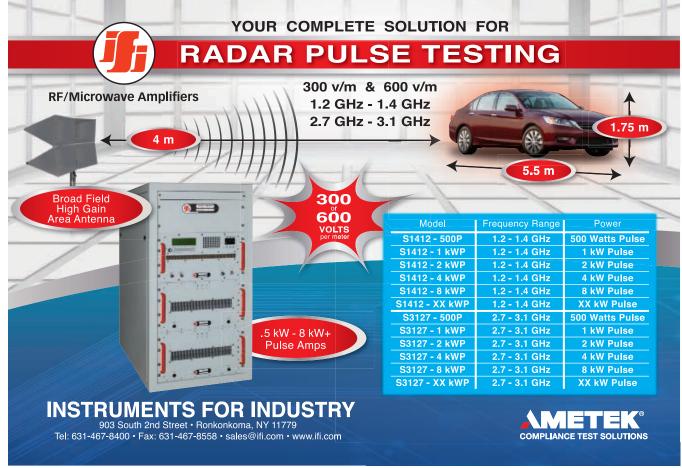
The resistances of each of the resistors are selected to simultaneously produce the nominal attenuation with very good input and output return losses. The attenuators with nominal attenuation values ≥ 6 dB contain a pair of cascaded T sections. The 0 dB attenuator is a 50 Ω microstrip transmission line with identical footprint and bond pads. The assembly technique of simply mounting the pad to the ground floor of the module or thin film circuit gives the user shorter bond wires and lower loss.

The high values also work as a 50 Ω load while the smaller values allow

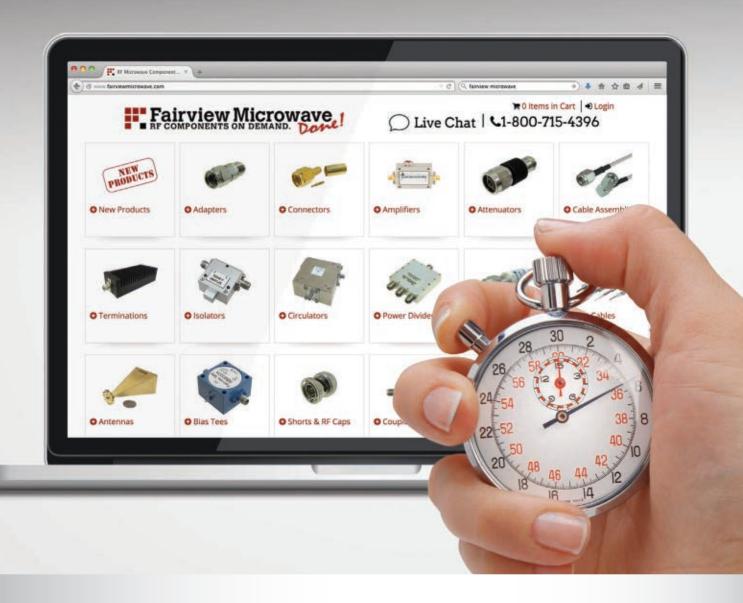
the user good signal level control. The ground wraps allow the pads to be small with an overall size of 0.030" × 0.030". The pads are optimized for coplaner waveguide or microstrip PCB and microwave module assemblies. Bond wire or ribbon is used to connect the input and output terminals to the transmission lines. Connection to ground is achieved through the topside wraps connecting to the bottom metalized surface. The size, ground wrap and process controlled resistor values allow the user enhanced power handling to over 5 W and return loss in the 30 dB range.

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he HSM18001B RF synthesizer module is a broadband signal source (10 MHz to 20 GHz, 0.001 Hz minimum step size) providing excellent spectral purity from sub-VHF through Ku-Band. Typical phase noise at 18 GHz is -106 dBc/Hz at 10 kHz offset. The HSM18001B has an adjustable output power dynamic range covering -20 to +20 dBm in 0.01 dB steps as well as an integrated pulse modulation function with rise and fall times as fast as 10 ns. While performance is crucial for many applications, reliability is extremely valuable if not critical for most. This compact, CW source has a field proven mean time between failures (MTBF) of greater than 240,000 hours, making it optimal for both commercial and defense applications.

RF Synthesizer Module

The proprietary, non-PLL architecture of the HSM series RF synthesizer modules creates a phase coherent relationship between multiple channels (synthesizers) when synchronized to a common reference signal. Each HSM18001B module hosts an internal 100 MHz precision ovencontrolled crystal oscillator (OCXO), which can be phase locked to an external 10 MHz reference signal or superseded by an external 100 MHz reference signal. Phase coherency is unique for this class of signal generator because each channel can be independently tuned for frequency, amplitude and phase offset while maintaining a phase coherent relationship.

Popular automatic test equipment (ATE) applications benefit from phase coherency, including intermodulation distortion and load-pull testing. Preci-

sion timing provided through phase coherent signals is advantageous for many other applications, from particle accelerator timing to SATCOM. The most apparent use of phase coherent signals in the defense market is for radar system local oscillators (LO).

The HSM18001B offers phase coherency coupled with compact size, high reliability, fast switching and excellent phase noise performance. Holzworth also offers the HSM12001B RF synthesizer module covering 10 MHz to 12.5 GHz (sub-VHF through X-Band), offering the same performance and features as the HSM18001B for applications not exceeding X-Band at a lower price point.

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Low PIM Loads and Attenuators

ECA announces a new family of low and "ultra-low" PIM terminations and attenuators. The compact terminations cover 698 MHz to 2.7 GHz, with typical VSWR of 1.10:1 (1.20:1 maximum). Typical PIM performance is -160 to -165 dBc. The loads are available in 10, 50, 100 and 250 W ratings at +85°C and with 7/16 DIN, mini-DIN (4.1/9.5) or Type N connectors. Mounting brackets and accessories are also available.

The new line of attenuators offers the same robust frequency, VSWR and PIM performance and is available with 50 and 100 W power handling at +85°C. Connector styles and configuration within series and between series include mini-DIN (4.1/9.5), 7/16 DIN, Type N and the soon-to-be-finalized 4.3/10.0 DIN.

All MECA low and "ultra-low" PIM products are tested and validated for RF performance. PIM testing follows the industry IEC standard of $2 \times 20 \text{ W}$ tones at 25°C, unless otherwise limited by the model's maximum rated power During development, dissipation. all product designs are qualified per MECA's internal highly accelerated life test (HALT) for power handling, following portions of MIL-DTL-39030. The designs have demonstrated an impressive margin of over 50 percent $(1.5\times)$ the rated power. All products have a 36 month warranty.

Lead times for termination and at-

tenuator models in the most common connector styles range from immediately, for units in stock, to two weeks. Some versions can be customized in as little as two additional weeks. Since 1961, MECA Electronics (Microwave Equipment & Components of America) has served the RF/microwave industry with equipment and passive components covering Hz to 40 GHz. A global designer and manufacturer for the communications industry, MECA is ISO9001:2008 certified, privately held and manufactures products in the U.S.

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High-stability miniature OCXOs

WITH VERY LOW POWER CONSUMPTION





15x15x9 mm



15x21x9 mm

8-300 MHz

10 MHz

2 ppb in (-40 +85)°C 0.2 ppb/day, 20 ppb/year aging 5x10⁻¹²/1s Allan variance to 30 s warm-up time

100 MHz

10 ppb in (-40 +85)°C 2 ppb/day, 0.2 ppm/year aging

UTMOST PHASE-NOISE PATTERN

- -100 dBc/Hz@1 Hz
- -130 dBc/Hz@10 Hz
- -160 dBc/Hz@1 kHz
- -165 dBc/Hz@10 kHz
- -170 dBc/Hz@100 kHz

5x10⁻¹²/1s Allan variance to 60 s warm-up time

- -97 dBc/Hz@10 Hz
- -127 dBc/Hz@100 Hz
- -155 dBc/Hz@1 kHz
- -167 dBc/Hz@10 kHz
- -172 dBc/Hz@100 kHz

<180 mW power consumption

To 2 ppb temperature stability DIP8 and DIP14 compatible sizes

APPLICATION:

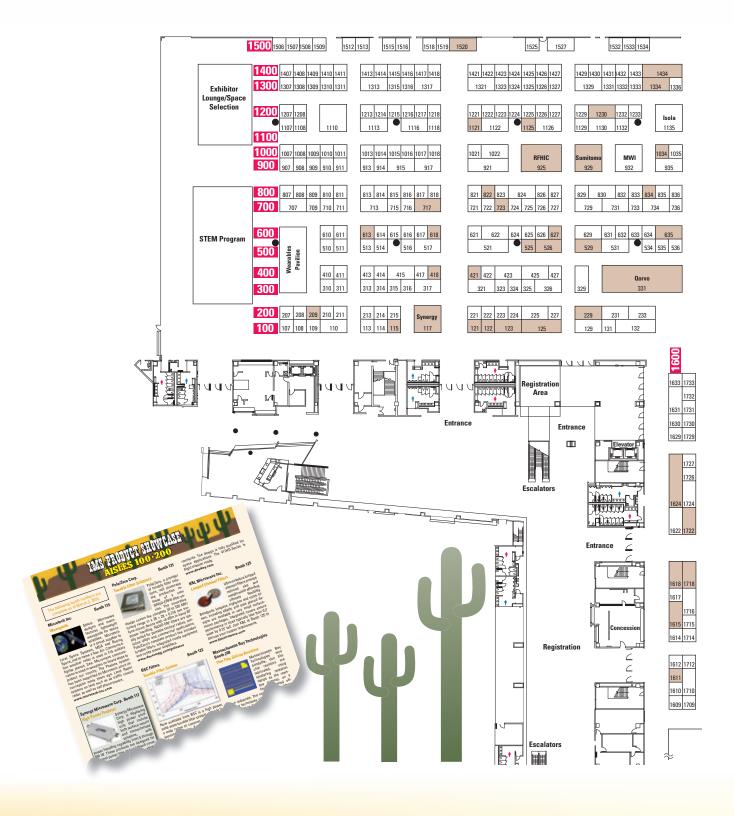
- High-end mobile radio
- Portable test equipment
- Avionics, underwater geological and geophysics sensors
- Rescue beacons, etc.



IMS FLOOR PLANT (1)

YOUR PRODUCT GUIDE TO THE SHOW FLOOR

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www.mwjournal.com/
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Journal Journal

These booth numbers are complete as of March 2. 2015.

IMS PRODUCT SHOWCAST

The following booth numbers are complete as of March 2, 2015.

Microtech Inc.

Booth 115

Waveguide



Space: Microwave designs and manufactures lightweight waveguide for space satellites. Microtech is a proud supplier to

Loral Space Systems, MDA and Boeing Space, just to name a few. Air: Communication weather radar is used in F15 military fighter planes. Sea: Microwave communication is used in weapons on board ships to protect our country. The Phalanx system has been supported by Microtech since its conception many years ago. Land: Radar systems on land such as air traffic control radar, as well as cell phone towers.

www.microtech-inc.com

Synergy Microwave Corp. Booth 117 High Power Products



Synergy Microwave Corp. is displaying high power products that include both surface-mount and connectorized solutions. with

power handling capability from 5 through 500 W. These products are designed for minimal power loss and wideband coverage starting from kHz through several GHz in optimized bands. A large selection of power dividers/combiners, couplers and 90 degree hybrids are readily available for your applications in signal distributing, power monitoring and amplifier designs.

Dual or Single Loop Synthesizers



Synergy Microwave Corp. is proud to include very high performance synthesizer modules among its standard product offerings.

Proprietary, low phase noise design yields phase noise character of -125 dBc/Hz at 3 kHz offset for 6.5 GHz fundamental output. Options include SPI interface for programmable outputs or selectable frequencies in octave or 20% bandwidths up to 15 GHz and a 2.25" square connectorized form factor.

www.synergymwave.com

Pole/Zero Corp.

Booth 121

Tunable Filter Solutions



Pole/Zero, a provider of tunable filter solutions, will showcase the production release of a new NANO-ERF® filter series. The innovative

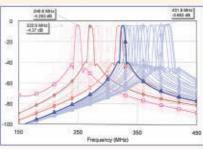
design covers the complete 30 to 520 MHz tuning range in a 28 × 28 × 0.216 mm surface-mount device with +6 dBm in-band RF power handling. NANO-ERF filters are ideally suited for portable tactical radios, miniature UAVs and commercial applications. Pole/Zero's complete product line includes tunable filters, integrated cosite equipment and cosite power amplifiers.

www.dovermpg.com/polezero

BSC Filters

Booth 122

Tunable Filter System



Now available from BSC is a high power, solid-state tunable filter system, suitable for a wide range of common cosite and antijamming scenarios. A typical VHF/UHF unit offers a cross-coupled response with 50 W CW power handling, 10 µs tuning speed and only 4 dB typical loss with nominally 2.5% passband width. The entire architecture is scalable in both bandwidth and frequency.

www.bscfilters.com

Dow-Key Microwave

Booth 123

Qualified Lightweight C-Switch

VENDORVIEW



Since the 1970s, Dow-Key has taken pride in supplying space qualified switches and assemblies to the world's premier manufactur-

ers of satellites and launch vehicles. The latest innovation includes the lightweight (less than 55 grams) C-Type coaxial transfer switch, 411HQ series that operates from DC to 34 GHz with insertion loss of 0.55 dB max. The ruggedized design of the actuator allows the unit to operate under harsh envi-

ronments. The design is fully qualified for space applications. The 411HQ-Series is flight mission ready.

www.dowkey.com

K&L Microwave Inc.

Booth 125

Lumped Element Filters



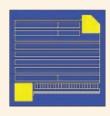
Ultra miniature lumped element filters provide reduced size and weight while affording ultimate flexibility.

Bandpass, lowpass, highpass and notch filters, including elliptic and pole placed designs are available in very small surface-mount packages. Integrated covers assure performance in sizes typically less than 0.2" wide by 0.15" tall. Join K&L at Booth 125 to discuss your custom requirements.

www.klmicrowave.com

Massachusetts Bay Technologies Booth 209

Thin Film Silicon Resistors



Massachusetts Bay Technologies' wire bondable, thin film chip resistors are fabricated, using sputtering tantalum nitride as the resistive material, on a highly polished sili-

con substrate. The company's photolithography techniques can produce geometries of less than five microns. This tightly controlled process creates a resistor with a low TCR, low current noise as well as insignificant nonlinearity.

www.massbaytech.com

Cernex Inc.

Booth 229

Benchtop Amplifiers VENDORVIEW



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



Ultra Small 2x2mm

2WATTENUATORS DC-20 GHz from 1 ea.(qty. 1000)

Save PC board space with our new tiny 2W fixed value absorptive attenuators, available in molded plastic or high-rel hermetic nitrogen-filled ceramic packages. They are perfect building blocks, reducing effects of mismatches, harmonics, and intermodulation, improving isolation, and meeting other circuit level requirements. These units will deliver the precise attenuation you need, and are stocked in 1-dB steps from 0 to 10 dB, and 12, 15, 20 and 30 dB.

The ceramic hermetic *RCAT* family is built to deliver reliable, repeatable performance from DC-20GHz under the harshest conditions. With prices starting at only

\$4.95 ea. (qty. 20), these units are qualified to meet MIL requirements including vibration, PIND, thermal shock, gross and fine leak and more, at up to 125°C!

The molded plastic **YAT** family uses an industry proven, high thermal conductivity case and has excellent electrical performance over the frequency range of DC to 18 GHz, for prices starting at \$2.99 ea. (qty. 20).

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Ceramic

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Qorvo

Booth 331

High Efficiency 0.05 W Small Cell PAs



Qorvo's TQP9309 and TQP9321 are high efficiency, two-stage PAs in low cost, surface-mount packag-

es with on-chip bias control and temperature compensation circuitry. Optimized for small cell base stations, picocells and enterprise femtocells, these RF solutions deliver high gain (30 dB) and > 27 dBm linear power with predistortion correction over 1.8 to 2.2 GHz for multiple bands with a single component. Learn more by visiting Qorvo at IMS2015.

www.qorvo.com

Z-Communications Inc. Booth 418

Ceramic Resonator Oscillator VCOs



The TRO2400A-LF is the first in a new series of ceramic resonator oscillator VCOs, which saves precious

board space but still delivers exceptional phase noise performance. The TRO2400A-LF covers 2.4 GHz within 0.5 to 4.5 V of tuning and provides -113 dBc/Hz phase noise at 10 kHz offset. This innovative design operates off 5 V while consuming 25 mA and provides a 68% reduction in overall volume size in comparison to other CRO topologies. www.zcomm.com

Delta Microwave Inc. Booth 421

GaN SSPA Power Amplifier



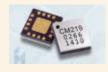
Operating over 29 to 31 GHz, model DM-HPKA-10-102 delivers 8 to 10 W of linear output power. SSPA offers gain of 50

dB and excellent AM-PM (< 3°/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

Custom MMIC Booth 525

4 to 8 GHz GaN LNA
VENDORVIEW



Custom MMIC's CMD219C4 is a GaN low noise amplifier covering 4 to 8 GHz that features a gain of +22.5 dB, a noise figure of 1 dB, an output 1 dB compression point of +17 dBm, and an input survivability of greater than 5 W. Housed in a leadless 4 \times 4 mm ceramic package, the CMD219C4 is ideally suited for C-Band radar applications where high signal levels may be present.

www.custommmic.com

Delta Electronics Mfg. Corp. Booth 526

Low PIM Connectors



Delta's 4.1/9.5 and 4.3/10 Mini DIN series of coaxial connectors and complementary cable assemblies were developed to meet the growing demands of today's high performance mobile communications systems. The connectors have an operational frequency range of DC to 14 GHz, offers excellent VSWR performance and low passive intermodulation (low PIM) < -165 dBc. This makes the products ideally suited for use in cellular base stations, distributed antenna systems (DAS) and small cell applications.

www.deltarf.com

American Technical Ceramics

Booth 529

Q-Bridge Thermal Conductor



ATC's Q-Bridge is constructed with aluminum nitride or beryllium oxide and is available in standard EIA case sizes. It provides superior ther-

mal management by directing heat to a thermal ground plane or other specific thermal points. It provides additional thermal protection to adjacent components resulting in increased circuit reliability. The inherently low capacitance makes this device virtually transparent at microwave frequencies. Q-Bridge is manufactured using a one-piece RoHS compliant SMT package. It is fully compatible with automated pickand-place processing.

www.atceramics.com

VIDA Products Inc. Booth 613

Patented Differential Oscillator Module

VIDA Products introduces the 6 to 24 GHz, patented differential oscillator module with excellent phase noise and spurious response. Its small size fits all magnetic



packages. Use your existing magnetic tuning package or design your own with VIDA application notes. Oscillator is in

a sealed 1 \times 4 mm diameter pill package and is working in VIDA's proprietary or all industry standard packages.

www.vidaproducts.com

Networks International Corp.

Booth 618

Miniature Filters



NIC's engineering expertise in hi-reliability RF products includes a specialty in miniature filters that range from 20 MHz to 7 GHz.

These low profile (0.15") LC and ceramic filters can be customized to meet passband requirements from 1 to 100% 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 communication needs.

www.nickc.com

RLC Electronics Inc.

Booth 627

Surface-Mount Cavity Filter



RLC Electronics introduces a series of high frequency surfacemount cavity filters for small scale, low profile system inte-

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

www.rlcelectronics.com



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VA Diodes Inc.

Booth 635

Mini VNA Extension Modules



VDI's VNA extenders provide high performance frequency extension of vector network analyzers from 50 GHz to 1.1 THz.

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 its original designs. The power supply is simplified and the cooling fans have been eliminated. Mini-modules are currently available for WR15, WR12 and WR10, with higher frequency bands coming soon.

www.vadiodes.com

Gowanda/TTE Filters/Instec **Filters**

Booth 717

RF/Microwave Filters



1956, U.S.-Since based TTE Filters has been designing and manufacturing and microwave filters. Designs are now

available to 26 GHz. Standard and custom LC and combline designs, multiplexers and bias tees are offered. Dedicated to customer service, TTE provides lead times as short as 3 to 5 days. New LC9S lowpass Chebyshev filters are available from stock. Filters from TTE, inductors from Gowanda Electronics and EMI/RFI filters from Instec Filters will be on display at IMS2015; all affiliates of Gowanda Holdings.

www.gowandaholdings.com

Greenray Industries Inc. Booth 723

Temperature Compensated Oscillator



Greenray Industries Inc. announces the availability of the T1241 TCXO. The new, high performance T1241 temperature compensated oscilla-

tor, available from 50 to 100 MHz with squarewave, CMOS output, features low phase noise and vibration compensation. The T1241 offers low g-sensitivity while providing superior phase noise performance, which are ideal characteristics for demanding mobile applications. Supply voltage is +3.3 or +5 V DC, and supply current is 30 mA max. EFC is provided for precise tuning or phase locking applications.

www.greenrayindustries.com

Keysight Technologies Inc.



UXG and Signal Studio Software



Better testing done sooner equals deeper confidence in electronic warfare (EW) system performance. The N5193A UXG agile signal generator is a powerful building block, whether you need a dependable LO or a scalable threat simulator. It provides complex EW threat simulation, in an off-the-shelf solution, lowering the barriers between new intelligence and up-to-date signal scenarios. To simplify signal creation, N7660B Signal Studio for multi-emitter scenario gen-

Booth 739

eration (MESG) delivers Keysight-validated, performance-optimized signals that can be downloaded directly into one or more UXGs as a pulse descriptor word (PDW) list.

UXA Signal Analyzer and 89600 VSA Software



In developing mission-critical radar, electronic warfare and communication systems, leading-edge signal analysis requires excellent performance. Keysight's N9040B UXA signal analyzer delivers industry-leading phase-noise performance of -136 dBc/Hz at 10 kHz offset (-142 dBc/Hz at 100 kHz for 1 GHz carrier) along 510 MHz analysis and real time bandwidths. With a large 14.1-inch multi-touch display, the

UXA provides wider, deeper views of elusive and wideband signals, Adding 89600 VSA software with Option BHQ provides in-depth synchronized pulsed radar analysis, enabling you to see through complex interactions and find answers faster.

Phase Coherent PXIe Multi-Channel Vector Signal Analyzer



Keysight's multi-channel phase coherent M9391A PXIe vector signal analyzer (VSA) and M9381A PXIe vector signal generator (VSG) enable characterization and test of wireless designs requiring multiple time-synchronized or phase-coherent channels. These new capabilities address rapidly evolving wireless technology challenges, including validating critical multi-antenna techniques, such as diver-

sity, carrier aggregation, 8x8 MIMO spatial multiplexing and beamforming, used in the development and verification of next-generation cellular, wireless connectivity and 5G devices. Keysight's LTE/LTE-Advanced Multi-Channel Reference Solution combines multiple phase-coherent PXIe VSAs and VSGs, bringing together hardware and software to accelerate test setup and enable deeper insight into complex LTE and LTE-Advanced designs.

FieldFox Analyzers



Keysight's FieldFox handheld combination analyzers provide a precise and comprehensive solution for satellite ground station maintenance in the aerospace/defense and commercial markets. FieldFox analyzers quickly assures system performance with a high level of confidence to help speed satellite ground station installation and maintenance. FieldFox handheld analyzers offer the precision, fre-

quency coverage (up to 26.5 GHz), and all-in-one capability (e.g., spectrum analyzer, full 2-port vector network analyzer and power meter) needed to perform a range of benchtopquality measurements in difficult test environments. Now, with the introduction of measurement Option 208, FieldFox is the perfect tool for satellite communication field test.

www.keysight.com

Maury Microwave

Booth 745

Measurement and Modeling Solutions



Maury Microwave will be demonstrating state-of-the-art measurement and modeling solutions including a patent-pending noise parameter sys-

tem, 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 LXTM-certified automated impedance tuners. Visit Maury for demos at IMS2015.

www.maurymw.com

IMS PRODUCT SHOW CASE AT STATES 800 * 900

EZ Form Cable Corp.

Booth 822

Cable Assemblies



EZ Form Cable Corp. introduces a new line of high performance flexible cable assem-

blies that replace the need for custom 0.086 semi-rigid cable assemblies with special lengths and bends. EZ Mini-Flex 405 cable assemblies are complete with SMA males, fully tested and are available in a variety of standard lengths. The SMA plugs are solderless crimp versions that eliminate solder concerns and facilitate low profile applications.

www.ezform.com

OML Inc.

Booth 834

Signal Generator Frequency Extension Module

OML introduces a new option for its signal generator frequency extension module.



Source module (SxxMS-EA) now includes an option for electronic attenuation. Master your power with this mod-

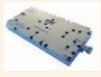
ule by controlling the attenuation through a DC control voltage. Power leveling and power flatness can now be achieved through computer control. Currently available in waveguide bands from 50 to 110 GHz; above 110 GHz contact factory. This option also includes typical attenuation values of 20, 40 and 60 dB.

www.omlinc.com

RFHIC Corp.

Booth 925

Pulse Power Amplifier



RFHIC's new pulse power amplifier, RRP52571K0-41, is a low cost C-Band solution designed for radar system appli-

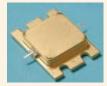
cations. It operates between 5.25 and 5.75 GHz and typically provides 41 dB of gain, 1200 W of output power, 30% of efficiency and 10% duty cycle. The module utilizes GaN HEMT technology, providing excellent power density, high breakdown voltage, wide bandwidth and high efficiency.

www.rfhic.com

Sumitomo Electric Device Innovations Booth 929

GaN IMFET

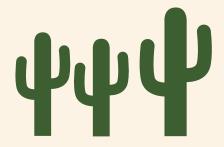
Sumitomo Electric introduces new devices to its line of high power GaN products for



S-Band radar applications. The new internally matched device provides 600 W output power in pulsed operation. This device covers

frequencies from 2.7 to 2.9 GHz with excellent efficiency. Visit Sumitomo's Booth 929 for a live demonstration.

www.sei-device.com





MIL Qualified Components Available

KRYTAR* 1288 Anvilwood Ave. Sunnyvale, CA 94089

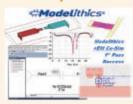
Toll Free: (877) 734-5999 • Fax: (408) 734-3017 • sales@krytar.com

www.krytar.com lists complete specifications and application ideas for all products

Modelithics Inc.

Booth 950

CLR Library for ANSYS HFSS



Modelithics Inc. announces significant hancements and capabilities to the Modelithics libraries. Its high accuracy,

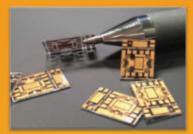
scalable, high frequency simulation models for Keysight ADS and NI/AWR Design Environment (MWO) feature model setsys, Modelithics will soon add a library that supports ANSYS Electronics Desktop

www.modelithics.com

tings for convenient and accurate electromagnetic co-simulation. In addition to the annual major releases of the Modelithics library for ADS, MWO and Keysight Gene-

Flexible Integration for Custom RF Components in Glass

GECCO™ Process: Developed for Chip Level Integration



Complete RF solutions in glass



A GECCO™ High-Q Inductor. 50um wide, 5um thick, metal coil resting on 20um wide glass rails

Integrate high frequency components into simple or complex systems.

Integration of glass with sensors, MEMS, optoelectronics, and RF devices

Custom application-specific RF integration reduces power consumption by up to 10x, reduces chip size by up to 70%, all while simplifying and reducing production costs.



Come see us at IMS 2015 Booth No. 2412

www.3dglasssolutions.com

1(866)-559-8981

Charter Engineering Inc. Booth 1034 SP12T Terminated RF Switch

CEI model T12P-941518 is a SP12T internally terminated latching switch with indicator circuitry operating from DC to 15 GHz. The





superior PIM switch features a -160 dBc minimum 3rd order IM. The T12 series is also offered as a fail-

safe or normally open switch along with various actuator and mounting options. CEI offers a complete line of coaxial RF switches for ATE, matrix and critical switching systems. CEI specializes in highly repeatable and superior PIM switches.

www.ceiswitches.com

KRATOS General Microwave

Booth 1048

Solid-State Power Amplifiers



KRATOS General Microwave presents its X and Ku-Band solidstate power amplifiers (SSPA). These GaN based SSPAs offer up

to 400 W of output power in up to 1000 MHz bandwidth. Units offer graceful power output degradation, ultra quiet switching power supply, fast on/off response and have built-in test capability. The family of SSPAs offer high performance and are cost effective alternatives to electron tube devices.

www.kratosepd.com/solutions/kratosgeneral-microwave

Piconics Inc.

Booth 1121

Broadband Conical Inductors



Piconics Inc. announces its new line of substrate mounted conical inductors for chip & 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

MCV Microwave

Booth 1125

Ceramic Duplexer



MCV Microwave has extensive experience in thick film microcir-

cuits, microwave dielectric materials and

IMS PRODUCT SHOWGAST

filter design, MCV Microwave is a major supplier of RF/microwave bandpass, lowpass, highpass, band reject and multiplex filters using ceramic, LC, combline/cavity and helical topology. Shown here is its LTE 60 W ceramic duplexer with low PIM.

www.mcv-microwave.com

Crane Aerospace & Electronics Microwave Solutions

Booth 1137

Ku-Band Iso-Divider





Crane Aerospace & Electronics Microwave Solutions continues to expand their Ku-Band iso-divider product family with the introduction of an eight-way unit. Featuring similar exceptional performance as the previously introduced four- and two-way products, exceptional insertion loss and band flatness performance is continued in this product. Small size, low weight and high reliability are features that are crucial

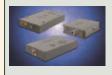
for the target applications. Stop by Booth 1137 to learn more and see samples.

www.craneae.com/mw

Teledyne Microwave Solutions

Booth 1149

ITAR-Free Products



TMS offers a complete suite of ITAR-Free products for Ka-Band systems specifically developed for legacy and new designs. Both up and down-converters can electronically switch between commercial and military Ka/K-Bands. By combining these converters with the company's standard SSPA, a full transceiver can be configured operating over the 29 to 31 GHz transmit band and the 19.2 to 21.2 GHz

receive band with three hermetically sealed modules.

www.teledynemicrowave.com

Teledyne Relays

Booth 1149

RF Relay



Teledyne Relays announces its new 121 relay. The RF121 is a high repeatability, SPDT, broadband, magnetic-latching RF relay with performance to 12 GHz. The RF121 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 through-hole, surface-mount

stub pin (GRF121) and J-lead configurations. The GRF121 has a frequency range of DC to 16 GHz.

www.teledynerelays.com

Teledyne Storm Microwave

Booth 1149

Stranded Cable Assembly



Meet the new FlexCore™ product—a stranded center conductor cable assembly that will benefit both systems and test & measurement applications when requirements call for an extended flex life cycle, mechanical reliability and repeatability. Operating up to 26.5 GHz, this durable, 7-strand cable offers flex performance similar to a 19-strand product, as well as excellent connector retention (35 lbs pull).

www.teledynestorm.com

Komax Wire

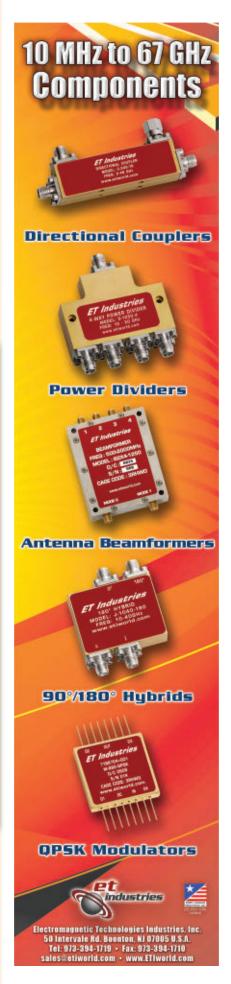
Booth 1230

Kappa 331 UX



Komax Wire will feature the new Kappa 331 UX modular wire cut and strip machine at IMS2015. 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 1230 at the show!

www.komaxgroup.com/en/wire/products-and-solutions/products/cut-and-strip/kappa-331/



IMS PRODUCT SHOWCASH IN COLUMN THE STREET ST

SignalCore

Booth 1334

20 GHz Signal Source



SignalCore's new, high performance 20 GHz RF/microwave signal source, available in PXIe, USB, SPI and RS-232 platforms, is cost effective, compact and designed for seamless integration. With frequency spanning 50 MHz to 20 GHz (1 Hz resolution), typical amplitude ranging -30 to +10 dBm, and phase noise of -117 dBc/Hz at 10 kHz offset at 10 GHz carrier, this product is ideal for research and development, academic, military and commercial applications.

www.signalcore.com

Rosenberger North America LLC

Booth 1351

Intermodulation Site Analyzer



Rosenberger presents its brand new broadband passive intermodulation site

analyzer for multi-function on-site tests and measurements of active and passive elements. The Rosenberger site analyzer features PIM detection over CPRI (incl. cancellation function), broadband Rx & Tx base model 700 to 2700 MHz with exchangeable filter units, continuous wave signal (no pulse), portability with a rugged design, sunlight readable 12" touch screen, antenna isolation measurement, DTF measurement (VSWR vs. Dist.; PIM vs. Dist.), VSWR/return loss measurement and battery, and 110/220 V AC operation.

www.rosenberger.de

Skyworks Inc.

Booth 1354

Wireless LAN Front-End Module

VENDORVIEW



Skyworks' SKY85806-11 features an integrated 2.4 GHz PA, 5 GHz PA, transmit filter, diplexers and T/R switches. It is ideal

WEINSCHEL

for set-top box, wireless high fidelity, USB dongle and personal computer applications. The device provides local oscillator

filters for the 2 and 5 GHz transmit paths in a compact QFN 28-pin, $4 \times 3 \times 0.8$ mm package. Visit Booth 1354 to learn more about its broad product portfolio for diverse markets. **www.skyworksinc.com**

-

MPI Corp.

Booth 1434

Automated Probe System

MPI Corp. announces the new automated engineering probe system - TS2000-SE for accurate and reliable DC/CV, RF and high power measurements. The ShieldEnvironmentTM is designed



to ensure the advanced EMI/RFI/Light-Tight shielding, Fem to Amp low-leakage capabilities and integrated active vibration isolation, with a temperature range

of -60° to +300°C. With the unique automated wafer loader, vertical controlled environment (VCE) and the revolutionary, multitouch operation software suite SENTIO $^{\text{TM}}$, MPI is offering great values for device characterization for modeling and process development.

www.mpi-corporation.com

Signal Hound

Booth 1442

Spectrum Analyzer and RF Recorder



The BB60C is a broadband real time spectrum analyzer and RF recorder that

captures and displays RF events as short as 1 μ s. It has selectable IF streaming bandwidths from 250 kHz up to 27 MHz. With accurate operation from 9 kHz to 6 GHz over its entire temperature range (-40° to +65°C available), the BB60C is well-suited for lab or field use. It sells for \$2879 USD, and includes an API for custom software development.

www.signalhound.com

Anokiwave

Booth 1520

Fabless Semiconductors

Pioneering the mmWave revolution, Anokiwave is a fabless semiconductor company providing highly integrated SiGe core chips



and III/V front-ends for emerging mmWave and AESA markets.

Anokiwave's creative system architectures feature rich solutions and optimal selection of semiconductor technologies that deliver solutions to your most challenging mmWave applications. Anokiwave specializes in mmWave Si Core ICs, AESA ASICs and mmWave III/V front-ends.

www.anokiwave.com



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Voice: 301.963.4630

Fax: 301.963.8640

Gaithersburg, MD 20879

RF@WeinschelAssociates.com

Exodus Advanced Communications

Booth 1611

High Power SSPA



Exodus Advanced Communications introduces a new high power SSPA module covering 4 to 18 GHz at 20 W P1dB and 30

W Psat. This small form factor module uses state-of-the-art chip and wire GaAs and GaN devices, exhibits good linearity and operates at 32 VDC with 19A max consump-

www.exoduscomm.com

B&Z Technologies

Booth 1615

Microwave Amplifiers



B&Z **Technologies** manufactures a full line of state-of-theart microwave amplifiers spanning from 100 kHz to 50 GHz.

B&Z offers ultra-low noise, high dynamic range, medium power (up to +30 dBm) amplifiers for military, satcom and commercial markets. The company's in-house designing, machining and manufacturing capabilities allow them great flexibility to customize amplifiers with quick turn-around time and the option of waveguide and weatherproof housing. Stock amplifiers and data are routinely updated on the company's website and can be shipped within 3 to 5 days.

www.bnztech.com

Dynawave Inc.

Booth 1618

Cable Assemblies



Dynawave announces the DynaTest™ series cable assemblies, designed to deliver repeatable, precision measure-

ments while lowering your overall total cost. Available with standard SMA and Type N connector interfaces, these assemblies offer exceptionally low VSWR and insertion loss across a broad frequency range (DC to 26.5 GHz). These assemblies are highly flexible, yet maintain critical phase stability to ensure repeatable results. The rugged mechanical design and high flexibility of these assemblies also offer greater ease of use and long service life.

www.dynawave.com

Cinch Connectivity Solutions

Booth 1624

Cable Assemblies and Connectors



Johnson, Midwest Microwave, Semflex, Stratos, Trompeter and Vitelec are now part of Cinch Connec-

tivity Solutions, a bel group company. The company's full spectrum of broadband coaxial connectors, cable and fiber optic connectivity products serve the needs of military, aerospace, wireless communication, data network, industrial and healthcare markets. The company continues to evolve its product portfolio with a special focus on customized, engineered solutions for the delivery of voice, video and data in your challenging applications. Learn more at cinchconnectivity.com or call (800) 247-8256.

www.cinch.com

QuinStar Technology Inc. Booth 1718

Millimeter Wave Amplifiers and Multi-**Function Assemblies**



QuinStar Technology offers complete product lines of millimeter wave 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

Remcom Inc.

Booth 1722

XFdtd 3D Electromagnetic Simulation Software



Shorten your development time and release your products to market sooner! XFdtd® is unrivaled for solving the largest

and most complex EM problems at the fastest speeds. Featuring XStream GPU Acceleration for both CPUs and GPU clusters, plus unlimited memory support, XF can simulate massive problems exceeding billions of cells. Visit Remcom at Booth 1722 to see XF's new features, including matching circuit optimization and projected capacitive touch capability.

www.remcom.com

PRODUCTS TO **SOLUTIONS**

RF Products



Ducommun has more than 45 years of experience with the design, testing and manufacturing of coaxial switches and integrated systems.



Long Life Switch

- DC to 26.5 GHz
- SMA connectors
- Operating life: 5,000,000 cycles
- Operating temp: -25°C to +65°C

High Power Switch

- DC to 5 GHz
- · Peak power: 50 kw
- Operating life:
- 1,000,000 cycles Operating temp:
- -35°C to +85°C



USB Switch

- 1P3T to 1P10T
- Compact design
- Compatible with LabView
- Up to 16 switch interface

Switch Matrices

- Modular design
- Common control & command protocol
- Flexible system
- · Compact physical format



For additional information, contact our sales team at 310.513.7256 or rfsales@ducommun.com

See us at IMS Booth 2018

HIGH POWER BROAD BAND LIMITERS 0.5 - 12 GHz







- Low Limiting Threshold (+6 dBm Typical)
- 40 Watt CW and 200 Watt Peak
- (1 microsec) power handling capability Built-In DC Block @ input and output
- **Hermetically Sealed Module**
- Typical Recovery Time is less than 10 Microsec

Typical Performance @ + 25 Deg. C

MODEL	FREQ. RANGE (GHz)	MAXIMUM INSERTION LOSS (dB)	MAX VSWR	MAX LEAKAGE @ 40 W CW INPUT (dBm)
LS0510 P40B	0.5 - 1.0	0.5	1.4.1	+21
LS0520 P40B	0.5-20	0.6	1,41	+21
LS0540 P40B	0.5 - 4.0	0.8	1.41	+21
LS0560 P40B	0.5-6.0	1.3	1.5.1	+21
LS05012P40B	0.5 - 12.0	1,7	1.7:1	+21
LS1020 P40B	1.0-2.0	0.6	1,41	+21
L\$1060 P40B	1.0-6.0	1.2	1.5:1	+21
LS1012P40B	1.0 - 12.0	1.7	1.7:1	+21
L\$2040P40B	2.0-4.0	0.7	1,41	+20
LS2060P40B	2.0 - 6.0	1.3	1.5.1	+20
LS2080P40B	2.0 - 8.0	1.5	1.6.1	+20
L\$4080P40B	4.0 - 8.0	1.5	1.6:1	+20
LS7012P40B	7.0 - 12.0	1.7	1.7:1	+18

Note: 1. Insertion Loss and VSWR tested at -10 dBm.

Note: 2. Typical limiting threshold: +6 dBm.

Note: 3. Power rating derated to 20% @ +125 Deg. C.

Other Products: Detectors, Amplifiers, Switches, Comb Generators, Impulse Generators, Multipliers, Integrated Subassemblies

Please call for Detailed Brochures



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SV Microwave

RF Interconnect System

Booth 1818

Check out SV Microwave's FeatherMate

RF interconnect svs-

tem combining a high

density (0.085" center-

to-center spacing) 40

DiTom Microwave

Booth 1833

Ka-Band Space Qualified Isolator VENDORVIEW



DiTom Microwave has released a new Ka-Band (27 to 31 GHz) space qualified isolator. The DS1017 is manufactured to meet or exceed envi-

ronmental space-level reliability including thermal shock, sine and random vibration, temperature cycling, and thermal vacuum survivability over a specified qualification and acceptance test plan. The company's current space level manufacturing process allows for delivery in as quickly as four weeks depending on test requirements.

www.ditom.com

GHz multiport concept with a zero disengage-

ment mating mechanism force that eliminates

damage to PCB solder joints. Direct connec-

tion to board trace, solder-free board mounts

and small diameter coax cable connectors

are available. Ideal for high density, low-force

applications including bench-top testing,

evaluation boards and ATE. Get more band-

width and signal density in your application

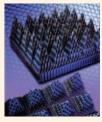
without worrying about destructive demating

Cuming Microwave Corp. Booth 1827

forces with SV Microwave's FeatherMate!

Microwave Materials

www.svmicrowave.com



Featuring C-RAM SFC-HC high power, broad-banded pyramidal honeycomb RF absorber, a phenolic coated honevcomb with the ability to handle up to 10 W/in2 of power with no

forced air. Cuming Microwave Corp. is an ISO 9001:2008 and AS9100:2009 microwave materials manufacturer focusing on EMI absorbers and EMI suppression materials; C-RAM™ microwave and radar absorbing materials, turnkey anechoic and EMC chambers, and C-STOCK™ low-loss dielectric materials.

www.cumingmicrowave.com

Passive Plus Inc.

Booth 1831

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 mil-

itary, 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.

www.passiveplus.com

Werlatone Inc.

Booth 1919

High Power, 2 to 6 GHz **Passive Components**



Celebrating 50 years, Werlatone remains committed to high power, efficiency and bandwidth. In 2015. Werlatone introduces

its newest line of in-phase and hybrid combiners, covering the full 2 to 6 GHz bandwidth. Both connectorized and surfacemount options are available, generating scalable building blocks for wideband combining applications. Model H10126, a surface-mount 180° combiner, is conservatively rated at 100 W CW.

www.werlatone.com

Eclipse Microwave Inc.

Booth 1925

PIN Diodes



The Eclipse EGP7000 series of PIN diodes are processed with a high resistivity epi that have intrinsic

layers ranging in thickness from 4 to 200 micron depending on performance specifications. These diodes are made with a grown junction P++ layer that yields abrupt junction structures that provide low punch through voltages and minimize autodoping. They are available as chips or in your choice of 19 packages.

www.eclipsemdi.com

EMS PRODUCT SHOW CASE ANS PRODUCT SHOW CASE ANS PRODUCT SHOW CASE ANS PRODUCT SHOW CASE AND PRODUCT SHOW CASE

Planar Monolithics Industries Inc.

Booth 1927

VPX TransceiverVENDOR**VIEW**

PMI model number PTRAN-100M18G-SFB-3UVPX-MAH is an ultra-compact, 3U open VPX transceiver covering 100 MHz to 18 GHz utilizing VITA67 RF backplane connections. The receive path includes an integrated CW immune SDLVA featuring linear



and limited RF outputs and a time-gating/sampling signal that controls an output blanking switch.

The IF frequency range is 100 MHz to 4 GHz and two LO inputs accept 4 to 20 GHz signals. Two customizable 6-channel switch filter banks are included for the transmit and receive paths.

www.pmi-rf.com

Coilcraft

Booth 1929

Conical Inductors for Ultra-Wide Bias Tees

Designed specifically for broadband and high frequency applications, Coilcraft conical inductors offer flat bandwidth with high



impedance to 40 GHz. The company's BCL series includes a full-length cap that protects the coil and provides a large surface

for pick and place. The BCL series features "flying leads" for precise positioning and adjustment of the mounting angle. Both series are offered in nine inductance values ranging from 0.22 to 8.0 μ H. Free samples are available.

www.coilcraft.com

SAGE Millimeter Inc.

Booth 2009

E-Band Active ×4 Multiplier



Model SFA-713863410-12KF-S1 is a 71 to 86 GHz ×4 active multiplier that is designed for E-Band communications and automotive



radar applications. The active multiplier converts 17.75 to 21.5 GHz/+5 dBm input signal to deliver 71 to 86 GHz frequency

band with a typical +10 dBm output power. The spurious and harmonic suppressions of the multiplier are 60 and 20 dBc or better, respectively. The multiplier draws 250 mA current from a +8 V DC power supply.

www.sagemillimeter.com

Ducommun Inc.

Booth 2018

Ka-Band Power Amplifier



Ducommun power amplifier model AHP-33142530-01 is a power amplifier designed to cover the entire Ka-Band 26.5 to 40

GHz. It provides small signal gain of over 30 dB across the frequency range, with larger than +25 dBm output power at 1 dB compression. Employing monolithic microwave integrated circuit (MMIC) technology, the amplifier operates from a single bias supply of +8 to +12 VDC with an internal voltage regulator and bias sequencing circuitry, consuming about 1 A of DC current.

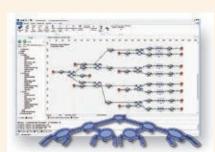
www.ducommun.com

Mician GmbH

Booth 2026

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 as well as horn antennas with reflectors, particularly single parabol, dual cassegrain, dual gregory and displaced axis antennas. Mician's signature



product µWave Wizard combines the flexibility of fast and powerful numerical methods with an appealing and ergonomic GUI that enables flexibility and openness including CAD export formats interfacing with most mechanical design tools.

www.mician.com

IMS2015

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Frequency Matters.

IMS PRODUCT SHOWCASE ALSIES 2000*2200

Instruments for Industry

Booth 2029

Solid-State Pulse Amplifier



Instruments for Industry (IFI), a unit of AMETEK Compliance Test Solutions, now offers a dual-mode,

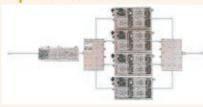
solid-state amplifier that combines continuous (CW) and pulse (P) operating modes. The new S31-500-900P amplifier has been optimized for performing 600 V/m radar pulse radiated immunity testing in the 0.8 to 3.1 GHz band.

www.ifi.com

MILMEGA

Booth 2029

Amplifiers Modules and Kits



MILMEGA, a unit of AMETEK Compliance Test Solutions, offers solid-state microwave amplifiers from 80 MHz to 6 GHz with power output from 25 to 1000 W. Modules and kits with bandwidths ranging from 800 MHz to 6 GHz and power outputs from 1 to 230 W are also available. These lightweight modules are highly reliable and compact, making them ideal for a range of applications.

www.milmega.co.uk

Infineon Technologies Booth 2032

RF Power Transistor

Developed using Infineon's rugged 50 V LDMOS process, PTVA127002EV is an input/



output matched RF power transistor optimized for pulsed L-Band radar applications. The device

provides over 700 W of output power with a typical gain of over 17 dB and efficiency of 61%. It has a low thermal resistance, VSWR mismatch tolerance of 10:1 and low pulse droop of less than 0.2 dB. This device can also be used effectively in CW applications such as particle accelerators. The PTVA127002EV is in production.

www.infineon.com

Pivotone

Booth 2117

Quadruplexer

The quadruplexer LTE700/AMPS/PCS/AWS operates from 698 to 790 MHz, 824 to 896 MHz, 1850 to 1990 MHz, 1710 to 1755 MHz, and 2110 to 2155 MHz. This high performance part is designed for multi-band,



co-located sites. Although it is relatively small in size, it has low insertion loss, low PIM and allows for DC and AISG issue 2.0 passthru on selected ports. This

quadruplexer is available to mount on the wall or poles and is suitable for outdoor and indoor applications.

www.pivotone.com

SGMC Microwave

Booth 2129

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 series: 1.0, 1.85, 2.4, 2.92 and 3.5 mm, SMA, N, TNC and SSMA. SGMC Microwave's hallmarks are always: quality, performance and reliability.

www.sgmcmicrowave.com

Custom Microwave Components Inc. Booth 2214

Switch Matrices



CMCI1080 is a 24×12 solid-state, non-blocking switch matrix covering 0.7 to 3 GHz with 70 dB cross-channel isolation.

Each output is 70 dB adjustable in 0.5 dB increments. It is a 6U/17"D rack mount unit, operates at up to 1 W RF power and requires less than 20 W prime power. The matrix is networkable with secure access. It is controlled through the front panel touch screen locally and/or a browser remotely. An intuitive GUI with practically zero training time makes it plug-n-play.

www.customwave.com

TMS PRODUCT SHOWCASH TO THE PR

LPKF Laser & Electronics Booth 2218

PCB Prototyping System



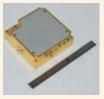
The LPKF ProtoMat D104 is a rapid PCB prototyping system that features both mechanical tools and a UV laser beam. By combining mechani-

cal and laser processing, a wide range of applications are possible. The laser can be used to etch fine line circuit traces on high frequency materials and ceramics while milling and drilling tools can be used to route boards and drill vias and throughholes.

www.lpkfusa.com

Millitech

Active Up-Converters and Down-Converters



Millitech series BUC/BDC are compact active up and down-converters. Each BUC/BDC integrates up to a mixer, filter, and up to three stages of amplification.

Booth 2236

Standard models are available for WiGig (57 to 66 GHz), E-Band (71 to 76 and 81 to 86 GHz), and W-Band (92 to 96 GHz). Combining these components into single packages saves volume, weight and cost. Pulse/mute control is available on all units for powering down one stage of amplifiers. Custom options are available for gain, output power, noise figure and other frequencies.

www.millitech.com

RelComm Technologies Inc.

Booth 2319

1P2T Coaxial Relay



RelComm Technologies complements its product line with a high performance 1P2T coaxial relay configured with 'SC'

type connectors and excellent RF performance to 6 GHz. Power rating is 1250 W CW to 1 GHz and 500 W CW to 6 GHz. Operating temperature range is 30° to +70°C. The relay measures 3.50" in width with a depth of 1.00" and is less than 2.4" tall. It is fitted with standard eyelet terminals for ease of wire up and is fully RoHS compliant.

www.relcommtech.com

3D Glass Solutions

Booth 2412

High-Q Inductors



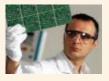
3D Glass Solutions introduces a new manufacturing technology enabling production of High-Q inductors surrounded by up to 99% air. The GECCOTM process offers several advantages for inductors including: higher Q factors and self-resonance frequencies, lower power consumption, the elimination of wire bonds, wafer level packaging for lower production and packaging costs, and integration possibilities of High-Q inductors into custom IC packaging that reduces packing size and cost.

www.3dglasssolutions.com

Transline Technology

Booth 2417

PCBs



Transline Technology has been working side-by-side with visionary engineers in the RF/microwave industry for over 20

years to produce innovative printed circuit boards (PCB). TTI offers rigid, rigid-flex and flex PCB fabrication services as well as photo-chemical metal etching and forming. The company stocks Rogers, Taconic and Arlon materials with the ability to turn product in as little as 24 hours.

www.translinetech.com

West-Bond Inc.

Booth 2418

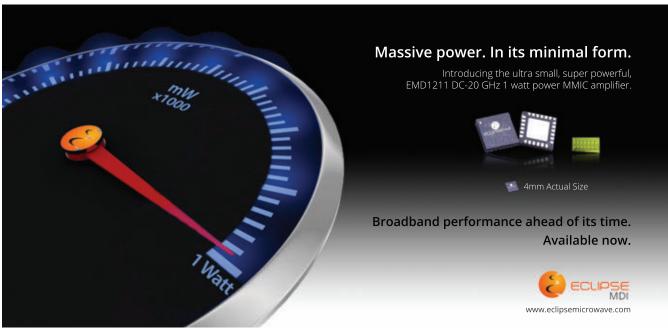
Wire Bonders



Introducing the most flexible, complete wire bonders system available today, 7KE and 4KE series wire bonders. Bonding at

45 degree feed for tail control, 90 degree for ribbon and deep access and ball bonding without changing heads. Wedge bonding Au, Al, Cu; ball bonding Au, Cu; automatic, semi-automatic, 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



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National Instruments (formerly AWR Corp.)

Booth 2431

VENDORVIEW

NI AWR Design Environment



Visit NI AWR in Booth 2431 at IMS2015 to preview the new load-pull and antenna features slated for the V12 release of NI AWR Design Environment software. Additional demonstrations that showcase

ease-of-use, speed enhancements as well as third-party integration, such as ANSYS HFSS, will also be on display.

www.ni.com/awr

National Instruments

Booth 2431

High Performance Microwave Instrumentation





The PXIe-5668R is a high performance 26.5 GHz VSA that delivers low noise floor, high linearity and low phase noise with up to 765 MHz of instantaneous bandwidth. It offers a unique combination of RF measurement performance, measurement speed and flexibility to meet the requirements of applications such as wireless communications, RFIC characterization, radar test and spectrum monitoring and sig-

nal intelligence. It also includes a LabVIEW-programmable Xilinx Kintex-7 FPGA to customize the instrument's behavior through triggering, signal processing routines and more.

www.ni.com/microwave

NI Microwave Components

Booth 2431

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

Richardson RFPD

Booth 2436

Booth 2438

Electronic Component Distribution





Richardson RFPD, an Arrow Electronics company, is a specialized electronic component distributor providing technical expertise and global design support for the latest products from leading suppliers of RF, wireless, energy and power technologies. Richardson RFPD offers the newest products from leading suppliers of RF and wireless technologies to more than 10,000 customers, through its sales team of engineering experts. The company supports the design efforts of RF engineers in markets such as cellular infrastructure, avionics and defense, ISM, CATV, T&M, IoT/M2M and many others.

www.richardsonrfpd.com

Anritsu

VNA Performance

VENDORVIEW



For applications ranging from microwave component testing to on-wafer device characterization, the VectorStar

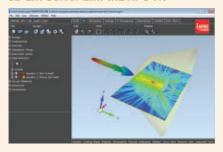
vector network analyzer family uses nonlinear transmission line (NLTL) technology to provide best-in-class performance — and it is only from Anritsu. Get the confidence you need in every VNA measurement. Visit Anritsu's Booth 2438 at IMS2015 to see the latest features and functionality of the full VectorStar product line.

www.anritsu.com/VectorStar

IMST

Booth 2522

3D EM Solver EMPIRE XPU 7.1



EMPIRE XPU is one of the leading 3D EM solvers for design of antennas, RF circuits and components. Due to its unique software controlled workflow among CPUs EMPIRE is highly efficient and extremely fast on plain conventional hardware. New features of EMPIRE XPU 7.1 include an enhanced 3D graphical user interface, a new 3D modeling kernel for fast import and handling of large and complex objects, extended libraries and a circuit simulator for the inclusion of active components.

www.imst.com

Peregrine

Semiconductor Corp. Booth 2622

Monolithic Phase and Amplitude Controller



The UltraCMOS® PE46120 is the first product available from Peregrine's monolithic phase and amplitude con-

troller (MPAC) product family. Covering 1.8 to 2.2 GHz, the monolithic RFIC integrates a 90-degree hybrid splitter, phase shifters, digital step attenuator and a digital SPI interface. Ideal for optimizing dual-path, dynamically load-modulated amplifier architectures such as Doherty amplifiers, the PE46120 enables precise high resolution phase and amplitude control and features wide phase range and small step size.

True DC RF Switch



The UltraCMOS® PE42020 is the industry's first and only RF integrated switch to operate at true DC, zero Hz.

The True DC RF switch features high power handling and maintains excellent RF performance and linearity from DC through 8 GHz. A reliable alternative to problematic mechanical relays and micro-electromechanical systems (MEMS), the PE42020 is ideal for test and measurement and automated test equipment applications.

www.psemi.com

Presented by:



center

April Short Course Webinars

Technical Education Training

EMIT 4.0 – The Next Generation in RF Cosite Interference Modeling and Simulation

Presented by: Delcross Technologies

Live webcast: 4/8/15

Innovations in EDA

How to Design an RF/Microwave Power Amplifier: The Basics

Presented by: Keysight Technologies

Live webcast: 4/9/15

Technical Education Training

Understanding Filter Technology and the Selection Process Including Qorvo's Specialized LowDrift™ and NoDrift™ Filters

Presented by: Qorvo Live webcast: 4/14/15

Technical Education Training

Multipactor Basics and How Numerical Analysis Can Safely Increase Margins

Presented by: Aurora Software Live webcast: 4/21/15

Technical Education Training

Advanced Multi-Emitter Radar Simulation with Off-the-Shelf T&M Equipment

Presented by: Rohde & Schwarz

Live webcast: 4/22/15

Technical Education Training

Narrowband Combline Filter with ANSYS HFSS

Presented by: ANSYS Live webcast: 4/23/15

Keysight Technologies Webcast

LTE-A Multi-Channel Phase Coherent MIMO

Live webcast: 4/28/15

Technical Education Training

Linearity: The Key to Successful Data Transmission in Cable and Beyond

Presented by: Peregrine Semiconductor

Live webcast: 4/30/15

Past Webinars On Demand

RF/Microwave Training Series

Presented by: Besser Associates

• RF and Microwave Filters

Technical Education Training Series

- Effect of Laminate Properties on PIM Distortion in Microstrip Transmission Lines
- Modern Trends in Broadband Diode Mixers
- Practical Antenna Design for Advanced Wireless Products
- RF and Microwave Heating with COMSOL Multiphysics
- Tips and Techniques for Making Microwave Vector Network Analysis Measurements in the Field
- Laser Test of RIN, Linewidth and Optical Noise Parameters
- Marchand Balun and Its Evolution into Modern Microwave Systems
- Non-Destructive Testing of Powders, Ceramic, Oils and Other Composite Materials
- Design Challenges for Handset Power Amplifiers Due to LTE-Advanced
- RF PCB Design, Inclusive of EM Analysis

CST Webinar Series

- CST STUDIO SUITE 2015 Update Webinar on MW&RF Simulation
- CST STUDIO SUITE 2015 Update Webinar on EDA/EMC Analysis
- Simulation-Enabled 5G Antenna Design
- Antennas for Automobile Applications

Innovations in EDA

Presented by: Keysight Technologies

- Understanding 5G and How to Navigate Multiple Physical Layer Proposals
- RF System Design, Prototype & Production with X-Parameters in One Pass

Keysight in LTE/Wireless Communications Series

• LTE-Advanced: 3GPP Release 12 and 13

Keysight Technologies Webcast

- Bridging the Gap from Benchtop to PXI: A Common Software Strategy
- MVG-Orbit/FR μ Lab A Compact Integrated Test Facility for mm-Wave Antenna Testing
- One Size Does Not Fit All Choose the Right Instrument Form Factor

FieldFox Handheld Analyzers Series

Presented by: Keysight Technologies

 Transmission Line Theory and Advanced Measurements in the Field

RF and Microwave Education Series

Presented by: Keysight Technologies

• Understanding Available Measurement Techniques for Spurious or Unknown Signals

IMS PRODUCT SHOWCASH ALSTHES 2700*2800

Accel RF

Booth 2712

Characterization Platform



Accel-RF supplies equipment for performing measured long-term reliability assessment on compound semiconduc-

tors. The Accel-RF characterization platform is an integrated solution of benchtop RF and thermal characterization. It allows for easy measurement of critical performance characteristics used for high temperature RF bias (HTRB) testing, performance degradation studies, or parameter variation analysis. Accelerate your time to market with the Accel-RF characterization platform.

www.accelrf.com

Pickering Interfaces

Booth 2814

RF and Microwave Switching Solutions

VENDORVIEW



Pickering Interfaces will be showcasing its broad catalog of PXI and LXI (Ethernet)

RF and microwave switching solutions.

Ranging from low-level DC signals to RF and microwave, these switching solutions can be used to increase the flexibility of test and measurement systems with signal bandwidths up to 65 GHz. Configurations available within their PXI and LXI platforms include multiplexers, matrices, transfer and general-purpose switches. Pickering will also be showing its new eBIRST switching system test tools used to quickly identify faulty relays.

www.pickeringtest.com

RFMW

Booth 2826

RF SOI Switch VENDORVIEW

The UltraCMOS® PE42524 is an RF SOI switch that operates up to 40 GHz. This SPDT RF switch significantly extends Peregrine Semiconductor's high frequency port-



folio into frequencies previously dominated by gallium arsenide (GaAs) technology. As an alternative to GaAs-based solutions, the PE42524 features high reliabil-

ity and performance advantages in linearity, isolation, settling time and ESD protection. These attributes make the switch ideal for test and measurement, microwave backhaul, radar and military communications devices.

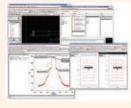
www.rfmw.com

Cadence

Booth 2832

RFIC Simulation Solution

Cadence's Spectre® RF is a production proven, accurate and high performance RFIC simulation solution. Integrated in the Virtuoso analog design environment, Spectre RF delivers a unique and comprehensive



set of analyses in the time and frequency domains for fast and accurate characterization of RFIC circuits. The

latest release adds LTE, Wi-Fi 802.11ac and 802.11af to the rich set of supported wireless standards in envelop analysis. The release also features automatic harmonic balance set-up, and the simulation of two LTE transceiver channels simultaneously.

www.cadence.com

Besser Associates Inc.

Booth 2833

RF and Wireless Training



Besser Associates is a worldwide leader in RF and wireless training. Besser's instruc-

tion 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 its 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 clients' specific needs.

www.besserassociates.com

MACOM

Booth 2839

S-Band GaN Power Pallet VENDORVIEW





drain efficiency.
The compact size
of the integrated
pallet, combined
with excellent RF
performance makes

this product an ideal solution for pulsed radar and medical applications where small size, lightweight and high power performance (SWaP) are required.

28 V GaN on Silicon Amplifier



The NPA is a 28 V GaN on silicon amplifier, with broadband operation between 30 and 2500 MHz. Ideal for test

and measurement, hand-held radios, and wireless and defense communications, the amplifier provides a broadband 50 ohm input impedance in an industry standard 6×5 mm DFN plastic package.

www.macom.com



EUROPEAN MICROWAVE WEEK 2015 PALAIS DES CONGRÈS, PARIS, FRANCE6 - 11 SEPTEMBER 2015



EUROPE'S PREMIER MICROWAVE, RF, WIRELESS AND RADAR EVENT

THE CONFERENCES (6 - 11 SEPTEMBER)

- European Microwave Integrated Circuits Conference (EuMIC)
 7th 8th September 2015
- European Microwave Conference (EuMC) 7th -10th September 2015
- European Radar Conference (EuRAD) 9th 11th September 2015
- Plus Workshops and Short Courses (From 6th September 2015)
- In addition EuMW 2015 will include the 'Defence, Security and Space Forum'

DISCOUNTED CONFERENCE RATES

Discounted rates are available up to and including 6th August 2015.

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THE FREE EXHIBITION (8 – 10 SEPTEMBER)

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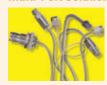
Register online now as a delegate or visitor at:

www.eumweek.com

Insulated Wire Inc.

Booth 2922

Multi-Port Solutions



IW presents multiport solutions for system-level interconnect. Where rapid mate/de-mate for multiple signal paths

is a key concern, IW now offers high frequency contacts for 38999 using standard inserts. Contacts are designed to accept IW's Tuf-FlexTM low loss cable designs for protection against accidental damage. The ruggedization also ensures bundling will not crush the cables. The Re-FlexTM range is extended with RF250 (RG401 replacement) and 0471, for high power and high density applications respectively; standard length SMA assemblies using RF141 are now in stock at HASCO.

www.iw-microwave.com

Herotek Inc.

Booth 2924

DC to 3 GHz Voltage Limiter



Herotek offers a DC to 3 GHz voltage limiter for DC, AC analog, digital, RF, impulse and microwave LV3000A signals. does not have a frequency break be-

tween DC and 3 GHz and no bias is required. The typical threshold level is ±0.7 VDC or 0 dBm microwave. LV3000A has low output leakage level (1.5 V typical at ±10 V input, +13 dBm typical at +30 dBm input microwave). It has low harmonics generation (-20 dBc typical at rated input power).

www.herotek.com

Southwest Microwave Inc. Booth 3022

1 mm (W) DC to 110 GHz Connectors



Southwest Microwave will showcase its high frequency 1 mm (W) DC to 110 GHz connectors, including field-replace-

able two and four-hole flange-mount and thread-in connectors, direct-solder cable connectors and clamp-on end launch connectors. Built in the U.S. to rigorous performance and quality standards, these rugged, durable solutions feature a 360° raised grounding ring and temperature rating of -55° to 165°C. Mode-free operation through 110 GHz, well-matched impedance, excellent repeatability and the industry's lowest VSWR, insertion loss and RF leakage.

www.southwestmicrowave.com

Freescale

Booth 3031

Doherty Alignment Module

The MMDS09254H is a 700 to 1000 MHz advanced Doherty alignment module (ADAM) designed to enable accurate alignment of



phase and amplitude on the carrier and peaking amplifiers used in high power Doherty amplifiers, in particular asymmetric implementations.

The MMDS09254H enables superior linearity/efficiency trade-off while improving output power. It contains a coupler, SPI selectable phase shifters and step attenuators. The ADAM modules are suitable for all 3G and 4G protocols.

www.freescale.com/rflowpower

Analog Devices Inc.

Booth 3036

IF Transceiver Chipset VENDORVIEW



Analog Devices Inc. announces a new chipset in a 4 × 6 mm wafer level package to support the emerging 60 GHz small cell backhaul market. This chipset includes

HMC6300BG46 transmitter HMC6301BG46 receiver which together constitute a fully integrated analog baseband to millimeter wave transceiver with on-board synthesizer, analog gain control and support for bandwidths up to 1.8 GHz and up to 64-QAM modulation. They also include ports for an external LO. Contact RFMG-txrx@analog.com for more informa-

www.analog.com

AR RF/Microwave Instrumentation **Booth 3040**

25 to 100 W, 1 to 6 GHz Amplifier

VENDORVIEW

Models 25S1G6AB, 50S1G6AB, 100S1G6AB are solid-state, 25, 50, and 100 W Class AB amplifier designs that instantaneously cov-



er the 1 to 6 GHz frequency band in single benchtop unit. These amplifiers provide 25, 50 or 100 W output

power, depending on model, in approximately half the size of a traditional Class A design with increased efficiency and a more economical price.

www.arworld.us/post/100SIG6AB.pdf

Micable Inc.

Booth 3126

Cable Assemblies



C04 series are highly reliable and cost-effective cable assemblies, ideal for broadband tests and various connections. The triple-shielded cable has rugged construc-

tion employing an advanced strain relief system and is equipped with reinforced stainless steel connectors. They are tough enough to be qualified for over 20,000 flex cycles without changes in electrical performance up to 26.5 GHz. They are available in custom lengths with SMA or N type connectors.

www.micable.cn

Pasternack Enterprises Booth 3214

Connectorized RF Amplifiers





Pasternack provides the industry's largest selection of off-the-shelf, connectorized RF amplifiers available to same-day. ship Over 120 unique

high power, high-rel, broadband, limiting, power, low noise, log, USB-controlled amplifiers and gain blocks are now instock. Frequencies up to 40 GHz, gain levels ranging from 10 to 60 dB, P1dB from 2 mW to 100 W, noise figures as low as 0.8 dB and gain variation down to ±0.3 dB.

RF Components



With the industry's largest selection of RF components, expert technical support and same-day shipping, Pasternack is the engineer's RF source. Its vast product offering includes am-

plifiers, custom cable assemblies, switches, attenuators, waveguides, adapters, connectors, power dividers, circulators, isolators and many more. Stop by the booth to speak with RF engineers and learn how Pasternack can satisfy your company's urgent RF requirements. And while you are there, enter to win your very own drone.

www.pasternack.com

IMS PRODUCT SHOWCASH OUT OF STATES 3200 *3300

KRYTAR

Booth 3218

7 to 12.4 GHz Directional Coupler

VENDORVIEW



KRYTAR's new coupler, model 120706, covers 7 to 12.4 GHz with nominal coupling (with respect to output) of 6 dB, ±0.5 dB, and frequency

sensitivity of ±0.30 dB. The directional coupler exhibits insertion loss (including coupled power) of less than 1.8 dB, directivity of greater than 15 dB, maximum VSWR (any port) is 1.35, input power rating is 20 W average and 3 kW peak. The directional couplers come with industry-standard 2.4 mm SMA female connectors.

www.krytar.com

CTT Inc.

Booth 3224

80 W Power Amplifier



This GaN-based solid-state power amplifier, model AGM/060-4960, covers 2 to 6 GHz with CW output power ranging from

20 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 dB; noise figure, 6 dB; Psat, +49 dBm (+48 dBm at band edge); VDC +30 V; DC current, 15.0 A. The amplifier is 6.32" \times 4.50" \times 0.80".

www.cttinc.com

Empower RF Systems Inc. Booth 3226

Next Generation High Power Amplifiers

VENDORVIEW



Empower will be running live demos of their next generation power amplifiers. Showcasing a unique

combination of broadband frequency coverage and high power RF output, visitors to IMS2015 Booth 3226 will be introduced to "portability" and "end use adaptability" that has not been considered possible with commercially available, and much larger, power amplifiers. The designs on display utilize a standard architecture (hardware and software) that maximizes re-use of key building blocks and interface capabilities.

www.empowerrf.com

API Technologies

Booth 3236

Active Antenna Array Solutions



API Technologies has developed a solution that streamlines system integration, simplifies repair and reduces the cost of

ownership of AESA/E-Scan radar platforms. The Scaleable Active Antenna Array Unit (AAAU) is constructed from T/R module common building blocks, called Quad Transmit Receive Modules (QTRM). These QTRMs are contained within modular plank assemblies. Applications include tactical datalinks, maritime radar, air traffic control radar and air/vehicle based radar.

www.micro.apitech.com

Reactel

Booth 3242

Filters, Multiplexers and Multifunction Assemblies

VENDORVIEW



Reactel manufactures a line of filters, multiplexers and 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 the company's talented engineers can design a unit specifically for your application. Visit Booth 3242 to learn more.

www.reactel.com

CST

Booth 3244

CST STUDIO SUITE 2015
VENDORVIEW



CST announces the 2015 version of its flagship electromagnetic simulation software CST STUDIO SUITE®. The result of

years of research and development, CST STUDIO SUITE 2015 includes improvements and innovations at every level, from the optimized solver technology to the user interface and integration with other tools. CST STUDIO SUITE 2015 offers considerable product to market advantages such as shorter development cycles, virtual prototyping before physical trials and optimization instead of experimentation.

www.cst.com

Metrigraphics

Booth 3312

Additive Process Yields Consistent Substrate-based Thin Film Circuits

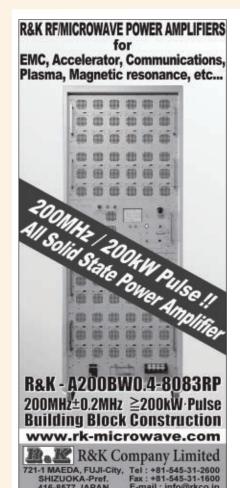
VENDORVIEW



Metrigraphics' new breakthroughs in processing substrate-based, ultra-miniaturized circuits enables them to manufacture circuits in high volume with

properties that include: circuit lines and spaces as small as 10 microns, vias as small as 25 microns in diameter, plated through holes (PTH) to ground with "metal-backed" ceramics, and multilayer devices with up to six metal layers. The fabrication process is ideal for applications such as aerospace, defense, telecommunications, commercial printing and photonics.

www.metrigraphicsllc.com



See us at IMS Booth 2519

INS PRODUCT SHOW CASE

Mini-Circuits

VENDORVIEW

Power Splitter/Combiner



Mini-Circuits' EP2C+ is a MMIC splitter/ combiner designed for wideband operation from 1800 to 12500 MHz. This mod-

el provides excellent power ratings in a tiny device package (4×4×1 mm), with up to 1.85 W power handling (as a splitter) and up to 0.4A DC current handling. Manufactured using GaAs IPD technology, it provides a high level of ESD protection and excellent reliability.

Monolithic Amplifier

Mini-Circuits' PMA2-43LN+ is an E-PHEMT based, ultra-low noise MMIC amplifier with



a unique combination of low noise and high IP3, making this amplifier ideal for sensitive, high dynamic-

range receiver applications. This design operates on a single 5 V supply, is well matched for 50 V systems, and comes in a tiny, low profile package, accommodating dense circuit board layouts.

USB Smart Power Sensor



Mini-Circuits' PWR-8GHS Smart Power Sensor is a pocket-sized, 4.89" × 1.74" ×

0.95", precision test USB HID device (no driver installation required) that turns a Windows® or Linux® PC into a power meter. All specifications provided in the data sheet apply to continuous wave (CW) signals. Each unit is shipped with its N-to-SMA adapter and a quick-locking USB cable for reliable connectivity. Native software and detailed user guides are provided on the included CD, or can be downloaded from minicircuits.com anywhere an internet connection is available, providing a full range of data analysis options.

Wideband Double Balanced Mixer-Amplifier



MDA4-752H+ is a multi-chip module incorporating a mixer (InGap HBT), LO amplifer (InGap HBT) and IF amplifier (E-

and IF amplifier (E-PHEMT) dice in as single package. It has flat conversion gain over a broad frequency range and with high IP3. In addition, the MDA4-752H+ has good input and output return loss over a broad frequency range without the need for external matching components. It is packaged in a tiny 4×4 mm MCLP package with tin-silver over nickel plating passing tin whisker testing.

Coaxial, High-Directivity Directional Coupler



ZHDC-10-63-S+ is a coaxial, high directivity directional coupler. It features wideband, 50 to 6000 MHz,

high directivity, 33 dB typ., flat coupling, ±0.3 dB typ. and good VSWR, 1.20:1 typ. Applications include military defense and test and measurement.

Ceramic Directional Coupler



The DCW series is a ceramic directional coupler. It features wideband, 1200 to 3300 MHz, low insertion loss, 0.4 dB typ., excellent return loss

for input/output ports ideal for signal-tap, ultra small size, 0603 (1.6 \times 0.8 mm), temperature stable and LTCC construction. Applications include ISM, WiMAX, Wi-Fi, UMTS, PCS and LTE.

Ceramic Diplexer



The LDPG Series is a ceramic diplexer. It features small size 0805 (2.0 × 1.25 mm), low insertion loss, 0.7 dB typ., high rejection, temperature

stable and LTCC construction. Applications include communication systems, ISM and Wi-Fi.

RF Transformer



Mini-Circuits' NCR2 family of ultra-wideband balun transformers covers 3.5 to 18 GHz with an impedance ratio of 1:2. They are commonly

used for unbalanced to balanced applications. LTCC construction provides exceptional reliability, thermal stability, and a high degree of repeatability. A small footprint

Booth 3331

 $(0.08" \times 0.10")$ offers flexibility of integration with RF integrated circuits.

Synthesized Signal Generator

Mini-Circuits' SSG-6001RC is a wideband synthesized signal generator operating over 1 to 6000 MHz. The signal generator



is cased in a rugged metal shielded package (11" × 8.5" × 2.15") and equipped with an N-type 50 V connector at the RF output

port. The signal generator is supplied with a CD containing user friendly GUI control software and programming APIs for 32 and 64 bit environments. Using the supplied software, the user can easily select one of several different output modes including multiple pulse modulation options, frequency sweep and power sweep (up, down or bidirectional).

Ultra-Wideband 50 W Directional Couplers



Mini-Circuits' ZUDC series of ultra-wide-band directional cou-

plers covers a wide range of applications from 0.5 to 18 GHz including cellular, WiMAX, ISM, GSM, lab use and more. Available in models with 10, 20 and 30 dB coupling, these couplers are capable of handling up to 50 W RF input power and passing DC current up to 3A from input to output. They provide coupling flatness as steady as ±0.3 dB over their entire frequency range, mainline loss as low as 0.4 dB, and directivity up to 23 dB enabling accurate sampling of input signal power. They come housed in rugged aluminum alloy cases (6.47" × 0.73" × 0.51") with SMA connectors at all ports.

Monolithic Amplifier



Mini-Circuits' GVA-91+ (RoHS compliant) is an advanced wideband amplifier fabricated using GaAs HBT technology, offering high gain and

excellent power output with excellent power added efficiency in application bands. Lead finish is tin-silver over nickel. It has repeatable performance from lot to lot and is housed in an SOT-89 package for very good thermal performance.

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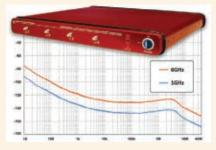
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Holzworth Instrumentation Booth 3339

Broadband Signal Generators





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high compliance range, 1 dB bandwidth > 50 GHz and > 1 amp current capacity. Invisipin also offers flexibility with standard pin configurations of 0.23 to 0.64 mm diameter supporting pitches from 0.4 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

Ciao Wireless Booth 3418

Amplifiers and Assemblies



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dustries, from 30 kHz to 44 GHz, including the various narrow and ultra-broadband

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www.ciaowireless.com

Vaunix

Booth 3423

Digital AttenuatorsVENDOR**VIEW**



Vaunix has added a 75 Ohm model to its family of LDA series digital attenuators. This product family offers attenuators with up to 120 dB of

programmable attenuation through 6000 MHz. The LDA-102-75F has input power of up to 1 W, attenuation range to 95 dB, and offers frequency coverage of 10 to 1000

MHz. It is powered and controlled by connection to a PC or self-powered USB hub.

www.vaunix.com

Communications & Power Industries

Booth 3426

X-Band High Power Amplifier

CPI's VSX3629 solid-state power amplifier (SSPA) is designed to provide a very reliable, air-cooled amplifier for airborne mobile radar requirements. The VSX3629 SSPA



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SSPA transmitter is ruggedized for the harsh environments typical to airborne use. www.cpii.com/bmd

Cobham Inmet

Temperature Compensating Attenuators



Cobham Inmet introduces the TCAF-X-N09 series of RoHS compliant temperature compensating chip attenuators to their attenuator line. These 2 W, DC to 12 GHz chip attenuators have a temperature coefficient of -.009 dB/dB/°C and can be used in place of standard chip attenuators in level setting or line buffering applications where a negative temperature compensation is required. Sample orders can be request-

ed by stopping by booth 3436 or via email at inmetsales@aeroflex.com. www.cobham.com/inmet

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Booth 3436

Programmable AttenuationVENDOR**VIEW**



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and 2.92 mm series. The standard hermeticity specifies 10-8 atm. cm³/s minimum. As several applications do not need this high standard, more economically priced products with a hermeticity of 10-5 atm. cm³/s were added. All adapters use fused in glass seals between the center contact and outer conductor. The adapters are normally used at vacuum chambers testing products that are undergoing tests for space applications.

www.spectrum-et.org

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Vector Signal Generator up to 40 GHzVENDOR**VIEW**

With its new microwave frequency options, the R&S SMW200A vector signal generator supports development applications requiring complex multichannel scenarios up to 40 GHz. It is the only



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www.rohde-schwarz.com

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www.wenzel.com

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Pressurized Connectors VENDORVIEW



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VENDORVIEW



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(down/up) for use in military applications. These converters can incorporate LNA's on the RF input port, frequency multiplication on the LO port, AGC, image rejection mixers and IF amplification. Shown is the latest 18 to 40 GHz converter that Norden designed and is presently manufacturing for an aerospace company.

www.nordengroup.com

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ed, double sided, multi-layer, hybrid boards with a wide variety of materials. ASC is also adept at blind/buried vias, cavity boards and edge plating. The company understands the tight tolerances required for RF/microwave work. ASC is also capable of building metal-backed boards. It builds them pre-bonded and post-bonded. The company can post bond using commercially available sheet film adhesive, its proprietary silicone based adhesives and sweat solder.

www.asc-i.com

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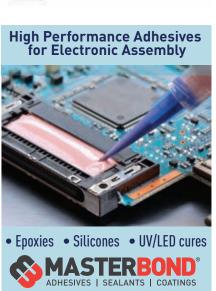
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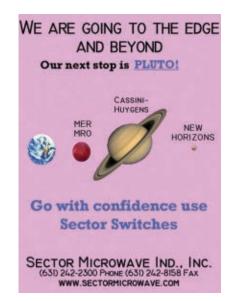














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BookEnd



What To Do When It's Your Turn (and It's Always Your Turn)

Seth Godin Reviewed by Gary Lerude

first learned of Seth Godin through his blog. At the time, several years ago now, he wrote a lot about permission marketing. In his own words, "Permission marketing is the privilege (not the right) of delivering anticipated, personal and relevant messages to people who actually want to get them. It recognizes the new power of the best consumers to ignore marketing. It realizes that treating people with respect is the best way to earn their attention."

His words resonated with me — still do. They create a vision of how companies should establish trusting relationships with customers and earn their loyalty. My personal experience of that was when Keysight Technologies was HP and I had not yet abandoned the technical ladder for the dark side. Periodically, HP would come through town offering a daylong technical

seminar, including lunch, at a local hotel. A team of HP engineers would present tutorials on a range of measurement topics. Their motivation was to sell more HP test equipment, of course, yet company management recognized that HP's success depended on their customers designing products that succeeded in the market – which required accurate measurements.

Seth Godin subsequently started writing about personal empowerment, exploring the idea that the Internet enables societies to democratize. His writing suggests a frustration that we don't exercise the freedom we have. "What to Do When It's Your Turn (and It's Always Your Turn)" is his latest book addressing this theme. He writes "Your turn to: Ship. Speak up. Stand out. Build a following. Market a product. Make a connection. Solve an interesting problem. Write, sing, invent, create, ask a question, launch a product, organize a protest, open the door for someone, question authority make a short film, direct, produce, create or adopt. Learn a new skill. Help someone who needs you. Be missed if you're gone. Your turn to make a ruckus.'

Seth Godin recognizes that we often fail to exercise our freedom because we know it comes with responsibility and the real possibility of failure. He argues that risking failure will lead us to our human potential.

As with virtually all of Seth Godin's writing, I find his ideas in "What To Do When It's Your Turn" thought provoking and compelling. The book is artfully designed and written to be consumed in short reads. In just one or two pages, he creatively constructs an idea worth mulling over. His ideas are best savored, not speed read.

Godin also designed the book to share. If you order one, you'll get two. Order three, he ships you five. Keep one for yourself and give the others away.

There are few books I've read that I have found potentially transformative. This is one of my favorites.

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15 July 2015

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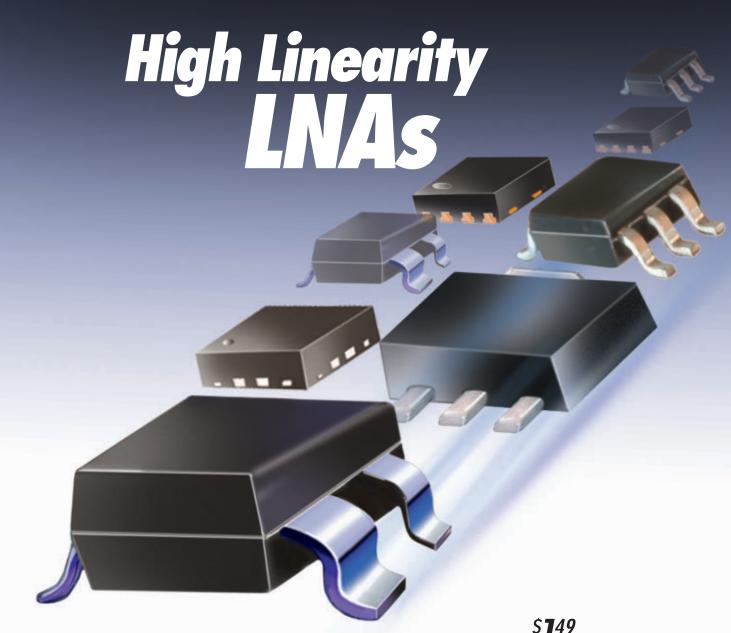




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PMA-5452+	50-6000	14.0	0.7	34	18	40	1.49
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PMA-5455+	50-6000	14.0	8.0	33	19	40	1.49
PMA-5451+	50-6000	13.7	8.0	31	17	30	1.49
PMA2-252LN+	1500-2500	15-19	8.0	30	18	25-55 (3V) 37-80 (4V)	2.87
PMA-545G3+	700-1000	31.3	0.9	33	22	158	4.95
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PGA

PMA

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Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P _{out} (dBm)	Current (mA)	Price \$ (qty. 20)
PGA-103+	50-4000	11.0	0.9	43	22	60 (3V)	1.99
PMA-5453+	50-6000	14.3	0.7	37	20	97 (5V) 60	1.49
PSA-5453+	50-4000	14.7	1.0	37	19	60	1.49
PMA-5456+	50-6000	14.4	8.0	36	22	60	1.49
PMA-545+	50-6000	14.2	8.0	36	20	80	1.49
PSA-545+	50-4000	14.9	1.0	36	20	80	1.49
PMA-545G1+	400-2200	31.3	1.0	34	22	158	4.95
PMA-545G2+	1100-1600	30.4	1.0	34	22	158	4.95
PSA-5455+	50-4000	14.4	1.0	32	19	40	1.49



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Sales Representatives



Chuck Boyd Northeast Reg. Sales Mgr. (New England, New York, Eastern Canada) 685 Canton Street Norwood, MA 02062 Tel: (781) 619-1942 FAX: (781) 769-5037 cboyd@mwjournal.com

Michael Hallman Michael Hailman Eastern Reg. Sales Mgr. (Mid-Atlantic, Southeast, Midwest) 4 Valley View Court Middletown, MD 21769 Tel: (301) 371-8830 FAX; (301) 371-8832 mhallman@mwjournal.com

Pacific and

Pacific and Mountain Time Zones Brian Landy Western Reg. Sales Mgr. (CA, AZ, OR, WA, ID, NV, UT, NM, CO, WY, MT, ND, SD, NE & Western Canada) 144 Segre Place Santa Cruz, CA 95060 Tel: (831) 426-4143 FAX: (831) 515-5444 blandy@mwjournal.com

International Sales Richard Vaughan International Sales Manager

16 Sussex Street London SW1V 4RW, England Tel: +44 207 596 8742 FAX: +44 207 596 8749 rvaughan@horizonhouse.co.uk

Germany, Austria, and Switzerland (German-speaking) WMS.Werbe- und Media Service Brigitte Beranek Gerhart-Hauptmann-Street 33, D-72574 Bad Urach Germany Tel: +49 7125 407 31 18 FAX: +49 7125 407 31 08 bberanek@horizonhouse.com

Spinner GmbH......96

Israel Liat Heiblum

Oreet International Media 15 Kineret Street 51201 Bene-Berak, Israel Tel: +972 3 570 6527 FAX: +972 3 570 6526 liat@oreet-marcom.com

Korea

Young-Seoh Chinn JES Media International JES Media Internation 2nd Floor, ANA Bldg. 257-1, Myungil-Dong Kangdong-Gu Seoul, 134-070 Korea Tel: +82 2 481-3411 FAX: +82 2 481-3414 yschinn@horizonhouse.com

Japan Katsuhiro Ishii Ace Media Service Inc. 12-6, 4-Chome, Nishiiko, Adachi-Ku Tokyo 121-0824, Japan Tel: +81 3 5691 3335 FAX: +81 3 5691 3336 amskatsu@dream.com

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China

Michael Tsui ACT International Tel: 86-755-25988571 Tel: 86-21-62511200 FAX: 86-10-58607751 michaelT@actintl.com.hk

Hong Kong Mark Mak ACT International Tel: 852-28386298 markm@actintl.com.hk

Ed Kiessling Traffic Manager/Inside Sales Norwood, MA 02062
Tel: (781) 619-1963
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ARC Technologies - Materials Expertise with Customer Focus



ast summer, ARC Technologies opened a new 75,000 square foot facility in rural Amesbury, Mass., not far from the mill buildings on the Merrimack River where the company started manufacturing absorbers in 1989. Controlling the unwanted propagation of electromagnetic (EM) energy creates a never-ending demand for absorbing material, the core business for ARC Technologies. Their value proposition stems from expertise in materials science and processing and their willingness to tailor solutions for customers. Performing all steps internally — design, manufacturing and testing — differentiates the company and has fueled their growth in these five product areas:

Foam and MAGRAM products: ARC blends proprietary fillers with elastomeric compounds to create dielectric foam absorber. The material can be tailored to the application, including the frequency range. MAGRAM products are available in, but not limited to, silicone, urethane, nitrile, neoprene, Hypalon® and Viton®.

Composites: The company designs and builds lightweight and high strength materials that are used for radomes, RADAR absorbing, camouflage and conformal antenna structures.

Wave-X: These absorber products are for near field applications in the 5 MHz to 110 GHz spectrum. In addition to sheets, the material can be manufactured in heat-shrinkable tubes or extruded directly onto cables to replace ferrite chokes. Wave-X is also available as pellets and can be molded into 3D shapes.

Thermoplastics: ARC can combine various thermoplastic materials and fillers to create cast, molded, extruded or pellet shapes.

Advanced materials: Drawing on their experience and capabilities, the company offers custom solutions using polymer and caulk, spray, cast or resin systems.

ARC Technologies has invested in internal test systems to support their five business lines. ARC has the unique capability to measure permittivity and permeability to 110 GHz with both arch and focused beam systems. Their focused beam system was developed by Georgia Tech Research Institute, one of only a few in the U.S.

The company's success and growth build on a commitment to R&D, with a focus on defense needs. However ARC is aggressively applying their capabilities to commercial markets, with the goal of increasing the commercial base to half their revenue. The company is serving several unique commercial applications: absorber for automotive radar, transparent heaters for automotive LED lights and absorber material that increases the read accuracy of RFID tags. ARC is also pursuing opportunities in the medical market and is proving radiation shielding materials for specialized cancer treatment. To accelerate growth, ARC is developing a line of standard products and offers testing and CNC milling as services.

With over 120 employees, the company retains an informal, small company culture. People often wear multiple hats and can change roles, which keeps the work interesting.

Planning for the future, ARC recently purchased the land next to their new facility, which will provide space for the company's continued growth. Once built, ARC will have over 200,000 square feet of office research, and manufacturing space in Amesbury.

As electronic systems become even more complex, integrating more functionality while reducing size, the need for controlling electromagnetic energy will only increase — which promises a bright future for ARC Technologies.

ARC Strategy: To understand and provide rapid response to customers' needs, deliver high quality products on time and engineer innovative, value-added solutions.

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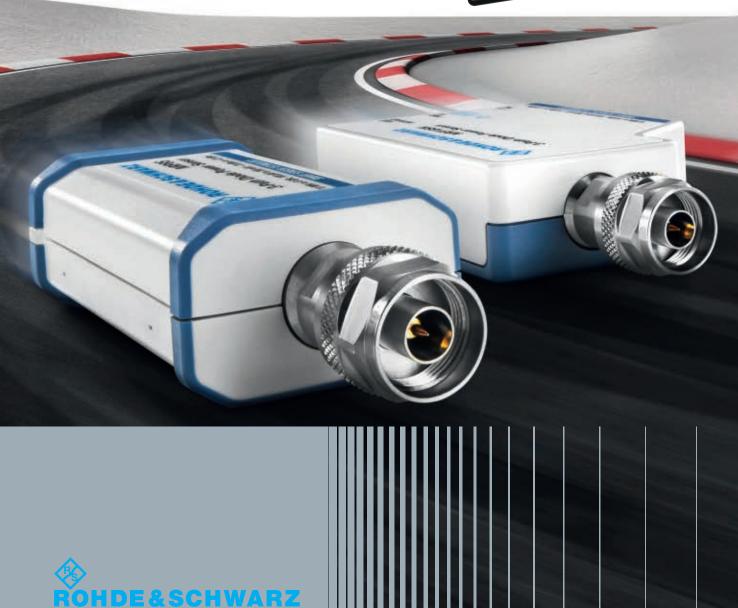
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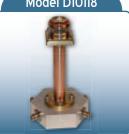
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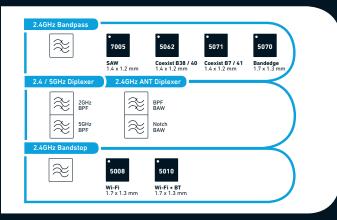
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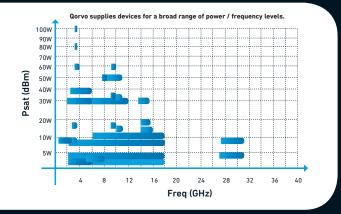
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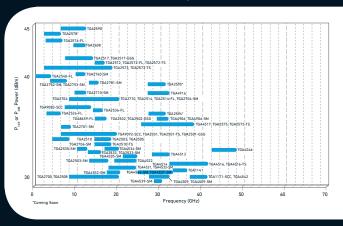
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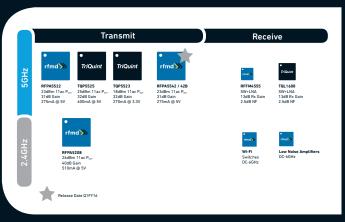
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