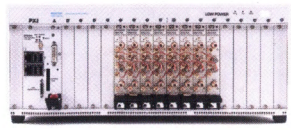
NSIDE TRACK
ith Rogers Corp.'s
rt Aquayo | 32



PXI/PXIe VNAs
Reach 26.5 GHz | 86



microwaves&rf

CTOBER 2014 TRUSTED ENGINEERING RESOURCE FOR OVER 50 YEARS www.mwrf.com

ENGINEERING BY THE numbers

2014 ENGINEERING SALARY SURVEY

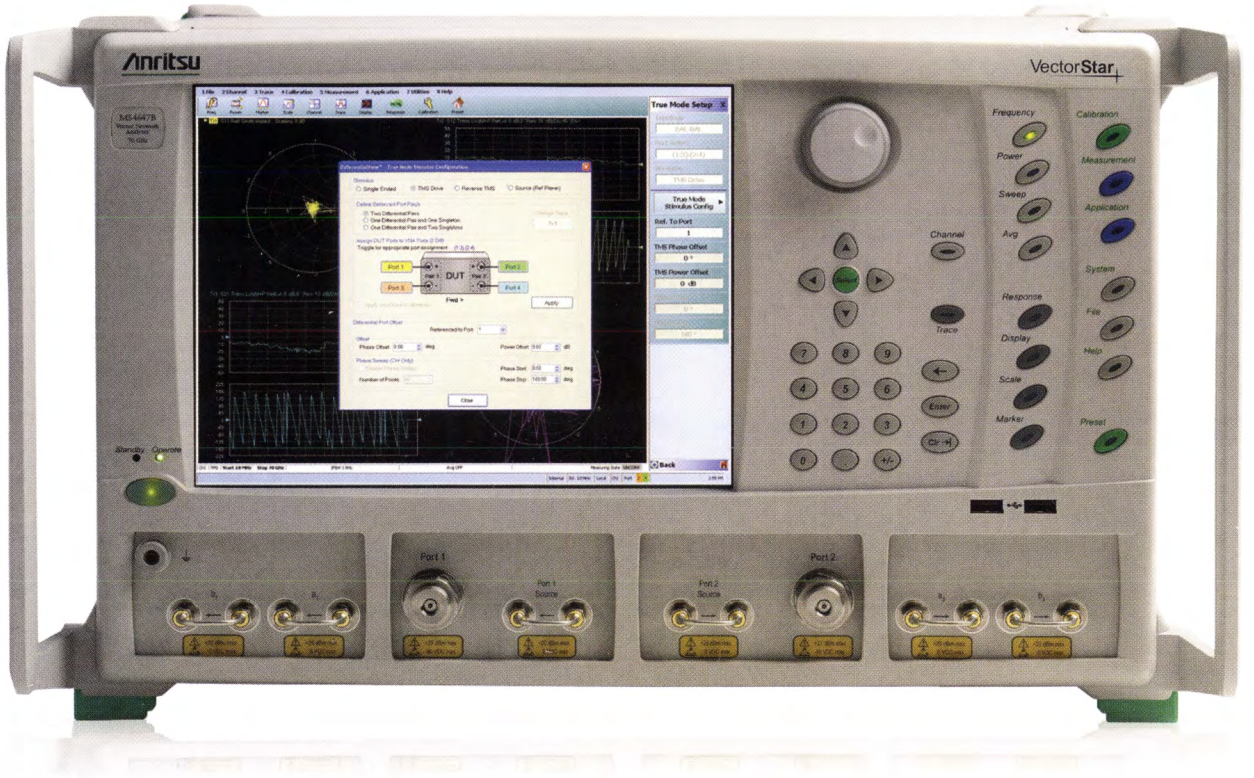
SEARCH PARTS FAST
sourceesb
Search Parts
Part # Manufacturer

$10.00 A Penton® Publication Periodicals Postage Paid • USPS 100 Approved Poly

Vector Network Analysis

Since 1895

MS4640B



VectorStar™ now with DifferentialView™

True mode stimulus capability with non-linear devices.

VectorStar's industry-leading low frequency measurement capability to as low as 70 kHz, coupled with single sweep frequencies to as high as 145 GHz, ensures that simulation-busting DC-extrapolation and causality issues are minimized so that your simulations match reality.

Get the true view. Download our complimentary white paper,
Overcoming High-Speed Interconnect Challenges

Learn more: www.anritsu.com/en-us/VectorStarMWRF

1-800-ANRITSU
www.anritsu.com
© 2014 Anritsu Company

Designed and Manufactured in U.S.A.

Anritsu
envision : ensure

Planar Monolithics Industries, Inc.

Offering State-Of-The-Art RF and Microwave Components & Integrated Assemblies From DC to 40GHz

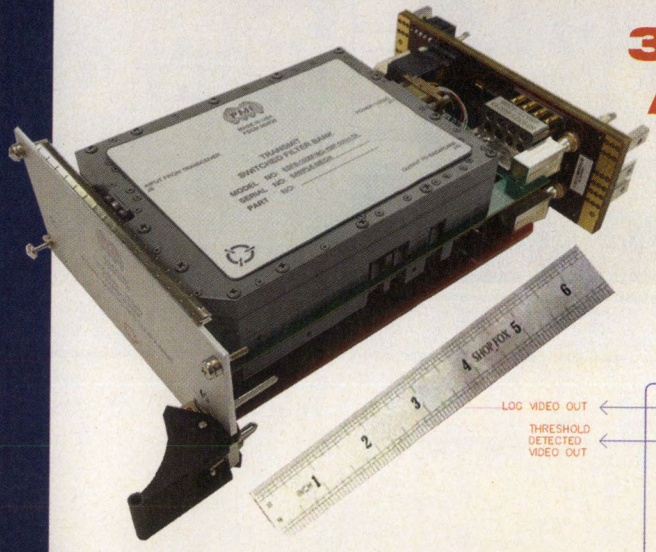
- Amplifiers
- Attenuators - Variable
- DLVA & ERDLVA & SDLVA's
- DTO's & Frequency Synthesizers
- Filters
- Form, Fit & Function Products
- IFM's & Frequency Discriminators
- Integrated MIC/MMIC Modules
- I/Q Vector Modulators
- Limiters & Detectors
- Log Amplifiers
- Pulse & Bi-Phase Modulators
- Phase Shifters
- Rack & Chassis Mount Products
- Receiver Front Ends & Transceivers
- Single Sideband Modulators
- SMT & QFN Products
- Solid-State Switches
- Switch Matrices
- Switch Filter Banks
- Threshold Detectors
- USB Products

ASSOCIATION OF OLD CROWS
Booth #711
October 6 - 9

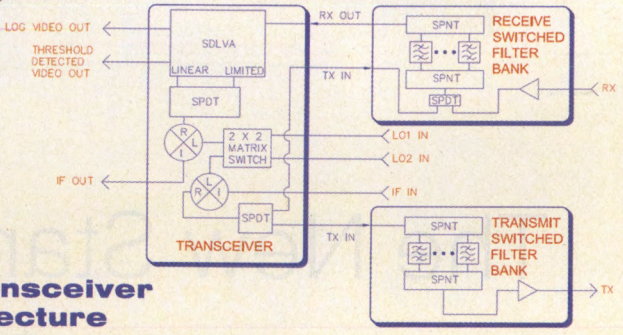
WASHINGTON, D.C. ★ OCTOBER 6-9, 2014
51ST ANNUAL AOC INTERNATIONAL SYMPOSIUM & CONVENTION

ANTENNA MEASUREMENT TECHNIQUES ASSOCIATION
2014 TUCSON
Booth #30
Tucson, Arizona
October 12 - 17

100MHz to 18GHz Transceiver
3U Open VPX Architecture



Simplified Functional Block Diagram



- 0.1 to 18.0 GHz Transceiver
- 3U Open VPX Architecture
- VITA 67 RF Interface
- Up to 4GHz Instantaneous Bandwidth
- Customizable Switched Filter Banks
- BIT Test Mode for Closed Loop Testing
- Linear & Limited RF, SDLVA Output Channels
- Log & Threshold Video SDLVA Output Channels
- Time Gated SDLVA's for Pulse Blanking
- CW Immunity
- Input Selection for Two Independent LO frequencies (4 to 20GHz)
- -80 to +10dBm Input Power Range
- IF Frequency of 100MHz to 4.0GHz
- LVDS Control Logic
- Ruggedized Construction for Military Applications
- 160mm x 100mm x 12HP per VITA 46 Standards (6.299" x 3.937" x 2.388")

West Coast Operation:
4921 Robert J. Mathews Pkwy, Suite 1
El Dorado Hills, CA 95762 USA
Tel: 916-542-1401 Fax: 916-265-2597
ISO9001:2008 REGISTERED
Email: sales@pmi-rf.com

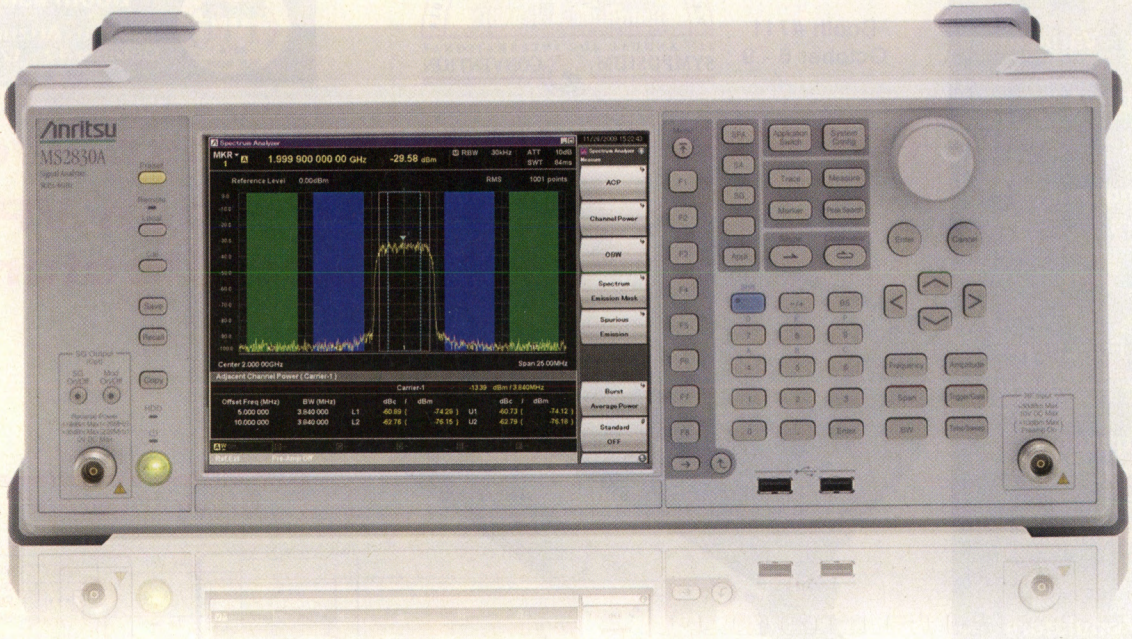
East Coast Operation:
7311-F Grove Road
Frederick, MD 21704 USA
Tel: 301-662-5019 Fax: 301-662-1731
ISO9001:2008 REGISTERED
Website: www.pmi-rf.com

Hermetic Sealing, High Reliability to Mil-Std-883, Small Quantity Requirements accepted & we offer Custom designs too.

Spectrum/Signal Analyzers

Since 1895

MS2830A



The New Standard

ONE Box, Many Uses, ONLY from Anritsu.

The MS2830A Signal Analyzer from Anritsu – smart, innovative design at its best. A Spectrum Analyzer, Signal Analyzer and Signal Generator, this single chassis has the unique ability to meet varying test needs efficiently.

FREE Guide to Spectrum Analysis www.goanritsu.com/2830MRF10

1-800-ANRITSU

www.anritsu.com

© 2014 Anritsu Company

Anritsu

envision : ensure

NARDA

Celebrating **60 Years!**



60TH ANNIVERSARY narda an L3 company SERVICE • SUPPORT • SELECTION

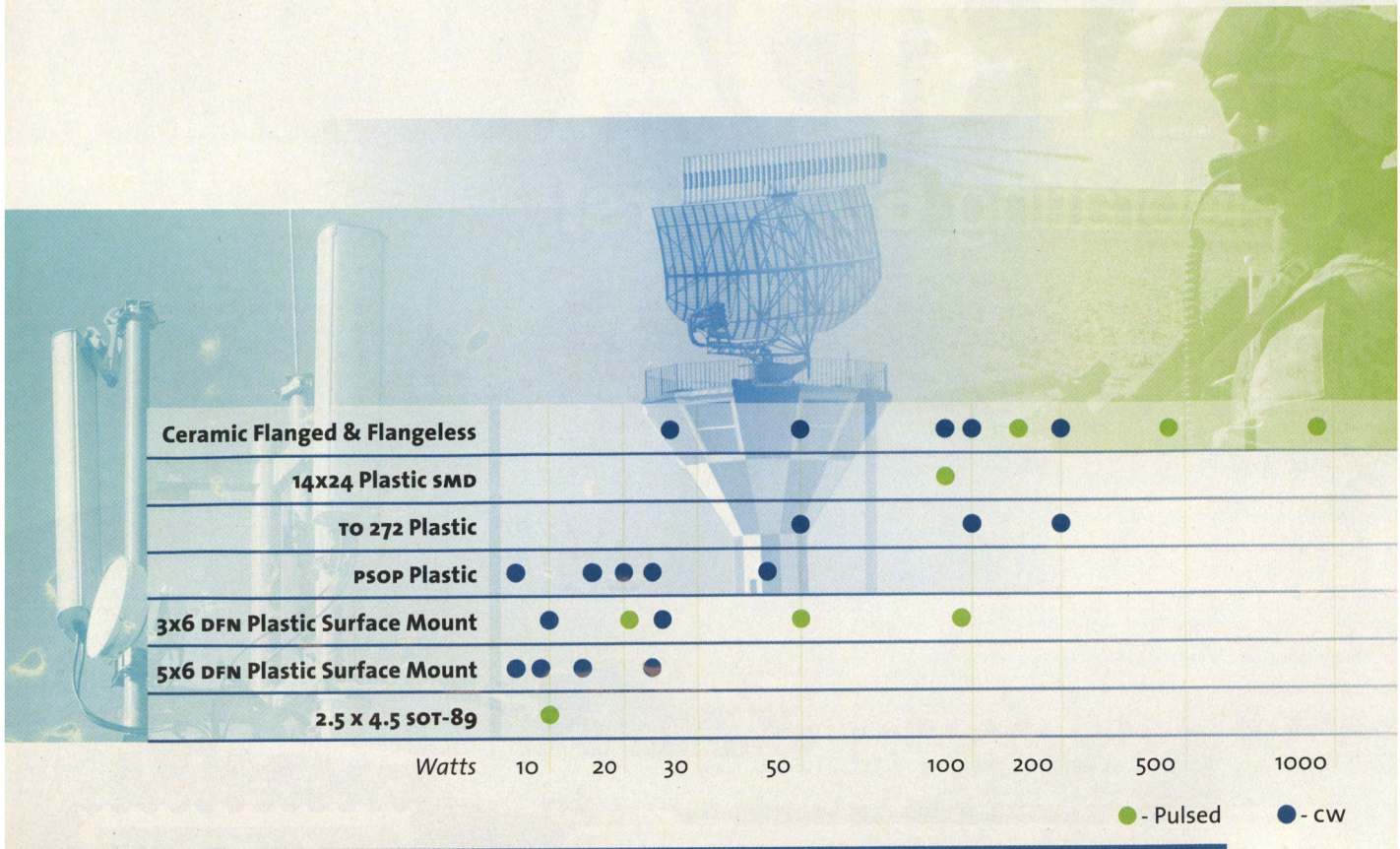
Narda started in 1954 as a small group of engineers on Long Island offering new and innovative technology to a growing RF and microwave industry. Sixty years later, Narda has become the global standard for quality and durability by continually producing the industry's most reliable RF and microwave components. ***We thank you for sixty years of loyalty to Narda Microwave, and look forward to serving you in the years to come.***

narda

an L3 company

www.nardamicrowave.com • 631.231.1700

Six decades of technological innovation



Shattering the Barriers to Mainstream GaN Adoption

MACOM revolutionizes RF applications by securing the supply of the industry's only proven, performance-driven GaN portfolio

MACOM GaN transistors improve upon the high-power handling and voltage operation of LDMOS with the high-frequency performance of GaAs. Improved bandwidth, efficiency and power density give your applications greater power in a variety of packages.

Leveraging deep experience in RF, MACOM engineers are expanding our power transistor family to fuel the future of military and commercial radar as well as other commercial applications. These rugged devices deliver greater flexibility and multi-function capability in your radar communications.

Our growing pulsed power GaN portfolio includes 5W-90W Pk transistors in DFN and SOT-89 plastic packaging, up to 1000W ceramic packages and L-, S-band fully matched modules. Our new CW GaN portfolio includes ceramic package transistors up to 200W, DFN packages from 5W to 25W and TO-272 plastic packages from 50W to 200W.

Only MACOM shatters the final barriers to mainstream GaN adoption by offering dual sourcing for surety of supply.

MACOM™

Partners from RF to Light

Get Samples & Learn How MACOM is Shattering the Barriers to Mainstream GaN Adoption at www.macom.com/gan

In This Issue

FEATURES

38 **COVER STORY:**
2014 RF ENGINEERING SALARY SURVEY
Microwaves & RF recently polled our community, finding out what really makes RF engineers tick and how they are compensated.

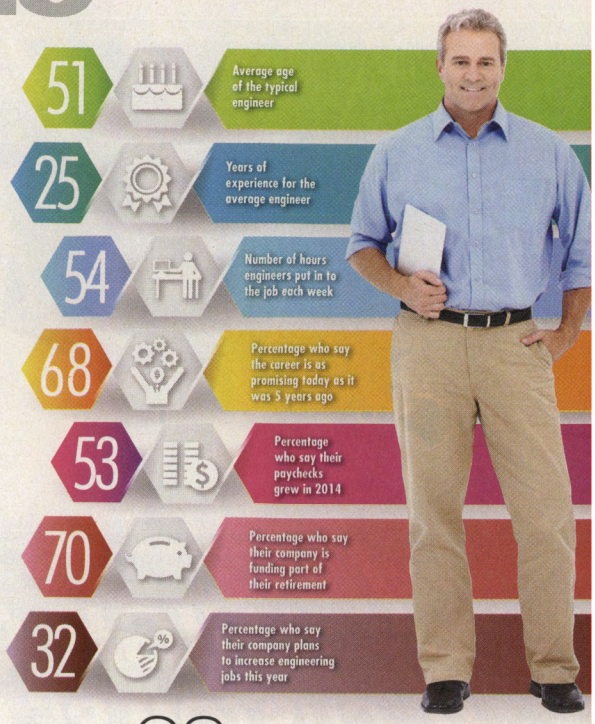
54 UWB POWER DIVIDER HAS STOPBAND FILTERING
This multilayer power divider features good impedance matching at all ports with high isolation.

60 SLOT ANTENNA TAMES THREE WIRELESS BANDS
This novel antenna design incorporates a pair of U-shaped slots to handle three frequency bands.

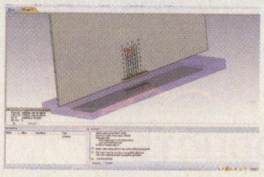
65 HANDOVERS HELP WIRELESS SENSOR NETWORKS
Through the use of a new handover scheme, wireless sensor networks can be used more efficiently.

71 MICROSTRIP LPF BOASTS ULTRAWIDE STOPBANDS
A compact lowpass filter with 3-dB cutoff at 1.78 GHz was designed and fabricated by pairing two different resonator types.

76 CMOS LNA AIDS UWB RECEIVERS
This broadband low-noise amplifier design provides more than 16-dB small-signal gain from 3 to 11 GHz.



38



48

INDUSTRY TRENDS & ANALYSIS

48 **RF ESSENTIALS**
Silicon-platform optimization

50 **INDUSTRY INSIGHT**
Boosting PA efficiency

PRODUCT TECHNOLOGY

86 **PRODUCT FEATURE**
Compact VNAs

90 **PRODUCT TRENDS**
MIMO testing

98 **PRODUCT FEATURE**
High-speed DAC

100 **PRODUCT FEATURE**
GaN MMIC switch

102 **PRODUCT BRIEFS**

NEWS & COLUMNS

11 ON MWRF.COM

13 EDITORIAL

18 FEEDBACK

20 NEWS

28 COMPANY NEWS

32 INSIDE TRACK
with Rogers Corp.'s Art Aquayo



34 R&D ROUNDUP

36 MICROWAVES IN EUROPE

96 APPLICATION NOTES

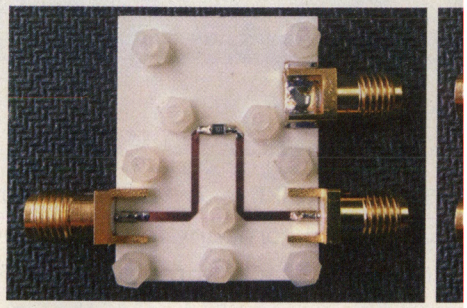
104 ADVERTISER'S INDEX

108 NEW PRODUCTS

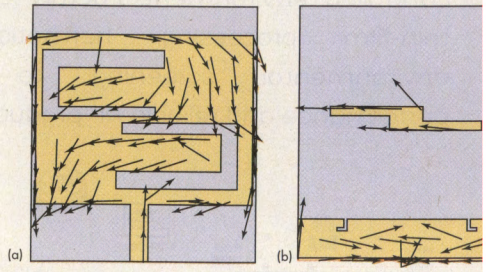
JOIN US ONLINE

follow us @MicrowavesRF

become a fan at facebook.com/microwavesRF



54



60

CEL INTRODUCING **TOKYO KEIKI**

SERVING AEROSPACE & DEFENSE MARKETS

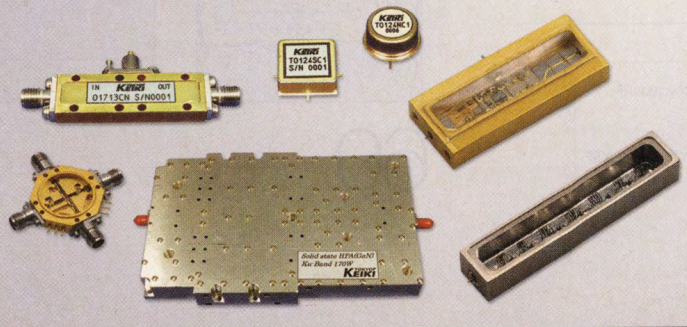


HIGH QUALITY
CUSTOM RF PRODUCTS

JIS-Q9100 CERTIFIED FACTORY
(AS9100 U.S. EQUIVALENT)

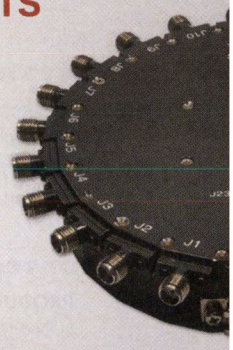
ABOUT TOKYO KEIKI

TOKYO KEIKI is a well established medium sized Japanese company founded over 100 years ago with headquarters in Kamata, Tokyo. Their factory in Yaita, Japan is certified per the quality standard for Aerospace manufacturing, where microwave products are assembled and tested under a clean and controlled environment. Factory capabilities include thin-film processing, hermetic sealing, and environmental screening to produce high performance and reliable RF products.



CUSTOM RF PRODUCTS

- Broadband VCOs
- PIN Diode Switches
- Wideband Filters
- Switched Filters Banks
- Broadband Amplifiers
- High Power Amplifiers
- Transceiver Sub-assmblies

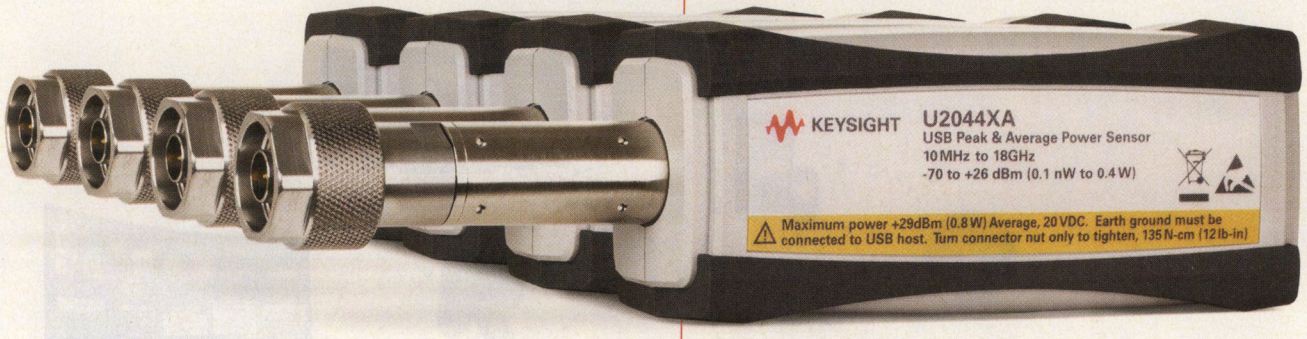


CEL | TOKYO KEIKI

Scan code to learn more or visit:
www.cel.com/TK-MWRF

Keysight U2040 X-Series Wide Dynamic Range Power Sensors

- The world's widest dynamic range: -70 to +26 dBm (96 dB)
- Fast measurement speed: 10,000 readings-per-second
- Choice of form factors: USB and LAN
- Accuracy and repeatability across all common wireless signals
- Internal zero and automatic calibration



Super fast. Super accurate. Super wide dynamic range.

Introducing a variety of power sensors that offer extremely high measurement speed and the world's widest dynamic range. Using Keysight BenchVue software for data capture/analysis, the sensors will allow you to obtain fast, accurate and repeatable measurements over a wide range of power levels. Choose from four USB models to test chipsets, radio systems, radar, mobile and handsets. Or choose the industry's first LAN and thermal vacuum-compliant power sensor for satellite testing.

HARDWARE + SOFTWARE + PEOPLE = INSIGHTS



USB LAN

Download an app note on fast, accurate power measurements for wireless test.
www.keysight.com/find/rfpowertips

USA: 800 829 4444
CAN: 877 894 4414

Scan to view video demo.

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights

© Keysight Technologies, Inc. 2014

Agilent's Electronic Measurement Group has become **Keysight Technologies.**

SKYWORKS®

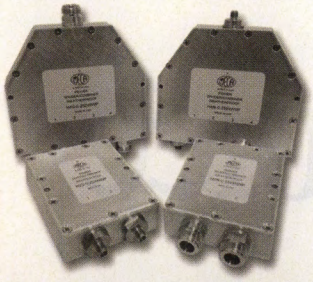
Broadband RF and Analog Solutions

Amplifiers • DC to DC • Display Drivers • Diodes • Front-end Modules
Filters • Mixers • PLLs / Synthesizers / VCOs • Switches



Visit Us at Electronica 2014 • Hall A4, Booth 553 • Munich • November 11–14

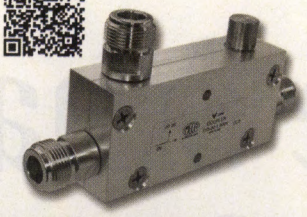
USA: 781-376-3000 • Asia: 886-2-2735 0399 • Europe: 33 (0)1 43548540 • Email: sales@skyworksinc.com
www.skyworksinc.com • NASDAQ: SWKS •



Low Frequency Power Combiners
MECA introduces Low Frequency addition to the H-Series, 100-watt Wilkinson high power combiner/dividers. Available in 2 & 4-way configurations covering 5 to 500 MHz. VSWR of 1.30:1 accommodating load VSWR's of 2.0:1 or better! N and SMA connectors. Weatherproof IP 67 rated.

Low PIM Compact 50 Watt Terminations
Industry leading PIM performance of -160dBc (Typ) and covering the 698 – 2700 MHz frequency bands available in 7/16 DIN, Type-N and 4.1/9.5 Mini-DIN, all in a compact 8.5" x 3.0" package. Ideal for IDAS / ODAS, In-Building, base station, wireless infrastructure, 4G, and AWS applications.





Low PIM Couplers
MECA's Low PIM (-160 dBc Typ) Directional Couplers for DAS Applications feature unique air-line construction that provides for the lowest possible insertion loss, high directivity and VSWR across the 0.698-2.700 GHz bands. Rated for 500 watts average power. Nominal coupling values of 15, 20, 30 & 40 dB.

Low PIM Reactive Splitters
MECA's Low PIM (-160dBc Typ) 0.698 – 2.700 GHz make them ideal for in-building or tower top systems. Available 2-way and 3-way, 7/16 DIN and Type-N configurations.



Low PIM Adapters
MECA's Low PIM (-155 dBc Typ) Adapters for DAS Applications feature industry leading PIM performance of -160 dBc Min. Available in 7/16 DIN, Type N to SMA and 4.1/9.5 Mini-DIN connectors.



BETTER BUILDINGS / BETTER NETWORKS

Dr. D.A.S. © Prescribes: MECA Low PIM Products & Equipments

For next generation DAS there is only only one name in passives.

It's simple. Better signals equal better performance. Today's buildings personify the need for next-level Distributed Antenna Systems (DAS). And the engineers that are building them turn to MECA for passive components. American ingenuity and 53 years of experience have resulted in the deepest, most reliable product line of ready-to-ship and quick-turn solutions, such as:

Power Dividers: Up to 16 way and 18 GHz
Attenuators: Up to 60dB and 500W
Terminations: Up to 500W
Couplers: Up to 40dB and 1kW
Integrated Rack Units: Delivered in 3-6 weeks



They come with an industry leading 3 year guarantee and true MECA pride. Ready to build a better DAS? Start with a visit to **www.e-MECA.com.**
"delivered on time every time!!"

Dr. D.A.S. © Prescribes...

Low PIM Compact 100 Watt Terminations
ndustry leading PIM performance of -165 dBc (Typ) and covering the 698 – 2700 MHz frequency bands available in 7/16 DIN, Type-N and 4.1/9.5 Mini-DIN, all in a compact 3.5" x 3.0" package. Ideal for IDAS / ODAS, In-Building, base station, wireless nfrastructure, 4G, and AWS applications.



Integrated D.A.S. Equipment
Let MECA create an integrated assembly with any of our RF/Microwave products on 19" panels, shelves or NEMA enclosures.



MECA

www.e-MECA.com

MECA Electronics, Inc.
Microwave Electronic Components of America
The Professional's Choice for RF/Microwave Passive Components
459 E. Main St., Denville, NJ 07834
Tel: 973-625-0661 • Fax: 973-625-9277 • Sales@e-MECA.com

iBwave

The Smart Choice for Small Spaces



Coilcraft is the brand engineers trust most when specifying tiny inductors for wearable technology

Boost the performance and battery life of your wearable products with these tiny RF and power inductors from Coilcraft:

- Wirewound chip inductors as small as 0201 size for wireless communications
- Shielded power inductors as thin as 0.71 mm for power management
- Coupled inductors as small as 2.2 x 1.45 mm for LED display drivers

You can get started by using our suite of web tools to quickly locate the perfect inductors for your design. Compare and analyze multiple parts based on your true operating conditions, and then order free evaluation samples with just a click.

Learn why we're the biggest name in ultra-miniature inductors. Visit us at **www.coilcraft.com.**

Coilcraft®

WWW.COILCRAFT.COM

coilcraftdirect.com
No min order. Next day delivery.

on microwaves&rf.com

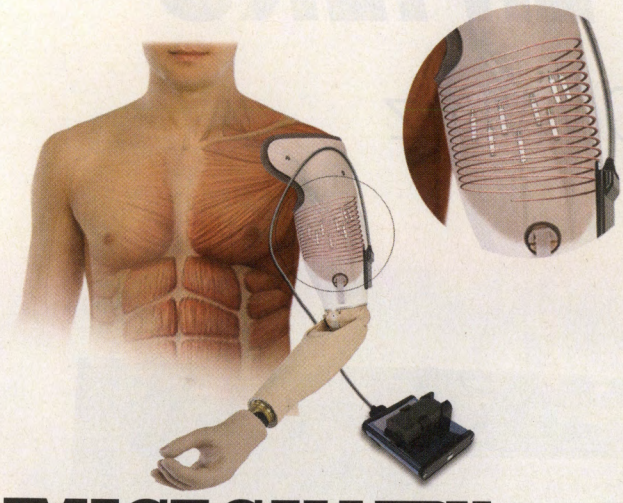


IMAGE GALLERY: WIRELESS PROSTHESIS

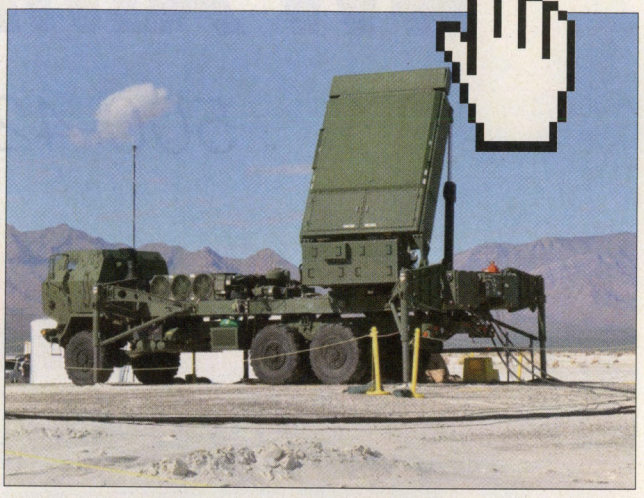
http://mwrf.com/systems/how-great-gift-wireless-prosthesis

From environmentally resilient microprocessor joints to direct nerve-controlled robotic limbs, helping our wounded return to full, productive lives has never been more possible.



VIDEO: AN OVERVIEW OF NEW CREE RF COMPONENTS

Tom Dekker, director of sales and marketing for Cree's RF components, discusses the company's new products, including plastic devices for telecom small cells, over-mold plastic devices for cellular infrastructure, plastic devices for L/S/C/X-band RADAR, and a new line of GaN HEMTs. View this and all our videos by checking out Microwave Videos at *www.mwrf.com*.



MEADS UPDATE: MISSILE-TRACKING TESTING COMPLETED

http://mwrf.com/systems/update-meads-radar-performs-360-deg-rotation-missile-tracking

A six-week performance test was recently completed on the MEADS MFCR where it successfully demonstrated several capabilities including tracking and cancelling jamming signals, searching, cueing, and tracking in ground clutter, and classifying target data using kinematic information.

DESIGN TIPS ON DIELECTRIC WAVEGUIDE



Material selection, plating methods, joining multiple sections, temperature stability and tests of parameters are detailed together with suggestions for extended applications. Check out this and other learning resources in our RF Classics section at *http://mwrf.com/learning-resources/rf-classics*.

join us online

twitter.com/MicrowavesRF facebook.com/microwavesrf

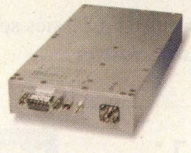
WIDEBAND
4W AMPLIFIERS

500-4200 MHz



$1495 ea.

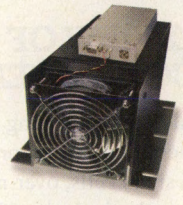
With 4W output power and ±1 dB gain flatness across 500 to 4200 MHz, Mini-Circuits new ZHL-4W-422+ Class-A amplifiers meet your needs for a wide range of applications! With ***RUGGED CONSTRUCTION*** and extensive built-in safety features, they're perfect for lab uses such as production test, burn-in, life test, and IP3 measurements where filtering and attenuation matching is needed. Used in conjunction with Mini-Circuits power splitters, they can be used to drive up to 32 simultaneous test channels or more, improving test efficiency and throughput. Consistent performance across very wide band also makes them excellent candidates for systems ranging from satellite L-Band and cellular to transmitters, GPS, and more! They're available off the shelf for immediate shipment, so visit minicircuits.com and place your order today!



ZHL-4W-422+

- Gain, 25 dB
- Gain Flatness, ±1 dB
- IP3, +44 dBm
- IP2, +45 dBm
- Unconditionally Stable

- Protected against:
  - → *Opens and Shorts*
  - → *Overheating*
  - → *Over-Voltage*
  - → *Reverse Polarity*



Available with Heat Sink

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

Editorial

NANCY K. FRIEDRICH
Content Director
nancy.friedrich@penton.com



Don't Trust that Tower

Current news headlines seem to scream weekly about hackers getting credit-card and other secure information from stores, banks, etc. Meanwhile, concerns are already being voiced about spying that can be done via the "Internet of Things" (IoT). It also is possible to steal user information and data usage from cellular phones. Beyond identity theft, these threats raise concerns about what such breaches can mean for our national security—especially when our wireless infrastructure is called into question.

In an article titled, "Rogue cell towers discovered in Washington, D.C." on CSO (www.csoonline.com), the author reports that engineers and customers of ESD America (makers of the ultra-secure CryptoPhone) had discovered more than a dozen rogue cell towers (also known as interceptors or IMSI catchers) around the U.S. this past summer. There is a good chance that this number is only a small representation of the total interceptors that exist. It also fails to take into account mobile base stations.

The article notes that these interceptors are only supposed to be used by law enforcement or the government. According to CSO, "That's because once a device connects to them, the interceptor's operator can perform a number of tasks, including eavesdrop on calls or text messages, or in some cases, push data (spyware for example) to the device." Due to the suspected large number of interceptors in the U.S., it is possible that other countries or entities could be spying on the U.S. as well.

Realizing the threat that could be posed by interceptors, the U.S. Congress has pressured the Federal Communications Commission (FCC) to tackle this topic. Reportedly, the FCC responded by creating a task force "to combat the illicit and unauthorized use of IMSI catchers." Truly, though, this is not much of a fix. The carriers need to step up to secure the spectrum they use. While the official parties wrangle over this topic and try to come up with mandatory solutions, individuals need to be aware. In particular, for those engineers working for defense contractors: If your employer trusts you with design, financial, or any other types of secrets, it is time to think about securing your cell phone with more than just a password. mw

JOIN US ONLINE follow us @mwrf
become a fan facebook.com/microwaves & RF

HIGH POWER BROAD BAND
LIMITERS
0.5 - 12 GHz
New
25 WATT CW





- Low Limiting Threshold (+6 dBm Typical)
- 25 Watt CW and 200 Watt Peak (1 microsec) power handling capability
- Built-In DC Block @ input and output
- Hermetically Sealed Module
- Typical Recovery Time is less than 10 Microsec

Typical Performance @ + 25 Deg. C

MODEL	FREQ. RANGE (GHz)	MAX. INSERT. LOSS (dB)	MAX VSWR	MAX LEAKAGE @ 25 W CW INPUT (dBm)
LS0510P25A	0.5 – 1.0	0.5	1.4:1	+20
LS0520P25A	0.5 – 2.0	0.6	1.4:1	+20
LS0540P25A	0.5 – 4.0	0.7	1.4:1	+20
LS0560P25A	0.5 – 6.0	1.3	1.5:1	+20
LS05012P25A	0.5 – 12.0	1.7	1.6:1	+20
LS1020P25A	1.0 – 2.0	0.6	1.4:1	+20
LS1060P25A	1.0 – 6.0	1.2	1.5:1	+20
LS1012P25A	1.0 – 12.0	1.6	1.6:1	+20
LS2040P25A	2.0 – 4.0	0.7	1.4:1	+20
LS2060P25A	2.0 – 6.0	1.2	1.5:1	+20
LS2080P25A	2.0 – 8.0	1.3	1.6:1	+20
LS4080P25A	4.0 – 8.0	1.3	1.5:1	+18
LS7012P25A	7.0 – 12.0	1.6	1.6:1	+18

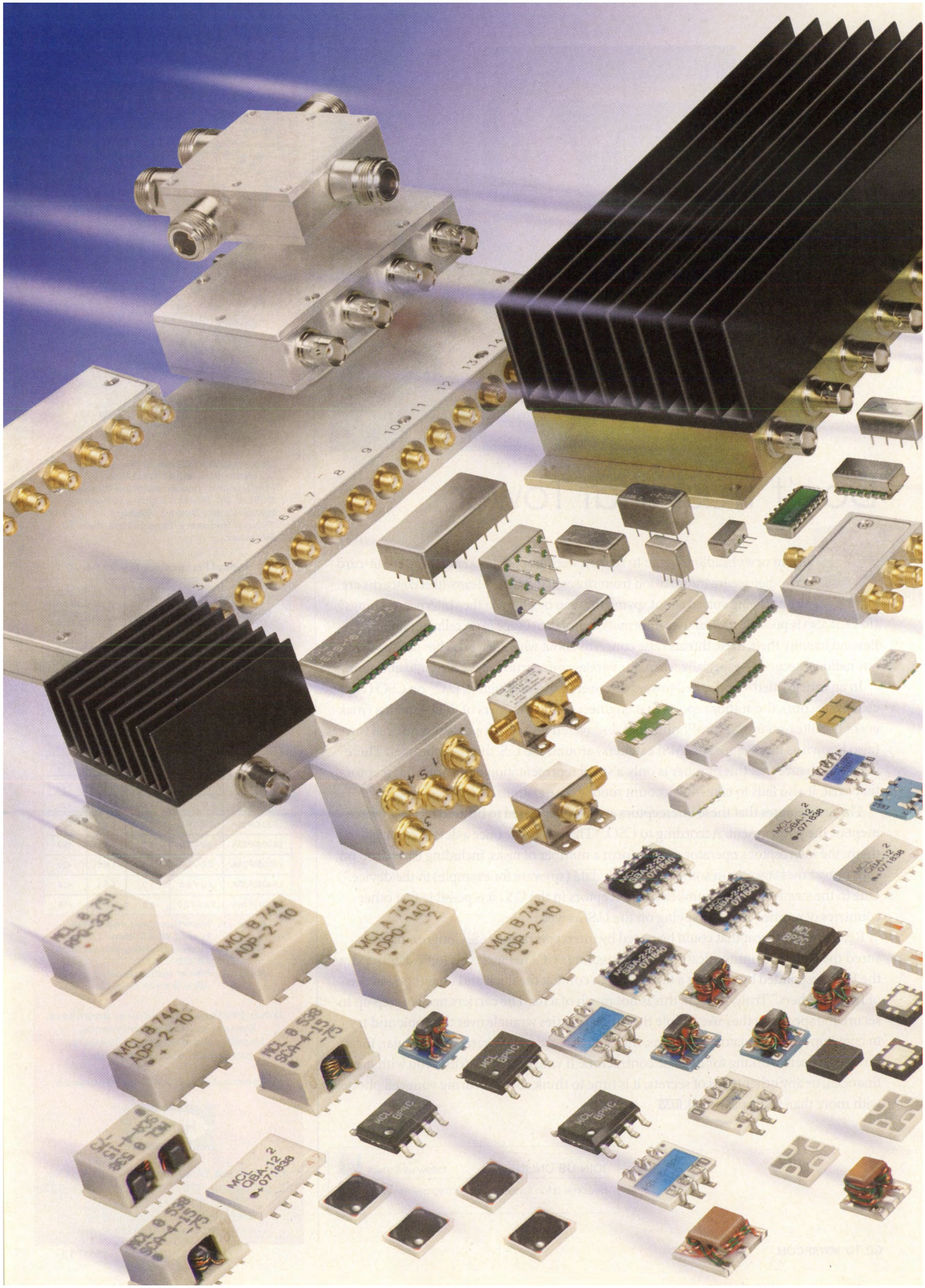
Note: 1. Insertion Loss and VSWR tested at -10 dBm.
Note: 2. Typical limiting threshold: +6 dBm.
Note: 3. Power rating derated to 20% @ +125 Deg. C.

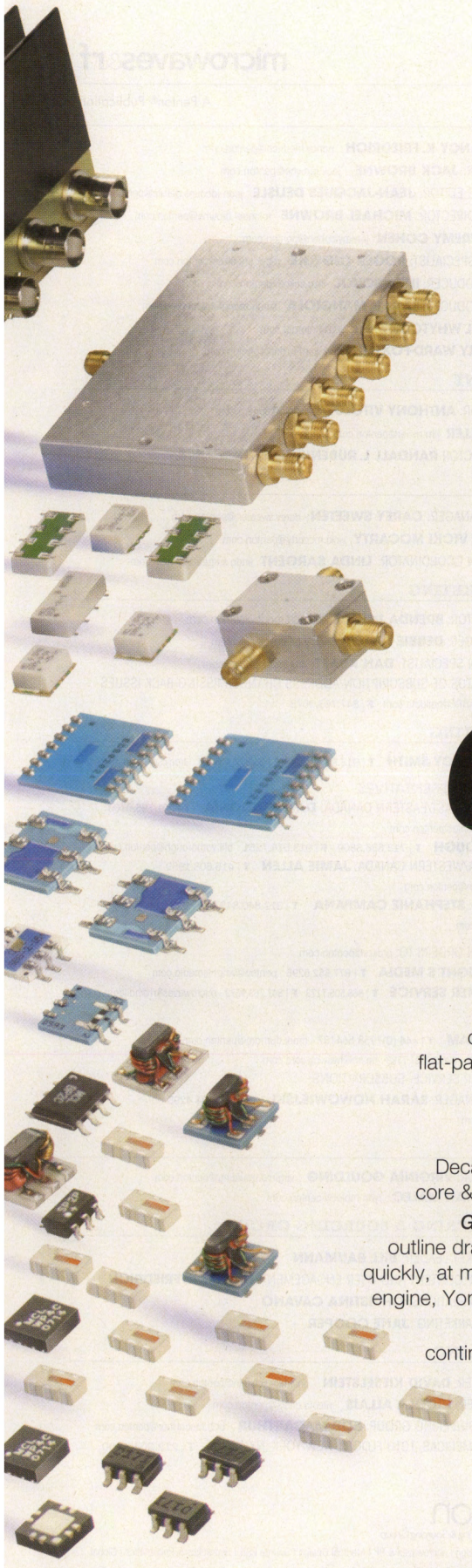
Other Products: Detectors, Amplifiers, Switches, Comb Generators, Impulse Generators, Multipliers, Integrated Subassemblies

Please call for Detailed Brochures

Herotek

155 Baytech Drive, San Jose, CA 95134
Tel: (408) 941-8399 . Fax: (408) 941-8388
Email: info@herotek.com
Website: www.herotek.com
Visa/Mastercard Accepted





POWER SPLITTERS/ COMBINERS

NOW! from **2 kHz to 18 GHz** as low as **79¢**

The Industry's Largest Selection includes THOUSANDS of models, from 2 kHz to 18 GHz, at up to 300 watts power, in coaxial, flat-pack, surface-mount and rack-mount housings for 50 and 75 Ω systems.

From 2-way through 48-way designs, with 0°, 90°, or 180° phase configurations, Mini-Circuits power splitters/combiners offer outstanding performance for insertion loss, isolation, and VSWR. Decades of experience with multiple technologies make it all possible, from core & wire, microstrip, and stripline, to semiconductors and LTCC ceramics.

Get easy-to-find, detailed data and performance curves, S-parameters, outline drawings, PCB layouts, and everything else you need to make a decision quickly, at minicircuits.com. Just enter your requirements, and our patented search engine, Yoni2, searches *actual test data* to find the models that meet your needs.

All Mini-Circuits catalog models are in stock, continuously replenished, and backed by our 1-year guarantee. We even list *current stock quantities and real-time availability*, as well as pricing, to help our customers plan ahead and make quick decisions. So why wait? Take a look at minicircuits.com today!

RoHS Compliant
Product availability is listed on our website.

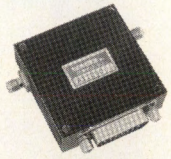
Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

448 rev N

PIN DIODE CONTROL DEVICES

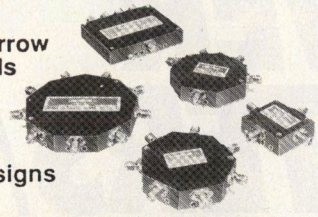
PIN DIODE ATTENUATORS



- 0.1–20GHz
- Broad & narrow band models
- Wide dynamic range
- Custom designs

Attenuator types offered are: Current Controlled, Voltage Controlled, Linearized Voltage Controlled, Digitally Controlled and Digital Diode Attenuators.

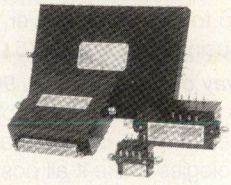
PIN DIODE SWITCHES



- Broad & narrow band models
- 0.1–20GHz
- Small size
- Custom designs

SPST thru SP8T and Transfer type models are offered and all switches are low loss with isolation up to 100dB. Reflective and non-reflective models are available along with TTL compatible logic inputs. Switching speeds are 1μsec.—30nsec. and SMA connectors are standard. Custom designs including special logic inputs, voltages, connectors and package styles are available. All switches meet MIL-E-5400

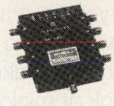
PIN DIODE PHASE SHIFTERS



- 0.5-20GHz
- Switched Line
- Varactor Controlled
- Vector Modulators
- Bi-Phase Modulators
- QPSK Modulators
- Custom Designs

SUBASSEMBLIES

Passive Components and Control Devices can be integrated into subassemblies to fit your special requirements. Call for more information and technical assistance.



Custom Designs

CALL OR WRITE

waveline® SOLID STATE INC

P.O. Box 718, West Caldwell, NJ 07006
(973) 226-9100 Fax: 973-226-1565
E-mail: wavelineinc.com

OCTOBER | 2014 microwaves&rf

A Penton® Publication

EDITORIAL

CONTENT DIRECTOR: **NANCY K. FRIEDRICH** nancy.friedrich@penton.com
TECHNICAL CONTRIBUTOR: **JACK BROWNE** jack.browne@penton.com
TECHNICAL ENGINEERING EDITOR: **JEAN-JACQUES DELISLE** jean-jacques.delisle@penton.com
CONTENT PRODUCTION DIRECTOR: **MICHAEL BROWNE** michael.browne@penton.com
PRODUCTION EDITOR: **JEREMY COHEN** jeremy.cohen@penton.com
CONTENT PRODUCTION SPECIALIST: **ROGER ENGELKE** roger.engelke@penton.com
ASSOCIATE CONTENT PRODUCER: **ILIZA SOKOL** iliza.sokol@penton.com
ASSOCIATE CONTENT PRODUCER: **SARAH MANGIOLA** sarah.mangiola@penton.com
EUROPEAN EDITOR: **PAUL WHYTOCK** p.whytock@btinternet.com
ASSOCIATE EDITOR: **SALLY WARD-FOXTON** sally.ward-foxton@penton.com

ART DEPARTMENT

GROUP DESIGN DIRECTOR: **ANTHONY VITOLO** tony.vitolo@penton.com
SENIOR ARTIST: **JIM MILLER** jim.miller@penton.com
CONTRIBUTING ART DIRECTOR **RANDALL L. RUBENKING** randall.rubenking@penton.com

PRODUCTION

GROUP PRODUCTION MANAGER: **CAREY SWEETEN** carey.sweeten@penton.com
PRODUCTION MANAGER: **VICKI MCCARTY** vicki.mccarty@penton.com
CLASSIFIED PRODUCTION COORDINATOR: **LINDA SARGENT** linda.sargent@penton.com

AUDIENCE MARKETING

USER MARKETING DIRECTOR: **BRENDA ROODE** brenda.roode@penton.com
USER MARKETING MANAGER: **DEBBIE BRADY** debbie.brady@penton.com
MARKETING AUTOMATION SPECIALIST: **DAN KRAFT** dan.kraft@penton.com
FREE SUBSCRIPTION/STATUS OF SUBSCRIPTION/ADDRESS CHANGE/MISSING BACK ISSUES
T | 866.505.7173 microwaves&RF@halldata.com **F** | 847.763.9673

SALES & MARKETING

MANAGING DIRECTOR: **TRACY SMITH** **T** | 913.967.1324 **F** | 913.514.6881 tracy.smith@penton.com

REGIONAL SALES REPRESENTATIVES

BRAND CHAMPION: NORTHEAST/EASTERN CANADA: **DAVE MADONIA** **T** | 201.785.0700 **F** | 913.514.3966 dave.madonia@penton.com
SOUTH: **BILL YARBOROUGH** **T** | 713.636.3809 **F** | 913.514.7251 bill.yarborough@penton.com
NORTHWEST/CALIFORNIA/WESTERN CANADA: **JAMIE ALLEN** **T** | 415.608.1959 **F** | 913.514.3667 jamie.allen@penton.com
MIDWEST/MID-ATLANTIC: **STEPHANIE CAMPANA** **T** | 312.840.8437 **F** | 913.514.3645 stephanie.campana@penton.com

PLEASE SEND INSERTION ORDERS TO: orders@penton.com
PENTON REPRINTS: **WRIGHT'S MEDIA** **T** | 877.652.5295 penton@wrightsmedia.com
CIRCULATION: **CUSTOMER SERVICE** **T** | 866.505.7173 **F** | 847.763.9673 microwaves&rf@halldata.com

INTERNATIONAL SALES

EUROPE: **MARK DURHAM** **T** | +44 (0)7958 564137 mark.durham@penton.com
PAN-ASIA: **HELEN LAI** **T** | 886 2-2727 7799 helen@twoway-com.com
LIST RENTALS, CUSTOMER SERVICE--SUBSCRIPTIONS:
ONLINE MARKETING MANAGER: **SARAH NOWOWIEJSKI** **T** | (212) 204 4295 Sarah.nowowiejski@penton.com

ONLINE

GROUP DIGITAL DIRECTOR: **VIRGINIA GOULDING** virginia.goulding@penton.com
COMMUNITY LEADER: **RYAN MALEC** ryan.malec@penton.com

DESIGN ENGINEERING & SOURCING GROUP

VICE PRESIDENT & MARKET LEADER: **BILL BAUMANN**
EXECUTIVE DIRECTOR OF CONTENT AND USER ENGAGEMENT: **NANCY K. FRIEDRICH**
GROUP DIRECTOR OF OPERATIONS: **CHRISTINA CAVANO**
GROUP DIRECTOR OF MARKETING: **JANE COOPER**

PENTON MEDIA INC.

CHIEF EXECUTIVE OFFICER: **DAVID KIESELSTEIN** david.kieselstein@penton.com
CHIEF FINANCIAL OFFICER: **NICOLA ALLAIS** nicola.allais@penton.com
SENIOR VP, DESIGN ENGINEERING GROUP: **BOB MACARTHUR** bob.macarthur@penton.com
1166 AVENUE OF THE AMERICAS, 10TH FLOOR NEW YORK, NY 10036 **T** | 212.204.4200

Penton Design Engineering & Sourcing Group

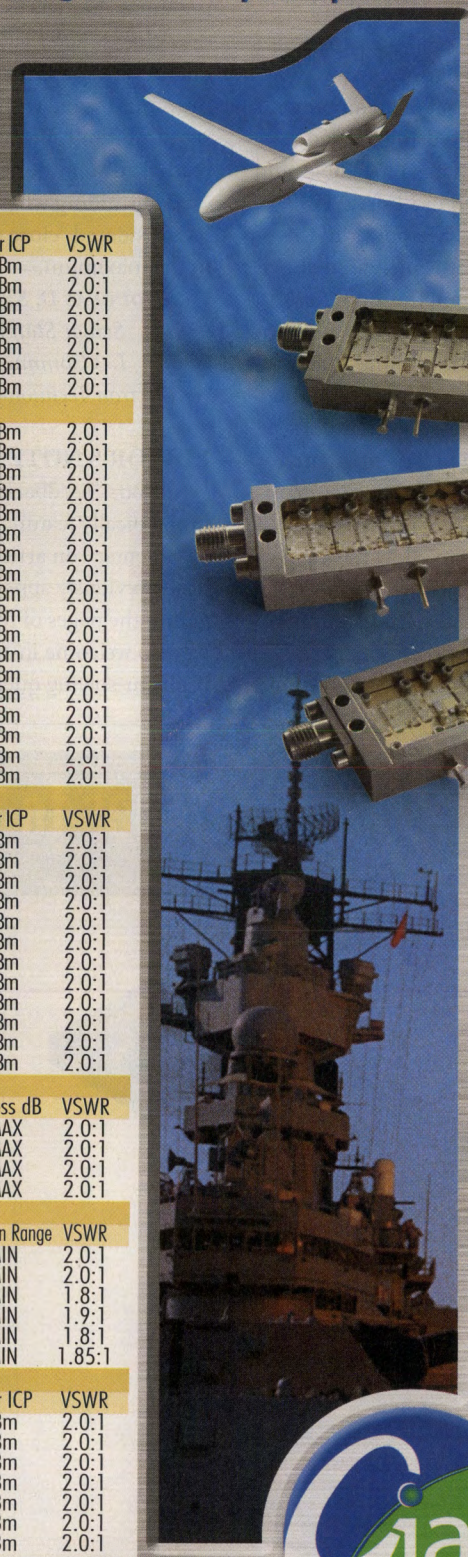
Electronic Design | Machine Design | Microwaves & RF | Medical Design | Source ESB | Hydraulics & Pneumatics | Global Purchasing | Distribution Resource | Power Electronics | Defense Electronics | Electronic Design Europe | Engineering TV

RF Amplifiers and Sub-Assemblies for Every Application

Delivery from Stock to 2 Weeks ARO from the catalog or built to your specifications!

- Competitive Pricing & Fast Delivery
- Military Reliability & Qualification
- Various Options: Temperature Compensation, Input Limiter Protection, Detectors/TTL & More
- Unconditionally Stable (100% tested)

ISO 9001:2000 and AS9100B CERTIFIED



OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

CIAO Wireless can easily modify any of its standard models to meet your "exact" requirements at the Catalog Pricing.

Visit our web site at **www.ciaowireless.com** for our complete product offering.

Ciao Wireless, Inc. 4000 Via Pescador, Camarillo, CA 93012

Tel (805) 389-3224 Fax (805) 389-3629 sales@ciaowireless.com

HOW CLOSE IS TOO CLOSE?

I have a question that I would like to pose to the readers of *Microwaves & RF*: The output of an amplifier is saturated using an algorithm that is repeatable, and has been used since 1997. As the drive power to the amplifier is increased above saturation, the amplifier's output power decreases. The algorithm assumes that the transfer curve is parabolic in the neighborhood of saturation. For standard amplifiers, the curvature of the transfer curve is great enough to allow the algorithm to converge.

For linearized amplifiers, however, the transfer curve looks more like the response of a limiter and resembles tanh(x) or 1 – exp(–x) functions. In this case, as the drive is increased, the output power approaches a maximum value without any significant roll-off. I'd like readers to submit their ideas on determining what should be considered "close enough" to the maximum.

Douglas D. Strother
Senior Staff Engineer
L-3 Communications
Electron Technologies, Inc.

EDITOR'S NOTE

While our "Feedback" section typically features reader commentary on articles that have previously appeared within the pages of *MWRF*, we also welcome in-the-field, problem-solving queries along the line of Mr. Strother's question. Any readers who would like to submit their own—or an answer in response to the above—may e-mail correspondence to jack.browne@penton.com. Many thanks to Mr. Strother for his contribution.

CORRECTION

Owing to an oversight, the authors of the article "UWB Imaging Aids Breast Cancer Detection" (May 2014) were listed in the incorrect sequence of Xia Xiao, Li Xu, Liang Wang, Qinwei Li, and Hang Song. The correct sequence should be Xia Xiao, QinWei Li, Li Xu, Song Hang, and Liang Wang.

The article provided an excellent overview on the use of a multiple-antenna array and ultrawideband (UWB) high-frequency signals to detect hidden breast cancer tumors. It was also a valuable contribution to our modern medical technologies for the fight against cancer. We sincerely regret this error.

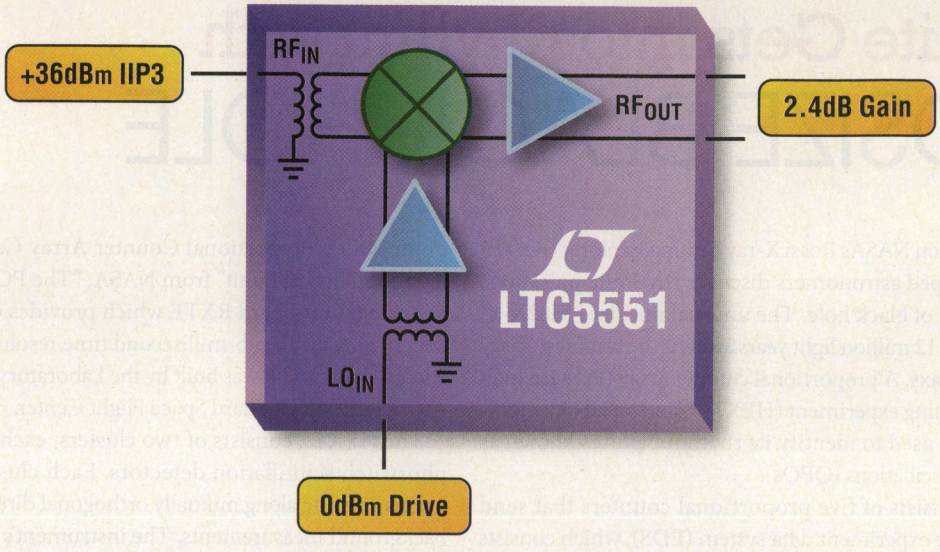
Microwaves & RF welcomes mail from its readers. The magazine reserves the right to edit letters appearing in "Feedback." Address letters to:

Jack Browne
Technical Contributor
jack.browne@penton.com

Nancy Friedrich
Content Director
nancy.friedrich@penton.com

Pin Diode Switches to 18 GHz
Absorptive - Reflective - Custom Designs
PULSAR MICROWAVE CORPORATION
25 Years of Service
16-Way, 0.5-10 GHz
Wideband Absorptive
Isolation: 60 dB
Insertion Loss: 5.2 dB
SP4T Pin Diode, 0.3-16 GHz
Reflective
Isolation: 55 dB
Insertion Loss: 3.2 dB
SP3T Broadband, 0.3-18 GHz
Reflective
Isolation: 60 dB
Insertion Loss: 3 dB
SPDT 0.3-18 GHz Switch
Absorptive
Isolation: 50 dB
Insertion Loss: 3.5 dB
SPST 0.3-18 GHz Switch
Absorptive
Isolation: 60 dB
Insertion Loss: 2.5 dB
RoHS Compliant
48 Industrial West, Clifton, NJ 07012 | Tel: 973-779-6262 | Fax: 973-779-2727 | sales@pulsarmicrowave.com

+36dBm IIP3 Mixer Boosts Dynamic Range with 2.4dB Gain



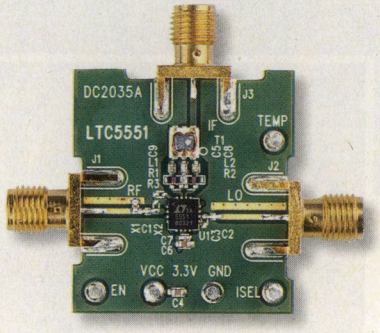
Wideband 300MHz to 3.5GHz Integrated Mixer Lowers Power and Reduces External Components

The LTC®5551's +36dBm IIP3, combined with 2.4dB conversion gain and 9.7dB noise figure, produces outstanding dynamic range performance. Its high gain saves an expensive IF amplifier stage while minimizing noise gain. And its 0dBm LO drive eliminates a high power RF amplifier, ensuring consistent performance without sensitivity to LO level or power supply variations.

Product Features

- 300MHz to 3.5GHz Frequency Range
- +36dBm IIP3
- 2.4dB Conversion Gain
- 9.7dB NF
- 0dBm LO Drive
- Low Power: 670mW

LTC5551 Demo Board



(Actual Size)

Info & Free Samples

www.linear.com/product/LTC5551

1-800-4-LINEAR

LT, LTC, LTM, Linear Technology and the Linear logo are registered trademarks of Linear Technology Corporation. All other trademarks are the property of their respective owners.

LINEAR TECHNOLOGY

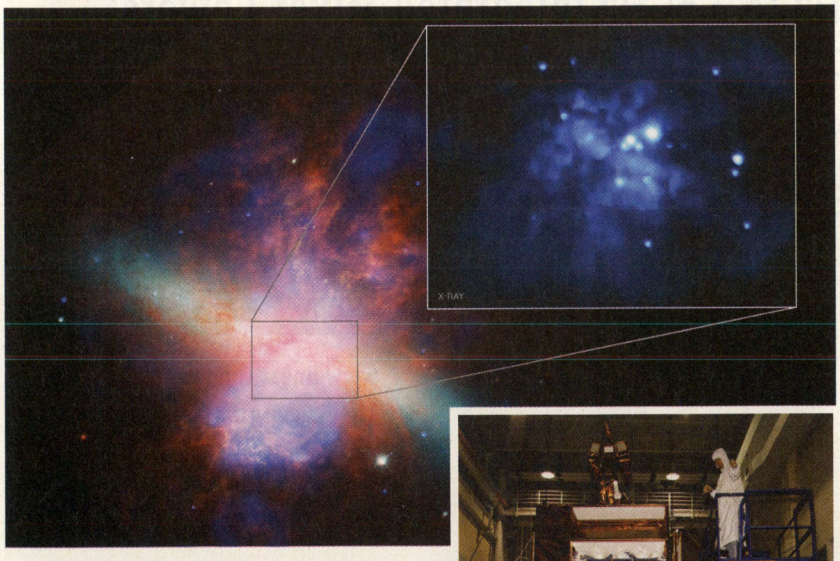
News

Satellite Gets into Rhythm with MIDSIZE BLACK HOLE

Instruments on NASA's Rossi X-ray Timing Explorer (RXTE) satellite helped astronomers discover rhythmic pulsations from a rare type of black hole. The unusual midsize "M82X-1" black hole, some 12 million light years away, is the brightest X-ray source in the galaxy. A proportional counter array (PCA), a high energy X-ray timing experiment (HEXTE), and an all-sky monitor (ASM) were used to identify its rhythmic pulses known as quasi-periodic oscillations (QPOs).

The PCA consists of five proportional counters that send event data to the experiment data system (EDS), which consists of eight event analyzers (EAs). According to the paper "Advances in the RXTE Proportional Counter Array Calibration: Nearing the Statistical Limit" from NASA, "The PCA is the primary instrument on-board RXTE which provides data in 3-50 keV energy range with sub-millisecond time resolution in up to 256 energy channels." It was built by the Laboratory for High Energy Astrophysics at Goddard Space Flight Center.

The HEXTE consists of two clusters, each containing four phoswitch scintillation detectors. Each cluster is capable of beamswitching along mutually orthogonal directions to provide background measurements. The instrument's data system processes captured events, such as event modes and binned spectra, before inserting them into the telemetry stream. It was designed and built by the Center for Astrophysics & Space Sciences (CASS) at the University of California.



This composite image shows the nearby galaxy Messier 82. The intermediate-mass black hole M82X-1 is the brightest object in the inset. *(Images courtesy of NASA)*



Launched in late 1995 and decommissioned in 2012, RXTE is one of NASA's longest-serving astrophysics missions.

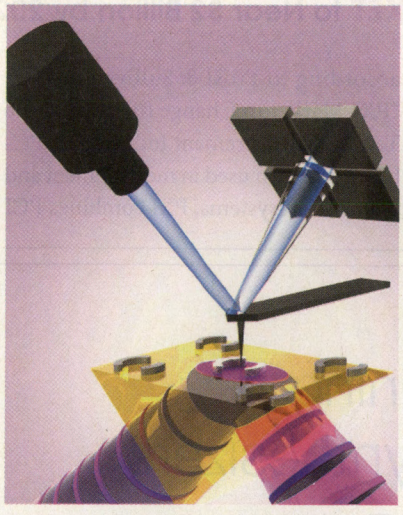
The ASM utilizes three scanning shadow cameras (SSCs) equipped with proportional counters. The three SSCs, mounted on a motorized rotation drive, each contain a position-sensitive proportional counter (PSPC) that views the sky through a slit mask. The ASM then measures the displacements and strengths of the shadow patterns cast by X-ray sources within the field of view. It was built by the Center for Space Research (CSR) at the Massachusetts Institute of Technology.

After analyzing six years of RXTE data, specific changes in brightness helped the team determine that the M82X-1 measures approximately 400 solar masses. The scientists located X-ray variations that reliably repeat about 5.1 and 3.3 times a second, or a 3:2 relationship. The combined presence of slow QPOs and a faster pair in the 3:2 rhythm set the standard for proving the mass of the black hole. All results were published in *Nature*. ■

CHARACTERIZE PLASMONIC-RESONATOR SPECTRA at Nanoscale Resolution

FURTHER ADVANCES IN nanotechnology require measurement methods for characterizing materials at appropriately small length scales. On that front, scientists recently found that photothermal induced resonance (PTIR) can be used to characterize individual plasmonic nanomaterials to obtain absorption maps and spectra with nanometer-scale resolution. Nanostructuring of plasmonic materials enables the engineering of their resonant optical response, opening the door to applications that would benefit from enhanced light-matter interactions, such as sensing, therapeutics, photovoltaics, and photocatalysis.

As part of the study, researchers from the National Institute of Standards and Technology (NIST) Center for Nanoscale Science and Technology (CNST) and the University of Maryland applied two methods to collect nanoscale absorption information. First, they mapped infrared absorption while scanning a tip on a sample under constant wavelength illumination. Then, using tunable lasers, they measured location-specific absorption spectra while sweeping a laser across infrared wavelengths ranging from 1.55 μm to 16.00 μm. Armed with the data acquired via the nanoscale infrared absorption spectra of gold resonators, the research team could interpret the images and guide further experiments.



A wavelength-tunable, pulsed IR laser (purple) illuminates a sample consisting of plasmonic gold resonators from the below. The resulting thermal expansion of the sample is detected locally by the AFM cantilever tip, which is monitored by reflecting a laser (blue) off the back of the cantilever. *(Schematic courtesy of NIST)*

PTIR measures light absorption in a material through the use of a wavelength-tunable laser and a sharp tip in contact with the sample that acts as a local detector. Unlike other methods, the PTIR tip is passive and subsequently doesn't interfere with the measurement. This means that light absorption in a sample can be measured directly without the need for a model of the tip or prior knowledge of the sample. Consequently, plasmonic materials that have large thermal conductivity and relatively small thermal expansion coefficients, such as gold, can be accurately measured. ■

MANPACK RADIO PLUS MUOS Satellite Equals Long-Distance Military Comms

To deliver next-generation narrowband satellite communications (SATCOM), the U.S. Navy's Mobile User Objective System (MUOS) satellites leverage technology similar to that of…an average smartphone? Integral to the system is General Dynamics C4 Systems' AN/PRC-155 two-channel Manpack radios. General Dynamics recently demonstrated how the radios could close a 2000-mile communications gap, bridging Line of Sight Rifleman Radio and Single Channel Ground and Airborne Radio System (SINCGARS) radio communications to orbiting MUOS satellites.

For the demonstration, radio operators equipped with PRC-154A Rifleman radios in Taunton, Mass., formed a local network using the Soldier Radio Waveform (SRW). Also part of the network was a PRC-155 Manpack radio located nearby. The two-channel Manpack radio seamlessly bridged the SRW communications to the necessary MUOS frequency. The voice and data communications jumped from the ground in Taunton to the MUOS satellite, back to the ground in Phoenix, Ariz., to connect to a second Manpack radio. That second radio then bridged MUOS communications on one channel to the SINCGARS frequency needed for the second dismounted group of users with SINGCAR radios.

In the end, they successfully created a real-time SATCOM "radio check" voice conversation that was loud and clear for the operators in both locations. The technology could provide a 16-fold increase in transmission throughput compared to current ultra-high-frequency (UHF) satellites. PRC-155 Manpack radios had previously been used to complete secure voice and data calls from Alaska and the Arctic Circle. ■



General Dynamics technicians test the two-channel AN/PRC-155 Manpack radio in production at the Scottsdale facility. *(Image courtesy of General Dynamics C4 Systems)*

PXI MARKET WILL SKYROCKET to Near $2 Billion by 2020



EXPECTATIONS FOR THE PXI market over the next five-plus years are high, with estimates of $1.75 billion in revenue by 2020. PXI will have a particularly strong impact on the test and measurement industry, according to Frost & Sullivan's report "PXI Market to Change the Face of the Test and Measurement Industry." A PC-based platform used in measurement and automation systems, PXI combines PCI electrical-bus features with CompactPCI, adding specialized synchronization buses and key software features.

More OEMs have adopted PCI extensions for instrumentation (now know more commonly as PXI), simply because they reduce the time to market and overall costs due to measurement speed, small footprint, low power consumption, and flexibility. The PXI market's lofty multi-billion-dollar forecast, up from the $563.3 million earned in 2013, will be driven by increased activity around radio-frequency (RF) along with greater demand from the communications and semiconductors sectors.

PXI solutions are being used to satisfy new test requirements for RF wireless technologies adopted by aerospace and defense programs, as well as the industrial and consumer electronics industries. The semiconductor automatic-test-equipment (ATE) market offers another avenue for PXI.

PXI's transition has been slowed by test engineers' unwillingness to change from trusted traditional box instruments. However, the report indicated a new generation of more-computer-savvy test engineers may turn that tide. Its integration can prove challenging, though, as they sometimes lack the tools and services to quickly assemble systems. PXI participants, however, are offering subsystems, hardware/software bundles, and box solutions that use the extensions to help facilitate this.

In addition, 5G and its influence on the Internet of Things (IoT) will also benefit PXI, mainly due to include integration of the wireless technology in various industrial and consumer electronics. ■

Redefining
Frequency Synthesizers
With QuickSyn Technology



Design smaller and more efficient instruments with National Instruments QuickSyn synthesizers. The revolutionary phase-refining technology used in QuickSyn synthesizers enables blazing fast switching speeds, very low spurious and phase noise performance, wide frequency range, and small footprint.

QuickSyn Models

Full-Featured	Lite Version
FSW-0010 10 GHz	FSL-0010 10 GHz
FSW-0020 20 GHz	FSL-0020 20 GHz

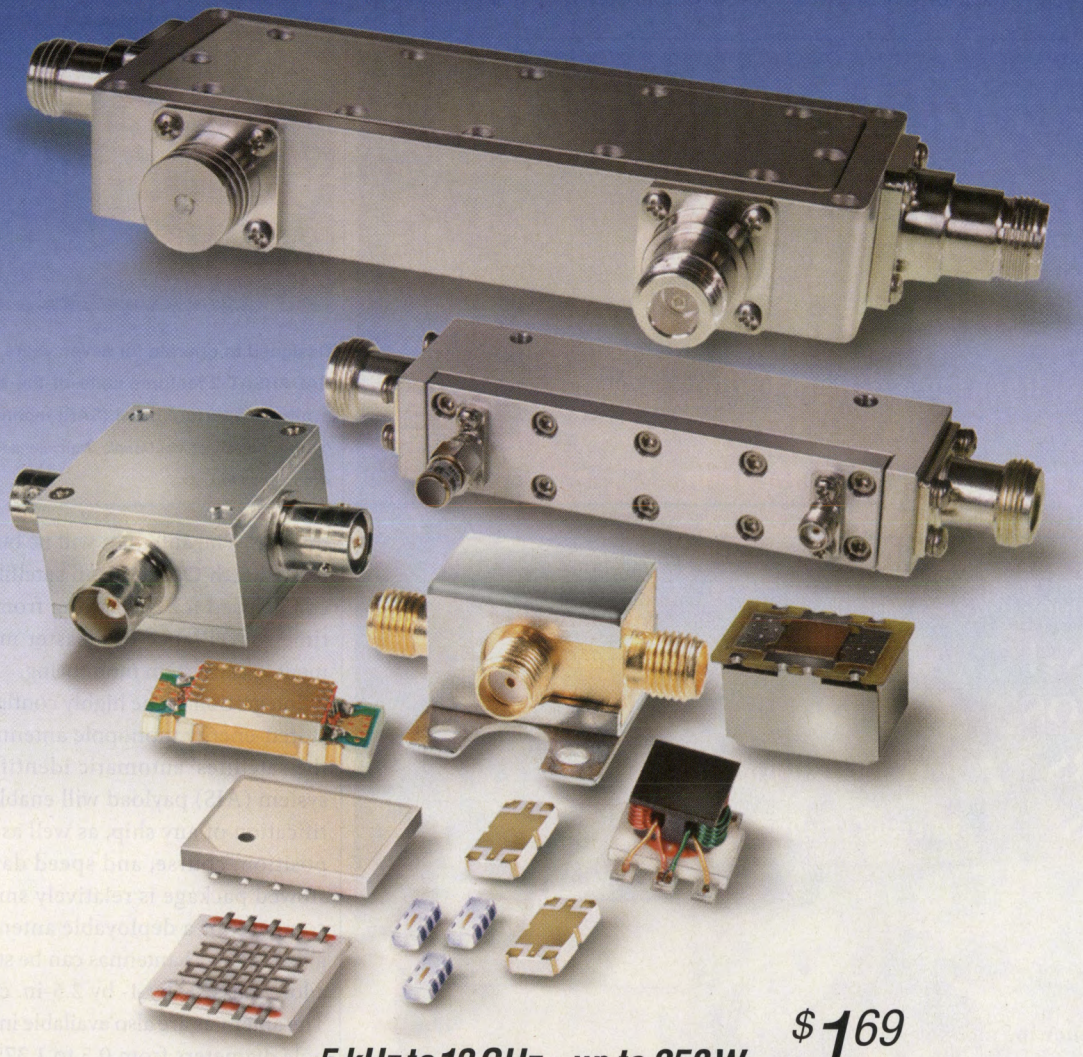
ni-microwavecomponents.com/quicksyn

408 610 6810

NATIONAL INSTRUMENTS™

©2014 National Instruments. All rights reserved. National Instruments, NI, and ni.com are trademarks of National Instruments. Other product and company names listed are trademarks or trade names of their respective companies. 17281

Directional / Bi-Directional
COUPLERS



5 kHz to 12 GHz **up to 250 W** **$1.69** *from ea. (qty. 1000)*

Now! 279 ~~236~~ Looking for couplers or power taps? Mini-Circuits has models in stock, and we're adding even more! Our versatile, low-cost solutions include surface-mount models down to 1 MHz, and highly evolved LTCC designs as small as 0.12 x 0.06", with minimal insertion loss and high directivity. Other SMT models are designed for up to 100W RF power, and selected core-and-wire models feature our exclusive Top Hat™, for faster pick-and-place throughput.

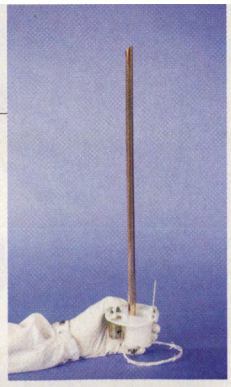
At the other end of the scale, our new connectorized air-line couplers can handle up to 250W and frequencies as high as 12 GHz, with low insertion loss (0.2 dB @ 9 GHz, 1 dB @ 12 GHz) and exceptional coupling flatness! All of our couplers are RoHS compliant. So if you need a 50 or 75 Ω, directional or 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!

Mini-Circuits®

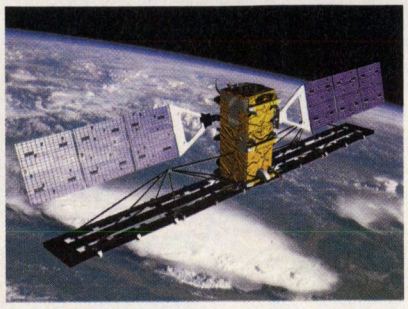
www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

SELF-DEPLOYING MONOPOLE ANTENNAS
Seize Greater Coverage of the Seas

CANADA'S RADARSAT CONSTELLATION Mission (RCM), which aims to ensure C-band data continuity via enhanced synthetic aperture radar (SAR), received a helping hand from Astro Aerospace. The company recently delivered 13 lightweight antennas—all capable of self-deploying in 200 ms—in support of the mission. The antennas will be built into RCM Earth Observation satellites that can be used for everything from maritime surveillance to disaster management to ecosystem monitoring.



The RADARSAT Constellation Mission antenna unit in deployed state. *(Image courtesy of Northrop Grumman)*



Designed to operate for seven years, RADARSAT-2 features state-of-the-art synthetic aperture radar (SAR) technology. *(Image courtesy of MacDonald, Dettwiler and Associates Ltd.)*

Integration of the highly configurable, stored-energy monopole antennas into the satellites' automatic identification system (AIS) payload will enable identification of any ship, as well as supply position, course, and speed data. The stowed package is relatively small and compact for a deployable antenna of a given size—13 antennas can be stored in a low-mass, 4- by 4- by 2.5-in. canister. The antennas are also available in monopole diameters from 0.5 to 1.375 in., as well as any length up to 25 ft. They can be used as very-high-frequency (VHF), ultra-high-frequency (UHF), or broadband receive antennas.

Complementing the SAR payload, the AIS payload will be able to receive messages in a wider swath. The three-satellite RADARSAT constellation, expected to launch in 2018, will provide complete coverage across Canada. The monopole antennas were previously used for the latest GPS III satellites. ■



You're developing a prototype for a critical project.

You promised delivery tomorrow.

And, one of the components is MIA.



At Fairview, we realize that having the correct part shipped directly to you the same day can mean the difference between success and failure. That's why you can count on us to stock the components you need, and reliably ship them when you need them. We're RF on demand. When you add Fairview to your team, you can consider it done!

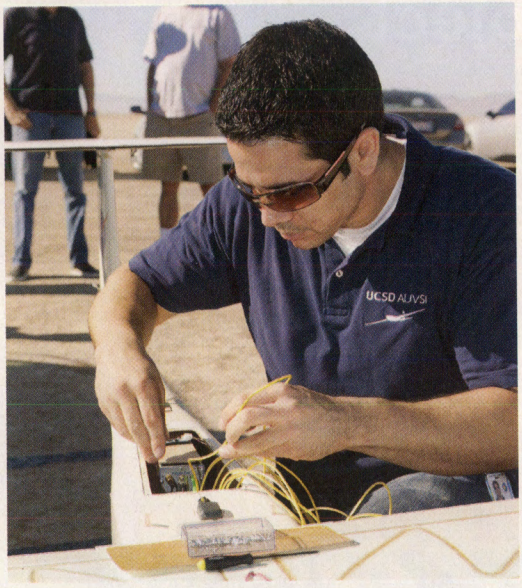
fairviewmicrowave.com
1.800.715.4396

Fairview Microwave
RF COMPONENTS ON DEMAND. Done!

MULTIPLE SPACE CONSORTIUMS Receive NASA-Backed STEM Education Awards

NASA'S NATIONAL SPACE GRANT and Fellowship Programs issued 35 awards, totaling more than $17.3 million, to winning proposals that focused on greater science, technology, engineering, and mathematics (STEM) awareness in community colleges and technical schools. Specifically, the winners outlined ways to attract and retain more students in STEM curricula, develop stronger collaborations to increase student access to NASA, and increase the number of students who advance on to bachelor's degrees.

Award winners included the California Space Grant Consortium, which proposed enhancing STEM preparation at 12 state community colleges to improve opportunities for approximately 300 students that transfer into the California State University system. Enhancements to the curriculum consist of near-space ballooning, small satellites, autonomous ground robots, wearable sensor vests for sports and health monitoring, and programmable microcomputer programs.



Benjamin Martins, supported by a grant, was able to work with several NASA mentors and develop flexible wing concept technologies at the Aeronautics Academy at NASA's Armstrong Flight Research Center. *(Image courtesy of Thomas Tschida at NASA's Armstrong Flight Research Center)*

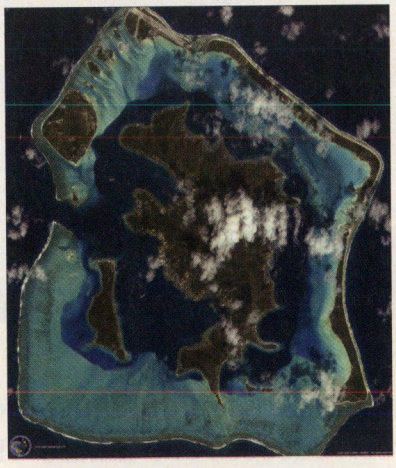
The Colorado Space Grant Consortium proposed adding four community college campuses as affiliates to its consortium. Students and faculty members from those institutions would participate in STEM activities by designing, building, and launching high-altitude balloon payloads. The students would also have the opportunity to compete for scholarships and internships, as well as participate in NASA workshops.

The North Carolina Space Grant Consortium proposed offering competitive STEM scholarships at the community-college level to attract and retain students through graduation and possibly enroll in four-year universities. They also plan to offer a team design challenge and competition, featuring NASA content, for faculty and students across the state to promote STEM education.

All told, 34 states were represented by winning Space Grant Consortiums. Each individual award has a two-year performance period and a maximum value of $500,000. ■

PIONEER EARTH IMAGING SATELLITE Turns 15

THE IKONOS SATELLITE, built by Lockheed Martin, is the first satellite to collect and publicly share high-resolution Earth images. Launched on September 24, 1999, IKONOS recently celebrated its 15th birthday in orbit. The satellite collects 0.82-meter resolution black-and-white imagery and 3.28-meter resolution multispectral data. It has taken thousands of photos of Earth for applications ranging from national security and disaster relief to agriculture and mapping. This image of the Bora Bora islands, taken on October 25, 2001, is one of many initially captured by IKONOS. The image centers on the main island, commonly referred to as "The Marvelous Island," located 240 km northwest of Tahiti. ■



Market BRIEF

THE MARKET FOR electronic test equipment—including oscilloscopes, signal generators, spectrum/signal analyzers, network analyzers, etc.—was

$3.45 BILLION in 2013

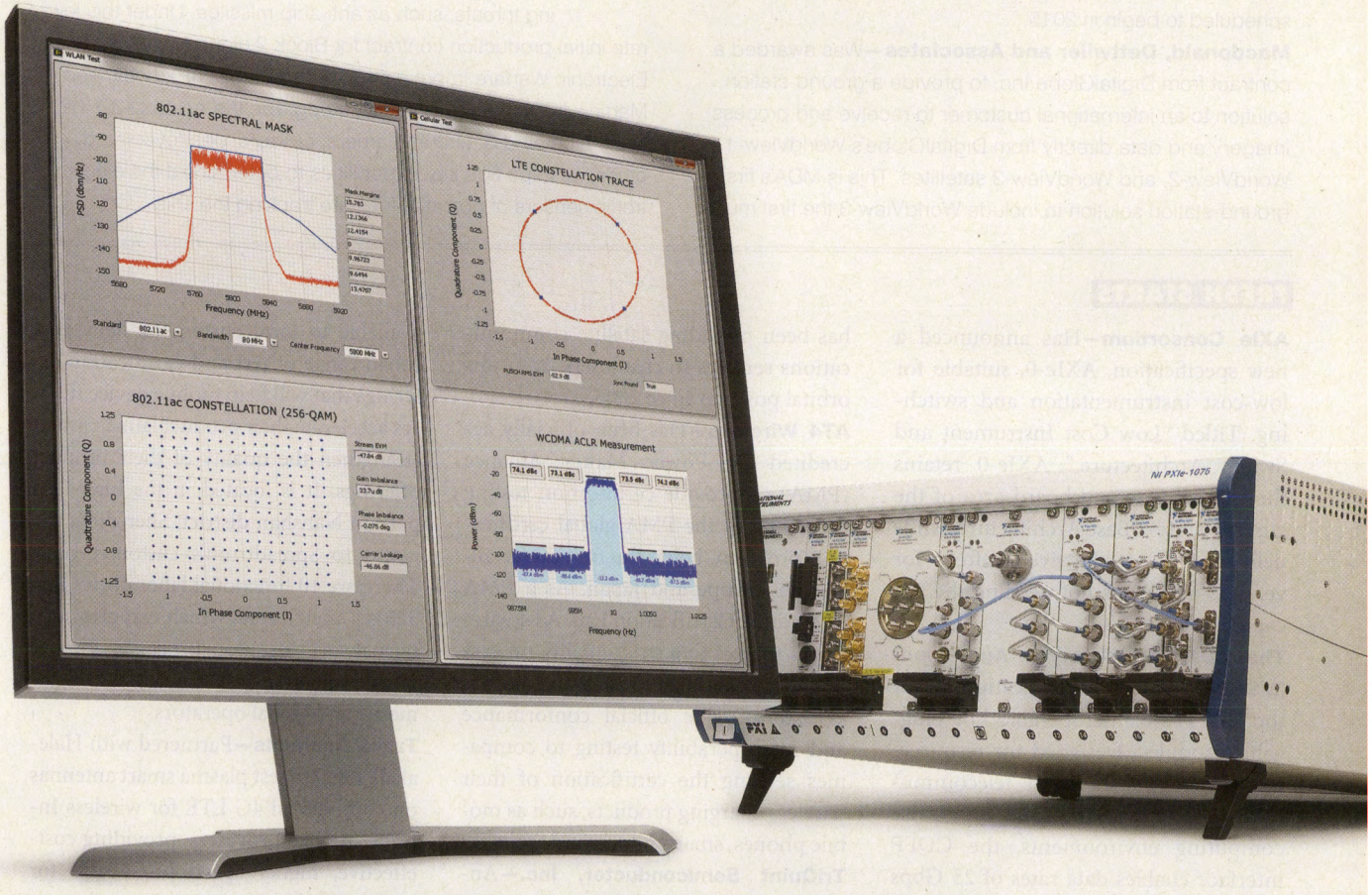
and estimated to reach

$4.64 BILLION in 2018.

—"Global Outlook for Electronic Test Equipment," Frost & Sullivan

Redefining RF and Microwave Instrumentation

with open software and modular hardware



Achieve speed, accuracy, and flexibility in your RF and microwave test applications by combining National Instruments open software and modular hardware. Unlike rigid traditional instruments that quickly become obsolete by advancing technology, the system design software of NI LabVIEW coupled with NI PXI hardware puts the latest advances in PC buses, processors, and FPGAs at your fingertips.

WIRELESS TECHNOLOGIES

National Instruments supports a broad range of wireless standards including:

LTE	GSM/EDGE
802.11a/b/g/n/ac	CDMA2000/EV-DO
WCDMA/HSPA/HSPA+	Bluetooth

>> Learn more at ni.com/redefine

800 813 5078

©2012 National Instruments. All rights reserved. LabVIEW, National Instruments, NI, and ni.com are trademarks of National Instruments. Other product and company names listed are trademarks or trade names of their respective companies. 05532

NATIONAL INSTRUMENTS™

CONTRACTS

Raytheon Co.—Was awarded a $251-million contract from the U.S. Navy to procure Tomahawk Block IV tactical cruise missiles for fiscal year 2014 with an option for 2015. The contract calls for Raytheon to build and deliver Tomahawk Block IV cruise missiles to the U.S. Navy and U.K. Royal Navy. Raytheon will also conduct flight tests and provide life-cycle support. Production and delivery of the missiles is scheduled to begin in 2015.

Tomahawk Block IV to NAVY

MDA Deal to Include WorldView-3

Macdonald, Dettwiler and Associates—Was awarded a contract from DigitalGlobe Inc. to provide a ground-station solution to an international customer to receive and process imagery and data directly from DigitalGlobe's WorldView-1, WorldView-2, and WorldView-3 satellites. This is MDA's first ground-station solution to include WorldView-3 the first multi-payload, super-spectral high-resolution commercial satellite, which was successfully launched on Aug. 13, 2014. The ground station is based on MDA's multi-satellite architecture and can be extended to support additional satellites.

Lockheed Martin—Was awarded an additional $147-million contract from the U.S. Navy to upgrade the fleet's electronic warfare defenses against evolving threats, such as anti-ship missiles. Under this low-rate initial production contract for Block 2 of the Navy's Surface Electronic Warfare Improvement Program (SEWIP), Lockheed Martin will provide 14 systems to upgrade the AN/SLQ-32(V)2 system on all U.S. aircraft carriers, cruisers, destroyers and other warships with key capabilities to determine if the electronic sensors of potential foes are tracking the ship.

FRESH STARTS

AXIe Consortium—Has announced a new specification, AXIe-0, suitable for low-cost instrumentation and switching. Titled "Low Cost Instrument and Switch Architecture," AXIe-0 retains the module size and board area of the current AXIe-1 Base Architecture, while delivering a cost-effective platform for vendors and users not needing the full capability of AXIe-1.

The CDFP Multi-Source Agreement (MSA)—Released specifications for the CDFP 2.0 interoperable hot pluggable modules. Designed for resource-intensive applications in telecommunications, networking, and enterprise computing environments, the CDFP interface enables data rates of 25 Gbps over 16 lanes for an aggregate of 400 Gbps on a single module with excellent signal integrity, thermal cooling properties, and EMI protection.

EchoStar Satellite Operating Corp.—Has chosen Airbus Defence and Space, the world's second-largest space company, to construct the EchoStar 105 satellite. This new satellite, providing EchoStar with 24 × 36 MHz Ku-band transponders, will be positioned at the 105 degrees West orbital position, offering comprehensive coverage of the Americas, including Alaska, Hawaii, Mexico, and the Caribbean. EchoStar has been providing satellite communications services to customers from this orbital position since 2006.

AT4 Wireless—Has been officially accredited by Power Matter Alliance (PMA) to provide certification testing according to the PMA global certification program, being the first one available in Europe and Japan. As a PMA Accredited Certification Lab, AT4 wireless is subject to a strict quality process defined by ISO/IEC 17025 and now is able to provide official conformance and interoperability testing to companies seeking the certification of their wireless charging products, such as mobile phones, smartphones, and tablets.

TriQuint Semiconductor, Inc.—Announced the preliminary results of its special meeting of shareholders held last month to approve its agreement and plan of merger and reorganization with RF Micro Devices, Inc. and Rocky Holding Inc. TriQuint and RFMD anticipate the closing of the transaction will occur in the second half of calendar 2014 subject to the receipt of required regulatory approval and other customary closing conditions.

Spreadtrum Communications (Shanghai) Co. Ltd.—Opened its Spreadtrum Shenzhen Center for Innovation in Engineering Center. The Center, now available to local customers, delivers a broad range of test and certification offerings that will help mobile device makers accelerate their product launches and strengthen the quality of their product offerings. It is located in the high-tech park in Nanshan district, Shenzhen, adjacent to Spreadtrum's customer base. There are 10 functional laboratories in a 500-sq.-meter area, which can also support the certification processes for devices launching on the networks of domestic and global operators.

Tazca Connects—Partnered with Haleakala R&D to test plasma smart antennas on commercial 4G LTE for wireless Internet service providers, providing cost-effective, higher speed broadband for underserved communities in rural areas.

The Wi-SUN Alliance—Announced the addition of the Graduate School of Informatics at Kyoto University and Purdue University to the Alliance as Contributor Members. Wi-SUN Alliance members include international companies helping to build Smart Utility Network (SUN) infrastructure on five continents. The growth of Smart Grid markets and products is taking place on a world-wide basis, and on a fast track in Asia, Australia, Europe, and North and South America. The inclusion of educational institutions in Wi-SUN further signals this growth.



HAND FLEX™

CABLES

Hand Flex Cables conform to any shape required.

from $9.49 ea. (qty.1-9) IN STOCK

DC to 18 GHz

Get the performance of semi-rigid cable, and the versatility of a flexible assembly. Mini-Circuits Hand Flex cables offer the mechanical and electrical stability of semi-rigid cables, but they're easily shaped by hand to quickly form any configuration needed for your assembly, system, or test rack. Wherever they're used, the savings in time and materials really add up!

Excellent return loss, low insertion loss, DC-18 GHz. Across their entire bandwidth, Hand Flex cables deliver excellent return loss (>26 dB typ for up to 50" runs) and low insertion loss (0.2 dB typ at 9 GHz for a 3-inch cable). So why waste time measuring and bending semi-rigid cables, when you can easily install a Hand Flex interconnect?

Two popular diameters to fit your needs. Hand Flex cables are available in 0.086" or 0.141" diameters, with a turn radius of 6 or 8 mm, respectively. Straight SMA connectors are standard, and now we've added right-angle connectors to our Hand Flex lineup, for applications with tightly-packed components.

Standard lengths in stock, custom models available. Standard lengths from 3 to 50" are in stock for same-day shipping. You can even get a Designer's Kit, so you always have a few on hand. Custom lengths, or two-right-angle models, are also available by preorder. Check out our website for details, and simplify your high-frequency connections with Hand Flex! RoHS compliant

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

UP TO 100 Watt AMPLIFIERS

NOW! 100 kHz to 18 GHz



$995 from ea. qty. (1-9)

High-powered performance across wide frequency ranges. These class A/AB linear amplifiers have set a standard throughout the RF & microwave industry. Rugged and reliable, they feature over-voltage and over-temperature protection, including the ability to withstand opens and shorts! And they're all in stock, whether with a heat sink/fan (for design labs and test benches), or without (for quick integration into customer assemblies). Go to minicircuits.com, where it's easy to select the models that meet your needs, including new features like TTL-controlled RF output. Place an order today, and you can have them in your hands as soon as tomorrow—or if you need a custom model, just give us a call for an engineer-to-engineer discussion of your requirements!

Model	Frequency (MHz)	Gain (dB)	Pout @ Comp. 1 dB (W)	Pout @ Comp. 3 dB (W)	$ Price (Qty. 1-9)
ZVE-3W-83+	2000-8000	35	2	3	1295
ZVE-3W-183+	5900-18000	35	2	3	1295
NEW ZHL-4W-422+	500-4200	25	3	4	1570
NEW ZHL-5W-422+	500-4200	25	3	5	1670
ZHL-5W-2G+	800-2000	45	5	6	995
ZHL-5W-1	5-500	44	8	11	1020
ZHL-10W-2G	800-2000	43	10	13	1295
• ZHL-16W-43+	1800-4000	45	13	16	1595
• ZHL-20W-13+	20-1000	50	13	20	1395
• ZHL-20W-13SW+	20-1000	50	13	20	1445
LZY-22+	0.1-200	43	16	32	1495
ZHL-30W-262+	2300-2550	50	20	32	1995
ZHL-30W-252+	700-2500	50	25	40	2995
LZY-2+	500-1000	47	32	38	2195
LZY-1+	20-512	42	37	50	1995
• ZHL-50W-52+	50-500	50	40	63	1395
• ZHL-100W-52+	50-500	50	63	79	1995
• ZHL-100W-GAN+	20-500	42	79	100	2395
ZHL-100W-13+	800-1000	50	79	100	2195
ZHL-100W-352+	3000-3500	50	100	100	3595
ZHL-100W-43+	3500-4000	50	100	100	3595
LZY-5+	0.4-5	52.5	100	100	1995

Listed performance data typical, see minicircuits.com for more details.

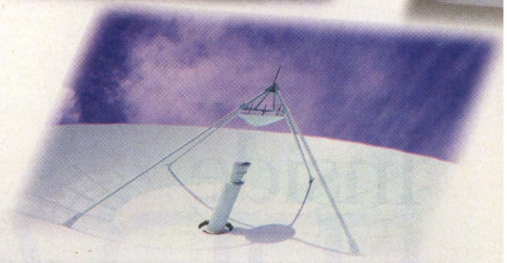
• Protected under U.S. Patent 7,348,854

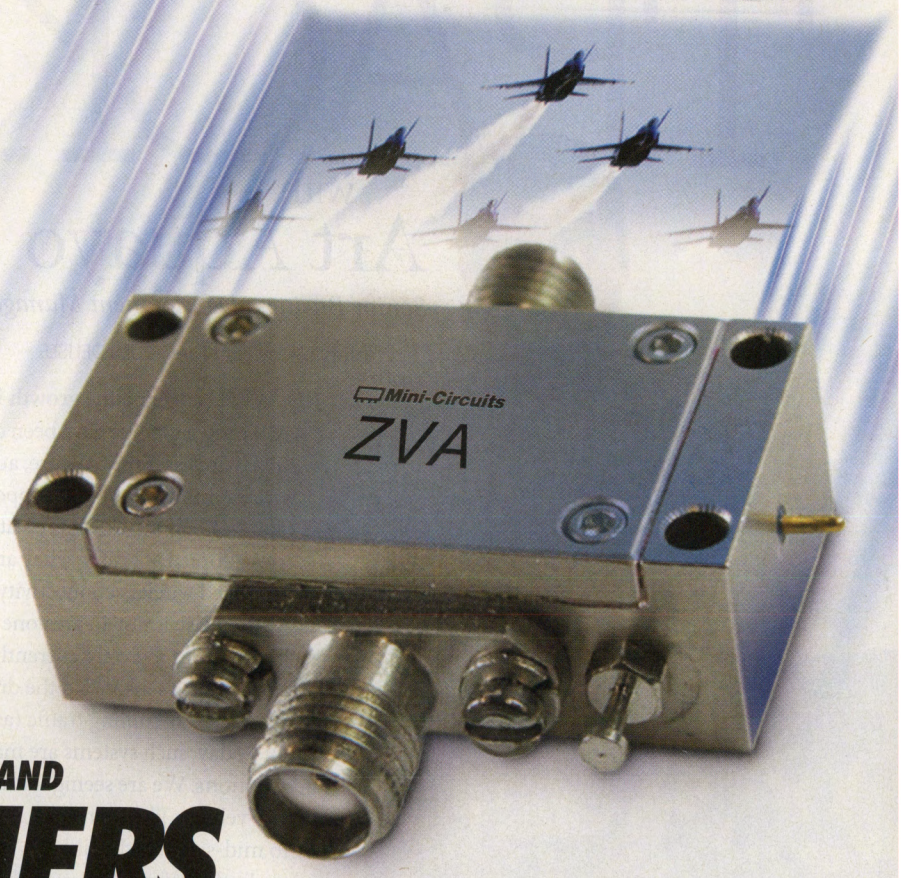
Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

416 rev A







SUPER ULTRA WIDEBAND

AMPLIFIERS

up to +27 dBm output... ***0.1 to 21 GHz***

from $845 *ea.*

Ultra wide coverage and super flat gain make our ZVA family ideal for ECM, instrumentation, and test systems. With an output power up to 0.5 Watts, they're simply some of the most usable amplifiers you'll find, for a wide range of applications and architectures!

All of our ZVA models are unconditionally stable, ruggedly constructed, and able to withstand open or short circuits at full output. For more details, from data sheets to environmental ratings, pricing, and real-time availability, just go to minicircuits.com!

All models IN STOCK!

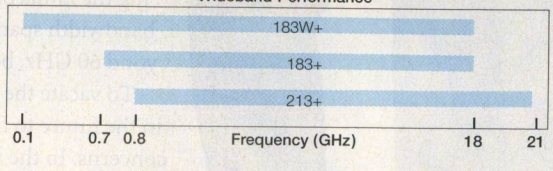
RoHS compliant

Electrical Specifications (-55 to +85°C base plate temperature)

Model	Frequency (GHz)	Gain (dB)	P1dB (dBm)	IP3 (dBm)	NF (dB)	Price $ * (Qty. 1-9)
NEW ZVA-183WX+	0.1-18	28±3	27	35	4.0	1345.00
ZVA-183X+	0.7-18	26±1	24	33	3.0	845.00
ZVA-213X+	0.8-21	25±2	24	33	3.0	945.00

* Heat sink must be provided to limit base plate temperature. To order with heat sink, remove "X" from model number and add $50 to price.

Wideband Performance



Mini-Circuits®

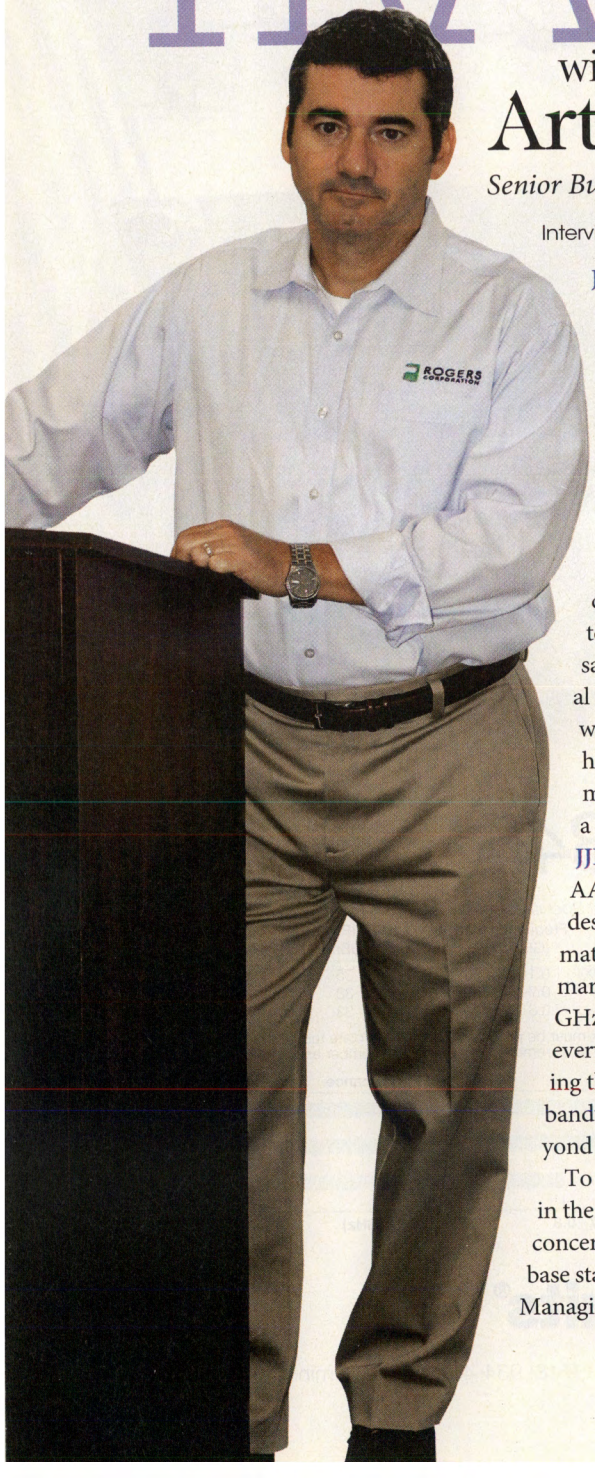
www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

440 rev R

Inside TRACK with Art Aquayo

Senior Business Development Manager, Rogers Corp.

Interview by JEAN-JACQUES DELISLE



JJD: What is driving the growth in sales of RF/microwave circuit materials?

AA: Three segments have been driving RF and microwave market growth in 2014: wireless infrastructure, automotive, and defense. The deployment of wireless infrastructure in support of 4G services (LTE and LTE-A) in regions like Asia and the U.S. has created significant opportunities, as these countries adopted 4G early. They are striving to lead the world when it comes to advanced wireless connectivity.

Automotive is not an area one first thinks of when it comes to microwave circuitry. But there are currently RF sensors operating at 24 GHz in vehicles (radar). These sensors aid the driver in making decisions pertaining to lane changes and on-coming traffic (as part of Advanced Driver Assistance Systems). Today, such systems are marketed as convenience features rather than safety options. We are seeing the adoption of these sensors beyond the traditional luxury vehicles like Mercedes, Acura, and Cadillac. They are now making their way to mid-size vehicles like VW, Ford, and Toyota, where volumes are much higher. In the defense industry, the current growth is a result of renewed government spending on several major programs. Those efforts were delayed in 2013 as a part of the effects of the sequestration on government spending.

JJD: What problems faced by design engineers require new material solutions?

AA: Within the markets listed above, we are seeing changes that are driving design engineers toward new solutions. Those solutions require innovations in materials. One trend that affects both the automotive and wireless-infrastructure markets is the use of operating frequencies above 60 GHz—in particular, 77 to 79 GHz. The amount of data that is being transmitted wirelessly is doubling roughly every year, according to Cisco's annual VNI report. As a result, data usage is reaching the limits of available bandwidth for microwave backhaul. Limits for available bandwidth span the 7-to-40-GHz spectrum. A solution is to move to frequencies beyond 60 GHz, both licensed and unlicensed, where there is much greater availability.

To vacate the spectrum around 24 GHz, automotive sensors will be transitioning in the future to frequencies close to 79 GHz. This shift is a product of interference concerns. In the area of wireless infrastructure, power levels are increasing within base stations. This means that operating temperatures are increasing as well. Managing this increase in thermal density—along with the decrease in housing size—

is creating new thermal-management issues for designers.

JJD: In which ways have traditional RF/microwave circuit materials changed to meet these needs?

AA: In the area of higher operating frequencies, reducing circuit losses is a key element in developing material solutions for use beyond E-band. Existing resin systems can still be used, such as polytetrafluoroethylene (PTFE) and possibly those used in low-loss thermoset materials. However, reducing the conductor loss component of the total circuit loss is critical. This is done by using copper with a lower surface roughness profile while maintaining good copper peel strength to the dielectric.

At frequencies above 60 GHz, conductor loss is much greater than dielectric loss. Smoother foils are now available on both thermoplastic and thermoset resins, resulting in reduction of the insertion loss of 30% to 50%. To better handle increased operating temperatures, heatsinks, metal plates for groundplanes, and metal alloy coins can be added. They offer increased thermal conductivity for areas below the power device.

Thermally, the circuit would also benefit significantly by having PCB materials with increased thermal conductivity. In the past, higher thermal conductivity was a "nice" bonus for substrate performance. But recent thermal-density increases in microwave circuits are necessitating higher thermal conductivity with the substrate.

Some designs have required little change, as they were already using thermoset materials with high ceramic loading. These materials have raised thermal conductivity over traditional RF/microwave materials. Now, the industry is seeing needs for thermal conductivity to increase by as much as 30% to 100% above current industry standards. As a solution, special ceramic fillers are being incorporated in existing resins. Their goal is to evolve the thermal behavior of substrate products in a controlled manner.

JJD: Operating frequencies continue to get higher in volume applications, such as 79 GHz for automotive and wireless backhaul. In those cases, what is critical about selecting circuit materials?

AA: There is always great emphasis on the electrical properties of the substrate materials at these frequencies. And they are important in both dielectric-constant control and low loss with the dielectric and conductor. However, one property that usually gets overlooked by RF designers is thickness control. Often, when a customer discusses material needs in this space, they ask about tightening Dk tolerance. Typically, Dk tolerances are already around ±1% to ±1.5%. Many designers forget that thickness tolerances can be as much as ±10%.

In many RF equations, the effect of Dk is a factor of the square root while the thickness impact is a direct product. If improved stability is truly needed, going through the analysis in the electromagnetic (EM) simulator may reveal that there is more of an advantage in circuit performance. The focus simply needs to be on thickness control improvements rather than on the dielectric constant.

JJD: What markets should we be watching as possible drivers of future growth?

AA: There are still many opportunities in several of the existing markets. Full-out 4G/LTE adoption is still confined to few countries, although the rest will eventually follow. Additionally, there is the discussion about 5G. With no standards set yet, the form that 5G will take is still quite fluid. We don't know what it means for the materials industry yet.

Meanwhile, the automotive market is expanding from ADASs to cars as wireless-communications hubs. Ford and Volvo provided demonstrations of the "car of tomorrow" at World Mobile Congress in Barcelona this year. Eventually, organizations like Google will be pioneering self-driving vehicles.

The Internet has brought about many changes in the past 15 years. Without these changes, who knows if we would be seeing the explosions in broadband data that have driven so much of the infrastructure capital expenditures (CAPEX)? It is likely that the next technology wave will be driven by what is today called the Internet of Things/Internet of Everything (IoT/IoE). It is too early to say with any degree of confidence which applications will drive material development. But many potential market opportunities would benefit from the flow of wireless data to improve process yields, increase energy efficiencies, keep us safer, or just plain entertain us.

JJD: What is changing about how material properties are characterized compared to the past?

AA: Obviously, what makes these materials unique are their properties in the RF and microwave frequency bands. Most common test methods were developed in the 1970s, when the only markets were defense and aerospace. This has led to materials being characterized at X-band frequencies (10 GHz), as that is where many of these applications operated. Today, we have wireless communications from 800 MHz to 2.5 GHz, microwave backhaul radios from 7 to 40 GHz, and now millimeter-wave backhaul to 60 GHz and beyond.

Additionally, automotive sensors as high as 77 GHz are being developed. And there is demand for data specific to their frequency bands. This frequency-specific data is not only for circuit modeling. Ultimately, this information also is used for standardized quality testing.

Unfortunately, there is no standard test method. Material suppliers have had to rely on their knowledge of testing and microwave theory. The data on these materials is out there now. But I would caution designers to have discussions with their suppliers and ask questions about testing protocols, signal launch schemes, and calibration methods. Ultimately, the best approach is to look at the data and verify if it matches what you are seeing in the applications and if it make sense. MW

MILLIMETER-WAVE IDENTIFICATION TAG USES WIDEBAND RECTIFIER

AS DATA RATE demands and expectations increase, the amount of data derived from our environment is also expected to increase. With greater emphasis on massive data from sensors distributed throughout our environment, Pascal Burasa and Ke Wu from the Poly-Grames Research Center of the Ecole Polytechnique de Montreal and Nicolas G. Constantin from the Ecole de Technologie Superieure in Montreal have developed a millimeter-wave-to-DC-energy conversion circuit that enables a millimeter-wave identification (MMID) tag. This MMID device is theoretically capable of much greater data rates than traditional RFID technology.

The millimeter-wave-to-DC-energy conversion method enabled the use of a single-chip CMOS device without substrate and wiring to operate without a battery. A 65-nm bulk CMOS process was used to implement the chip. Using layout optimization and intelligent transistor sizing, an overall power conversion efficiency (PCE) of 20% was achieved at 20GHz, 18% at 35 GHz, and 11% at 60 GHz. The power transceiver produced available power of 6 dBm at 20 GHz and 35 GHz with 3 dBm available at 60 GHz. This research may have been the first reporting of PCE of a millimeter-wave to DC rectifier.

See "High-Efficiency Wideband Rectifier for Single-Chip Batteryless Active Millimeter-Wave Identification (MMID) Tag in 65-nm Bulk CMOS Technology," *IEEE Transactions on Microwave Theory and Techniques*, April 2014, pp. 1005-1011.

FIGHTING BLACK HOLE ATTACKS ON WIRELESS SENSOR NODES

WIRELESS SENSOR NETWORKS (WSNs) are distributed autonomous sensors spread throughout an environment in order to monitor physical conditions remotely. WSNs were originally inspired by military demands for battlefield monitoring and border surveillance, and have also garnered interest from commercial industries for home automation, traffic control, health care, and other internet-of-things (IoT) applications.

As the utility of WSNs increases, so does the need to optimize the links between WNSs and increase the security. With such thoughts in mind, Gaurav Gulhane and Nikita V. Mahajan from the G. H. Raisoni College of Engineering in Nagpur, India, have developed an authentic multipath protocol for secure data communication between nodes that also could extend the operational lifetime of a WSN.

The most common routing protocol used for WSN is ad hoc on demand multipath distance vector (AOMDV) routing and dictates passive waiting until connection is needed. Eventually with this method a log is built up that details the data paths between nodes. This way a shortest route can be chosen by the originating broadcast node, thus decreasing the overall power usage from hops throughout the network.

A black hole attack consists of a malicious node that vectors all traffic through that node for the purpose of either WSN disruption or information theft. Using an active WSN performance monitoring scheme could enable the detection and avoidance of black hole nodes, consequently preventing critical data from being stolen and WSNs being compromised.

See "Securing Multipath Routing Protocol Using Authentication Approach for Wireless Sensor Network," *2014 International Conference on Communication Systems and Network Technologies (CSNT)*, April 2014, pp. 729-733.

METAMATERIALS ENABLE SUPERDIRECTIVE PATCH ANTENNA

INCREASING THE DIRECTIVITY of a patch antenna array would enable much higher data rates as a function of the lower signal-to-noise ratio to the receiver antenna. Additionally, the data could be transferred more securely and reduce the risk of interference externally and internally. Using recent advances in metamaterial techniques, Monish Gupta and Jyoti Saxena from India have developed a method for using split-ring resonators as isolating filters in between antenna array elements at ISM bands.

The split-ring resonator elements, when placed in between the antenna array elements, act as a band stop filter, and in simulation introduced attenuation of over 35dB at 2.4 GHz. Both a series- and corporate-fed patch antenna array were analyzed in simulation, and the series fed patch array experienced a 1.8-dB gain in antenna array directivity with the corporate fed patch array experiencing a 1 dB increase. The benefits of this approach are derived from the planar structure that is easy and cost-effective to fabricate and install, as opposed to other methods to increase antenna array isolation.

See "Superdirective Patch Antenna Array Using Metamaterial," *2014 International Conference on Electronics, Computing, and Communication Technologies (IEEE CONECCT)*, January 2014, pp. 1-6.



USB & Ethernet Programmable

ATTENUATORS

0–30, 60, or 90 dB 1 MHz to 6 GHz from $395

Mini-Circuits programmable attenuators give you more options and more freedom with both USB and Ethernet control. Available in versions with maximum attenuation of 30, 60, and 90 dB with 0.25 dB attenuation steps, all models provide precise level control with accurate, repeatable performance for a wide range of test applications. Our unique designs maintain linear attenuation change per dB over the entire range of attenuation settings. Supplied with user-friendly GUI control software and everything you need for immediate use out-of-the-box, Mini-Circuits programmable attenuators offer a range of solutions to meet your needs and fit your budget. Visit minicircuits.com for detailed performance specs, great prices, and off-the-shelf availability!

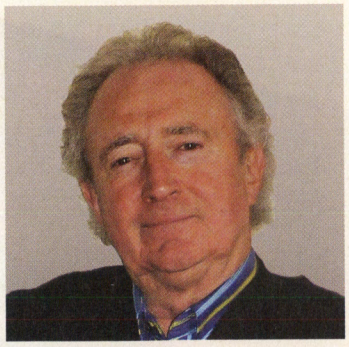
RoHS compliant

	Models	Attenuation Range	Attenuation Accuracy	Step Size	USB Control	Ethernet Control	RS232 Control	Price $ ea.
	RUDAT-6000-30	0 – 30 dB	±0.75 dB	0.25 dB	✓	-	✓	$395
NEW	RCDAT-6000-30	0 – 30 dB	±0.75 dB	0.25 dB	✓	✓	-	$495
	RUDAT-6000-60	0 – 60 dB	±1.00 dB	0.25 dB	✓	-	✓	$625
	RUDAT-6000-90	0 – 90 dB	±1.70 dB	0.25 dB	✓	-	✓	$695
NEW	RCDAT-6000-60	0 – 60 dB	±0.30 dB	0.25 dB	✓	✓	-	$725
NEW	RCDAT-6000-90	0 – 90 dB	±0.40 dB	0.25 dB	✓	✓	-	$795

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

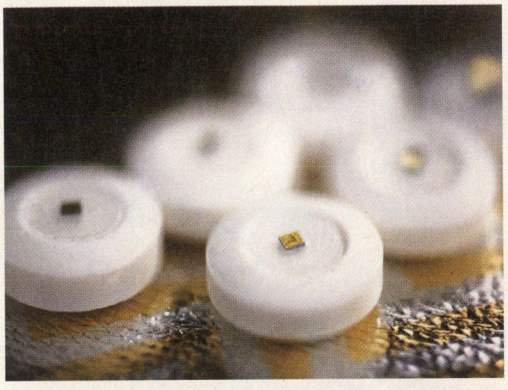
PAUL WHYTOCK | European Editor



PAUL WHYTOCK

Drug Delivery Reaches Sci-Fi Highs

DRUG DELIVERY methods have achieved science fiction status following news of two breakthroughs: a wirelessly controlled contraceptive chip that can be implanted in women, and pills that are able to text medical professionals and caregivers that patients have taken their medicine. Whereas this may sound like a storyline from an episode of "Star Trek," what we are talking about are here-and-now realities.



This sensor from Proteus Digital Health can be embedded in pills and will text medical professionals after they have been swallowed.

So, what about these pills that can send texts? Who needs them? According to the U.S. Department of Health and Human Services, five out of six Americans aged 65 and older are taking at least one medication daily, and almost half of the elderly take three or more. It is to this latter group that texting medication could prove invaluable. Elderly patients can forget to take their medicine, and a pill that texts caregivers or medical professionals that the medication is being ingested could save lives.

How is the text sent? Enter Proteus. No, not the sea god from Greek mythology or the microscopic submarine in the film "Fantastic Voyage." This is a tiny sensor that can be embedded into medicine tablets and then swallowed. Developed by digital medicine company Proteus Digital Health (www.proteus.com; *see photo*), the sensor is activated and powered by the hydrochloric acid, potassium chloride, and sodium chloride that form stomach acid.

Proteus works on the basis that when certain dissimilar elements are immersed or embedded in an ionic solution it creates power. What the developers have done with this sensor is taken two fundamental and required dietary elements—copper and magnesium—and embedded them in a tiny sensor that is less than 1 mm square.

After the pill is ingested, the stomach acid acts as the ionic fluid. This creates sufficient power for the sensor to link with and communicate to an adhesive patch worn by the patient.

It is this patch that communicates all of the patient's data to a server, which can then be accessed by phone, tablet, or PC by medical professionals or designated members of the patient's family. The data will include a description of the medicine taken, the dosage, and what batch it was issued from.

Importantly, the system also has the ability to analyze what effects the medicine is having or in some cases not having, whether it's been prescribed at the right dosage, or if it simply isn't working. This information can be crucial for people who have cardiac and diabetes-related conditions. Not only can it save lives, but it also significantly reduce health-care costs.

ON-OR-OFF CONTRACEPTIVE

A computerized contraceptive chip implanted below a woman's skin could be wirelessly activated or deactivated for up to 16 years. The chip, which is about the size of a thumbnail, releases a small dose of the hormone levonorgestrel—commonly used as an oral contraception.

The levonorgestrel is held within the device in minute compartments and kept in place by a thin platinum and titanium seal. The seal is melted by a small electrical charge, which releases a 30-microgram dose into the woman's body. This will happen automatically on a daily basis unless the chip is deactivated.

But while this on-off ability is very convenient, it does raise concerns about system security: Could somebody else turn the system off? Could it become a target for hacking pranksters?

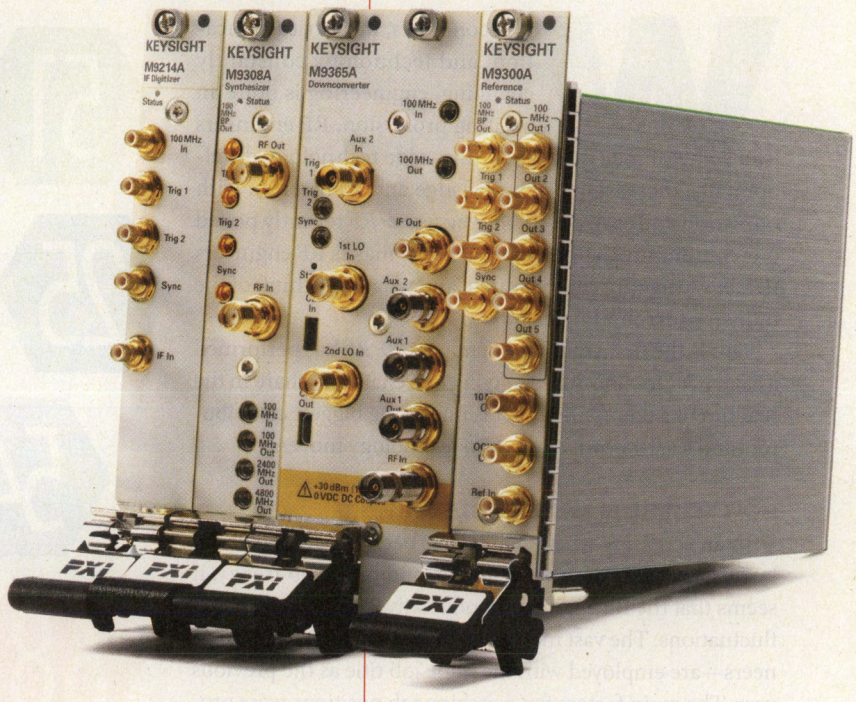
Not surprisingly, the developers insist this could not happen. They say that secure algorithms and data encryption and the fact that communication has to be done at skin level would prevent inadvertent or pernicious interference.

A final question regarding this form of digital birth control focuses on just how reliable the device will be in mechanical terms. There are currently no studies that can emulate what 16 years of being housed in the human body might do to the chip. And let's face it: 16 years equates to 5840 daily doses of levonorgestrel. That's a lot of operations that have to consistently and accurately maintain 30-microgram doses. mw

Performance is its middle name.

KEYSIGHT M9393A PXIe PERFORMANCE VECTOR SIGNAL ANALYZER

Introducing the world's fastest, 27 GHz high performance PXIe vector signal analyzer (VSA), the realization of Keysight's microwave measurement expertise in PXI. The M9393A integrates core signal analysis capabilities and proven measurement software with modular hardware speed and accuracy. So you can tailor your system to fit specific needs today and tomorrow. Deploy the M9393A and acquire the performance edge in PXI.



M9393A PXIe performance VSA	
Frequency Range	9 kHz to 27 GHz
Analysis Bandwidth	Up to 160 MHz
Frequency Tuning	150 µs
Amplitude Accuracy	± 0.15 dB

Download new app note on innovative techniques for noise, image and spur suppression.
www.keysight.com/find/M9393APXI

USA: 800 829 4444 CAN: 877 894 4414

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights

© Keysight Technologies, Inc. 2014

Agilent's Electronic Measurement Group has become **Keysight Technologies**.

JEAN-JACQUES DELISLE | Technical Editor

2014 RF ENGINEERING SALARY

With economies, industries, education, and technology constantly changing, engineering is quite an exciting profession. RF engineers lead some of today's most cutting-edge technology developments, increasing our knowledge and connection with our world and each other. *Microwaves & RF* recently polled our community to find out what really makes RF engineers tick, how they are compensated, and what they think of the industry surrounding us.

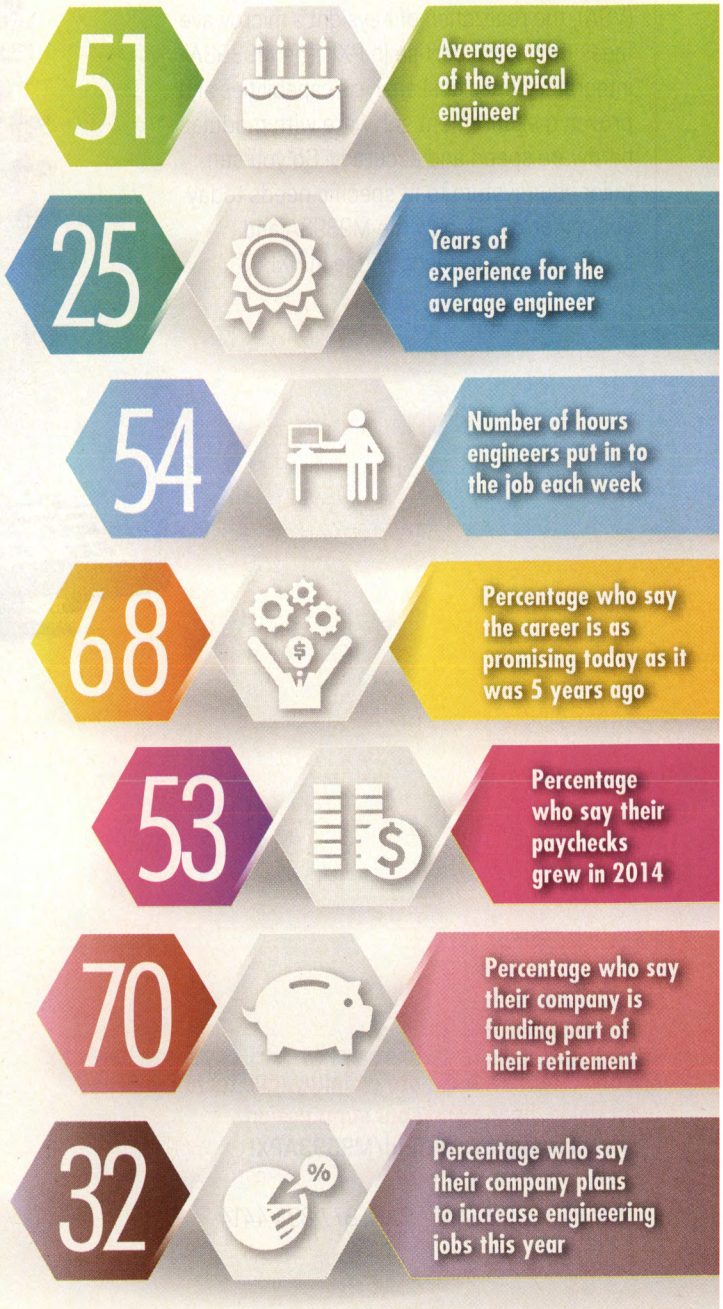
This is the first year that *Microwaves & RF* has performed a Salary & Opinion Survey, giving us a chance to share in the realities of a community that is one of the biggest contributors and least-known of modern technology movers.

HOW SECURE IS AN RF ENGINEER?

In an economy where many have been concerned about layoffs, downsizing, restructuring, and pink-slip frenzy, it seems that the RF engineer stood relatively immune to such fluctuations. The vast majority—more than 86% of RF engineers—are employed with the same job title as the previous year. The main factors for switching job positions were promotion, reassignment, job-switching, and retirement. This makes sense, as the majority of RF engineers are working for full-time employers and have for some time.

The average length of employment with the same employer is almost 13 years (though this figure may have been skewed by the large number of RF engineers who have been working for an employer longer than 20 years). Fully a quarter of all RF engineers reported a stay of such length with their present employers. But the data indicates that another quarter of RF engineers may have swapped jobs between 2009 and 2013.

All and all, RF engineers are paid very well compared to other, more traditional engineering disciplines. The average total compensation for an RF engineer is close to $112,000 a year, with over a quarter of RF engineers reporting six-figure salaries. Most RF engineers don't receive bonuses or additional compensation. Yet those who do appear to be very well compensated, with most reporting an additional $10,000 in income from either bonuses, stock options, or other sources.



SURVEY ENGINEERING BY THE Numbers

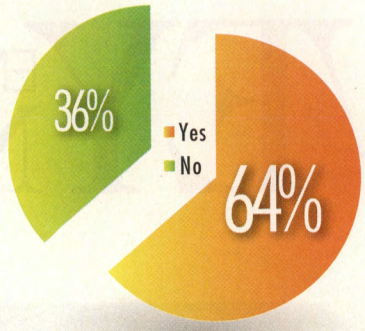


Average total compensation in 2014 in dollars	111,616
Number of years they've worked at their present company	13
Percentage who say they've been contacted by a headhunter this year	44
Percentage who express satisfaction in their current positions	88
Percentage who feel adequately compensated for the work they do	64
Percentage who say their company outsources engineering work	54
Percentage who say their company is less focused on employee retention this year	66

Additionally, the majority of RF engineers reported an increase in salary in 2014—an eighth with a greater than 10% increase. Over a third did report that their salary didn't receive an increase, but less than 10% reported a decrease in salary.

Most RF engineers also indicate that they are equally or better compensated than their peers, with only a third of RF engineers reporting that they may be compensated less. In addition, almost two-thirds of RF engineers feel adequately compensated, with a third feeling they may deserve more. These RF engineers don't appear to be greedy, though, as those who claimed they should be compensated more only requested about a 20% increase in compensation.

DO RF ENGINEERS FEEL ADEQUATELY COMPENSATED?



The RF engineers who are offered bonuses receive them based upon personal and company/division performance. Additional sources of income are derived from patent awards, project milestone completions, and company profit sharing. An interesting note is that many RF engineers seem to feel the strain of changing health insurance laws. Many companies don't appear to be offering health benefits comparable to past years.

HOW DO RF ENGINEERS FEEL ABOUT JOBS?

Either way, RF engineers appear to be a rather satisfied bunch in terms of their employment. Almost 88% of all RF engineers report feeling at least satisfied where they work. It can be construed that the quarter of RF engineers who decided to change employers must have found a company or position with which they are happier. Close to two-thirds of RF engineers are also of the opinion that there is a reasonable potential for salary advancement compared to the past five years.

In answer to a question regarding the outlook of salary increases, a respondent stated, "Technology still needs engineers. Capable engineers are in demand and well-compensated. The key is to have expertise in the key areas of demand. Outside of that, I would have answered no."

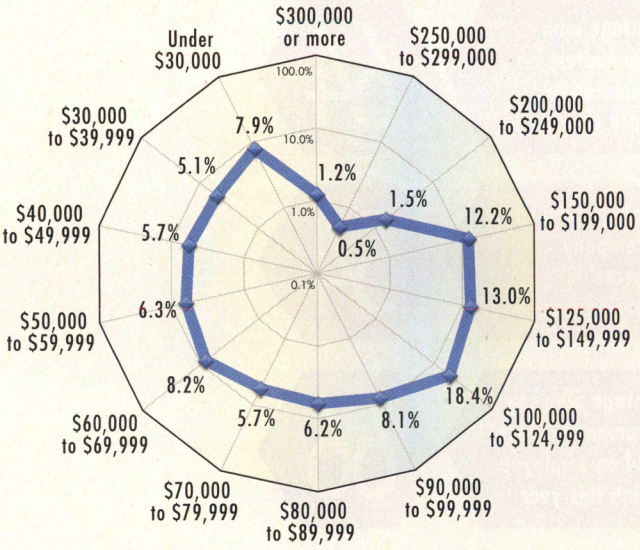
Yet another shared, "It is all about adding value. Engineering today has great opportunities to add value as long as we think not only about the product, but the people building the product and using it."

Not all RF engineers have such a rosy opinion, as some claimed that government funding cuts and corporate stinginess were providing less opportunities for promising engineers. This contrasts significantly with many other respondents, who claim that they are not able to staff enough skilled engineers. Some concern was voiced, in regard to potential salary increases, surrounding the use of work visas, and the growing use of computer tools in the engineering environment.

Regardless of any negative trends and views, just over two-thirds of RF engineers said they wouldn't even consider leaving the engineering profession. Those who shared that they may be interested in phasing out of engineering seemed to be looking for a change of pace, less stress, and more free time to explore other avenues of interest. Also, almost 90% of RF engineers would recommend engineering as a profession to the next generation. This being said, it appears that RF engineers are very passionate about engineering and are very willing to recommend the challenging work environment brought about by a career in engineering.

And challenging it is: More than 90% of RF engineers responded that they feel challenged in their positions. Over two-thirds of respondents said that the challenges associated with design represent one of the most important factors influencing job satisfaction. RF engineers seem to enjoy exploration and researching new technology solutions while working in a team environment. The biggest hold-ups in this process, which seem to add a lot of frustration, are shrinking project deadlines. RF engineers like to stay current and feel that such deadlines limit their ability to stay on the cutting edge.

HOW MUCH ARE RF ENGINEERS MAKING? [%]



HOW IS YOUR COMPANY?

While many industries are cutting back and attempting to "go lean" with staffing, it seems that most RF engineers don't have to be too concerned with this trend. Only about an eighth of RF engineers report that their companies are considering scaling back their engineering staff. Over half of RF engineers report that their companies will maintain their present staff,

TINY TOUGHEST MIXERS UNDER THE SUN



Rugged, tiny ceramic SIM mixers *from* $4.95 *ea. qty. 1000* offer unprecedented wide band, high frequency performance while maintaining low conversion loss, high isolation, and high IP3.

0.2"x 0.18"

Over 21 models IN STOCK are available to operate from an LO level of your choice, +7, +10, +13, and +17 dBm. So regardless of the specific frequency band of your applications, narrow or wide band, there is a tiny SIM *RoHS* compliant mixer to select from 100 kHz to 20 GHz. Built to operate in tough environments, including high ESD levels, the SIM mixers are competitively priced for military, industrial, and commercial applications. Visit our website to view comprehensive performance data, performance curves, data sheets, pcb layouts, and environmental specifications. And, you can even order direct from our web store and have it in your hands as early as tomorrow!

Mini-Circuits...we're redefining what VALUE is all about!

U.S. Patent # 7,027,795 *RoHS compliant*

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

428 rev K

with almost a third indicating that their companies are looking to expand their engineering staffs.

From these responses, it seems that the majority of companies are having trouble finding qualified candidates for their engineering positions. Most RF engineers report that RF engineering is the engineering discipline with the highest demand. Given the audience surveyed, this opinion may at first seem rather biased.

Yet when compared to the Salary & Opinion Surveys of our sister brands, *Electronic Design* and *Machine Design*, it appears that most engineers actually agreed on this point. A few of the those commenting shared what is in the greatest demand: "microwave/electromagnetic engineers with experience," "microwave and millimeter-wave hardware design," and "electromagnetic interference, electromagnetic compliance, and RF interference engineers."

Interestingly enough, over two-thirds of RF engineers reported that their companies aren't focused on employee retention. This could just be a function of what the prior data indicated—that RF engineers are generally happy with their current employers and don't need extra incentive to stick around. Yet some respondents said, "With the difficulty in finding good, experienced help, it underlines the need to retain current experienced staff." Another respondent stated, "Although it should be, the company isn't doing anything different than last year. We have low turnover in our company. But we can't afford to lose anyone right now, so retention should be a hot topic."

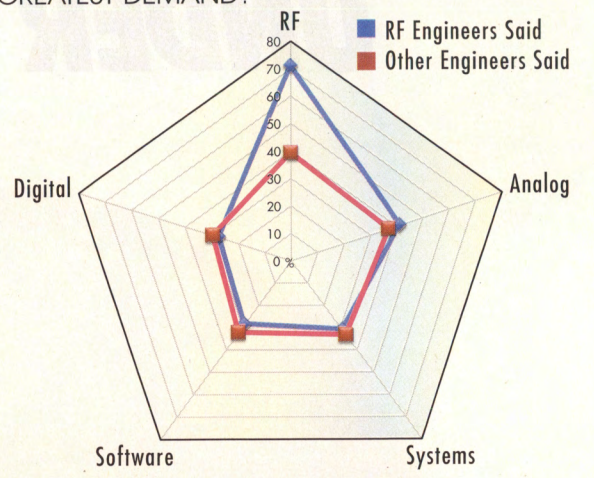
When asked about headhunting or recruitment specialists contacting our respondents with offers, over two-thirds of RF engineers claimed that they had no such contact. This also coincides with a full third of RF engineers sharing that they have no interest in changing jobs in the foreseeable future. Another third said that they would only consider new employment if they were personally approached with an opportunity that was much more interesting than their current situation. Only a tenth of the RF engineers claimed to be actively looking for other employment.

Regarding the industries and markets on which they focus, almost a quarter of RF engineers report working at a location where the dominant focus of the end product is communications systems/equipment. In size, that focus is followed by R&D, government/military, avionics/marine/space, semiconductors/ICs, and test and measurement equipment. Another core group works at consultancy agencies or consults privately for the industries mentioned above.

WHAT CONCERNS AN RF ENGINEER?

RF engineers are most concerned about looming project deadlines, product reliability issues, product quality issues, and price/performance issues. It makes sense that someone with an engineering mind would demand that every product should perform better, be more reliable, and be affordable—while

WHAT DISCIPLINE OF ENGINEERS IS IN THE GREATEST DEMAND?



simultaneously complaining about customers demanding that their latest product be produced better and at a faster schedule. That desire to push the boundary of excellence does seem to keep a few engineers awake. One respondent reported, "How can I get people to see a vision and embrace it such that we are always moving forward," while another highlighted stress over "technical issues that I cannot yet resolve."

Contrary to popular mythos, it appears that RF engineers actually prefer working with peers in teams. They value the recognition they receive from their peers significantly. Yet RF engineers don't seem to appreciate that recognition as much as they enjoy compensation and the opportunity to design products that benefit society. For many, this may indicate that some stereotypes are true: Engineers are dreamers who are willing to put elbow grease behind their vision.

Given a list of the problems of funding, non-optimal components, and having to compromise designs approaches, the engineers polled said they are more impacted by the lack of qualified people to help get the job done. Another revelation is that RF engineers, though very opinionated, seem to care far less about the sociopolitical aspects of the workplace than they do about getting the job done.

One of the biggest complaints seemed to be engineers having to respond to customer's needs, even though they didn't deem those needs worthwhile. For example, one respondent listed this as a chief point of concern: "the growing gap between customers' desires and their willingness to pay, combined with the fact that we are in an industry with relatively few large customers and many small vendors."

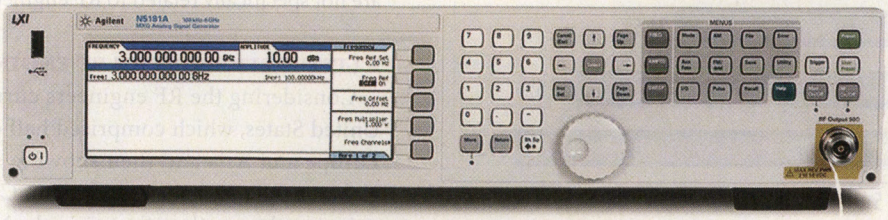
HOW ABOUT OUTSOURCING?

Many RF engineers voiced concerns about outsourcing. Over half of the RF engineers surveyed reported that their companies outsource to some degree. Unlike many industries, however,

RF Signal Generators

There's always room for improvement

The Agilent N5181A-503 is an excellent 100 kHz to 3 GHz signal generator.

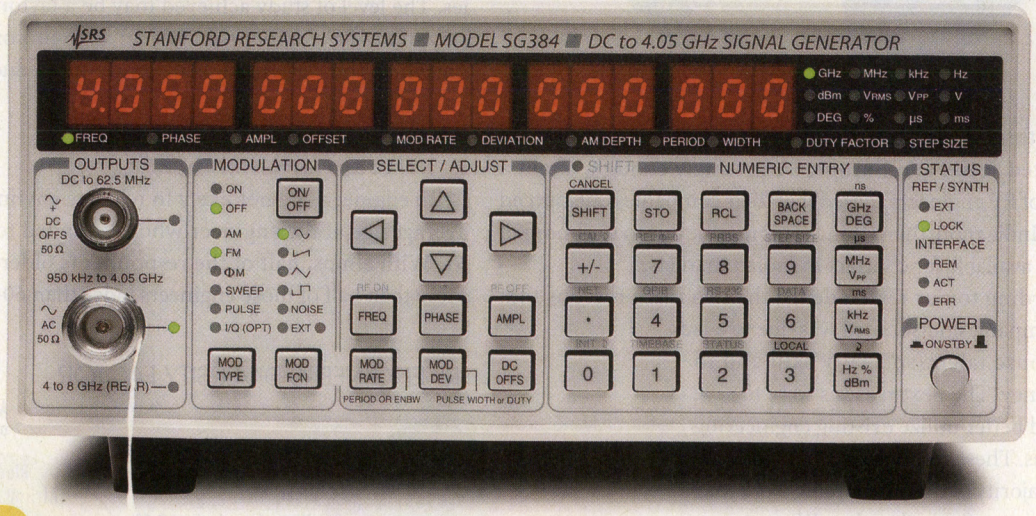


100 kHz to 3 GHz ...
$8,749

Still, we saw room for improvement ...

- Extending the frequency range to 4 GHz
- Going all the way down to DC
- Adding a low-noise OCXO timebase
- Making AM, FM, ΦM & PM all standard
- And, cutting the price (about in half)

Introducing the SG384 RF Signal Generator ... only from SRS

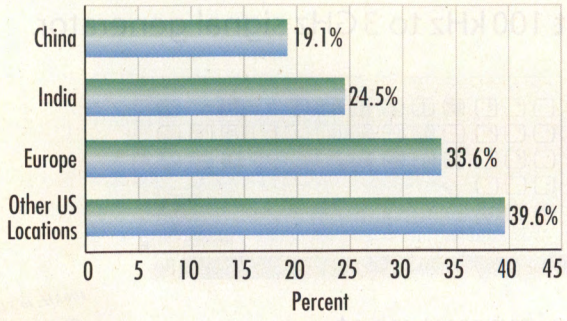


DC to 4 GHz ...
$4,600

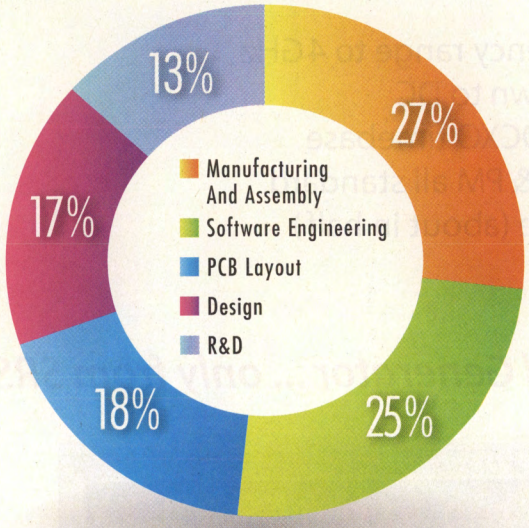
You'll even like the fine print: **US List Price $4,600. Standard features:** DC to 4.05 GHz with 1 µHz resolution. Output power from +13 dBm to −110 dBm. Phase noise of −116 dBc/Hz at 20 kHz offset from 1 GHz. A 1 s Allan variance of 1×10^{-11}. 10 MHz timebase input and output. AM, FM, ΦM, pulse modulation and sweeps from internal or external sources. Ethernet, GPIB, and RS-232 interfaces. **Option 1:** Differential clock outputs on SMAs with 35 ps transition times ($750). **Option 2:** Rear-panel SMA output for 4.05 GHz to 8.10 GHz ($750). **Option 3:** I/Q modulator with external BNC inputs ($750). **Option 4:** Rubidium timebase for 0.001 ppm/yr aging ($1500). Please visit **www.thinkSRS.com** for complete specifications.

SRS Stanford Research Systems **Tel: 408-744-9040 • www.thinkSRS.com**

WHERE DOES YOUR COMPANY OUTSOURCE ENGINEERING WORK?



WHAT DOES YOUR COMPANY OUTSOURCE?



most of this outsourcing is directed toward other locations in the United States and Europe. Surprisingly enough, about a quarter of RF engineers shared that their companies outsourced work to India more than China. This may be due to the boom of IT firms available for contract in Indian markets.

According to our respondents, the two main reasons that their companies outsourced was due to a lack of in-house talent/specialty skill and to save money. The next reasons were to save time and better utilize existing engineering resources. These responses seem to indicate that a majority of the outsourcing work may take place in a field other than RF engineering—mainly software. To note, most RF engineers—nearly 90%—were confident that their companies were not looking to outsource in the future.

For the negative effects of outsourcing, RF engineers listed fewer engineering jobs being available, lower employee morale, new hires with reduced salaries, and less opportunity for advancement. When asked if they were personally concerned about their jobs being outsourced, however, over 75% of respondents shared that they had little to no concern. This could be another indicator that the jobs being outsourced are not specifically related to RF engineering.

A LITTLE BIT ABOUT AN RF ENGINEER

Considering the RF engineers currently employed in the United States, which comprised half of our list (followed by Europe and Asia and then showing smatterings across the globe), a full quarter are working in California. They must be enjoying the weather. Surprisingly, New York State was the next-largest employer. Texas, New Jersey, Massachusetts, Maryland, and even Florida also provide significant home bases for many RF engineers.

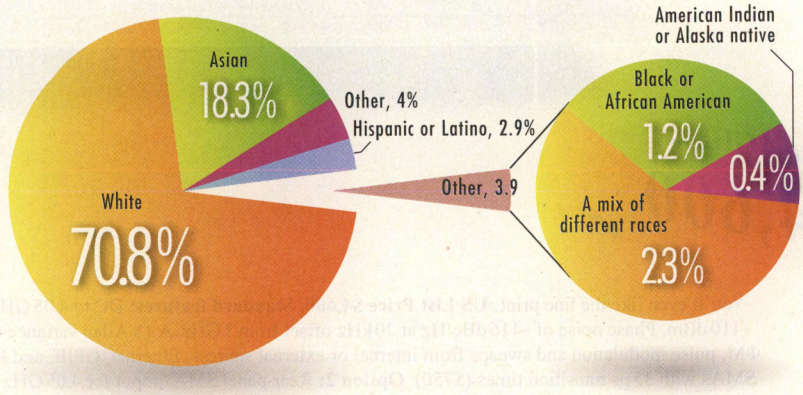
With Maryland, Massachusetts, and Pennsylvania all showing significant numbers of RF engineers, the Northeast coast is the area with the largest concentration of RF engineers. In smaller numbers, however, RF engineers are surprisingly spread out across the country. This could be the result of the majority of RF engineers working for companies that are worth less than $25 million. These smaller companies may be located in areas that are less likely to be the hubs of commerce.

In terms of schooling, RF engineers tend to be highly educated. Over half of RF engineers are equipped with either a Master's or a Doctoral degree. Another third have a Bachelor's degree and may even have had some additional graduate studies. The level of study achieved may be a factor of the lengthy stay many RF engineers have had at their companies, during which they benefited from continuing-education benefits and/or support.

A FEW STARTLING NUMBERS

RF engineers are not likely to relocate anytime soon, as the average age of the engineer who responded to our survey is 51. With almost half of the respondents older than 55—and more than half of those engineers older than 60—this could be

RF ENGINEERS DIVERSITY FACTOR



Explore the limits.

T&M solutions for aerospace and defense.

Today's aerospace and defense technologies demand ever more sophisticated test and measurement solutions to stretch the limits of what is feasible. As a full-range supplier, Rohde & Schwarz offers a broad portfolio that proves its capabilities in even the most demanding applications. Our leading-edge expertise in microwave, RF and EMC helps customers assess performance, optimize platforms and get the most out of systems. Convince yourself.

www.rohde-schwarz.com/ad/sat/pow



Technological highlights: power measurement

- Unrivaled range of easy-to-use USB sensors
- Highest precision and measurement speed
- Wideband sensors up to 44 GHz
- Thermal sensors up to 110 GHz
- Time domain measurement of radar pulses
- Ultra-fast statistical analyses

ROHDE&SCHWARZ

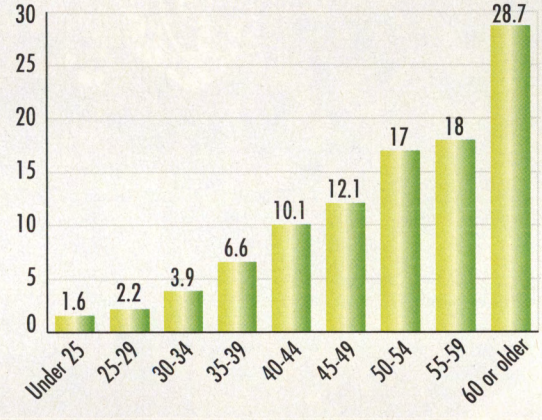
a sign of a troubling trend in our industry. There are likely to be many openings for skilled and experienced RF engineers in the next 5-10 years. In addition, most RF engineers identify as being white, which corresponds to the majority of RF engineers originating from the United States and Europe. The next largest ethnic demographic is Asian, with only a smattering of other ethnicities. The huge majority of our RF engineering respondents are also men, with women coming in at only 3%.

These demographics bring up some startling and significant truths. The diversity of RF engineers is currently very narrow. If this doesn't change, there will be fewer and fewer skilled engineers to take on the latest challenges. In our results, this gap was underscored by the total percentage of RF engineers who are younger than 30—less than 10%.

If RF engineering firms don't jump on the bandwagon by encouraging STEM education in ethnically diverse and mixed-gender environments, there may be fewer young people and students who would even consider a career in RF engineering. Meanwhile, the projections for the advancement of connectivity through communications and the wireless world are predicted to skyrocket in the next 10 to 15 years.

To fill the coming void, companies who employ RF engineers may need to bring on less skilled engineers with an interest in RF. They can then leverage the more experienced, and even retiring engineers, to coach and mentor them to a higher level of technical achievement. This method may be counter-intuitive for many organizations to employ. But as the resource of available RF engineers shrinks, so will the industry's options.

RF ENGINEERS: AN AGING POPULATION [%]



STUDENTS AND NEW HIRES

Most RF engineers seem to feel that recent graduates and students aren't adequately educated to be a productive member of the workforce. Almost half feel that these new recruits need as much as a year or more to be able to do their jobs independently upon being hired. These results coincide with RF engineers reporting that their companies appear to be hiring more engineers who were not born or raised in the United States.

The majority of RF engineers (over 70%) share the opinion that education abroad is poorer at preparing a new hire for real-world job duties. Although some of these new hires may have had some education in the United States, the majority seem to be educated abroad.

For instance, one respondent claims, "Most engineers from abroad seem to have less practical experience." Another comments, "Engineers from abroad are very heavy on theory/textbook, but have little practical knowledge." Of course, such statements may not be reflective of where the engineer was raised, as much as where they were educated. Another respondent, "Engineers we hired with either U.S. or foreign undergraduate degrees both seemed smart and competent—though they both had U.S. graduate degrees."

Most RF engineers seem to feel that US universities are focusing on the right material; they are just not enabling the students to have enough hands-on experience. In addition, almost three-quarters of RF engineers feel that internships, or cooperative education, should be mandatory for engineering education. When RF engineers work for companies that have developed a relationship with a local college or university, they believe the organization can more effectively hire new graduates with the skill sets they are seeking.

Unfortunately, less than half of RF engineering companies seem to be fostering any STEM education whatsoever. This situation may need to be change rapidly, as less and less U.S. engineers are coming from these companies' local communities.

CONTINUING EDUCATION

Consistent with many other technology fields, RF engineers mostly continue their education from engineering/technology publications. Seminars, webcasts, and white papers are also highly popular. Engineering textbooks, trade shows/conferences, and engineering association meetings also rank on the list of favorites. It's not surprising that the most accessible educational tools are the most popular, as many RF engineers confided that they are having more and more difficulty keeping current due to time constraints.

RETIREMENT

According to almost 70% of RF engineers, their companies are funding part of their retirement. The majority of this funding is in the form of a 401(k) or similar plan. Unlike many other industries, over 40% of RF engineers are also looking forward to a pension. A quarter of them enjoy either stock options or employee stock ownership.

Of course, much of this retirement assistance depends on the continuing health of these engineers' current/former employers. Given the impending lack of RF engineering knowledge, it may behoove RF engineers and their employers to enhance the drive for STEM education with youth. Otherwise, many RF companies may lack the employee base upon which they may continue to grow into the very bright future for this field. MW

Industry pros are talking about us behind our backs ...*and we love it!*



IW designs and manufactures high performance microwave cable and cable assemblies for both military and commercial markets. Applications include telecommunications, data links, satellite systems, airborne electronic warfare and counter measures, missile systems, UAV applications, avionics and instrumentation, fire control systems, medical electronics, and geophysical exploration.

We offer a wide variety of products providing extremely low attenuation at frequencies up to 67 GHz and ranging from .050 inch to 0.50 inch in diameter. Our unique PTFE lamination process, combined with our high performance shield design, has made us one of the leaders in low-loss microwave transmission lines. IW's broad range of microwave cables and connectors assures every customer the proper cable assembly for each of their specific application needs.

Our major products include:

- Low-loss microwave cables optimized for use to 11, 18, 26.5, 40, 50, and 67 GHz
- Microwave cable assemblies with connectors for SMA, TNC, N, SC, 7/16, 1.85mm, 2.4mm, 2.92mm, 3.5mm, 7mm, ZMA, SMP, SMPM & more
- RE-FLEX™ semi flexible assemblies
- TUF-FLEX™ assemblies – improved crush resistance without using armor
- Water-blocked cables for submarines
- Composite cables – combination microwave/signal/power/data
- PTFE insulated hook-up wires
- Multi-conductor cables
- Dielectric cores
- Twisted pair and triaxial cables
- Low smoke, zero halogen cable jackets
- Cable protection options such as armor, PEEK, NOMEX, Neoprene weatherproofing, PET monomer braid

AS9100:2009 and ISO 9001:2008 certified.

INSULATED WIRE, INC.
203.791.1999
www.iw-microwave.com
sales@iw-microwave.com

Scan code to find out how you can ***get connected***

We're how the microwave industry ***gets connected!***

ROHIT MITTAL and ANAND KONANUR

A top down methodology for silicon-platform optimization

With regard to short-range wireless applications, this dual-tool approach may be the best bet for ensuring rapid silicon applications and system specifications.

RECENTLY THERE HAS been an explosion of short-range wireless applications. Some well-known examples include NFC payment systems, wireless charging, and more. These applications require an interaction of electromagnetism (EM), electrical, and mechanical domains.

Unfortunately, there is no tool which can computationally solve the complete system efficiently for rapid silicon applications and system specifications. The net effect is that either the silicon is not properly specified or the system needs to be redesigned.

Traditional electrical simulators such as Spice are effective in solving lumped element equations. However, such tools cannot model EM fields present in sensors, especially when they are embedded in the vicinity of other components and a metallic chassis. Other products can solve Maxwell's equations using finite-element methods (FEM) but are woefully inefficient in importing transistor parameters.

This article presents a unified methodology which takes into account the best of both tools, creating a top-down view of a complete system. A representative system is used in demonstration, but this methodology can be extended to other interdisciplinary optimization problems.

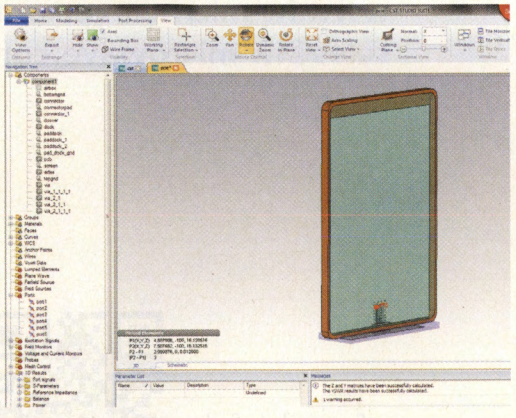
One application could involve sending a PCIe clock over a contactless system. Traditional PCIe clocks propagate from a system-on-chip (SoC) over FR4 traces to a PCIe card. There is a wealth of literature using signal integrity tools to model this effect.

However, in this scenario a docking connector for a hermitically sealed tablet is considered where PCIe signals are to be transmitted over a short-range wireless link.

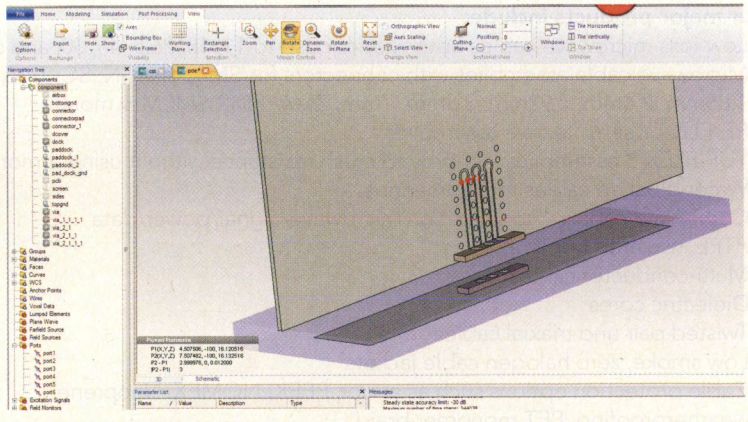
This scheme allows for more rugged tablets with no exposed contacts. Pads on the tablet capacitively couple to corresponding pads on the docking connector and enable PCIe signal and clock information to be transmitted across the wireless link *(Fig. 1)*. The big question is how to model the contactless system and specify the silicon parameters to still meet the PCIe specifications.

A 3D EM solver (CST Studio) is used to create a network model for the system—without the driver, which is in silicon *(Fig. 2)*. A six-port S-parameter reciprocal network is extracted from the full wave simulations *(Fig. 3)*. Ports 1, 2, and 3 are considered part of the tablet, while ports 4, 5, and 6 are considered part of a dock. As such, S14 or S41 would provide the path loss for signals traveling from one PCI trace to the corresponding trace on the dock.

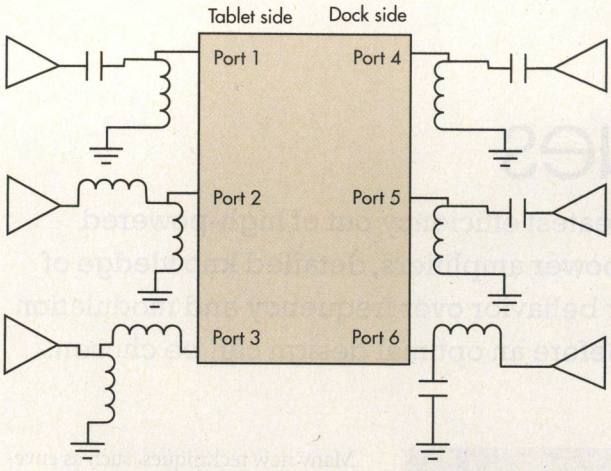
S12 would provide the coupling between ports on the same



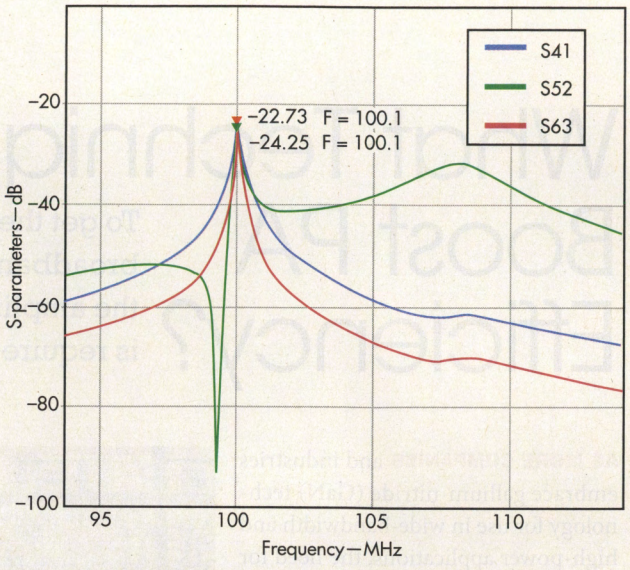
1. The tablet on dock.



2. A close-up of the dock showing sample traces on the tablet.



3. The simulated transfer parameter between ports on the tablet and corresponding ports on the dock.



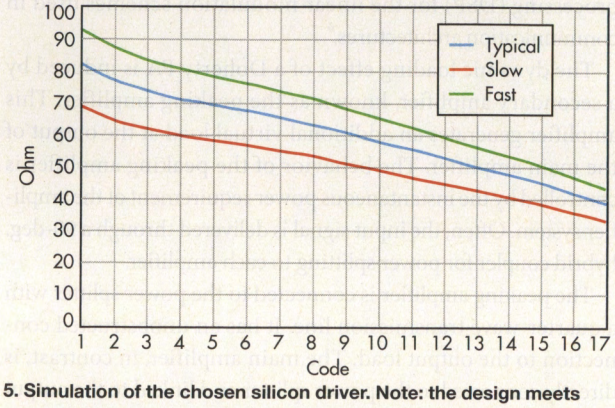
4 . Each of the ports can be appropriately matched for a band of frequencies.

tablet device and has to be minimized to reduce cross talk. Conceptually, Ports 1, 2, and 3 can be considered drivers, with ports 4, 5, and 6 being the receivers. That being said, reciprocity ensures the link is identical in the opposite direction from the dock to the tablet.

Optenni Lab (a matching circuit generation program) was used to retrieve optimal matching values for all the ports *(Fig. 4)*. It is seen that matching leads to a minimization of losses at the target frequency of 100 MHz (PCIe clock spec). The matching tool outputs a requirement of 55-Ω driver impedence. This then forms the basis of silicon specification.

Once the impedence matching required for maximum power transfer through the link is known, it is feasible to specify the silicon parameters. In addition, a sensitivity analysis can be performed to measure the range required on the impedance—to account for both silicon skew as well as system variation over manufacturing tolerances, temperature, humidity, voltage, and more.

In order to model the silicon, an electrical simulator Spice is required. Spice allows a transistor-level representation of the driver, which can take the device-level parameters into account. It can also do a much better job modeling manufacturing tolerance, voltage, and other factors. The desired impedence range also enables the right architecture for this application *(Fig. 5)*.



5. Simulation of the chosen silicon driver. Note: the design meets optimal impedence requirement over process skew of transistors.

Lastly the transistor-level model can be assembled with the s2p model of the link to build a complete end-to-end system. This enables a non-linear transient simulation to be performed to measure slew rates and large signal reflections.

CONCLUSION

The continuing advances in both silicon modeling, circuit simulators, and 3D EM simulators have meant that increasingly a design team has access to simulation and computer tools. These tools allow for a robust co-design of silicon, PCB, and system design.

This article uses a hypothetical example of transmitting PCI-e clock over an air interface to describle one such co-design possibility using Spice for circuit modeling, CST for 3D EM modelling, and Optenni for impedance matching.

The rapid miniaturization of consumer devices coupled with the use of challenging materials such as an all-metallic chassis and severe-power-consumption constraints has meant that complete system design is required to converge on performance targets.

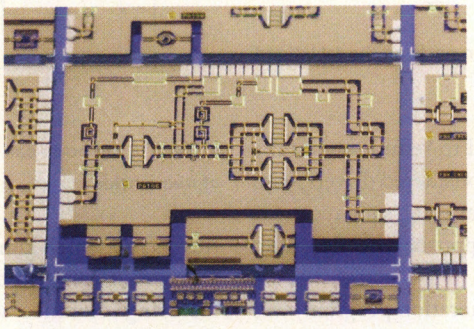
The maturation of computer tools across the workflow has meant that there are multiple off the shelf tools to accomplish this co-design flow. These tools are available even for traditionally low cost designs, such as those used for consumer devices, tablets, phones, and wearables. MW

JEAN-JACQUES DESLISE | Technical Editor

What Techniques Boost PA Efficiency?

To get the greatest efficiency out of high-powered broadband power amplifiers, detailed knowledge of the amplifier behavior over frequency and modulation is required before an optimal design can be chosen.

AS MORE COMPANIES and industries embrace gallium-nitride (GaN) technology for use in wide-bandwidth and high-power applications, the need for power-efficient and compact typologies is increasing. Booming areas for RF/microwave applications include portable electronics, electronic warfare (EW)/military, and wireless infrastructure. For all of these applications, the efficiency of a power amplifier's (PA's) operation is critical. GaN's performance capability has required some significant ingenuity on the part of design engineers to take this technology to the next level of efficiency and deployability.



1. To implement a GaN X-band PA, many microstrip, resonant, and lumped-element filters and matching networks are required. *(Courtesy of Leibniz Ferdinand-Braun-Institut)*

GaN technology is very flexible and robust, which has led to significant discussions on how a designer can cleverly manipulate the greatest efficiency and power dissipation from this highly promising semiconductor. "For example, GaN devices/amplifiers are routinely operating at 50 V with efforts pushing this to 65 V," notes Timothy Boles, technology fellow and director of strategy for MACOM (www.macom.com). "Since power equals current multiplied by voltage for a fixed output power, doubling the supply voltage will mean that the amplifier can be designed with a device the only requires half to one-fifth of the current compared to other active-device material systems."

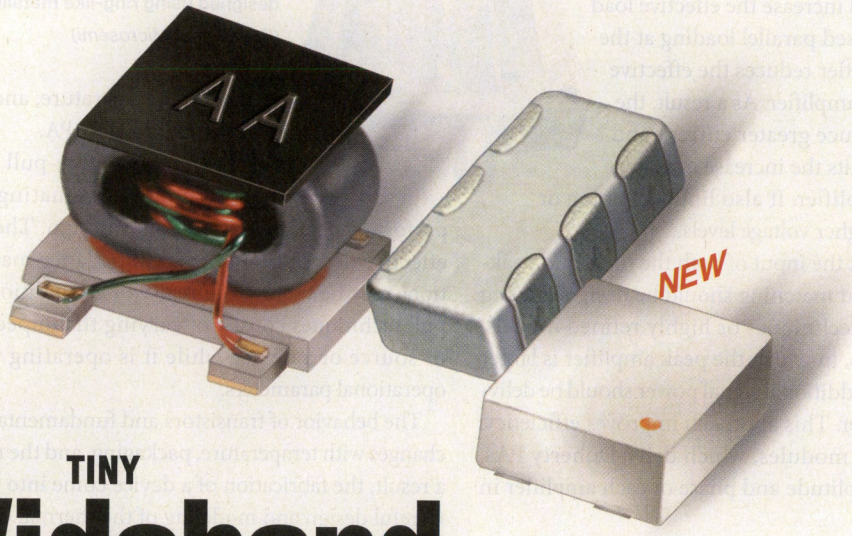
A few major factors relate to the efficiency of a power amplifier: typology, impedance matching, thermal management, input bias, and bandwidth. Also, several parameters require a tradeoff when considering increasing the efficiency—namely linearity, modulation accuracy, gain, spectral regrowth, size, and cost. It helps to know the dynamics of these design considerations as well as the tradeoffs to drive the best performance from a PA. With many military organizations switching to commercial-off-the-shelf (COTS) components, these concerns also impact the military organizations looking to increase their tactical networking capability to better compete on the modern battlefield.

Many new techniques, such as envelope tracking (ET) and digital pre-distortion (DPD), enhance PA efficiency. But hardware-level efficiency will still limit the maximum efficiency of the device. For this reason, designers have sought PA circuit designs that could enable greater efficiency while being dependent upon the instantaneous power requirement of the transmitted signal. A typology that has experienced increased adoption is the Asymmetric Doherty PA or Doherty PA.

The Doherty typology is used to induce a loading effect on the output of a PA—generally a Class-B main amplifier and Class-C peaking amplifier. That load is then adjusted to an optimized efficiency curve based upon the RF signal level. According to Mark Faulkner, vice president, RF Integrated Solutions Engineering for Microsemi (www.microsemi.com), "Though a bit tricky to design, lower-frequency narrowband microwave amplifiers in a Doherty configuration with a peaking amplifier and a carrier amplifier demonstrate great efficiency. The Doherty is highly nonlinear and may require additional digital signal processing (DSP) for the linear modulation schemes used in communication architectures."

The dynamic loading effect of a Doherty PA is induced by a secondary amplifier, known as the peaking amplifier. This amplifier generates an additional virtual load at the output of the main amplifier. The behavior of the peaking amplifier is controlled by the instantaneous power requirement of the amplifier system. Often, the input signal is delivered through a 90-deg. hybrid coupler for power splitting to each amplifier.

The peaking amplifier is connected to the power splitter with a quarter-wave transmission line. It has an unobstructed connection to the output load. The main amplifier, in contrast, is directly connected to the power splitter and linked to the output load through a quarter-wave transmission line. This configura-



TINY

Wideband Transformers & Baluns!

NOW!

4 kHz - 18 GHz From 99¢ ea.(qty.20)

To support an even wider range of applications, Mini-Circuits tiny surface-mount transformers and baluns now cover frequencies up to 18 GHz! Our latest designs achieve consistent performance across very wide frequency bands, and our baluns have demonstrated great utility for chipsets. With over 250 trusted models in stock representing a wide selection of circuit topologies and impedance ratios, chances are, we have a solution for your needs!

Our Low Temperature Co-Fired Ceramic (LTCC) models provide reliable performance in tough operating conditions, tiny size – as small as 0805 – and very low cost. All core-and-wire models are available with our exclusive Top Hat™ feature, improving pick-and-place accuracy and throughput. We even manufacture our own transmission wire under rigorous control and use all-welded connections to ensure reliability and repeatability you can count on.

Visit minicircuits.com and use **Yoni2™**, our patented search engine to search our entire model database by performance criteria and find the models that meet your requirements. Order today and have them in hand as soon as tomorrow! Cost-effective custom designs and simulations with fast turnarounds are just a phone call away!



TC
0.15" x 0.15"



NC
0.08 x 0.05"
Ceramic



NCR2
0.08 x 0.10"
Ceramic

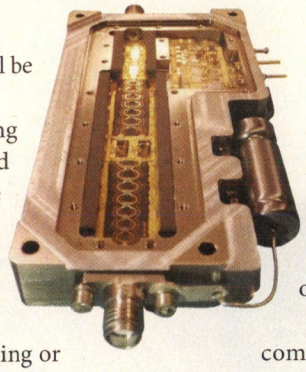
RoHS compliant.

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

tion ensures that the signals from each amplifier will be delivered in-phase to the load.

Under large-power signal conditions, the peaking amplifier will turn on and increase the effective load at the output. The increased parallel loading at the output of the main amplifier reduces the effective load as seen by the main amplifier. As a result, the main amplifier can produce greater current and power. This approach limits the increase in voltage output for the main amplifier. It also limits clipping or increased distortion at higher voltage levels.



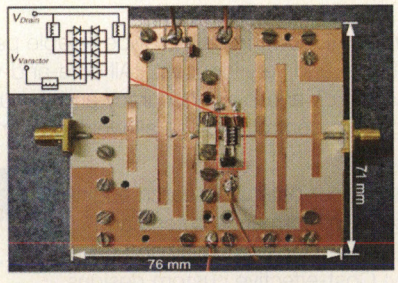
2. The Wilkenson and branchline coupler typologies for power combining require a high number of quarter-wave transformers, which are often designed using ring-like metallic structures. *(Courtesy of Microsemi)*

Matching is required at the input of both the main and peaking amplifiers. The output matching should be designed using sophisticated load-pull techniques or highly refined models. For Doherty design cases, in which the peak amplifier is larger than the main amplifier, additional signal power should be delivered to the peak amplifier. This approach improves efficiency. Commercially available modules, which drive Doherty PAs, enable control of the amplitude and phase of each amplifier in the configuration.

The Asymmetric Doherty configuration can generally achieve an increased average efficiency of greater than 50%. In contrast, an ideal Class-B amplifier—with an average efficiency of 27% and a symmetric Doherty configuration— often exhibits 5% less efficiency than an Asymmetric Doherty.

Beyond Asymmetric Doherty typologies, there are other multi-amplifier typologies that can increase efficiency beyond the capability of a single-amplifier architecture. "Another high-efficiency topology, given enough drain-voltage headroom, is the shared current topology," says Faulkner. "The efficiency of a balanced amplifier stage can be doubled by sharing the current between the upper and lower devices. Using this stack topology, half of the drain voltage is dropped across the top device with a DC-elevated source and gate voltage."

Input and output impedance matching is another critical stage in the design of a PA, as the bandwidth, frequency, and load impedances all dictate the specification requirements for the matching circuitry. GaN devices benefit from greater efficiency in these stages, which is partially due to the decreased current through the matching circuitry. This, in turn, reduces current and resistive losses through the conductors of the matching elements.



3. Microstrip and stripline impedance-matching networks are commonly employed at the input and output of a PA, as the raw-metal geometries can often perform better than variable lumped-element typologies. *(Courtesy of Cree)*

The lower current also reduces high-frequency losses in the combining/transformation networks. However, adapting matching circuitry for GaN devices does become more complicated as a function of the effects of increased voltage swing, bandwidth, temperature, and low impedance on the output of a GaN PA.

Load-pull and source-pull techniques are a common method for evaluating the impedance performance parameters of a PA design. They also enable an effective description of what impedance matching specifications may be required in real-world conditions. Load/source-pull techniques consist of varying the impedance at the load or source of a device while it is operating under predicted operational parameters.

The behavior of transistors and fundamental circuit elements changes with temperature, packaging, and the materials used. As a result, the fabrication of a device come into play significantly. Careful design and modeling of the thermal characteristics of a package and its material components is becoming more relevant. As PAs shrink in size and power efficiency, thermal performance is becoming a more critical feature.

"Both materials and packaging are key to a reliable and efficient design," says Faulkner. "The thermal design goal is to create a low-thermal-resistance path from the GaN-transistor junction to the system heatsink, which might be metal fins in a convective airflow. Typically, these low-thermal-resistance materials are further constrained to also match the expansion coefficient of GaN. Depending on the device size and bonding material, copper (Cu), copper tungsten (CuW), and copper-molybdenum (CuMo) are often used in this low-thermal-resistance path."

Although thermal characteristics largely contribute to a package's thermal behavior, several design techniques can lead to more thermally efficient assemblies. Faulkner continues, "This path must also be uninterrupted, meaning channels and voids to route DC cannot be located under the devices. Assembly processes and equipment must ensure that voiding in the attach material, which bonds the GaN to the package, is minimized."

As the performance of GaN and other high-powered, high-frequency, and compact devices continues to advance, designers will increasingly be forced to delve into the minute details of a device's design. Fortunately, software and computerized tools also are increasing in capability. Soon, design engineers may find that they are relying more on these tools. MW

HIGH POWER

5 - 500 WATTS PRODUCTS

POWER DIVIDERS RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.] ▫	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3.0	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	2	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	2	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316
4-WAY								
CSDK3100S	30 - 1000	0.7 / 1.1	0.05 / 0.2	0.3 / 2.0	28 / 20	1.15:1	5	169S

▫ With matched operating conditions

HYBRIDS RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS RoHS

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

* Add suffix - LF to the part number for RoHS compliant version.
▫ With matched operating conditions

Unless noted, products are RoHS compliant.

SYNERGY® MICROWAVE CORPORATION

Phone: (973) 881-8800 | Fax: (973) 881-8361
E-mail: sales@synergymwave.com
Web: WWW.SYNERGYMWAVE.COM
Mail: 201 McLean Boulevard, Paterson, NJ 07504

Design Feature

LONG XIAO | Engineer
e-mail: XL740512@126.com

HAO PENG | Engineer
e-mail: ph1984.1.25@163.com

TAO YANG | Engineer
e-mail: tyang@uestc.edu.cn

School of Electronic Engineering, University of Electronic Science and Technology of China, Chengdu, People's Republic of China, 611731,

UWB POWER Has Stopband Filtering

This multilayer power divider features good impedance matching at all ports with high isolation and excellent amplitude and phase balance across a wide bandwidth.

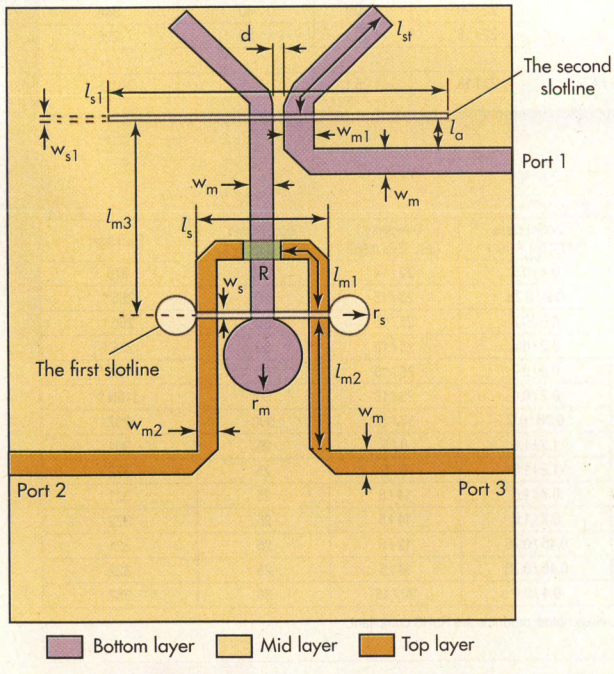
A power divider with bandpass response and high isolation between ports was developed for use in ultrawideband (UWB) communications systems. The design, which incorporates two slotline resonators, achieves excellent amplitude and phase balance between channels and ports.

Featuring a frequency range of 3.8 to 10.0 GHz, is well suited for UWB applications. One of the resonators helps improve isolation between output ports, while the other helps generate a tunable transmission zero so that a wide upper stopband could be obtained.

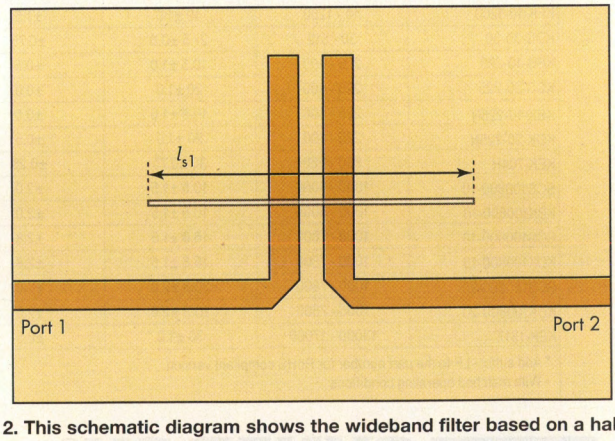
Interest in UWB systems and components has increased steadily since about 2002, when UWB communications systems concepts were first introduced and developed. A number of components for UWB applications have been designed and fabricated since that time.[1-6] Power dividers are among the most crucial of RF/microwave devices, since signals must be split and channeled through communications signals for proper detection and processing.

To meet the requirements for UWB systems, a number of UWB power dividers have been developed, with different configurations based on traditional Wilkinson power dividers.[7-9] For the sake of shrinking the dimensions of power dividers for UWB applications, slotline techniques have been studied and applied.

As an example, a single-wavelength slotline was applied to structure a noncoplanar, in-phase UWB compact power divider with a flat passband over the UWB frequency range.[10] By adding one circular stub at the end of each output branch



1. This diagram shows the parameters of the UWB power divider as used for simulations with the HFSS finite-element software.



2. This schematic diagram shows the wideband filter based on a half-wavelength slotline that is incorporated into the UWB power divider.

DIVIDER

as compensatory circuits, it was possible to extend the operating frequency range of the power divider, and also helped to achieve a flat passband.[11,12]

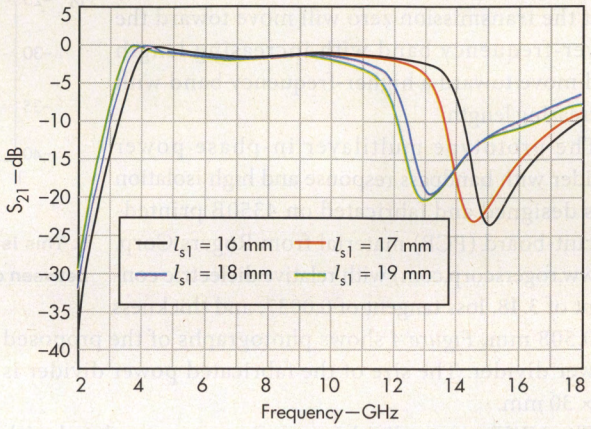
However, due to the inherent properties of three-port networks, a lossless and reciprocal three-port network cannot obtain good impedance matching at all ports simultaneously. As a result, for the UWB power divider designs that had been developed with slotline techniques, the impedance matching at the output ports was poor, with low isolation between output ports.

Even worse, the bandwidths of the stopbands for these designs were relatively narrow,[13,14] enabling undesired signals to enter into systems employing these UWB power dividers. Of course, additional filtering can be added to the systems to suppress the unwanted signals, but this adds to the cost of the system.

To meet the needs of UWB systems for power dividers at reduced costs and compact sizes, a novel compact in-phase multilayer power divider with wide stopband was designed using slotline techniques. The output branches of the proposed UWB power divider are placed on the same layer symmetric to the input arm to achieve in-phase output signals.

To improve the impedance-matching limitations that are traditionally suffered by UWB power dividers based on slotline techniques, an isolation resistor was added to the power divider circuitry as used in a traditional Wilkinson power divider. To obtain a wide stopband with the power divider, a one-half-wavelength slotline resonator was placed at the input port to generate another transmission zero in the stopband, resulting in a wide stopband range.

The results from computer simulations and measurements



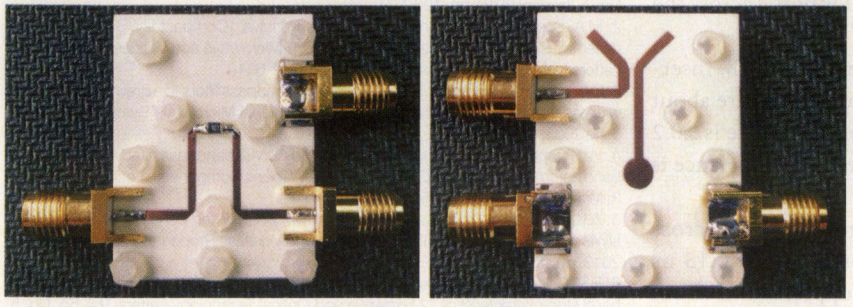
3. The plot shows the frequency response for the slotline as a function of length.

agree quite closely for this UWB power divider, showing that the multilayer circuit design achieves good impedance matching at all ports, with high isolation between ports and excellent amplitude and phase balance between output ports over the UWB frequency range from 3.8 to 10.0 GHz.

Figure 1 shows the configuration of the proposed in-phase UWB power divider, which consists of three layers (top, middle, and bottom layers). The input port (1) is located in the bottom layer, while the output ports (2 and 3) are placed in the top layer.

The slotlines are etched in the middle layer, which is the ground plane. The length of the first slotline is decreased relative to slotlines used in previous UWB power-divider designs so that an isolation resistor could be installed at the ends of the output branches.

Two short-circuited circular slotline stubs and one open-circuited circular microstrip stub, which act as compensatory circuits, were included to reduce passband amplitude ripple. The short microstrip stubs at the ends of the output branches can also help increase the passband flatness, at the same time making installation of the isolation resistor easier.

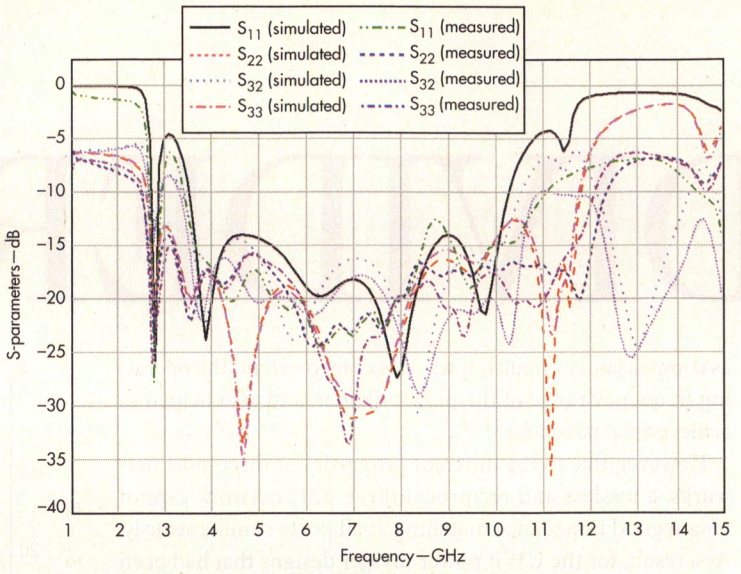


4. Above, the UWB power divider as it is fabricated on commercial PCB material.

Figure 2 shows the half-wavelength slotline resonator, consisting of a UWB filter with microstrip lines. This filter can achieve several transmission poles for an UWB operating frequency range and generate one transmission zero at stopband. By adjusting the length of the slotline, the transmission zero will shift towards a high-frequency band or a low-frequency band.

Figure 3 offers simulated results for the UWB filter designed for this power divider, indicating that the transmission zero will move toward the lower-frequency band with increasing length and move toward a higher-frequency band with decreasing length.

The prototype multilayer in-phase power divider with bandpass response and high isolation was designed and fabricated on 4350B printed-circuit-board (PCB) material from Rogers Corp. (www.rogerscorp.com) with relative dielectric constant of 3.48, loss tangent of 0.0037, and thickness of 0.508 mm. *Figure 4* shows photographs of the proposed power divider. The size of the fabricated power divider is 24 × 30 mm.



5. This is the return loss for the UWB power divider at all ports and isolation between output ports.

The UWB power divider was computer simulated with the aid of Version 13.0 High Frequency Structure Simulator (HFSS) electromagnetic (EM) finite-element simulation software from ANSYS Corp (www.ansys.com). The dimensions of the power divider's parameters from the simulation software (and as detailed in *Fig. 1*) are: w_m = 1.15 mm, w_{m1} = 1.4 mm, w_{m2} = 0.91 mm, d = 0.5 mm, l_{st} = 6.92 mm, l_a = 1.72 mm, l_{s1} = 16.09 mm, l_s = 6.21 mm, l_{m1} = 4.93 mm, l_{m2} = 6.64 mm, l_{m3} = 9.62 mm, w_s = 0.23 mm, w_{s1} = 0.26 mm, r_s = 0.93 mm, and r_m = 1.86 mm.

The isolation resistor is R = 100 Ω. For the sake of compatibility with other systems, the port impedances are fixed at 50 Ω.

Figures 5, 6, and 7 provide comparisons of simulated and measured results for the UWB power divider, showing fairly good agreement across the wide frequency range. In fact, light differences can be traced from machining errors. The measured return losses are more than 17 dB for port 1, more than 15.5 dB for port 2, and more than 15.4 dB for port 3 across the frequency band from 3.8 to 10.0 GHz.

Isolation between output ports is better than 16 dB. Insertion losses, including losses from SMA connectors, are about 1 ± 0.7 dB and 1 ± 0.6 dB. The amplitude unbSalance is ±0.2 dB for the same frequency range while the phase unbalance is about ±2 deg.

In addition, the group delay exhibits good flatness across the bandwidth, with maximum difference of just 0.13 ns across the wide frequency band. Signal suppression is about 20 dB for the frequency band from 11.5 to 17.5 GHz, and attenuation reaches 20 dB at 2.5 GHz, ensuring that the power divider can reject undesired signals.

As was demonstrated, it is possible to construct a novel in-phase multilayer power divider with a bandpass response and high isolation by using slotline techniques. The width of the stopband was successfully extended by introducing a one-half-wavelength slotline resonator to the power-divider circuitry.

The measured and simulated results for the UWB power divider show good impedance matching at all ports by introducing one resistor at the ends of the output branches. The UWB power divider shows good amplitude and phase balance between its output ports from 3.8 to 10.0 GHz, making it a suitable candidate for a variety of UWB applications. mw

ACKNOWLEDGMENTS

This work was sponsored by the National Natural Science Foundation of China (Grant No. 61006026) and the Fundamental Research Funds for the Central Universities (Grant No. ZYGX2012J030).

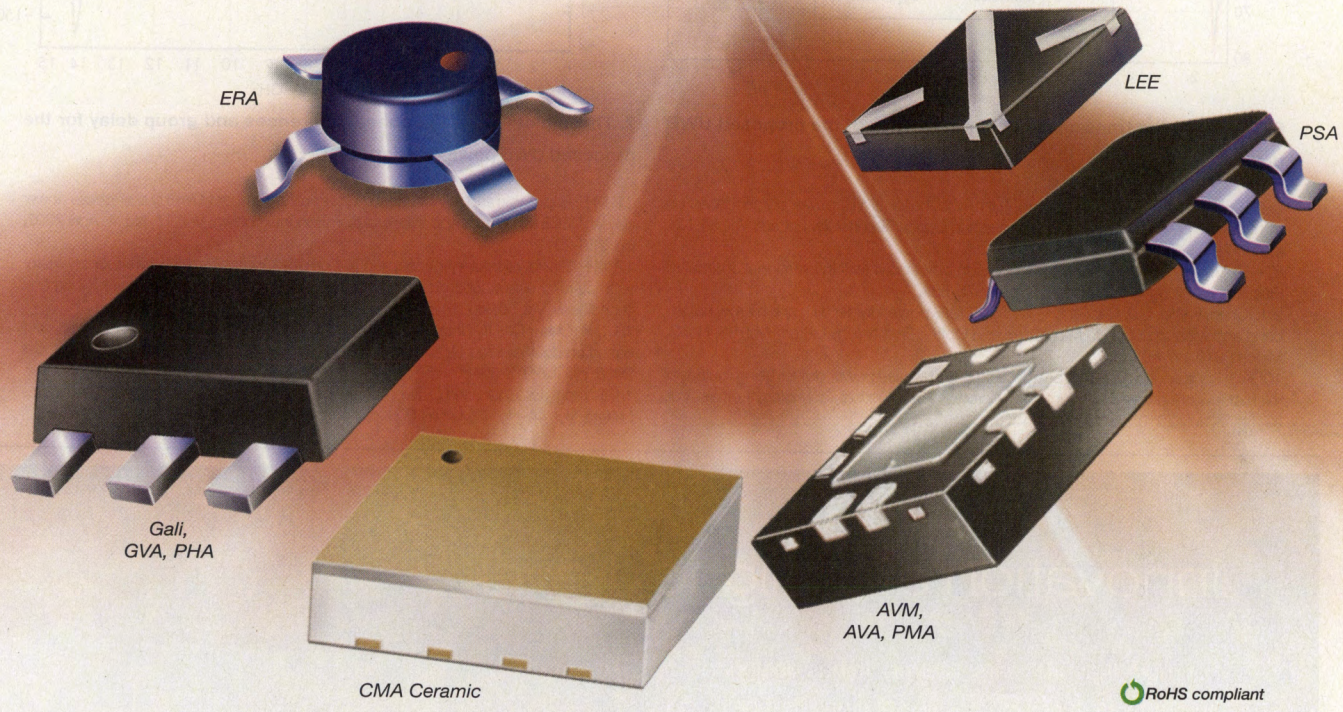
REFERENCES

1. A.M. Abbosh, "Ultra-wideband three-way power divider using broadside-coupled microstrip-coplanar waveguide," Microwave and Optical Technology Letters, Vol. 54, No. 1, January 2012, pp. 196-199.
2. M.A. Sanchez-Soriano and G. Torregrosa-Penalva, "Compact UWB bandpass filter based on signal interference techniques," IEEE Microwave and Wireless Components Letters, Vol. 19, No. 11, November 2009, pp. 692-694.
3. C.L. Hsu, F.C. Hsu, and J.T. Kuo, "Microstrip bandpass filters for ultrawideband (UWB) wireless communications," IEEE MTT-S International Microwave Symposium Digest, June 2005, pp. 12-17.
4. H. Shaman and J.S Hong, "Ultrawideband (UWB) bandpass filter with embedded band notch structures," IEEE Microwave and Wireless Components Letters, Vol. 17, No. 3, March 2007, pp. 193-195.
5. A.K. Gautam, S. Yadav, and B.K. Kanaujia, "A CPW-fed compact inverted L-strip UWB microstrip antenna," IEEE Antennas and Wireless Propagation Letters, Vol. 12, 2013, pp. 151-154.
6. P.N. Shinde and B.K. Mishra, "Compact thin ground plane UWB antenna with dual band stop characteristics," Microwave and Optical Technology Letters, Vol. 55, No. 5, May 2013, pp. 1045-1049.

MMIC AMPLIFIERS

NOW!

DC to 26.5 GHz from 73¢ qty.1000



NF from 0.5 dB, IP3 to +48 dBm, Gain from 8 to 39 dB, Pout to +30 dBm

Now with over ~~145~~ 170 MMIC amplifier models covering frequencies from DC to 26.5 GHz*, chances are, Mini-Circuits has your application covered. Our ultra-broadband InGaP HBT and PHEMT amplifiers offer one of the industry's broadest selections of gain, output power, IP3, and noise figure to optimize your commercial, industrial, or military system performance. They can even meet your most critical size and power requirements with supply voltages as low as 2.8V, current consumption as low as 16mA, and packages as small as SOT-363 (1.35 x 2.25mm). Our tight process control guarantees consistent performance across multiple production runs, so you can have confidence in every unit.

Visit minicircuits.com and use our Yoni2™ search engine to search our entire model database by performance criteria for the model that meets your needs. You'll find pricing, full model specs, characterization data, S-parameters, and even free samples of select models! So why wait? Place your order today, and have units in your hands as soon as tomorrow!

*Low-end frequency cut-off determined by external coupling capacitors and external bias choke.

Yoni2™ Searching millions of actual data points to meet your specific requirements.

U.S. Patents 7739260
7761442

EZ To Get SAMPLES

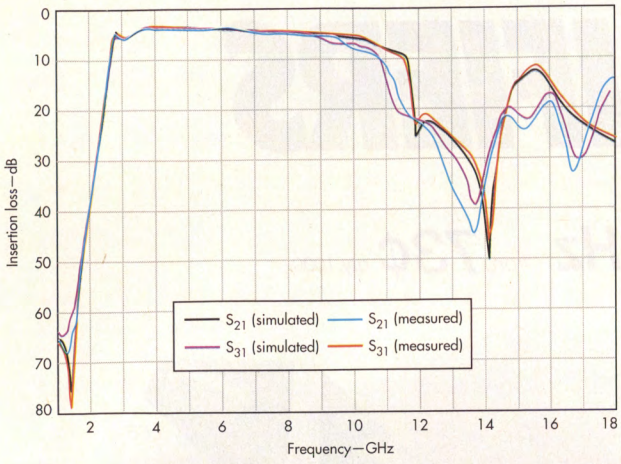
FREE Samples On Demand!

www.minicircuits.com/products/ez_samples.shtml

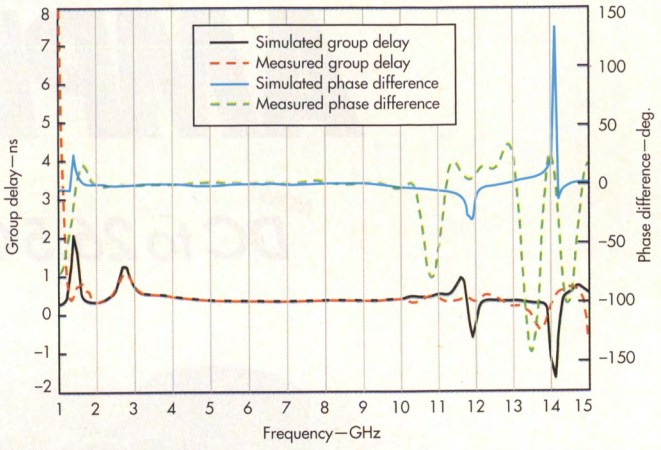
Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

476 Rev K



6. These are the transmission characteristics of the proposed UWB power divider.



7. These plots show the phase differences and group delay for the proposed UWB power divider.

7. C.L. Zhuge, K.J. Song, and Y. Fan, "Ultra-wideband (UWB) power divider based on signal interference techniques," Microwave and Optical Technology Letters, Vol. 54, No. 4, April 2012, pp. 1028-1030.
8. A.R. Hazeri, "An ultrawideband Wilkinson power divider," International Journal of Electronics, Vol. 99, No. 4, April 2012, pp. 575-584.
9. L. Chen, F. Wei, C.J. Gao, and W.Q. Wu, "UWB power divider with one narrow notch-band and wide stop-band," Microwave and Optical Technology Letters, Vol. 55, No. 3, March 2013, pp. 597-600.
10. K.J. Song and Q. Xue, "Ultra-wideband out-of-phase power divider using multilayer microstrip-slotline coupling structure," Microwave and Optical Technology Letters, Vol. 52, No. 7, July 2010, pp. 1591-1594.
11. M.E. Bialkowski and A.M. Abbosh, "Design of a compact UWB out-of-phase power divider," IEEE Microwave and Wireless Components Letters, Vol. 17, No. 4, April 2007, pp. 289-291.
12. M.E. Bialkowski, A.M. Abbosh, and N. Seman, "Compact microwave six-port vector voltmeters for ultrawideband applications," IEEE Transactions on Microwave Theory and Techniques, Vol. 55, No. 10, October 2007, pp. 2216-2223.
13. J.X. Chen, C.H.K. Chin, K.W. Lau, and Q. Xue, "180°out-of-phase power divider based on double-sided parallel striplines," Electronics Letters, Vol. 42, No. 21, October 2006, pp. 1229-1230.
14. T. Yang, J.X. Chen, and Q. Xue, "Three-way out-of-phase power divider," Electronics Letters, Vol. 44, No. 7, March 2008, pp. 482-483.



TDK

Talk to TDK for leading ideas in SAWs.

Superior SAW components are crucial for signal quality in communications. TDK supports you with the most advanced EPCOS SAW components:

- Discrete SAW filters
- Combined filter products that unite multiple filter functions in a single, space-saving component
- Ultra-miniaturized modules that integrate discrete filters and duplexers in RF modules manufactured to customer- and application-specific criteria.

Count on TDK for innovative SAW components for demanding applications:

- Automotive: Remote keyless entry, tire-pressure monitoring, automotive telematics/navigation, and automotive toll systems
- Industrial: Advanced metering infrastructure, container tagging, fire and burglar alarms, and radio modules.
- Home: Wireless switches, garage door openers, wireless audio, and remote controls.

Download free brochures at www.epcos.com/publications_saw.





www.epcos.com

Design Feature

WANG MAOWEN | Professor CAO JIANZHONG | Professor PENG WENJUAN | Professor

Huizhou University, Department of Electronic Science, Huizhou City, Guangdong Province, People's Republic of China; e-mail (Maowen): wangfan198@qq.com, www.hzu.edu.cn

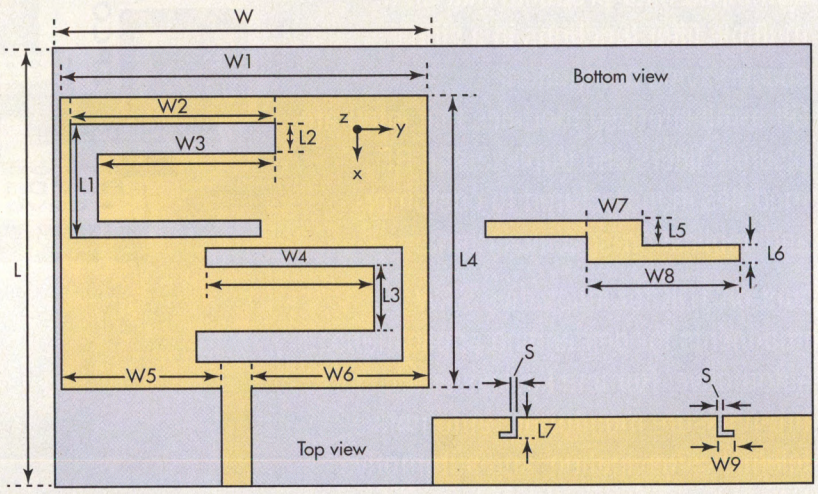
Slot Antenna Tames Three Wireless Bands

This novel antenna design incorporates a pair of U-shaped slots to handle three frequency bands at 2.45, 2.64, and 3.44 GHz for different wireless applications.

Expanding wireless applications are creating unprecedented needs for equipment (such as antennas) at different frequency bands, as well as for different applications. Fortunately, a novel antenna was developed capable of handling three separate wireless bands within the same compact structure.

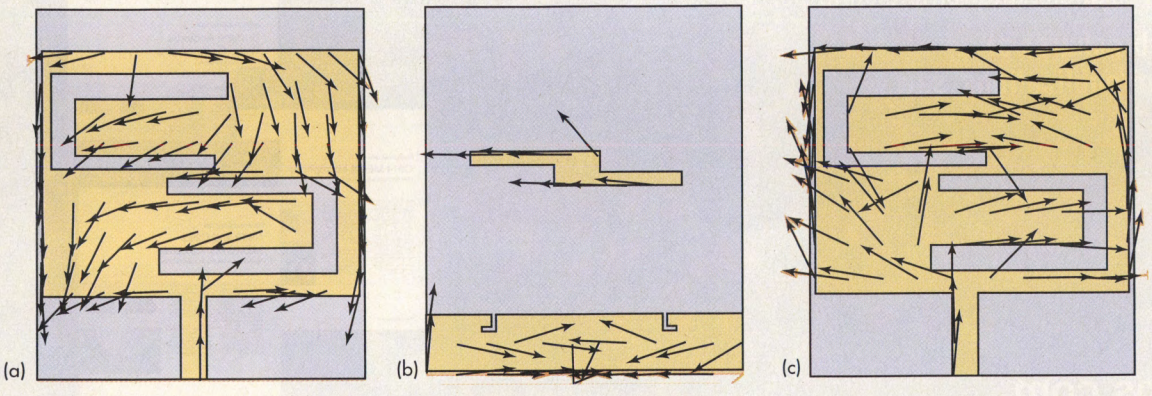
The antenna structure in question consists of two U-shaped slots in a rectangular patch and a Z-shaped strip at the ground plane. It can handle three distinct frequency bands centered at 2.45, 2.64, and 3.44 GHz for wireless communications applications. The two U-shaped slots support two of the frequency bands, while the Z-shaped strip is used for the other resonant frequency.

The antenna, which is printed on low-cost FR-4 substrate material with thickness of 0.8 mm and relative dielectric constant of 2.95, has overall dimensions of 34.5 × 40.0 mm. Simulation and measurement results show that the proposed antenna configuration can be applied to applications in wireless local area networks (WLANs), Fourth-Generation (4G) cellular equipment, and WiMAX devices with almost omnidirectional radiation patterns.

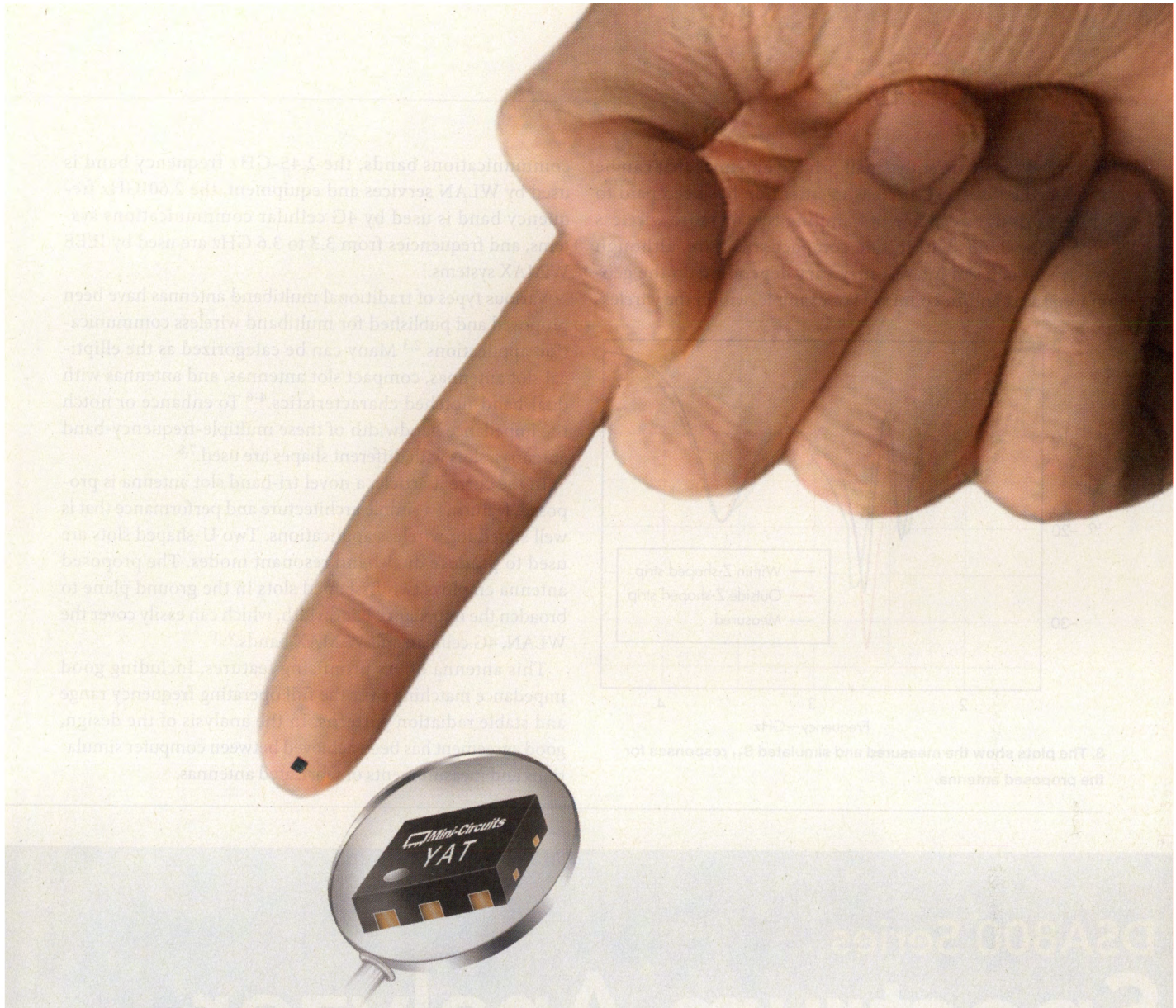


1. These illustrations show the top (left) and bottom (right) views and dimensions of the proposed antenna.

As wireless applications have spread, requirements have



2. The surface current distributions for the proposed antenna can be seen here at (a) 2.45 GHz, (b) 2.64 GHz, and (c) 3.44 GHz.

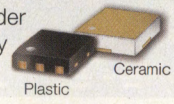


Ultra Small 2x2mm

2W ATTENUATORS DC-20GHz from $1.99 ea.(qty. 1000)

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

The ceramic hermetic ***RCAT*** family is built to deliver reliable, repeatable performance from DC-20GHz under the harshest conditions. With prices starting at only $4.95 ea. (qty. 20), these units are qualified to meet MIL requirements including vibration, PIND, thermal shock, gross and fine leak and more, at up to 125°C!



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

For more details, just go to minicircuits.com – place your order today, and you can have these products in your hands as soon as tomorrow!

RoHS compliant

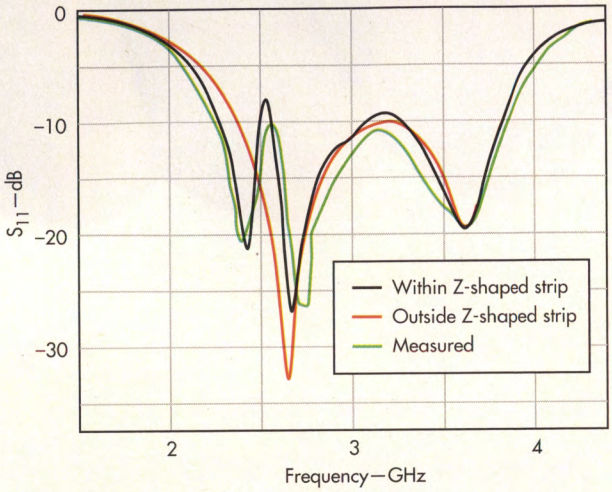
FREE Simulation Models! Modelithics®

http://www.modelithics.com/mvp/Mini-Circuits/

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

increased for sufficiently small printed antennas that can be produced at low cost. Increasing attention has been paid to antenna designs capable of handling two or more wireless frequency bands within one compact structure, although the frequencies of interest may vary depending on the geographic area and/or country.[1] For example, within the wireless communications bands, the 2.45-GHz frequency band is used by WLAN services and equipment, the 2.60-GHz frequency band is used by 4G cellular communications systems, and frequencies from 3.3 to 3.6 GHz are used by IEEE WiMAX systems.



3. The plots show the measured and simulated S_{11} responses for the proposed antenna.

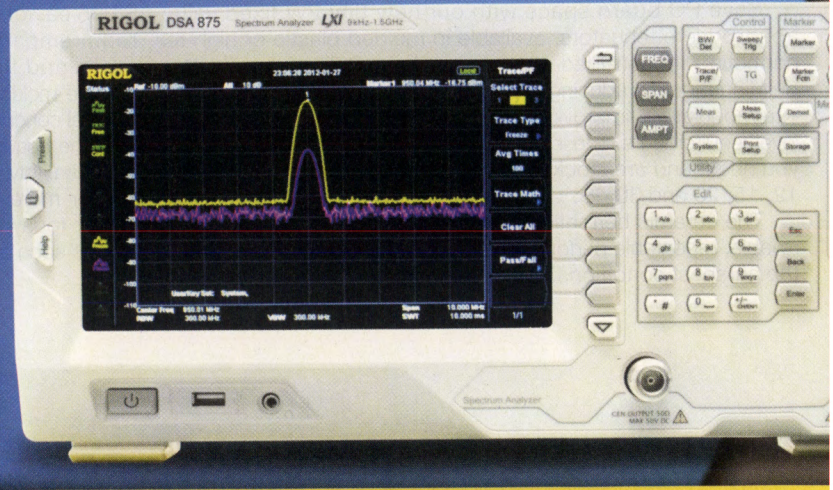
Various types of traditional multiband antennas have been proposed and published for multiband wireless communication applications.[2,3] Many can be categorized as the elliptical slot antennas, compact slot antennas, and antennas with dual-band-notched characteristics.[4-6] To enhance or notch the impedance bandwidth of these multiple-frequency-band antennas, slots with different shapes are used.[7,8]

In the current article, a novel tri-band slot antenna is proposed, featuring a simple architecture and performance that is well suited for wireless applications. Two U-shaped slots are used to produce dual-band resonant modes. The proposed antenna employs two L-shaped slots in the ground plane to broaden the impedance bandwidth, which can easily cover the WLAN, 4G cellular, and WiMAX bands.[9,10]

This antenna offers promising features, including good impedance matching over the full operating frequency range and stable radiation patterns. In the analysis of the design, good agreement has been achieved between computer simulations and measurements of fabricated antennas.

DSA800 Series
Spectrum Analyzer
Ideal for WiFi & 2.4 GHz Apps

- 3 Models with Frequencies to 1.5 GHz, 3.2 GHz & 7.5 GHz
- DANL of -161dBm (typ) Normalized to 1 Hz
- Available Tracking Generator
- EMI and VSWR Packages
- View 3rd Harmonic of 2.4 GHz Wireless Signals
- Models Starting at $1,295

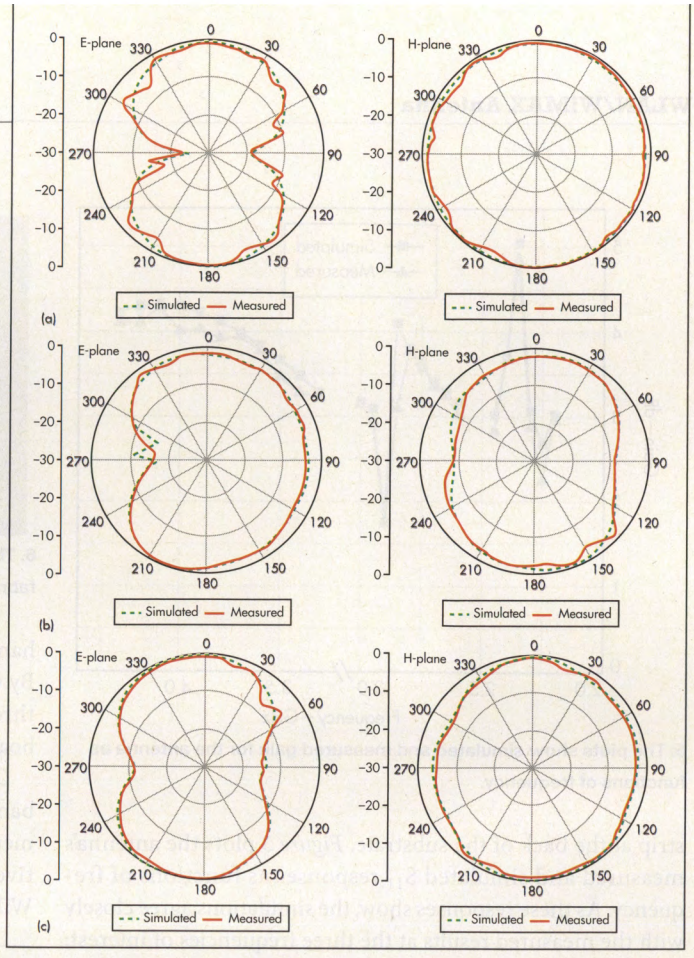


Visit RigolRF.com or call 877-4-RIGOL-1

Figure 1 shows the configuration of a triband slot antenna as well as the coordinate axis. The antenna is printed on FR-4 substrate with thickness of 0.8 mm, relative permittivity of 4.3, and loss tangent of 0.02. The antenna is fed by means of a 50-Ω signal strip transmission line. Two U-shaped slots in the rectangular radiating patch generate two resonant modes, while the other resonant frequency is produced by the Z-shaped strip. The L-shape slots help enhance the impedance bandwidth.

The antenna was simulated and optimized with the help of the High-Frequency Structure Simulator (HFSS) electromagnetic (EM) simulation software from Ansoft (www.ansys.com) using the finite-element method (FEM). The table shows the antenna parameters and their optimized values (in mm).

Figures 2(a) and 2(b) illustrate the current distributions of the proposed triband slot antenna at different frequencies. As shown in *Fig. 2*, the U-shaped slots increase the current routes to achieve two resonant bands while the third band is achieved by the Z-shaped



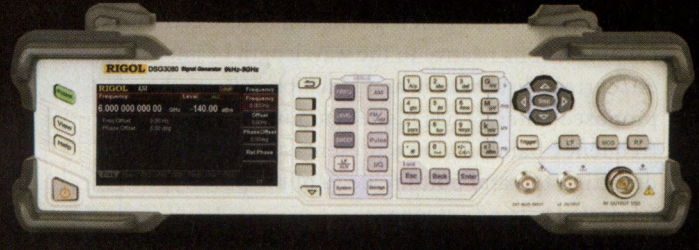
4. These plots show radiation patterns for the proposed antenna at (a) 2.45 GHz, (b) 2.64 GHz, and (c) 3.44 GHz.

Uncompromised Performance...
Unprecedented Value

RIGOL
Beyond Measure

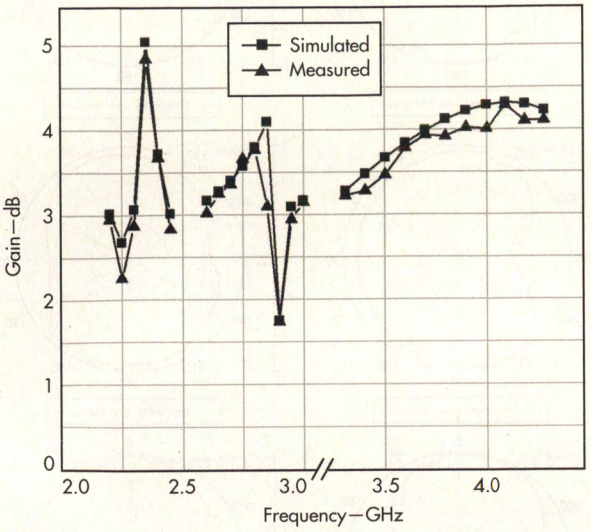
- Full RF Portfolio
- Spectrum Analyzers, RF Signal Generators & Application Software
- Lower Your Cost of Test

TRY RISK FREE
for 30 days



DSG3000 RF Signal Generator

Oscilloscopes • MSOs • Waveform Generators
RF Test • Precision Measurement



5. The plots show simulated and measured gain for the antenna as functions of frequency.

strip at the back of the substrate. *Figure 3* plots the antenna's measured and simulated S_{11} responses as functions of frequency. As these responses show, the simulations agree closely with the measured results at the three frequencies of interest: 2.45, 2.64, and 3.44 GHz.

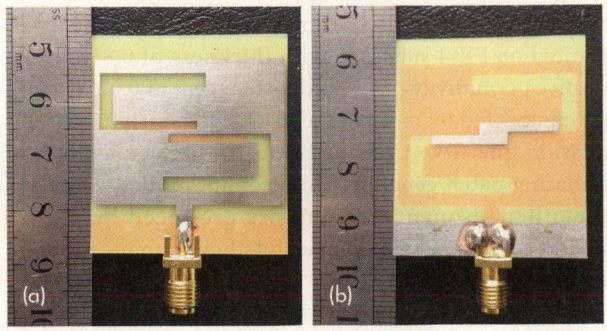
Figure 4 shows radiation patterns for the prototype antenna measured at 2.45, 2.64, and 3.44 GHz. The radiation patterns in the xz-plane and yz-plane correspond to the antenna's E-planes, while the radiation patterns in the xy-plane correspond to the antenna's H-plane.

At low-band frequencies, a figure-eight radiation pattern is obtained in the E-plane, while a nearly omnidirectional radiation pattern is associated with the H-plane. Although the patterns obtained for this antenna are admittedly not as good as those obtained for a simple conventional monopole antenna, they are nevertheless close to monopole-like patterns for a multiband configuration.

In *Figure 5*, the measured gain varies across a range of about 2.24 to 4.89 dBi in the first frequency band, about 1.71 to 4.70 dBi in the second frequency band, and about 3.12 to 4.19 dBi in the third frequency band. However, the gain variations extend more than 1.0 dB across the operating bandwidths in the first and second frequency bands.

Because antenna gain is a function of its electrical dimensions relative to the wavelength of interest, current distribution, and radiation pattern, the proposed antenna has higher gain in the lowest-frequency band. *Figure 6* presents a photograph depicting top and bottom views of the prototype fabricated triband antenna.

In short, the antenna descibed in this article is a compact design that shows great promise for handling multiple frequency bands in wireless applications. By using two U-shaped slots and a Z-shaped slot, it achieves three resonant operating bands utiizing low-cost circuit-board material.



6. These photographs provide (a) top and (b) bottom views of the fabricated antenna.

Owing to the L-shaped slot in the ground plane, the bandwidths are enhanced further. Simulations and measurements have indicated that the proposed antenna can be effectively used for WLAN, 4G cellular communications, and WiMAX applications. mw

ACKNOWLEDGMENT

This research was supported financially by a grant from the National Science and Technology Major Project (No. 2012ZX03006003).

REFERENCES

1. A. Kerkhoff and H. Ling, "Design of a planar monopole antenna for use with ultra-wideband (UWB) having a band-notched characteristic," in IEEE AP/S International Symposium Digest, Columbus, OH, June 2003, Vol. 1, pp. 830-833.
2. Z.N. Chen, D.X. Liu, and B. Gaucher, "A planar dual band antenna for 2.4 GHz and UWB laptop applications," in Proceedings of the IEEE Vehicular Technology Conference, Melbourne, Australia, May 2006, Vol. 6, pp. 2652-2655.
3. S.K. Mishra, R.K. Gupta, A. Vaidya, and J. Mukherjee, "A compact dual-band fork-shaped monopole antenna for Bluetooth and UWB applications," IEEE Antennas & Wireless Propagation Letters, Vol. 10, 2011, pp. 627-630.
4. R. Fallahi, A.A. Kalteh, and M.G. Roozbahani, "A novel UWB elliptical slot antenna with band-notched characteristics," Progation of Electromagnetic Resonances, Vol. 82, 2008, pp. 127-136.
5. L. Dang, Z.-Y. Lei, G.L. Ning, and J. Fan, "A Compact Microstrip Slot Triple-Band Antenna for WLAN/WiMAX Applications," IEEE Antennas & Wireless Propagation Letters, Vol. 9, 2010, pp. 1178-1181.
6. Wen Tao Li, Yong Qiang Hei, Wei Feng, and Xiao Wei Shi, "Planar antenna for 3G/Bluetooth/WiMAX and UWB applications with dual band-notched characteristics," IEEE Antennas & Wireless Propagation Letters, Vol. 11, 2012, pp. 61-64.
7. R. Caso, A. Serra, A. Buffi, M. Rodriguez-Pino, P. Nepa, and G. Manara, "Dual-polarized slot-coupled patch antenna excited by a square ring slot," Microwave Antennas & Propagation, Vol. 5, 2011, pp. 605-610.
8. L.H. Ye and Q.X. Chu, "Improved band-notched UWB antenna," Electronic Letters, Vol. 45, No. 25, December 2009, pp. 1283-1285.

OPTIMIZED PARAMETERS (WITH VALUES IN mm) FOR THE TRIBAND ANTENNA

W	L	S	W1	W2	W3	W4	W5	W6	W7
34.5	40.0	0.3	33.6	18.9	16.4	14.9	14.7	16.0	5.0
W8	W9	L1	L2	L3	L4	L5	L6	L7	
14.1	1.5	6.3	2.7	6.3	26.7	2.3	1.5	2.0	

Design Feature

TIANCHI ZHAO | Professor JIA DONG | Professor BOAO MIN | Professor

International School, Beijing University of Posts and Telecommunications (BUPT), No. 10, Xitucheng Rd., Haidian District, Beijing, People's Republic of China 100876; +86-10 62281949, FAX: +86-10 62285057, e-mail: aztc101@bupt.edu.cn (Zhao), www.bupt.edu.cn

Efficient Handovers Help Wireless Sensor Networks

Direct-digital-synthesizer (DDS) technology can provide the agility and frequency and phase control needed to drive high-performance frequency-modulated-continuous-wave radar systems.

Wireless sensor networks are playing a more significant role in daily life, sending data from different locations of wireless and wired communications networks. Of course, all of these different sensor nodes require power, and the efficient use of network energy requires a delicate balance between sending and receiving sensor data and switching times to and from the various parts of the wireless network.

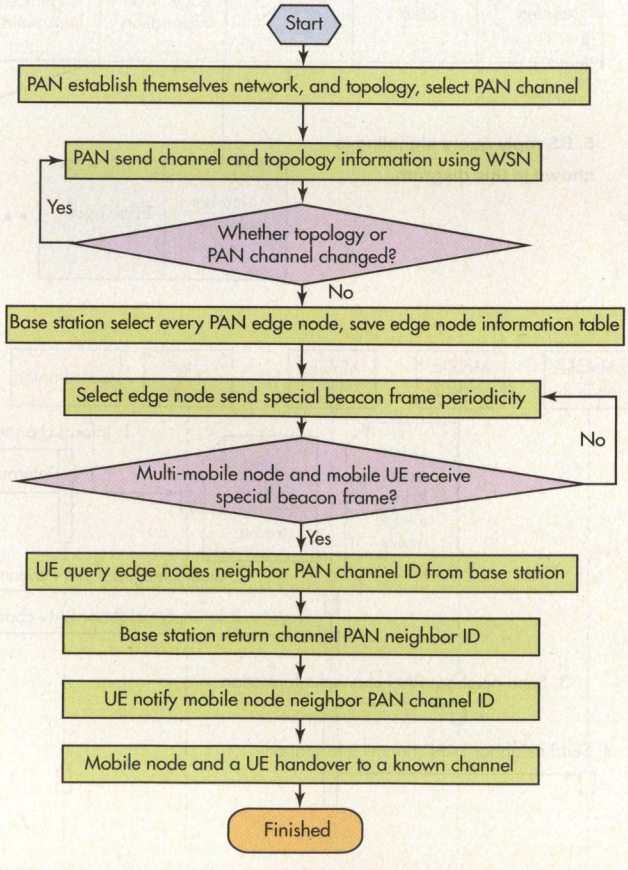
Fortunately, work is being done on how to effectively accomplish data transmissions in these wireless sensor networks without compromising energy efficiency, at the same time following the guidelines set by the IEEE 802.15.4 standard. The novel handover approach was modeled with commercial mathematical simulation software. It has been found to provide the necessary performance for timely switching and data transfer while also saving power compared to conventional handover schemes.

All wireless sensor networks suffer some node switching delays; the challenge in improving performance is to reduce power consumption while also diminishing those delays. Unfortunately, a great deal of energy is consumed when switching sensor data among different Personal Area Networks (PANs), and an effective and efficient handover scheme must handle multiple-node systems while reducing power consumption.

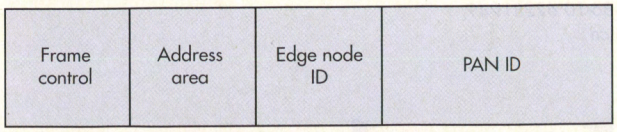
MAC header	MAC load				MAC tail
	2 B	Variable	Variable	Variable	
	Super frame parameter	GTS region	Unused address	Beacon frame load	

1. The diagram shows an edge node beacon frame.

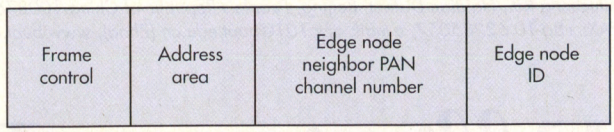
The proposed new handover scheme takes advantage of the fact that cellular base stations can manage over PAN in a wireless network and use the cellular network to control the



2. This flow chart depicts an efficient handover scheme for wireless sensor networks.



3. Edge node notify signaling is represented here.



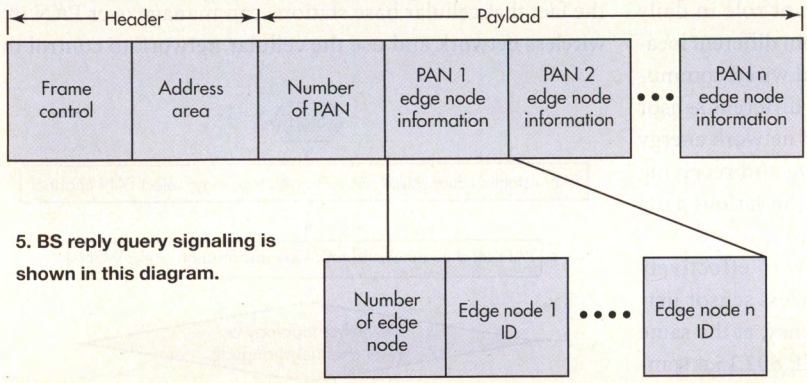
4. UE request query signaling is represented here.

handovers of wireless sensors. By managing the PANs in the larger cellular network—and setting "edge nodes" at the edges of the PANs in order to send signals to associated user equipment when handovers occur—mobile wireless sensors need only scan a target channel to realize efficient handovers.

Edge nodes are static sensor nodes which distribute data in overlapping areas between two PANs *(Fig. 1)*. They are used for mobile nodes to provide warnings at these edges of a network, and they are equipped with strong communication capabilities (such as routing nodes). When edge nodes are determined by a cellular base station, they will send a special beacon frame to notify mobile nodes located in PAN edge areas. The beacon frame is defined in part by the selection of the edge node.

When a wireless sensor network is established, every PAN coordinator in the network has access to the locations and topologies of the nodes and can send related messages to a cellular base station controlling the network. The base station saves the information and determines which are edge nodes for the PANs in the full network. If changes are made to the network or PANs, a PAN coordinator can send new channel and topology information to help base stations stay current with the network conditions.

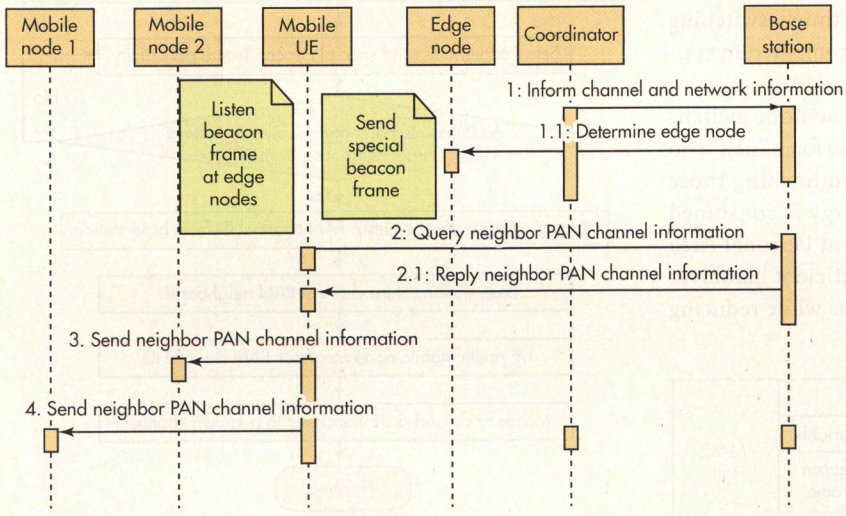
A number of steps are involved for wireless sensor networks with multiple-mobile nodes to perform efficient handovers within cellular networks *(Fig. 2)*. In the first step, the PANs within the larger network send rough locations and nodes of sensors to the base station when a wireless sensor network is first established. Next, the base station selects which of the nodes will be the edge nodes, defining the special beacon frame and using wireless sensor networks to notify these nodes *(Fig. 3)*. The edge nodes will then send a special beacon frame rather than the ordinary frame.



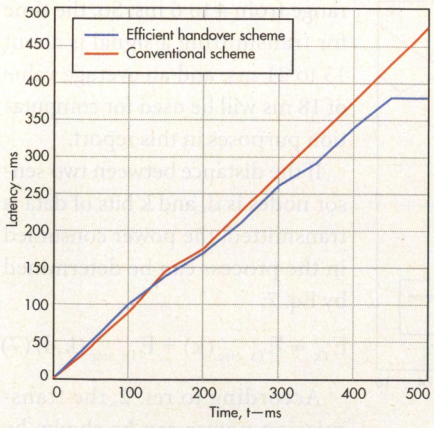
5. BS reply query signaling is shown in this diagram.

In the next step, if a PAN connects to several mobile nodes and mobile user equipment (UE), a mobile UE unit can become leader or serve as the ordinary node of a cluster. When it moves to a PAN edge, it will receive a special beacon frame from the edge nodes. If the UE unit is a cluster leader, it will send a request to a base station directly through the cellular network to inquire about neighbor PANs of the edge nodes and channel information *(Fig. 4)*. In the event that the UE unit operates as an ordinary node, it will be notified by the leader to make an inquiry of the cellular base station.

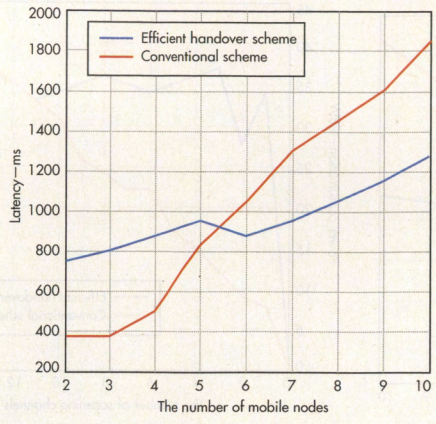
Next, the cellular base station will send query information to the UE user *(Fig. 5)* using information table of edge nodes. Then, the UE or its cluster leader will send information about the neighbor PAN channels of the mobile nodes. In this way, they do not need to scan 16 ZigBee channels according to IEEE 802.15.4



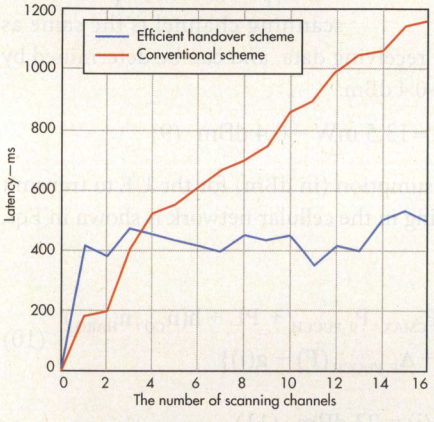
6. This flowchart shows an efficient handover scheme for wireless sensor networks with multiple mobile nodes.



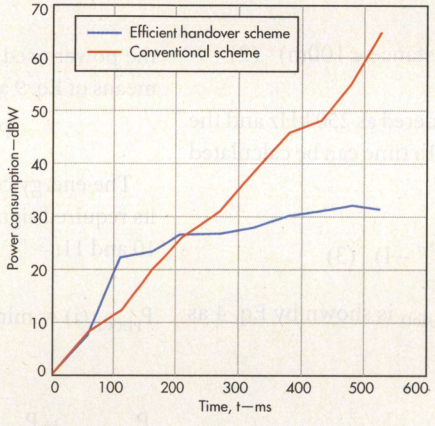
7. The plot shows random handover latency when the number of mobile nodes is five.



8. The radiagram depicts the relationship between the number of mobile nodes and the handover latency.



9. This is the handover latency when the channel being scanned changes (for five mobile nodes).



10. This is the energy consumption when the channel to scan is random (for five mobile nodes).

MAC layer requirements. They only need to scan the channels notified to achieve an efficient handover.

If a node drops out, moves, or suffers from interference, the wireless sensor network topology or channels will change. Every PAN will establish a new network topology, select a channel identification (ID), and send new information to the cellular base station to determine new edge nodes and update the network's edge node information table.

EFFICIENT HANDOVERS

The proposed new handover scheme introduces some new signaling based on cellular and wireless sensor network links *(Fig. 6)*. When a network is established or PAN topology and channels are changed, the PA coordinator will update the base station with the current network topology and channel information. The base station will send signals to notify every edge node in a wireless sensor networks area. The signals contain necessary header information, the number of edge nodes, PAN ID, and 16-b addresses of the edge nodes. The edge nodes send a special beacon frame periodically to warn that there is a mobile node reaching the edge of the PANs.

When a mobile node moves, it will continuously monitor the beacon frame of the connected sensor node. When a special beacon frame is found, a mobile node will notify all the UE units in a mobile cluster. The UE will send signaling and query information about neighbor PAN channels from the base station. It contains header, PAN ID, and edge node ID *(Fig. 5)*.

The base station will signal the UE with the appropriate channel number. This message contains header information, edge node ID, and edge node neighbor PAN channel number *(Fig. 6)*. The UE receives this information and sends it to all mobile sensor nodes. The mobile nodes will then prepare for the handover.

This approach can be adapted to multiple-mobile nodes or frequency handover between several PANs. As the procedure shows, it is not necessary to scan 16 ZigBee channels when a handover occurs, and the process can be managed by the PANs within a wireless sensor network.

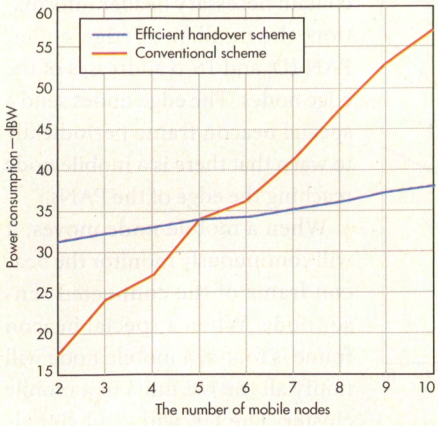
The new scheme only scans object channels instead of scanning all ZigBee channels. When the number of sensor nodes increases in a cluster, it can be used to reduce energy consumption.

To better understand the operation of the new wireless sensor network handover scheme and how it can reduce delays times in switching signals from those sensors through the network, it may help to analyze the system with the aid of mathematical relationships.

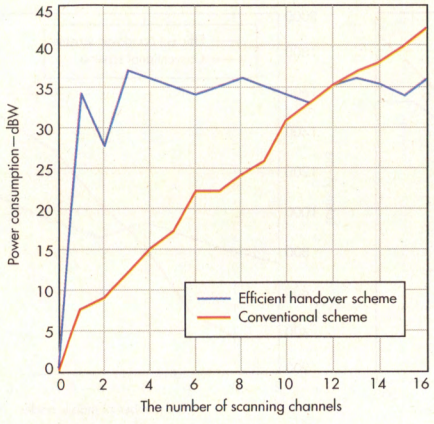
For example, in a wireless sensor network, the delay for transmission of signaling at every hop can be described by Eq. 1:

$$T_{l-hop} = \sum_{i=1}^{N} T_{i\text{-backoff}} + T_{tr} \quad (1 \le N \le 4) \quad (1)$$

where the transition time, T_{tr}, can be determined by Eq. 2:



11. This is the handover energy consumption when the number of mobile nodes changes.



12. This is the handover energy consumption when the channel to scan changes (for five mobile nodes).

$$T_{tr} = \frac{DataLength}{BandWidth} + \frac{Distance}{velocity} \quad (Distance \le 100m) \quad (2)$$

In this case, the bandwidth is considered as 250 kHz and the velocity is 3×10^8 m/s. Backoff at the ith time can be calculated by Eq. 3:

$$T_{i\text{-}backoff} = T_{backoff_slot} \times \alpha \ (1 \le \alpha \le 2^{2+i} - 1) \quad (3)$$

where the backoff slot time, $T_{backoff_slot}$, is shown by Eq. 4 as 0.32 ms:

$$T_{backoff_slot} = 0.32 \text{ ms} \quad (4)$$

According to the product of twice the backoff time and 12 times the backoff time slot, it is possible to calculate the delay time for a single time transmission by means of Eq. 5:
]

$$T_{wsn} = (0.32 \times 12 \times 2 \text{ ms} + 1 \text{ ms}) \times 2 = 17.36 \text{ ms} \quad (5)$$

According to the IEEE 802.15.4 standard, the time needed to scan a channel is defined by Eq. 6:

Time needed to scan a channel = super frame duration × (2n + 1) symbols (6)

where n is equal to the scan period, with value from 0 to 14.

According to Eq. 6, the time needed to scan a channel can be computed as lasting from 8 to 200 ms in duration. For the purposes of the current calculations, a time of 30 ms will be used because the super frame contains a dormancy period with no symbol to transmit.

According to ref. 1, transmission time for a cellular network is 3 to 5 ms at the physical layer, while interactive signaling connections require 9 to 15 ms, and data transmission times range from 4 to 6 ms. So, the time for transmitting a signal is about 13 to 21 ms, and an average value of 18 ms will be used for computation purposes in this report.

If the distance between two sensor nodes is d, and k bits of data is transmitted, the power consumed in the process can be determined by Eq. 7:

$$E_{Tx} = E_{Tx_elec}(k) + E_{Tx_amp}(k,d) \quad (7)$$

According to ref. 2, the transmission power can be shown by means of Eq. 8:

$$P_{RX} = 24.75 \text{ mW} = 0.74 \text{ dBm} \quad (8)$$

The power consumption of the scanning channel is the same as the power used in receiving data, and can be determined by means of Eq. 9 as +0.4 dBm:

$$P_{RX} = 13.5 \text{ mW} = 0.4 \text{ dBm} \quad (9)$$

The energy consumption (in dBm) for the UE to transmit its required signaling in the cellular network is shown in Eqs. 10 and 11:

$$P_{PUCCH}(i) = \min\{P_{CMAX}, P_{0_PUCCH} + PL + h(n_{CQ}, n_{HARQ}) + \Delta_{F_PUCCH}(F) + g(i)\} \quad (10)$$

$$P_{UE_request} = P_{PUCCH}(i) = 23 \text{ dBm} \quad (11)$$

In addition, the energy consumption (in dBm) of the base station to transmit the required signaling for a wireless sensor network update can be determined by Eq. 12:

$$P_{eNB_reply} = \delta_{power_offset} + P_A + 10\log_{10} 2 = 46 \text{ dBm} \quad (12)$$

Because this wireless sensor network handover scheme is based on the IEEE 802.15.4 standard, the latency for a standard handover can be determined by Eq. 13:

$$T_{handover_WSN} = hop \times T_{request_original} + N \times T_{scan} + hop_2 \times T_{request_new} \quad (13)$$

In Eq. 13, the term "hop" refers to the number of hops from mobile nodes to a standard PAN coordinator; $T_{request_original}$ is the corresponding time required per hop; N is the number of channels to scan; T_{scan} is the time to scan each channel; hop_2 is the number of hops from the mobile nodes to the new PANs coordinator; and $T_{request_new}$ is the corresponding time required for each hop.

According to these parameters, the latency for mobile nodes

to use a standard handover arrangement is shown by Eq. 14:

$$T_{handover_WSN} = hop \times 17.36 + N \times 30 + hop_2 \times 17.36(ms) \quad (14)$$

where, in Eq. 14, the handover latency is related with the functions hop and hop_2. For a handover in the new, more efficient wireless sensor network scheme, the latency can be calculated by Eq. 15:

$$T_{handover_new} = T_{UE_request} + T_{eNB_reply} + hop \times T_{request_original} + T_{scan} + hop_2 \times T_{request_new} \quad (15)$$

where $T_{UE_request}$ refers to the UE inquiry time; T_{eNB_reply} represents the base station reply time; and the other parameters are the same as those in the standard base station handover scheme. In the new proposed scheme, the network only needs to scan once, because the channel information of neighbor PANs is already notified.

The latency can then be found by means of Eq. 16:

$$T_{handover_new} = 18 + 18 + hop \times 17.36 + 30 + hop_2 \times 17.36(ms) \quad (16)$$

Handover latency is also related with hop and hop_2. By comparing Eqs 14 and 16, when the hop number is determined, it can be shown that the proposed wireless sensor network scheme requires less handover latency than a standard handover scheme, since the standard approach must scan channels more than twice.

Another important consideration in comparing the new handover scheme with standard handover schemes is energy consumption, which can be compared by means of Eq. 17:

$$P_{handover_wsn} = hop \times P_{request_original} + M \times N \times P_{scan} + hop_2 \times P_{request_new} \quad (17)$$

where $P_{request_original}$ is the energy consumption of the mobile node to send a message to the old PANs; M is the number of mobile nodes in the cluster; P_{scan} is the energy consumption to scan a channel; and $P_{request_new}$ is the energy consumption of the mobile node to send a message to the new PANs.

The resulting calculation of power $P_{handover_wsn}$ is shown in Eq. 18:

$$P_{handover_wsn} = hop \times 0.74 + M \times N \times 0.4 + hop_2 \times 0.74 \quad (18)$$

When using the new proposed handover scheme, the power level, $P_{handover_new}$ for the new approach can be found from Eq. 19:

$$P_{handover_new} = P_{UE_request} + P_{eNB_reply} + M \times P_{scan} + hop \times P_{request_original} + hop_2 \times P_{request_new} \quad (19)$$

where $P_{UE_request}$ is the energy consumption of UE query signaling and P_{eNB_reply} is the time required for the base station to reply to the query signaling. Because a base station does not use this energy in a cellular network and in wireless sensor networks, it need not be considered for its energy consumption. As a result, with the help of the efficient handover scheme for wireless sensor networks, Eq. 20 can be used to determine the energy consumption of the new handover scheme, $P_{handover_new}$:

$$P_{handover_new} = 23 + M \times 0.4 + hop \times 0.74 + hop_2 \times 0.74 \quad (20)$$

By comparing Eqs. 18 and 20, the proposed handover scheme can be seen to have many advantages when there are few mobile nodes in the network. However, most of sensor nodes are powered by battery, so they cannot charge frequently, while user equipment represents a useful option for solving this problem. In this way, it is meaningful to use energy consumption of cellular network instead of wireless sensor networks. The theoretical analysis can also be verified by application of computer analysis with a commercial software tool, MATLAB from MathWorks (www.mathworks.com). MATLAB can be used not only to analyzer the physical operation of the wireless sensor network within a cellular network, but the software algorithms used in the system as well.

SIMULATION PARAMETERS

MATLAB was used to analyzer the operation and performance of the new handover scheme and ensure that it could function properly as part of a wireless cellular communications network. Simulation parameters were set up as shown in the *table*. The edge nodes were located at the edges of PAN area with coordinates of (0,0), (0,4), (0,8), (4,0), (4,8), (8,0), (8,4), and (8,8).

To evaluate the functionality of the new handover scheme, it was compared to a standard handover approach in terms of energy consumption and handover latency time. As *Fig. 7* shows, when the handover time is 100 ms, the handover latency of the new scheme is slightly longer than a standard scheme, because the new approach will require time for the UE to send query requests to the base station. For handover

SIZING UP SYSTEM PARAMETER VALUES

Personal area network area (cm^2)	8 x 8
Number of edge nodes	8
Location of mobile nodes and UE	Random distribution
The time to transmit signaling per hop	17.36 ms
Time to scan a channel	30 ms
Time for cellular network to transmit signaling	18 ms
The energy consumption to transmit signaling per hop in wireless sensor networks	+0.74 dBm
The energy consumption to scan a channel	0.4 dBW
The energy consumption of cellular network	23 dBW
Time unit for simulation (ms)	0.5 ms

times between 100 and 450 ms, the latency time is somewhat less in the new approach than in a standard handover scheme.

Before a handover can occur, the mobile nodes must physically move and signal using a random number of hops. When the time is longer than 450 ms, the new scheme will finish a handover while the standard scheme is still in the process of completing a handover. It can be seen that latency times are less in the proposed new approach than in standard handover schemes.

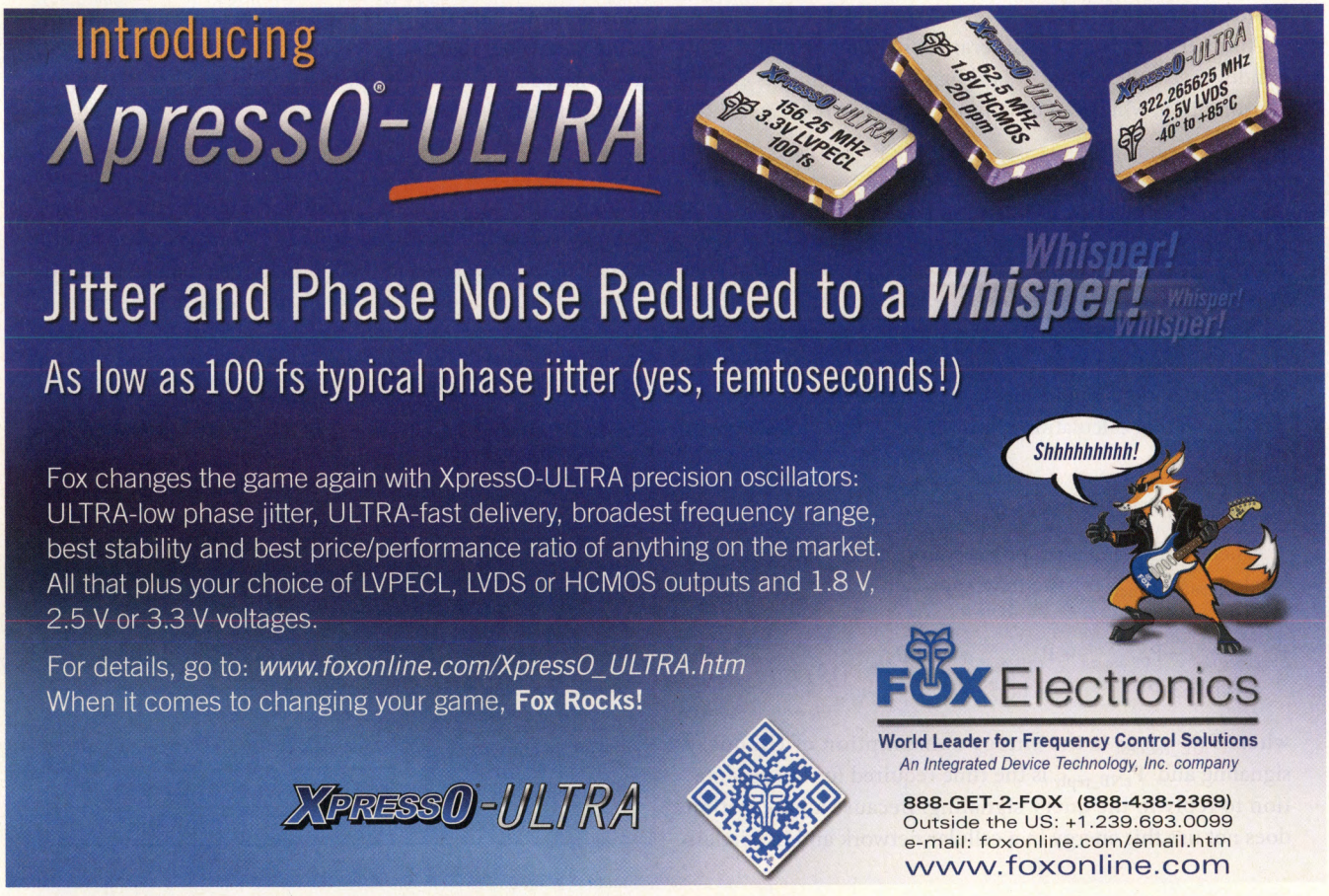
Figure 8 shows the relationship between handover latency and the number of mobile nodes when scanning five channels. For standard scheme, when the number of mobile nodes increases, the handover latency time increases quickly. The latency time of the new handover scheme increases at a much slower rate. A standard scheme must scan every ZigBee channel with random location of mobile nodes; the new scheme only scans the given channel, for less latency time.

In *Fig. 9*, when the number of channels increases, the handover latency of the standard scheme increases dramatically. However, the proposed scheme maintains stable latency. When the number of channels is larger than four, the new scheme can be seen to outweigh the old scheme in terms of network latency. As *Fig. 10* shows, when the time is between 50 and 200 ms, the new scheme suffers more energy consumption than a standard scheme. But beyond that, the new approach has much lower energy consumption than a standard scheme. In a standard handover scheme, every mobile node must scan all ZigBee channels, with energy consumption growing with the number of mobile nodes.

In the new approach, only a given channel is scanned. As *Fig. 11* shows, when the number of mobile nodes exceeds five, the new handover scheme offers great advantages in energy consumption compared to a standard handover scheme. Similarly, as *Fig. 12* shows, when the number of channels rises above 11, the new scheme offers advantages in power consumption compared to a standard handover scheme. The new approach can contribute to useful energy savings within a cellular communications network. MW

REFERENCES

1. R1-060932. EUTRA TDD Random Access Procedure. CATr, RITI, TD-Tech, 3GPP TSG RAN WG1#44bis Meeting, Athens, Greece, March 27-31, 2006.
2. Hui-fang Deng, Qi-ping Ma, and Shang-wei Zhou, "Use of RFID technology for indoor location," Computer application.
3. H. Gao, V. Leung, and C. Chow, "Enabling technologies for wireless body area networks: A survey and outlook," IEEE Communications Magazine, Vol. 47, No. 12, 2009, pp. 84-93.
4. M. Chen, S. Gonzalez, and A. Vasilakos, "Body area networks: A survey," Journal of Mobile Networks and Applications, Vol. 16, No. 2, 2011, pp. 171-193.
5. N.F. Timmons and W.G. Scanlon, "Analysis of the performance of IEEE 802.15.4 for medical sensor body area networking," First Annual IEEE Communications Society Conference on Sensors and Ad Hoc Communications and Networks, 2004, pp. 16-24.



Design Feature

DONG LIANG | Professor WENQIAN XUE | Postgraduate Assistant ZHIYUAN XU | Postgraduate Assistant

Key Laboratory of Universal Wireless Communications, Beijing University of Posts and Telecommunications, Beijing 100876, People's Republic of China, e-mail (Liang): eleliangdong_bupt@163.com

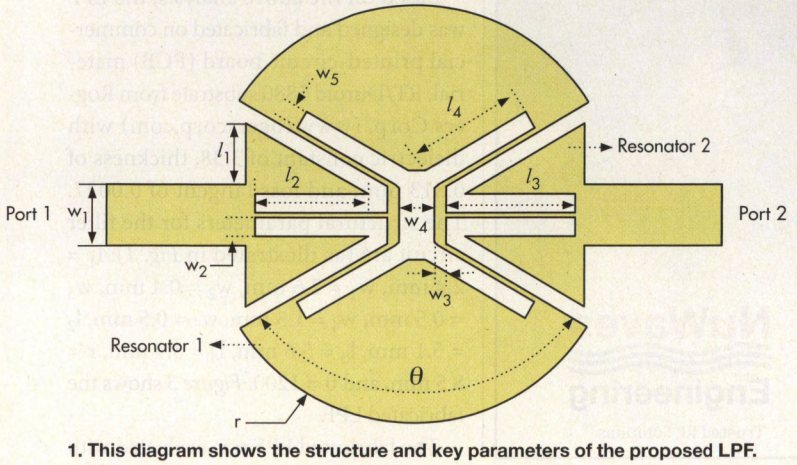
Microstrip LPF Boasts Ultrawide Stopband

A compact lowpass filter with 3-dB cutoff at 1.78 GHz was designed and fabricated by pairing two different resonator types to achieve wide stopband in a small size.

Lowpass filters (LPFs) with wide stopbands are often required in high-frequency communications systems to suppress unwanted harmonic and spurious signals. To meet some of these requirements, a compact LPF based on triangular patch resonators and a butterfly patch resonator with two 120-deg. radial wing patches was developed to provide ultrawideband (UWB) signal rejection.

In demonstrating the design, a microstrip filter with 3-dB cutoff frequency at 1.78 GHz was designed, fabricated, and characterized, and was found to achieve an UWB stopband of 158.2% for suppression of unwanted signals as high as the 12th harmonic signals. The fabricated filter measures just 14.5×18.0 mm^2, which corresponds to $0.133\lambda_g \times 0.165\lambda_g$, where λ_g represented the guided wavelength at 1.78 GHz.

Planar LPFs are often required in communications systems where higher-frequency spurious and harmonic signals must be rejected. A conventional approach for realizing a microwave LPF involves using high-to-low-impedance lines with shunt stubs and semi-lumped circuit elements.



1. This diagram shows the structure and key parameters of the proposed LPF.

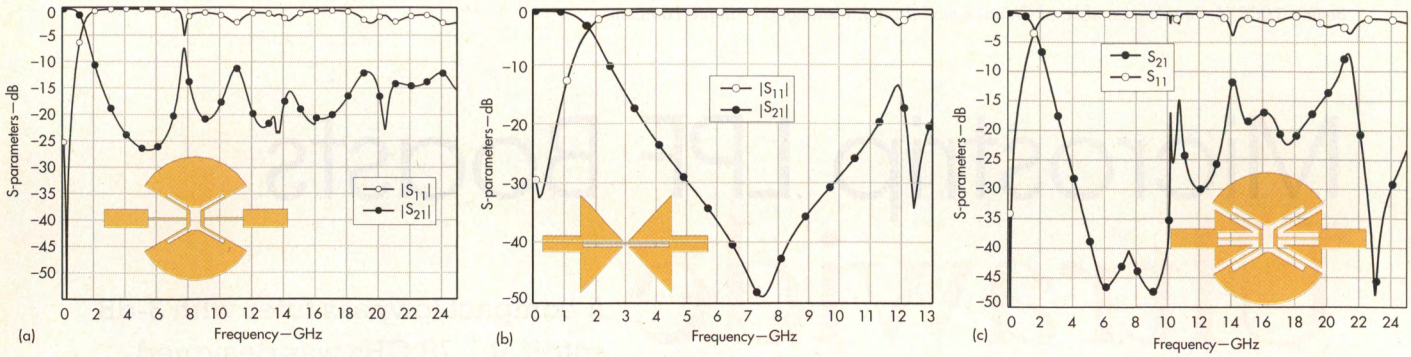
Unfortunately, while these components combine for good stopband rejection with relatively flat filter rolloff characteristics, they combine for large package sizes.[1,2] As a result, techniques to reduce the filter size and enhance the performance have been widely studied in recent years.[3-7] By cascading multiple stepped-impedance hairpin resonators, an LPF with sharp rolloff characteristics and wide stopband suppression resulted.[3] Unfortunately, the design approach also results in large size and increased passband insertion loss. By cascading multiple semicircular and semielliptic patch resonators, wide stopband suppression was achieved in an LPF design.[4]

Once again, however, this approach suffered in electrical performance when it was made in a small size. To further improve stopband performance, one group of researchers proposed an LPF by cascading inductive-capacitive (LC) resonant structures and transformed radial stubs.[5] Unfortunately, this method results in large circuit size and increased design complexity.

In one LPF design approach, conventional low-impedance stubs were replaced by the radial stubs to realize a wide stopband rejection.[6] But the rolloff performance was not ideal and further improvements were needed in stopband bandwidth. One LPF design effort involved the use of a defected ground structure (DGS) and multilayer circuit techniques,[7] but, again, this approach increased the LPF circuit complexity.

As part of an effort to realize a microstrip LPF with small size and UWB stopband, both triangular patch and butterfly patch resonators were used in the design. Meandering transmission lines were also employed to achieve a reduction in filter size. The design approach achieved a compact LPF with UWB stopband from 2.83 to 21.60 GHz with better than 15-dB rejection.

The filter also exhibits low passband insertion loss,



2. These plots offer simulated S-parameters for the LPF's resonators: (a) the filter with only resonator 1, (b) the filter with only resonator 2, and (c) the filter with resonators 1 and 2.

with less than 0.3 dB insertion loss in the passband. Also of note, it is small—featuring electrical dimensions of $0.133\lambda_g \times 0.165\lambda_g$, where λ_g is the guided wavelength at 1.78 GHz.

Figure 1 shows the layout of the proposed LPF. It consists of high-to-low-impedance microstrip main transmission lines and two types of resonators, i.e., resonators 1 and 2. Resonator 1 consists of a high-impedance transmission line and a butterfly patch, connected in series. Resonator 2 is a triangular patch. To better understand the design theory, the frequency responses of the two types of resonators were analyzed.

Figure 2(a) shows the frequency response of the filter with resonator 1 only. As can be seen, in addition to the parasitic narrow passband around 7.5 GHz, the filter with resonator 1 only has wide harmonic-suppression characteristics. Thus, to eliminate the parasitic passband and improve the rectangular coefficients, a triangular patch resonator was introduced. *Figure 2(b)* shows the resonant characteristic of the triangular patch resonator, where the filter loaded with resonator 2 has a wide stopband response and, in the vicinity of 7.5 GHz, one transmission zero which can be adjusted by controlling the size of the structure.

Based on this analysis, both resonators were used to achieve an LPF with wide stopband response. *Figure 2(c)* shows the filter response curve loading resonators 1 and 2. As expected, the combination of the two resonators results in an LPF with extremely wide stopband characteristics.

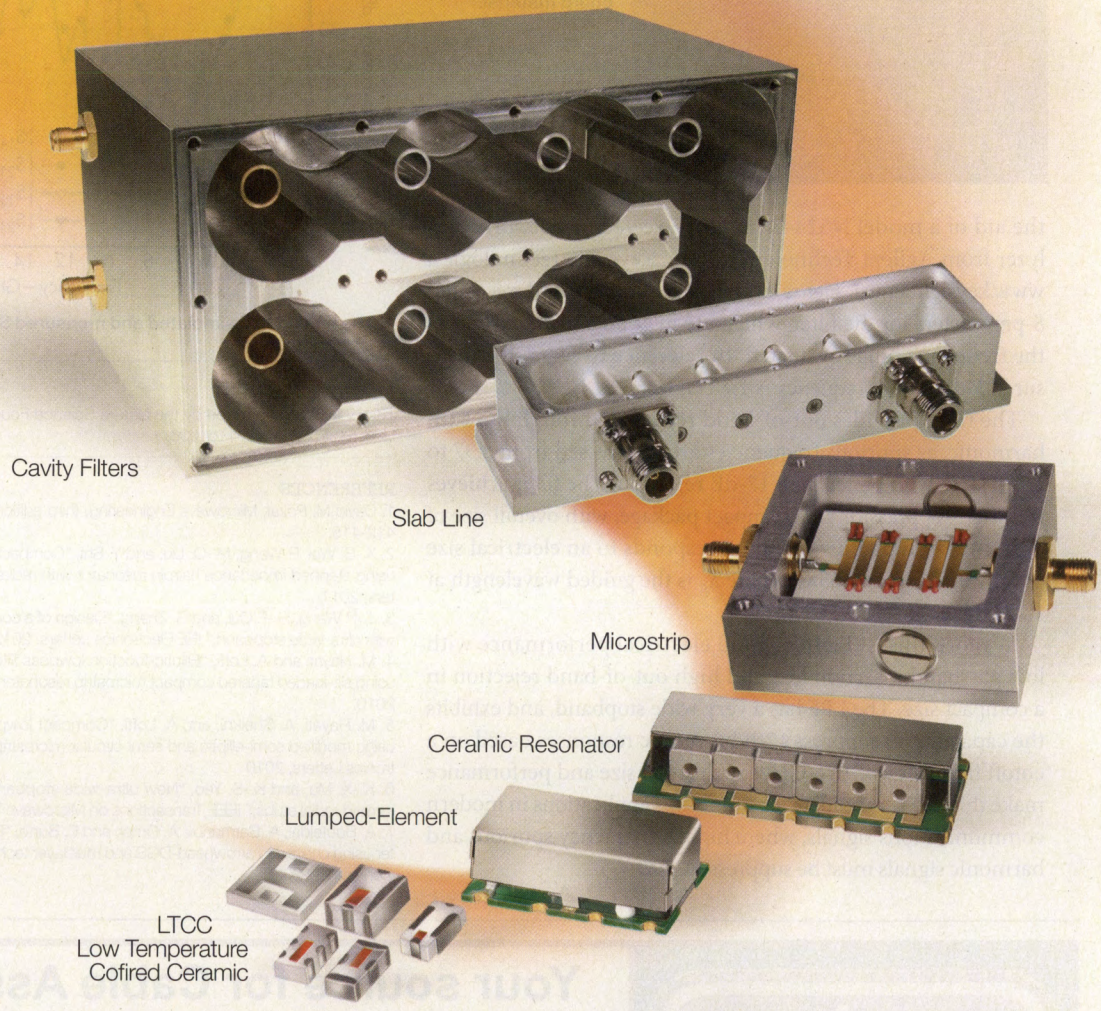
Based on the above analysis, the LPF was designed and fabricated on commercial printed-circuit-board (PCB) material, RT/Duroid 5880 substrate from Rogers Corp. (www.rogerscorp.com) with dielectric constant of 3.38, thickness of 0.813 mm, and loss tangent of 0.0027. The structural parameters for the filter circuit are (as illustrated in *Fig. 1*): l_1 = 2.4 mm, w_1 = 2.6 mm, w_2 = 0.4 mm, w_3 = 0.5 mm, w_4 = 1.5 mm, w_5 = 0.5 mm, l_2 = 5.1 mm, l_3 = 5.6 mm, l_4 = 3.9 mm, r = 8.5 mm, and θ = 1200. *Figure 3* shows the fabricated LPF.

The fabricated LPF was evaluated with

Let your communications system take flight.
At NuWaves, SWaP (Size, Weight and Power) is the name of the game.
We offer COTS products and custom solutions that meet the demanding needs of today's military, government and industrial customers.
• Broadband Power Amplifiers from 225 MHz to 6 GHz, as small as 1.3 in³
• Bidirectional Amplifiers from 1 GHz to 6 GHz, as small as 6.0 in³
• Fully Programmable RF Upconverters, Downconverters, Transverters, etc.
• High Intercept Low Noise Amplifiers from 2 MHz to 12 GHz
nuwaves.com/mrf
513.360.0800
sales@nuwaves.com
AS9100 & ISO 9001 Certified
Photo courtesy of Northrop Grumman Corp.
NuWaves Engineering
Trusted RF Solutions.™

FILTER SOLUTIONS

DC to 18 GHz



Over 900 Models IN STOCK ...Immediate Delivery! from $1.99 ea. (qty. 20)

Different needs require different technologies, and with over 900 catalog models and counting, Mini-Circuits' line of RF/microwave filters has you covered. High pass, low pass, band pass, and band stop designs provide low pass band insertion loss and high stop band rejection, covering pass bands from DC – 18 GHz. Choose from our wide range of filter technologies in coaxial and surface mount packages for the right solution to meet your requirements.

Visit minicircuits.com and use Yoni2™, our patented search engine, to search our entire model database by performance parameters. Just enter your desired specifications, and see a list of models that meet your criteria!

Yoni2™ U.S. Patent 7739260, 7761442 *The Design Engineers Search Engine... finds the model you need, Instantly.*

Still don't see what you're looking for? Custom designs at catalog prices with lightning-fast turnarounds are just a phone call or email away. Contact us, and our engineers will find a quick, cost-effective custom solution and deliver simulation results within a few days.

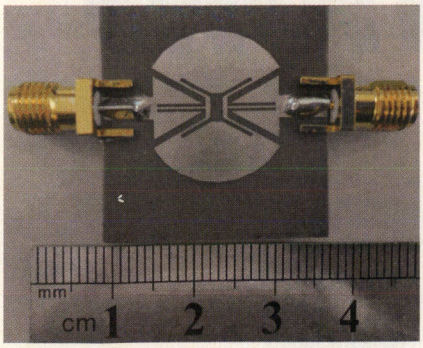
Performance data, curves, high-accuracy simulations, quantity pricing, and everything you need to make your selection are all available on our website. Place your order today and have them in your hands as soon as tomorrow!

Free, High-Accuracy Simulation Models for ADS Modelithics®
www.modelithics.com/mvp/Mini-Circuits.asp

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

484 Rev E

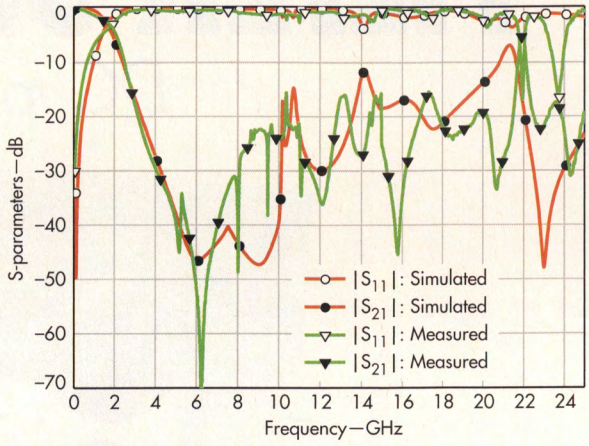


3. This photograph shows the proposed filter fabricated on microwave circuit-board material.

the aid of a model N5244A microwave vector network analyzer from Agilent Technologies (now Keysight Technologies; www.keysight.com). *Figure* 4 offers the simulated and measured S-parameters for the filter, which are in good agreement across the frequency range evaluated. In reference to *Fig.* 4, the measured 3-dB cutoff frequency is 1.78 GHz.

The filter provides out-of-band rejection through the 12th harmonic, as spurious frequencies are suppressed from 2.37 to 18.20 GHz with better than 17-dB rejection. The filter achieves this high suppression in a compact package, with overall size of only 14.5×18.0 mm^2, which corresponds to an electrical size of only $0.133\lambda_g \times 0.165\lambda_g$, where λ_g is the guided wavelength at 1.78 GHz.

In short, this LPF offers good electrical performance with low passband insertion loss and high out-of-band rejection in a compact size. The LPF has a very wide stopband, and exhibits the capability to suppress 12th harmonic responses based on a cutoff frequency of 1.78 GHz. Such small size and performance make this LPF a candidate for numerous applications in modern communications signals, where higher-frequency spurious and harmonic signals must be suppressed. mw



4. The plots detail simulated and measured S-parameters for the LPF.

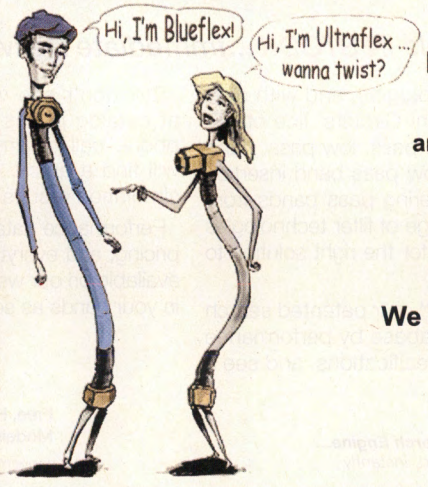
ACKNOWLEDGMENT

This work was supported by the Nature Science Foundation of China under Grant Nos. 51365035 and 51164036.

REFERENCES

1. David M. Pozar, Microwave Engineering, third edition (Wiley, New York, 2005), pp. 412-415.
2. X.-B. Wei, P. Wang, M.-Q. Liu, and Y. Shi, "Compact wide-stopband lowpass filter using stepped impedance hairpin resonator with radial stubs," IEEE Electronics Letters, 2011.
3. J.-P. Wang, H.-F. Cui, and G. Zhang, "Design of a compact microstrip lowpass filter with ultra-wide stopband," IEE Electronics Letters, 2012
4. M. Hayati and A. Lotfi, "Elliptic-function lowpass filter with sharp cutoff frequency using slit-loaded tapered compact microstrip resonator cell," IEEE Electronics Letters, 2010.
5. M. Hayati, A. Sheikhi, and A. Lotfi, "Compact lowpass filter with wide stopband using modified semi-elliptic and semi-circular microstrip patch resonator," IEEE Electronics Letters, 2010
6. K.-X. Ma, and K.-S. Yeo, "New ultra-wide stopband low-pass filter using transformed radial stubs," IEEE Transactions on Microwave Theory and Techniques, 2011.
7. A. Bouteidar, A. Batmanov, A. Omar, and E. Burte, "Design of compact lowpass filter using cascaded arrowhead-DGS and multilayer technique, Asia-Pacific Microwave Conference, 2008.

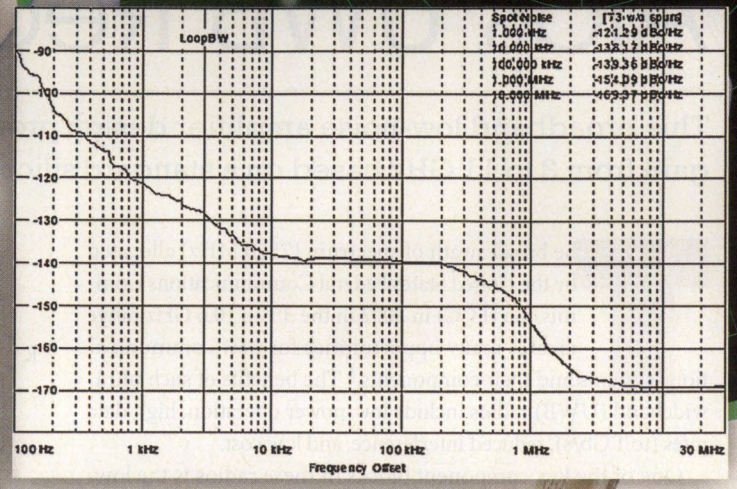
coaxicom
USA Manufacturer Since 1984!
Precision Connectors, Adapters, Cable Assemblies & More!
Coaxial Components Corp.
1-866-COAXICOM, 1-772-287-5000
Sales@Coaxicom.com
AS9100 ISO 9001 NSF NSF-ISR

Your source for Cable Assemblies


We'll make sure your project doesn't get twisted.
Blue-Flex & Ultra-Flex are flexible and hand formable cables with the performance of semi-rigid.
Most cable assemblies delivered in 24 to 72 hours.
We have standard products that ...
WE'LL SHIP TODAY
Proud Supporter of WOUNDED WARRIOR PROJECT

PHASE LOCKED DRO

Typical Phase Noise	Offset	Phase Noise
	@ 100 Hz	-95 dBc/Hz
	@ 1 kHz	-121 dBc/Hz
	@ 10 kHz	-136 dBc/Hz
	@ 100 kHz	-136 dBc/Hz
	@ 1 MHz	-154 dBc/Hz
	@ 10 MHz	-168 dBc/Hz



Frequency	10.24 GHz
AC Power (Normal Operation)	Voltage: 120 VAC @ 250 mA Voltage: 240 VAC @ 235 mA
Output Power	+10 dBm (Typ.)
Spurious & Ref. Sideband	75 dBc (Typ.)
Harmonic Suppression	30 dBc (Typ.)
Temperature	+25 °C (Room Temperature)
Warm-up Time	15 Minutes
Internal VCO	SMC Model: DRO1024
Output Impedance	50 Ohms (Nominal)
Output Connector	Type N Female



RoHS

REL∞PRO®

Patented Technology

Talk To Us About Your Custom Requirements.

SYNERGY®
MICROWAVE CORPORATION

Phone: (973) 881-8800 | Fax: (973) 881-8361
E-mail: sales@synergymwave.com
Web: WWW.SYNERGYMWAVE.COM
Mail: 201 McLean Boulevard, Paterson, NJ 07504

XU XIA | Professor
Hunan Vocational College of Security Technology, Changsha, 410151, Hunan Province, People's Republic of China; e-mail: ljxz1987@163.com

FENGYING HAN | Professor
Changsha Aeronautical Vocational and Technical College, Changsha, 410014, Hunan Province, People's Republic of China

CMOS LNA Aids UWB Receivers

This broadband low-noise amplifier design provides more than 16-dB small-signal gain from 3 to 11 GHz based on a standard silicon CMOS semiconductor process.

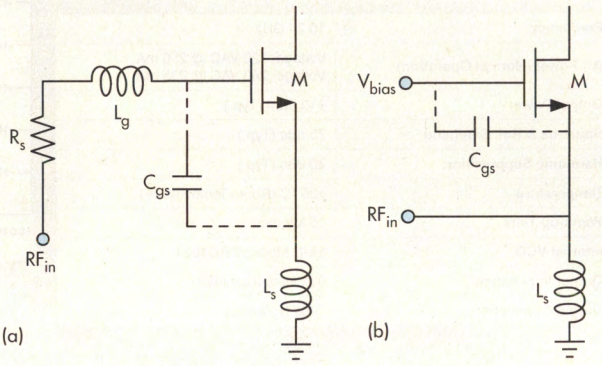
The broad swath of spectrum (7500 MHz) allocated by the United States Federal Communications Commission (FCC) in 2002 in the 3.1 to 10.6 GHz range creates many opportunities for new communications systems and their components.[1] The benefits of such ultra-wideband (UWB) radios include low-power operation, high data rates (to 1 Gb/s), reduced interference, and low cost.

One of the key component blocks in these radios is the low-noise amplifier (LNA), which must meet several stringent requirements—including broadband input matching, flat and high power gain, low noise figure, high linearity, and low power consumption. The design of such an amplifier can be a great aid to these UWB radios and systems.

A number of UWB LNAs have been developed based on CMOS technology.[2-8] The distributed amplifier (DA) has been one of the more popular architectures for this application. Since DA LNAs provide good wideband input matching, flat gain, and generally high input third-order intercept (IIP3) performance, they are well suited to these UWB applications.[2-4] But DA LNAs consume a great deal of power with relatively low power gain in a large chip area.

Resistive feedback is a good solution for obtaining wide bandwidth and flat power gain.[5-7] However, the use of a resistor in the feedback path reduces the power gain and degrades noise performance. One recent LNA topology of note is the cascode configuration with a Chebyshev input matching filter, which provides good wideband input matching and high power gain[8]; however, the noise figure is degraded by the filter's insertion loss.

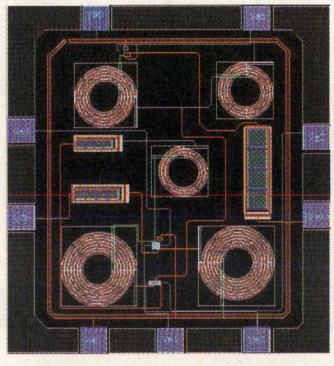
One challenge for UWB LNAs is posed by the linearity requirements, owing to the large numbers of in-band interference sources in that frequency range and the cross-modulation/intermodulation caused by blockers or transmitter leakage in a reconfigurable receiver.[9] Plus, while the transmit frequency (f_T) increases with technology scaling, linearity tends to degrade due to lower supply voltages in use and high-field mobility effects.[9] This makes wideband linearization important.[10,11]



1. These are versions of (a) a common-source (CS) LNA and (b) a common-gate (CG) LNA.

Linearization techniques which optimize overdrive voltage ($V_{gs} - V_{th}$) can be used to obtain peak IIP3. However, the bias voltage range for peak IIP3 is narrow, so that boosting linearity can be sensitive to process variations. The derivative super-position (DS) method[12-14] uses an additional transistor's nonlinearity to cancel that of the main device; it involves MOS transistors working in triode[12] or in the weak inversion region.[13,14]

Therefore, using the DS method, it is difficult to match the transistors working in different regions, resulting in a linearity improvements that are highly sensitive to variations in pressure volume and temperature (PVT). The body biasing technique[15] is suitable for improving linearity performance; unfortu-



2. This schematic diagram shows the proposed UWB LNA design.

TABLE 1: CIRCUIT PARAMETER VALUES AT A GLANCE	
Devices	**Design values**
M_1	124 μm/0.18 μm
M_2	48 μm/0.18 μm
M_3	25 μm/0.18 μm
M_4	30 μm/0.18 μm
L_s	4.4 nH
L_d	6.6 nH
L_L	2.5 nH
L_g	3.0 nH
L_p	2.9 nH
R_L	50 Ω
R_{b1}	5000 Ω
R_{b2}	5000 Ω
V_{g1}	0.59 V
V_{g2}	0.94 V
V_{g5}	0.6 V
V_{b1}	0.29 V
V_{b2}	0.29 V
C_{in}	5.1 pF
C_{out}	3.4 pF

niques to achieve low power consumption. In addition, shunt-series peaking techniques are used to extend the 3-dB bandwidth, and a post-distortion technique is employed to improve the linearity performance.

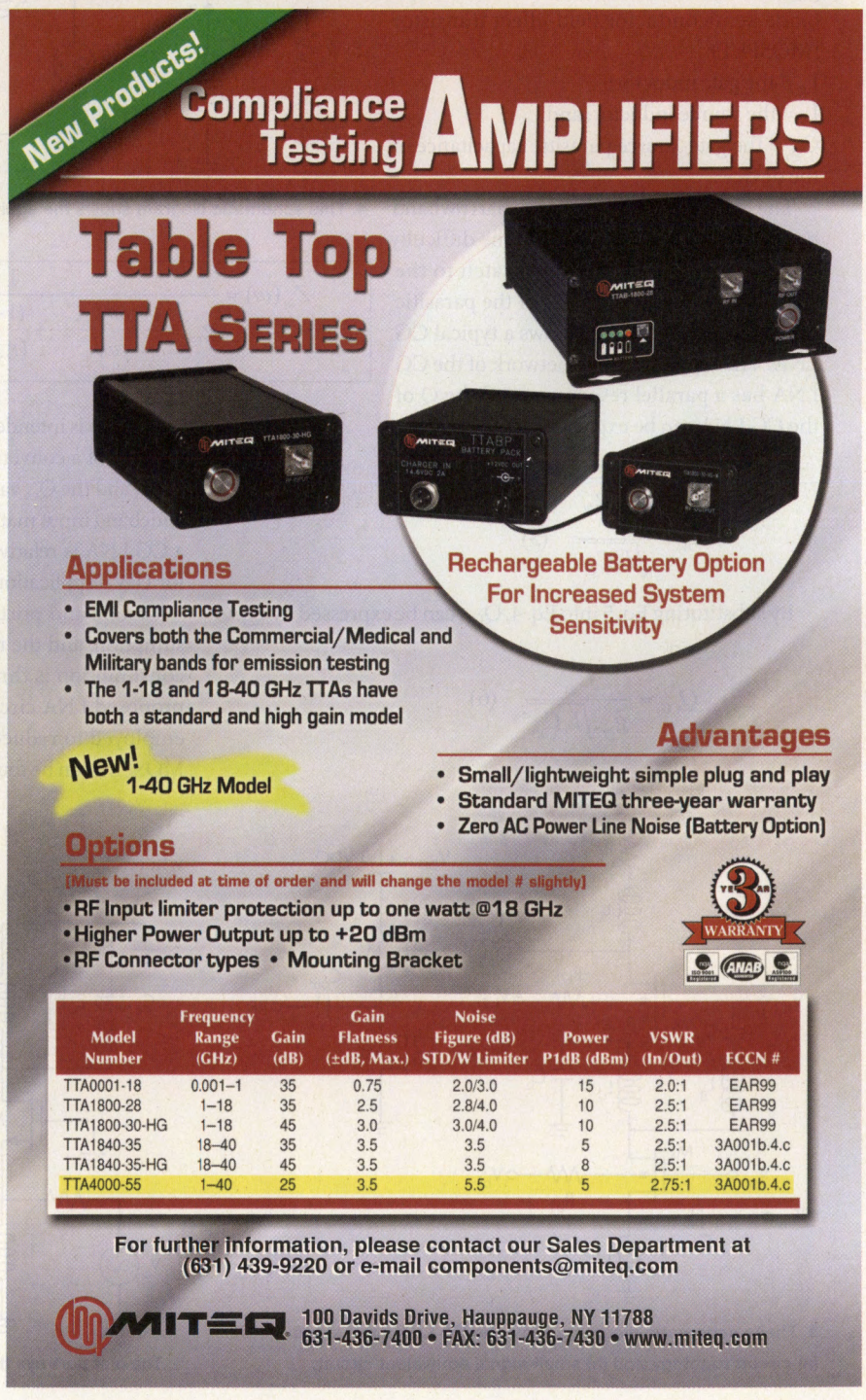
Based on their input matching characteristics, reported CMOS UWB LNA architectures can be divided into two major groups: CS and CG LNAs[18] *Figure 1* offers the two general topologies for these amplifier types. *Figure 1(a)* is a CS LNA that requires at least two inductors (L_g and L_s) for simultaneous noise and input matching (SNIM). Assuming the channel resistance, γ_0, and the gate-drain parasitic capacitance, C_{gd}, are negligible, the CS LNA's quality factor (Q) can be derived as:

$$Q_{CS} = \frac{1}{\omega_0 g_m L_s} \quad (1)$$

$$\omega_0 = \frac{1}{\sqrt{(L_g + L_s)C_{gs}}} \quad (2)$$

nately, it degrades gain and noise performances. In ref. 16, the post-distortion technique was used to improve linearity, with good results.

To achieve good performance for UWB systems, a common-gate (CG) LNA design is proposed. These LNAs offer simple input matching networks with good linearity and low power consumption compared to common-source (CS) LNAs. Because the power gain of a CS LNA tends to be low,[17] a CS amplifier is used in this design as a second stage. The proposed LNA design employs current-reuse and forward body biasing tech-



Substituting Eq. 2 into Eq. 1 yields Eq. 3:

$$Q_{CS} = \frac{\sqrt{(L_g + L_s)C_{gs}}}{g_m L_s} \quad (3)$$

where:

ω_0 = the resonant angular frequency of the input impedance;

g_m = the transconductance of the metal-oxide-semiconductor field-effect transistor (MOSFET);

L_g = the gate inductor;

L_s = the source inductor; and

C_{gs} = the gate-source parasitic capacitance of the device.

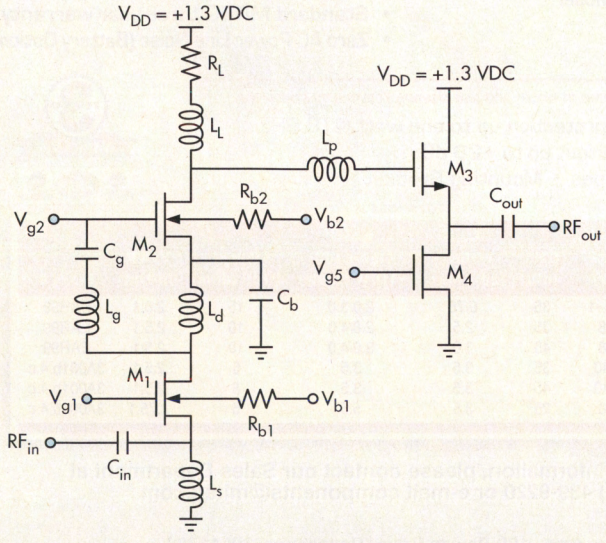
The architecture is inherently narrowband because of the high Q value and the difficulty in achieving wideband input match to the signal source in the presence of the parasitic capacitances. *Figure 1(b)* shows a typical CG LNA. The input matching network of the CG LNA has a parallel resonance, and the Q of the CG LNA can be expressed as:

$$Q_{CG} = \omega_0 \frac{C_{gs}}{g_m} \quad (4)$$

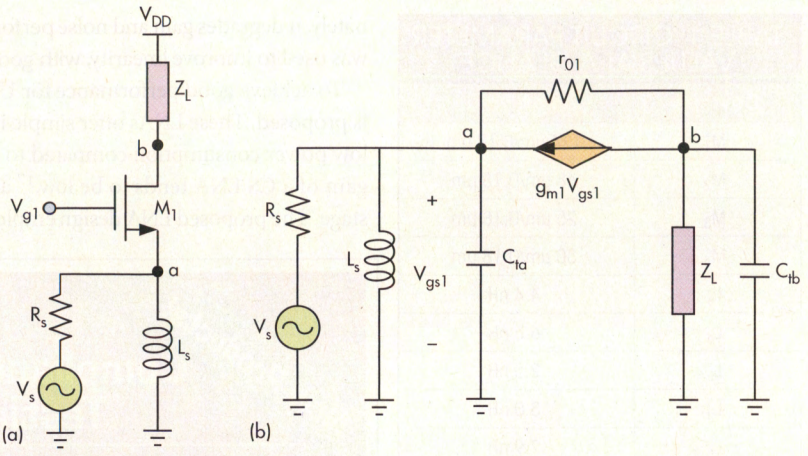
$$\omega_0 = \frac{1}{\sqrt{L_s C_{gs}}} \quad (5)$$

By substituting Eq. 5 into Eq. 4, Q_{CG} can be expressed by Eq. 6:

$$Q_{CG} = \frac{C_{gs}}{g_m \sqrt{L_s C_{gs}}} \quad (6)$$



3. These schematic diagrams show the CG LNA input stage (a) circuit topology and (b) small-signal equivalent circuit.



4. This schematic diagram shows the equivalent circuit of the proposed UWB LNA.

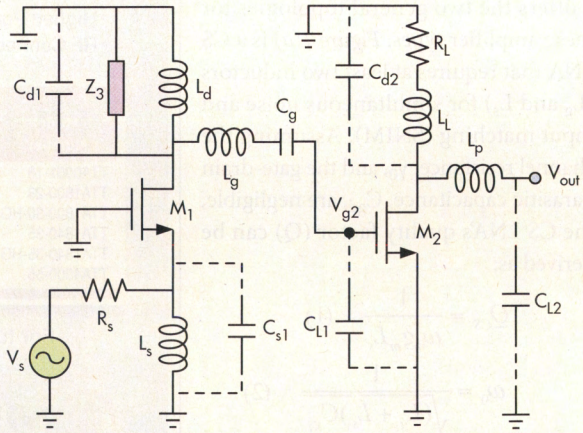
$$Z_{in}(\omega) = \frac{1}{g_{m1} + \frac{1-\omega^2 L_s C_{ta}}{j\omega L_s} + \frac{(1-g_{m1}Z_L) + j\omega Z_L C_{tb}}{(r_{o1} + Z_L) + j\omega r_{o1} Z_L C_{tb}}} \approx \frac{1}{g_{m1}} \quad (8)$$

Since L_s is intended to block the RF leakage to the ground, the L_s value of a conventional CG LNA is higher than that of a CS LNA, and the Q_{cs} value is higher than the Q_{cg} value. Obtaining a wideband input match and absorbing parasitic capacitances with a CG LNA is relatively simple, making this a suitable topology for UWB applications.

Mobile and portable applications require low power consumption, and the most efficient approach for reducing power consumption is through power supply voltage scaling. In the proposed LNA circuit, the forward body biasing technique is employed to reduce the threshold voltage, V_{th}. The V_{th} for a MOSFET can be found from Eq. 7:

$$V_{th} = V_{th0} + \gamma(\sqrt{2\varphi_f - V_{bs}} - \sqrt{2\varphi_f}) \quad (7)$$

where:



5. The plot portrays the amplifier's input reflection coefficient (S_{11}).

V_{th0} = the threshold voltage when $V_{bs} = 0$;
γ = the body-effect coefficient;
σ_f = the surface potential; and
V_{bs} = the voltage between the body and the source.

Usually, $V_{bs} \leq 0$, so $V_{th} \geq V_{th0}$. To reduce V_{th}, V_{bs} is set greater than zero so that $V_{th} < V_{th0}$. The typical value of V_{th} is about 0.5 V. For the proposed LNA design, $V_{bs} = 0.29$ V and $V_{th} = 0.43$ V.

The UWB LNA was designed and simulated in a standard 0.18-µm RF CMOS process. *Figure 3* shows a schematic diagram of the proposed LNA, including the output buffer stage (M_4, M_5). The current-reuse configuration can be considered as a two-stage cascade amplifier, where the first stage is the CG amplifier (M_1) and the second stage is the CS amplifier (M_2).

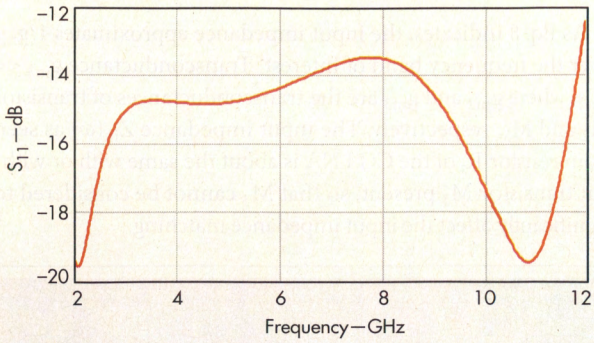
The signal amplified by M_1 is coupled to the gate of M_2 by series resonance (L_g and C_g) while the source of M_2 is bypassed by capacitor C_b. C_b determines the low-frequency band expansion and gain flatness. The circuit saves power through the reuse of the bias current.

The CG topology LNA exhibits low power gain, so a CS amplifier is included in the second stage. It employs a gain peaking technique which consists of R_L, L_L , M_2, and L_P. To reduce the threshold voltage of the transistor, the forward body biasing is employed. The post-distortion technique is used in the first stage (M_3), reducing the nonlinearity of the main device (M_1). *Table 1* summarizes the LNA's circuit parameters.

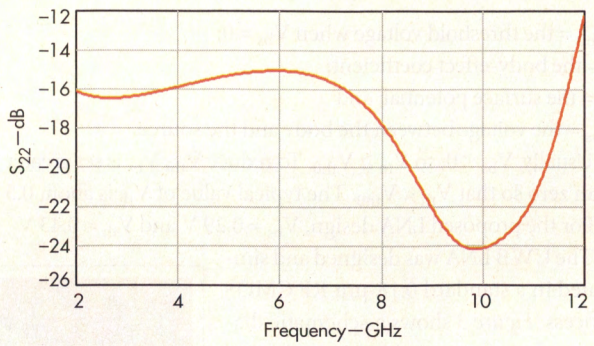
RF/microwave components and systems are typically designed for a standard impedance of 50 Ω, so the input stage of the UWB LNA should match to 50 Ω with minimal power reflection. [21] For simplicity in this analysis, body effects are ignored. *Figure 4* shows the CG input stage of the proposed UWB LNA, and the input impedance can be derived by Eq. 8 *(see box on facing page)*, where:
C_{ta} = the total capacitance at node a;
C_{tb} = the total capacitance at node b;
C_{gs1} = the gate-to-source capacitance;
g_{m1} = the transconductance;
r_{01} = the output resistance of M_1; and
Z_L = the CS stage equivalent load impedance.

As Eq. 8 indicates, the input impedance approximates $1/g_{m1}$ over the frequency band of interest. Transconductance $g_{m3} << g_{m2}$, where g_{m2} and g_{m3} are the transconductances of transistor M_2 and M_3, respectively. The input impedance $Z_{in}(\omega)$ as seen from resistor R_s of the CG LNA is about the same with or without transistor M_3 present, so that M_3 cannot be considered to significantly affect the input impedance matching.

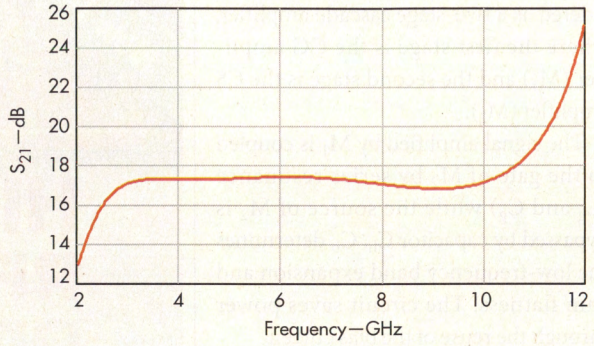




6. This plot shows the amplifier's output reflection coefficient (S_{22}).



7. The S_{21} plots represent the proposed amplifier's gain performance.



8. The plots show the proposed amplifier's noise figure.

However, for a wideband input match, Eq. 8 indicates that g_{m1} of M_1 in the CG stage should slightly exceed 20 mS. Through simulation, input matching is considered good when g_{m1} approaches 26 mS.

The achievable maximum power gain also depends on the output impedance matching. In the proposed LNA, a simple source follower, which consists of M_4 and M_5, is employed to obtain output impedance matching. If the source of M_2 is perfectly grounded by C_b, the equivalent schematic of the proposed LNA can be redrawn in *Fig. 5*, where the proposed UWB LNA is created by the two-stage amplifier.

The first stage is a CG amplifier and the second stage is a CS amplifier. For simplicity, body effects are not considered. The voltage gain of the first stage, A_{V1}, can be expressed by Eq. 9:

$$A_{V1} = \frac{V_{g2}}{V_s} = \frac{g_{m1} Z_s (Z_t * r_{o1})}{\{Z_s + R_s(1 + g_{m1} Z_s)\}(1 + sC_{L1} Z_g)} \quad (9)$$

where:

$$Z_s = sL_s * \frac{1}{sC_{s1}} \quad (10)$$

$$Z_d = sL_d * Z_3 * \frac{1}{sC_d} \quad (11)$$

$$Z_g = sL_g + \frac{1}{sC_g} \quad (12)$$

$$Z_t = Z_d * (Z_g + \frac{1}{sC_{L1}}) \quad (13)$$

where:

g_{m1} = the transconductance of M_1;
r_{01} = the channel resistance of M_1;
R_S = the input source resistance (50 Ω);
C_{s1} = the source parasitic capacitance caused by C_{gs1};
C_{d1} = the drain parasitic capacitance caused by C_{gd1};
C_{L1} = the parasitic load capacitance of the second stage; and
Z_3 = the equivalent impedance of M3.

For simplicity's sake, the direct-current (DC) blocking capacitors C_{in} and C_{out} are ignored in the analysis.

The voltage gain of the second-stage, A_{V2}, is given by Eq. 14:

$$A_{V2} = \frac{V_{out}}{V_{g2}} = \frac{-g_{m2} Z_{out2}}{1 + s^2 L_p C_{L2}} \quad (14)$$

where:

$$Z_{out2} = r_{o2} * Z_L * (sL_p + \frac{1}{sC_{L2}}) \quad (15)$$

$$Z_L = (R_L + sL_L) * \frac{1}{sC_{d2}} \quad (16)$$

where:

g_{m2}, γ_{02}, and C_{L2} are the transconductance of transistor M_2, the channel resistance of M_2, and the total load capacitance at the second-stage output, respectively. Additionally, C_{d2} is the calculated parasitic capacitance at the drain of M_2, which is produced by the gate-to-drain parasitic capacitor (C_{gd2}). The overall circuit frequency response of S_{21} has a good flatness and a high power gain because of the cascaded first and second stages.

The first stage of a receiver typically includes an LNA and its noise figure is critical to the receiver's performance, such as sensitivity, distortion, and signal range. For the purpose of simplicity, the parasitic effects, body effects, and the influence of M_3 on the noise performance are ignored in this analysis. For the proposed LNA, the mean-square noise voltage and the mean-square noise current can be expressed by Eqs. 17-20:

$$\overline{V^2_{ns}} = 4kTR_s \Delta f \quad (17)$$

$$\overline{i^2_{nd1}} = 4kT\gamma g_{m1}\Delta f \quad (18)$$

$$\overline{i^2_{nd2}} = 4kT\gamma g_{m2}\Delta f \quad (19)$$

$$\overline{i^2_{nR}} = 4kT / R_L\Delta f \quad (20)$$

which are produced by source resistor R_s and the channel noise of M_1, M_2, and load resistor R_L. Parameters k, T, γ, and Δf represent Boltzmann's constant, the absolute temperature (in degrees Kelvin), the thermal noise coefficient (having a value from 1 to 2 in the saturation region of a short channel MOSFET), and the noise bandwidth (in Hz), respectively.

The noise factor of the LNA can be expressed by Eq. 21 *(see box at top right)*, where $V_{2n,out}$ is the total noise at the output and AV is the total voltage gain.

$$F = \frac{V^2_{n,out}}{(A_V)^2} \times \frac{1}{V^2_{ns}}$$
$$\approx 1 + \frac{1}{(A_{V1})^2 R_s} \quad (21)$$
$$\times[(\frac{Z_t}{1+sC_{L1}})^2 \gamma g_{m1} + \frac{\gamma}{g_{m2}} + \frac{R_L}{g^2_{m2}(R_L + sL_L)}]$$

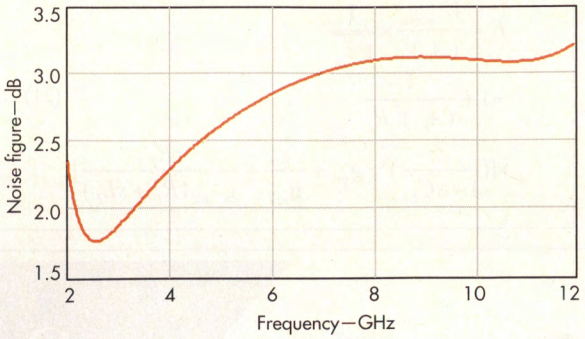
The total voltage gain AV can be obtained by Eqs. 17 and 21. From Eq. 21, it can be seen that the effects of g_{m1} and g_{m2} can be seen on achieving a lower noise factor; for low noise and low power consumption, g_{m1} should have a low value. But this can also have adverse effects on the total noise factor since low g_{m1} leads to low first-stage gain.

Alternately, from Eq. 21, it can be seen that a high g_{m2} value is beneficial for low noise factor, although the high value will also increase power dissipation. For best performance, the values of g_{m1} and g_{m2} should be optimized. Because both transconductance values depend on transistor width (W_1 and W_2), in the proposed LNA design, the optimal values of W_1 and W_2 are 124 and 48 μm, respectively.

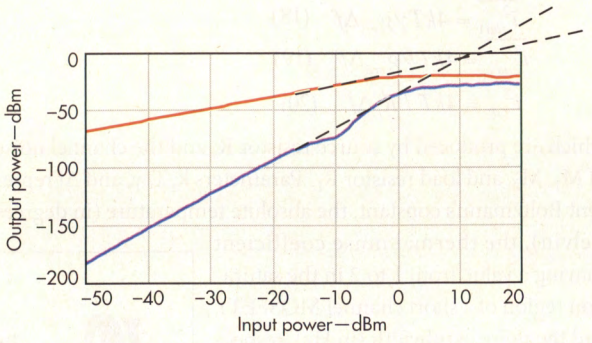
The UWB LNA was designed and simulated with the aid of the Advanced Design System (ADS) software from Agilent Technologies, using a standard 0.18-μm silicon RF CMOS process. With current reuse and forward body biasing, the supply voltage is only +1.3 VDC and the power consumption 3.1 mW.

Figure 6 shows simulated input reflection coefficient (S_{11}), which is less than −13 dB from3 to 11 GHz. Figure 7 shows simulated output reflection coefficient (S_{22}), which is less than −14 dB from 3 to 11 GHz. *Figure 8* shows voltage gain (S_{21}) for the LNA, which ranges from 16.8 to 18.9 from 3 to 11 GHz. *Figure 9* plots the noise figure of the proposed LNA, which





9. This plot represents the proposed amplifier's input third-order intercept point (IIP3).



10. This is the layout for the proposed UWB amplifier following computer simulation.

ranges from 1.9 to 3.2 dB across 3 to 11 GHz. *Figure 10* plots the input third-order intercept point (IIP3), at +10 dBm. *Figure 11* shows the layout of the proposed LNA. *Table 2* summarizes its performance and compares it with previous work. mw

ACKNOWLEDGMENT

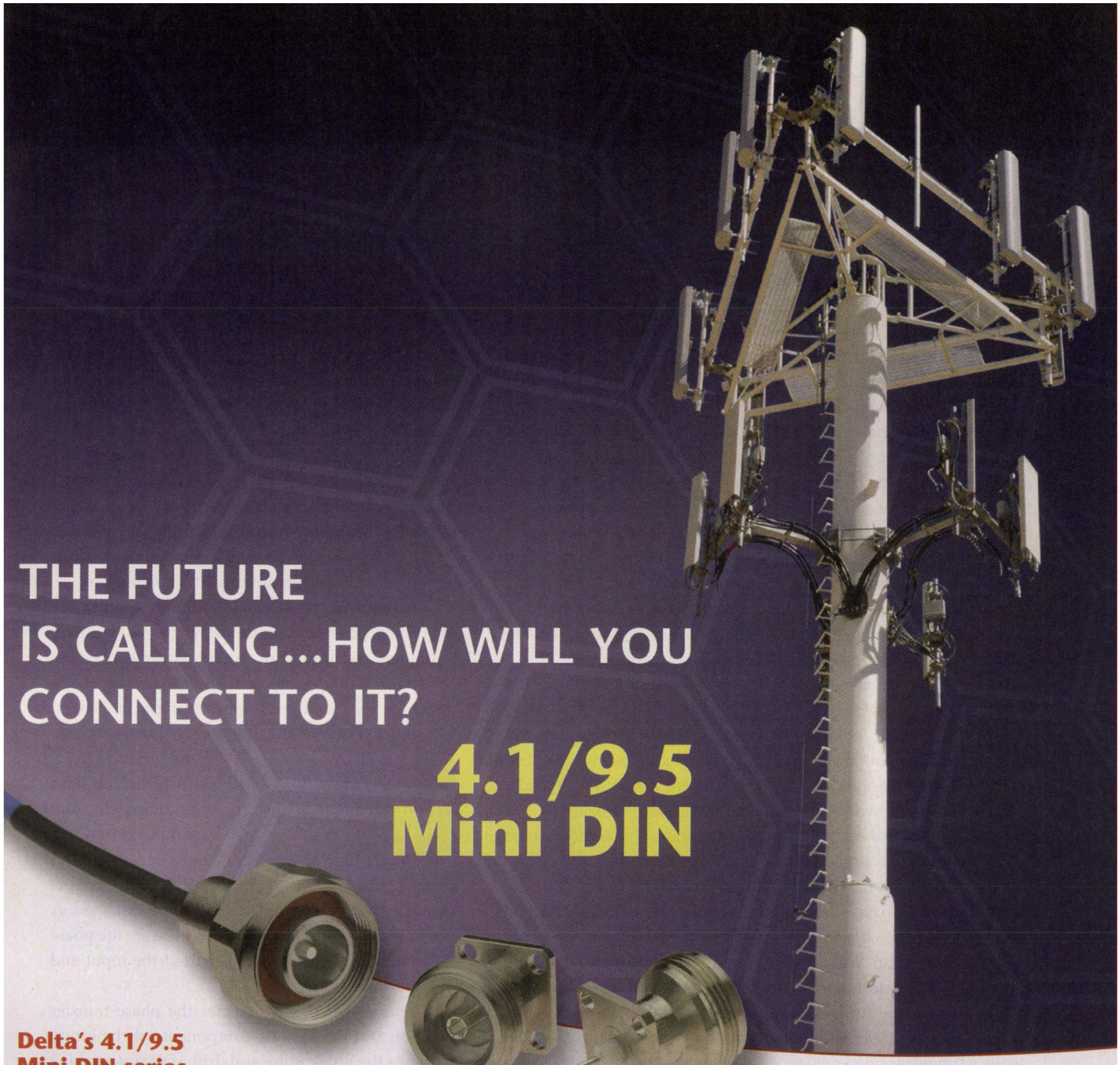
The authors would like to thank the research platform of the Open Fund Project for access to the coal mine monitoring network based on the wireless sensor networks in the Department of Education of Hunan Province, grant No. 12C0986.

REFERENCES

1. G. Roberto Aiello and Gerald D. Rogerson, "Ultra-wideband Wireless Systems," IEEE Microwave Magazine, June 2003, pp. 36-47.
2. Ren-Chieh Liu, Chin-Shen Lin, Kuo-Liang Deng, and Huei Wang, "A 0.5-14-GHz 10.6-dB CMOS Cascode Distributed Amplifier," in IEEE International Symposium on Very Large Scale Integrated (VLSI) Circuits Digest of Technology Papers, December 2003, pp. 139-140.
3. Yueh-Hua Yu, Yi-Jan Emery Chen and Deukhyoun Heo, "A 0.6-V Low Power UWB CMOS LNA," IEEE Microwave and Wireless Components Letters, Vol. 17, No. 3, March 2007.
4. Frank Zhang, and Peter Kinget, "Low Power Programmable-Gain CMOS Distributed LNA for Ultra-Wideband Applications," IEEE International Symposium on Very Large Scale Integrated (VLSI) Circuits Digest of Technology Papers, June 205, pp. 78-81.
5. Herbert Knapp, Dietmar Zoschg, Thomas Meister, Klaus Aufinger, Sabine Boguth, and Ludwig Treitinger, "15 GHz Wideband Amplifier with 2.8 dB Noise Figure in SiGe Bipolar Technology," IEEE International Symposium on Radio Frequency Integrated Circuits (RFIC), 2001, Digest of Technology Papers, pp. 287-290.
6. Stefan Andersson, Christer Svensson, and Oskar Drugge, "Wideband LNA for a Multistandard Wireless Receiver in 0.18μm CMOS," IEEE Solid-State Circuits Conference, September 16-18, 2003, pp. 655-658.
7. Ranjit Gharpurey, "A Broadband Low-Noise Front-End Amplifier for Ultra Wideband in 0.13 um CMOS," IEEE Custom Integrated Circuits Conference, October 3-6, 2004, pp. 605-608.
8. J.Y. Lee, J.H. Ham, Y.S. Lee, and T.Y. Yun, "CMOS LNA for full-band ultra-wideband systems using a simple wide input matching network," IEEE Transactions on Microwave Antennas & Propagation, Vol. 4, No. 12, December 2010, pp. 2155-2159.
9. Wei-Hung, Gang Liu, Boos Zdravko, and Ali M. Niknejad, "A Highly Linear Broadband CMOS LNA Employing Noise and Distortion Cancellation," IEEE Journal of Solid-State Circuits, Vol. 43, No. 5, May 2008, pp. 1164-1176.
10. Sudip Shekhar, Jeffrey S. Walling, and David J. Allstot, "Bandwidth Extension Techniques for CMOS Amplifiers," IEEE Journal of Solid-State Circuits, Vol. 41, No. 11, November 2006, pp. 2424-2439.
11. Vladimir Aparin, Gary Brown, and Lawrence E. Larson, "Linearization of CMOS LNA'S Via Optimum Gate Biasing," International Symposium on Circuits and Systems (ISCAS), Vol. 4, May 23-26, 2004, pp. 748-751.
12. Yong-Sik Youn, Jae-Hong Chang, Kwang-Jin Koh, Young-Jae Lee, and Hyun-Kyu Yu, "A 2 GHz 16dBm IIP3 Low Noise Amplifier in 0.25-μm CMOS Technology," IEEE Conference on Solid-State Circuits, Vol. 1, 2003, pp. 452-507.
13. Vladimir Aparin and Lawrence E. Larson, "Modified Derivative Superposition Method for Linearizing FET Low-Noise Amplifiers," IEEE Transactions on Microwave Theory and Techniques, Vol. 53, No. 2, February 2005, pp. 571-581.
14. Tae Wook Kim, "A Common-Gate Amplifier With Transconductance Nonlinearity Cancellation and Its High-Frequency Analysis Using the Volterra Series," IEEE Transactions on Microwave Theory and Techniques, Vol. 57, No. 6, June 2009, pp. 1461-1469.
15. Aya Mabrouki, Thierry Taris, Yann Deval, and Jean Baptiste Begueret, "CMOS Low-Noise Amplifier Linearization through Body Biasing," IEEE International Symposium on Radio Frequency Integration Technology (RFIT), January 2009, pp. 150-153.
16. Namsoo Kim, Vladimir Aparin, Kenneth Barnett, and Charles Persico, "A Cellular-Band CDMA 0.25-μm CMOS LNA Linearized Using Active Post-Distortion," IEEE Journal of Solid-State Circuits, Vol. 41, No. 7, July 2006, pp. 1530-1534.
17. J.-Y. Lee, H.-K. Park, H.-J: Chang, and T.-Y. Yun, "Low-power UWB LNA with common-gate and current-reuse techniques," IEEE Transactions on Microwave Antennas & Propagation, Vol. 6, No. 7, May 2012, pp.793-799.
18. Muhammad Khurram and S.M. Rezaul Hasan, "A 3-5 GHz Current-Reuse gm-Boosted CG LNA for Ultrawideband in 130 nm CMOS," IEEE Transactions on Very Large Scale Integration (VLSI) Systems, Vol. 20, No. 3, March 2012, pp. 400-409.
19. Heng Zhang and Edgar Sanchez-Sinencio, "Linearization Techniques for CMOS Low Noise Amplifiers: A Tutorial," IEEE Transactions on Circuits and Systems, Vol. 58, No. 1, January 2011, pp. 22-36.
20. Heng Zhang, Xiaohua Fan, and Edgar Sanchez Sinencio, "A Low-Power, Linearized, Ultra-Wideband LNA Design Technique," IEEE Journal of Solid-State Circuits, Vol. 44, No. 2, February 2009, pp. 320-330.
21. P. Andreani and H. Sjoland, "Noise optimization of an inductively degenerated CMOS low noise amplifier," IEEE Transactions on Circuits and Systems-II: Analog and Digital Signal Processing, Vol. 48, No. 9, September 2001, pp. 835-841.

TABLE 2: COMPARING THE PERFORMANCE LEVELS OF PREVIOUSLY REPORTED LNAs

Reference	[3]	[4]	[8]	[17]	[20]	This work
Maximum gain (dB)	10	8.6	15.3	14.8	11.7	18.2
Minimum noise figure (dB)	3.8	4.2	2.8	3.9	3.6	2.1
Bandwidth (GHz)	2.7-9.1	0.03-6.2	2.5-11.7	2.4-11.2	1.5-8.1	3-11
S11 (dB)	≤10	≤16	≤10	≤12	≤9	≤13
IIP3 (dBm)	-	+1.8	-	−11.5	14.1	10
Area (mm^2)	1.57	1.16	1.04	1.1	0.58	0.7
PD (mW)	7	9	11.6	3.4	2.62	3.1



THE FUTURE IS CALLING...HOW WILL YOU CONNECT TO IT?

4.1/9.5 Mini DIN

Delta's 4.1/9.5 Mini DIN series of coaxial connectors were developed to meet the growing demands of today's high performance mobile communications systems.

The **4.1/9.5 Mini DIN** has an operational frequency range of DC-14 GHz, offers excellent VSWR performance and Low Passive Intermodulation **(Low PIM) < -165 dBc,** making it ideally suited for use in **Base Stations, Distributed Antenna Systems (DAS)** and **Small Cell** applications.

Features
- IEC standardization
- 30% smaller and lighter compared to 7/16 series
- Reduced center to center spacing
- Albaloy plating

Benefits
- Global standard interface
- Increased package density
- Low PIM: < -165 dBc

DELTA
ELECTRONICS MFG. CORP.
Connect Here.

Get your copy of our new **4.1/9.5 Mini DIN** catalog, contact Delta today!

AS9100/ISO 9001:2008 CERTIFIED ROHS COMPLIANT

(978) 927-1060 • www.deltarf.com

IT'S A QUADRATURE COUPLER, NOT A QUADCOPTER

IN THIS LAGGING economy, much hope has been pinned on future jobs in broadband communications—and for good reason. Between 2002 and 2010, capital spending in the wireless industry is said to have exceeded $185 billion. On average, it created about 420,000 jobs throughout the economy (based on CTIA investment figures and the BEA 2010 employment multiplier). In a new study by Mobile Future and David Sosa and Marc Van Audenrode from Analysis Group, Inc., financial analysis is provided to show how robust private-sector investment can lead to substantial job creation.

The 90° hybrid coupler, or quadrature coupler, is a 4-port device used to aggregate the inputs/outputs of two RF devices in order to connect them to the signal path of a single antenna without interference between the two devices. These features enable various applications, such as the Long Wavelength Array (LWA) crossed-dipole antenna as used in the e-Callisto solar radio spectrometer network. In an application note provided by Reeve Engineers, the characteristics of a quadrature coupler are discussed along with the use of a quadrature coupler in the LWA system.

Ideally, a quadrature coupler is a fully symmetric 4-port device that evenly splits the input signal into two output ports, at a loss of 3 dB of power to the output ports less than the originating signal. One output signal is phase-shifted by 90° and the other signal should experience no phase shift. Both output ports should also be fully isolated from each other, meaning that signals/reflections from the secondary ports do not feedback to other ports in the device. The fourth port is an isolation port and is usually terminated with the characteristic impedance of the port with a terminator of adequate quality and power-handling capability.

As a result of this behavior, a circularly polarized radio wave can be decomposed into two perpendicular linearly polarized component waves. The application note uses the example of a crossed-dipole antenna, where two dipole antennas are placed perpendicularly, in order to capture the right-hand (RHCP) and left-hand (LHCP) circularly polarized radio waves. Because the symmetry of these signals is critical in the analysis of them, impedance mismatch is a concern as it shifts the amplitude of the received signals and causes internal reflections. Impedance mismatch may also cause a reemission of reflected signals as interference to other highly sensitive antennas in the array.

To coordinate the alignment of the antennas in the LWA, a system for nomenclature uses north-south, east-west, RHCP, and LHCP as descriptors for the ports of the coupler—input, isolated, +90° phase output, and 0° phase output.

Reeve Engineers,
2211 Kissee Court
Anchorage, AK 99517-1004,
+1-907-243-2263,
www.reeve.com

WHAT TO KNOW ABOUT SATELLITE FREQUENCY UPCONVERTERS

AS SATELLITE COMPONENTS are deployed in an environment in which it is difficult to diagnose and service failures, the reliability and performance of satellite components are key. Upconverters are a vital block in the transmission of RF/microwave signals from satellite communication equipment, and it is often difficult to have access to the internal local oscillator (LO) for performing characterization measurements. In this application note, Rohde & Schwarz details the process of characterizing a satellite frequency upconverter using phase noise, 1-dB compression point, conversion gain, spurious output, and third-order intermodulation testing.

The standard measurement technique for measuring relative phase and group delay, the golden mixer technique, requires ready access to the converter's LO. As this is not possible with the latest of embedded devices, a new technique for measuring an embedded LO source without direct access is discussed. This technique uses high-performance modern test equipment and a stimulation with a two-tone signal, in which the performance characteristics of the LO can be extracted. A vector network analyzer is used to measure the phase difference between the two signals at the input and output of the device.

Rohde & Schwarz
GmbH & Co.
KG, Mühldorfstraße
15 | D - 81671 München,
+ 49 89 4129 - 0,
www.rohde-schwarz.com

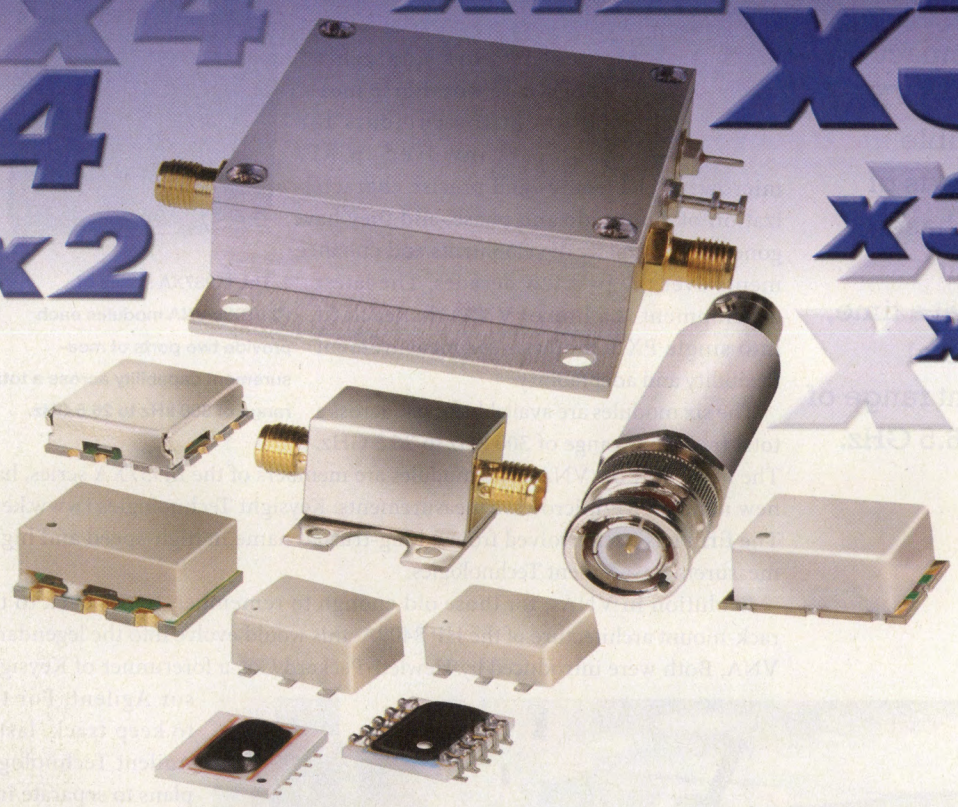
The analyzer then calculates the phase-transfer function and the various components of the group delay. As the phase noise and drift of the internal LO signal affect both tones used in the measurement, the analyzer can use the common-mode components of the signal to cancel out these factors and reveal the desired parameters. To perform this method with a high degree of accuracy, the tones need to be synchronized and have a stable frequency offset.

A Work Microwave commercial satellite upconverter that converts an intermediate-frequency (IF) signal from 70-140 MHz to 5.85-6.45 GHz is used as the demonstration device for the note, at 5.98 GHz with a conversion gain of 15 dB. The 3rd-order intermodulation product, phase noise, and spurious output are measured using two identical microwave signal generators and a signal/spectrum analyzer.

Now!

MULTIPLY UP TO 20 GHz

x4 x12 x3 x4 x3 x2 x2



Frequency Multipliers from $5.95 qty. 10-49

For your leading-edge synthesizers, local oscillators, and Satellite up/down converters, Mini-Circuits offers a large selection of ***broadband doublers, triplers, quadruplers, and x12 frequency multipliers.***

Now generate output frequencies from 100 kHz to 20 GHz with excellent suppression of fundamental frequency and undesired harmonics, as well as spurious. All featuring low conversion loss and designed into a wide array of, off-the-shelf, rugged coaxial, and surface mount packages to meet your requirements.

Visit our website to choose and view comprehensive performance curves, data sheets, pcb layouts, and environmental specifications. And you can even order direct from our web store and have a unit in your hands as early as tomorrow!

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

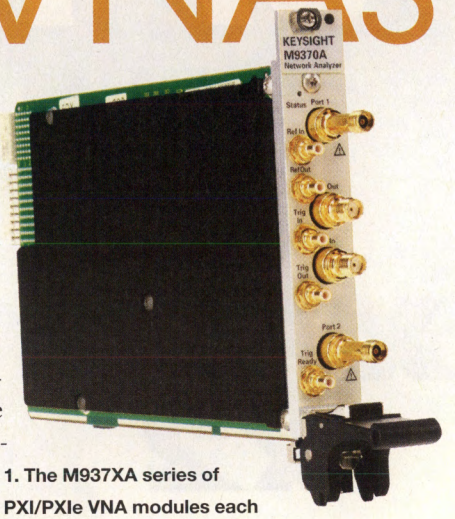
455 rev H

Product Feature

JACK BROWNE | Technical Contributor

PXI/PXIe VNAs Reach 26.5 GHz

Built into compact modules, these VNAs make it possible to add two ports of amplitude/phase measurement capabilities at a time, spanning a total measurement range of 300 kHz to 26.5 GHz.

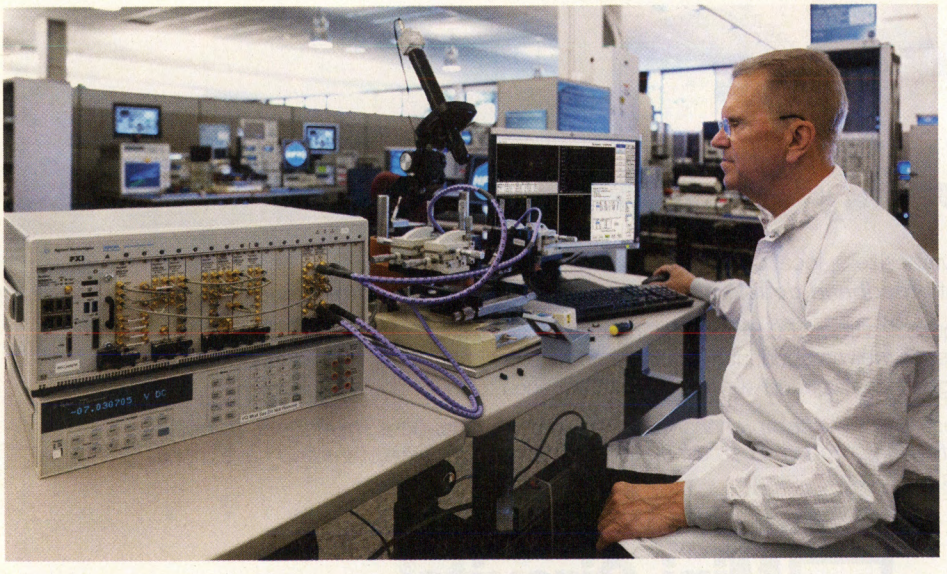


1. The M937XA series of PXI/PXIe VNA modules each provide two ports of measurement capability across a total frequency range of 300 kHz to 26.5 GHz.

Vector network analyzers (VNAs) are workhorse measurement instruments for engineers involved in RF/microwave electronics and precise characterization of amplitude and phase, and they have gone through many developments and enhancements over the past few decades. The latest development is a line of VNAs that each fit into single PXIe modules for measurement flexibility and adaptability.

The six modules are available for use across a total frequency range of 300 kHz to 26.5 GHz. The new two-port VNA PXIe modules are members of the M937XA series, hailing from a new name in RF/microwave measurements: Keysight Technologies (www.keysight.com). The firm has itself evolved from a long-trusted name in high-speed and high-frequency measurements: Agilent Technologies.

Evolution in VNAs, for those old enough to remember, traces back to the standard rack-mount architecture of the HP 8409A; this would evolve into the legendary HP 8510A VNA. Both were introduced by Hewlett-Packard Co., a forerunner of Keysight predecessor Agilent. For those trying to keep track, last September Agilent Technologies revealed plans to separate into two publicly traded companies through a tax-free spinoff of its electronic measurement business.

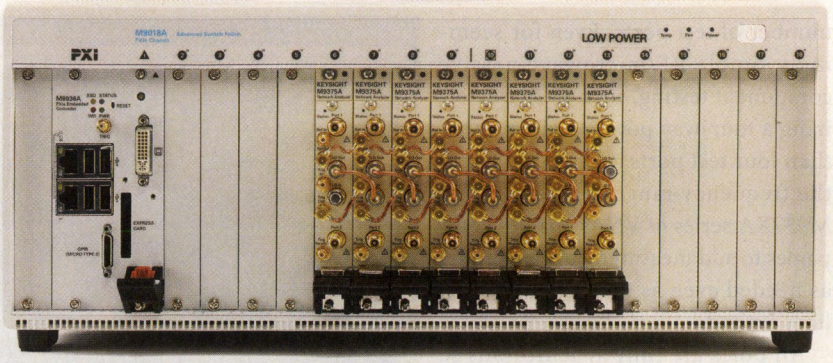


2. PXI/PXIe function modules such as the M937XA VNAs are typically used in an equipment chassis with an instrument controller in the leftmost slots.

The new spinoff company, Keysight Technologies, Inc., began operating as a wholly owned subsidiary of Agilent Technologies on August 1, and

is expected to begin trading on the New York Stock Exchange (NYSE) as a totally separate public company beginning in early November. If the M937XA series of PXIe VNAs is representative of the new products to be developed by Keysight, there will be long lines at the NYSE to purchase the company's stock.

The M937XA VNAs (*Fig. 1*) build upon those early rack-mount VNAs, with each managing to fit the functionality of a two-port microwave VNA into a single PXIe module. Gregg Peters, vice president and general manager of Keysight's Component Test Division, notes: "With our new PXI VNA, we now offer a choice in form factor that addresses emerging needs in aerospace, defense, wireless communications, and more." (For more on PXI, see the sidebar, "What is PXI?")



3. Multiple M937XA VNA modules within a single chassis can provide the measurement power in a fraction of the space occupied by a traditional 19-in. rack of test equipment.

Each module features a pair of high-density printed-circuit board (PCBs) and includes a precision signal source for the appropriate frequency range. The modularity and flexibility allows engineers to add two ports of VNA measurement capability at a time, with as many as 16 VNA modules contained within a PXI/PXIe chassis for a total of 32 fully synchronized VNA measurement ports. The six new VNA modules in the M937XA series are model M9370A (300 kHz to 4.0 GHz); model M9371A (300 kHz to 6.5 GHz); model M9372A (300 kHz to 9.0 GHz); model M9373A (300 kHz to 14.0 GHz); model M9374A (300 kHz to 20.0 GHz); and model M9375A, 300 kHz to 26.5 GHz.

Clearly, a user can select just the frequency range needed, then assemble the number of modules required for a sufficient

WHAT IS PXI?

A NUMBER OF different modular architectures have been developed over the years in support of electronic instrumentation, including PXI, which is an abbreviation for PCI eXtensions for Instrumentation. Building upon the available computer buses at the time, PXI was originally developed by and introduced by National Instruments (www.ni.com) in 1997. It is now backed by a large group of test-and-measurement companies as part of the PXI Systems Alliance (PXISA; www.pxisa.org).

The group oversees the use of PCI technology within hardware and software manufactured to the PXI standards. A typical 3U PXI module measures about 4 × 6 in. (100 × 160 mm). A typical full rack-mount PXI chassis is 4U high and holds as many as 18 PXI slots. The global market for PXI products is expected to grow steadily; it is larger than the global markets for VME eXtensions for Instrumentation (VXI) and local-area-network (LAN) eXtensions for Instrumentation (LXI) modular instrument products.

With the growth in modular measurement solutions, PXI Express (PXIe) was developed in 2005 as a compatible chassis/module format that could also support faster data rates (to 6 GB/s). A PXIe chassis supports the use of hybrid module slots, compatible for use with both PXI and PXIe modules. PXI modules are register-based circuits that work with software drivers hosted on a personal computer (PC) or on an embedded controller contained in the PXI/PXIe chassis.

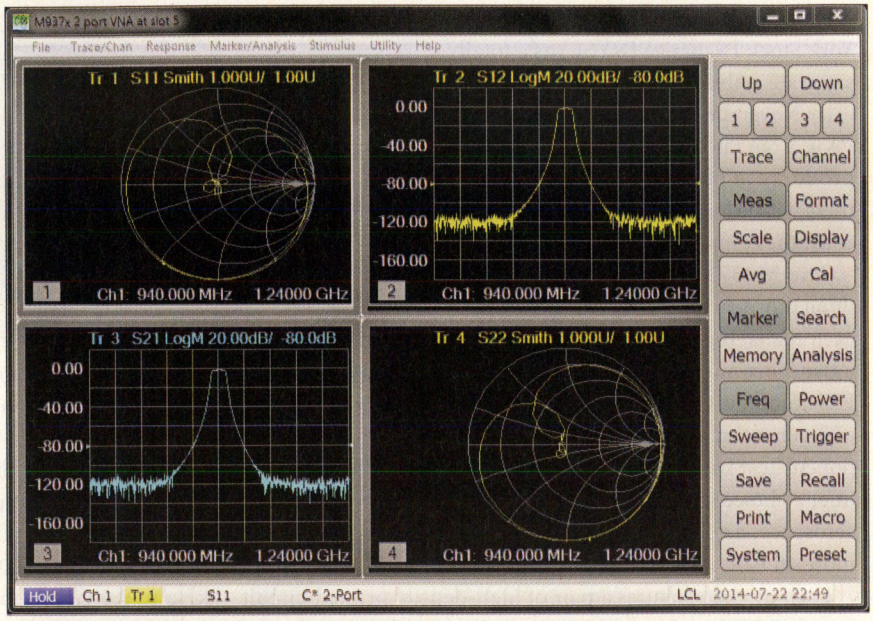
PXI/PXIe systems are compatible with a range of PC operating systems, including Microsoft Windows Vista SP1 and SP2, along with Microsoft Windows 7. They are also compatible with IVI-COM, IVI-C, LabVIEW, and MATLAB drivers, and with a range of application development environments that includes Visual Studio, LabVIEW, MATLAB, VEE, and LabWindows/CVI. PXI/PXIe modules and systems incorporate many common interface buses for flexibility, such as Universal Serial Bus (USB) connections, enabling electronic calibration (eCal) control via USB interface.

A PXI chassis may include its own controller running a standard operating system, such as Microsoft Windows XP or Windows 2000, or a PCI-to-PXI bridge that provides a high-speed link to a desktop PC controller. To build large systems, multiple PXI/PXIe racks can be linked by means of PCI bridge cards. The PXI/PXIe chassis provides the power, cooling, and communication buses for a PCI/PCIe controller and modules.

Though compatible, the PXI and PXIe specifications each carry their own lists of operating parameters. The PXI specification requires that a minimum of 25 W of power be available to each peripheral slot. In contrast, the PXI Express specification boosts the minimum power level a bit, to 30 W, with each slot capable of dissipating the same amount of heat. MW

number of test ports. Even for seemingly simple RF/microwave passive component testing, such as characterizing a four-way power divider, more than four test ports are needed across the frequency range of interest. The M937XA series of VNAs enables companies to add measurement capabilities as needed even as their own product lines expand.

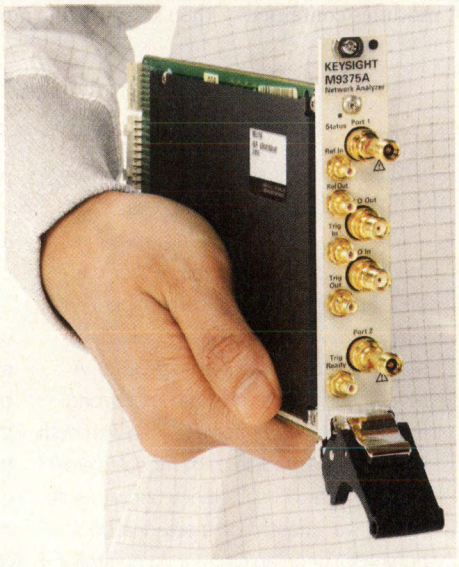
All ports are fully synchronous so that they can be measured simultaneously and multiport error correction can be applied. This capability to increase measurement capabilities by simply adding modules to an equipment chassis can greatly simplify a high-frequency measurement setup while reducing the requirements for test-equipment space in a laboratory (*Fig. 2*) or production line.



4. The M937XA Series VNA modules work with the same user interface as the popular Agilent/ Keysight PNA series of RF/microwave VNAs.

Each M937XA series module is a four-receiver, two-port VNA. Although compact, they do not scrimp on performance, with standard leveled power ranges of −40 to +7 dBm from their built-in test sources, adjustable with 1-dB resolution. In fact, the compact VNA modules are capable of delivering as much as +7 dBm leveled test power for measurements on a wide range of active and passive components, subsystems, and systems.

These VNA modules boast amplitude stability of better than 0.020 dB/°C from 300 kHz to 26.5 GHz, with trace noise of less than 0.003 dB. They are capable of dynamic range of better than 114 dB at 9 GHz and better than 110 dB at 20 GHz. Each VNA module can achieve sweep speeds of 18 ms across 401 points and can capture as many as 16,001 total measurement points.



5. Model M9375A is one of the M937XA VNA modules, a two-port instrument with a frequency range of 300 kHz to 26.5 GHz.

The M937XA series VNA modules employ the same user interface and SCPI programming commands (*Figs. 3 and 4*) as the benchtop PNA line of RF/microwave network analyzers popularized by Agilent Technologies and now offered by Keysight Technologies. This provides a simple transition to these new modules for users familiar with PNA instruments.

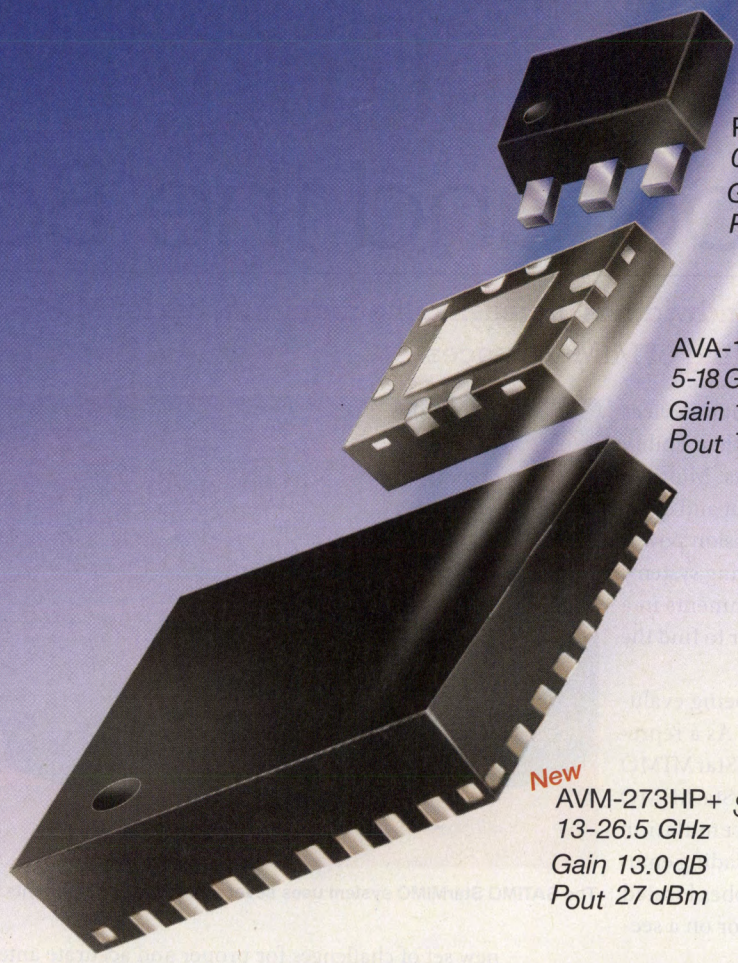
The new PXI/PXIe VNAs also use the same measurement science and calibration routines used in the PNA line of microwave network analyzers, including through-reflect-line (TRL), short-open-load-through (SOLT), and others that have proven their value in earlier vector analyzers from Agilent. The PXI/PXIe VNAs are also available with a wealth of calibration support and guidance. They are compatible with a host of mechanical calibration kits from various vendors—as well as the ECal kits now available from Keysight—to simplify the process of calibrating a measurement setup with any number of VNA modules, whether in a single chassis or in multiple PXI/PXIe chassis.

The modular VNAs are also available with a wide range of software options, including time-domain analysis capability and capabilities in support of advanced test fixture/simulator setups. The small size of these PXI/PXIe modules (*Fig. 5*) makes it possible to assemble complete measurement systems in the area once occupied by a single RF/microwave measurement instrument, and at a fraction of the cost. It is not difficult to understand the growing interest in modular measurement solutions such as PXI/PXIe. mw

KEYSIGHT TECHNOLOGIES, INC., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-2663, *www.keysight.com*

50 MHz to 26.5 GHz

THREE AMPLIFIERS COVER IT ALL!



PHA-1+ $1.99 ea. (qty. 20)
0.05-6 GHz
Gain 13.5 dB
Pout 22 dBm

AVA-183A+ $6.95 ea. (qty. 10)
5-18 GHz
Gain 14.0 dB
Pout 19 dBm

New
AVM-273HP+ $27.95 ea. (qty. 10)
13-26.5 GHz
Gain 13.0 dB
Pout 27 dBm

Mini-Circuits' New AVM-273HP+ wideband, 13 dB gain, unconditionally stable microwave amplifier supports applications from 13 to 26.5 GHz with 0.5W power handling! Gain flatness of ±1.0 dB and 58 dB isolation make this tiny unit an outstanding buffer amplifier in P2P radios, military EW and radar, DBS, VSAT, and more! Its integrated application circuit provides reverse voltage protection, voltage sequencing, and current stabilization, all in one tiny package!

The AVA-183A+ delivers excellent gain flatness (±1.0 dB) from 5 to 18 GHz with 38 dB isolation, and 19 dBm power handling. It is unconditionally stable and an ideal LO driver amplifier. Internal DC blocks, bias tee, and microwave coupling capacitor simplify external circuits, minimizing your design time.

The PHA-1+ + uses E-PHEMT technology to offer ultra-high dynamic range, low noise, and excellent IP3 performance, making it ideal for LTE and TD-SCDMA. Good input and output return loss across almost 7 octaves extend its use to CATV, wireless LANs, and base station infrastructure.

We've got you covered! Visit minicircuits.com for full specs, performance curves, and free data! These models are in stock and ready to ship today!

RoHS compliant

FREE X-Parameters-Based
Non-Linear Simulation Models for ADS

Modelithics®

http://www.modelithics.com/mvp/Mini-Circuits.asp

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

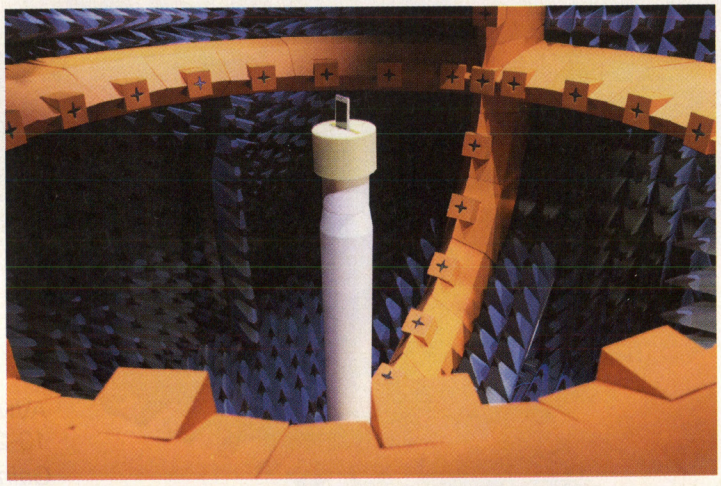
ALESSANDRO SCANNAVINI | RF Engineer
Microwave Vision, ascannavini@satimo.com

MIMO Testing: The Good and the Bad

The growing demand for bandwidth is increasing the requirements for MIMO technology, and thus the testing of MIMO devices.

MULTIPLE INPUT MULTIPLE output (MIMO) devices make 4G performance possible through their ability to function in complex RF environments. Multiple antennas enable increased data throughput and quality of service without increasing transmission power or bandwidth. But these devices need testing systems capable of simulating various RF environments in a repeatable and controlled manner in order to find the right antenna configuration.

There are several methods currently being evaluated to simulate these RF environments. As a representative of these methods, SATIMO's StarMIMO MIMO testing system will be evaluated. StarMIMO *(Fig. 1)* is based on the spatial fading emulation technique. It relies on the use of a spatial fading emulator and a number N of transmitting probes located in an array around the device under test or on a sector of the array itself.



The SATIMO StarMIMO system uses several hardware components.

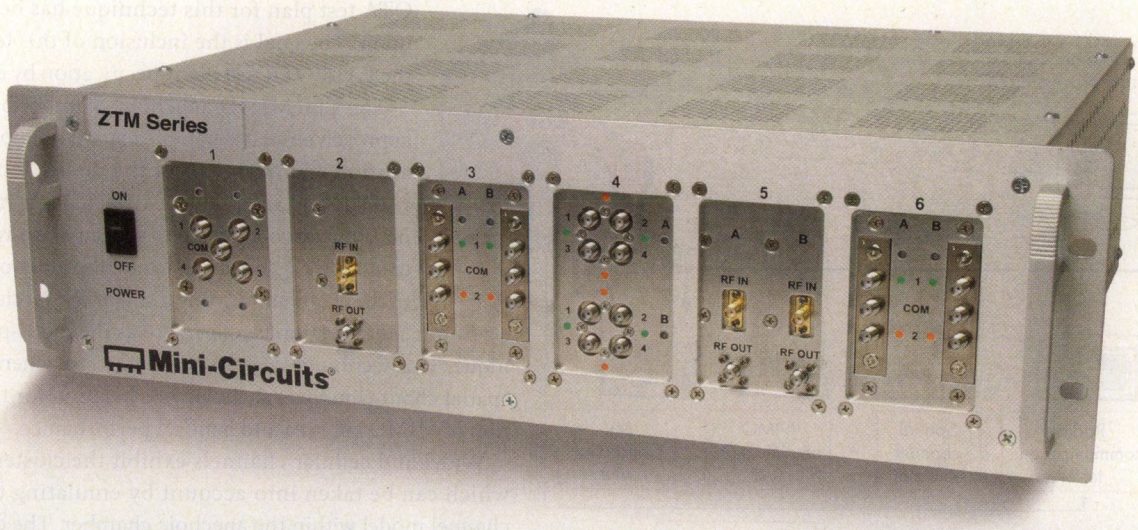
This technique enables users to properly emulate the standardized channel models such as SCME UMi (Spatial Channel Model Extended Urban Micro), and UMa (Urban Macro) at the device-under-test (DUT) location. The goal is to understand whether the proposed MIMO OTA methodology is suitable for discriminating between good and bad MIMO antenna systems in terms of the absolute data throughput performances.

Presented is the channel model validation results along with the throughput versus power results of the same DUT when using different antenna systems, with measurement in the LTE BAND 13 (751MHz) where the good, nominal, and bad antenna systems are available. With a baseline established, we can gain deeper insight on how to maximize MIMO antenna performance in a wide range of real-world environments.

MIMO devices are delivering consumers better bandwidth and quality of service. But their development creates a whole new set of challenges for proper and accurate antenna testing environments. MIMO uses multipath propagation to improve data throughput, therefore a configurable RF environment is needed to reliably test antenna performance. A successful simulator to test MIMO devices must emulate an entire spectrum of RF environments in a repeatable and controlled manner.

In order to understand the end-to-end reception performance of a MIMO device, over-the-air (OTA) testing is needed. This is primarily due to the fact that correlation plays an important role in multiple-antenna systems. The level of correlation cannot be determined based on the antenna characteristics alone without knowing the propagation characteristics. When testing devices with multiple antennas, it is therefore necessary to include both the antenna and propagation characteristics in the setup, thus the need of a new OTA testing methodology.

The SISO OTA measurements setup is no longer suitable for such testing, which relies on measuring the 3D power or



CUSTOM RACK MOUNT TEST SOLUTIONS

Built Your Way and Delivered within 2 Weeks!

Signal Routing & Attenuation Control for Production Test, R&D and More!

Mini-Circuits' new ZTM-Series RF test matrices dramatically accelerate custom solutions for a wide range of applications in test environments. Choose from our lineup of extra-long-life SP4T, SPDT and transfer switches, and programmable attenuators with attenuation ranges of 0 to 30, 60, or 90 dB. We'll build and ship a solution tailored to your exact requirements *within just 2 weeks!*

It's that simple! Give us a call and talk to our engineers about how Mini-Circuits' ZTM-Series custom rack mount test solutions can improve efficiency, increase throughput, and save cost in your business!

Features

- *Rugged 19" Rack Mountable Chassis*
- *Customizable Front Panel Layout*
- *Light Weight*
- *USB and Ethernet Control*
- *User-friendly GUI and DLLs Included*
- *Qualified to 100 Million Switch Cycles*
- *Affordable Cost*
- *Delivery within 2 Weeks!*

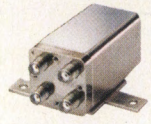
Choose from hundreds of possible configurations!



SPDT Switches
DC – 18 GHz



SP4T Switches
DC – 18 GHz



Transfer Switches
DC – 18 GHz

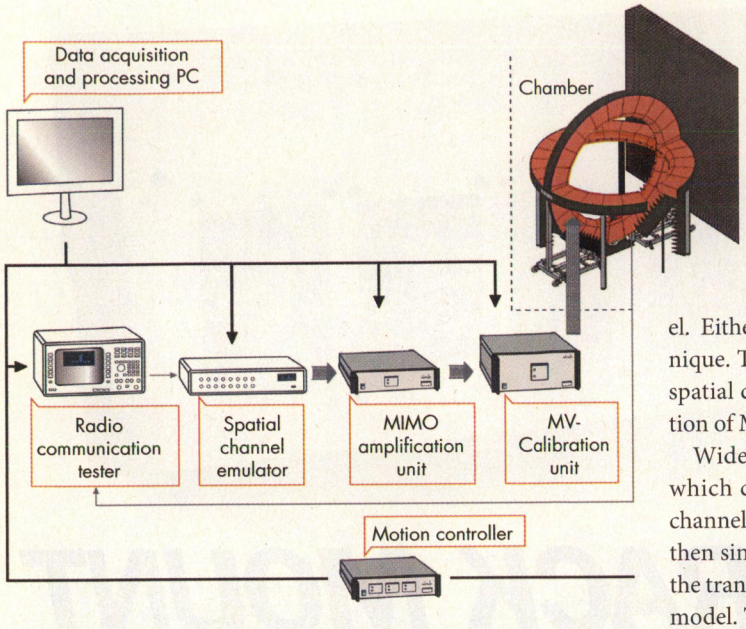


0 – 30, 60, or 90 dB
Programmable Attenuators
1 MHz – 6 GHz

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

527 rev. orig.



1. This MIMO test system relies on the use of several hardware components.

received sensitivity pattern measurements with an isotropic weighting, uniform channel model. Therefore, total radiated power (TRP) and total isotropic sensitivity (TIS) are no longer used as a standard figure of merit, since they are not taking into account the propagation model's characteristics. Due to the complexity of multiple antenna setups, a flexible and accurate testing solution becomes a major asset in the antenna design cycle, final product verification—and most importantly, time-to-market for the device.

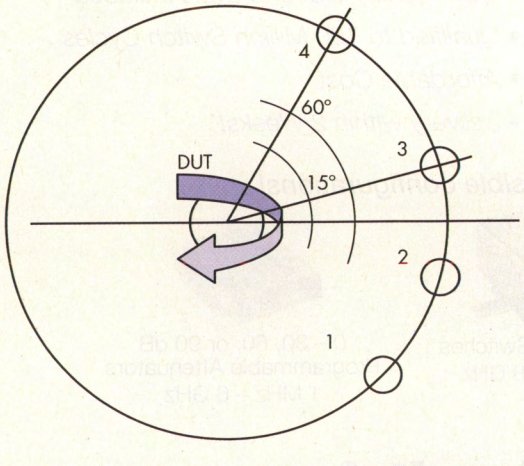
The wireless industry, through the CTIA and 3GPP standardization bodies, has been studying the anechoic-chamber-based OTA technique since 2009. In CTIA, a draft MIMO OTA test plan for this technique has been agreed upon. The goal is the inclusion of this test plan in the CTIA OTA test plan specification by early 2015.

The LTE MIMO anechoic chamber based OTA approach emulates complex spatial-temporal propagation environments at the device location in a realistic and repeatable way by using a radio channel emulator connected to a circular array of probes (multiple cluster) or an array of probes on one side of the chamber forming a single spatial cluster model. Either configuration is referred to as the multi-probe technique. This technique addresses the need to generate precise spatial channel models at the device location for the evaluation of MIMO antenna and handset performance.

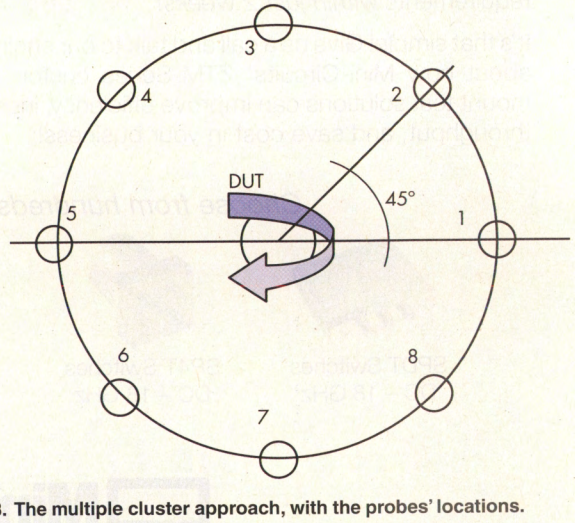
Wideband cellular channels exhibit the cluster behavior which can be taken into account by emulating the spatial channel model within the anechoic chamber. The clusters are then simultaneously mapped to the probes so that the sum of the transmitted signals at the DUT location is as defined in the model. These measurement-based channel models include all dimensions of the radio channel (time, frequency, space, and polarization). Each cluster is split between several probes to enable angular spread. As a result, the geometry-based environment of the channel model is accurately reproduced within the anechoic chamber.

It must be noted that on such a measurement system, the signals are coming simultaneously from N (number of probes) directions around the DUT (device-under-test) as opposed to SISO, in which the signal is coming from one direction at a time. This characteristic combined with a spatial channel emulator, provide the ability to emulate a spatial-temporal propagation model at the DUT location.

The probes' locations play an important role here. Probes can be located on a single sector (single cluster approach) or on a full circle (multiple cluster approach):



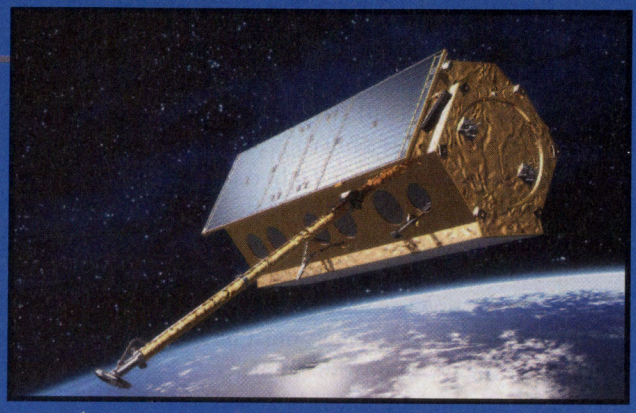
2. The single cluster approach, with the probes' locations.



3. The multiple cluster approach, with the probes' locations.

Instantly Improve the Performance of Your Phased Array Radar!



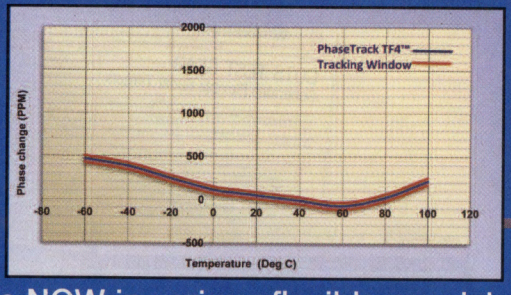


Phased Array Radar system performance has long been limited by the phase change over temperature of coaxial cables.

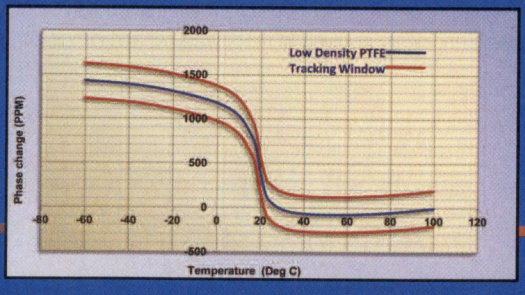
Not anymore!

TF4™ - our proprietary, ultra stable dielectric material significantly improves Phased Array Radar system performance by reducing the phase change of the interconnecting coaxial cables.

Typical PhaseTrack TF4™ Performance



Typical Low Density PTFE Performance



Available NOW in various flexible coaxial cable and semi rigid coaxial cable assembly sizes
Perfect for all Ground, Naval, Airborne or Spaceflight Phased Array Radar applications
Frequency ranges to 40 GHz
Wide range of connector types available
Best Phase Tracking and Absolute Phase Change performance available

TIMES MICROWAVE SYSTEMS
An Amphenol Company

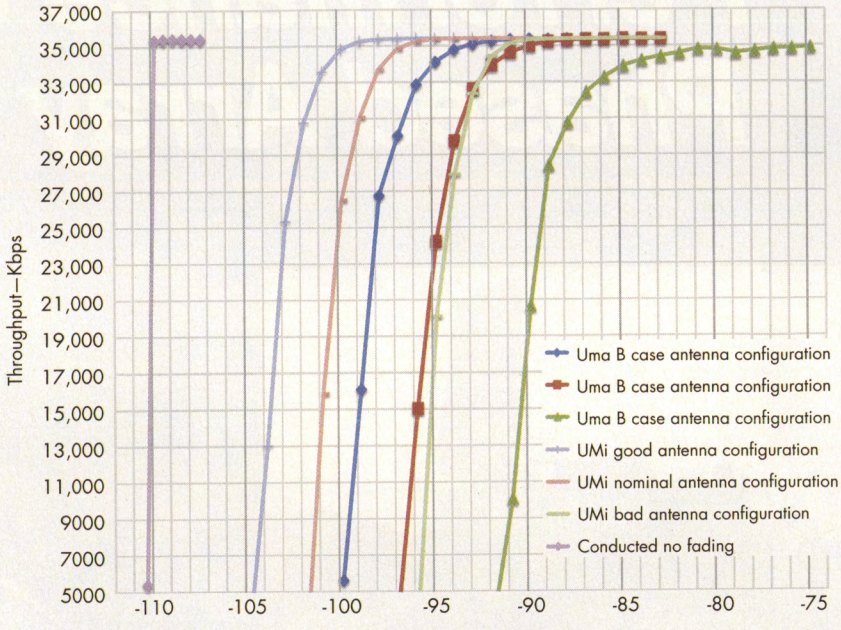
World Headquarters: 358 Hall Avenue, Wallingford, CT 06492 • Tel: 203-949-8400, 1-800-867-2629 Fax: 203-949-8423
International Sales: 4 School Brae, Dysart, Kirkcaldy, Fife, Scotland KY1 2XB UK • Tel: +44(0)1592655428
www.timesmicrowave.com

Single cluster (sector setup). *Figure 2* shows a possible implementation of a single sector setup, utilizing a single cluster approach. Four dual polarized probes are located on a sector of the array.

Geometry based stochastic channel model (GSCM) can be then built and emulated at the DUT location. Complexity of the setup is then reduced by using this approach versus the full ring setup.

Multiple cluster (full ring setup). The next depiction is of a full ring, multiple cluster implementation. Eight dual polarized probes are located at 45 deg. distance on a full ring.

Once the channel models are defined and before starting any testing activity, the emulated channel models must be verified at the DUT location in order to address any impairments which will be added by the setup to the channel models. The verification will consist in



4. Depicted is a comparison between SCME UMi and UMa for three antenna configurations, with measurement in the LTE BAND 13 (751MHz).

Defense Electronics serves electronic design engineers working in defense and aerospace markets with the latest technology-based news, design, and product information. It reviews the latest advances in electronics technologies related to military and aerospace electronic systems, from the device and component levels through the system level, also covering the latest developments in the software needed to simulate those defense/aerospace systems and the test equipment needed to analyze and maintain them. It is the industry's most trusted source of technical information for electronic engineers involved in military/aerospace circuit and system design.



WE SUPPORT THE DESIGN PROCESS FROM INTENT TO ACTION

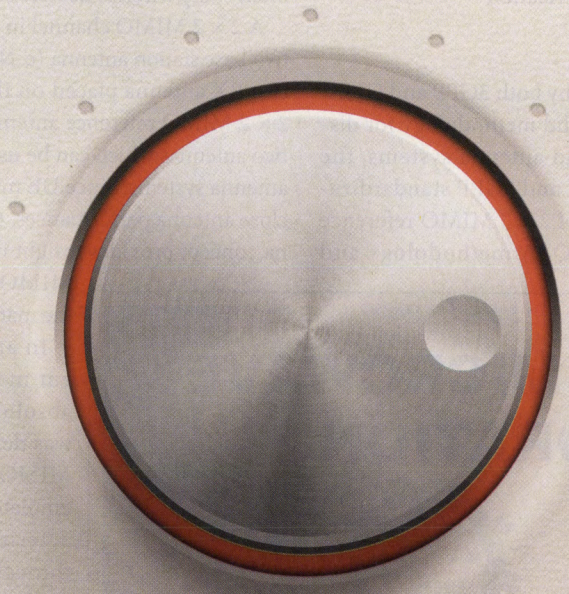
defense electronics

A Special Section to PENTON'S DESIGN ENGINEERING & SOURCING GROUP

Penton

Agilent Technologies

Agilent's Electronic Measurement Group



Keysight Technologies

Agilent's Electronic Measurement Group, including its 9,500 employees and 12,000 products, is becoming **Keysight Technologies**.

Learn more at www.keysight.com

MEASURE DELTA SUMMARY					
	EPRE good (dBm/15kHz)	EPRE nominal (dBm/15kHz)	EPRE bad (dBm/15kHz)	Good versus bad (dB)	Good versus nominal (dB)
SCME UMi case throughput = 34MBps	–100.5	–97.5	–92	8.5	3
SCME UMa case throughput = 34MBps	–95	–91.5	–85	10	3.5
EPRE = energy resource element					

The table summarizes the measured delta in dB between good, nominal, and bad antenna systems when the throughput is 34MBps. The data demonstrates that the measured deviations are in line with what is expected for the different antenna configurations for both the SCME UMi and UMa cases.

measuring the following four main parameters which would characterize spatial-temporal channel models:

- PDP – power delay profile
- Doppler spectrum – temporal correlation
- Spatial correlation
- XPR – cross polarization ratio

The testing procedure is approved by both 3GPP and CTIA.

To test whether StarMIMO is a valid methodology for discriminating between Good and Bad antenna systems, the wireless industry through the CTIA and 3GPP standardization bodies agreed to develop a set of 2 × 2 MIMO reference antennas to validate each MIMO OTA methodology and understand whether the methodology is suitable in discriminating between Good and Bad antenna systems in terms of the absolute throughput performance of the UE (User Equipment—any wireless devices supporting 3G and 4G).

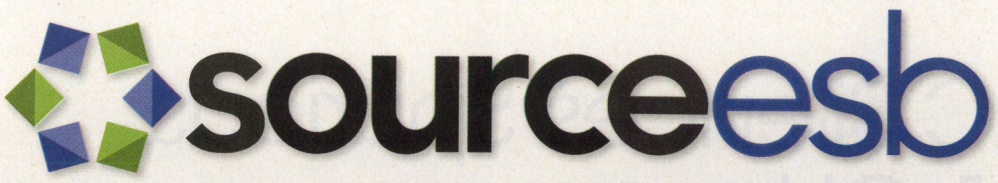
A 2 × 2 MIMO channel in downlink (reception) consists of two base station antenna (e-NodeB antennas) transmitting and two RX antenna placed on the UE. Based on this concept, a 2 × 2 MIMO reference antenna is an antenna system made by two antennas which can be used as a baseline for designing UE antenna systems. Since UE manufacturers typically do not disclose antenna performances, the MIMO 2 × 2 reference antenna concept provides insight into the performances of the LTE MIMO devices currently available on the market.

In an effort to compare the different methodologies to a baseline, the absolute data throughput framework was defined and used to compare each MIMO OTA testing method's ability to emulate the specified propagation characteristics based on an absolute data throughput metric *(Fig. 4)*.

As markets continue to be saturate with MIMO systems, it becomes ever more critical to speed up time-to-market on any product that has the ability to stand out from the competition. This need will continue to drive the search for the best testing approach that will ultimately help bring good products to market faster.

While there are many testing systems and methodologies still under evaluation, a method was shown that did prove itself effective in discriminating between good and bad MIMO antenna systems. It provides clear evidence that is validated by running absolute data throughput testing on the same reference device by using the same channel models. MW





The Original Electronics Parts Search & Procurement Tool

Search Parts

Part # | Manufacturer

SEARCH PARTS FAST

Your Trusted Source

www.SourceESB.com

JACK BROWNE | Technical Contributor

DAC Silences Spurious for 1-GHz Bandwidth

This high-speed digital-to-analog converter operates at 2.5 GSamples/s to provide a low-noise, 1-GHz instantaneous bandwidth with excellent spectral purity.

PRECISE SIGNAL GENERATION often starts with an oscillator. In the case of the LTC2000 digital-to-analog converter (DAC) from Linear Technology (www.linear.com), however, it can start in the digital realm with little or no compromise in spectral purity and other critical signal characteristics.

This high-performance DAC achieves −74 dBc spurious-free dynamic range (SFDR) at 200 MHz by means of its 16-b resolution and 2.5-GSamples/s sampling rate; it delivers instantaneous output bandwidths as wide as 1 GHz for a wide range of applications, from communications systems to test-and-measurement gear. The SFDR across the full 1-GHz output range is a still-impressive −68 dBc.



The LTC2000 is a RoHS-compliant, BGA-packaged DAC capable of delivering a full 1-GHz outrput bandwidth with 16-b resolution.

The LTC2000 DAC (*see photo*) is available in a number of different versions—with 11, 14, or 16-b resolution—each supplied in a 170-lead, RoHS-compliant, BGA package measuring 9 × 15 × 1.54 mm. The parallel data input ports support low-voltage-differential-signaling (LVDS) and differential-high-speed-transceiver-logic (DHSTL) input data signals, with data input clocks working to 625 MHz and data rates to 1.25 Gb/s using a double data rate (DDR) scheme. The data input clock can be in quadrature or in phase with the data arriving at the input ports.

Each DAC version has two input ports, and the DACs can be operated in single- or dual-port modes. In single-port mode, one of the input ports is grounded and the DAC operates at sampling rates to 1.25 GSamples/s. In dual-port mode, data is written to both ports simultaneously and then interleaved inside the DAC, enabling operation at sampling rates to 2.5 GSamples/s.

The LTC2000 DACs are available in commercial and industrial versions for operating temperatures from 0 to +70° (model LTC2000C) and −40 to +85°C (model LTC2000I), respectively. The DACs offer ±1-V compliant outputs with 40-mA full-scale current which can be adjusted to as low as 10 mA and as high as 60 mA. Running the DACs faster consumes a bit more power, but offers impressive performance levels for output signals to 1 GHz.

The single-sideband (SSB) phase noise, for example, at 2.5 GSamples/s, is −147 dBc/Hz at an offset of 10 kHz from a 65-MHz carrier and a mere −165 dBc/Hz at an offset of 1 MHz from the same carrier. The spurious-free dynamic range (SFDR) for a sampling rate of 1.25 GSamples/s in single-port mode is −82 dBc for an output frequency of 100 MHz, −74 dBc for an output of 250 MHz, and −74 dBc for an output of 500 MHz. For a sampling rate of 2.50 GSamples/s in dual-port mode the SFDR is −76 dBc for an output frequency of 100 MHz, −72 dBc for an output of 500 MHz, and −68 dBc for an output of 1000 MHz.

The two-tone intermodulation distortion (IMD) for these DACs is also minimal. For a sampling rate of 1.25 GSamples/s, the two-tone IMD is −100 dBc at 50 MHz, −90 dBc at 250 MHz, and −82 dBc at 500 MHz. For a sampling rate of 2.50 GSamples/s, the two-tone IMD is −87 dBc at 100 MHz, −84 dBc at 500 MHz, and −78 dBc at 1000 MHz.

These DACs are well suited for generating wide-bandwidth, high-frequency signals for wired and wireless communications systems, radar and other defense systems, and in test equipment. They are capable of generating signals with minimal delays from applied input data. At 2.5 GSamples/s, the DACs consume 2.2 W from dual +1.8- and +3.3-VDC supplies, dropping the power consumption to just 1.3 W at 1.25 GSamples/s. mw

LINEAR TECHNOLOGY CORP., 1630 McCarthy Blvd., Milpitas, CA 95035-7417; (408) 432-1900, FAX: (408) 434-0507, *www.linear.com*

LOW NOISE BYPASS AMPLIFIERS



500 MHz-5 GHz

Very rarely does a new product achieve many breakthrough features in one model. Mini-Circuits' TSS-53LNB+ is this rare exception. With ultra-wide frequency range and excellent gain flatness, this revolutionary amplifier is ideal for broadband and multi-band applications from military and commercial wireless to instrumentation and more! Its integrated, switchable bypass circuit allows you to protect the LNA in the presence of large signals and extend the usable dynamic range – all in a tiny, 3x3mm package! Visit minicircuits.com for full specs and off-the-shelf availability for delivery as soon as tomorrow!

$1.89 *from ea.(qty.1000)*

- *21 dB Gain in LNA Mode*
- *Ultra Flat Gain, ±1.5 dB from 500 to 3500 MHz*
- *Internal Bypass Switch for Large Signals*
- *Low Noise, 1.4 dB*
- *+21 dBm Output Power*
- *+34 dBm IP3 in LNA Mode*
- *+50 dBm IP3 in Bypass Mode*
- *Tiny Size, 3x3mm*

RoHS compliant.

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

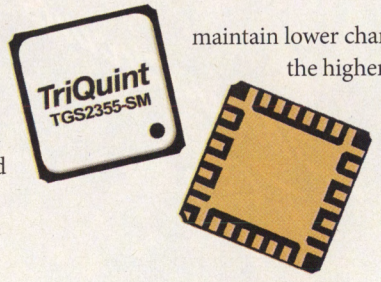
525 rev A

JACK BROWNE | Technical Contributor

GaN MMIC Switch Controls 100-W Pulses

This low-loss GaN-on-SiC SPDT switch can handle signals from 500 MHz to 6 GHz, both at CW power levels to 40 W and pulsed power levels to 100 W.

GALLIUM-NITRIDE (GAN) SEMICONDUCTOR devices are quickly capturing the attention of high-frequency circuit designers for their excellent performance at high frequencies. In addition, many of these devices also offer good high-power signal-handling capabilities, such as the model TGS2355-SM monolithic-microwave-integrated-circuit (MMIC) single-pole, double-throw (SPDT) switch from TriQuint (www.triquint.com).



Supplied in a compact QFN housing, the TGS2355-SM GaN MMIC switch handles as much as 40 W CW power and 100 W pulsed power from 0.5 to 6.0 GHz.

This compact SPDT switch operates from 500 MHz to 6 GHz, handling as much as 40 W continuous-wave (CW) input power and 100-W (+50 dBm) pulsed (20-µs pulse width) input power across that frequency range. It also channels signals with low loss and good isolation and is a solid candidate for applications in communications systems, electronic-warfare (EW) systems, radar, and test-and-measurement equipment.

The TGS2355-SM reflective switch *(see photo)* is fabricated on the firm's gallium-nitride-on silicon-carbide (GaN-on-SiC) 0.25-µm production semiconductor process. The high thermal conductivity of the SiC substrate material helps to channel heat generated within the active devices away from the semiconductors; it is then dissipated in other structures, such as a heat sink or surrounding circuit or system package materials. The GaN switch is rated for maximum channel temperature of +275°C.

The switch is turned on and off by means of control voltages of 0 and –40 VDC. It is supplied in an air-cavity, quad-flat-no-leads (QFN) package measuring just 5 × 5 × 1.42 mm that is lead free and RoHS compliant.

The TGS2355-SM boasts the key features desirable in a broadband switch, in addition to its high power-handling capability, and these include low losses and high isolation. For example, the GaN SPDT switch is rated for less than 1.1-dB insertion loss from 500 MHz to 6 GHz, with typical insertion loss of 0.8 dB or less across that full frequency range. The low loss helps to maintain lower channel temperatures in the tiny switch even at the higher input power levels.

The return-loss performance is also outstanding for such a broadband, high-power switch, at better than 15 dB across the full frequency range. The TGS2355-SM offers better than 25-dB isolation between ports across the full operating frequency range, and provides better than 10-ns switching speed for critical high-speed applications.

Of course, the switch isn't the only big news to come out of the TriQuint camp: Following the completion of its merger with RF Micro Devices, the firm will be renamed Qorvo. The combined company will merge the different talents of the two companies, spanning various technologies and application areas. Bob Bruggeworth, currently president and chief executive officer of RFMD, will become CEO of the new entity. Bruggeworth notes: "As a new leader in RF solutions, Qorvo will offer the agility, innovation, and precision customers need for success in mobile, infrastructure, and defense markets."

TriQuint's current CEO, Ralph Quinsey, who will serve as non-executive chairman of Qorvo following closing of the merger, explains: "Qorvo is building from our foundation of true innovation to solve our customers' most difficult challenges. We do this so that their customers, whether mobile consumers or troops on the move, will be able to connect with loved ones, protect our security, or voyage to new lands."

The merger is expected to close later this year, with the new company traded publicly on the NASDAQ Global Stock Market. With the combined talents of these two companies, there should be many more outstanding product developments such as the TGS2355-SM SPDT GaN switch in the years to come. MW

TRIQUINT SEMICONDUCTOR, INC., 2300 NE Brookwood Pkwy., Hillsboro, OR 97124; (503) 615-9000, FAX: (503) 615-8900, *www.triquint.com*

MINIATURE FOOTPRINT

ULTRA WIDE BANDWIDTH VCO

Perfect for portable radios and T & M equipment

0.3" x 0.3" x 0.1"

Model	Frequency Range (MHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Typ.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]
DCO4351-8	430 - 510	0.3 - 3	+8 @ 27 mA	-105
DCO50100-5	500 - 1000	0.5 - 15	+5 @ 28 mA	-100
DCO5260-3	525 - 600	0 - 3	+3 @ 12 mA	-105
DCO6080-3	600 - 800	0 - 3	+3 @ 12 mA	-105
DCO7075-3	700 - 750	0 - 3	+3 @ 10 mA	-108
DCO8087-5	800 - 870	0.5 - 5	+5 @ 22 mA	-111
DCO80100-3	800 - 1000	0 - 3	+3 @ 12 mA	-105
DCO80100-5	800 - 1000	0.5 - 8	+5 @ 21 mA	-111
DCO8190-5	810 - 900	0.5 - 16	+5 @ 28 mA	-118
DCO100200-5	1000 - 2000	0.5 - 24	+5 @ 30 mA	-95
DCO1198-8	1195 - 1205	0.5 - 8	+8 @ 24 mA	-115
DCO143158-8	1430 - 1515	0.3 - 3	+8 @ 17 mA	-105
DCO170340-5	1700 - 3400	0.5 - 24	+5 @ 24 mA	-90
DCO200400-5	2000 - 4000	0.5 - 18	+5 @ 38 mA	-90
DCO230245-5	2300 - 2450	0.5 - 20	+5 @ 29 mA	-102
DCO300600-5	3000 - 6000	0.3 - 16	+5 @ 12 mA	-78
DCO400660-5	4000 - 6600	0.5 - 11	+5 @ 29 mA	-75
DCO400800-5	4000 - 8000	0.3 - 15	+5 @ 17 mA	-78
DCO432493-3	4325 - 4950	0.5 - 11	+3 @ 18 mA	-87
DCO432493-5	4325 - 5000	0.5 - 12	+5 @ 17 mA	-88
DCO473542-3	4650 - 5420	0.3 - 22	+3 @ 18 mA	-88
DCO473542-5	4730 - 5420	0.5 - 22	+5 @ 20 mA	-88
DCO490517-3	4900 - 5400	0.3 - 10	+3 @ 14 mA	-83
DCO490517-5	4900 - 5175	0.5 - 5	+5 @ 17 mA	-88
DCO495550-5	4950 - 5500	0.5 - 12	+5 @ 17 mA	-83
DCO579582-5	5725 - 5880	0.5 - 10	+5 @ 16 mA	-90
DCO608634-3	6080 - 6340	0.5 - 5	+3 @ 22 mA	-86
DCO608634-5	6080 - 6340	0.5 - 5	+5 @ 16 mA	-85
DCO615712-5	6150 - 7120	0.5 - 12	+5 @ 18 mA	-85
DCO680700-5	6760 - 7000	0.5 - 5	+5 @ 28 mA	-88
DXO810900-5	8100 - 8925	0.5 - 15	+5 @ 26 mA	-82
DXO880920-5	8800 - 9200	0.5 - 15	+5 @ 22 mA	-80
DXO900965-5	9000 - 9650	0.5 - 12	+5 @ 22 mA	-80
DXO10021022-5	9700 - 10225	0.5 - 15	+5 @ 21 mA	-78
DXO10701095-5	10700 - 10950	0.5 - 15	+5 @ 21 mA	-82
DXO11441200-5	11440 - 12000	0.5 - 15	+5 @ 24 mA	-82
DXO11751220-5	11750 - 12200	0.5 - 15	+5 @ 24 mA	-80
DXO13901400-5	13900 - 14000	0.5 - 8	+5 @ 18 mA	-77
DXO14851515-5	14850 - 15150	0.5 - 15	+5 @ 25 mA	-74

Patented Technology

SYNERGY® MICROWAVE CORPORATION

Phone: (973) 881-8800 | Fax: (973) 881-8361
E-mail: sales@synergymwave.com | Web: www.synergymwave.com
Mail: 201 McLean Boulevard, Paterson, NJ 07504

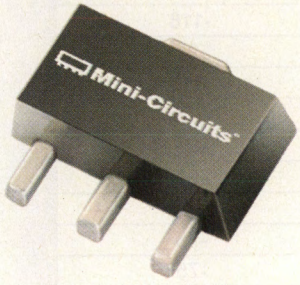
The Signal Source Noise Control & Signal Processing Experts.

Amp Achieves Flat Gain to 12 GHz

BROADBAND COMMUNICATIONS APPLICATIONS can cover large portions of bandwidth in small packages, often requiring multiple amplifiers to provide gain. But when one amplifier can deliver suitable gain across a wide-enough bandwidth, that one amplifier may be sufficient to handle multiple applications within a single product.

Such is the case with the model GVA-123+ monolithic amplifier from Mini-Circuits (www.minicircuits.com). Based on gallium arsenide (GaAs) heterojunction-bipolar-transistor (HBT) technology, it covers 10 MHz to 12 GHz with 16.9 dB typical gain at 2 GHz and typical gain flatness of ±0.7 dB from 50 MHz to 8 GHz. This economical amplifier is supplied in an SOT-89 housing for excellent thermal stability.

The RoHS-compliant model GVA-123+ (see figure) provides a frequency range covering many of the wireless communications bands in a single amplifier, including cellular and WiMAX frequencies, and it is also well suited for use in satellite communications (satcom) systems and in test equipment.



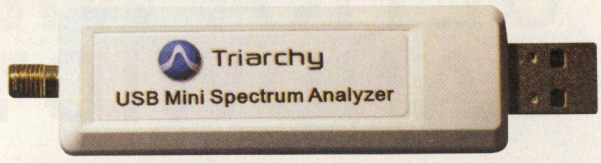
Monolithic GaAs amplifier model GVA-123+ covers 10 MHz to 12 GHz with 16.9 dB gain at 2 GHz and flat gain across the frequency range.

The amplifier exhibits typical gain of 16.2 dB at 50 MHz, 16.9 dB at 2 GHz, 16.4 dB at 6 GHz, 16.3 dB at 8 GHz, and 12.5 dB at 10 GHz, dropping to 7.1 dB at 12 GHz. The output power at 1-dB compression is typically +15.9 dBm at 50 MHz, +16.2 dBm at 2 GHz, +13.4 dBm at 6 GHz, +10.3 dBm at 8 GHz, and +7.4 dBm at 10 GHz, again dropping to +5.1 dBm at 12 GHz.

The output third-order intercept point (IP3) is typically +30.2 dBm at 200 MHz, +29.9 dBm at 2 GHz, +24.5 dBm at 6 GHz, +21.8 dBm at 8 GHz, +19.1 dBm at 10 GHz, and +14.9 dBm at 12 GHz. Although this is not meant as a low-noise amplifier, the noise-figure performance is respectable, with typical noise figures of 3.8 dB at 200 MHz, 4.0 dB at 2 GHz, 4.4 dB at 6 GHz, 4.9 dB at 8 GHz, and rising somewhat to 6.9 dB at 12 GHz.

The model GVA-123+ features good input and output return loss without additional external impedance-matching components, and with input/output return loss of typically 20 dB at 2 GHz. The reverse isolation is typically 20.7 dB at 6 GHz. The compact, broadband amplifier is rated for 0.34 W maximum power dissipation and draws 52 mA typical current at +5 VDC, with maximum current consumption of 100 mA at +5 VDC. The robust amplifier is designed for use at operating temperatures from –40 to +85°C.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, FAX: (718) 332-4661, *www.minicircuits.com*



Each TSA spectrum analyzer fits in a standard USB memory stick.

Spectrum Analyzers Fit in USB Stick

LEVERAGING THE PROCESSING power of a personal computer (PC), the TSA range of spectrum analyzers from Saelig Co. (www.saelig.com) measure signals beyond while fitting within low-cost Universal Serial Bus (USB) memory "sticks."

In spite of their pocket-sized packages, these PC-powered spectrum analyzers can provide the functionality and most of the performance of a much larger benchtop spectrum analyzer. The product line includes the model TSA4G1 (with frequency range of 1 MHz to 4.15 GHz), the model TSA6G1 (with frequency range of 1 MHz to 6.15 GHz), and the model TSA8G1 (with frequency range of 1 MHz to 8.15 GHz).

While one connector provides the link to a PC's USB port, the other is a standard SMA coaxial input connector covering the full range of each analyzer. The SMA connectors accept input signals from –110 to +30 dBm and the analyzers achieve noise levels as low as –110 dBm. The software supplied with the USB spectrum analyzers runs on the connected PC and displays test results on the computer's screen.

The USB spectrum analyzers also include a remote feature that allows control of the USB instruments and their online host computers by means of access with a second computer. The resolution bandwidth of each analyzer can be set at 50, 100, 200, or 500 kHz, with frequency stability of ±5 ppm. Scanning times across the full frequency range of analyzers are 0.2 s for fast scans and 2.3 s for normal scans. The minimum scanning step is 2 kHz for a 1-MHz span.

The PC software provides all the signal processing and measurement functions required for "normal" spectrum analysis. Once instrument parameters, such as center frequency, span, sweep time, and reference level, are set, a frequency sweep can be performed simply by pressing the analyzer's start button. The resolution bandwidth of a measurement is automatically selected based on the frequency span. The compact spectrum analyzers can even be used for electromagnetic-compatibility (EMC) precompliance testing with an optional near-field probe set (model TNP6Gx).

Each TSA spectrum analyzer is supplied with a 60-in.-long USB extension cable, software, and a fixed 30-dB attenuator for higher-power measurements. The analyzers, which are designed and built by Triarchy Technologies Corp. (www.triarchytech.com) and available from Saelig, measure just 87.5 x 23 x 15 mm and weigh just 20 g.

SAELIG CO., 71 Perinton Parkway, Fairport, NY 14450; (888) 772-3544, (585) 385-1750, FAX: (585) 385-1768, e-mail: info@saelig.com, *www.saelig.com*

Analyzer Checks Cables & Antennas

SMALLER TEST INSTRUMENTS are gaining in popularity, if the introduction of the SiteHawk SK-4000-TC Antenna and Cable Analyzer from Bird Technologies (www.birdrf.com) is any indication. This successor to the firm's portable model SA-3600 XT Site Analyzer covers 85 MHz to 4 GHz—and it comes in a package that is 80% smaller and 60% lighter than its predecessor, with many new features.



The SiteHawk SK-4000-TC Antenna and Cable Analyzer operates from 85 MHz to 4 GHz in a compact housing.

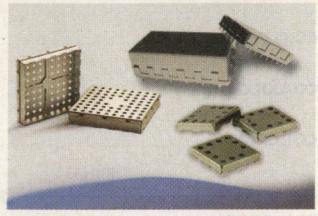
The SiteHawk SK-4000-TC Antenna and Cable Analyzer can check the signal transmission path from the transmitter through the antenna and cables in commercial and military communications systems. The instrument can measure return loss, impedance mismatch (in the form of VSWR), and even cable insertion loss over its full frequency range or a frequency range specified by the user, with results shown on a 1920-x-1080 pixel display.

The compact analyzer includes 16 GB of high-speed flash memory for storing measurement results and instrument setups. It features a touchscreen user interface, and data can be offloaded to a computer or memory card by means of a Universal Serial Bus (USB) interface. P&A: $2500; stock.

BIRD TECHNOLOGIES, 30303 Aurora Rd., Solon OH 44139; (440) 248-1200, (866) 695-4569, FAX: (440) 248-5426, *www.birdrf.com*

Shielding Materials Available Quickly

ELECTROMAGNETIC-INTERFERENCE (EMI) SHIELDING can be one of those afterthoughts required for making a design work, especially at the printed-circuit-board (PCB) level. Fortunately, one supplier has developed various lines of board-level shields that it is offering as part of its "Quick Ship" program to provide shielding material solutions in as little as 24 hours. The company in question is Leader Tech. Depending upon the specific shielding requirements and delivery deadlines, the firm is offering a large selection of off-the-shelf surface-mount shields (SMS) from its standard circuit-board-shield (CBS) line of shielding materials.



A wide range of surface-mount shielding solutions are now available for rapid delivery as part of the Quick Ship program.

The Quick Ship shields are offered in one- and two-piece design styles to accommodate a broad range of circuit assembly and rework requirements. Each of these board-level shielding solutions provides as much as 60-dB shielding effectiveness (SE) across a wide range of RF and microwave frequencies, with cover retention of 1.5 to 2.5 lb/linear inch in the two-piece configuration. The shielding materials are available in standard and tape-and-reel packaging options.

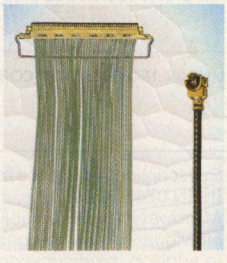
Standard materials are 0.015 in. thick and available in sizes of 0.50 x 0.50 in. to 12 x 24 in. The shielding materials can be specified in a variety of shapes.

LEADER TECH, INC., 12420 Race Track Rd., Tampa, FL 33626; toll-free: (866) 832.4364, (813) 855.6921, FAX: (813) 855.3291, e-mail: *sales@leadertechinc.com,*

Cable Assemblies Pack Multiple Conductors

A WIDE RANGE of discrete and multiple-conductor high-frequency coaxial cable assemblies are available for custom applications in a wide range of systems, including in avionics and surveillance systems requiring a large number of low-loss cable conductors. The cable assemblies, from High Speed Interconnects (www.highspeedint.com), are usable from DC to 8 GHz.

The multiple-conductor cable assemblies are extruded and manufactured to specific requirements using a combination of MHF (IPEX), U.FL (Hirose), and SMA connectors. They are rated for voltages to 200 V and for velocity of propagation as high as 80% at 6 GHz. The cable assemblies, which can channel both AC/DC power and RF/microwave signals, exhibit typical insertion loss of less than 3 dB through 6 GHz. The feature outstanding electromagnetic-interference (EMI) and radio-frequency-interference (RFI) characteristics.



Custom high-density, multiple-conductor cable assembles are available for carrying power and RF/microwave signals to 8 GHz.

The cable assemblies are manufactured to exacting AS9100 and IPC-620 standards. They are available using discrete, taped, or ribbonized constructions to meet a wide range of market needs, including for aerospace, marine, medical, robotics, wireless, and automotive applications.

HIGH SPEED INTERCONNECTS, 8777 North Gainey Center, 136, Scottsdale, AZ 85258; (480) 998-2540, *www.highspeedint.com*

ADVERTISER	PAGE
A	
AMERICAN MICROWAVE CORP	96
www.americanmic.com	
ANRITSU COMPANY	2
www.goanritsu.com/2830MRF10	
ANRITSU CORPORATION	c2
www.anritsu.com/en-us/VectorStarMWRF	
ARRA INC.	c3
www.arra.com	
B	
BOONTON	c4
www.boonton.com	
C	
CALIFORNIA EASTERN LAB	6
www.cel.com/TK-MWRF	
CIAO WIRELESS INC	17
www.ciaowireless.com	
COAXICOM	74
www.coaxicom.com	
COILCRAFT	10
www.coilcraft.com	
D	
DBM CORP	24
www.dbmcorp.com	
DELTA ELECTRONICS MFG	83
www.deltarf.com	
E	
ELECTRONICA 2014	112
fnovak@munich-tradefairs.com	
F	
FAIRVIEW MICROWAVE	25
www.fairviewmicrowave.com	
FOX ELECTRONICS	70
www.foxonline.com	
H	
HEROTEK INC	13
www.herotek.com	
I	
INSULATED WIRE INC	47
www.iw-microwave.com	
K	
KEYSIGHT TECHNOLOGIES - USA	7
www.keysight.com/find/rfpowertips	
KEYSIGHT TECHNOLOGIES - USA	37
www.keysight.com/find/M9393APXI	
KEYSIGHT TECHNOLOGIES - USA	95
www.keysight.com	
L	
LINEAR TECHNOLOGY CORPORATION	19
www.linear.com/product/LTC5551	

ADVERTISER	PAGE
M	
M/A COM TECHNOLOGY SOLUTIONS, INC	4
www.macom.com/gan	
MECA ELECTRONICS INC	9
www.e-MECA.com	
METROPOLE PRODUCTS	58
www.MetropoleProducts.com	
MINI-CIRCUITS/SCI COMPONENTS	12, 14-15,23,29,30-31,35,41,51, 57,61,73,85,89,91,99,109
www.minicircuits.com	
MITEQ	77,79,81
www.miteq.com	
N	
NARDA DIV OF L-3 COMMUNICATIONS	3
www.nardamicrowave.com	
NATIONAL INSTRUMENTS	27
www.ni.com/redefine	
NUWAVES ENGINEERING	72
www.nuwaves.com	
P	
PHASE MATRIX INC.	22
www.ni-microwavecomponents.com/quicksyn	
PLANAR MONOLITHICS INDUSTRIES	1
www.pmi-rf.com	
PULSAR MICROWAVE CORP	18
www.pulsarmicrowave.com	
R	
RIGOL USA	62-63
www.RigolRF.com	
ROHDE&SCHWARZ GMBH&CO KG	45
www.rohde-schwarz.com/ad/sat/pow	
S	
SKYWORKS	8
www.skyworksinc.com	
STANFORD RESEARCH SYSTEMS (SRS)	43
www.thinkSRS.com	
SYNERGY MICROWAVE	53, 75, 101
www.synergymwave.com	
T	
TDK EPCOS	59
www.epcos.com	
TIMES MICROWAVE SYSTEMS	93
www.timesmicrowave.com	
W	
www.gore.com/test	
WAVELINE INC	16
www.wavelineinc.com	

This index is provided as an additional service by the publisher, who assumes no responsibility for errors or omissions.

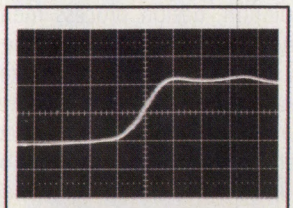
Subscription Assistance and Information:
(ISSN 0745-2993)
Microwaves & RF is published monthly. Microwaves & RF is sent free to individuals actively engaged in high-frequency electronics engineering. In addition, paid subscriptions are available. Subscription rates for U.S. are $95 for 1 year ($120 in Canada, $150 for International). Published by Penton Media, Inc., 9800 Metcalfe Ave., Overland Park, KS 66212-2216. Periodicals Postage Paid at Shawnee Mission, KS and at additional mailing offices.
POSTMASTER: Send change of address to Microwaves & RF, Penton Media Inc., P.O. Box 2095, Skokie, IL 60076-7995. For paid subscription requests, please contact: Penton Media Inc., P.O. Box 2100, Skokie, IL 60076-7800. Canadian Post Publications Mail agreement No. 40612608. Canadian GST# R126431964. Canada return address: IMEX Global Solutions, P.O Box 25542,London, ON N6C6B2.

Back issues of MicroWaves and Microwaves & RF are available on microfilm and can be purchased from National Archive Publishing Company (NAPC). For more information, call NAPC at 734-302-6500 or 800-420-NAPC (6272) x 6578. Copying: Permission is granted to users registered with the Copyright Clearance Center, Inc. (CCC) to photocopy any article, with the exception of those for which separate copyright ownership is indicated on the first page of the article, provided that a base fee of $1.25 per copy of the article plus 60 cents per page is paid directly to the CCC, 222 Rosewood Dr., Danvers, MA 01923. (Code 0745–2993/02 $1.25 +.60) Copying done for other than personal or internal reference use without the expressed permission of Penton Media, Inc., is prohibited. Requests for special permission or bulk orders should be addressed in writing to the publisher.

Copyright 2014 • Penton • All rights reserved. Printed in the U.S.

40 to 300 ps Rise Time Pulse Generators

Avtech pioneered the design of subnanosecond rise time pulse generators and now offers over 35 models which provide 40-300 ps rise times with 5 to 100 Volt output amplitude and PRF to 250 MHz. These models are ideal for testing high speed semiconductors and optoelectronics in both laboratory and factory floor applications. See www.avtechpulse.com/speed for details. Customized models are also available.



50 ps/DIV, 5V/DIV
Model AVP-3SA-C

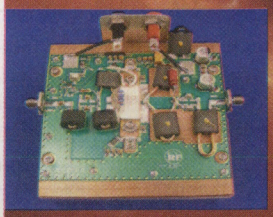


And Model AVI-V-HV2A-B provides a 100 Volt 300 ps rise time output!

Pricing, manuals, datasheets & test results:
www.avtechpulse.com
AVTECH ELECTROSYSTEMS LTD.
Tel: 888-670-8729 Fax: 800-561-1970 info@avtechpulse.com

AVTECH

LDMOS Device
LR2501
170W CW 30-512MHz



28VDC
18dB
60%

Samples & eval amp available.

RF Your Power MOSFET People
polyfet rf devices
www.polyfet.com
TEL (805)484-4210

APPLICATIONS ENGINEER: Required by RF Micro Devices for position in Greensboro, NC. Responsible for the benchmarking of RFMD products through analysis of RFMD and competitor product performance and technology. Responsible for disseminating findings to design engineers during IC development for current and next generation products. Perform detailed application circuit reverse engineering, interpretation and analysis for switches, RF amplifiers, and power amplifiers. Create, test and debug custom product evaluation PCBs (EVBs) as required to facilitate evaluation of competitor's products. Analyze cellular radio system architectures for performance and cost advantages. Provide customers internal to RFMD with RF technical support for competitor products at the RF system and component level. Knowledge of test, characterization and debug of RF front end products (FEMs) including ASMs, SFMs, PA/PAMs (SB, DB QB and MMMB), PADs and TXMs for mobile wireless applications. Knowledge of the creation of evaluation PCB (EVBs) for component, systems analysis and budgeting. Knowledge of industry specific lab equipment including network analyzers (VNA), spectrum analyzers, function generators, signal generators, oscilloscopes, power meters, switch controllers, switches, communications test sets, and power supplies. Knowledge of measurement and digital control of cellular FEMs for key specifications, including IP3, IP2, ACPR, harmonics, EVM, switching and modulation spectrum (ORFS), efficiency (PAE), small signal measurements and RX band noise as well as interpretation and manipulation of S-parameter data including de-embedding, impedance matching and extraction/presentation of frequency responses, return loss, insertion loss, etc. Knowledge of modern cellular wireless protocols including LTE, TD-SCDMA, WCDMA, CDMA, GSM, and EDGE. BSEE or BS in Instrumentation and Control Engineering (or foreign equivalent) and two (2) years experience practicing the above skills in the cellular industry making regular use of the knowledge required for this position. Qualified candidates send resumes to **employment@rfmd.com** and refer to Job Code: **JLVAT**.

SENIOR DESIGN ENGINEER: Required by RF Micro Devices for a position in Greensboro, NC. Collaborate with customers/marketing engineers to architect/define/specify highly integrated solutions to wireless transceiver products for battery powered applications. Perform conceptual and detailed IC design of critical RF elements associated RF ASIC's. Critical RF elements include switches, amplifiers, mixers, VCO's, high-speed dividers, power amplifiers, etc. Knowledge of 802.11 power amplifiers and front end modules is required, including matching for linearity and efficiency, bias circuit optimization; turn on time, thermal stability, and out of band suppression. Design requirements include implementation of high rejection, low loss integrated filters for harmonic suppression. Design responsibilities include circuit level and EM simulation, IC layout, DRC/LVS, lab evaluation and tuning, and producing final production documents in a timely manner. Requires considerable amount of independent decision making and creativity in the design of circuits. Interacts with all areas of the company. Public interaction at conferences and in written articles/papers. PC and Workstation CAD/CAE tools used in the IC design process. Knowledge of RF lab equipment (network analyzer, spectrum analyzer, power supplies and soldering station). Knowledge of silicon, bipolar IC design, and transistor level design over 1GHz. Full-time position. MSEE or MS Electronics Engineering (or foreign equivalent) required. Qualified candidates send resume to **employment@rfmd.com** and refer to Job Code: **JLDIN**.

SENIOR MANAGER ENGINEERING: Required by RF Micro Devices for position in Greensboro NC. Responsible for the management of a variety of RF IC and module based product design engineering management functions, including but not limited to product design engineering oversight, technology selection/recommendation for particular product designs, engineering schedule oversight, engineering design simulation, design process management, and design reviews. Ensures the timely, thorough and accurate completion of all engineering projects, oversees the concept designs of new or modified future products. Interfaces as engineering representative with project management, marketing, sales and customers on product related issues. Establishes engineering metrics, objectives and assignments and delegates assignments to subordinate managers. Objectives and results are reviewed by senior management to assess engineering effectiveness. Erroneous engineering decisions will result in critical delay(s) in schedules and/or unit operations and may jeopardize overall business results. Requires the ability to change the thinking of, or gain acceptance of, others in sensitive situations. Manages activities of two or more design groups through subordinate managers who are responsible for multiple engineers, technicians and assembly operators. In some instances this manager may be responsible for managing staff function and may not have subordinate managers. Require BSEE (or foreign equivalent) and five years prior experience in an engineering capacity in a managerial role, preferably in a high tech company. Full time M-F. Qualified candidates send resume to **employment@rfmd.com**, Job Code: **JLBLO**.

SENIOR APPLICATIONS ENGINEER: Required by RF Micro Devices, Inc for a position in Greensboro, NC. This person is responsible for the documentation and marketing tools necessary for bringing new products into market place. This would include working with design engineers during IC development and supporting customers during design cycles and into production. Provide customers both internal and external to RFMD with RF technical product support at the RF system and component level. Perform detailed circuit design of RF amplifiers, mixers, VCO and power amplifiers for RF applications. Create and update product data sheets to include RF parameters schematics, tunings and applications information. Participate with new standard and custom RFIC product development efforts. Create application notes suitable for limited distribution as required. Perform testing and debugging of product evaluation boards, making improvements as appropriate. Require MSEE or MS in Electrical & Computer Engineering and two years experience. 40 hours a week, 8 a.m. 5 p.m. Qualified candidates send resumes to **employment@rfmd.com** and reference Job Code: **JLHEO**.

SENIOR REFERENCE DESIGN ENGINEER: Required by RF Micro Devices for position in Greensboro NC. Assist customers with the integration of products into a variety of phones and other wireless devices. Will work closely with our internal Design, Marketing, and Sales Teams to assure both present and future products effectively satisfy customer needs. Responsible for troubleshooting issues at the handset level including problems arising from platform shortfalls in addition to power amplifier issues. Responsible for designing, developing, modifying, and evaluating product designs to meet customer specifications. Knowledge of how to test power amplifiers in al modes according to customer requirements. Customer integration of existing and development products by optimizing matching, layout, and decoupling. Collaborate with design team on key aspects of system requirements driving specifications and performance. Good understanding of 3GPP specifications for mobile communication systems. Experience developing evaluation board PCBs and schematic generation. Interface and training of Field Application Engineers to assist their successful integration of products into customer platforms. Demonstrate good trouble shooting skills at PA level and test set-ups. Knowledge of Power Amplifier or other RF front end module products for cellular and tablet applications as well as PCB design of handsets with RF design tools. Knowledge of wireless protocols utilized including LTE, WCDMA, CDMA, GSM, and EDGE. MSEE and 1 year experience in a high-tech company. Qualified candidates send resumes to **employment@rfmd.com** and refer to Job Code: **JLMOR**.

TEST ENGINEER: Required by RF Micro Devices for position in Greensboro NC. Responsible for developing and implementing automated RF test solutions to support design engineering to transition the design into high volume production, and improve on existing solutions if applicable. Review product test specification and applicable test equipment requirements and generate/troubleshoot test software for device. Responsible for planning/advising support technician on generation of production test boards, generating device performance data in support of process development and generate device performance data in support of production release. Knowledge in all aspects of RF device test as well as spectrum analyzer, network analyzers, power meters, and signal generators. Knowledge of all facets of RF measurements for digital modulation formats as well as knowledge of high level programming language (C, C#, VB, .NET) and device handlers. Knowledge of RF test and remote equipment experience. BSEE or BS Electronics Engineering (or foreign equivalent) and 2 years experience in RF Large Signal / Load Pull characterization on Power Amplifiers, as well as analysis and presentation of measurement results. Qualified candidates send resumes to **employment@rfmd.com** and refer to Job Code: **JLDIV**.

SENIOR DESIGN ENGINEER: Required by RF Micro Devices for position in Greensboro NC. Design, test, and verification of RF ASIC designs. Collaborate with customers/marketing engineers to architect/define/specify highly integrated situations for wireless RF switch and signal conditioning products for battery powered applications. Will develop low cost solutions to high volume, commercial RFIC's using Silicon IC Technologies. Perform conceptual and detailed IC design of critical RF elements associated RF ASIC's. Critical RF elements include RF switches, IPD filters, and charge pumps. Interact with all areas of the company including other designers, project managers, test and characterization engineers. Knowledge of PC and Workstation CAD/CAE tools used in the IC design process including Cadence, ADS, and HFSS EM simulation tool. Knowledge of integrated IC CMOS and/or SOI design. MSEE required. Qualified candidates send resumes to **employment@rfmd.com** and refer to Job Code: **JLWAN**.

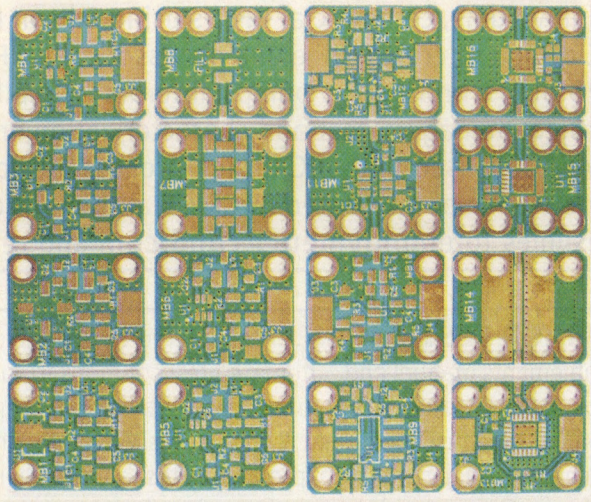
SENIOR TEST ENGINEER: Required by RF Micro Devices for a position in Greensboro, NC. Develops and implements manual and automated test solutions to support design engineering, to transition the design into high volume production, and improve test solutions on existing solutions if applicable. Reviews product test specification & applicable test equipment requirements. Generates/troubleshoots test software for device. Plans/advises support technician on generation of production test boards. Reviews/submits production documentation for documentation release. Generates device performance data in support of production release, provides guidance to entry level engineers. Interacts with senior internal and external personnel and receives little instruction on day-to-day work, general instructions on new assignments. Must be proficient in all aspects of power semiconductor device test, knowledge of high voltage measurements, oscilloscopes, curve tracers, and discrete packaging. Knowledge of all facets of power device measurements for high voltage products. Knowledge of high level programming language (C. C#, VB, .NET) and device handlers a plus. Full-time position. MSEE (or foreign equivalent) required. Qualified candidates send resumes to **employment@rfmd.com** and refer to Job Code: **JLBON**.

PLANNING ANALYST: Required by RF Micro Devices for position in Greensboro, NC. Will be responsible for materials planning duties including analyzing and planning the use of semiconductor devices to ensure on-time delivery and other RFMD objectives. This includes analyzing inventory, sales, and/or production in SAP for strategic management of global supply chain planning for the purpose of planning, initiating and implementing all applicable materials-related efforts to ensure on-time delivery and RFMD billings objectives are achieved. Will also analyze, maintain and close Production and Purchase orders to ensure accuracy of MRP data and proactively identify bottlenecks or areas that would delay material movement, delay production, and/or result in significant detrimental financial impact. This includes taking actions to prevent delays and negative financial impact and involving other departments and management as necessary to resolve issues. Will keep up-to-date on materials and systems used by the company, and more broadly within the entire industry, in order to identify trends and best practices that will allow the company to operate more efficiently. Require BS (or foreign equivalent) in Logistics or Statistics , and one year experience in SAP ECC with multi-country manufacturing planning responsibility. Full time. M-F. Qualified candidates send resume to **employment@rfmd.com** and reference Job Code **JLZHAN**.

PRINCIPLE ENGINEER: Required by RF Micro Devices for a position in Greensboro, NC. Design and develop innovative, next generation, leading edge Power Amplifiers (PA) and Front-End Module (FEMs) products targeting WiFi and Smart Energy Applications. Perform detailed RF Power Amplifier and Frond-End Module circuit design to targeted products for WiFi and Smart Energy Applications. Perform layout and design capture of RFIC's targeting low cost and optimum performance to targeted product specifications. Perform detailed tuning, optimization and evaluation of designs in lab working closely with RF Technicians and other Engineers. Determine design of experiments to optimize product performance and maximize product test yield. Drive innovative leading edge solutions into future products via core circuit design and development. Full-time position. BS Electronics Engineering (or foreign equivalent) required and 5 years experience in Power Amplifier Design. Qualified candidates send resumes to **employment@rfmd.com** and refer to Job Code: **JLGRU**.

Circuit Boards Assist Prototyping Chores

DESIGNERS AND prototypers will find some tasks simplified with the aid of the MicroAmp MB series printed circuit boards (PCBs). Designed for rapid prototyping of both low- and high-frequency circuits, these circuit boards can serve as building blocks for a wide range of active and passive circuit functions, including amplifiers, filters, frequency dividers, frequency multipliers, and voltage-controlled oscillators (VCOs). The easy-to-assemble circuit boards employ surface-mount-technology (SMT) components and can be turned into functional circuits in a matter of minutes. The prototyping circuit boards fit into the MicroAmp MH series of connectorized (with built-in SMA connectors) housings that allows them to be used as single (MH-1) or dual-cascaded (MH-2) circuits. The prototyping circuit boards are based on high-performance 13-mil-thick, RoHS-compatible RO-4350 laminate materials from Rogers Corp. (www.rogerscorp.com), featuring electroless nickel/immersion gold (ENIG) plating on both the

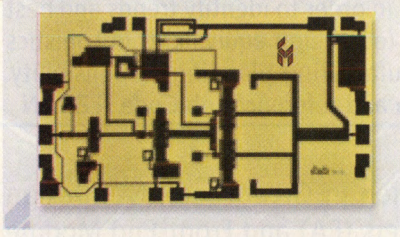


component and ground sides of the circuit board.

TWIN INDUSTRIES, 2303 Camino Ramon, Ste. 106, San Ramon, CA 94583; (925) 866-8946, FAX: (925) 866-8937, e-mail: sales@twinind.com, *www.twinind.com*

GaN Amplifier Powers 28 to 32 GHz

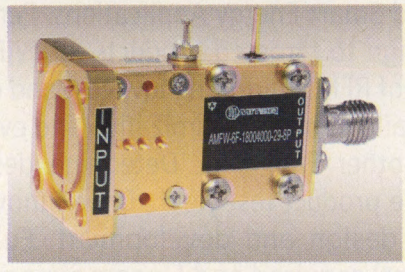
MODEL CMD217 is a monolithic-microwave-integrated-circuit (MMIC) gallium-arsenide (GaN) power amplifier available in die form for applications from 28 to 32 GHz. It provides more than 20-dB gain across that frequency range, with +36.7-dBm output power at 1-dB compression. It is capable of +39.3-dBm (8.5 W) saturated output power and can provide 28% to 35% power-added efficiency (PAE) across the operating frequency range. The monolithic power amplifier is fully matched to 50 Ω and only requires external bypass capacitors for bias circuitry. The passivated die is ideal for se in Ka-band communications systems, where high power and linearity are critical.



CUSTOM MMIC, 1 Park Dr., Unit 12, Westford, MA 01886; (978) 467-4290, *www.CustomMMIC.com*

Waveguide LNA Gains 18 to 40 GHz

MODEL AMFW-6F-18004000-29-8P is a waveguide low-noise amplifier (LNA) designed for applications from 18 to 40 GHz. It provides more than 35-dB gain with gain flatness maintained within ±3 dB across the frequency range. The maximum noise figure is 2.9 dB (typical noise figure of 2.6 dB), while the minimum output power is +8 dBm at 1-dB compression and typically +16 dBm at 3-dB compression. The amplifier is supplied in a housing that is 1.32 × 0.88 in., measured with input waveguide flange and without output field-replaceable 2.92-mm coaxial connector. The RoHS-compliant LNA, which draws maximum current of 275 mA from a single +15-VDC supply, has an operating temperature range of –40 to +75°C.



MITEQ, INC., 100 Davids Dr., Hauppauge, NY 11788; (631) 436-7400, FAX: (631) 436-7430, *www.miteq.com*

Amplifier Powers 8.5 to 10.5 GHz

MODEL BMC858109-600 is a solid-state amplifier module model capable of 600 W (+58 dBm) pulsed output power from 8.5 to 10.5 GHz. Based on GaN technology, the Class AB amplifier is suitable for phased-array applications, featuring 58-dB nominal gain with maximum gain deviation of ±2 dB across the full frequency range. The amplifier, which draws 9 A at +28 VDC, is designed for use with pulse widths of 2 to 100 µs



DC-12 GHz 1W Attenuators

only $18.95 ea. qty. 1-9

Accurate attenuation over ultra-wide frequency range at low cost!
Mini-Circuits' new FW-series fixed SMA attenuators cover your applications from DC – 12 GHz with a wide selection of attenuation values to meet your needs. All models offer excellent attenuation flatness versus frequency, low VSWR, and 1W input power handling, making them ideal, cost-saving solutions for impedance matching and signal level adjustment in a broad range of systems.

Built using Mini-Circuits rugged unibody construction with SMA(M) to SMA (F) connectors, FW-Series attenuators provide outstanding reliability in tough operating conditions. Just go to minicircuits.com for full specs and see how these attenuators can add performance and value to your design! They're available off the shelf for immediate shipment. Order today, and have them in hand as soon as tomorrow!

Model	ATTENUATION Nominal (dB)	Flatness (dB)	VSWR (:1) Midband Typ.	Power (W)
FW-1+	1	±0.15	1.15	1.0
FW-2+	2	±0.15	1.15	1.0
FW-3+	3	±0.20	1.15	1.0
FW-4+	4	±0.20	1.15	1.0
FW-5+	5	±0.20	1.15	1.0
FW-6+	6	±0.25	1.15	1.0
FW-7+	7	±0.25	1.15	1.0
FW-8+	8	±0.30	1.15	1.0
FW-9+	9	±0.30	1.15	1.0
FW-10+	10	±0.30	1.15	1.0
FW-12+	12	±0.30	1.20	1.0
FW-15+	15	±0.35	1.20	1.0
FW-20+	20	±0.50	1.20	1.0

RoHS compliant.

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

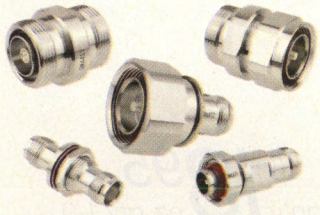
531 rev. orig.

at 10% duty cycle. It exhibits second harmonics of less than –40 dBc and third harmonics of less than –50 dBc, operating with 25% nominal RF-to-DC efficiency. It measures 10.0 x 8.5 x 1.0 in. and weighs 5 lbs. with SMA connectors on input and sample ports and TNC connector on the output port. It meets MIL-STD-810F requirements per shock and vibration.

COMTECH PST, 105 Baylis Rd., Melville, NY 11747; (631) 777-8900, FAX: (631) 777-8877, *www.comtechpst.com*

Coaxial Adapters Handle IP67 Chores

A LINE of IP67-rated coaxial adapters has been developed for use with a variety of different RF/microwave connectors, including Type N and TNC. These adapters are suited for use in applications in cellular, aviation, and military electronic systems. In-series adapters include 7/16 DIN, 4.1/9.5



mini-DIN, Type-N, and TNC adapters. Between-series versions include 7/16 DIN-to-4.1/9.5-mini-DIN, 7/16 DIN-to-Type-N, and 4.1/9.5 mini-DIN-to-Type-N-adapters. Each adapter operates to 6 GHz with low VSWR of 1.15:1 through 1.25:1, depending upon connector type. The adapters are available in "mated" and "unmated" versions; the former meets IP67 requirements when both ends of the adapter are terminated, while the latter meets IP67 requirements when either one or both ends of the adapter are terminated.

FAIRVIEW MICROWAVE, INC., 1130 Junction Dr., No. 100, Allen, TX 75013; (800) 715-4396, (972) 649-6678, FAX: (972) 649-6689, e-mail: sales@fairviewmicrowave.com, *www.fairviewmicrowave.com*

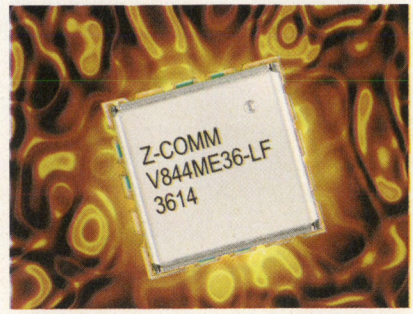
Analyzers Handle PIM Measurements

THE PEM42A series of passive interodulation (PIM) analyzers include S-parameter measurement capabilities. These PIM analyzers can handle as many as four frequency bands in the range from 385 to 2600 MHz; they can perform S-parameter measurements without reconnecting test cables to a device under test (DUT). The multiple-band PIM analyzers consist of a control and switching unit, as many as four frequency modules, and a model 5072A ENA measurement receiver from Keysight Technologies (formerly Agilent Technologies). The analyzer systems offer a noise floor of better than –135 dBm and can adjust test power levels from +20 to +44 dBm. They can measure forward PIM levels of less than –163 dBc and reverse PIM levels of –165 dBc or less. The systems feature transmit test signals with 2 ppm frequency stability and ±0.65 dB amplitude accuracy, along with overall measurement accuracy of ±1 dB. The system is equipped with a 10.2-in. touchscreen display (a separate display monitor can also be connected) and multiple GPIB and Universal Serial Bus (USB) ports.

AWT GLOBAL, 117 Grand Ave., Hackettstown, NJ 07840; (973) 321-3423, e-mail: sales@awt-global.com, *www.awt-global.com*

VCO Trims Noise from 4.1 To 4.3 GHz

MODEL V844ME36-LF is a RoHS-compliant voltage-controlled oscillator (VCO) that tunes from 4100 to 4300 MHz by means of voltages from 0.5 to 4.5 VDC with better than 1.10:1 tuning linearity. It offers typical tuning sensitivity of 93 MHz/V and achieves low phase noise of –110 dBc/Hz offset 100 kHz from the carrier. Well suited for microwave radio links and satellite-communications (satcom) applications that require low phase noise performance, the oscillator provides +3 dBm output power into a 50-Ω load and typically draws 15 mA current from a +5 VDC supply. Second harmonics are typically



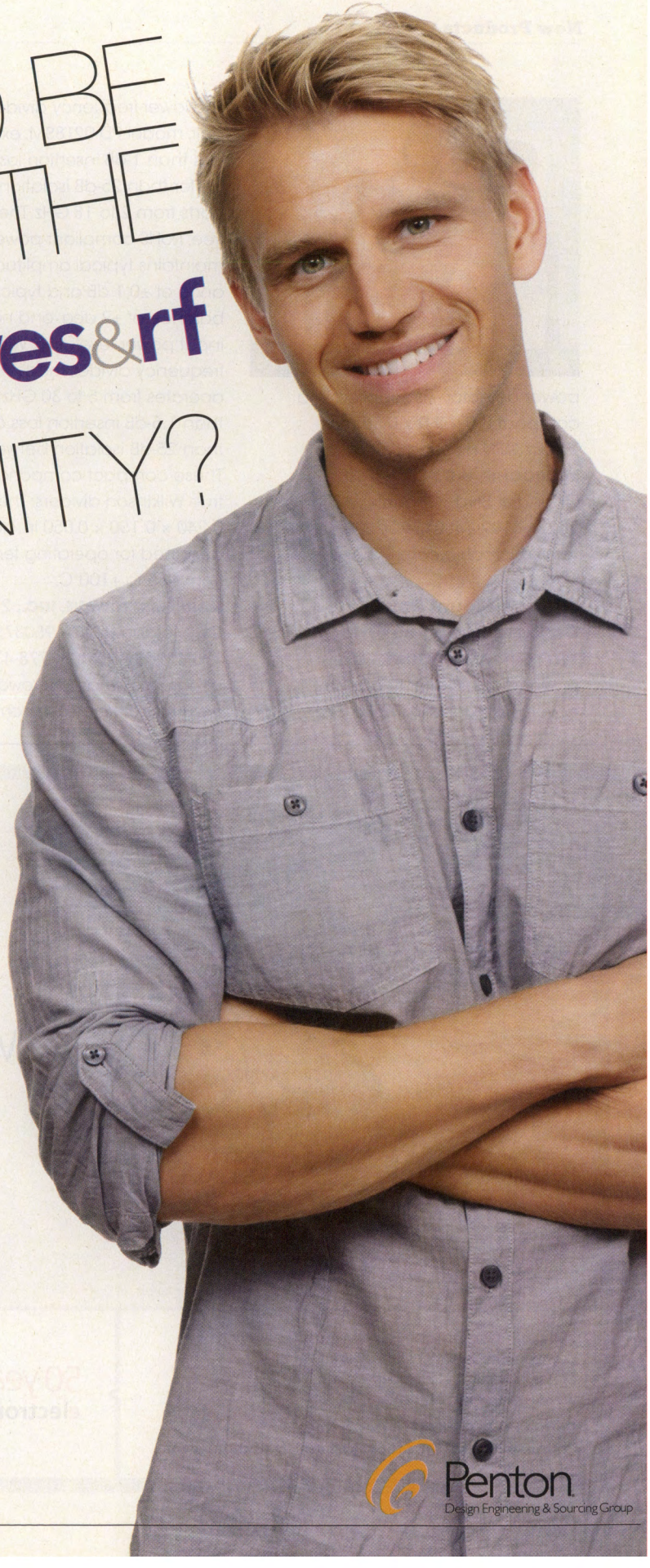
–18 dBc. The oscillator is supplied in a MINI-14S-L package measuring 0.5 in. x 0.5 x 0.13 in. and rated for operating temperatures from –40 to +85°C. It is available in tape-and-reel packaging.

Z-COMMUNICATIONS, INC., 14118 Stowe Dr., Ste. B, Poway, CA 92064; (858) 621-2700, FAX: (858) 486-1927, e-mail: applications@zcomm.com, *www.zcomm.com*

Power Amplifier Drives 2.5-GHz Systems

MODEL SST12CP21 is a power amplifier designed for 256-quadrature-amplitude-modulation (256QAM) applications at 2.5 GHz. It provides as much as +23 dBm output power at 1.75% error vector modulation (EVM) while running on 320 mA current and +5 VDC. It can also deliver +25 dBm linear power at 3% EVM with only 350 mA current consumption for IEEE 802.11g/n applications. The amplifier, which features 50-Ω on-chip impedance matching and simple output matching—in addition to an integrated

WANT TO BE PART OF THE microwaves&rf COMMUNITY?



With the most content and reach of any design focused publication in the electronics market, *Microwaves & RF* brings you the latest professional information through cutting-edge multimedia publishing.

Check out some statistics from our members:

Ninety-two percent (92%) of the respondents report taking one or more purchasing actions during the past year as a result of ads/editorials appearing in *Microwaves & RF.*

Seventy-six percent (76%) of respondents are regular readers of *Microwaves & RF* and report reading three or four of the four most recent issues.

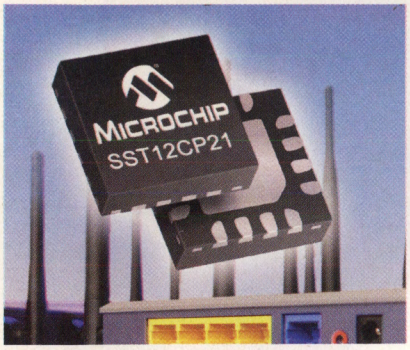
Join today and see what everyone is raving about!

To subscribe, visit:
http://mwrf.com/subscribe
or call 1-866-505-7173.

Connect with us:

Penton
Design Engineering & Sourcing Group

WHERE TECHNOLOGY COMES FIRST



power detector—is supplied in a compact 3.0 × 3.0 × 0.55 mm, 16-pin QFN housing.

MICROCHIP, INC., 2355 West Chandler Blvd., Chandler, AZ 85224-6199; (480) 792-7200, *www.microchip.com*

Surface-Mount Power Dividers Reach 30 GHz

TWO SURFACE-MOUNT Wilkinson power dividers offer frequency coverage extending to 30 GHz. The lower-frequency divider of the pair, model PD-0218SM, exhibits less than 1-dB insertion loss with better than 25-dB isolation between ports from 2 to 18 GHz. The lead-free, RoHS-compliant power divider maintains typical amplitude balance of ±0.1 dB and typical phase balance of ±2 deg. and handles input power levels to 1 W. The higher-frequency divider, model PD-0530SM, operates from 5 to 30 GHz with less than 1.5-dB insertion loss and better than 25-dB isolation between ports. These compact components are true Wilkinson dividers: They measure 0.240 × 0.150 × 0.050 in. and are designed for operating temperatures from –55 to +100°C.

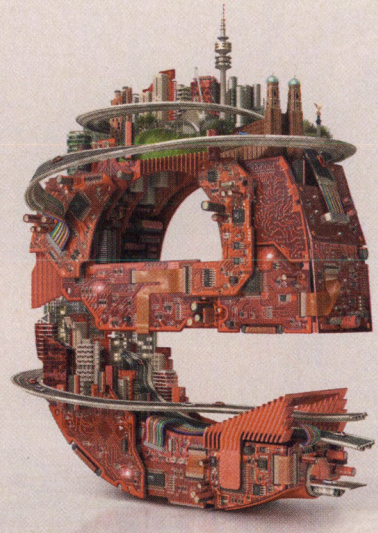
MARKI MICROWAVE, INC., 215 Vineyard Ct., Morgan Hill, CA 95037; (408) 778-4200, FAX: (408) 778-4300, e-mail: info@markimicrowave.com, *www.markimicrowave.com*

Amp Powers 100 W From 700 To 2700 MHz

MODEL HPA-272+ is a high-power, rack-mountable amplifier with 100 W typical output power from 700 to 2700 MHz. It features 48-dB typical gain and typically ±1.7 dB gain flatness across the full frequency range, with 89-dB typical isolation. It maintains low noise figure of typically 8.2 dB across the full frequency range with input/output VSWR of typically 1.30:1. The robust power amplifier, which draws 531 W from a 110/220-VAC supply, is well suited for a wide range of test applications for cellular, satellite-communications, and radar systems. It has over-temperature protection and is supplied in a rugged 3U rack-mount enclosure.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, FAX: (718) 332-4661, *www.minicircuits.com*

Messe München International



Welcome to Planet e.

26th International Trade Fair for Electronic Components, Systems and Applications
Messe München, November 11–14, 2014
www.electronica.de

Contact U.S. Office: Francesca Novak
Phone: 646.437.1016 | fnovak@munich-tradefairs.com

50 years electronica

electronica 2014
inside tomorrow

The best deal in town
. . . from ARRA, of course!

FIXED ATTENUATORS DC-18 GHz

- Models to 55 dB
- SMA or Type N conn.
- 50 W average models



4425 Types

Freq. Range (GHz)	Average Power (W)	Model No. N Conn.	Model No. SMA Conn.
DC-18.0	1	N9412 *	9412 *
DC- 5.0	1	N4402 *	4401 *
DC- 4.0	5	N4405 *	4405 *
DC- 4.0	10	N4410 *	4410 *
DC- 4.0	25	N4425 *	4425 *
DC- 4.0	50	N4450 *	4450 *

*Value of attenuation



9412 & 4401 Types (1.14")



N9412 Types (2.42")

Call (631) 231-8400 or
Fax (631) 434-1116

. . . the last word in variable attenuators

ARRA INC.
15 Harold Court • Bay Shore, N.Y. 11706

The best deal in town
. . . from ARRA, of course!

BROADBAND COAXIAL TERMINATIONS





- DC-18 GHz model
- 50 W model
- SMA or Type N conn.

Freq. Range (GHz)	Average Power (W)	Model No. N Conn.	Model No. SMA Conn.
DC-18.0	1		9512
DC-12.4	2	N9512	
DC-12.4	5	N9505	9505
DC-12.4	10	N9510	9510
DC- 8.0	25	N9525	9525
DC- 8.0	50	N9550	



Call (631) 231-8400 or
Fax (631) 434-1116

. . . the last word in variable attenuators

ARRA INC.
15 Harold Court • Bay Shore, N.Y. 11706

The best deal in town
. . . from ARRA, of course!

WAVEGUIDE LOADS



- Low VSWR
- Fast delivery!
- WR284 thru WR62

Freq. Range (GHz)	Medium Power Average (W)	Medium Power Model No.	High Power Average (W)	High Power Model No.
2.60- 3.95	1200	284-925	4500	284-920
3.30- 4.90	1000	229-925	3000	229-920
3.95- 5.85	750	187-925	2000	187-920
4.90- 7.05	625	159-925	1500	159-920
5.85- 8.20	500	137-925	1000	137-920
7.05-10.0	425	112-925	600	112-920
7.00-11.0	325	102-925	500	102-920
8.20-12.4	225	90-925	500	90-920
12.4 -18.0	200	62-925	250	62-920

Call (631) 231-8400 or
Fax (631) 434-1116

. . . the last word in variable attenuators

ARRA INC.
15 Harold Court • Bay Shore, N.Y. 11706

The best deal in town
. . . from ARRA, of course!

WAVEGUIDE COMPONENTS & SPECIAL ASSEMBLIES

Write for new literature or call (631) 231-8400



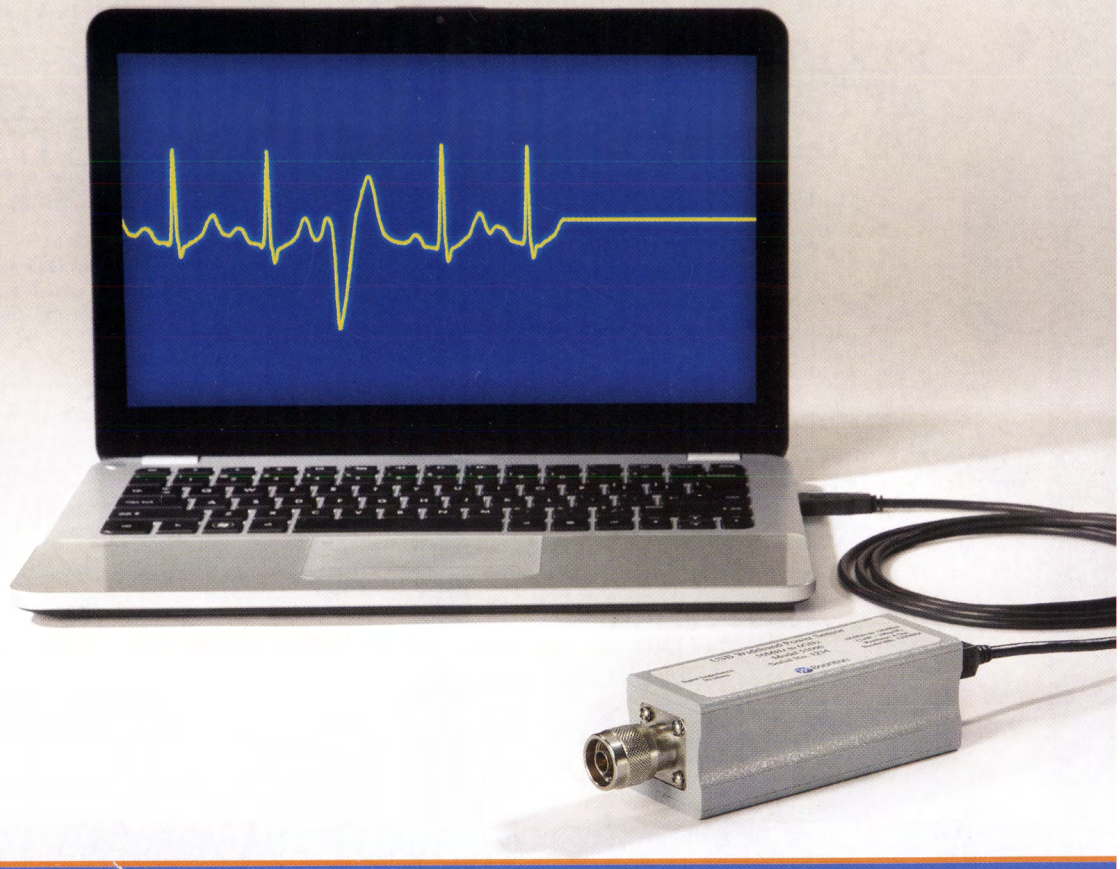
Call (631) 231-8400 or Fax (631)434-1116

. . . the last word in variable attenuators

ARRA INC.
15 Harold Court • Bay Shore, N.Y. 11706

Visit our website at www.arra.com

Missing a Pulse Can Be Deadly.



The Smartest, Fastest and Only Real-Time USB Peak Power Sensor.

Don't fall victim to conventional power measurement techniques that will leave you missing valuable data - we capture every pulse with no missed glitches. The new **55 Series** delivers unsurpassed speed and accuracy for the most demanding RF power measurements thanks to Boonton's **Real-Time Power Processing™** technology. With this revolutionary technique, all processing steps take place in parallel, guaranteeing gap-free signal acquisition and reliable capture of all transients, dropouts or interference.

The new Boonton **55 Series** delivers real results no one else can see.

Taking Performance to a New Peak.

- Real-Time Power Processing™ for gap-free analysis
- 100 MSa/sec SUSTAINED sample rate is world's fastest
- 10 GSa/sec effective rate for superb waveform fidelity
- <5 ns risetime and 70+ MHz video bandwidth
- 100 ps time resolution for enhanced trigger stability
- Triggered acquisition speeds over 40,000 sweeps/sec
- Capture and analyze data more than 100x faster than conventional power sensors

For more information visit us at boonton.com or call +1 973-386-9696.

Watch measurements come alive with **Real-Time Power Processing**

Wireless Telecom Group
Boonton Microlab Noisecom

Boonton