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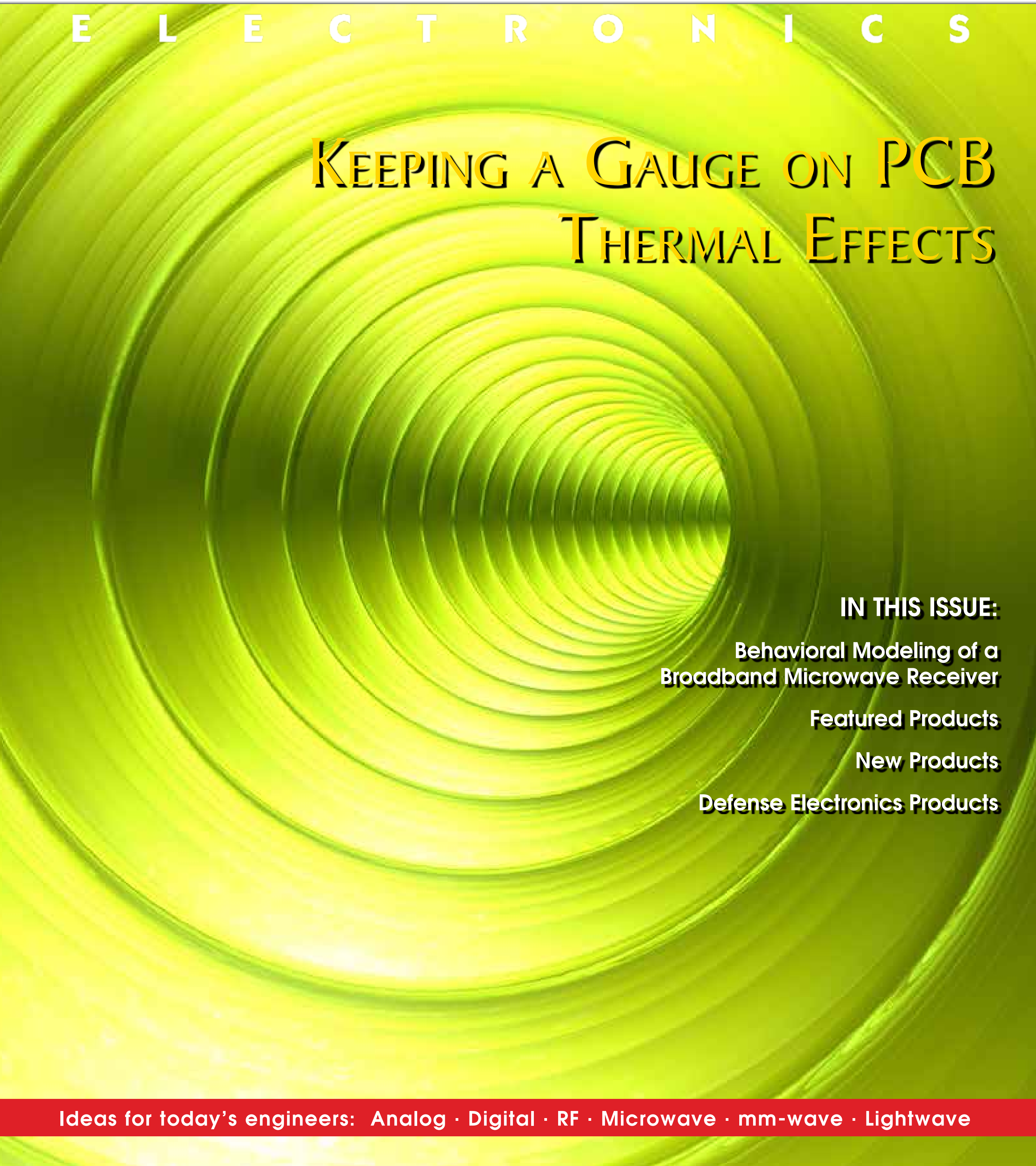
MARCH 2014

HIGH FREQUENCY ELECTRONICS



Keeping a Gauge on PCB Thermal Effects

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Featured Products

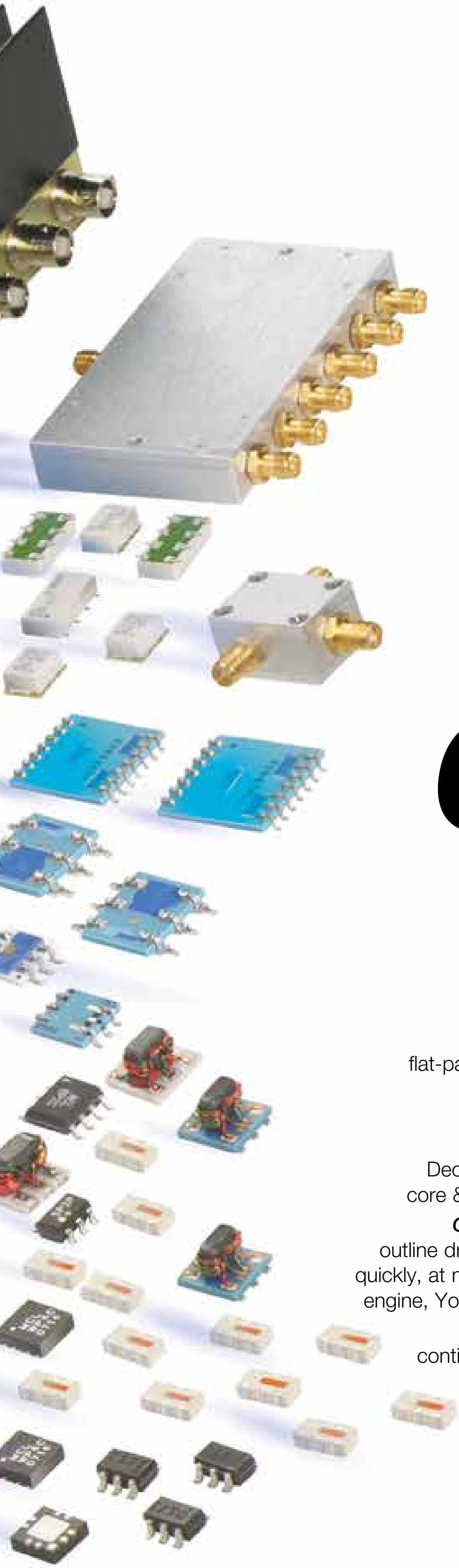
New Products

Defense Electronics Products

Ideas for today's engineers: Analog · Digital · RF · Microwave · mm-wave · Lightwave

AEROFLEX
INMET
Models 6FH & 18FH
6 and 18 GHz Full Hex
2-Watt Attenuators
Model AHC/RP
6 GHz Reverse-Polarity
2-Watt Attenuator


MCL B 744
ADP-2-10
MCL
GBA-12
071836



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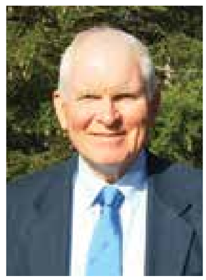
The Promise of 5G and Beyond

Tom Perkins
Sr. Technical Editor



Recently I took advantage of a great upgrade opportunity from my cellular provider and treated myself to a new 4G compatible smartphone. It has more features, including a larger display, than the previous 3G version. Its cellular phone (same provider) works better also, which implies possibly improved receiver or antenna(s) on board.

Then the thought occurred: as soon as I leave this store, the technology in the new device will be partially obsolete. Probably the following week they will announce deployment of 5G. I was wrong. 5G, or 5th generation wireless systems, generally describes beyond year 2020 mobile communications technologies. Each generation has appeared approximately 10 years after its predecessor.

Apparently at this time there has been no widespread 5G development collaboration. Traditionally the spectral bandwidth per frequency channel has widened for each generation, starting at 30 kHz for 1G and up to 100 MHz for 4G. Bandwidth is an overreaching requirement for enabling increased network capacity.

Promise of 5G

According to Wikipedia and other sources, technologies embraced with 5G could include:

- Advanced interference and mobility management
- Cognitive Radio using Software Defined Radio (SDR)
- Data rates of 10 Gbit/sec minimum
- Dynamic Adhoc Wireless Networks (DAWN) employing smart antennas, cooperative diversity, and agile modulation
- Enabling of *Internet of Things* and new heights for wireless monitoring and connectivity
- Li-Fi – uses LEDs to transmit data
- Massive Dense Networks providing Green Dense Small Cells
- Millimeter-Wave Frequencies, perhaps up to 90 GHz
- Multi-hop networks – macro-diversity techniques or group cooperative relay (relaying radio signals? – there's nothing new under the sun)
- *Real wireless world*
- Simultaneous and seamless connection to several wireless technologies
- Unified Global Standard – no limitations
- User Centric Networks
- Vandermonde-subspace frequency division multiplexing (VFDM)
- Wearable devices: e.g. optical display headsets and smartwatches
- World Wide Wireless Web (WWWW)

Research Projects

One consortium of European companies is enabling a project called METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society). This project seeks to lay a foundation for 5G with emphasis on a new generation network focused on energy efficiency, sustainability and affordability.

Researchers at Dresden University of Technology (TUD) have begun investigations into 5G technologies using a graphical system design approach and National Instruments' software defined radio platforms.

Samsung Electronics claims to have already developed the world's first 5G system, sending > 1 Gbit/sec a distance of approximately 2 kilometers. Core technology of 10's of Gbit/sec are claimed.

Huawei Technologies Co. Ltd. announced last year an investment of at least $600 million in 10Gbit/sec 5G technology. Huawei is a Chinese multinational networking and telecommunications and services company headquartered in Shenzhen, Guangdong. It is the largest telecommunications equipment maker in the world, having overtaken Ericsson in 2012. Other activities include collaborate development between India and Israel.

And Beyond

You may have heard of Intelligent Transport Systems (ITS). Within this initiative to make travel easier and safer, in the realm of *Internet of Things* could include Vehicle-to-Vehicle (V2V). V2V communications comprising a wireless network where automobiles and light trucks send messages to each other with information about their situation. Variables such as speed, direction of travel, location, braking, and loss of stability could be included.

Communicating with stationary devices is sometimes called V2I, or vehicle to infrastructure. While some of these devices historically communicated with our human optical or auditory senses, new ones may only hold embedded wireless features, not obvious because they consist of microwave devices operating at say, 5.9 GHz. Some automakers have their own catch-words for V2V such as Car-to-X, which encompasses other vehicles and the infrastructure. There's also a push for the term *Internet of Cars,* playing off *Internet of Things*.

Closing Thought

Considering all these possibilities and many more, there are significant opportunities for many innovations. Progress will likely be made this year towards the somewhat "moving target" goals of 5G. Any "disruptive technology" breakthrough could alter the 5G endgame. Meanwhile, I'll enjoy my new toy!

Conferences

March 19 – 20, 2014
Microwave & RF
Paris
www.microwave-rf.com

March 23 – 27, 2014
IEEE International Wireless Symposium (IWS 2014)
Xi'an, China
http://iws-ieee.org/

May 8 – 9, 2014
IEEE MTT-S International Wireless Power Transfer (WPTC 2014)
Jeju, Korea
http://www.wptc2014.org/

June 1 – 6, 2014
IEEE International Microwave Symposium (IMS2014)
Tampa, Florida
http://ims2014.mtt.org/

Short Courses

Besser Associates
besserassociates.com
Tel: 650-949-3300

New Courses
Course 227: Wireless LANs
Course 226: Wireless/Computer/Telecom Network Security
Course 228: GaN Power Amplifier Design
Course 223: Fundamentals of LTE, HSPA, & WCDMA
Course 221: BER, EVM, & Digital Modulation Testing for Test & Product Engineers

Company-Sponsored Training & Tools

Analog Devices
Training, tutorials and seminars.
http://www.analog.com/en/training-tutorials-seminars/resources/index.html

AWR
On-site and online training, and open training courses on design software.
http://web.awrcorp.com/Usa/News--Events/Events/Training/

Linear Technology
LTSpice IV
LTpowerCAD
LTpowerPlay
Amplifier Simulation & Design
Filter Simulation & Design
Timing Simulation & Design
Data Converter Evaluation Software
http://www.linear.com/designtools/software/

National Instruments
LabVIEW Core 1
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
LabVIEW Core 2
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
Object-Oriented Design and Programming in LabVIEW
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
Free, online LabVIEW training for students and teachers.
http://sine.ni.com/nievents/app/results/p/country/us/type/webcasts/
Webcasts on demand.
http://search.ni.com/nisearch/app/main/p/bot/no/ap/tech/lang/en/pg/1/sn/catnav:mm,n15:WebcastsOnDemand,ssnav:dzn/
LabVIEW user groups.
https://decibel.ni.com/content/community/zone/labviewusergroups

Call for Papers

September 1 – 3, 2014
IEEE International Conference on Ultra-WideBand (ICUWB)
Paris
Abstract submission deadline: March 11, 2014
Final submission deadline: June 6, 2014
Notification of acceptance date: May 12, 2014
http://www.icuwb2014.org/

September 14 – 19, 2014
International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz)
Tucson, Ariz.
Abstract submission deadline: March 21, 2014
Final submission deadline: May 25, 2014
Notification of acceptance date: April 20, 2014
http://www.irmmw-thz.org/

October 19 – 22, 2014
2014 IEEE Compound Semiconductor Integrated Circuit Symposium (CSISC)
La Jolla, Calif.
Abstract submission deadline: May 2, 2014
Final submission deadline: July 25, 2014
Notification of acceptance date: June 13, 2014
http://www.csics.org/

Micro Lambda's Bench Test Boxes...
Simple and Easy to Use!

MLBS-Synthesizer Test Box – 600 MHz to 20 GHz
Standard models cover the 0.6 to 2.5 GHz, 2 to 8 GHz, 8 to 20 GHz and 2 to 20 GHz frequency bands. All versions of the MLSP synthesizer product family can be easily inserted into the test box. Tuning consists of a control knob, key pad, USB and Ethernet connections. Units provide +10 dBm to +13 dBm output power levels and are specified over the lab environment of +15°C to +55°C and are CE certified.

Units are provided with a power cord, USB cable, Ethernet cable, CD incorporating a users manual, quick start guide and PC interface software.

MLBF-Filter Test Box – 500 MHz to 50 GHz
Standard models utilize any Bandpass or Bandreject filter manufactured by Micro Lambda today. Bandpass filter models cover 500 MHz to 50 GHz and are available in 4, 6 and 7 stage configurations. Bandreject (notch) filter models cover 500 MHz to 20 GHz and are available in 10, 12, 14 and 16 stage configurations. Units are specified to operate over the lab environment of +15°C to +55°C and are CE certified.

Units are provided with a power cord, USB cable, Ethernet cable, CD incorporating a users manual, quick start guide and PC interface software.

See our complete line of wideband, low noise components

MLSP-series Synthesizers
600 MHz to 20 GHZ

MLSW-series Synthesizers
600 MHz to 16 GHz

MLTO-series TO-8 Oscillators
2 to 16 GHz

MLSMO-series Surface Mount Oscillators
2 to 16 GHz

www.microlambdawireless.com

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In-Building Wireless Market to Reach $8.5B in 2019

ABI Research expects the market for in-building wireless equipment and deployments to grow to over $8 billion in 2019, up from a forecast $4.4 billion for 2014, representing a 14% compound annual growth rate (CAGR).

North America will continue to be the region with maximum DAS spending with sports venues and transportation continuing to be the verticals which attract the most DAS investment while shopping malls, healthcare and hotels/resorts finish a close second place. Together these verticals in North America account for about two-thirds of DAS spending. North America is followed by Asia-Pacific and then Europe for market size.

"While the Asia-Pacific region today accounts for less than a quarter of the total market, we expect it to grow to more than 25% by 2019 at a CAGR of more than 20%," says Nick Marshall, principal analyst at ABI Research.

"Also Active DAS systems will continue to account for the majority of deployment types with over 60% of the revenue throughout our forecast period," he said.

In its latest "In-Building Wireless" Market Data, ABI Research forecasts in-building wireless revenue by region, vertical, system type and component type. The component types included in the forecast are cabling, repeaters, antennas, active and passive DAS head ends and remotes and a new category – DAS trays. ABI Research believes that the DAS trays market will likely track LTE rollouts as DAS operators deploy systems with low PIM (Passive Intermodulation), and the low PIM DAS tray is emerging as a unique class of equipment, and a necessary building block for modern DAS systems.

—ABI Research
abiresearch.com

Over 800 Million Smartphones Using Indoor Location by 2018

iBeacons are fast becoming the foot soldiers of indoor location in retail, bringing awareness and adoption, but it is just one of over 10 indoor location technologies competing in this $5 billion space. A host of new, higher-accuracy, "infrastructure-free" technologies are forecast to change the face of and use case for indoor location in the future.

In ABI Research's report, "Indoor Location Technologies" the evolution of each of these technologies is considered. Senior analyst Patrick Connolly said, "We see huge growth for infrastructure-based technologies like Wi-Fi and iBeacons, with BLE deployments forecast to break 20,000 by 2015, largely focused on retail. But the arrival of high-accuracy handset-based technologies like sensor fusion, LED, magnetic field and a host of others, will also enable a whole new set of consumer applications and services around ambient intelligence, social networking, corporate/enterprise, fitness/health, mobile advertising, and gaming. With over 800 million smartphones actively using indoor location for applications by 2018, it will be as standard as GPS is today."

VP and Practice Director, Dominique Bonte added, "iBeacons and BLE location make indoor easy and cheap, but that also opens the door to a host of new competitors. Those at the forefront are already aggressively pursuing new, sub-meter handset-based technologies. This will give the edge in both the retail and consumer spaces."

—ABI Research
abiresearch.com

Cyberwarfare Kickstarts Security Industry in the Middle East & North Africa

The Middle East and North Africa (MENA) is a hotbed of cyber tensions. As the region embraces ICTs for economic and social development, long-standing conflicts have rapidly moved online. The MENA cyberspace is home to numerous highly-volatile attack groups: from patriotic hackers and hacktivist collectives to state-supported cyberattack groups and military cyberdefense units. Political and religious tensions, coupled with the growing economic prosperity of the energy sector, are attracting both foreign politically-motivated groups as well as cybercriminals looking for financial gain in a vulnerable environment. The region has been the target of the most sophisticated cyberattacks and espionage campaigns to date with Stuxnet and its associated variants, but it is also home to developing countries with the least cybersecurity structures in place.

"The main drivers for the cybersecurity industry in the region are the protection of the energy and financial services sectors, which are still considerably vulnerable despite the intensifying hostile cyber environment. Some countries like Israel are ahead of the game, fostering a dynamic homegrown market in next-generation offensive cybersecurity products and services," says Michela Menting, ABI Research's senior analyst in cyber security. The market will offer significant opportunities for vendors targeting critical infrastructure sectors. Government budgets are supporting military efforts in cyber unit development, and military contractors are a growing presence in the region. Spending by MENA governments to boost their national cyberdefense capabilities will represent US$316 million in 2014. Efforts will extend to intelligence gathering, logistics management, information system and network security improvements.

—ABI Research
abiresearch.com

TIP 1 For an inductor with the absolute maximum Q, pick one of these air core "Springs". They have flat tops for easy mounting and exceptional current ratings.

TIP 2 If you prefer conventional chip inductors, you'll get the highest Q with our new ceramic body 0402HP and 0603HP families. These tiny wirewound coils handle up to 2 times more current than the nearest competitor.

This new web tool finds inductors with the highest Q at your operating frequency

TIP 3 Need to find coils with the best Q at your L and frequency? Our **Highest Q Finder** web tool tells you in just seconds. Click again to plot the L, Q, Z and ESR of up to 4 parts simultaneously.

TIP 4 When it's time to build your prototypes, be sure to ask us for evaluation samples. They're always free and we can get them to you overnight.

To get started, visit **www.coilcraft.com/Q**

Here are some high Q tips

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WWW.COILCRAFT.COM

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Anritsu Company announced that its ME7873L RF/RRM **Conformance Test System** achieved the world's first Test Platform Approval Criteria **(TPAC)** for LTE-Advanced Carrier Aggregation (CA). This achievement in the Global Certification Forum (GCF) enables wireless device manufacturers to implement certification of devices employing this new technology. Anritsu started validations for LTE-Advanced CA (WI-162) in October 2013, and achieved TPAC for two band combinations (1-5 and 3-8) in January 2014. Concurrently, Anritsu achieved the 80% validation level for five additional inter-band combinations for PTCRB (RFT-103).


DARPA Artist Rendering

DARPA's Aerial Reconfigurable Embedded System (ARES) program aims to develop and demonstrate a modular transportation system built around a vertical takeoff and landing **(VTOL) flight module operated as an unmanned aerial vehicle (UAV).** The flight module would carry one of several different types of detachable mission modules, each designed for a specific purpose, such as Intelligence, Surveillance and Reconnaissance (ISR) (top left), casualty evacuation (top right) and cargo resupply (top center and bottom). The program seeks to provide flexible, terrain-independent transportation that avoids ground-based threats, in turn supporting expedited, cost-effective operations and improving the likelihood of mission success.

AWR Corp.'s Graduate Gift Initiative played a role in helping **Dr. Dominic FitzPatrick** found **PoweRFul Microwave**, an engineering consultancy specializing in RF and microwave amplifier design. Upon graduation from Cardiff University, Cardiff, UK, Dr. FitzPatrick took advantage of AWR's Graduate Gift Initiative program, which gifts a one-year complete **AWR Design Environment™ software license** to graduates in order to help them jump-start their careers. In the year since founding PoweRFul Microwave, Dominic has secured customer design wins that called upon the use of Microwave Office® nonlinear engine to design power amplifiers in frequency bands from VHF to 20 GHz.

Altium Limited released a new range of PCB **component libraries** for Altium Designer supporting a wide range of Rosenberger's board-mount connectors. **Rosenberger** develops and produces a wide range of standard and customized connectivity solutions spanning high frequency and fiber optic technologies. Their product portfolio includes RF connectors, cable assemblies, RF test and measurement devices, automotive products, fiber optics, and custom copper and fiber optic assemblies.

Lockheed Martin Corp., Lockheed Martin Aeronautics Co., Fort Worth, Texas, was awarded a $16,814,091 bilateral modification (P00171) for an existing firm-fixed-price, cost-plus-fixed-fee contract (FA8611-08-C-2897) for engineering change proposal (ECP) 0533, follow-on agile sustainment for the **F-22 Raptor**, Reliability and Maintainability Maturation Program Project AF100 Acceleration Plan. This effort is to procure retrofit kits that will provide a more durable material for the actuated doors on the bottom of the aircraft.

Rolls-Royce Corp., Indianapolis, Ind., is being awarded a $90,164,920 modification to a previously awarded firm-fixed-price contract (N00019-12-C-0007) to exercise an option for the procurement of 40 AE1107C install engines in support of the **MV-22 aircraft** for the United States Marine Corps. Work will be performed in Indianapolis, Ind., and is expected to be completed in November 2015. Fiscal 2013 and 2014 aircraft procurement, Navy funds in the amount of $90,164,920 will be obligated at time of award, none of which will expire at the end of the current fiscal year.

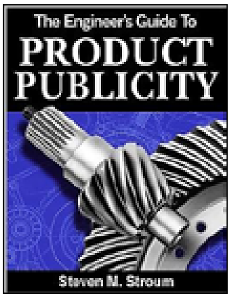
Agilent Technologies and **FIME**, an advanced secure-chip testing provider, have announced an agreement to work together to deliver pioneering testing solutions to the **payments and telecommunications markets**. The advancement of innovative tools to test and certify **secure-chip mobile payment technology** will be a key priority. This work will capitalize on FIME's expertise

in the payments sector together with Agilent's heritage in the telecommunications industry. In November 2014 Agilent's Electronic Measurement Group will spin off as a separate company, **Keysight Technologies**.

The **new 2014 Pasternack website** is the first major redesign since the company's previous 2012 website overhaul. Most noticeable to the average user is the simplified, stripped-down look and feel of the new homepage. Pasternack's main objective with the new site was to provide engineers and buyers the easiest, most intuitive process for searching and finding any of the company's +40,000 RF components and cable assemblies with as few clicks as possible.

MITEQ Inc. announced the appointment of **Proton LLC** as the company's non-exclusive sales representative in **Russia**. Proton LLC will represent MITEQ's **Component and SATCOM divisions**. Component products include amplifiers, mixers, frequency multipliers, passive power components, switches, attenuators, phase shifters, IF signal processing components, oscillators, synthesizers, integrated multifunction assemblies and fiber optic products. SATCOM products include upconverters and downconverters, LNAs and LNBs, translators, redundant LNA and block converter systems, and RF fiber optic links.

Signal Hound, manufacturer of small, USB-based spectrum analyzers that perform on par with traditional, higher-cost analyzers, signed **Debra Seifert Communications** for all marketing programs, including public relations, advertising, and email marketing. Signal Hound miniature spectrum analyzers are compact and simple to use, and yet feature the sensitivity, accuracy, and dynamic range offered by more expensive and bulky test equipment.



The **Engineer's Guide to Product Publicity** is a 5-page paper that explains what publicity is, why it is a cost effective marketing tool, and how to use it get a company branded as a problem-solver. Featured are 10 rules for preparing effective news releases including adopting a giving mindset, eliminating advertising jargon, and quantifying all performance claims. It is available free from Venmark International: venmarkinternational.com.

Tom Butler joined **RFMW** as **Director of Sales for North America.** He held successful prior stints at companies including Crescend Technologies, TriQuint, and RFMD. Mr. Butler graduated with a Bachelor of Science degree in Electrical Engineering from the University of Connecticut. RFMW is a specialty electronics distribution company focused on RF and microwave components and semiconductors. w

RF Micro Devices and TriQuint Semiconductor announced a **merger** under which the companies will combine in an all-stock transaction. The new company will have a new name and shared leadership team.

Quality, Performance and Reliability in Precision Coaxial Connectors

ADAPTERS · CABLE CONNECTORS · RECEPTACLES · CUSTOM DESIGNS

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1.85mm	DC-65 GHz	2.92mm	DC-40 GHz	7mm	DC-18 GHz
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ISO 9001:2008

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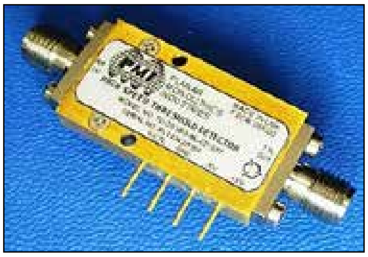
FEATURED PRODUCTS



Detector

PMI Model No. TD-2G18G-RL-CD-SFF is a high speed threshold detector designed to operate over the 2.0 to 18.0 GHz frequency range with an adjustable threshold level of -30 to -10dBm and a VSWR of 3.0:1 max. This unit is supplied with field removable SMA Female connectors in a small package measuring 1.1" x 0.6" X 0.19".

Planar Monolithics Industries
pmi-rf.com

EMI Tape

Molex launched its HOZOX™ Electromagnetic Interference (EMI) Absorption Tape and Sheets, ideally suited for manufacturers of high-frequency equipment in data/telecommunications and microwave/radio frequency. HOZOX absorption technology utilizes a unique dual-layer design to maximize the EMI noise mitigation performance.

Molex
molex.com

Divider

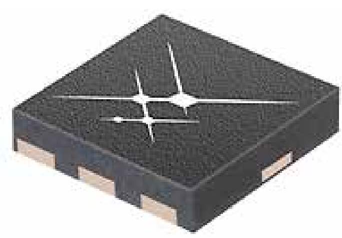
Renaissance Electronics has designed a high power divider that divides power from 6 to 18 dB across the output ports. Operating between 1100 and 1500 MHz, this 8-way divider has a footprint of 8" x 5". The divider can handle 350W Peak and 35 W CW.

Renaissance Electronics
rec-usa.com

Inductors

Coilcraft's XAL1010 Series of high-temperature, shielded power inductors combines excellent current handling and exceptionally low DC resistance in a rugged, molded package. The XAL1010 is available with thirteen inductance values from 0.22 to 15 µH, current ratings to 98.8 Amps and DCR as low as 0.45 mOhms. The package measures just 10.0 x 11.3 x 10.0 mm.

Coilcraft
coilcraft.com



Switch

RFMW supports Skyworks SKY13446-374LF, a high isolation SPDT switch covering 0.1 to 6.0 GHz. Targeted at WLAN applications in the 2.4 - 2.5 GHz and 4.9 - 5.9 GHz bands, the SKY13446-374LF offers 38 and 30 dB typical isolation, respectively. Low insertion loss improves transmit signal efficiency. Excellent EVM performance is attributed to linearity of 32 - 33 dBm P1dB.

RFMW
rfmw.com

Circular Connectors

TE Connectivity now offers a full complement of high-performance

circular connectors, including DEUTSCH connectors, to its portfolio of circular connectors serving nanominiature, microminiature and compact small form factor applications. It is one of the largest selections of small circular connectors designed for rugged durability and space and weight savings (SWaP) within the military and aerospace markets.

TE Connectivity
te.com

Signal Generators

Aeroflex Limited enhanced its S-Series signal generators (SGA and SGD) with improved phase noise and better RF level accuracy. At a carrier frequency of 1 GHz, phase noise is now improved by 6 dB at frequency offsets from 100 kHz to 1 MHz, giving a figure of typically -140 dBc/Hz between these offsets. The S-Series does this while maintaining its industry-leading frequency settling time of 100 µs.

Aeroflex
aeroflex.com

VCO

Crystek's CVCO55CC-2700-2700 VCO operates at 2700 MHz with a control voltage range of 0.5V~4.5V.


AWR
A National Instruments Company™
© 2014 AWR Corporation. All rights reserved.

FEATURED PRODUCTS

This VCO features a typical phase noise of -118 dBc/Hz @ 10KHz offset and has excellent linearity. Output power is typically +7 dBm. Model CVCO55CC-2700-2700 is packaged in the industry-standard 0.5-in. x 0.5-in. SMD package.

Crystek
crystek.com

Connectors

Emerson Network Power introduced the Johnson™ line of coax connectors, SMPM ideal for applications such as radar, satellite, high density packaging, and require higher frequencies up to 65 GHz. These subminiature connectors feature a push-on style micro interface that is 35 percent smaller than our SMP design. The SMPM bullet adapter provides the same blind mate functionality as the larger SMP connectors.

Emerson Network Power
emersonconnectivity.com

MPM

The dB-4127 is a microwave power module (MPM) operating in the frequency range of 6 to 18 GHz. This MPM is a power amplifier that provides 200 Watts pulsed/CW RF output power. The RF signal path consists of a solid state amplifier and a vacuum power booster. The power supply topology uses proprietary low-noise, high-efficiency designs to operate the RF signal path.

dB Control
dbcontrol.com

Timing Reference

The DROR-II is a 10MHz/5MHz/1PPS GPS-Disciplined Atomic Frequency and Timing Reference (GPSDO). It is a ruggedized reference with a Cesium Vapor Atomic Oscillator followed by a precision SC-cut Crystal Double-Oven Oscillator and an actively vibration-compensated VCXO oscillator, with specific emphasis on ultra-low phase noise performance.

Jackson Labs Technologies
jackson-labs.com

Filters

ES Microwave's wideband bandpass/highpass filters feature: Frequency Range: DC to 40 GHz; Passband: DC to 40 GHZ (or any segment thereof); Insertion Loss: 1.0 dB Typical within Passband; Rejection/Isolation: 55 dB minimum; VSWR: 2:1 max.; Connectors: SMA; Selectivity: from N = 3 to N = 15 Pseudo Elliptic Response; Size: miniature; Low Profile.

ES Microwave
esmicrowave.com

Diplexer

Microlab Hybrid Combiners are known for their low PIM, low loss, and high isolation which make them ideal for efficiently combining RF signals particularly in active and passive DAS deployments. The CM-20 is an integrated 4 x 2 hybrid

multi-band combiner with a unique design that combines two low band signals within 698 - 960 MHz with two high band signals within 1710 - 2170 MHz.

Microlab
microlab.fxr.com

LNA

RF Bay's GNA-904F is a high performance Microwave Low Noise (& Driver) Amplifier with standard frequency range of 24 GHz to 36 GHz. Features: Frequency Range: 24 - 36 GHz; Gain: 22 dB; P1dB: +11 dBm; IP3: +21 dBm; Noise Figure: 3 dB (typ.); DC Power: 5V @ 80 mA; 2.92 mm K-female connectorized.

RF Bay
rfbay.com

Phase Shifter

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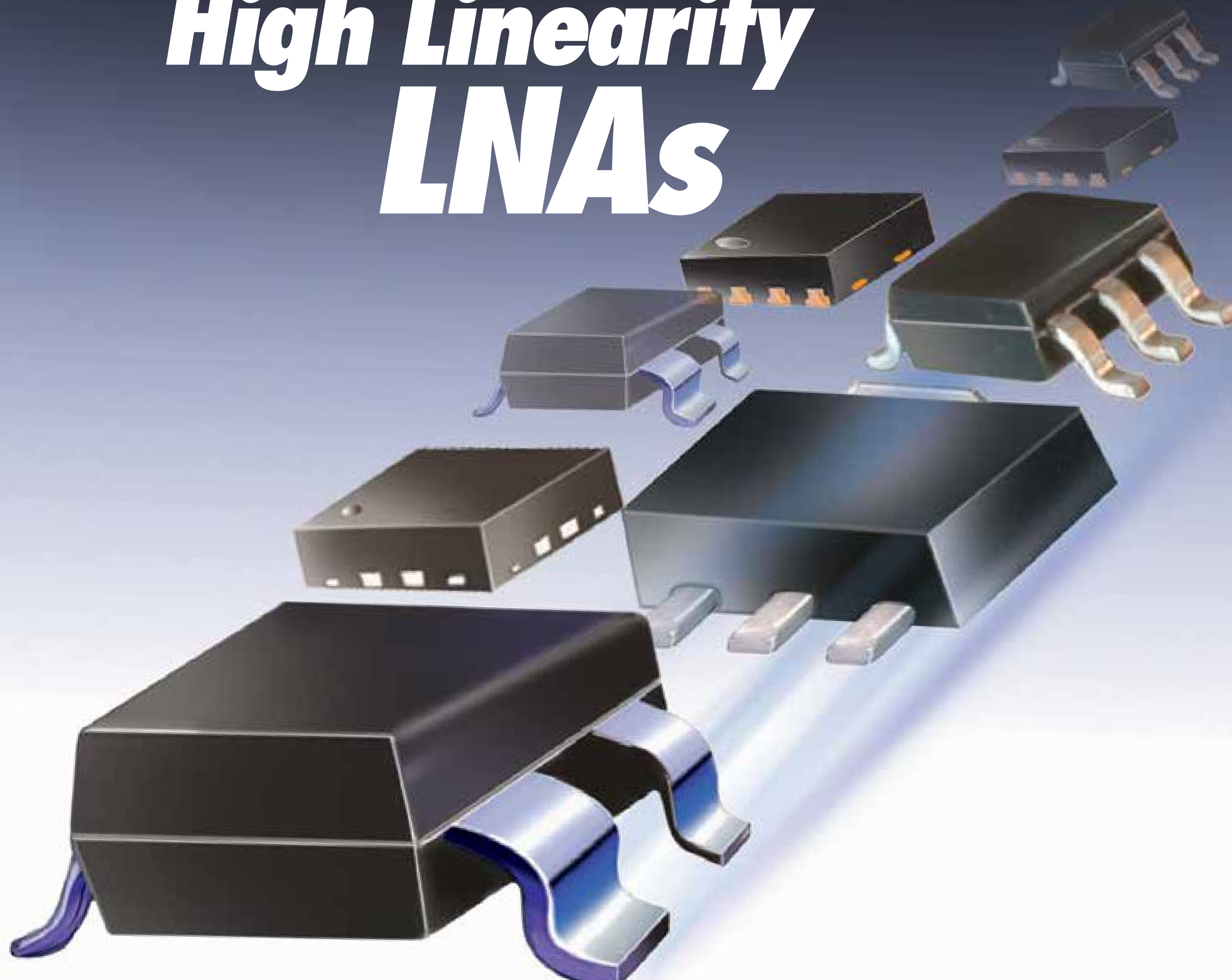

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PMA-5452+	50-6000	14.0	**0.7**	**34**	18	40	1.49
PSA4-5043+	50-4000	18.4	**0.75**	**34**	19	33 (3V) 58 (5V)	2.50
PMA-5455+	50-6000	14.0	**0.8**	**33**	19	40	1.49
PMA-5451+	50-6000	13.7	**0.8**	**31**	17	30	1.49
PMA2-252LN+	1500-2500	15-19	**0.8**	**30**	18	25-55 (3V) 37-80 (4V)	2.87
PMA-545G3+	700-1000	31.3	**0.9**	**33**	22	158	4.95
PMA-5454+	50-6000	13.5	**0.9**	**28**	15	20	1.49

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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) 97 (5V)	1.99
PMA-5453+	50-6000	14.3	**0.7**	**37**	20	60	1.49
PSA-5453+	50-4000	14.7	**1.0**	**37**	19	60	1.49
PMA-5456+	50-6000	14.4	**0.8**	**36**	22	60	1.49
PMA-545+	50-6000	14.2	**0.8**	**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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Behavioral Modeling of a Broadband Microwave Receiver[1]

By Jiang Liu, Hugo Morales, and Larry Dunleavy

Characterization and modeling of a broadband 0.5 to 18 GHz tuner/receiver system.

Overview

This application note documents results from the characterization and modeling project of a broad-band 0.5 to 18 GHz tuner/receiver system intended for defense applications. Measurements such as S-parameter and power/frequency swept conversion gain were performed during the project. Equipment used in acquiring measured data include RF source, power meter, spectrum analyzer and DC sources. All measured data is properly calibrated at each frequency and de-embedded to the coaxial RF test port of the receiver system. The receiver system model was developed using the measurement-based behavioral modeling approach for usage in Agilent Technologies' Advanced Design System (ADS) software. This note highlights the good agreements achieved between the measured and simulated conversion gain as a function of both input RF power and frequency. This leads to good TOI performance as validated in given result.

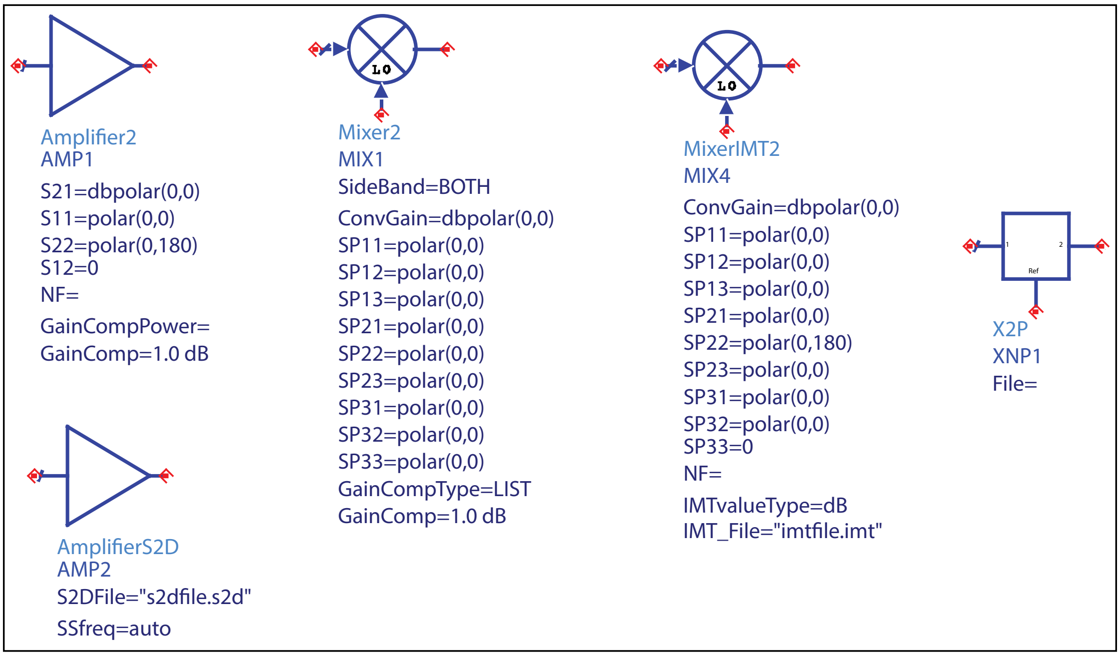
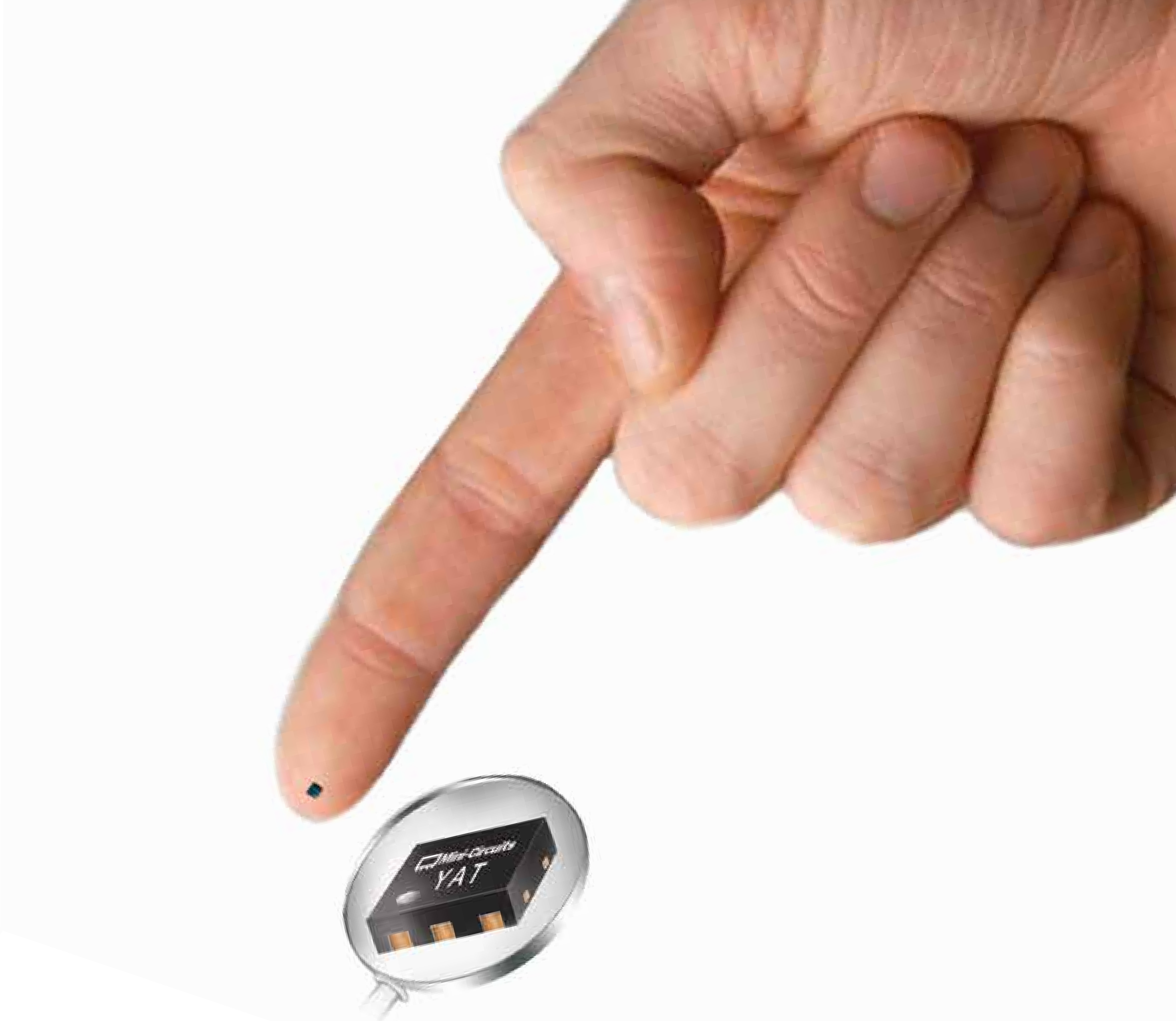


Figure 1 • Candidate ADS amplifier and mixer system models that can be used for construction of behavioral models for receivers and transmitters[2].



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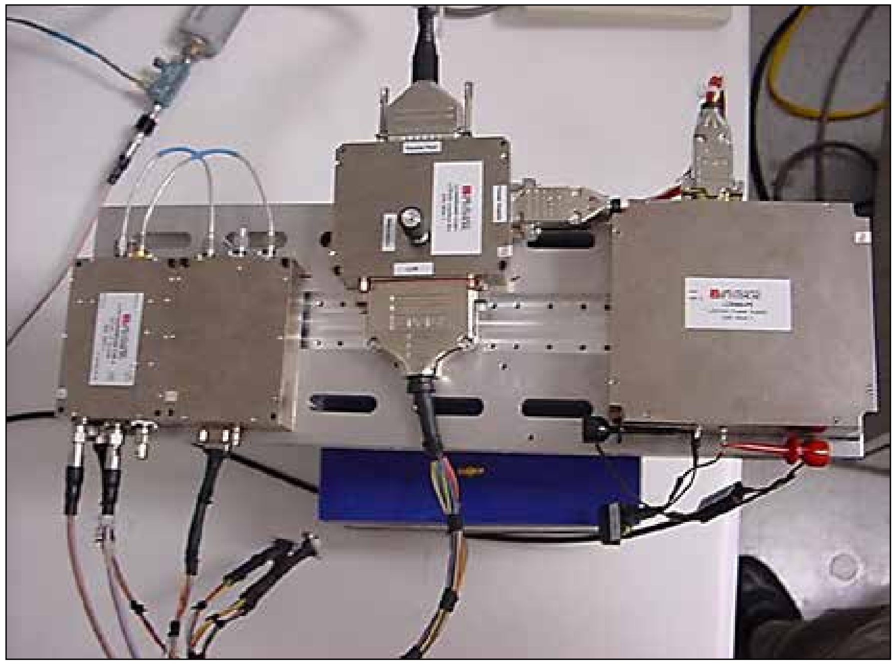

Figure 2 • Subject receiver system includes an IF module, an LO module, a power supply and an interface controller (not shown), mounted together on a large metal carrier for convenient handling.

Basic Description of the Receiver to be Modeled

The receiver to be modeled is a two-stage superheterodyne down converter with an RF input frequency range of 0.5 to 18 GHz, and an IF output frequency of either 160 MHz or 1 GHz, with corresponding IF output band of either 100 MHz or 500 MHz, respectively. The noise figure is rated at 20 dB, and gain 20 or 40 dB. Maximum input CW power is +20 dBm, and the unit has two LO inputs required, that are supplied by an adjacent

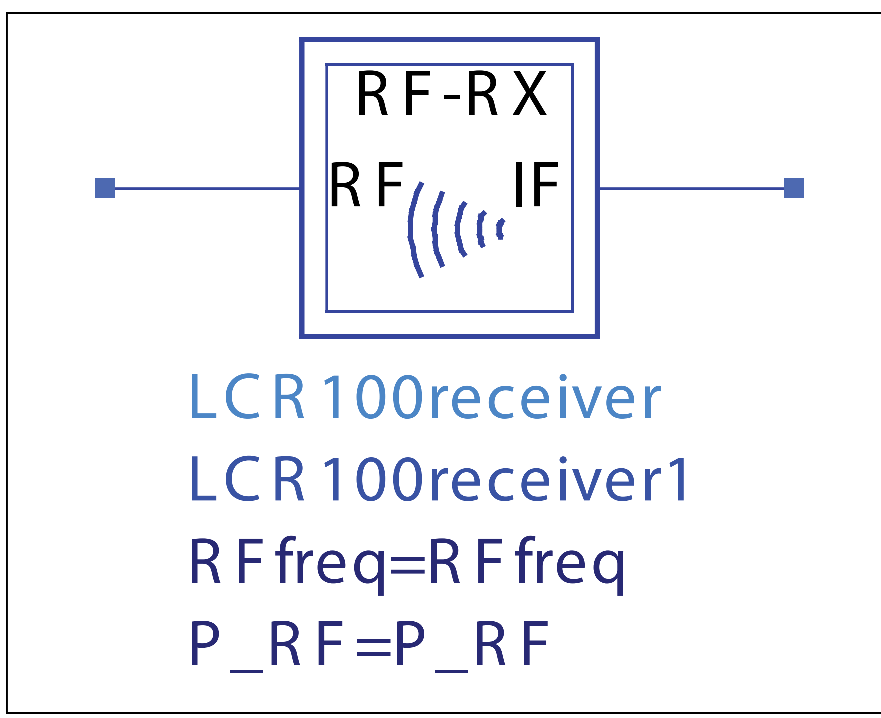

Figure 3 • Schematic symbol of the 0.5 to 18 GHz receiver model. The input RF frequency and power are passed in as parameters to the model.


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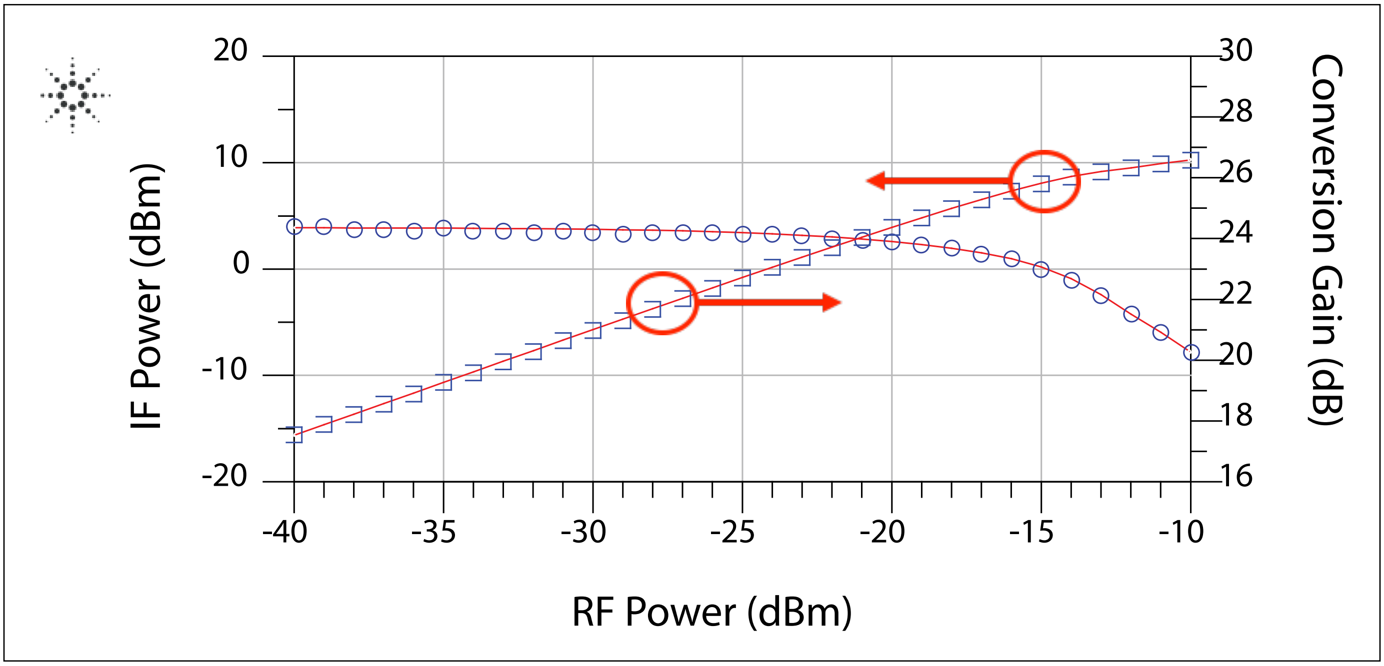

Figure 4 • Measured (symbols) and simulated (solid line) conversion gain of receiver. Input signal is at RF frequency of 10 GHz, output signal is at IF frequency of 1 GHz.

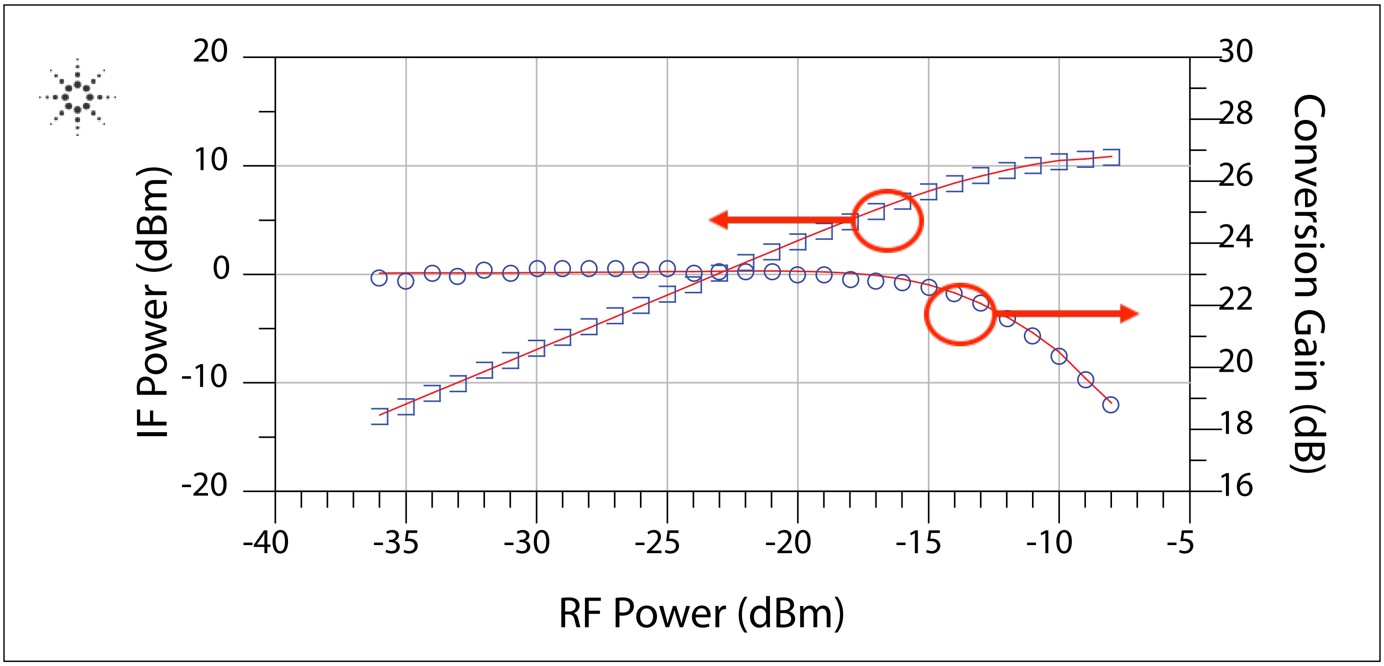

Figure 5• Measured (symbols) and simulated (solid lines) conversion gain of receiver. Input signal is at RF frequency of 0.5 GHz, output signal is at IF frequency of 1 GHz.

(modular) unit. The system uses coaxial SMA connectors on all inputs and outputs. Maximum output power is approximately +10 dBm.

Technical Approach

Modelithics performed a series of measurements to characterize the receiver in terms of conversion loss vs. frequency and power, noise figure vs. frequency, and nonlinear intermodulation distortion levels. The developed model uses built-in ADS system level amplifier and mixer model with parametric inputs derived and conforming to measurement observations. For the purposes of this project, the LO input sources are considered to be integral to the receiver.

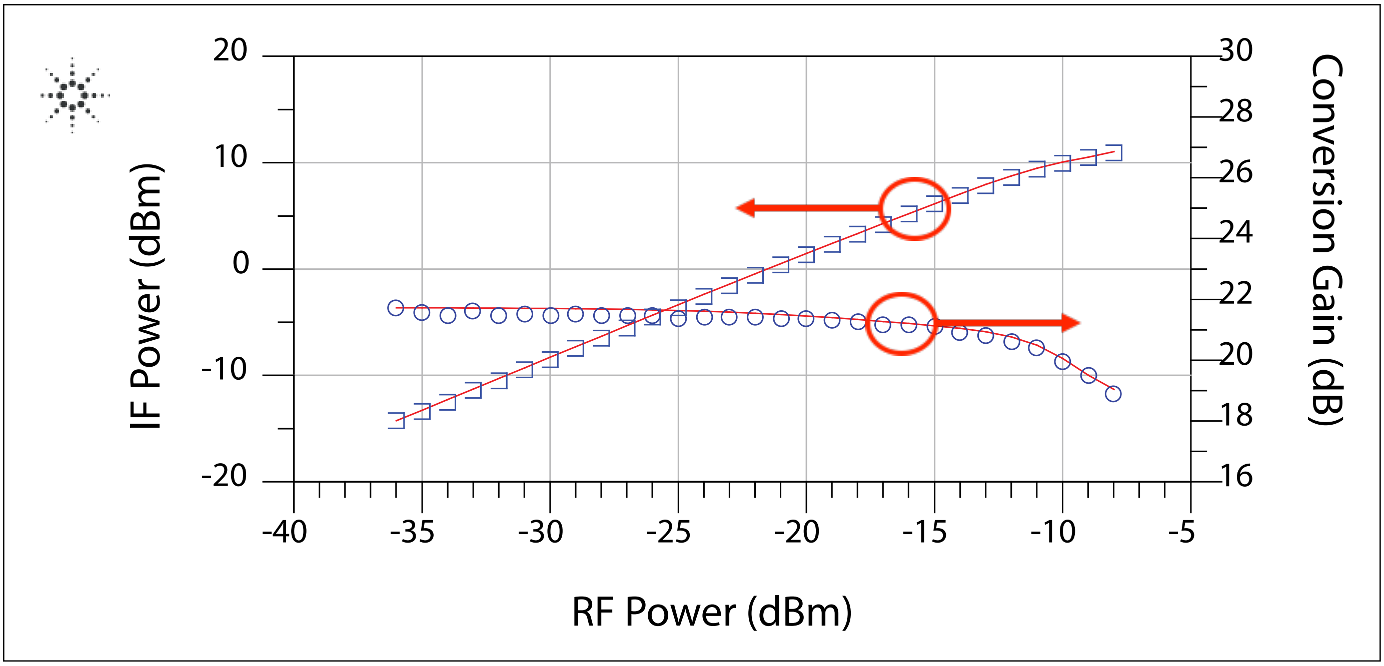

Figure 6 • Measured (symbols) and simulated (solid lines) conversion gain of receiver. Input signal is at RF frequency of 18 GHz, output signal is at IF frequency of 1 GHz.

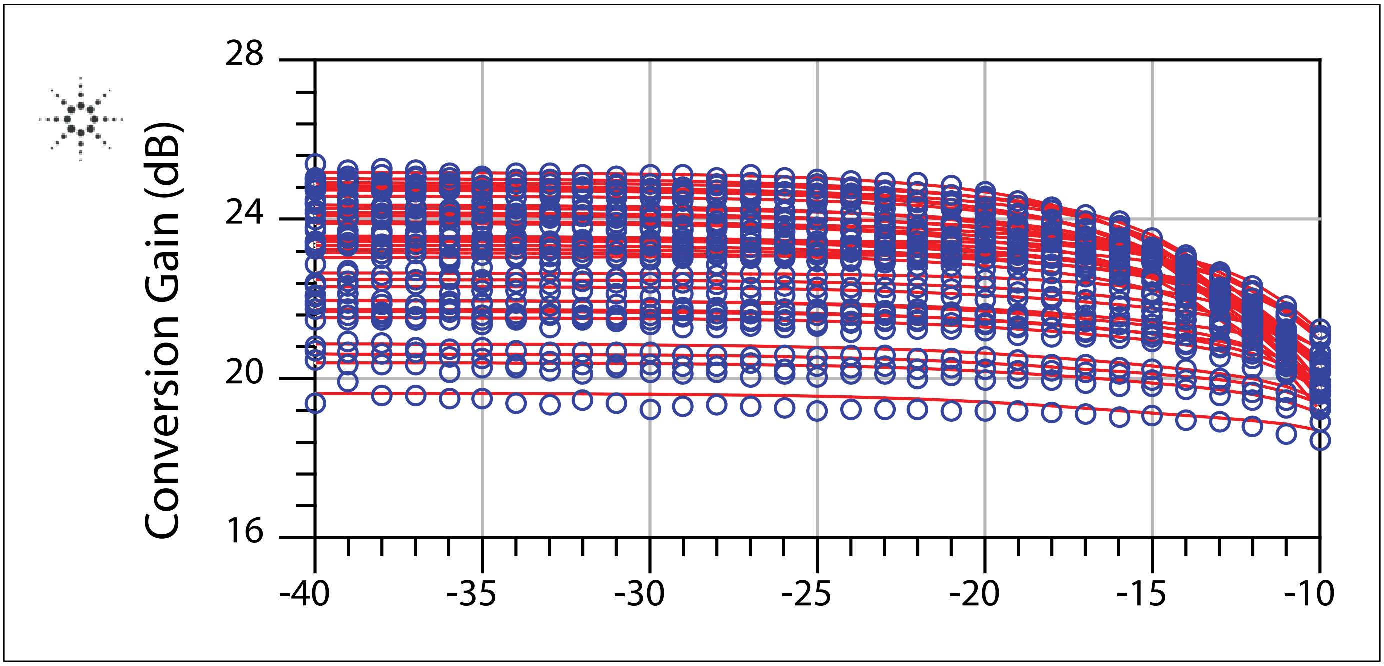

Figure 7 • Measured (symbols) and simulated (solid lines) conversion gain vs RF input power for frequencies 0.5 GHz to 18 GHz in 0.5 GHz steps (excluding RF frequency at 1GHz).

Frequency (GHz)	Measured NF (dB)	Simulated NF (dB)
0.5	15.72	16.05
3	15.54	15.77
9	13.93	14.26
18	12.78	13.21

Table 1 • Measured and simulated noise figure.

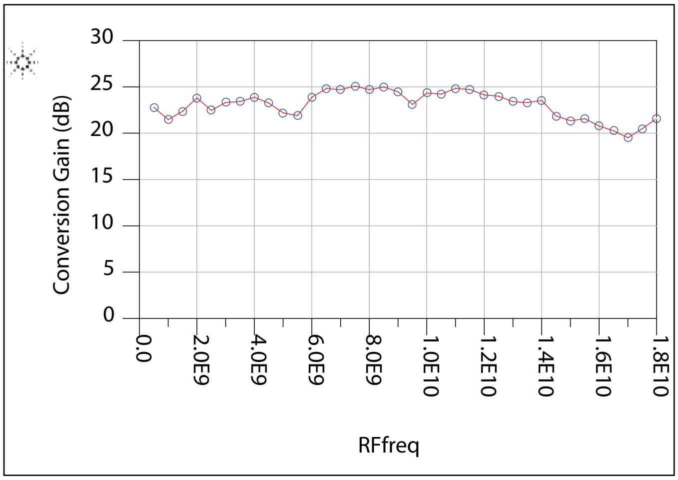

Figure 8 • Measured (symbols) and simulated (solid line) conversion gain at RF input power = -30 dBm. Frequency is from 0.5 to 18 GHz with 0.5 GHz steps.

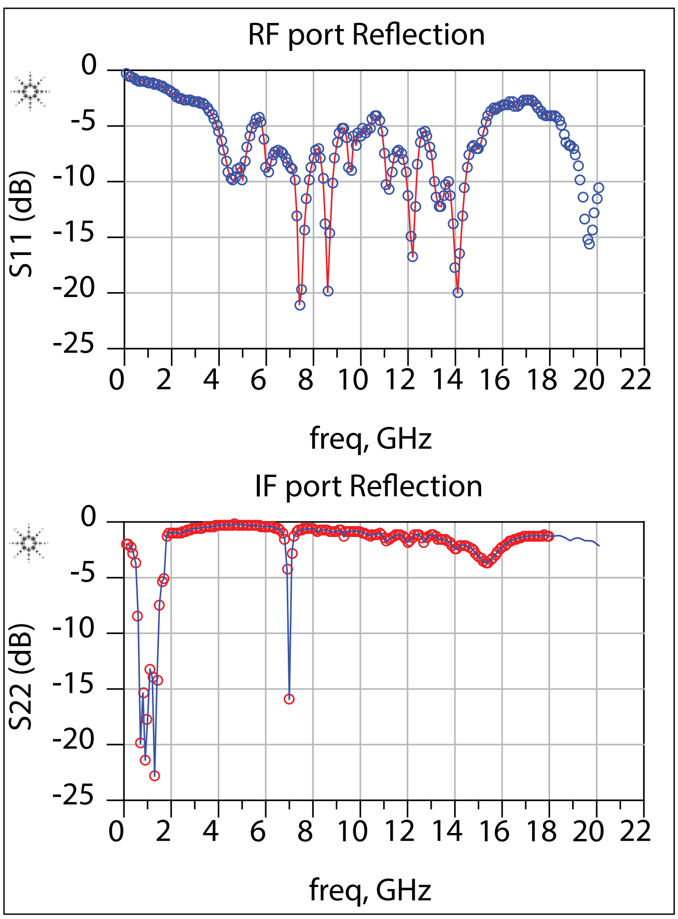

Figure 9 • Measured (symbols) and simulated (solid line) input (RF) port and output (IF) port reflection coefficients for the case of RF frequency of 10 GHz and IF frequency of 1 GHz and an input RF power of -30 dBm.

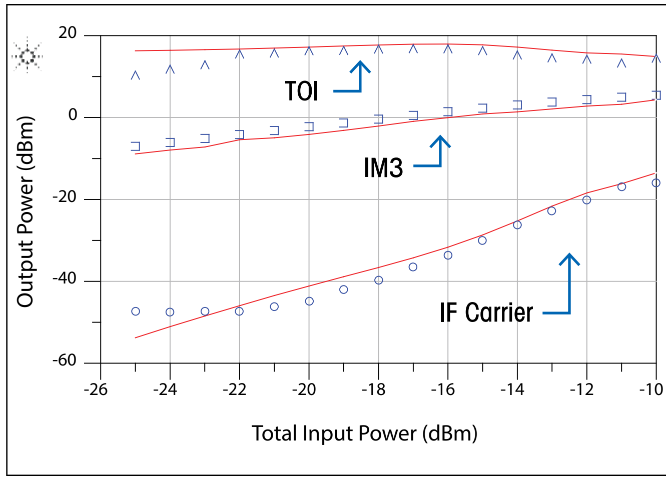

Figure 10 • Measured (symbols) and two-tone simulated model predictions (solid lines) for the case of RF frequency of 15 GHz and IF frequency of 1 GHz and an RF input power swept from -22 to -10 dBm. Shown are results for third-order intercept (TOI), third order power level (IM3) and carrier power level at the receiver output (IF Carrier).

ADS provides several built-in behavioral models that can be utilized to characterize the receiver of interest. Figure 1 shows some of the candidate models. The core of the developed model utilizes the built-in Mixer^2 ADS model which provides key features to characterize typical mixers' nonlinearities, such as conversion gain. An additional filter module is added at the output side to provide better representation of the IF spectrum contents.

Figure 2 shows the ADS symbol representation of the receiver model. The receiver model requires the RF input frequency to be entered as a parameter, with a valid range of 0.5 to 18 GHz in 0.5 GHz step. The total RF power into the receiver is also passed along as an input parameter. The LO frequency is automatically set in the receiver model as (RFfrequency + IFfrequency), with the IF frequency at 1 GHz. Harmonic balance simulations must be evaluated at both the RF frequency and LO frequency.

Simulation Results

The presented results shown in Figures 4-8 compare measured and simulated conversion gain and power compression characteristics for various frequency setups. Based on S-parameter results, not specifically shown in this note it was found that the RF port reflection, RF to IF leakage, and IF to RF leakage are dependent upon the frequency band used (i.e. 0.5-6 GHz band or 6-18 GHz band). The receiver model automatically detects from the input parameter "RFfreq" what reflections and leakage levels to use, and properly predicts the simulated port reflections and leakage. The model can predict third-order two-tone intermodulation behavior, input and output reflection coefficients and noise figure as exemplified in Figures 9 and 10 and Table 1.

For spectral analysis, spur measurements were made under narrow bandwidth settings and low noise floor. The noise floor on the spectrum analyzer was lowered to -95 dBm, and the receiver was driven up to 2 dB compression. No significant spurs were detected on the spectrum analyzer. Therefore, the model was configured to suppress all spurs (with the help of a filter module).

Conclusions

This note has presented results of a custom system level modeling project that demonstrates how a fairly complex receiver system can be reduced to a simple and accurate behavioral model within Agilent ADS. The resulting system can reproduce many relevant system linear and non-linear performance characteristics. Although not part of the scope of the described modeling effort, further improvement may be possible with the use of the X-parameters[2] approach. This could enable, for example, better accuracy in combining the described system with other non-linear system components in terms of the phase representation of various non-linear frequency components.

About this note:

Jiang Liu, Hugo Morales, and Larry Dunleavy are with Modelithics, Inc., Tampa, Florida. The authors would like to thank Marvin Marbell, now with Infineon Technologies, Rick Connick, now with TriQuint Semiconductor, previously with Modelithics for their contributions. We would also like to thank Paul Watson, of the Air Force Research Laboratory for his helpful collaboration.

Footnotes:

1 Based on a project funded by Air Force Research Laboratory, Sensors Directorate, WPAFB, OH.

2 Included in this list of model icons (as the “X2P” element) is the Agilent Technologies X-parameters file-based modeling approach, which can also be considered for modeling amplifiers, mixers , receivers and transmitters. X-parameters is a trademark of Agilent Technologies

Keeping a Gauge on PCB Thermal Effects

By John Coonrod

It is possible to avoid high-temperature-related performance and reliability problems with PCBs.

High RF/microwave signal power applied to a high-frequency printed-circuit board (PCB) will inevitably generate some amount of heat due to loss through the circuitry and the circuit material. Quite simply, higher power levels through PCB materials with higher loss will produce higher levels of heat. Operating above certain temperature levels can cause problems. For example, PCBs are characterized by a parameter known as maximum operating temperature (MOT), and the performance and reliability of any PCB can be put at risk by operating above the MOT. By understanding the thermal properties of basic RF/microwave PCBs, with help of measurements and electromagnetic (EM) models, it is possible to avoid high-temperature-related performance and reliability problems with PCBs.

Understanding how insertion loss takes place through circuit materials can help to describe some of the critical tradeoffs that are associated with the thermal performance of high-frequency PCBs. To explore some of these tradeoffs, a common example will be used, a microstrip transmission line circuit. The losses associated with this double-sided PCB construction include dielectric, conductor, radiation, and leakage losses. The amounts of the losses can vary widely, with leakage losses typically low for high-frequency PCBs, although there can be exceptions. For this article, the leakage losses will be considered minimal and will be ignored.

Radiation Losses

Radiation losses depend on a number of different circuit parameters, including operating frequency, circuit substrate thickness, PCB dielectric constant (relative permittivity or ε_r), and various design aspects. Concerning this last item, radiation losses often stem from poor impedance transitions in circuits or differences in wave propagation that can take place in a circuit. Some of the areas for concern in circuit transitions include the signal launch area, stepped-impedance points, stubs, and matching networks. When properly designed, these circuit features will exhibit smooth impedance transitions with minimal radiation losses; still, there should be an awareness of the possibility of impedance mismatches (and their associated radiation losses) taking place at any kind of a circuit junction. In terms of operating frequency, radiation losses are typically more troublesome at higher frequencies.

Circuit material issues related to radiation loss are most often the dielectric constant and the thickness of the PCB material. Thicker circuit laminates tend to have more potential for radiation loss, while PCB substrates with lower ε_r values will suffer more radiation losses than substrates with higher ε_r values. In terms of material tradeoffs, the benefits of a thin circuit laminate sometimes offset concerns with using a lower ε_r material. The thickness and ε_r of a circuit laminate will affect performance as a function of frequency, and it is generally true that a circuit laminate with thickness of 20 mils or less will usually not suffer much radiation loss below 20 GHz. For that reason, most of this article will focus on circuit models and measurements below 20 GHz, and will not consider radiation loss a concern (as related to circuit thermal issues) below 20 GHz.

By neglecting radiation loss below 20 GHz, the insertion loss of a microstrip transmission-line circuit can be considered largely due to dielectric loss and conductor loss. The ratio of the

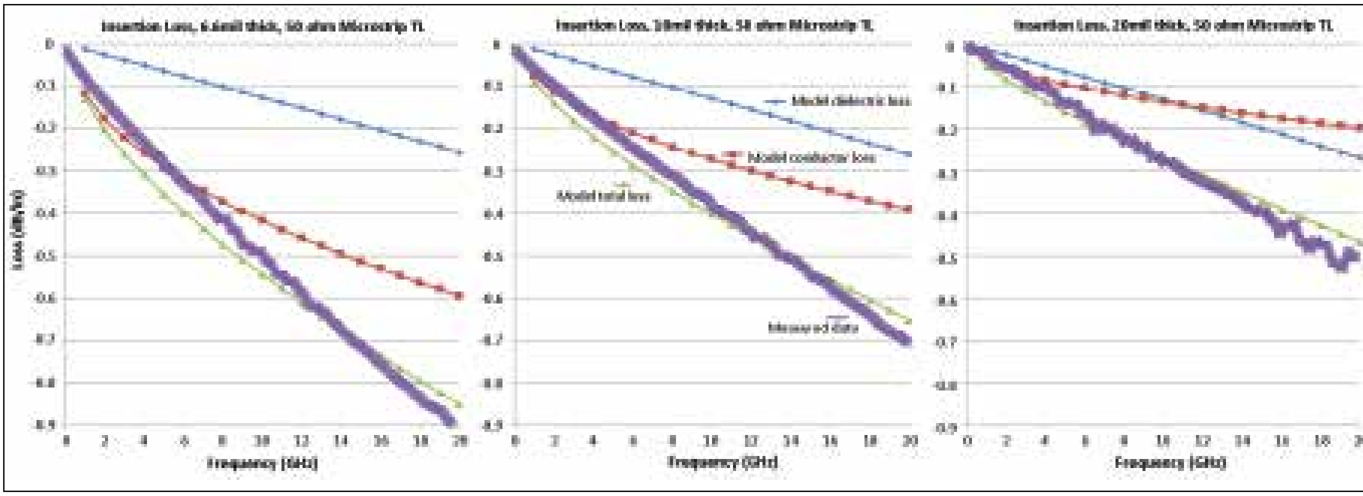

Figure 1 • Comparing 50-Ω microstrip transmission-line circuits fabricated on one type of circuit material with different thicknesses.

two losses comprising a microstrip circuit's insertion loss is based on the thickness of the circuit substrate material. For thinner substrates, conductor losses dominate. But conductor losses can be difficult to predict for a number of reasons. For one thing, the surface roughness of a conductor can have a significant impact on wave propagation properties. Not only can the copper surface roughness alter the wave propagation constant of a microstrip circuit, it can also increase conductor losses[1]. Due to skin effects, the impact of copper surface roughness has a frequency-dependent impact on conductor losses. Figure 1 compares the insertion loss of 50-Ω microstrip transmission-line circuits, fabricated on PCB materials with three different thicknesses: 6.6, 10, and 20 mils thick.

Measured and Simulated Response

The curves of Figure 1 include measured and simulated responses, with the simulations produced by means of the MWI-2010 Microwave Impedance Calculator software from Rogers Corp. The MWI-2010 software uses closed-form equations from a well-known paper on microstrip computer modeling.[2] The measured data shown in Figure 1 are from a microwave vector network analyzer (VNA) using the differential length measurement method. Relatively good correlation can be seen in Figure 1 between the total loss curves from the software models and the measured data. As the plots show, a thin circuit (the left curve based on 6.6-mil-thick material) has conductor losses that dominate the total insertion loss. A thicker circuit (the plots on the right for the 20-mil-thick circuit) shows that dielectric and conductor losses tend to be more balanced and combine to form the total insertion loss.

The models and circuits measured in Figure 1 are based on circuit material with a dielectric constant of 3.66, dissipation factor of 0.0037, and high-profile copper with a surface roughness of 2.8 µm RMS. When this same material is used with low-profile (smoother) copper, the conductor losses can be reduced significantly for the 6.6- and 10-mil circuits shown in Figure 1, but there is less benefit for the 20-mil circuits. Figure 2 shows mea-

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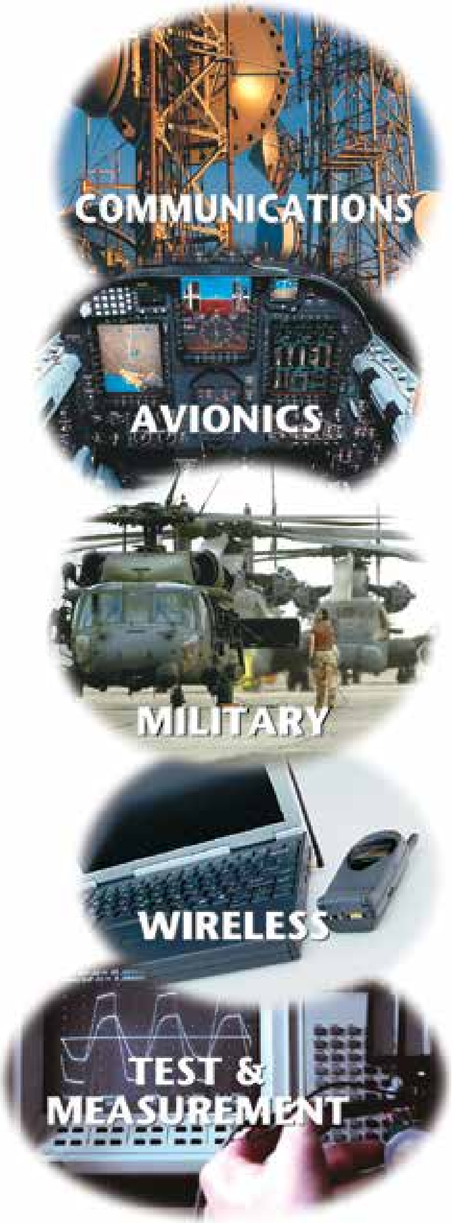

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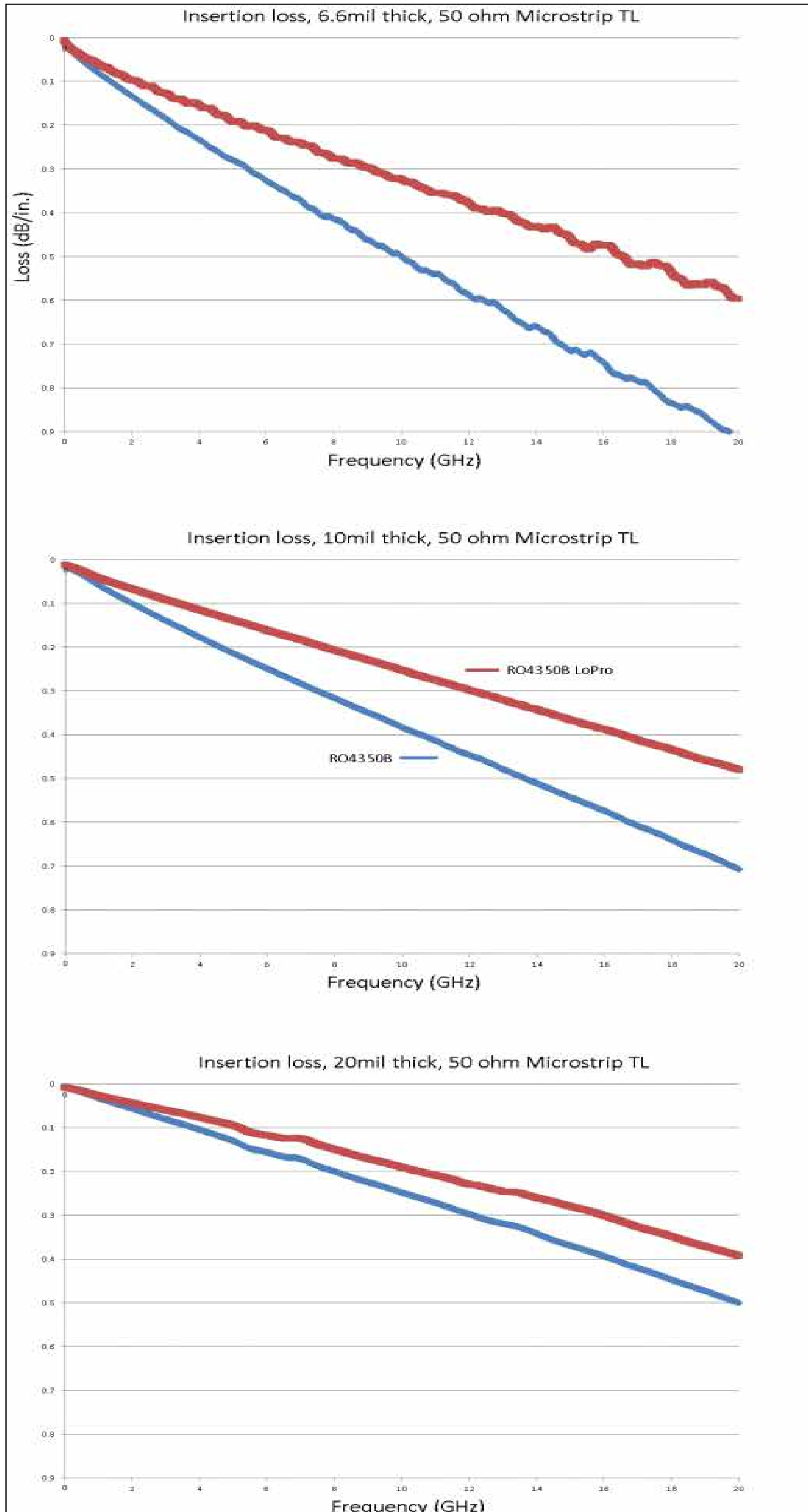

Figure 2 • These plots compare microstrip transmission lines using the same material type, but with different dielectric thicknesses and copper roughness.

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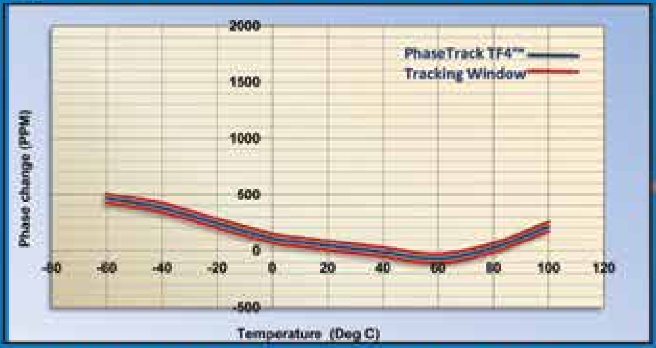

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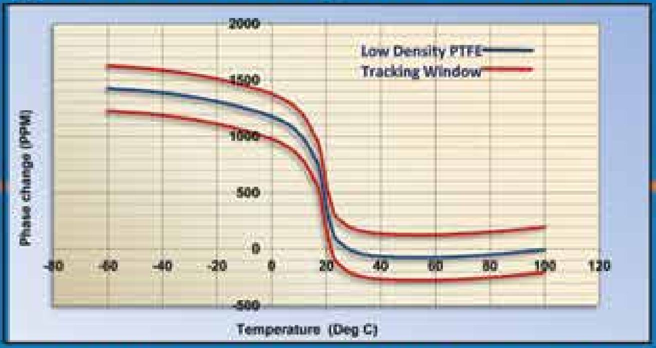

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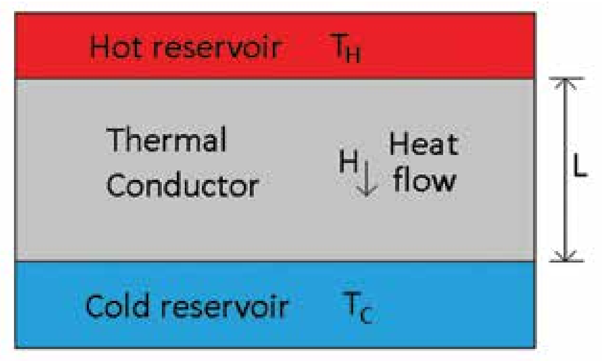
sured data of this same material with high-profile copper, which is standard RO4350B™ circuit material from Rogers Corp. and this same material with low-profile copper, which is RO4350B LoPro™ material from Rogers Corp.

Figure 2 shows the benefits of microstrip circuits fabricated on copper with a smoother surface, where the thinner laminates have a greater impact on reducing insertion loss. The 6.6-mil laminate on the left has an improvement in insertion loss of 0.30 dB at 20 GHz with the smoother copper. The 10-mil laminate has an improvement of 0.22 dB in insertion loss at 20 GHz using the smooth copper, while the 20-mil laminate (on the right) is improved by about 0.11 dB in insertion loss at 20 GHz using the smoother copper.

As shown in Figures 1 and 2, thinner circuits tend to suffer higher insertion loss, which means that they will generate more heat when sufficient RF/microwave signal power is applied. Tradeoffs to consider when addressing thermal concerns is that although a thinner circuit may generate more heat at higher power levels than a thicker circuit, it can be kept relatively cool by means of a more efficient heat flow path to a heat sink because of the thinner circuit.

For managing thermal issues, an ideal thin circuit would be based on circuit material with low dissipation factor, smooth copper, low ε_r, and high thermal conductivity. The low ε_r allows the use of a wider conductor than when using higher ε_r circuit material, which can result in reduced conductor loss. In terms of circuit thermal management, thermal conductivity is an important parameter, although most circuit substrates used in the high-frequency PCB industry are more thermal insulators than conductors, with very poor thermal conductivity.

A great deal of detail regarding the thermal conductivity of circuit laminates was reported in an earlier article,[3] and some of the information from that report will be presented here. For example, the following equation and Figure 3 are helpful in understanding the tradeoffs associated with PCB material thermal issues. In the equation, k is thermal conductivity (in W/m/K), A is area (m), T_H is the temperature (K) of the hot reservoir, T_C is the temperature (K) of the cold reservoir, and L is the distance (m) between the hot and cold reservoirs.



$$H = -k \cdot A \cdot \left(\frac{T_H - T_C}{L} \right)$$

Figure 3 • This basic thermal model can apply to a microstrip circuit, where the signal plane is assumed to be the hot reservoir and a ground plane with heat sink is assumed to be the cold reservoir.

Thermal Model

The equation with Figure 3 is a simple representation of a thermal model for a microstrip circuit. The circuit would have the signal plane as the top conductor layer and a ground plane as the bottom conductor with the dielectric substrate between these two planes. The thermal model of Figure 3 assumes that heat is generated on the signal plane and this plane serves as the hot reservoir. This is acceptable for a simple thermal model, although the heat generation in a microstrip circuit is much more complicated in reality. In the thermal model of Figure 3, the substrate serves as the thermal conductor to transfer heat from the signal plane to the ground plane, assuming that the ground plane has a heat sink and acts as a cold reservoir. In reality, the circuit substrate acting as the thermal conductor is a poor thermal conductor. To illustrate, the thermal conductivity of a good thermal conductor, copper, is about 400 W/m/K. In comparison, the thermal conductivity of most commercial PCB substrate materials is much worse (less), only about 0.2 to 0.3 W/m/K.

The heat flow equation explains why a thinner circuit (with smaller L) has improved heat flow and can achieve cooler operation under higher power levels. A substrate with improved thermal conductivity (k) will exhibit increased heat flow compared to a circuit material with poor k, providing the potential to achieve cooler operation under higher power levels.

The amount of power that can be applied to a high-frequency PCB is usually determined by knowing how hot the circuit will become with an applied RF/microwave power level. Circuit materials rated to Underwriters' Laboratory (UL) can also receive a rated thermal index (RTI), which is the maximum temperature that the PCB material can handle for an indefinite period of time without degradation of critical PCB performance parameters. When a substrate material is made into a circuit, other variables must be considered in terms of thermal management. For example, a circuit can receive an MOT rating for the maximum temperature to which it can be exposed for an indefinite period of time without degradation of critical circuit parameters. A circuit's MOT is always less than the RTI of the same circuit's PCB material.

The amount of RF/microwave power that can be applied to a PCB is based on the MOT as well as the operating environment. If the applied RF/microwave power does not heat the PCB above the circuit's MOT, it is acceptable. Still, applied power will result in circuit heating and will increase the temperature some amount above the ambient temperature. If the ambient temperature is +25°C, the heat generated by the applied RF/microwave power may not violate the MOT. But if the same power is applied to the same circuit at an ambient temperature of +50°C, it may violate the MOT and be a problem in that higher-temperature environment. As this example demonstrates, the amount of power that can be applied to a high-frequency PCB is somewhat dependent upon the operating environment.

Tradeoffs

To better understand tradeoffs in thermal issues for PCB materials, a study was conducted with 50-Ω microstrip transmission-line circuits similar to the constructions used in Figures 1 and 2. Circuits were fabricated on the same types of PCB materials but with differences in thickness and copper roughness. In addition, a circuit was evaluated on a higher-loss PCB material, as well as a tightly coupled grounded-coplanar-waveguide (GCPW) transmission-line circuit using the same low loss material as one of the other microstrip circuits. The applied RF/microwave power varied from 5 to 85 W. At 3.4 GHz, the return loss for all circuits was better than 18 dB, and all circuits were laminated to a 0.25-in. copper plate to be used as a heat sink. Circuits were laminated to the heat sinks by means of COOLSPAN® Thermally & Electrically Conductive Film. This thermoset adhesive material exhibits a thermal conductivity of 6 W/m/K.

As part of the study, an infrared (IR) camera was used to record the heat patterns of the circuits with applied power. To ensure accurate measurements, consistent color was used on all circuits and surfaces in the view of the camera. The color was a black paint with a known emissivity which the IR camera adjusts for accurate thermal imaging. Unfortunately, application of the black paint increased the insertion loss of the transmission lines, so the recorded heat rise is considered a worst-case scenario. In addition, the insertion loss (and heat rise) of the GCPW circuit was impacted to a greater degree than the microstrip circuits, since the black paint filled the gaps in the coplanar ground-signal-ground (GSG) area, which is an area of high current density.

Table 1 shows the circuits, material types and properties, insertion loss, and heat rise results of this multiple circuit/material study. It offers a great deal of information for comparing thermal effects on different circuit materials. For example, it allows a comparison of two

Circuit ID	Circuit material	Transmission line type	Dk	Df	Thermal Conductivity (W/m/K)	Copper surface roughness (RMS)	Insertion loss without black paint @ 3.4 GHz (dB/in.)	Insertion loss with black paint @ 3.4 GHz (dB/in.)	Heat rise (°C) 85W @ 3.4 GHz
1	10mil RO4350B	microstrip	3.66	0.0037	0.64	2.8	0.17	0.27	22
2	10mil RO4350B	GCPW	3.66	0.0037	0.64	2.8	0.20	0.43	27
3	20mil RO4350B	microstrip	3.66	0.0037	0.64	2.8	0.12	0.19	29
4	20.7mil RO4350B LoPro	microstrip	3.55	0.0037	0.64	0.6	0.10	0.14	22
5	20mil High Perf FR-4	microstrip	4.25	0.0200	0.25	1.4	0.36	0.37	74

Table 1 • Different circuits and materials exhibit different heat rises under similar operating conditions.

circuits based on the same circuit substrate but with two different types of copper, one with rough copper surface (circuit ID 3) and one with smooth copper surface (circuit ID 4). As expected, the circuit with smoother copper surface has lower insertion loss than the circuit with rougher copper surface, with less heat rise for the circuit with smoother copper surface than for the circuit with rougher copper surface.

Comparing circuit ID 1 with circuit ID 3 reveals the differences in heat rise with a change in PCB material thickness. These two circuits use the same material and copper type and are the same except for the thickness. Circuit ID 1 is thinner, with higher insertion loss than the thicker circuit ID 3. As noted earlier, higher insertion loss usually means higher levels of heat generated when high-enough levels of RF/microwave power are applied. However, as Table 1 shows, the thinner circuit ID 1 was actually cooler than the thicker circuit ID 3, and this is due to the shorter heat flow path, represented by parameter L in the equation with Figure 3.

Comparing circuit ID 1 and circuit ID 2 shows the use of the same circuit materials, but with different circuit configurations. Circuit ID 2 is a GCPW circuit, which is tightly coupled and with plated-through-hole (PTH) viaholes very near the coplanar ground-signal edges. Figure 4 shows the configurations for the microstrip and GCPW transmission-line circuits being compared.

Insertion Loss

The tightly coupled GCPW configuration has thermal benefits compared to the microstrip circuits. The GCPW circuit (circuit ID 2) employs a space of about 5 mils on the coplanar layer between the signal conductor in the middle and the adjacent grounds, and very near this are repetitive ground PTH viaholes. These viaholes are copper and behave as thermal paths to efficiently transfer heat from the signal plane to the ground plane. As can be seen in Table 1, the difference in insertion loss between the microstrip (circuit ID 1) and GCPW circuits (circuit ID 2) is significant. Since both of these circuits are fabricated on the same-thickness material, the circuit with the higher insertion loss should heat up much more. While the GCPW circuit does heat more than the microstrip circuit, it is not nearly as much of a difference due to the thermal benefits of the repetitive ground viaholes.

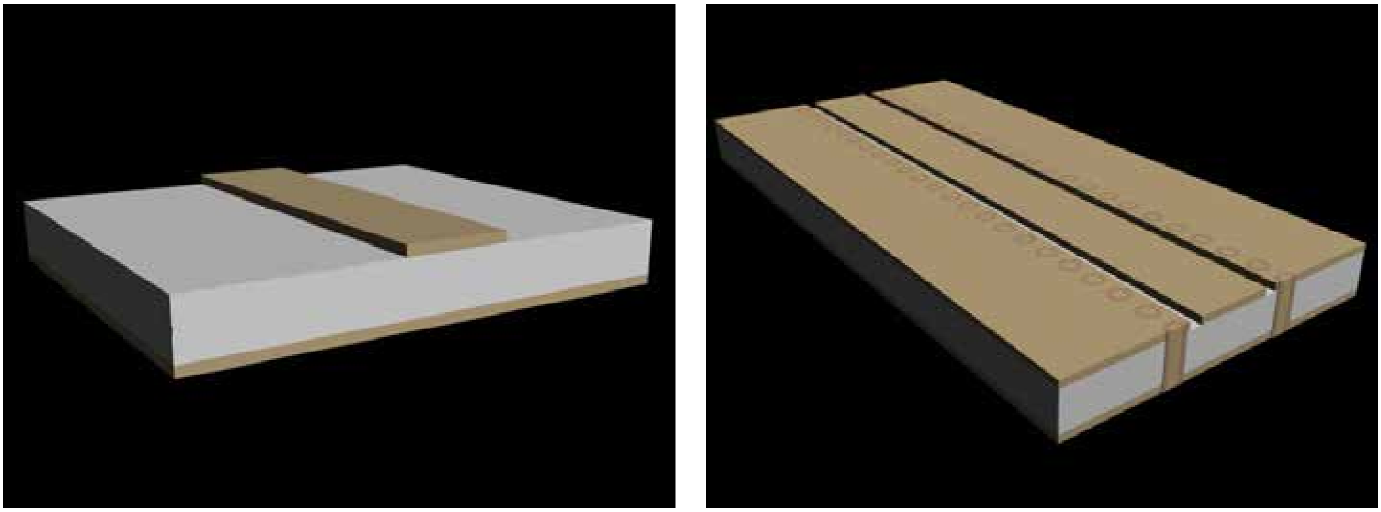


Figure 4 • The transmission-line circuits used in this thermal PCB study were mostly based on (a) microstrip configurations, although a (b) GCPW configuration was used for circuit ID 2.

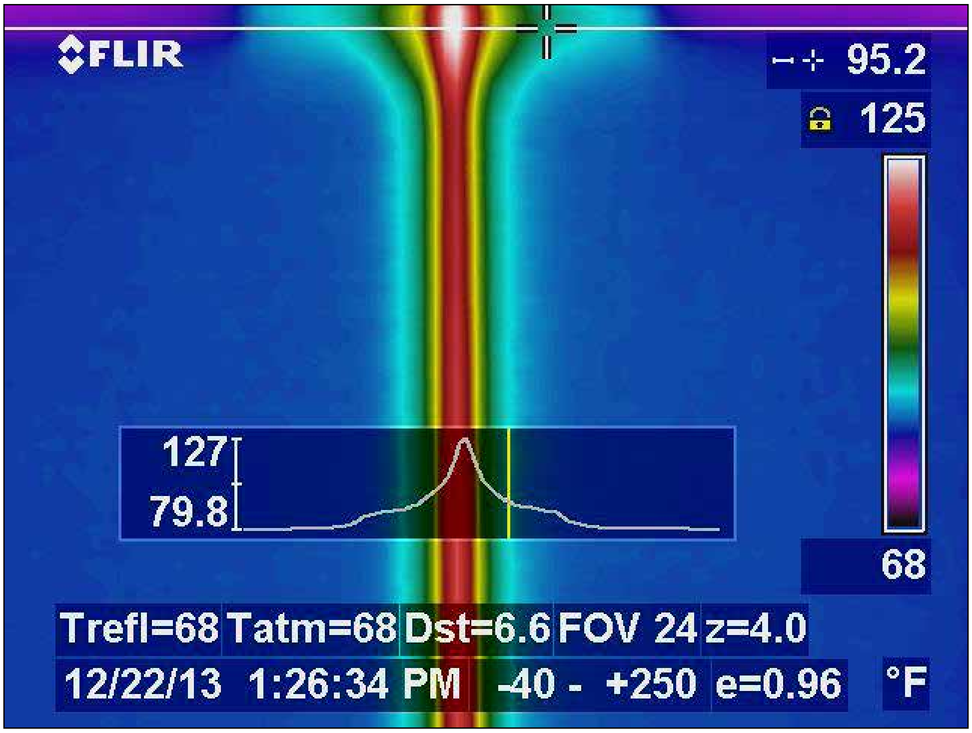


Figure 5 • This thermal image provides the top view of a microstrip transmission line, with the heat generated around the signal launch area shown at the top.

Finally, comparing circuit ID 3 and circuit ID 5 from Table 1 pits two circuits with the same 20-mil thickness, but with many other differences. Circuit ID 5 is based on low-cost FR-4 circuit material not truly intended for use at microwave frequencies, and the insertion loss for circuit ID 5 is significantly higher than that for circuit ID 3. As a result, the heat rise with applied power is much higher for circuit ID 5 than for circuit ID 3. Circuit ID 5 also suffers several shortcomings related to thermal performance, including poor dissipation factor, low thermal conductivity, and higher ε_r, which results in the conductor for the 50-Ω transmission line to be more narrow and with higher conductive loss than the conductor for the circuit ID 3 material with lower ε_r value.

For any circuit thermal study, signal launch can be an issue in attempting to transfer RF/microwave energy as efficiently as possible from an input connector to the circuit under test. For this study, all subjects used 3.5-mm end-launch connectors from Southwest Microwave (www.southwestmicrowave.com) which performed very well. As well as the circuits were designed for good signal launch, some RF/microwave energy will be lost around the signal-launch area, resulting in higher heat generated in that area. Since the connector is a good thermal conductor, some heat will be pulled away from the connector besides being drawn into the heat sink. As thermal imaging can reveal, under high-power conditions, the signal launch area for one of these test circuits tends to be hotter than the body of the microstrip circuit. Figure 5 shows the thermal image for such a case, for a circuit not part of the study in Table 1.

Figure 5 shows the thermal image of a 12-mil-thick, 50-Ω microstrip transmission-line circuit, which exhibited 0.23 dB/in. insertion loss after the black paint was applied for thermal imaging. The highest temperature in the signal launch area of this circuit was +127°F, reaching +119°F in the body of the circuit. Although this does not appear to be a large difference in temperature, it is worth noting since the signal launch area of the circuit has more heat sinking than the body of the circuit.

Conclusion

Reviewing the different components of insertion loss as well as this simple thermal model and several key circuit material properties can be useful in understanding the heating effects of high-power RF/microwave signals on high-frequency PCBs. Quite simply, a circuit material that is relatively thin, with good thermal conductivity, smooth copper and low dissipation factor, can provide the behavior needed for diminishing the heating effects of high-power RF/microwave signals on high-frequency PCBs.

About the Author:

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References:

[1] Allen Horn, III*, John Reynolds*, and James Rautio+; *Rogers Corporation, +Sonnet software, "Conductor Profile Effects on the Propagation Constant of Microstrip Transmission Lines, IEEE MTT-S, 2010.

[2] E. Hammerstad and O. Jensen, "Accurate models of microstrip computer aided design", 1980 MTT-S Int. Microwave Symp. Dig., May 1980, pp. 407-409.

[3] John Coonrod and Allen F. Horn III, "High Frequency Circuit Materials With Increased Thermal Conductivity," High-Frequency Electronics, Vol. 9, No. 11, November 2010.

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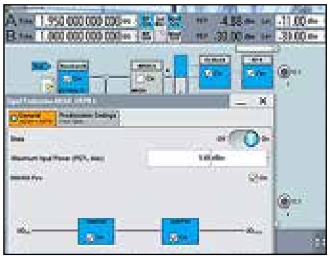


Signal Generator

The new SMW-K541 digital predistortion option allows users to import predistortion coefficient tables directly into the R&S SMW200A. The signal generator uses these delta values to adjust the baseband signal in real time. The option greatly reduces test times since predistorted waveforms no longer have to be tediously recalculated and imported into the generator.

Rohde & Schwarz
rohde-schwarz.com

Attenuator

PMI Model No. DTA-14G40G-32-CD-2 is a 10 Bit programmable attenuator with step resolution as low as 0.04 dB which provides over 32 dB of attenuation over the frequency range of 14.0 to 40.0 GHz. This model is offered in a slim line housing measuring 2.0" x 1.8" x 0.5" with 2.92 mm female connectors and operates on a single +15 VDC supply with only 40 mA of current consumption typically.

Planar Monolithics Industries
pmi-rf.com

Phase Shifter

Model P2P-61-5AR is a Broadband Digitally Controlled PIN 360 Degree Diode Phase Shifter operating from 9.5 to 10.5 GHz. The low phase noise option offers -132 dBc/Hz @ 10 kHz & -142 dBc/Hz @ 100 kHz, typical performance. This device offers up to 0.087 degree resolution with

12 BITs of TTL compatible binary logic.

G.T. Microwave
gtmicrowave.com

LNA

MITEQ Model AMF-3F-26004000-33-8P is a recent addition to its family of low noise, wideband, and ultra-small coaxial LNAs in the 26 to 40 GHz band. This LNA has over 18 dB of gain in a housing that is only 0.45 inch long and 0.75 inch wide without the field-replaceable 2.93 mm connectors.

Miteq
miteq.com

Adapters

Fairview Microwave introduced a line of mini-DIN 4.1/9.5 adapters intended for use in applications requiring low passive intermodulation (low PIM) performance such as cell sites or indoor/outdoor distributed antenna systems (DAS). Mini-DIN adapters used in RF applications are similar in design to 7/16 DIN connectors, but have a more compact body and offer more precise electrical performance.

Fairview Microwave
fairviewmicrowave.com

Frequency Extender

Model STE-SF612-03-S1 is an E band frequency extender that extends the input frequency of 10.0 to 15.0 GHz to a full waveguide bandwidth, 60 to 90 GHz operation. It combines high performance millimeter passive multipliers, amplifiers and filters to extend the low frequency sweeper or synthesizer to E band frequency band. Required input power is +3 dBm and resultant output power is +3 dBm typically.

SAGE Millimeter
sagemillimeter.com

Coaxial Circulator

Model F2585-0203-67 is an octave band SMA connectorized circulator covering 1.35 GHz to 2.7 GHz frequency range. It features 0.6 dB insertion loss, 17 dB reverse isolation, and 1.35:1 VSWR, and can handle 50 Watts of CW power. The package size of the circulator is 2.0 × 1.949 × 0.748".

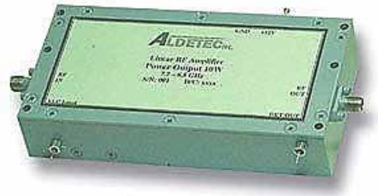
Wenteq Microwave
wenteqmicrowave.com

RF Loads

Pasternack Enterprises released new lines of medium and high power RF loads. They are commonly

used in military/aerospace, defense and test and measurement applications to protect radios and amplifiers under test from excess power in the system. They come in 25 Watt, 50 Watt and 100 Watt models and connector configurations including male and female versions of SMA, N, TNC and 7/16 DIN.

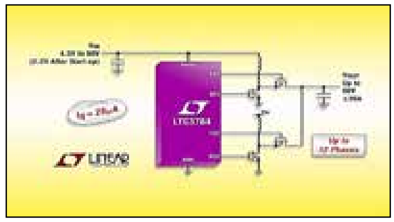
Pasternack Enterprises
pasternack.com



Microwave Amplifiers

Aldetec offers a variety of microwave amplifiers from 20 MHz to 33 GHz utilizing the latest technology to provide the highest performance available. Whether engineering prototypes or large scale programs, Aldetec has the expertise to accommodate most any amplifier requirement. We also provide full engineering support for today's complex RF and mechanical requirements.

Aldetec
aldetec.com



Controller

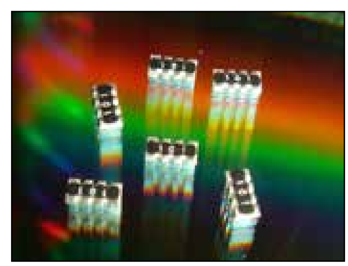
Linear Technology's LTC3784 is a high power two phase single output synchronous step-up DC/DC controller that replaces rectifying boost diodes with high efficiency N-channel MOSFETs. This device can produce a 24V output at 10A from a 12V input at up to 97% efficiency without any heat sink.

Linear Technology
linear.com

Power Amp

The HMC5879LS7 is a 4 stage GaAs pHEMT MMIC 4 Watt Power Amplifier that operates between 12 and 16 GHz. It provides 28 dB of gain, +37 dBm of saturated output power, and 22% PAE from a +7V supply. It exhibits excellent linearity and is optimized for high capacity digital microwave radio. It is also ideal for 13.75 to 14.5 GHz Ku Band VSAT transmitters as well as SATCOM applications.

Hittite Microwave
hittite.com



Resistors

RAVF Series convex thick film chip resistor arrays offer a wide variety of sizes, power ratings and schematics to help engineers reduce the amount of board space required by their designs. Changing from discrete chip resistors to chip arrays can reduce the size of a circuit design by up to 40% as well as a 20% reduction in weight.

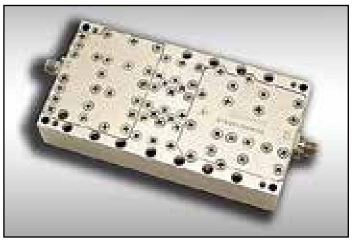
Stackpole Electronics
seielect.com

EMI White Paper

RFMW announced a new white paper explaining the properties and

advantages of various conductive rubber materials for use in RFI/EMI mitigation. The paper highlights three common material types; Multicon, Conductive Elastomer and Radthin. Process techniques are outlined with links to additional information.

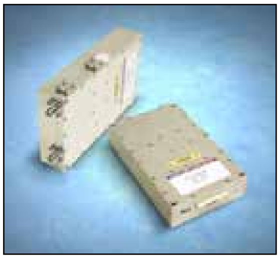
RFMW
rfmw.com



Doubler

SYS2H1324N01X microwave doubler is ideally suited for local oscillator drive into wideband microwave mixers. This doubler utilizes three internally switchable bands; 13.9 to 16.9, 16.9 to 20.5, and 20.5 to 24.9 GHz. Internal high rejection filters allow for 60 dBc suppression of input related harmonics with respect to the output utilizing the potential of a high dynamic range mixer.

Miteq
miteq.com



Synthesizers

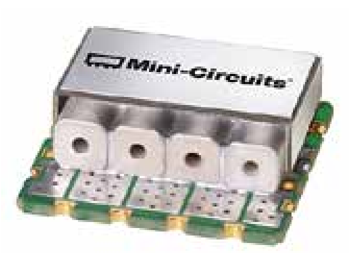
The MLSP-Series of YIG-Based wideband synthesizers are ideal as the main local oscillators in receiving systems, frequency converters and test and measurement equipment. They provide 1 kHz frequency resolution over the 18 to 33 GHz frequency range, in bands. Power levels of +13 dBm are provided and full band tuning speed is 6 mSec. The units are 5” x 3” x 1” high and fit a 2 slot PXI chassis.

Micro Lambda Wireless
microlambdawireless.com

Multiplier

Model SFA-183403220-KFSF-S1 is a broadband X2 active multiplier with output frequency covering 18 to 40 GHz. With an RF input signal from 9 to 20 GHz and power level of +3 dBm, it can deliver +20 dBm power in the frequency range of 18 to 40 GHz. The harmonic suppression is -20 dBc. It draws 420 mA current from a +8 Vdc DC power supply. The input connector is SMA (F) and output is K(F) connector.

SAGE Millimeter
sagemillimeter.com



Filter

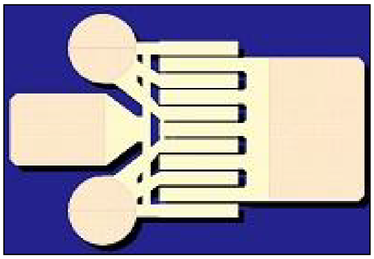
Mini-Circuits’ CBP-1250C+ is a ceramic-coaxial-resonator based bandpass filter in a shielded package fabricated using SMT technology. This filter operates from 1215 to 1285 MHz and offers outstanding close in rejection, low insertion loss and high power handling for use in aviation, mobile radio, broadband and fixed wireless.

Mini-Circuits
minicircuits.com

Phase Shifter

RFMW announced support for the Telemakus TEP2000-4 digital phase shifter. It has a minimum phase range of 360 degrees with 12-bit, 0.25 degree resolution and operates over the bandwidth of 1 to 2 GHz. Maximum RF input for linear operation is +6 dBm but the device can handle up to +20 dBm. Typical insertion loss through the TEP2000-4 is only 4 dB.

RFMW
rfmw.com



Simulation Models

Advanced non-linear simulation models for 14 TriQuint GaN transistors are now available for free (upon TriQuint approval) from the Modelithics website. Models are available for TGF2023-2 series of GaN die transistors, plus nine packaged transistor devices. Features include scaling of operating voltage, bias testing, temperature effect simulation, and internal node access.

Modelithics
modelithics.com

Battery Switch

Vishay Intertechnology introduced a 6.5 mΩ bidirectional battery switch with slew rate control for low-voltage battery isolation in portable electronics and instrumentation. Designed to save 91 % PCB space compared to using discrete MOSFETs in these applications, the Vishay Siliconix SiP32101 combines low on-resistance and ultra-low quiescent current in a compact 12-bump WCSP package.

Vishay Intertechnology
vishay.com

Circulator

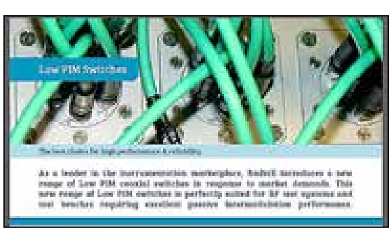
VidaRF offers 0.700-1.000 GHz coaxial circulator model VCC-07010-1 which has a rugged 2 piece body with S/Steel SMA connectors, sealed and painted black. Isolation 17 dB min, insertion loss of 0.6 dB or less, VSWR of 1.35:1, temp -10 to +70 C.

VidaRF
vidarf.com

Scanner

The R&S TSME is an ultracompact drive test scanner for wireless communications standards and frequency bands. Measuring just 151 mm x 47 mm x 93 mm and weighing just 650 g, it consumes very little power, making it ideal for testing communications channels in the field as well as inside buildings where high data traffic presents a difficult set of problems.

Rohde & Schwarz
rohde-schwarz.com



Switches

RFMW announced support for a new line of Low PIM (Passive Intermodulation) coaxial switches from Radiall. The rapid growth of 4G/LTE networks has led to the need for better performing Low PIM devices. As a result, Radiall developed a broad series of switches including the following configurations: SPDT, DPDT, SP4T, and SP6T.

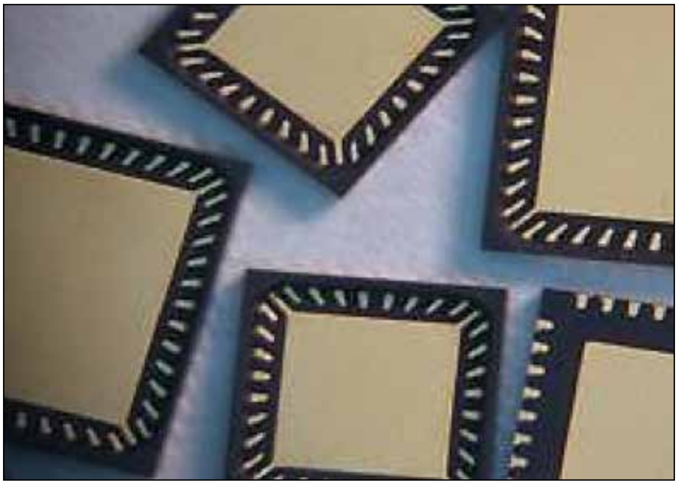
RFMW
rfmw.com

Transformer

Mini-Circuits' TCM4-452X+ surface mount RF transformer features: wide bandwidth 20 to 4500 MHz; balanced transmission line; good return loss; aqueous washable. Applications: PCS; wideband push-pull amplifiers; cellular.

Mini-Circuits
minicircuits.com

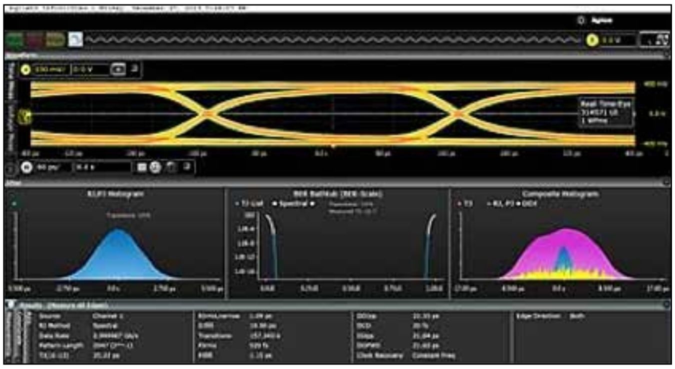
PRODUCT HIGHLIGHTS



QFN Package

Quik-Pak's exclusive Open-molded Plastic Package (OmPP) is a pre-molded, air cavity QFN package (Quad Flat No-Lead) designed to provide a high quality, fast solution for your IC packaging and assembly needs. These Open-molded Plastic Packages (OmPP) come in a variety of sizes and are ideal for prototype, mid volume or production volume applications.

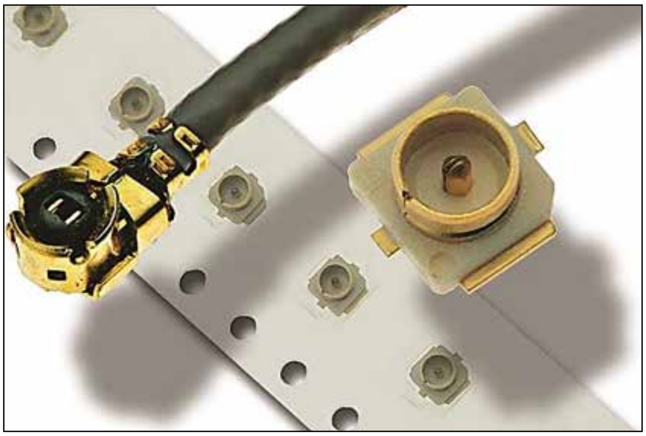
Quick-Pak
icproto.com



Oscilloscope

Agilent Technologies announced a next-generation user interface for its Infiniium real-time oscilloscopes. It is the first to take advantage of new display technologies and significantly enhance the user experience by offering faster documentation, personalized viewing and improved usability. The new interface allow engineers to easily manipulate their data across multiple monitors and move windows, charts and measurement results to where they want them on the screen.

Agilent Technologies
agilent.com



Interconnect System

Delta Electronics Manufacturing Corp.'s new MHF/U.FL series data sheet details the company's latest ultra-miniature coaxial interconnect system that operates from: DC-6 GHz. This connector interface was developed for applications in small form factor wireless mobile electronic devices. Full detail is provided on how to specify a MHF/U.FL cable assembly or "pigtail" assembly, including compatible coaxial cables and alternate end interfaces.

Delta Electronics
deltarf.com

Product Highlights

HDOs

HDO4000-MS and HDO6000-MS high definition oscilloscopes combine 16 channels of flexible mixed signal capabilities with HD4096 high definition technology, long memory, and a compact form factor, in bandwidths from 200 MHz to 1 GHz. All HDO models sport a large 12.1" touch-screen display and intuitive interface to enhance operation.

Teledyne LeCroy
teledynelecroy.com

Oscilloscope

2510 Series handheld digital storage oscilloscopes feature four units that include 60 MHz and 100 MHz bandwidth models in non-isolated and isolated designs. Suitable for general electronics, models 2511 and 2512 provide non-isolated 300 V CAT II rated inputs. For industrial applications, models 2515 and 2516 provide two fully isolated 1,000 V CAT II / 600 V CAT III rated inputs.

B&K Precision
bkprecision.com

Connector

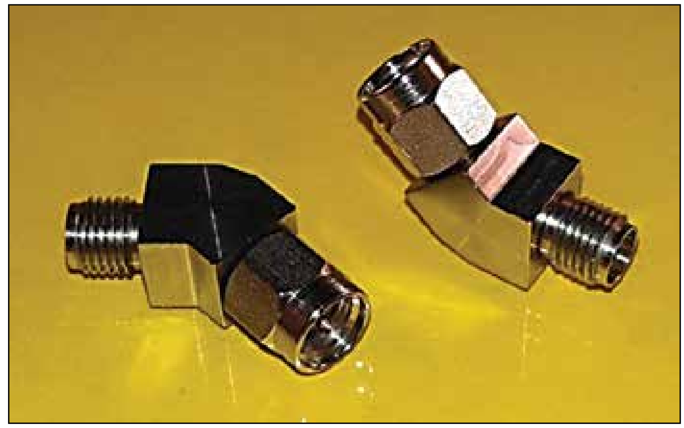
Molex introduced the Mega-Fit power connector, a wire-to-board, mid-range product line that fills a significant power void by delivering 23.0A in a small 5.70mm footprint. The compact design paired with the high current terminals provide one of the most power dense connectors in the industry. These feature-rich connectors are ideal for networking and telecommunications.

Molex
molex.com

USB Spectrum Analyzer

The Signal Hound BB60A Real-Time Spectrum Analyzer and RF Recorder employs a USB 3.0 SuperSpeed link to stream 140 MB/sec of digitized RF data to your PC, 14-bit samples at 80 million samples per second, with 20 MHz of useable bandwidth. As a spectrum analyzer, its proprietary Application Programming Interface performs up to 1.2 million FFTs every second, delivering real-time spectrum data to our Graphical User Interface (GUI), or to your own software application.

Signal Hound
signalhound.com



Between-Series Adapter

SGMC Microwave's SMA Male to SMA Female 45 Degrees Between-Series Adapter features: Frequency Range: DC - 26.5 GHz; Low VSWR and Insertion Loss (1.25:1 Max VSWR); Corrosion Resistant 303 Stainless Steel (Passivated); Rugged Construction for repeatability and reliability.

SGMC Microwave
sgmcmicrowave.com

Analyzer Extender

Model STN-SF908-00-P2 is an F band scalar network analyzer extender that covers the frequency range of 90 to 140 GHz. It offers an alternative way to achieve millimeter-wave scalar measurement at low cost without losing functionalities and features. The scalar network analyzer extender utilizes an X9 frequency extender (STE-SF908-00-S1) to extend the measurement range from 10.0-15.56GHz to 90-140 GHz.

SAGE Millimeter
sagemillimeter.com

eCall Test Setup

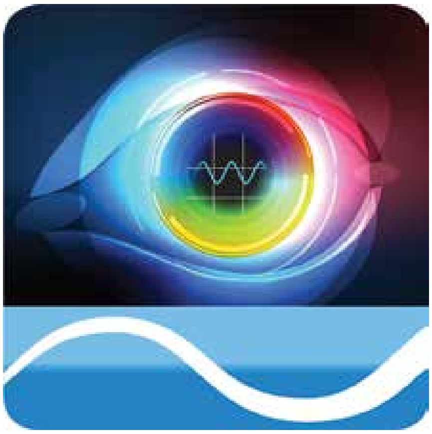
Rohde & Schwarz's compact eCall test solution for in-vehicle emergency call systems consists of the R&S CMW500 wideband radio communication tester and the R&S SMBV100A vector signal generator with integrated global navigation satellite system (GNSS) simulator. This setup allows suppliers of automatic in-vehicle system (IVS) to perform reliable and reproducible end-to-end conformance tests on their eCall modules.

Rohde & Schwarz
rohde-schwarz.com

Oscilloscope Software

Pico Technology released a beta version of the PicoScope 6 oscilloscope software for Linux. PicoScope 6 converts a PC into an oscilloscope, FFT spectrum analyzer, and measuring device. On-device buffering, using deep memory on some devices ensuresthe display is updated frequently and smoothly. The most important features from PicoScope for Windows are included: scope, spectrum and persistence modes; interactive zoom; simple, delayed and advanced triggers; and more.

Pico Technology
picotech.com



Software

Agilent Technologies introduced BenchVue, intuitive, easy-to-use software for the PC that provides multiple-instrument measurement visibility and data capture with no programming necessary. Enabling easy viewing, capturing and exporting of measurement data and screen shots, this no-cost software greatly accelerates testing for engineers and technicians in design and validation.

Agilent Technologies
agilent.com

mmW Radio Link

MIMOtech launched StarLink 60G, a fully-integrated millimeter-wave radio link optimized for short-range small-cell backhaul in urban network deployments. The StarLink 60G operates in the 57 - 66 GHz frequency band (V-band), providing cost-effective high-capacity wireless point-to-point Gigabit Ethernet connectivity for network operators and service providers.

MIMOtech
mimotechnology.com

Signal Sources

The SC5502A and SC5503A are 10 GHz synthesized CW signal sources with instrument-grade performance in very compact sizes. To meet demanding low phase noise applications, these sources incorporate multiple phase-locked loop architectures with YIG oscillators at the heart of their synthesizers, and they employ automatic leveling control (ALC) circuits to ensure precise amplitude control over frequency and temperature.

SignalCore
signalcore.com

Advanced Video Filters

LadyBug Technologies' latest LB480A RF power sensor filters and bandwidth option offers a broad selection of video filters suitable for various RF and microwave modulation applications. The filters include a selection of nine frequencies between 100 kHz and 10 MHz. The filters are ideal for honing in on your specific modulated signal or reducing noise that is not associated with the desired video information.

LadyBug Technologies
Ladybug-tech.com

Product Highlights

LNA

Mini-Circuits' CMA-545G1+ is an E-PHEMT based low noise MMIC amplifier operating from 0.4 to 2.2 GHz with a unique combination of low noise and high IP3, making it ideal for sensitive receiver applications. It operates on a single +5V supply and is internally matched to 50 ohms. It is bonded to a multilayer integrated LTCC substrate and then hermetically sealed under a controlled nitrogen atmosphere with gold-plated covers and eutectic AuSn solder.

Mini-Circuits
minicircuits.com

Isolators/Circulators

VidaRF offers a wide selection of isolators and circulators designed to cover 80 MHz to 90 GHz. Configured to coaxial, drop-In, surface mount or waveguide. Standard connector SMA female, other connectors available upon request. Magnetically shielded, clockwise or counter-clock wise rotation (CCW), LOW IMD -80 dBc, reflected power from 1(W) to 250(W) on pending models, single or double junction and RoHS compliant.

VidaRF
vidarf.com

Oscilloscope

Tektronix announced the MDO3000 Series of Mixed Domain Oscilloscopes. The ultimate integrated oscilloscope that includes a spectrum analyzer, logic analyzer, protocol analyzer, arbitrary function generator and digital voltmeter, the MDO3000 clears the design bench of costly, specialized equipment and provides the tools needed to test and debug virtually any embedded design.

Tektronix
tektronix.com

Product Highlights

Measurement Software

Agilent's latest X-Series measurement software application provides comprehensive RF conformance testing of LTE-Advanced FDD and TDD transmitters and components to the 3GPP Release 11 specification. It is available for both benchtop and modular products. The new measurement application provides one-button measurements for Agilent's X-Series and modular signal analyzers.

Agilent Technologies
agilent.com

Transceiver

National Instruments announced the NI PXIe-5646R vector signal transceiver with 200 MHz of RF bandwidth, making it ideal for testing the latest wireless standards such as IEEE 802.11ac, 160 MHz WLAN and LTE Advanced. Engineers can use its open software design to develop channel emulation systems, radio prototyping, custom real-time signal processing for spectrum analysis, and many other applications.

National Instruments
ni.com

Digital Oscilloscope

The new R&S RTE digital oscilloscope is available with bandwidths from 200 MHz to 1 GHz. An acquisition rate of more than one million waveforms per second helps users find signal faults quickly. The scope's highly accurate digital trigger system with virtually no trigger jitter delivers highly precise results. The single-core A/D converter with more than seven effective bits (ENOB) almost completely eliminates signal distortion.

Rohde & Schwarz
rohde-schwarz.com

Power Amp

Comtech PST announced the release of a solid state Class "AB" linear amplifier which operates over the full 2000 - 6000 MHz frequency band and delivers a minimum of 50 watts. The amplifier uses the latest Gallium Nitride (GaN) technology and is housed in a relatively small package measuring only 7.5" x 3.0" x 1.5" (excluding connectors).

Comtech PST
comtechpst.com

Filter

Spacek Labs' model HPF-700 is a waveguide high pass filter in WR-12 waveguide. This filter series is designed with a sharp cut off close to the passband. This filter will pass all of E-Band down to 71 GHz with an insertion loss of 1.5 dB typ and 2 dB max. The reject band is </= 68 GHz, with 20 dB rejection at 68 GHz and 40 dB at </=67 GHz. Spacek Labs offers this HPF series of filters up to 110 GHz.

Spacek Labs
spaceklabs.com

Microwave Antennas

RFS introduced the industry's most compact and lightest 3ft microwave antennas to overcome backhaul challenges and reduce total cost of ownership. The antennas are available in single-polarized and dual-polarized configurations for 6 GHz to 25 GHz frequencies and include three wideband models. Additionally, CompactLine® EASY microwave antennas provide best-in-class radiation patterns that reduce interference and enable easier configuration.

Radio Frequency Systems
rfsworld.com

Bias-T

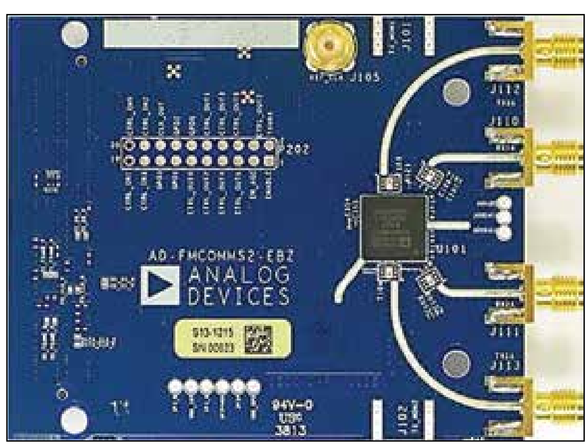
The AR Modular RF new model "AR-RBT" Remote Bias-T combines RF signals and DC power onto a single coax cable. This allows a warfighter to use his single KMW1031 (20 watt), AR-50 (50 watt) or AR-75 (75 watt) power amplifier to be boldly located remotely using a single RF coax cable. The new model "AR-RBT" Bias-T therefore eliminates the need to transport multiple heavy copper DC power lines to the remote amplifier.

AR Modular RF
arworld.us

High Power Amp

Aethercomm Model Number SSPA 7.6-7.8-150 is a high power, Gallium Nitride (GaN) amplifier that operates from 7600 MHz to 7800 MHz minimum and is packaged in a small, rugged enclosure. This X Band GaN power amplifier is smaller, more efficient and offers higher power than a conventional GaAs FET power amplifier. It is designed for operation in combat environments and is deployed on U.S. Military Ground Vehicles.

Aethercomm
aethercomm.com



SDR Platforms

Analog Devices announced two software-defined radio (SDR) platform solutions for defense electronics and RF instrumentation. The AD-FMCOMMS4-EBZ is a transceiver FMC module that includes the new AD9364 RF Transceiver IC in a cost-effective 1 x 1 SDR rapid prototyping FMC module. The AD-FMCOMMS3-EBZ was engineered for 70 MHz to 6 GHz wideband tuning applications such as hand-held and whitespace radios.

Analog Devices
analog.com

Product Highlights: Defense Electronics

EMC Test

Signal Antenna Systems markets an EMC test system for 20 - 220 MHz, with 10 kw compact LPA, shown on 2 - 4 m. adjustable height, roll-around dielectric crank-up mast. Mast is capable of polarization change from H to V, and up to 15 deg. forward tilt. SAS produces state of the art antennas and related systems for military and commercial applications in the frequency range 0.01 - 13 GHz.

Signal Antenna Systems
signalantenna.com

Graphics Display Card

Curtiss-Wright Corp.'s Defense Solutions division has begun shipping its highest performance embedded graphics module, the new VPX3-716 3U OpenVPX™ multi-head graphics display card, the first based on the next generation AMD Embedded Radeon™ E8860 "Adelaar" GPU. The rugged VPX3-716 module is designed for use on deployed airborne and ground vehicle platforms and meets the long lifecycle availability required for military programs.

Curtis Wright Controls
cwcdefense.com

Serial Radio

FreeWave Technologies' 3.4 GHz serial radio provides outstanding performance and versatility in a small footprint that is ideal for OEM applications. The board level 3400 SMR radio offers a cost effective solution that allows customers to incorporate wireless communications into a wide variety of applications. With more interface options available, a surface mount design and no additional RF shielding, the product has tremendous flexibility.

Freewave Technologies
freewave.com

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KEYNOTE

How Data, Devices and Personalization are Fueling Demand for Innovation

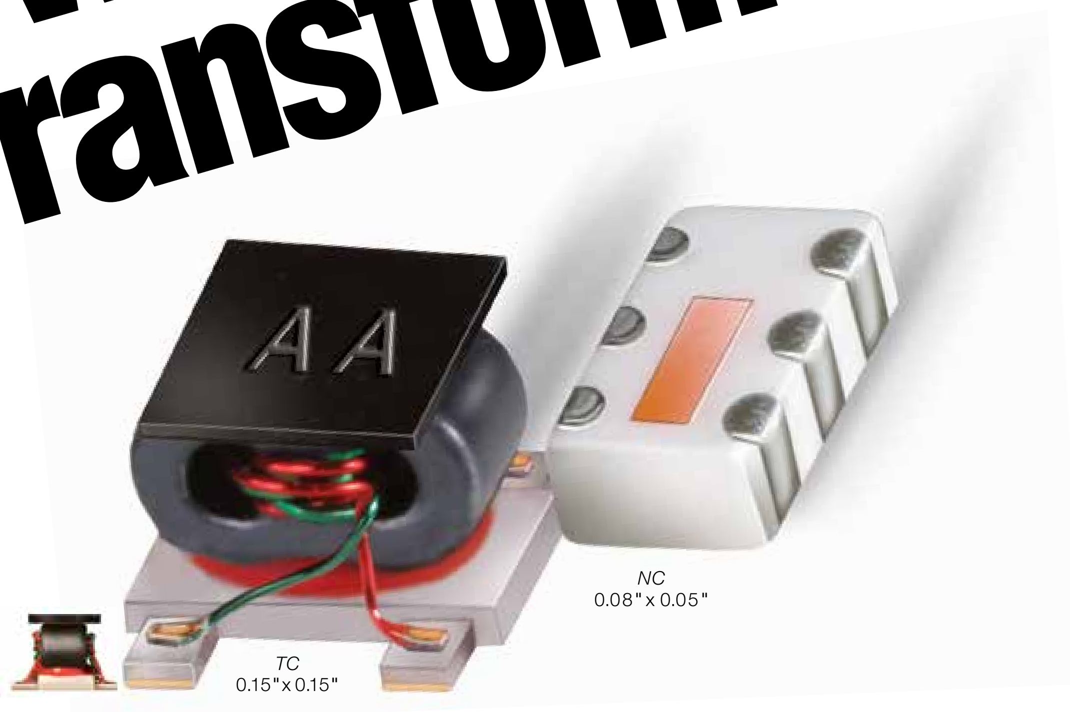
intel

Vida Ilderem - *Vice President, Intel Labs; Director, Integrated Computing Research, INTEL CORPORATION*

Vida Ilderem is Vice President of Intel Labs and Director of the Integrated Computing Research [ICR] for Intel Corporation. ICR explores the next revolution in computing with focus on new emerging platforms. The research vectors include breakthrough technology innovations for seamless connection, highly integrated small form factors, and enablement of Internet of Things. Prior to joining Intel in 2009, Vida served as vice president of Systems and Technology Research at Motorola's Applied Research and Technology Center. Vida holds a PhD in Electrical Engineering from Massachusetts Institute of Technology, and has 27 issued patents.

TINY

Wideband Transformers



0.15-8000 MHz *as low as* **99¢** *each (qty. 1000)* RoHS compliant.

Rugged, repeatable performance.
At Mini-Circuits, we're passionate about transformers. We even make own transmission line wire under tight manufacturing control, and utilize all-welded connections to maximize performance, reliability, and repeatability. And for signals up to 8 GHz, our rugged LTCC ceramic models feature wrap-around terminations for your visual solder inspection, and they are even offered in packages as small as 0805!

Continued innovation: Top Hat.
A Mini-Circuits exclusive, this new feature is now available on every open-core transformer we sell. Top Hat speeds customer pick-and-place throughput in four distinct ways: (1) faster set-up times, (2) fewer missed components, (3) better placement accuracy and consistency, and (4) high-visibility markings for quicker visual identification and inspection.

More models, to meet more needs
Mini-Circuits has over 250 different SMT models in stock. So for RF or microwave baluns and transformers, with or without center taps or DC isolation, you can probably find what you need at minicircuits.com. Enter your requirements, and Yoni2, our patented search engine, can identify a match in seconds. And new custom designs are just a phone call away, with surprisingly quick turnaround times gained from over 40 years of manufacturing and design experience!

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Now! 279 ~~236~~ models in stock

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At the other end of the scale, our new connectorized air-line couplers can handle up to 250W and frequencies as high as 12 GHz, with low insertion loss (0.2 dB @ 9 GHz, 1 dB @ 12 GHz) and exceptional coupling flatness! All of our couplers are RoHS compliant. So if you need a 50 or 75 Ω, directional or bi-directional, DC pass or DC block coupler, for military, industrial, or commercial applications, you can probably find it at minicircuits.com, and have it shipped today!

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