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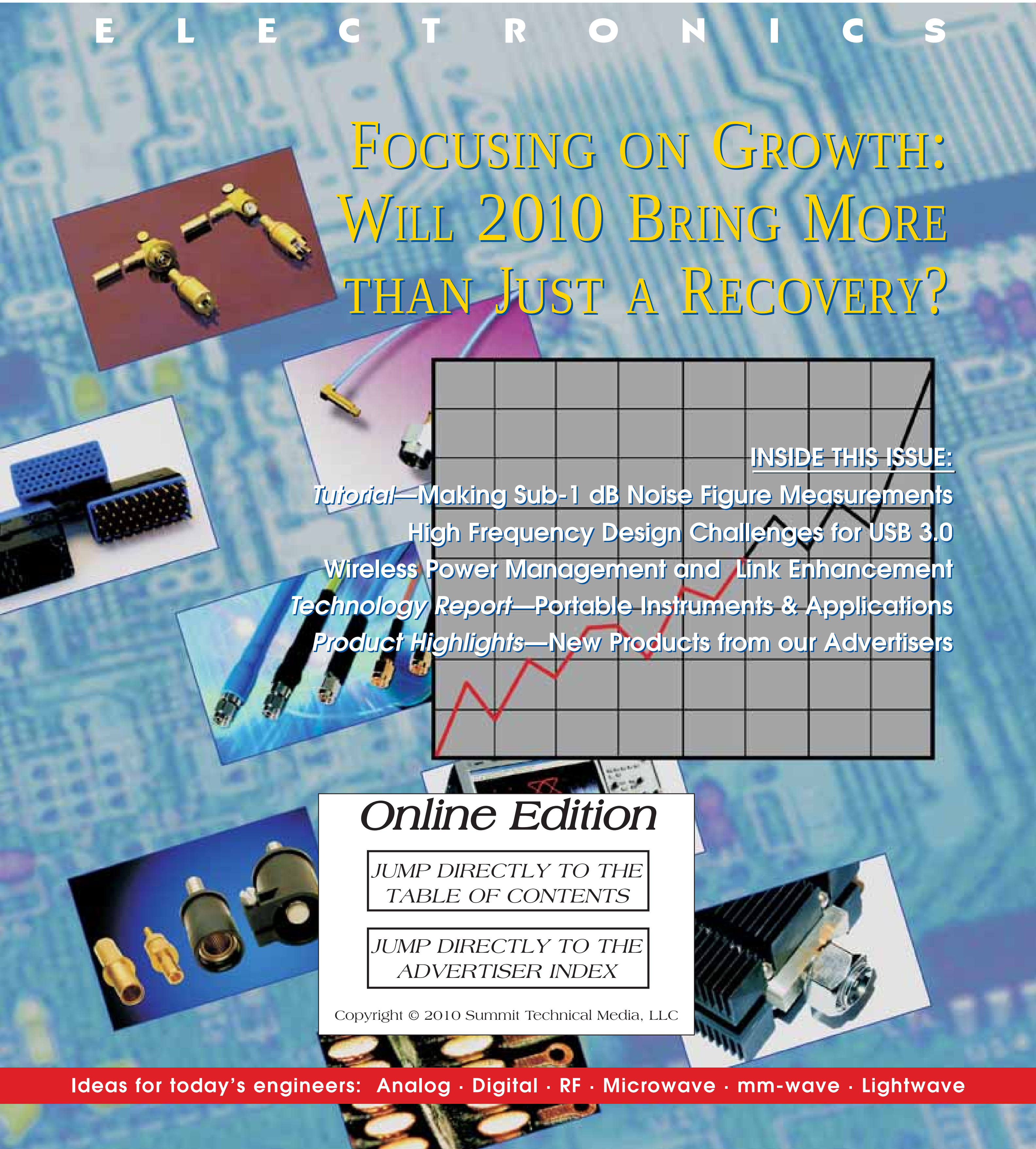
JANUARY 2010

HIGH FREQUENCY ELECTRONICS



Focusing on Growth: Will 2010 Bring More than Just a Recovery?

INSIDE THIS ISSUE:

Tutorial—Making Sub-1 dB Noise Figure Measurements

High Frequency Design Challenges for USB 3.0

Wireless Power Management and Link Enhancement

Technology Report—Portable Instruments & Applications

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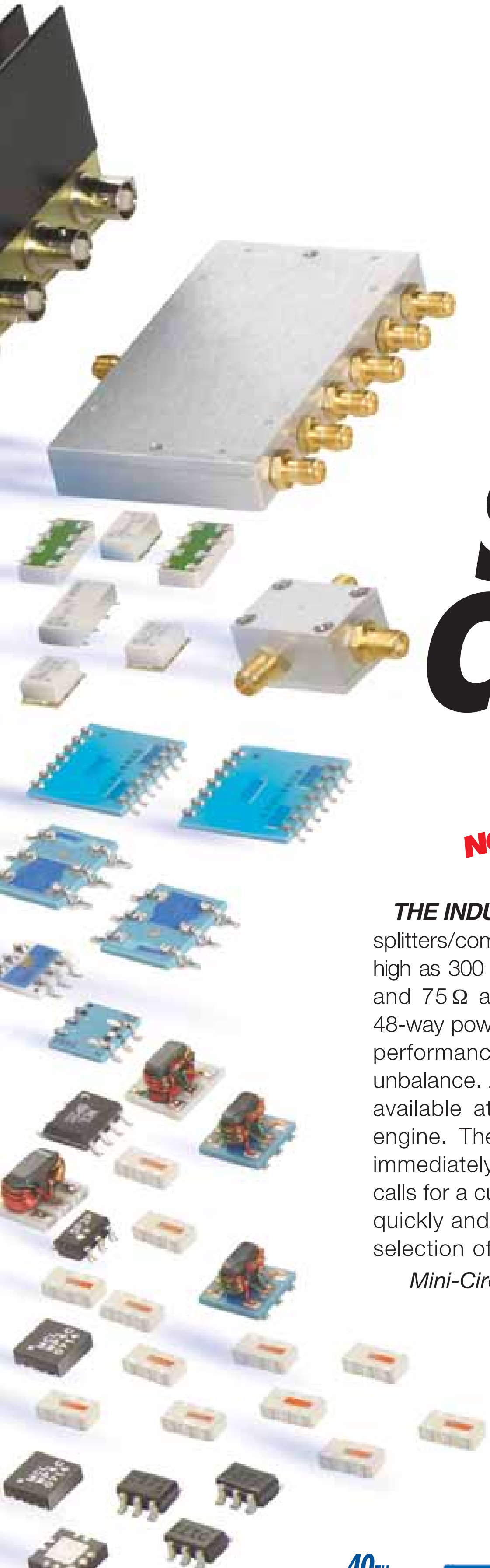

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JANUARY 2010
Vol. 9 No. 1

HIGH FREQUENCY ELECTRONICS

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Regular Columns

On the Cover—Our cover echos the subject of this issue's editorial, surrounded by photos from our Featured Products section, which starts on page 36.

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SUMMIT
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2010 Plans Should Go Beyond Recovery—Aim for Growth

Gary Breed
Editorial Director

I'm known for my positive attitude toward high frequency technology. I figure that any technology that has been a vital part of our lives for 100++ years must be important! I'm pretty sure my attitude is justified, given the incredible rise of wireless communications in the past 30 years, and all the other ongoing advances in electromagnetic simulation, networking theory and integrated device design; plus cross-technology linking of high frequency techniques with digital, medical, mechanical and environmental system developments.

Think about it—our branch of engineering deals directly with fundamental forces of nature: the electromagnetic force in both circuit behavior and signal propagation, and atomic-level forces in the devices and materials we use. Applying these fundamentals to help with problems of everyday life is both valuable to users, and fascinating to those of us involved in the process.

In 2010, a few companies are already beyond recovery and growing. Not many, but I'd characterize most of them as providing core products or technology that are not directed to specific applications. Of course, one or two companies that report current growth are simply in the lucky (or planned) position of being providers for products that are in a growth phase right now, despite economic conditions. RF power for fabrication of LCD displays and solar panels represents one area of high activity. RFID and ZigBee/802.15 are also growing application areas. 3G/4G wireless may not be growing at planned rates, but is growing nonetheless.

The "engineering information" part of the business that we represent had a challenging year in 2009, but toward the end of last year showed many signs of recovery. We are definitely planning for more than simply a recovery in 2010, because the flow of information among engineering professionals is more important than ever. It's our job to support two things: the sharing of technical knowledge and supporting companies in their marketing and advertising efforts. These things work together, since our readers require both design knowledge *and* product information.

In 2010, you can look for *High Frequency Electronics* to continue its direct involvement in industry and technology. One part of that involvement is seeing things in person. In just a couple weeks, I'll be at DesignCon for an update on high speed digital techniques. In this month's photo (taken at DesignCon 2009), I'm talking with Dr. Yuriy Shlepnev of Simberian, a company that specializes in electromagnetics-based design and analysis of high speed circuit board layouts and interconnects.

Among other events in early 2010 that we'll be attending—and learning from—are the IEEE Wireless and Microwave Conference (WAMICON), the National Association of Broadcasters show, and of course, the IEEE MTT-S International Microwave Symposium and its ancillary events. Most of those trips will also involve visits to important companies, universities and individual engineers.

Another part of our business is finding the best use of various media. Until now, our online presence has provided general information, largely extending the availability of the same information that is published in print. This role has been positive: our web hosting company reports that our site has the highest traffic of all the sites on their servers. The majority of that traffic is searches and downloads from the archives of past articles. We're pleased to provide part of the Web's technical library!

We will add new features to our Web site throughout the year. Although we emphasize engineering techniques, not news reporting, it's appropriate to add more news and event coverage. The Internet is real-time, so there is an opportunity for us to provide more timely information.

We do not get a lot of feedback from our readers (or advertisers) regarding specific online features, but we do get a lot of feedback on the content of our printed magazine. Those comments, combined with all the things we learn through reading, visiting, and talking with people in our industry, shapes our decisions on what subjects to cover, which submitted articles to accept, and what topics require a search for more information. Of course, this is the central part of an editor's job!

As the high frequency industry returns to strong growth, we will continue to be in the middle of things, sorting and delivering the information you need.

Conferences

February 7-11, 2010
IEEE International Solid-State Circuits Conference
San Francisco, CA
Information: Conference Web site
http://www.isscc.org

February 9-11, 2010
IDGA 8th Annual Software Radio Communications Summit
Vienna, VA
Information: Conference Web site
http://www.softwareradiosummit.org

March 1-3, 2010
2010 IEEE Int'l Workshop on Antenna Technology: *Small Antennas, Innovative Structure and Materials*
Lisbon, Portugal
Information: Conference Web site
http://www.iwat2010.it.pt

March 23-25, 2010
International CTIA Wireless 2010
Las Vegas, NV
Information: Conference Web site
http://www.ctiawireless.com

April 10-15, 2010
2010 NAB Show
Las Vegas, NV
Information: Conference Web site
http://www.nabshow.com

April 12-13, 2010
11th WAMICON 2010—IEEE Wireless and Microwave Technology Conference
Melbourne, FL
Information: Conference Web site
http://www.wamicon.org

April 12-14, 2010
Sarnoff 2010—33rd IEEE Sarnoff Symposium
Princeton, NJ
Information: Conference Web site
http://ewh.ieee.org/conf/sarnoff/2010/

April 12-16, 2010
European Conference on Antennas and Propagation
Barcelona, Spain
Information: Conference Web site
http://www.eucap2010.org

April 14-15, 2010
IEEE RFID 2010—International Conference on RFID
Orlando, FL
Information: Conference Web site
http://ewh.ieee.org/mu/rfid2010/

April 18-21, 2010
WCNC 2010—IEEE Wireless Communications & Networking Conference
Sydney, Australia
Information: Conference Web site
http://www.ieee-wcnc.org/2010/

May 23-28, 2010
Microwave Week 2010: IEEE MTT-S International Microwave Symposium (IMS); Radio Frequency Integrated Circuits Symposium (RFIC 2010); The 75th ARFTG Conference
Anaheim, California
Information: Conference Web site
http://www.ims2010.org

June 14-18, 2010
4th Microwave & Radar Week
Vilnius, Lithuania
Information: Conference Web site
http://www.MIKON-2010.lt

July 5-9, 2010
ANTEM/AMEREM—14th Int'l Symposium on Antenna Technology and Applied Electromagnetics, held jointly with the American Electromagnetics Conf.
Ottawa, ON, Canada
Information: Conference Web site
http:// antem.ee.umanitoba.ca/antem_amerem2010/

July 11-17, 2010
2010 IEEE AP-S/URSI—Int'l Symposium on Antennas and Propagation and CNC-USNC/URSI Radio Science Meeting
Toronto, ON, Canada
Information: Conference Web site
http://www.apsursi2010.org

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February 2-4, 2010, Atlanta, GA
Basic Antenna Concepts
February 16-18, 2010, Atlanta, GA
EMC/EMI for Engineers and Engineering Managers
March 30-April 2, 2010, Huntsville, AL
Phased Array Antennas for Radar and Communications
April 6-8, 2010, Denver, CO
Antenna Engineering
April 19-23, 2010, Atlanta, GA

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February 9-11, 2010, San Diego, CA
February 16-18, 2010, Orlando, FL

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E-mail: rfid@winmec.ucla.edu
http://winmec.ucla.edu/rfid/experience/2010-02/
RFID Hands On Workshop
February 23, 2010, UCLA-WINMEC RFID Lab

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February 22-25, 2010, San Diego, CA
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February 22-26, 2010, San Diego, CA
Frequency Synthesis and Phase-Locked Loop Design
February 22-24, 2010, San Diego, CA
Bluetooth: Operation and Use
February 22-26, 2010, San Diego, CA
Wireless Circuits, Systems and Test Fundamentals
February 22-26, 2010, San Diego, CA
WiMAX Broadband Wireless Access
February 24-26, 2010, San Diego, CA
Applied RF Techniques I
March 15-19, 2010, San Jose, CA
Advanced Wireless and Microwave Techniques
March 15-19, 2010, San Jose, CA
RF Measurements:Principles & Demonstration
March 15-19, 2010, San Jose, CA
IEEE 802.11 Operations
March 15-17, 2010, San Jose, CA
Practical Wireless Signal Fundamentals
March 17-19, 2010, San Jose, CA

CALLS FOR PAPERS

5th International Waveform Diversity & Design Conference
Niagara Falls, Canada
Conference Dates: August 8-13, 2010
Abstract Submission Deadline: March 1, 2010

Topics:
The WDD Organizing Committee invites original contributions to waveform diversity and design in the general areas of communications, radar, sonar, etc. Specifically, topics include but are not limited to: space-time adaptive processing, bistatic/multi-static operation, error correction coding, multiple-access schemes, target detection, synchronization, interference suppression, passive sensing operation, target-adaptive matched filtering, radar systems, RF hitchhiking, laser systems, Interferometry, tracking, SAR/ISAR, noise radar, tomography, and more. For a complete list of topics see the Web site.

Information:
Abstracts of 1-2 pages are solicited, which should include examples of data and illustrations. Abstracts are due on or before March 1, 2010 submitted via the online collection system available at www.waveformdiversity.org. Authors of accepted papers will be notified by May 17, 2010 and will receive instructions for publication at that time. Complete papers will be required by June 28, 2010.

2010 IEEE International Conference on Wireless Information Technology and Systems
Honolulu, Hawai'i
Conference Dates: August 28th-September 3rd, 2010
Paper Submission Deadline: April 1, 2010

Topics:
A complete list of topics is available on the Web site.

Information:
Summary submissions must be limited to 4 pages, including text, references, and figures. The introduction should indicate how the submission relates to previous work and the unique aspects of the current submission. Footnotes should not be used except for credits to sponsors. An IEEE copyright form must be mailed or faxed or generated online as part of the submission process. All papers must be submitted online as PDF documents. For complete details see: http://hcac.hawaii.edu/conferences/tcwct2010/call_for_papers.html.

Send announcements of upcoming meetings and short courses to: editor@highfrequencyelectronics.com
or send by mail to the Editorial & Production Office address shown on page 6.

29

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These tiny new air core inductors have the highest Q and current handling in the smallest footprint.

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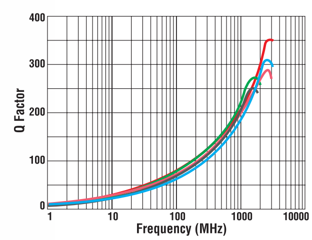
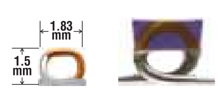


Q factors are 3X higher than standard chip inductors

And with their extremely low DCR, they can handle 4 to 8 times more current: up to 4.4 Arms.

SQ air core inductors are perfect for your LC filter and RF impedance matching applications. They come in 15 values ranging from 6 to 27.3 nH, all with 5% tolerance.

These coils are significantly smaller than existing air core inductors. We reduced the footprint by using close-wound construction and keeping the leads close to the body. The square shape cuts the height to as low as 1.5 mm and creates flat top and bottom surfaces for easy automated handling and stable mounting.



The square shape and narrow footprint reduce board space by 60-75% over conventional air core inductors.

See how the ultra-high Q and current handling of Coilcraft's new SQ air core inductors can maximize the performance of your next design. For complete specifications and free evaluation samples, visit **www.coilcraft.com/sq**

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Technology News

In total 15 papers were presented over two days at the November ARMMS Conference at Corby in England. Alexander Chenakin of Phase Matrix Inc. explained how rather than dividing the output of the VCO, frequency multiplication is applied, resulting in very low output phase noise of –122 dBc/Hz at 10 GHz measured at ±10 kHz offset. This figure is comparable with a YIG oscillator while maintaining fast tuning speeds. The 42 delegates awarded Alexander's paper the prize by popular vote. Damien Camut of Europa Electronics demonstrated a 10 MHz crystal oscillator having frequency accuracy approaching 10-9. This was achieved by microprocessor applied compensation utilising an innovative method of establishing the crystal temperature. Focus areas included CAD software tools where the phrase "Throw-The-Die-Over-The-Wall" was introduced to delegates. Advances in device non-linear modelling was addressed by Malcolm Edwards of AWR who described the Cardiff model, S functions and X parameters. Millimetric wave systems up to 400GHz were discussed by several presenters.

Business News

Agilent Technologies Inc. announced that it has qualified its Momentum Electromagnetic (EM) tool for Taiwan Semiconductor Manufacturing Corp.'s (TSMC's) 65-nm process as part of the TSMC EM Tool Qualification program. This program assists IC designers by providing certified process technology files, layout and measurements for 65-nm and 90-nm process technologies. Certified process files eliminate several error sources in the design process and enable designers to use a TSMC-qualified EM simulator on TSMC 65-nm processes with confidence. Today's qualification announcement demonstrates the fitness of Momentum in EM-based inductor device modeling for high-frequency and RF designs in TSMC's 65-nm process.

Nitronex and **Modelithics** have announced a collaboration to create non-linear models for Nitronex's high power gallium nitride (GaN) devices. Initial models will focus on Nitronex's new thermally improved products targeting broadband and high efficiency amplifiers for the military communications, electronic warfare, and radar markets. The models will be available as a free download from Modelithics' website for Agilent Technologies Advanced Design System (ADS) and AWR Microwave Office (MWO) software at http://www.modelithics.com/mvp/NIT/. The models will also be included in Modelithics® Select free shareware library, available for ADS and MWO, at www.modelithics.com.

RF Micro Devices, Inc. (RFMD®) announced that the company has received its first purchase order from a tier-one wireless base station original equipment manufacturer (OEM) for a product featuring RFMD's gallium nitride (GaN) process technology. The purchase order is for RFMD's RFG1M09180 180-watt GaN broadband power transistor (BPT) and is in support of the global expansion of 4G wireless networks.

Skyworks Solutions, Inc. announced that the Company's expanded ISO/TS 16949 certification now includes its entire Mexicali, Mexico manufacturing facility. Skyworks' 2007 ISO/TS 16949 certification previously covered only certain facets of its Mexicali operations.

Shipments of mobile WiMAX chipsets will reach 4 million by the end of 2009 according to the latest research by **Maravedis**, who in partnership with Reveal Wireless released its new report "WiMAX Wave2 Subscriber Station Chipset Vendors Competitive Analysis." Maravedis and Reveal Wireless found that the WiMAX subscriber station chipset ecosystem is acutely fragmented, with more than 14 chipset vendors competing for market share. "This puts pressure on vendors with insufficient customer traction, lacking funding or scale, or offering only partial chipset solutions," said Adlane Fellah, Maravedis CEO and Founder and co-author of the report.

Giga-tronics announced that it has entered into an agreement with **Aviatronik** in Italy for the service and repair of its Microwave Signal Generator products for customers located in the Europe, Middle East, and Africa (EMEA) region, including Turkey but excluding the UK.

Richardson Electronics, Ltd. announced it has signed a global distribution agreement with **Sarantel**, a manufacturer of filtering antennas for mobile and wireless devices.

AWR and **NXP Semiconductor** have announced that a small-signal RF design kit is available for NXP's SiGe:C silicon germanium bipolar junction complementary metal oxide semiconductor (BiCMOS) process. The design kit installs easily within AWR's Microwave Office software and functions as an integrated part of the simulation environment.

AWR and **United Monolithic Semiconductors** (UMS) announced the availability of enhanced process design kits (PDKs) for the UMS PH15 and PH25 advanced gallium arsenide (GaAs) foundry processes. These enhanced PDKs enable designers to take full advantage of the process capabilities of UMS within AWR's 2009 Microwave Office® design suite including its latest technologies such as iNets™, AC0E™, AXIEM™, and ICED DRC.

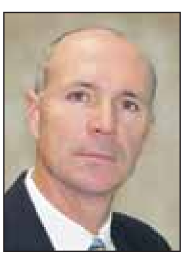
Rochester Electronics is actively expanding its mission critical product manufacturing capabilities to ensure a continuous supply of certified radiation hardened space-level semiconductors. An approved member of the Class V Qualified Manufacturer List (QML) by the Defense Supply Center Columbus (DSCC), Rochester Electronics is contractually licensed by National Semiconductor, TI, Fairchild and other leading semiconductor firms, to provide a continuing manufacturing source for products they no longer make. Rochester Electronics manufactures devices that meet MIL-PRF-38535 space-level certification requirements.

Laird Technologies, Inc. announced the opening of its new wireless M2M design center in Bangalore, India. This new wireless M2M design center focuses on complete end-to-end product development aspects such as hardware engineering, firmware development, and Quality Assurance. Being located in Bangalore, India allows Laird Technologies access to a large work force of talented and experienced personnel. The design center works in conjunction with other Laird Technologies wireless M2M design centers located in the UK and United States.

People in the News

ANSYS, Inc. announced that **Joshua Fredberg** has joined the ANSYS senior management team as the vice president of marketing. Fredberg will play an integral role in furthering the Company's vision and strategy, enhancing ANSYS global marketing initiatives, and leading all aspects of the Company's branding. Before joining ANSYS, Fredberg was senior vice president of product and market strategy at Parametric Technology Corporation (PTC). Prior to joining PTC, he held leadership roles with both ARIBA and Andersen Consulting Strategic Services. Fredberg has a B.S. in electrical engineering from Tufts University, an M.S. in systems engineering from the University of Pennsylvania, and an M.B.A in finance from The Wharton School.

LCR Electronics announced that **Eric Kessler** has been hired as director of commercial sales. Kessler will focus on customer support, strengthening relationships worldwide, as well as managing all commercial sales activities for the company. He will spend time onsite with customers as well as with LCR sales personnel and manufacturers' representatives. As director, Kessler will also identify additional commercial markets that could benefit from LCR's technologies and advanced customization techniques. Kessler has over 20 years of management experience in sales and marketing throughout a number of global industrial and commercial market segments. He has developed and implemented numerous marketing and sales programs geared towards bringing existing technologies into newer markets. He holds a BA in International Affairs with a business concentration and an MBA in International Business from Xavier University. During his work in industrial steam generation, he authored several published papers and spoke at a number of industry conferences.



Nitronex has named **Edwin Chen** as Director of Sales and Business Development for the Asia Pacific region. Mr. Chen has over 15 years experience in mobile and broadband communications, as well as infrastructure base station sales and business development. He also brings 10 years of experience in leading field sales, technical resources and channel partner teams in the Asia Pacific region. Mr. Chen most recently served as Senior Director at Pulse~LINK where he managed the sales and business development activities in introducing Pulse~LINK CWave high-definition television home-networking solutions to the Korean and Chinese markets. He has also held senior sales and business development positions at Cygnus Communications and Conexant Systems.

Bishop & Associates, Inc. is pleased to announce that **David W. Pheteplace** is taking on the position as Managing Director for its new Cable Assembly Division. Pheteplace joined Bishop & Associates, Inc. in 2008 as its market segment director for cable assemblies. Mr. Pheteplace has over 20 years of experience in the interconnect industry, holding executive leadership positions with Amphenol, Labinal/Cinch, and Robinson Nugent. His background includes full P&L responsibility for multi-million-dollar divisions of these companies. Pheteplace holds a BS degree from St Lawrence University and an MBA in marketing from Syracuse University. He resides in San Diego, CA.

ARRIS announces that its Chief Strategy Officer, **Dr. Tom Cloonan,** has been elevated to the rank of Fellow in the Institute of Electrical and Electronics Engineers (IEEE), singled out for his leadership in the development of Cable Modem Termination Systems (CMTS). As ARRIS CSO, Dr. Cloonan is involved in the architecture and planning of next-generation CMTS/EQAM systems, as well as providing company-wide guidance for many different cross-business unit programs being carried out within ARRIS. Dr. Cloonan will become an IEEE Fellow effective January 1, 2010.

Sales Appointments

California Eastern Laboratories (CEL) announced the addition of two new domestic sales representative firms, **Rep One Associates, Inc.,** which covers the southeastern United States, and **Anchor Engineering, Inc.,** which covers New England. Both firms will carry the full line of CEL products, including NEC-based RF and wireless ICs and discrete devices, optocouplers, solid state relays, lasers, and detectors for fiber optics. Both firms will also market CEL's MeshConnect™ line of 802.15.4/ZigBee modules and ICs, plus other modules.

Vaunix Technology Corporation has announced the hiring of two new sales representatives to handle customer relationships in the UK and Japan. **MCS Test Equipment** is a supplier of wireless test and measurement equipment in the UK. Located in North Wales, MCS covers all territory within the UK. Vaunix representative Bill Beck can be reached by phone 08453 62 63 65 or email info@mcs-testequipment.com. **Seki Technotron,** located in Tokyo, Japan, markets and distributes high tech products for commercial communications, defense electronics, test and measurement, and advanced scientific research. Hiroyasu Ishii, the account representative for Vaunix, can be reached by phone at +81-3-3820-1716 or by email at components@sekitech.jp.

Make Accurate Sub-1 dB Noise Figure Measurements Part 1: Noise Concepts

By Eric Marsan
Skyworks Solutions, Inc.

This two-part tutorial describes the theory and practice of noise figure measurement, focusing on the measurement of very low noise figures

One of the most important capabilities of a radio receiver is its ability to reliably detect very weak RF signals. The circuits of a radio receiver inevitably generate electrical noise, which may mask the received signal if the receiver is not properly designed to minimize this noise. The accurate measurement of the receiver's noise performance is of paramount importance in the assessment of its suitability for reliable communications. This concern is compounded by the fact that modern RF systems are increasingly powered by batteries which necessitates the reduction in transmitter output power, which commensurately reduces signal levels at the receiver.

Noise figure (NF) is a figure of merit of RF components that describes their noise performance, and is of particular importance in receiver applications. In addition to the voltage standing wave ratio (VSWR) and the gain of the system itself, the measurement of noise figure is affected by numerous environmental factors such as the ambient temperature and the presence of interference. This article describes practical techniques and methods for accurate noise figure measurement of amplifiers and other 2-port systems having a sub-1 dB noise figure.

First, noise figure concepts are defined and followed by theoretical considerations addressing component loss, impedance mismatch, and temperature. Then, noise figure measurement instrumentation is described and solutions for improving the accuracy of noise figure measurements are provided. Finally, the reference measurement setup used at Skyworks Solutions is described in detail and the characterization of amplifiers over temperature is briefly discussed.

Theoretical Concepts

Noise Factor, Noise Figure, Noise Temperature

As described by Equation 1, the noise factor (F) is defined as the ratio of the input signal to noise ratio to the output signal to noise ratio of the device under test (DUT). S and N respectively refer to signal and noise power.

$$F = \frac{S_i / N_i}{S_o N_o} \tag{1}$$

The noise factor therefore expresses the degradation in the signal to noise ratio caused by the DUT and is always greater than one. Since power gain is defined as the ratio of the output to the input power (Equation 2),

$$G_A = \frac{S_o}{S_i} \tag{2}$$

noise factor can also be expressed as in Equation 3.

$$F = \frac{N_o}{N_i G_A} = \frac{N_i G_A + N_{DUT}}{N_i G_A} \tag{3}$$

is the available thermal noise power at the input of the device and is calculated

$$N_i = kT_{AMB}B \tag{4}$$

where k is Boltzmann's constant (k = 1.374 × 10^{-23} J/K), T_{AMB} is the ambient temperature in Kelvins and B is the bandwidth in Hertz. N_o

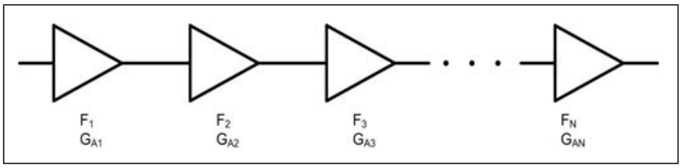


Figure 1 · Cascaded amplifier chain.

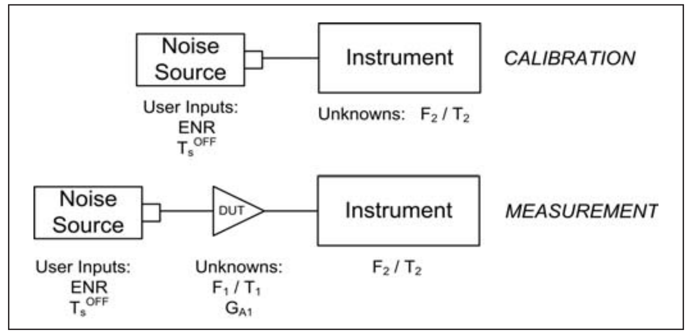


Figure 2 · Block diagram of a noise measurement with the Y-factor method.

is the noise present at the output of the DUT and is composed of the amplified noise available at the input (N_i) and the noise added by the DUT.

Noise figure (NF) is simply the noise factor expressed in decibels (dB) and is calculated using Equation 5.

$$NF = 10\log_{10} F \tag{5}$$

Any noise factor can be expressed as an equivalent noise temperature. Although noise temperature is not commonly used by RF system designers (except for space applications), it is used by most test instruments in their internal calculations and emphasizes the effect of ambient temperature on noise measurements. Noise temperature and noise factor have a linear relationship defined in Equation 6, where T_e is the equivalent noise temperature and T_0 is the reference temperature of 290 K. The noise figure of a DUT is by convention defined at 290 K (16.9 °C or 62.3 °F), regardless of the ambient temperature.

$$T_e = T_0(F-1) \tag{6}$$

Cascaded Noise Figure

It is critical to understand what determines the noise figure of an amplifier chain as it also applies to how the noise figure of an individual component is accurately measured. A noise measurement setup has its own noise figure which must be compensated either by calibration or by applying offsets to the measured results. Given an amplification chain as described in Figure 1 the total noise factor of this cascade is calculated by Equation 7, where F_n and G_{An} refer to the noise factor and gain of the nth stage, respectively.

$$F_{1N} = F_1 + \frac{F_2-1}{G_{A1}} + \frac{F_3-1}{G_{A1}G_{A2}} + \frac{F_4-1}{G_{A1}G_{A2}G_{A3}} + \ldots + \frac{F_N-1}{\prod_{n=1}^{N-1} G_{An}} \tag{7}$$

It can be observed looking at Equation 7 that the noise contribution of each stage to the total noise factor is reduced by the amount of gain of all preceding stages. For that reason one may assume the noise figure of a system is mostly set by the first stage, which is only valid if the gain of the first amplifier is large enough to obscure the noise contribution from the second and so on.

Equation 7 is also at the foundation of most noise measurements. The typical noise measurement setup is equivalent to a 2-stage amplification chain in which the DUT can be considered to be the first stage and the instrument the second stage. The noise factor of the DUT, F_1 or T_1, is calculated utilizing Equation 8 or 9 by removing the noise contribution from the instrument, F_2 or T_2, with calibration.

$$F_1 = F_{12} - \left[\frac{F_2-1}{G_{A1}}\right] \tag{8}$$

$$T_1 = T_{12} - \frac{T_2}{G_{A1}} \tag{9}$$

Y-Factor Method

The Y-Factor is how most instruments measure noise figure. It is a simple method that involves two steps: calibration and measurement. The calibration involves connecting a noise source directly at the input of the instrument as shown in Figure 2.

A noise source is a device that emits a known quantity of noise and has 2 states: ON and OFF. During the OFF state, the noise source emits thermal noise corresponding to its ambient or internal temperature. In the ON state, the internal device, normally a diode, is turned ON and a higher quantity of electrical noise is emitted. The offset in noise power between the ON and OFF states is measured during the factory calibration of the noise source and is expressed as an excess noise ratio (ENR) over frequency. The ENR is defined by Equation 10.

$$ENR = \frac{T_s^{ON} - T_s^{OFF}}{T_0} \tag{10}$$

By convention, the ENR table provided with any noise sources is always expressed at $T_s^{OFF} = T_0$. Consequently, the ENR data provided with the noise source is valid only if the noise source physical temperature is 290 K. One may correctly argue T_s^{OFF} may not be 290 K under actu-

al measurement conditions of a DUT as it is highly dependent on the ambient temperature. For that reason, most instruments allow the user to specify the temperature of the noise source so it can correct the provided ENR table thus accounting for any offset from 290 K. It is very important to accurately specify the noise source temperature, especially when measuring sub-1 dB noise figure devices. Figure 3 illustrates the measurement error due to an offset between the specified temperature value and the actual noise source temperature. In this particular case the temperature input from the user is assumed fixed at 290 K while the physical temperature of the noise source is varied. For example, a device having a true noise figure of 0.7 dB at an ambient temperature 6 ºC higher than the noise source temperature input provided by the user will read 0.8 dB on the instrument.

During the instrument calibration step, the instrument measures the noise power from the noise source at the ON and OFF state to calculate its own noise temperature T_2, as described by Equation 11. T_s^{OFF} is known from the user's noise source temperature input and T_s^{ON} is calculated from the ENR table. This completes the calibration step.

$$Y_2 = \frac{N_2^{ON}}{N_2^{OFF}} = \frac{T_s^{ON} + T_2}{T_s^{OFF} + T_2} \tag{11}$$

The second step consists of inserting the DUT between the noise source and the instrument. The instrument then repeats the same measurement while switching the noise source between the ON and OFF states as described in Equation 12. Then, it calculates T_{12}.

$$Y_{12} = \frac{N_{12}^{ON}}{N_{12}^{OFF}} = \frac{T_s^{ON} + T_{12}}{T_s^{OFF} + T_{12}} \tag{12}$$

As can be observed from Equation 9, the only parameter missing to calculate the noise temperature of the DUT is its gain (G_1) which is readily available from the measured data as described by Equation 13.

$$G_1 = \frac{N_{12}^{ON} - N_{12}^{OFF}}{N_2^{ON} - N_2^{OFF}} \tag{13}$$

Proper Calibration

Noise measurements are not always well understood which may lead to erroneous calibrations and therefore erroneous measurement results. When sub-1 dB noise figure measurements are performed, subtle calibration errors may be uncovered that would otherwise be barely perceptible with noisier devices. The most critical rule to remember is to never include components located before the DUT in the calibration loop unless the ENR table is corrected. The purpose of the calibration is solely to measure the noise contribution of the instrument so it can be removed from the total cascaded noise figure, thus allowing the noise figure of the DUT to be isolated. Input losses that cannot be avoided should always be accounted for during post-processing of the measurement. Output losses can either be accounted for in post-processing or during calibration. In the latter case, the noise source is connected to the instrument through other components required at the output of the DUT while the calibration is performed. The contribution from these components is then absorbed by the instrument during calibration. In this case, temperature adjustments are no longer possible which is typically not a problem as will later be demonstrated. It is also imperative the added components remain at the output of the DUT during measurement.

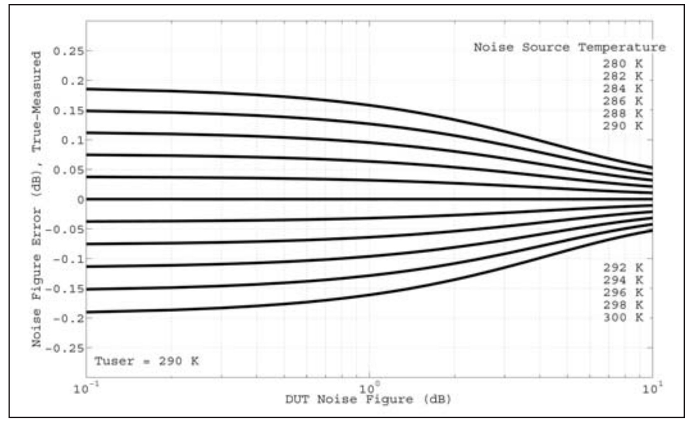


Figure 3 · Noise figure measurement error function of DUT noise figure, at various temperatures. (Assumptions: instrument noise figure is 10 dB, DUT gain is 20 dB, ENR = 6 dB).

Accounting for Losses

In a laboratory environment, a DUT may not be easily accessible and may require connectors, cables, attenuators, etc., to be measured with a noise measurement setup. These elements all create combined reflective and dissipative losses affecting the noise figure measurement by adding attenuation which may add directly to the noise figure, reduce gain, or add noise to the system. These losses are typically left in the setup because they are physically or mechanically required to perform the measurement. It is therefore necessary to remove their effects in a post processing step. Most noise figure measuring instruments have built-in menus and functions that allow corrections for losses automatically, based on user input.

Figure 4 shows a typical noise measurement setup in which the DUT is enclosed between lossy elements. $L_{IN/OUT}$ and T_L respectively represent the loss and the temperature of the element. $L_{IN/OUT}$ is calculated from

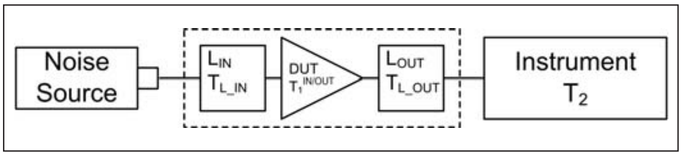


Figure 4 · Noise measurement setup including losses.

the loss in decibel using equation 14.

$$L_{IN/OUT} = 10^{L_{IN/OUT\_dB}/10} \tag{14}$$

Input Losses

Equation 15 describes the noise temperature of the DUT once compensated for input losses, defined as T_1^{IN}. Note the second term of the equation only applies to dissipative losses and should be omitted if the loss is purely reflective.

$$T_1^{IN} = \frac{T_1}{L_{IN}} - \frac{T_{L\_IN}\left(L_{IN}-1\right)}{L_{IN}} \tag{15}$$

A dissipative element is also a source of noise on the basis of its physical temperature as illustrated by the T_{L_IN} term in Equation 15. It is commonly assumed the effect on noise figure of an attenuator placed at the input of the DUT is equal to its the insertion loss (L_{IN}). This assumption is correct only at an ambient temperature of 290 K as described by Equation 16.

$$F_1^{IN}\Big|_{T_{L\_IN}=T_0} = 1 + \frac{T_1^{IN}\big|_{T_{L\_IN}=T_0}}{T_0} = \frac{F_1}{L_{IN}} \tag{16}$$

Figure 5 illustrates the combined effect of dissipative input loss and temperature on the corrected noise figure of the DUT for a 1 dB noise figure measurement. As can be seen, if $T_{L\_IN} = T_0$, the correction in dB is simply the $NF_{1\_dB} - L_{IN\_dB}$. In the case of higher loss, temperature may have a non-negligible contribution to the measurement and must be taken into account.

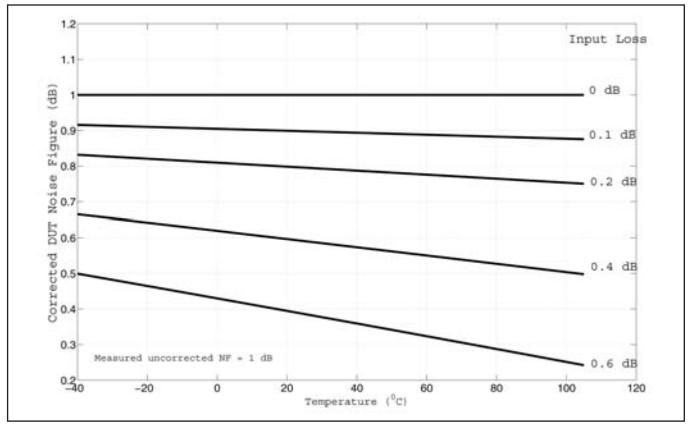


Figure 5 · Corrected noise figure function of the loss at the input and temperature. (Assumption: the measured uncorrected noise figure is constant at 1 dB).

Output Losses

Reasonably small output losses are less troublesome than input losses in typical noise measurement setups. In addition, their effect on the measurement can easily be calibrated out as was explained earlier.

There are two reasons that explain the lower sensitivity of noise figure measurements to output losses: the noise figure of the instrument and gain of the device. As described in Equations 17 and 18, the correction for output loss is applied to the noise temperature of the instrument, T_2, which can be high, especially for spectrum analyzers with a noise figure measurement personality. This means most loss at the output will be small compared to

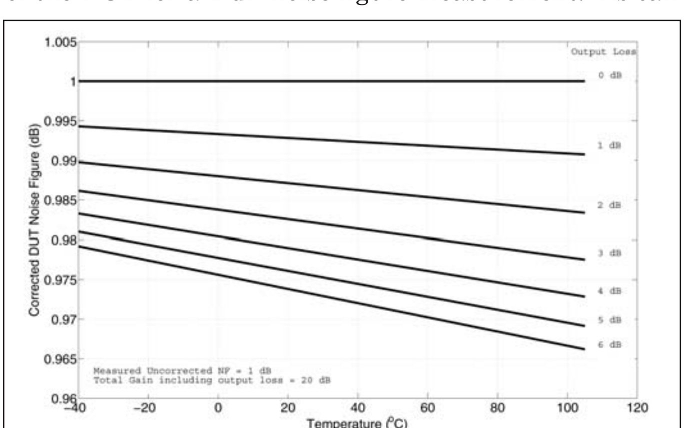


Figure 6 · Corrected noise figure function of the loss at the output and temperature. (Assumptions: instrument noise figure is 10 dB, the total cascaded gain is 20 dB and the total cascaded noise figure measured is 1dB).

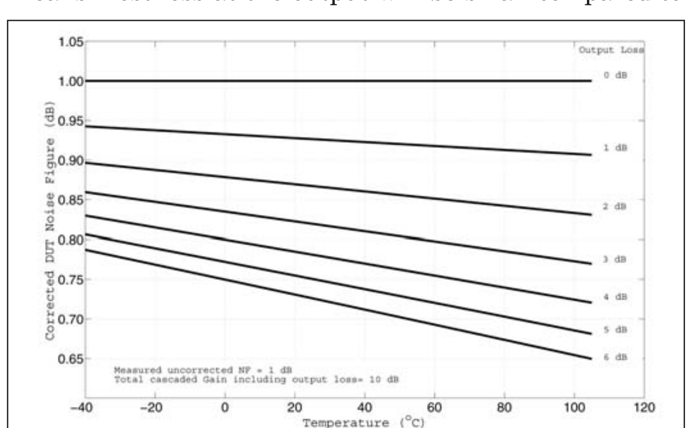


Figure 7 · Corrected noise figure function of the loss at the output and temperature. (Assumptions: instrument noise figure is 10 dB, the total cascaded gain is 10 dB and the total cascaded noise figure measured is 1dB).

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Phone: 1-650-949-3300 Fax: 1-650-949-4400 www.besserassociates.com the instrument's own noise figure unless a large value attenuator is used. As an example, the Agilent MXA N9020 with preamplifier has a noise figure of 10 dB at 2 GHz. The gain of the DUT reduces the sensitivity further by making corrections for output loss even less perceptible. T_2^{OUT} is the noise temperature of the instrument corrected for the loss at the output of the DUT that was *not* present during calibration. T_1^{OUT} is the corrected noise temperature of the DUT compensated for output loss.

$$T_2^{OUT} = T_2 L_{OUT} + T_{L\_OUT}\left(L_{OUT} - 1\right) \tag{17}$$

$$T_1^{OUT} = T_{12} - \frac{T_2^{OUT}}{G_{AI}} \tag{18}$$

Figure 6 illustrates the effect of dissipative output losses on the measured noise figure of the DUT when the total cascaded gain is 20 dB including the output loss. As can be seen, the measured noise figure is less sensitive to output loss and the variation of the correction over temperature is negligible. Figure 7 illustrates the increased sensitivity of the measurement to output loss and temperature when the same calculation is performed with a total cascaded gain of only 10 dB.

This article continues next month, with Part 2 covering noise figure measurement methods.

Acknowledgment

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Overcoming the High Frequency Design Challenges of USB 3.0

By Joseph Spisak
Pericom

New digital interface standards require special attention to high speed/ high frequency performance in order to obtain the required throughput and maintain high reliability

The beauty—and primary market appeal—of USB is its simplicity. USB has an installed base of more than 6 billion devices, making it the most successful interface among PC and peripheral devices. Part of the reason USB is nearly ubiquitous among these applications arises from the trust held by users that they can plug in devices using whatever cable is at hand. USB's relative low cost is also responsible for its unprecedented success.

Understandably, consumers have a fairly good idea of what to expect from USB 3.0 as it becomes widely available: low cost, simplicity, and reliable operation. Likewise, many manufacturers are confident that they can migrate their designs from USB 2.0 (High-Speed) to USB 3.0 (SuperSpeed) as easily they did from USB 1.0 (Full-Speed) to USB 2.0. However, SuperSpeed USB is no simple upgrade. The typical roadmap for most interfaces is to double their data rate, but the new USB 3.0 specification implements a full 10x increase in bandwidth. Moving to a 5 Gbps signaling rate introduces a wide range of signaling issues many developers have never had to manage before. With an actual signal frequency of 2.5 GHz—the 5 Gbps data rate is achieved by employing double data rate techniques—the overall system is far more sensitive to attenuation and jitter. In addition, USB 3.0 is no longer a simple bus-based architecture using host directed transactions. The new SuperSpeed spec utilizes a much more complex bi-directional and port-directed packetized environment. Further complicating design is the fact that the spec requires backwards compatibility with the USB 2.0 connector, which was designed for optimal operation at much lower data rates.

There is already a strong market need and demand for USB 3.0. Today, High-Speed USB running at 480 Mbps is acceptable for many applications, but the increasing storage capacity of portable devices coupled with the rising availability of high definition video and desire for faster transfers makes SuperSpeed USB a powerful differentiating feature for manufacturers. In order to meet the reliability expectations of the market, developers will have to approach USB 3.0-based designs with the same care and attention to detail necessary for the architecture of any high-frequency system. Doing so, while controlling costs and maintaining ease-of-use, requires careful management of attenuation and jitter while driving high-speed signals through varying lengths of cables, across multiple connectors, and over extended board traces.

Consumers Don't Care About Signal Margin

Signal losses at the higher frequency of USB 3.0 will be more pronounced than many designers familiar with USB 2.0 expect. USB poses a fairly challenging environment, as can be illustrated with a typical real-world application connecting a laptop to a peripheral (see Figure 1). The distance from the notebook's USB controller to the connector is commonly on the order of 10 inches. Next, as per the USB 3.0 spec, signals will need to be able to travel over up to 3 meters of cable before crossing over another connector and more board traces

to the peripheral controller. And, until USB 3.0 is integrated on notebook chipsets, an external host controller will also be required, potentially introducing additional signal losses.

Compliance testing measures signals after they have been equalized at the receiver, and the combination of trace, connector, and cabling losses quickly erodes signal quality. Keeping the signal eye sufficiently open will require careful budgeting of signal margin since the total distance over which high-frequency signals must be able to run begins to push the limits imposed by the USB 3.0 specification.

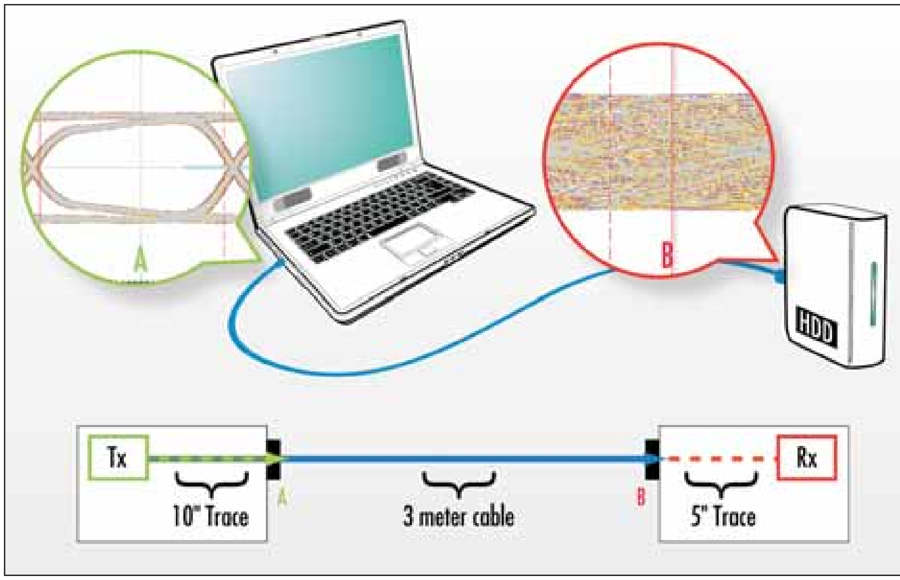

Figure 1 · USB 3.0 signals must not only run reliably over varying lengths of cable, but also across multiple connectors and traces between the transmitter and receiver.

Much of the signal loss occurs in the cable. Signal integrity can be maintained by using high-quality, thick gauge cables. The difficulty here is that such cabling is significantly more expensive than the low-quality unshielded twisted pair (UTP) cabling typically associated with consumer applications. OEMs do have the option of requiring that consumers use high-quality cables, but this approach poses several challenges. First, bundling high-quality cables with a product can substantially increase the bill of materials for a product, making its price less attractive and less competitive when compared to products that don't bundle cables. However, even if a high-quality cable is included with a product, consumers are used to mixing their USB cables together and may inadvertently use a lower quality cable provided with another device.

Alternatively, OEMs can employ product labeling to signify that a specific type of cable be used with a product. Consumers, however, have never had to worry about cable quality

USB Encroaches on PCI Express

Engineers who have worked with PCI Express 2.0 will find the migration to USB 3.0 to be more straightforward than it might otherwise be. While there are differences between the two standards, USB 3.0 and PCI Express 2.0 have equivalent data rates and use similar transmit and receive blocks including scrambling, 8b/10b encoding and serialization/de-serialization of data, while also sharing many characteristics at the physical layer.

One consequence of the similarity between USB 3.0 and PCI Express 2.0 is the encroachment of USB 3.0 into a number of PCI Express 2.0 applications. In a docking station, for example, using USB to connect to the notebook rather than PCI Express 2.0 eliminates the need to bridge USB traffic. In effect, the docking station effectively becomes a USB hub that fans out the signal, thus simplifying the overall architecture while lowering system cost.

The extensive penetration of USB into consumer electronics devices also gives platforms using USB 3.0 a tremendous advantage in the ability to immediately connect to the installed base of USB 2.0 devices already deployed. Certainly, PCI Express 2.0 will hold its own in applications where it is already the explicit off-chip interface, including internal bus interfaces from processors and in server, storage, and various embedded applications. However, this incumbent advantage only holds so long as PCI Express 2.0 remains the primary integrated interface.

As USB 3.0 is integrated onto chip-sets and processors, it will compete with other interfaces as well. With its high bandwidth and low cost—given its tremendous market volumes—USB 3.0 can be expected to compete with display interfaces such as HDMI, DisplayPort, PCI Express, and DVI. Effectively, USB 3.0 can be expected to markedly impact the market share of other protocols in any application where there is already at least one USB interface.

when using Full-Speed and High-Speed USB. Part of the appeal of USB is its ease-of-use and its perceived guaranteed interoperability. To ensure a quality end-user experience, OEMs of SuperSpeed devices will want to avoid forcing users to have to think about matching hosts, cables, and endpoints.

The crucial concern for OEMs is that if a low-quality cable is used and performance is degraded, it is the device that consumers will assume is at fault, not the cable. Such a perception could result in a higher rate of USB 3.0-based product returns, substantially eroding profit margin. It could also affect the overall adoption rate of USB 3.0 as an emerging technology, if the average user perceives that getting USB 3.0 to work reliably is difficult, market uptake will be adversely affected as well.

Accommodating Cabling Losses Through Signal Conditioning

Given that OEMs cannot control the type or length of cable that consumers will use with their devices, engineers must assume worst case losses. Cable losses, however, are fairly deterministic, and reductions in signal quality through noise and attenuation can be restored through signal conditioning technology.

Signal conditioning devices—often referred to as redrivers since the signal is restored and "redriven" across the channel—provide the clean passage of signals across longer distances and additional connectors through the use of emphasis and equalization techniques that reduce signal attenuation and jitter. Redrivers are used across a wide variety of high-speed interfaces and protocols to effectively open a closed eye so that data can be recovered at the receiver with an overall effect similar to breaking the signal path into several legs and restoring signal quality at each leg (see Figure 2).

Given the dynamic nature of the typical PC-peripheral environment—devices can be removed or attached at any time with varying cables lengths—the characteristics of the overall USB signal path can change over time. Over- and under-equalization can become a problem since the equalization ideal for a 3-meter cable will compromise signal integrity when applied to a thumb drive with an effective cable length of zero meters. Adaptive signal conditioning is required to continuously monitor and tune the channel to ensure that the redriver is adjusted to optimally match the actual signal path. However, for stable applications where the signal path does not change (i.e., a storage server environment where cables are never removed) continuous retraining is unnecessary and may even negatively impact performance. In these environments, configurable equalization that is set to match the channel is more appropriate.

Redrivers are introduced between the transmitter and receiver so that incoming signals can be restored, adjusted, and retransmitted, resulting in greater signal margin. A single redriver can add up to 11 dB of gain, thus significantly increasing the ability of a system to accommodate losses through SDP cables. This added signal margin will ensure that devices are able to reliably transmit data over even the lowest quality cables.

Typically, redrivers are placed before the receiver to open the signal eye. In an implementation such as an internal bus where the engineer controls both the transmitter and receiver, receive-side signal conditioning is quite effective. With USB, however, engineers have to create products that connect to devices they did not design.

Given the reality that consumers expect USB 3.0 to be available at near-USB 2.0 prices, there is considerable pressure on manufacturers to lower costs in any way possible, most notably leaving signal conditioning as a concern for the receiving device. The result will be the availability of inexpensive hubs and peripherals that do not have signal conditioning, which have passed compliance testing using high quality cables, but perform marginally when connected with the lower quality cables that the average consumer is likely to have on hand.

The challenge for manufacturers designing reliable USB-based products is that their products will be expected to work reliably when connected to these marginal devices. Consider a hard drive with receive-side signal conditioning. While the drive will receive data accurately, lack of transmit-side conditioning will result in poor signal quality from the drive as well as frequent errors and lower throughput. Users will perceive that the problem is with the drive, not the low quality cables or cheap hub that seem to work well enough with other peripherals. The result will be a returned drive and damage to the manufacturer's brand.

In order to ensure reliability, signals need to be conditioned both as they are transmitted and received. By properly restoring signals, both coming and going, devices will be able to interoperate with any other device across any cable length, even with those devices that do not condition signals on the receive side.

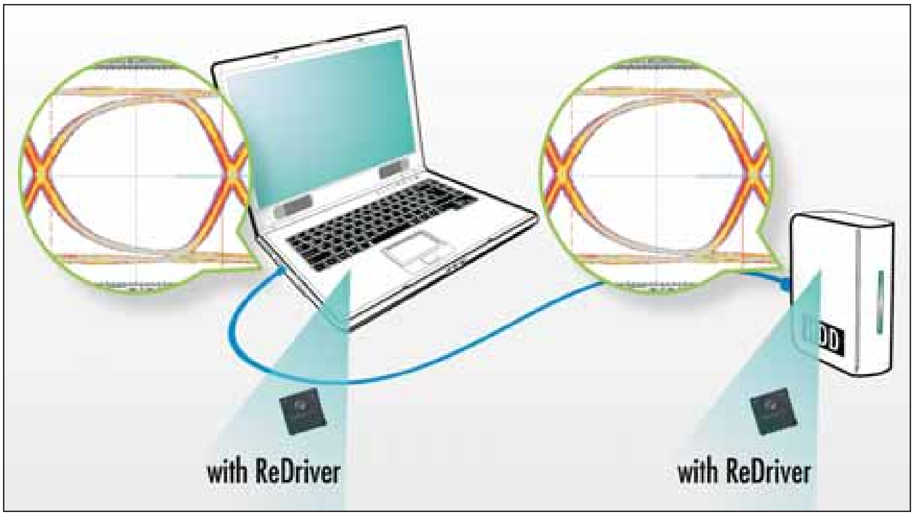

Figure 2 · Redrivers with emphasis and equalization signal conditioning technology ensure the integrity of high-frequency USB 3.0 signals by opening closed signal eyes to recover data and meet strict compliance testing requirements. Increased signal margin also supports longer drive lengths over even low-quality cables.

Lowering System Cost Through Higher Signal Margin

The extra signal margin gained through signal conditioning not only ensures interoperability with other devices, it also translates directly to greater flexibility and lower cost. Specifically, signal conditioning allows engineers to run signals longer distances and/or have more flexibility in how signals are routed across a printed circuit board (PCB). Such margin can enable engineers to achieve sufficient signal and ground isolation with fewer board layers, thus reducing system complexity and manufacturing cost. Improved signal quality also increases reliability by lowering the overall bit error rate (BER). This leads to higher system performance and an increase in effective throughput by reducing the number of transmission errors and retransmissions required.

The combination of emphasis, equalization, and increased drive also supports the use of longer, thinner, and lower cost cables while maintaining reliability and throughput. Thinner cables—which tend to be lower in cost, have greater flexibility and are typically more aesthetically pleasing compared to thicker gauge cables—are the likely choice of consumers.

Redrivers also provide protection against electrostatic discharge (ESD), such as when a user accidentally shocks a device. Consider that the cost of an interface is lowest when the controller is integrated onto the primary processor or chipset. When this controller is directly connected to the port connector, not only is the controller vulnerable to an ESD event, the entire chipset/processor is at risk, potentially rendering the entire system inoperable. Because a redriver sits between the port connector and controller, the redriver effectively isolates the chipset/processor. In the case of an ESD event, the redriver will protect the USB controller and chipset/processor with a worst-case outcome of losing the single USB port while leaving the rest of the system otherwise operational.

Clocking and Switching Integrity Issues

Clocks play an important role in high-frequency systems, for as signal rate increases, jitter budgets drop. Given the expense of high-frequency clocks, it is more cost-effective for engineers to multiply the clock signal from a lower frequency clock to supply the appropriate high-frequency clock required for USB. However, when a low-frequency clock is multiplied into a high-frequency signal, the jitter will be multiplied by an equal factor as well. The challenge for engineers is to balance induced jitter with input frequency. To minimize cost, USB clock buffers and generators need to introduce very low jitter.

Similarly, USB switches need to provide smooth transitions. Switches are an elegant way to reduce system cost in applications such as docking stations by reducing the number of physical ports a system has while increasing the number of devices that can be connected at any one time. Maintaining low resistance and impedance are the key concerns here to keep insertion losses low and prevent glitches from being reflected back to the transmitter so that signal quality is preserved.

Intelligent Power Management

The USB 3.0 spec introduces several new low power operating modes—including idle, sleep, and suspend—to support lower power consumption and longer battery-life in hosts and endpoint devices. To maximize power savings, signaling circuitry needs to be turned off when not in use.

USB 3.0 uses a bi-directional, differential interface so the transmit and receive channels can be powered down individually. Transmit channel power management is fairly straightforward: sleep when there is no data currently being sent. USB 3.0's hot-pluggable capabilities make receive-side power management somewhat more involved since data can arrive at any time. In addition, the front-end signal detect mechanisms in redrivers needed to support and

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MCA1-85	7	2800-8500	5.6	38	8.95
MCA1-12G	7	3800-12000	6.2	38	10.95
MCA1-24LH	10	300-2400	6.5	40	6.45
MCA1-42LH	10	1000-4200	6.0	38	7.45
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MCA1-80LH	10	2800-8000	5.9	35	9.95
MCA1-24MH	13	300-2400	6.1	40	6.95
MCA1-42MH	13	1000-4200	6.2	35	7.95
MCA1-60MH	13	1600-6000	6.4	27	8.95
MCA1-80MH	13	2800-8000	5.7	27	10.95
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IF/RF MICROWAVE COMPONENTS

maintain transparency are complex (i.e., redrivers are not USB endpoints and so cannot terminate signals but must pass them through).

First, the system determines whether a device is plugged in or not. Since USB receivers have a single-ended 50-ohm termination, if no termination is present, no endpoint is present either. In this case, the redriver can shut down and wake infrequently to poll the port to see if a device has been plugged in. Power efficiency and wake up latency is determined by how frequently the interface is polled.

When a device is plugged in, the redriver can check if the link is in electrical idle or transmitting data by measuring the level of the signal detector. When this level drops below a set threshold, there is no signal being sent and the redriver can drop into deep sleep or slumber, depending upon the application. Typically this threshold is set to 100 mV differential, although engineers may want to adjust the threshold to increase sensitivity for low signals sent over longer cables. In many applications the USB port connector may be relatively far from the actual controller; for example, in a digital TV, the circuitry may be centered in the TV while the port connector is located some distance away on the side of the screen.

Receive sensitivity also plays an important role in restoring a closed signal eye. While engineers know the drive capability of the transmitter in their device, they typically do not know the characteristics of the far-end transmitter. Lowering the electrical idle threshold is an excellent way to increase the sensitivity of the receiver. A lower threshold is also often desirable when USB signal traces may be relatively long, such as in a storage server.

The SuperSpeed 3.0 spec promises to bring significant change, both to how consumers use and access digital data as well as to how engineers design USB into the future (see the sidebar on page 28, “USB Encroaches on PCI Express”). The average consumer will expect USB to perform as it always has: reliably, easily, and inexpensively. Maintaining signal integrity and system performance across any quality cable and with marginal devices requires signal conditioning to compensate for

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board, connector, and especially cable losses. While consumer electronics devices cannot afford to bear the price of high-frequency components and quality cables that maintain signal integrity, they also cannot afford to allow signal quality—and thus application reliability and performance—to suffer.

Using redrivers to restore signal quality at both the receiver and transmitter using emphasis and equalization signal conditioning techniques enables engineers to increase signal margin. Not only does this permit more flexibility in routing while allowing signals to run over longer distances, it reduces overall system cost while increasing reliability. In this way, engineers can ensure not only that their USB 3.0-based products will pass strict compliance testing but also reliably interoperate with all other USB devices over even the lowest quality cables.

Author Information

Joseph Spisak is a product marketing manager for Pericom's PCI Express and USB3.0 products. He holds a B.S. in Electrical Engineering from Michigan State University and an MBA and MS in Finance from the University of Denver. He can be contacted at jspisak@pericom.com.

Additional Information

The USB 3.0 specification was developed by the USB Implementers Forum, Inc., (www.usb.org) and was released in November 2008.

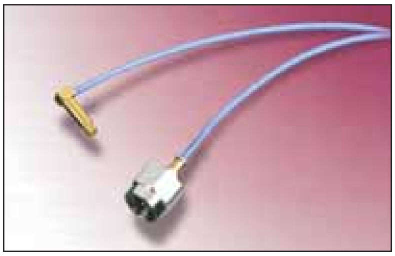
An information package for developers is available for interested designers:

"Universal Serial Bus Revision 3.0 Specification (.zip file format, size 3.80 MB) provides the technical details to understand USB 3.0 requirements and design USB 3.0 compatible products. Modifications to the USB 3.0 specification are made through Engineering Change Notices (ECNs). Enclosed in this zip file are the following documents:

· The USB 3.0 Specification released on November 12, 2008
· USB 3.0 Adopters Agreement
· New Addition of Link Command LDN Engineering Change Notice as of April 4, 2009
· USB 3.0 Standard-B and Standard-B Crosstalk Engineering Change Notice as of April 4, 2009
· Reset Propagation Engineering Change Notice as of May 8, 2009
· Reset Propagation Figure
· Q1 09 USB 3.0 Errata as of May 15, 2009"

http://www.usb.org/developers/docs/

Connectors



Flexible Miniature Cable Assemblies

Teledyne Storm Products introduces their new FlexFit™ highly flexible miniature cable assemblies. The FlexFit cable has a stranded center conductor that offers ultra flexibility (>500,000 flexures) with electrical and physical stability. Its small size (0.052" / 1.32 mm OD) satisfies weight and space constraints that can impact ease of installation.

Teledyne Storm Products
www.teledynestorm.com

Low-Loss RF Coaxial Cable Assemblies

Crystek has introduced a new line of low-loss RF coaxial cable assemblies featuring rugged stainless-steel solder-clamp construction and attenuation of 0.36 dB/ft. at 18 GHz. The LL142 Series cable offers shielding effectiveness of greater than –110 dB with an operating temperature range of –55 to +85°C (extended range of –55 to +125°C available through special order). The LL142 Series cable offers a minimum bend radius of 0.8 in. and is available in-stock with SMA Male to SMA Male connectors, as well as Type N and TNC connectors.

Crystek Corporation
www.crystek.com

SMB Connectors

The SMB connector is a follow-on design to the SMA and features a smaller interface with a snap-on coupling. For high vibration environments, the 2 pound minimum disengagement force of the standard SMB design is not sufficient. Aviel Electronics has added a push-lock feature to the standard MIL-STD-348 snap-on coupling SMB design. That increases the disengagement force to a minimum of 5 pounds. Connectors are hermetically sealed and meet the IP68 immersion test. Typical SMB electrical performance applies, 0-4 GHz low reflection frequency range and usable up to 10 GHz.

Aviel Electronics
www.avielelectronics.com

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XMA Corporation
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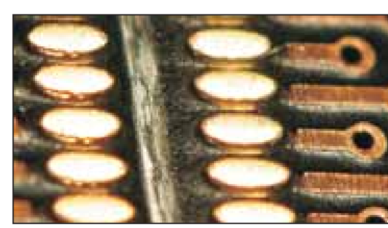
Samtec, Inc.
www.samtec.com

High Power Connectors

Sabritec announces the release of its new high power connectors and contacts. Sabritec's high power connectors utilize the Hypertac Hyperboloid® contact technology, ideal for harsh and demanding environments with low contact resistance. These connectors provide higher current ratings with smaller contacts as compared to standard bifurcated contact designs of similar size thus saving overall weight and space.

Sabritec
www.sabritec.com



Fine Pitch Bump Adapters

Aries Electronics has expanded the line of fine pitch bump adapters to include adapters that accommodate boards with pitches down to 0.40 mm. As part of the Correct-A-Chip series, the new fine pitch bump adapters allow customers to use higher pitch devices on smaller pitch boards. The adapter tops have landing pads that can be designed to accept any device on any pitch and easily settle into fine pitch footprints. Pricing for the

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Specifications

Frequency:		
BMA*		DC to 22 GHz
BMMA		DC to 28 GHz
BMZ		DC to 18 GHz
BZ**		DC to 2 GHz
VSWR:		
BMA		1.02 + .008 (f) GHz
BMMA		1.05 + .01 (f) GHz
BMZ		1.05 + .01 (f) GHz
BZ		1.02 + .05 (f) GHz
Insertion Loss:		
BMA		.03 x √(f) GHz
BMMA		.04 x √(f) GHz
BMZ		.06 x √(f) GHz
BZ		.15 x √(f) GHz
Float, Inches (mm):		
BMA	Radial: .020 (.51)	Axial: .060 (1.5)
BMMA	Radial: .020 (.51)	Axial: .060 (1.5)
BMZ	Radial: .020 (.51)	Axial: .060 (1.5)
BMZ	Radial: .020 (.51)	Axial: .150 (3.8)

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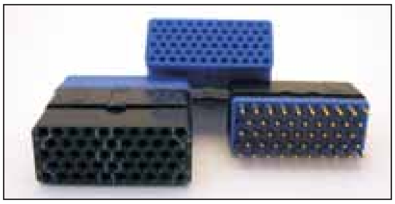


EPXB Inserts

Radiall USA, Inc., expands its EPXB and QM connector insert arrangements with the release of two new configurations. These two high density inserts, 48 (48 size 22 contacts) and a 69 (69 size 24 contacts), offer optimized space for signal contacts, a gain of 20 percent more contacts for the 48 insert and of 72 percent for the 69 insert compared to the existing 40 (40 size 22 contacts) insert. These new inserts are available in either environmentally sealed or unsealed versions. In addition, these new inserts are compatible with existing crimp and PC tail contacts.

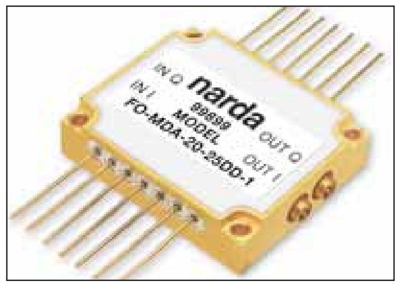
Radiall USA, Inc.
www.radiall.com

High Speed Digital

Optical Modulation Analyzer

Agilent Technologies Inc. announced it has added bit error ratio (BER) capabilities to its optical modulation analyzer. Agilent's optical modulation analyzer has the necessary receiver integrated to count the errors and calculate the BER from its detected data in real time or in large sample number capture modus. Being able to measure the BER of a physical layer signal allows transmitter and system designers and quality engineers to clearly distinguish which part of the transmission system caused the problem. Agilent's new BER test capability is priced at $2,700 and is available now.

Agilent Technologies
www.agilent.com



DQPSK Modulator Driver

Narda, an L-3 Communications company, introduced the Model FO-MDA-20-25DD-1, a dual-channel DQPSK modulator driver for 40-Gb/s and 100-Gb/s optical transponder applications that has been tested at data rates as high as 113 Gb/s. This driver is designed to interface with a Sierra Monolithics SMI 4025 DQPSK multiplexer/clock multiplier unit on the input and an Avanex Mach-Zehnder lithium-niobate MZ DQPSK modulator at its output. It integrates a separate channel for I and Q signals within its 36 × 28 × 8 mm package and uses GPPO connectors.

Narda Microwave-East
www.nardamicrowave.com/east

High-Speed I/O Module

Spectrum Signal Processing by Vecima announced the availability of a new high-speed I/O module: the XMC-2131. The XMC-2131 features a large Xilinx® Virtex®-5 FX130T FPGA combined with high speed dual 300 MSPS 14-bit DACs. The XMC-2131 module provides customers with new capabilities including access to high-speed, low latency wideband signal conversion and processing. The XMC-2131 is used in applications such as signals intelligence, electronic warfare, and military communications systems.

Spectrum Signal Processing
www.spectrumsignal.com

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Diversified Technologies, Inc.
www.divtecs.com

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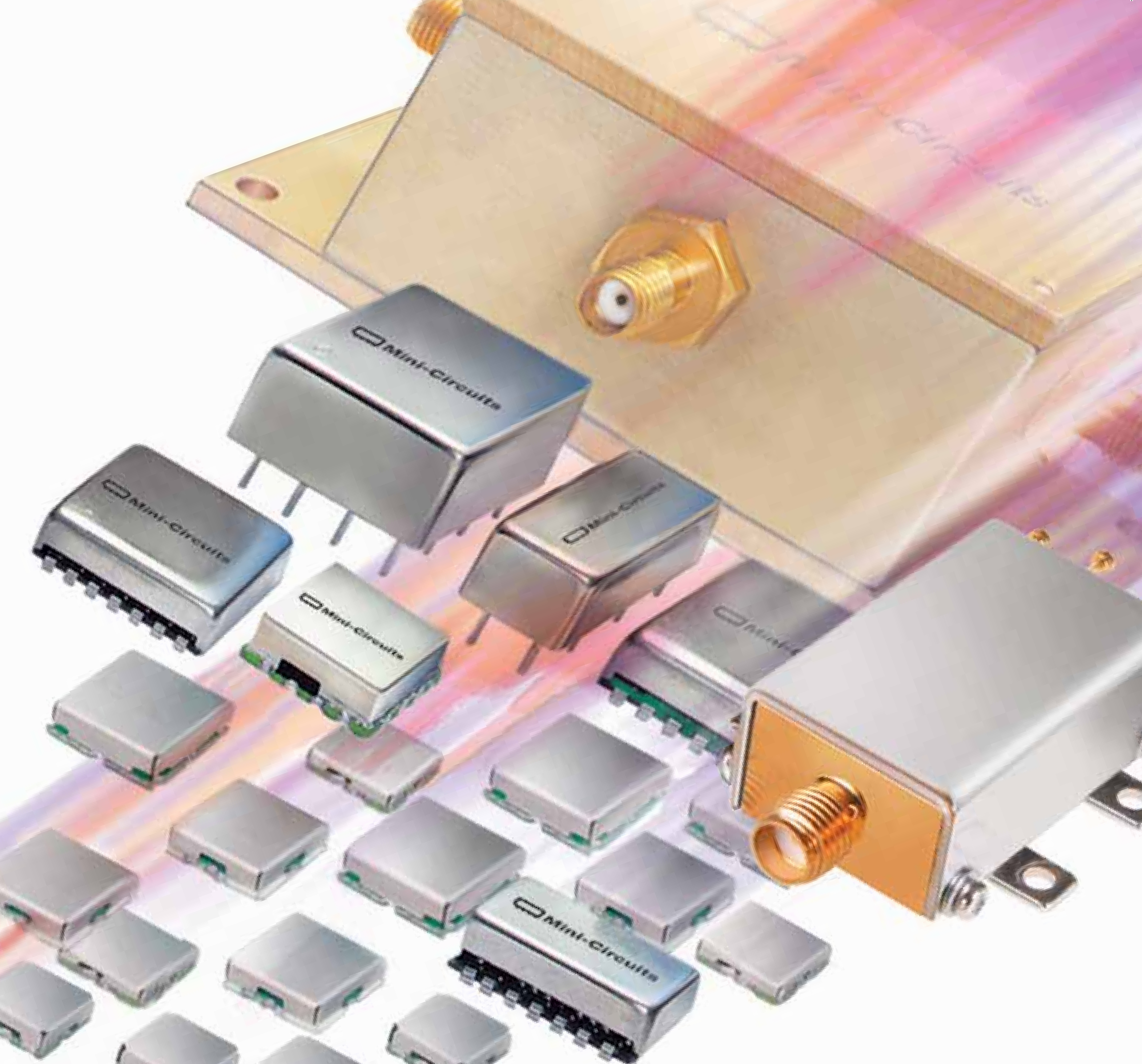

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Link Distance Enhancement and Battery Current Savings in Wireless Systems

By Oleksandr Gorbachov and Floyd Ashbaugh
RFaxis

This article describes the issues relating to power consumption, performance, cost, including the choice of semiconductor technology used in integrated wireless transceivers

Data wireless communication systems are becoming widespread on battery powered mobile and other portable platforms, and every effort is being made to reduce the power demand from these typically power hungry devices. One area of focus is the circuit that transmits and receives the RF signals because there is usually significant power drain related to this function. This article describe methods that can be employed to save on current drain, and at the same time improve system performance by increasing connection data bandwidth.

Modern digital communication technology requires a low layer link, known as the PHY (or physical) layer, to allow transmission and reception between connected devices. In most cases, an integrated transceiver cannot produce enough power to realize the full potential of the specification, typically +20 dBm. This is due to the design of the transceiver, which contains millions of CMOS gates to perform the DSP and MAC functions. These gates both take a lot of room, and dissipate a lot of power. For a fully integrated CMOS radio, fabricated on a single transceiver die, the output power seldom exceeds 0 dBm.

One approach is to include an additional die in the transceiver package to perform the radio power amplifier (PA) functions. This type of design can produce a few more dB of power output, but takes additional space on die, or results in a thicker package when the dies are stacked. The additional power dissipation can also limit performance. High power circuits can also couple to sensitive ones causing undesired interference, especially with digital modulation schemes where phase and amplitude of the modulated signals are critical.

These limitations to a fully integrated high power radio have resulted in the need for external amplifiers for systems such as 802.11 WiFi. Initially, these amplifiers were added as discrete parts—down to the transistors—requiring complex RF layouts. The industry has moved to higher levels of integration to save on space and cost, and to reduce the development time. A number of companies have developed devices that incorporate the necessary parts into one external device known as a Front End Module (FEM). These devices have now found extensive use in technology platforms such as 802.11, high powered Bluetooth, ZigBee, and other digital communication systems. These devices essentially are integrated versions of a discrete front end amplifier design, composed of a power amplifier (PA), a transmit/receive (TX/RX) switch and various optional components such as a low noise amplifier (LNA) for the receive path, baluns, filters, diplexers, power detectors, and matching components.

The FEMs in use on typical WiFi platforms, and other present day communication technologies, including ZigBee and WiMAX, have similar configurations and designs. They are typically fabricated using multiple chips, discrete components, filters, and other devices wire bonded, or connected, through traces and packaged into a single device. The integrated circuit (IC) technology used in FEMs varies by manufacturer, but generally falls into one of several types depending on the function performed. The following is a list of various RF IC

technologies and the typical functions of the devices made from them.

GaAs MESFET—This was the first of the GaAs semiconductors to be demonstrated. It is a great substrate for high frequencies as the bulk GaAs substrate has a high resistivity. This allows for the design of high quality passive components and low leakage switches with high isolation between ports. Most GaAs MESFETs require a dual polarity supply, making the designs more complex. Also, the thermal resistance of GaAs is 3 times greater than the equivalent silicon material, making heat dissipation a problem.

GaAs HEMT—This class of device also includes the PHEMT and the E-PHEMT. This technology can operate at very high frequencies, above the X-band, with Noise Figures (NF) well under 1 dB. It can be utilized in a PA with very good efficiency, and can be configured as an RF switch. This technology also generally requires a dual supply; however the PHEMT devices can operate also from a single power supply. It is even more expensive to produce HEMPT than MESFET.

GaAs HBT—The transistor is a vertical structure and the optical process results in better yields and lower cost to manufacture. These devices also operate on a single power supply. The typical integrated designs for GaAs HBT include PAs and LNAs, but the process has not yielded good RF switches, and heat dissipation can be a problem as well.

CMOS—This mainstream digital process can be used to fabricate RF devices, but they generally have less desirable performance in Noise Figures and output power. Silicon on Insulator (SOI) technologies has promising RF characteristics, allowing the creation of high performance RF circuits, including RF switches, but at high manufacturing cost.

BiCMOS—This technology allows the fabrication of high performance RF parts at a very low cost. These devices are the most rugged of any of the RF devices produced today making the die packaging simple, compact, and strong. They also have excellent thermal dissipation properties improving heat transfer. These qualities make silicon the first choice for portable and mobile RF electronic devices. Additionally, BiCMOS can also implement CMOS elements, which greatly enhances the complexity. BiCMOS can fabricate PAs, LNAs and most other RF components, and can operate from a single supply.

One of the main disadvantages is the poor electrical insulating characteristics of the silicon substrate. However, this can be overcome through the use of multiple metal layers available in the process. Traditionally, the biggest limitation for a front end design in BiCMOS is the lack of an RF switch.

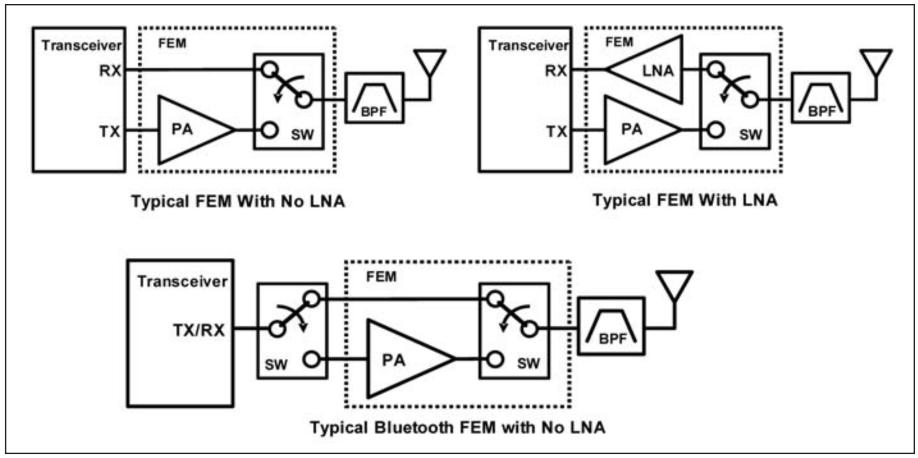

Figure 1 · Conventional FEM application circuits.

Front End Module (FEM) Design

In order to take advantage of the GaAs HBT process with high yields, designers of FEMs are forced to use additional die of different technology to provide the important TX/RX switch. The typical configuration might involve one PA die and one LNA die, both made from InGaP HBT, and a switch made with the GaAs HEMT process. Additionally, a bias and switch control circuit is required, which often means an additional die of some type. All these ICs are then mounted in a package and connected through bond wires and substrates. Matching and filtering components are often included in this package for the RF ports. This technology is proven and reliable, and is shipping in large quantities, but the use of multiple higher cost dies and complex packaging results in an expensive final component.

There is a number of packaging techniques used for FEMs and RF parts in general. These include QFN, LTCC, and MCMs among others. One of the most cost effective is the QFN package built using flip-chip techniques. A QFN with a lead frame can generally accommodate only one die, although it can contain multiple dies with wire bond interconnects.

RFaxis Inc., based in Irvine, California has developed a new design process that allows the fabrication of all the components needed for a front end module on a single die, including a proprietary method for switching the TX/RX RF antenna signal. This technique is being used to fabricate single die front end devices in BiCMOS, though the technology can be applied to any IC fabrication process. This new innovation is called an RF Front End Integrated Circuit (RFeIC) which allows the missing piece, the RF switch, to be included in the single die fully integrated front

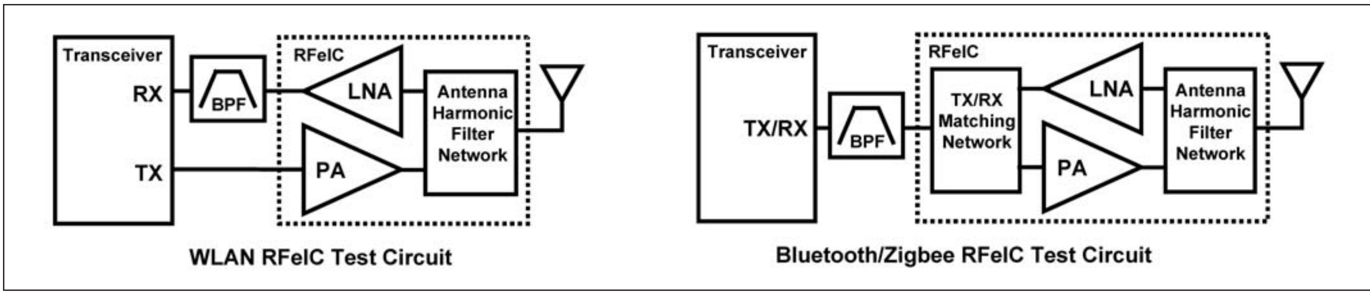

Figure 2 · RF front-end application circuits based on the RFeIC.

end device for use in modern digital communications systems.

RFaxis has designed multiple configurations of these devices to support highly integrated solutions for WLAN, Bluetooth, ZigBee, WiMAX, MIMO, WAVE, and other systems that require two way communications between RF connected platforms.

Application Circuit Descriptions

Figure 1 illustrates two circuit configurations, which are implementations of existing FEM products used in WLAN designs, and to a lesser extent Bluetooth class-1 and ZigBee systems, for extended communication link range applications. The first module is composed of an RF switch and a PA. The second implementation has also incorporated an LNA. The switch allows the module to operate in either transmit or receive mode, and is almost always fabricated in GaAs based technology. In addition, the PA and LNA are typically separate chips inside the module assembled together. Implementation of these circuits requires either multi-die modules, or expensive single-die technologies such as ED-pHEMT.

The circuits with no LNA architecture shown in Figure 1 adversely impact system Noise Figures because of the insertion loss of the switch, usually 0.5 dB or more. Additionally, the insertion loss of the band pass filter (BPF), in the range of 1.5 dB to 2.5 dB, will further degrade the system noise.

Figure 2 details the implementation of the RFaxis, Inc. circuit design using the RFeIC. The integrated harmonic filter allows for the placement of the band-pass filter between the transceiver and the LNA, minimizing the degradation of the system NF. Additionally, the low NF of the LNA provides additional improvement to the noise performance of the entire system. At the same time removing BPF loss at antenna side results in implementation of a PA with lower current drain from battery.

The typical system Noise Figure in a WLAN, Bluetooth, or ZigBee integrated transceiver is 7 dB to 9 dB, and is often even higher. Figure 3 demonstrates the improvement to system NF with the addition of LNA gain at the front end. Figure 4 graphically displays the improvement to link distance that results from this same LNA gain, and it is notable that an improvement of 200% can be easily achieved.

The communication link range enhancement is proportional to the square root of the relative sensitivity, which is impacted by the overall NF improvement. By utilizing the LNA to improve the system NF, the RFeIC application circuits detailed above can reduce transmit power and associated current consumption while increasing available network bandwidth.

Test Results and Examples

The Bluetooth design in RFeIC application circuit was tested with the following conditions:

- The transmit chain in this test contains only a final stage PA and a single-stage LNA.
- A basic rate GFSK modulated signal has been used.
- The Bluetooth chip itself was operated without forward error correction and with the on-board band-pass filter.

This resulted in a receiver sensitivity of –84.5 dBm with a BER of 0.1% as shown in Figure 5.

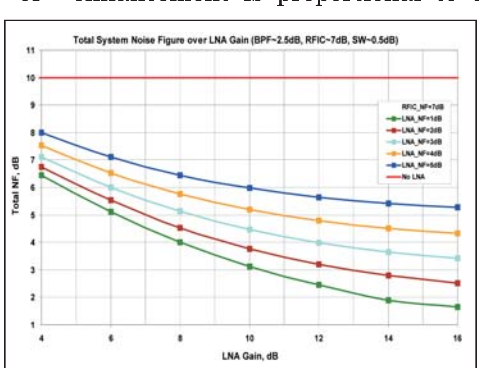

Figure 3 · LNA Noise Figure impact on system NF.

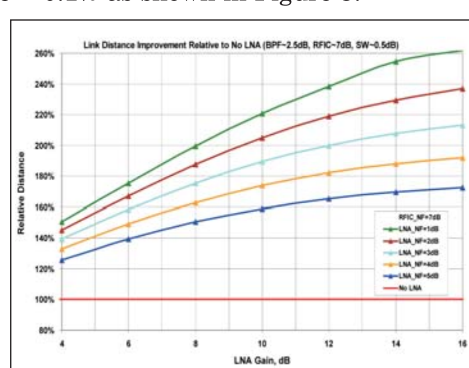

Figure 4 · Link distance enhancement due to the addition of an LNA.

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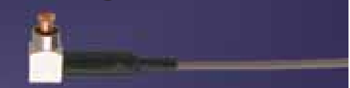

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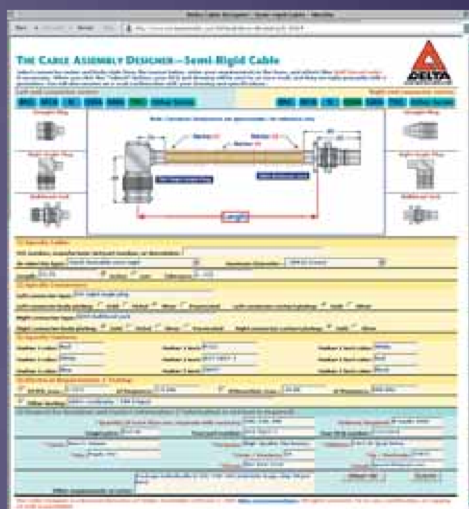

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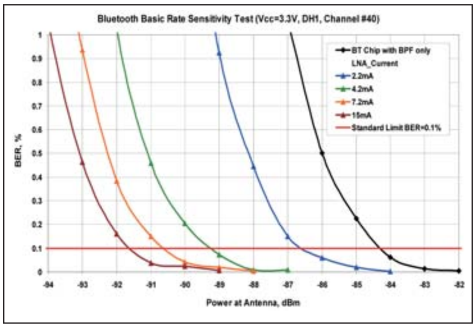

Figure 5 · Bluetooth sensitivity test results for varied LNA current.

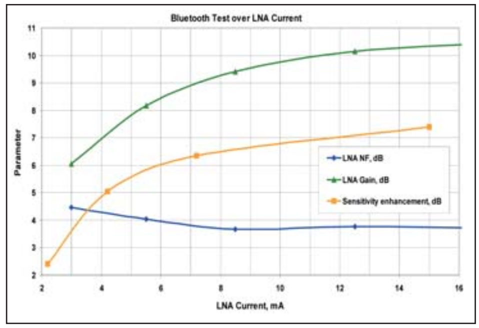

Figure 6 · RF front-end receive NF, gain, and sensitivity plotted over LNA current.

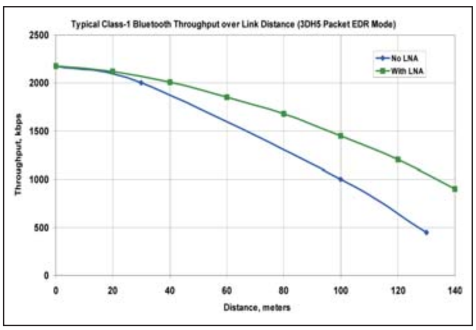

Figure 7 · Typical Bluetooth throughput over link distance.

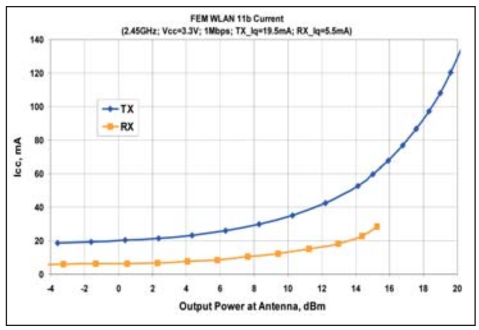

Figure 8 · Example of measured TX and RX current for the RF front-end versus power output at the antenna.

The LNA gain of this circuit was varied by controlling the current applied to the amplifier, and Figure 6 illustrates how the change in gain results in a sensitivity enhancement of between 2 dB to 7 dB. This graph presents the gain and NF of the LNA, and by plotting the data it is shown that an LNA with a gain of 8.5 dB and NF = 4 dB results in 6 dB of total system NF enhancement, which doubles the link range for the RFeIC application circuit.

To better understand the relationship of data throughput versus distance, refer to Figure 7. By using a transmit power of +16 dBm, the blue line shows the data throughput versus the distance for Bluetooth communication link based on the typical FEM circuit with no LNA. As the link distance increases, the data throughput decreases dramatically, and at 130 meters, the data rate has dropped to less than 500 kbps. The green line represents the performance of the LNA RFeIC Bluetooth circuit, and with 6 dB of LNA gain, where the system sensitivity will increase by almost 3 dB. As shown in the chart, the data throughput at 130 meters will be greater than 1000 kbps, which is more than double the throughput of the typical no-LNA circuit.

In order to increase a given link distance by 2 (or 6 dB of sensitivity improvement), the LNA amplifier may require as much as 7 mA of additional battery current. Instead of just increasing the link range, an option for some applications may be to save a substantial amount of current by implementing increased sensitivity on both ends of the link, and reducing transmit power. Consider the case for 802.11b operation as shown in Figure 8 where the transmitter PA is operating at +16 dBm with a current consumption of 70 mA. If the transmitter output power is reduced by 6 dB to +10 dBm, the current supply will be reduced to 35 mA. By implementing the LNA in the front end to make up for the 6 dB reduction in the PA, there will be a net savings of 28 mA of current.

Bluetooth typically operates in a burst mode with different packet widths and duty cycles. Figure 9 and Figure 10 show the power savings that can be realized by using the transmitter output power reduction strategy mentioned above. When the output power is reduced by 6 dB and sensitivity improvements of 6 dB are added to the receiver to make up for the smaller signal, the power saving are shown side by side for each packet type in Figure 9, and the percent power savings are summed up in Figure 10.

Wireless LAN and Current Consumption

The WLAN market is growing fast with new applications becoming available every day. The rise of Internet services and low-cost Voice over Internet Protocol (VoIP) phone calls has become a key driver for WLAN chips in mobile phones. WLAN systems have a time domain duplex architecture conveying information through data packet transmissions. Mobile phones with WLAN chipsets are typically the client devices, which are connected to an access point (AP) that manages the data traffic.

The 802.11 standard operates by using burst transmission techniques, which are more complicated than in a Bluetooth link and the communications occur without fixed time intervals. The burst length can lie between several tens of microseconds to several milliseconds, and depends on the data rate of the link, the data packet size being transmitted, the number of clients in a network and their activity, the distance to the AP, the priority of each link, and so forth. A figure of

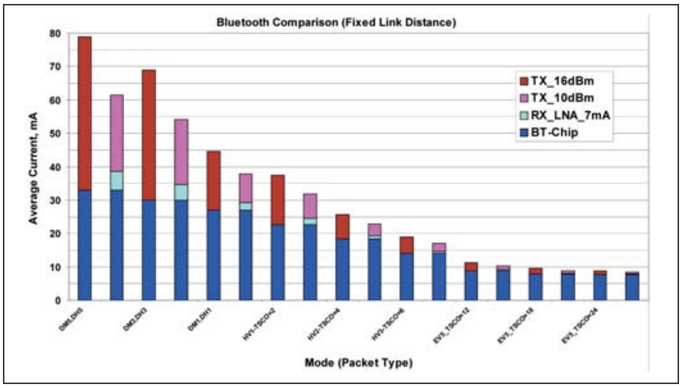

Figure 9 · Total Bluetooth system current with and without an LNA, for various tranmission modes.

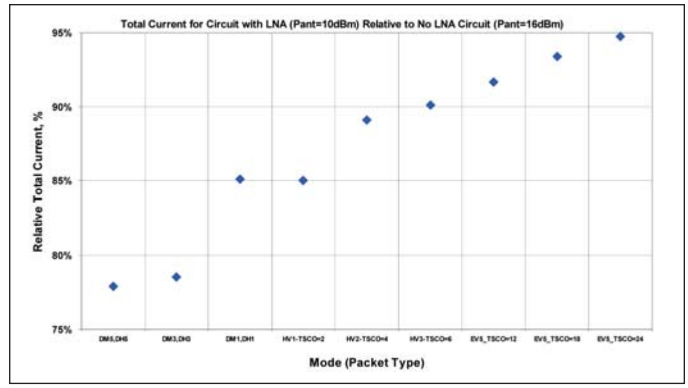

Figure 10 · Total battery current savings for a Bluetooth system with an LNA.

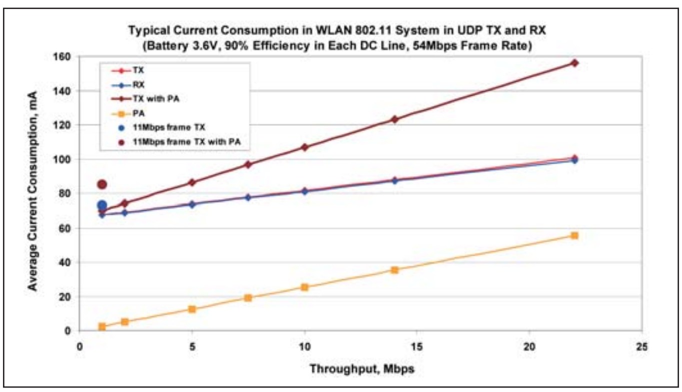

Figure 11 · Typical current consumption for a WLAN system versus throughput.

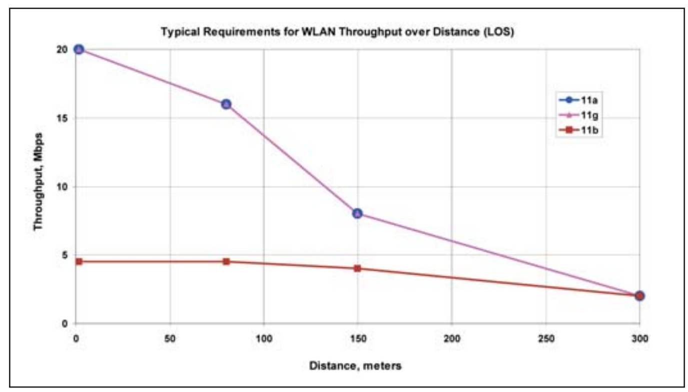

Figure 12 · Typical throughput capability for WLAN systems versus link distance.

merit of a communication link is throughput, which is the amount of useful data transferred between two network nodes.

There are two primary power management modes supported by the 802.11 standard also known as the "active" mode and "power save" mode. The purpose of the power save mode is to allow a client to turn off its radio for some period of time while the AP buffers packets for later transmission, thus saving power.

The high data rate of traffic used in WLAN systems along with the +16 dBm to +20 dBm power required at the antenna results in a large current drain from a battery for both transmit and receive mode on a mobile platform, and a number of power saving strategies have been developed to address this problem. Figure 11 details the current drain of a typical WLAN 802.11b/g chipset fabricated on conventional semiconductor technology. The graphs are average battery current consumption with operation at 2.4 GHz using the UDP protocol for transmitting and receiving data. The transceiver and RF radio circuits are powered up only during the time required to transmit/receive and process the data. As different parts of WLAN chipset require different voltages, for convenience a 3.6 V common battery was used with 90% efficiency for the power conversion.

As higher throughput is needed for a WLAN link, larger average current consumption is required by the transceiver and front end circuits. The red and blue lines are the current drain for receive and transmit operation with the maximum of 54 Mbps data rate without the PA current included, and these two modes are usually close due to similar circuitry used for those functions. The brown line presents the average current versus the UDP throughput in transmit mode with the PA current included. A 2 Mbps throughput typically used for low bandwidth applications such as MPEG3 download or JPG image upload results in 75 mA of battery current consumption and there is a little impact from the PA on the overall current. In more demanding applications requiring higher bandwidth such as video streaming, or faster processing of low bandwidth applications, the PA current contribution to the total current drain from the battery can rise significantly up to 50% of the transceiver current, which can as much as 150 mA for the throughput levels above 20 Mbps.

The data rate and packet duty

cycle can have a big impact on the current drain of the system. The data presented in Figure 11 shows that a throughput of 2 Mbps requires a current drain of 75 mA, and the current drain for 20 Mbps is 150 mA. This result shows a factor of two increase in current drain, but the throughput has increased by a factor of 10. Significant power saving is achieved by passing data at the highest rate possible, and thereby utilizing the packet duty cycle to go into the power save mode as much as possible.

The data in Figure 11 is based on full power applied through the PA. Many factors can influence the RF power requirements of a WLAN system, and additional current drain savings can be realized by using power control on the PA, and when the system Noise Figure is low, as is the case with the RFeIC designs.

Even WLAN VoIP applications that require a relatively low bandwidth in the sub-100 kbps range can reduce current drain if connected at a very high data rate and the burst transmissions are interleaved with the power save mode.

Figure 12 presents typical throughput capability for a WLAN system versus link distance. Many factors can influence throughput including interference, environment, and communication system quality. The RFeIC designed by RFaxis can improve system quality by assuring an excellent system Noise Figure and utilizing a high quality PA, which will further extend the range and bandwidth, especially when an RFeIC is present on both ends of the communication link.

Conclusion

As operation of wireless data communication systems become more common on battery operated mobile platforms, it is crucial that these systems minimize their impact on battery current drain. The information presented in this article details how WLAN and Bluetooth systems will realize the lowest current drain from the system battery when data throughput is operated at the highest clean data rate possible while maximizing the duty cycle of the low power standby mode of operation. By improving system Noise Figure through the use of an LNA, and transmitting with a clean efficient PA, range and throughput can also be increased, and additional power savings can be realized by reducing the PA output power.

The integrated single die front end device (RFeIC) developed by RFaxis in BiCMOS represents a state of the art solution to help realize these advantages. System noise figures can be reduced by a factor of two or three, and the use of the high efficiency PA will also save current drain, thereby extending the range and increasing useable throughput. In addition, this increased efficiency is offered in a small, cost-effective package.

Author Information

Alex Gorbachov is RFaxis CTO and Chief Scientist. He has worked 28+ years in the electronics and semiconductors industry (different engineering and management positions). He has a Ph.D. in Electrical Engineering from Kiev Polytechnic Institute. His current work includes low-cost, small-sized and high-performance RF integrated circuits and modules for wireless communications.

Floyd Ashbaugh is Sr. Director of System Engineering. He has worked 30+ years on Hardware and System Engineering in product and semiconductor industries. He has a Bachelor of Science in Engineering Technology from DeVry University, Phoenix Arizona. His interests include combining RF and digital circuits on single die semiconductors.

For further information, see the company Web site: www.rfaxis.com, or send an e-mail to their general address: marketing@rfaxis.com

Portable Instruments Improve Performance and Handle More Applications

Portable test instruments have recently grown in popularity, especially as instrument manufacturers have combined functionality and high performance in those units. System installers and maintenance staff no longer need to find the space, power, and gentle transportation needed for laboratory instruments that once were the only way to obtain accurate measurement data.

The trend toward greater capability in portable, especially handheld, instruments is continuing. Below are listed some examples of offerings from various companies, along with notes on performance and capabilities.

Agilent Technologies launched the FieldFox line of RF test instruments in early 2009. This handheld RF analyzer includes these functions: spectrum analyzer, power meter with USB power sensor, and a vector network analyzer option. The unit can make the necessary insertion gain/loss, VSWR and distance-to-fault measurement common in wireless system installation and maintenance. A key feature of the FieldFox is QuickCal, a built-in calibration system that does not require a calibration kit. QuickCal also corrects drift due to temperature changes during field usage.

Rosenberger Hochfrequenztechnik recently introduced a newly-designed portable Passive Intermodulation Analyzer instrument. Although not a handheld unit, the PIA provides on-site measurement of this key parameter in high performance base stations. The analyzers are available for common wireless frequency bands: LTE 700, AMPS 800, EGSM 900, DCS 1800, PCS 1900, TD-SCDMA 2000, UMTS 2100, UMTS II / LTE / BRS-EBS and WiMAX.

Anritsu Company is a pioneer in high performance handheld instruments, and has an extensive lineup with capabilities ranging from basic RF testing to advanced high performance analysis. Among the latest developments from this company is a new platform and package for its family of handheld Site Master™, Spectrum Master™ and Cell Master™ analyzers. The S331E/S332E/S361E/S362E are full-featured handheld analyzers for installing, provisioning, maintaining, and troubleshooting wireless base station cable and antenna systems. The MS2712E/MS2713E handheld spectrum analyzers have dynamic range of >95 dB in 10 Hz RBW, DANL of –152 dBm in 10 Hz RBW, and phase noise of –100 dBc/Hz max at 10 kHz offset at 1 GHz. The MT8212E is a handheld multi-function base station analyzer that combines all the tools required to deploy, maintain and troubleshoot wireless base stations into a lightweight, battery-operated package.

For optical system testing, *EXFO Electro-Optical Engineering Inc.* offers the AXS-200/855 DSn/PDH/Ethernet Test Set. This unit is a handheld multi-service test solution that increases technician efficiency by seamlessly transitioning from E1/DS1, DS3 or PRI circuit testing to comprehensive Ethernet/IP performance testing without swapping modules or test units. Housed in the AXS-200 SharpTESTER platform, the AXS-200/855 is a lightweight, rugged, handheld unit optimized for rapid, simple testing. The AXS-200/855 offers field technicians a single unit to perform comprehensive dual DSn/PDH and ISDN PRI testing, including real-time insertion of voice traffic and one-time setup of tests to be run across all ISDN channels simultaneously, as well as turnkey Ethernet testing, including RFC 2544, multistream traffic generation and monitoring, BERT and IP connectivity tools.

These are just a few examples of high performance portable instruments. Watch for new introductions in the New Product announcements published in future issues of *High Frequency Electronics*.

USB POWER SENSOR

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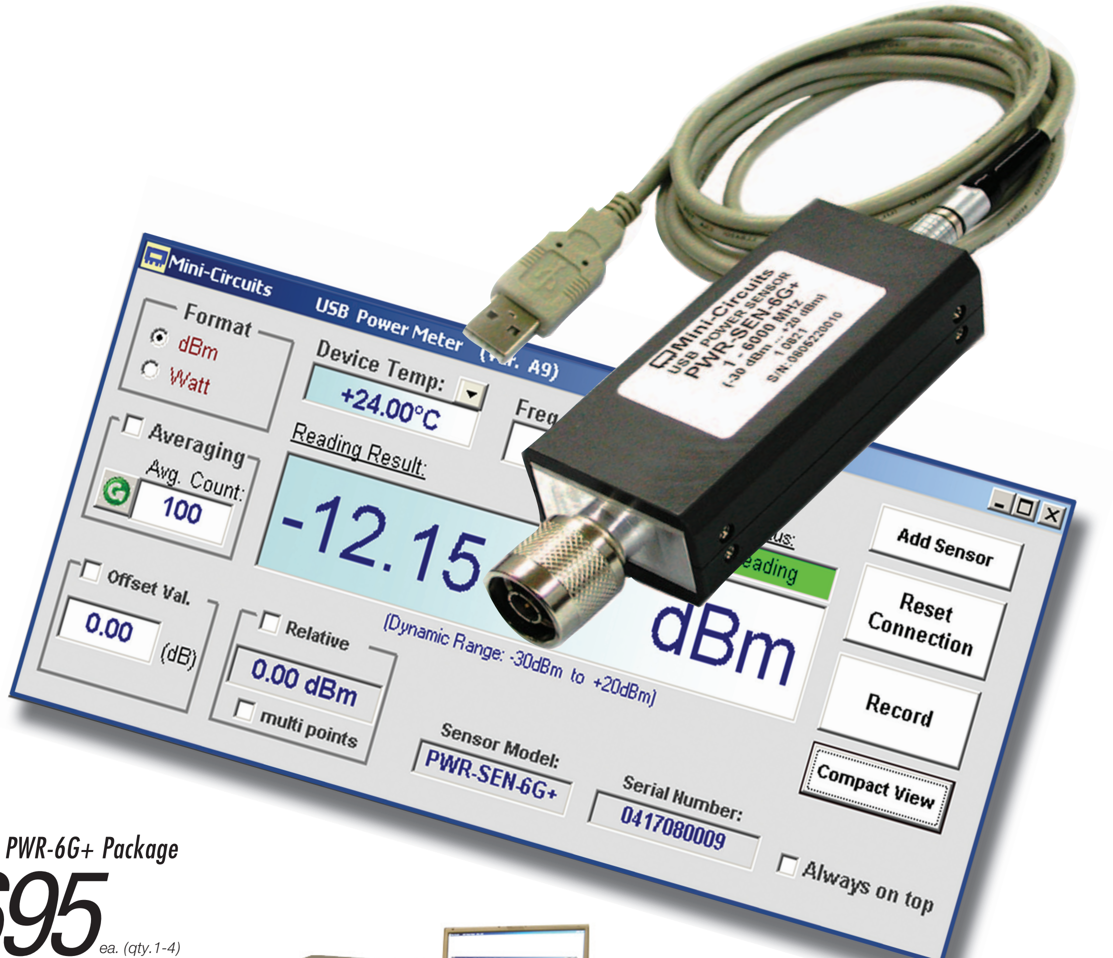

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Now, Mini-Circuits offers a USB Power Sensor and software together with your laptop that will ***reduce your equipment costs*** and provide new application features that will simplify your power measurements. Having a measurement range of -30 to +20 dBm at frequencies from 1 to 6000 MHz. The PWR-6G+ is supplied with easy-to-use, Windows-compatible measurement software to speed and simplify your power measurements, allowing you to set as many as 999 averages and to record results for further analysis. The PWR-6G+ USB Power Sensor provides 0.01-dB measurement resolution and impressive accuracy over temperature.
Visit the Mini-Circuits' web site at www.minicircuits.com to learn more.

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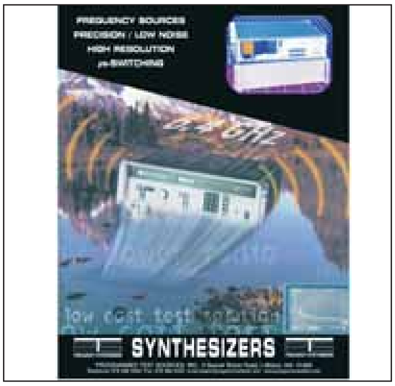


Agile Precision Frequency Sources

The new catalog by Programmed Test Sources, Inc., describes the complete line of PTS frequency synthesizers. These synthesizers produce fast-switching, low phase-noise precision frequencies. With easy remote programming they are vital in advanced measurement or production systems and also serve as stand-alone test equipment. Numerous options and accessories can be combined in a virtually limitless manner to provide a product that, although not custom-built, will closely match your specifications. Models are available ranging from 0.1 to 6400 MHz.

Programmed Test Sources, Inc.
www.programmedtest.com

Antenna Mounting Adapters

AR RF/Microwave Instrumentation has introduced three new antenna mounting adapters that are designed to allow horizontal and vertical polarization changes during testing without removing the antenna from the tripod. The three new adapters are designed to be compatible with existing AR antenna models. Adaptor Model AM1000 is designed for use with AT1000 and AT1000A Antenna Models. Adapter Model AM1001 is compatible with Antenna Models AT1080 and AT1080A. Adapter Model AM6000 is for use with Antenna Models AT5080 and AT6080. Each adapter includes a 20-inch non-metallic mast. Because the center of gravity is offset when moving the antenna between horizontal and vertical polarizations, it is recommended that users purchase a new tripod along with the antenna mount. The Model TP1000B tripod features a more robust design and a new angle-adjustment mechanism. The tripod also includes 24” and 51” interchangeable masts that allow a test height of up to 2.5 meters.

AR RF/Microwave Instrumentation
www.ar-worldwide.com

Extended Range Module

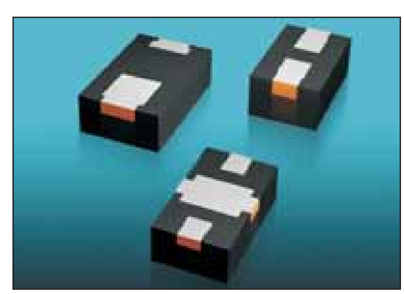
CEL is now shipping its new MeshConnect™ Extended Range Module for 802.15.4/ZigBee applications. Building on its extensive MeshConnect family of modules and ICs, the new module enables long range applications as well as those that must maintain robust mesh connections even in harsh, noisy, indoor RF environments. With its ability to maintain strong connections, even in environments already congested with wireless interference such as Wi-Fi and Bluetooth, the extended range module enables such new applications as intelligent lighting control for LED lighting, in-hospital patient monitoring, baby monitors with two-way voice, and RF4CE, a new technology for RF-based TV and set top box remote control. The new module also delivers special features such as extended data rates and a built-in voice CODEC processor. The Extended Range Module is shipping now. Part number is ZICM2410P2. Pricing is <$17 in thousand-piece quantities.

California Eastern Laboratories
www.cel.com

Voltage-Controlled Oscillator

Z-Communications, Inc. announces a new RoHS compliant VCO model ZRO2407A1LF in S-band. It operates at 2400-2415 MHz with a tuning voltage range of 0.5-4.5 Vdc. This VCO features a typical phase noise of –115 dBc/Hz at 10 kHz offset and a typical tuning sensitivity of 14 MHz/V. The ZRO2407A1LF is designed to deliver a typical output power of 3 dBm at 5 Vdc supply while drawing 21 mA (typical) over the temperature range of –40º to 85º C. This VCO features typical second harmonic suppression of –18 dBc and comes in Z-Comm’s standard MINI-16-SM package. It is available in tape and reel packaging for production requirements. The ZRO2407A1LF is also ideal for automated surface mount assembly and reflow.

Z-Communications, Inc.
www.zcomm.com

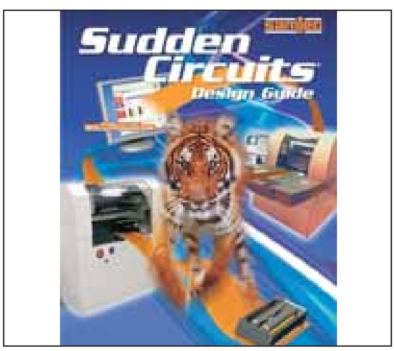


Plastic Surface Mount Switch and Attenuator Diodes

Aeroflex / Metelics has announced the release of a suite of surface mount PIN diode switch elements and attenuator diodes for high vol-

ume pick-and-place applications. These control devices are delivered in plastic SMT packages with standard 31 mils high bodies. Their performance and mechanicals allow them to be easily dropped into existing designs. These medium and high power PIN diode SPST switch elements are available in series (SE), shunt (SH), and series shunt (SS) configurations and offer maximum frequency options ranging from 1 to 10 GHz. 10 models are available, which offer max rated power from 5 to 50 watts, insertion losses at 1 GHz ranging from 0.15 through 0.40 dB and isolation at 1 GHz of 10 through 63 dB.

Aeroflex / Metelics
www.aeroflex.com/metelics



Design Guide

Samtec has introduced its new Sudden Circuits® Design Guide, which outlines the company's expanded flex circuit data link product offering and capabilities. Samtec Sudden Circuits® are quick-turn, highly configurable high speed flex circuit data links that provide literally millions of design permutations with standard product lead-times and pricing. Design permutations include the choice of connector, number of position, gender, pitch, orientation; length (up to 16.3" (414.02mm)), signal mapping, and customer specified signal/ground assignments. Popular Samtec connector and terminations including Q Series®, Q2™, Edge Rate™, and micro and standard pitch strips up to .100" (2,54mm) pitch are available.

Samtec, Inc.
www.samtec.com

USB controlled RF Switch

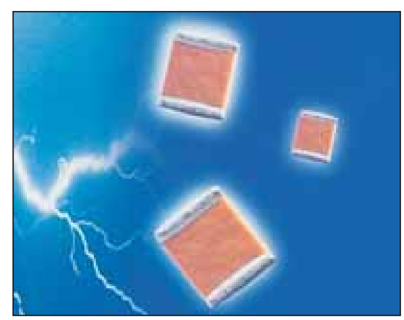
Telemakus, LLC introduces the TES6000-30, laboratory-quality, RF SPDT switch with 30 dB isolation and <2 dB insertion loss. The switch is fully terminated at all ports with a return loss better than 20 dB at 4 GHz. The TES6000-30 is the smallest USB microwave switch available on the market. The RF connectors are SMA, with the common port male and ports 1 and 2 female allowing for easy interconnection. The DC/control connector is USB type A allowing direct connection to a PC or via a USB extender cable. The device also has 0.5 GB of flash memory containing all the installation files, data sheet and test results. The Windows-based user interface allows simple control of the switch configuration including both ports isolated. Applications include RF routing for various test configurations, switching between two RF sources or loads, pulse modulation for amplifier testing, redundancy switching and filter banks.

Telemakus, LLC
RFMW, LTD.
www.rfmw.com/Telemakus

SPDT Switches

Peregrine Semiconductor Corp. announced the first pair in a series of new SPDT RF switches addressing the needs of wireless infrastructure, 2.4 GHz ISM and broadband applications for fiber optics and MMDS. The PE4250 and PE4251 are the result of a joint design and development activity with long-standing partner OKI Electric Ltd. (Tokyo). The new PE4250 reflective and PE4251 absorptive 50-ohm SPDT RF switches are HaRP™-enhanced devices and are offered in the tiny RoHS-compliant 8-lead MSOP package. They operate near DC through 3 GHz and deliver market-leading RF performance with P_{1dB} of +30.5 dBm and IP3 (typ) of +59 dBm; and fast switching speed of 150 ns. In addition, the devices have extremely low insertion loss of 0.55 to 0.75 dB typical from 10 MHz to 3 GHz; high isolation across the operating range (51-40 dB for PE4250 and 62-43 dB for PE4251); and excellent ESD protection of 4000 V HBM. The new devices are in volume production and are priced at $0.66/25k units (PE4250) and $0.68/25k units (PE4251).

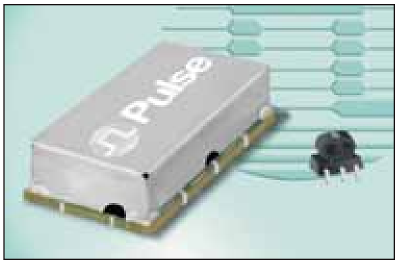
Peregrine Semiconductor
www.psemi.com



High-Voltage Capacitor Ratings

AVX Corporation has further expanded its high-voltage surface mount capacitor offering to include smaller case sizes, higher voltage ranges and higher capacitance values. AVX's high-voltage ceramic capacitors are now available in case sizes ranging from 0805 to 3640 with voltage ratings from 600 V to 5000 V and capacitance values of 10 pF to .56 µF. These new values are available in all terminations including tin, tin/lead, and AVX's flexible termination called Flexiterm™. The Flexiterm technology was developed to prevent flexture cracks and minimize thermal issues with ceramic devices and is available for voltage ratings up to 3,000V.

AVX Corporation
www.avx.com



RF Transformers and Diplex Filters

Pulse, a Technitrol Company, announces a new family of cable television (CATV) RF transformers and RF diplex filters that meet Data Over Cable Service Interface Specification (DOCSIS) 3.0 design requirements for applications such as set-top boxes, cable modems, and gateways. These components support frequency bands 5-65/85-1002 MHz, 5-42/54-1002 MHz, and 5-85/108-1002 MHz, and are tuned and tested by Pulse to exacting specifications. Pulse's initial offerings for this new family are two RF balun transformers, a transmission line transformer, part CX2240NL, and a flux coupled transformer, part CX2244NL. Also included is a new, small-package, surface mount RF diplex filter, part C6164NL. All parts have been designed for new CATV technology products to exacting electrical specifications and come in industry-standard mechanical packages.

Pricing for the family of RF transformers ranges from $0.10 to $0.30 and parts are available in tubes or tape-and-reel. The RF diplex filter costs $1.50 and is available in trays.

Pulse, a Technitrol Company
www.pulseeng.com

6 to 18 GHz High Efficiency Dual Output Amplifier

AML Communications introduces Model AML618P5012, a high efficiency dual (combined) input, dual output power amplifier operating over 6-18 GHz bandwidth. This PA delivers +31 dBm power at each output and is designed to operate up to +95°C base plate temperature. AML618P5012 is available with input power protection option up to 2 W CW. This design is available in a high-density package with 3.5" × 1" × 0.3". RF connectors are SMP. The DC supply is +10V at 2.2 amps.

AML Communications
www.amlj.com

Ceramic Chip Antennas

Vishay Intertechnology, Inc. announced multilayer ceramic chip antennas for mobile devices to cover the entire UHF band from 470 MHz to 860 MHz. The new Vitramon chip antennas comply with the MBRAI standard while maintaining small outlines of 35 × 5 × 1.2 mm for the VJ 3505, and 10.5 × 15.5 × 1.2 mm for the VJ 6040. The devices are designed for mobile UHF TV receivers, including DVB-T, DVB-H, ISDB-T, and MediaFLO™ devices, where they eliminate the need for large external antennas in portable consumer electronics. The VJ 3505 and VJ 6040 feature a 50 ohm unbalanced interface and operating temperature range of –40 °C to + 85 °C. Samples and production quantities are available now, with a lead time of eight weeks for larger orders. Pricing for U.S. delivery starts at $1.70 each for the VJ 6040 and $2.50 each for the VJ 3505.

Vishay Intertechnology, Inc.
www.vishay.com

High Stability OCXO and OCVCXO

Connor-Winfield's new high stability OH200 series are exceptionally precise OCXO frequency standards, excellent for use in cellular base stations, test equipment, Synchronous Ethernet, VSAT and Stratum 3E applications. These unique OCXOs and OCVCXOs provide temperature stabilities in the range from 6 ppb to 20 ppb absolute, over both commercial and industrial temperature ranges. Power requirements are 3 W over the commercial temperature range and 4.5 W over the industrial temperature range. Additionally, excellent aging (0.3 ppb/day) is achieved through the use of High Q overtone SC cut crystals. The OH200 series is available in LVCMOS and HCMOS outputs along with electronic frequency tuning. Frequencies are available from 5.0 to 40.0 MHz. The OH200 is housed in the standard hermetically sealed, resistance welded, CO-8 package. Volume pricing: 1,000 pieces at $58 each.

The Connor-Winfield Corporation
www.conwin.com

Reference Platform for 3G and 4G Femtocells

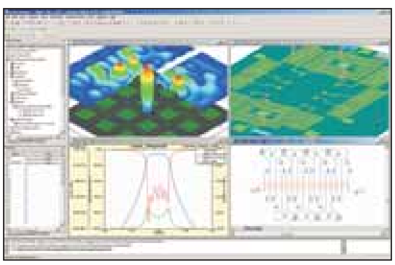
Lime Microsystems and picoChip are collaborating to develop a reference platform for 3G and 4G femtocells. The highly frequency-agile platform will operate in all frequency bands of interest, including existing and emerging bands. It will be based on Lime's multi-band multi-standard RF transceiver IC, the LMS6002, alongside picoChip's picoXcell™ baseband solutions for femtocells. This jointly developed platform will enable femtocell designs based on 3G or 4G standards (WCDMA/HSPA, CDMA2000, LTE, and WiMAX). Its configurable nature will accelerate adoption of emerging standards and enable femtocell deployment using less common cellular frequencies—for instance at 700 MHz or 1.5 GHz.

Lime Microsystems
www.limemicro.com

Ultra-High Temp Oscillator

Vectron International announced its new solution for the timing of ultra high-temperature electronics, the PX-420 crystal oscillator. Able to withstand continuous operating temperatures of up to 250 °C, the product is ideal for harsh environment applications, including oil and gas downhole operations. With the PX-420, Vectron successfully combines its advanced quartz resonator design for outstanding frequency stability with silicon on insulator (SOI) technology to meet the high-reliability requirements demanded by these harsh environment applications. Design engineers now have a solution for applications requiring continuous, high-reliability operation at temperatures ranging from –55 to 250 °C.

Vectron International
www.vectron.com



Updated Software

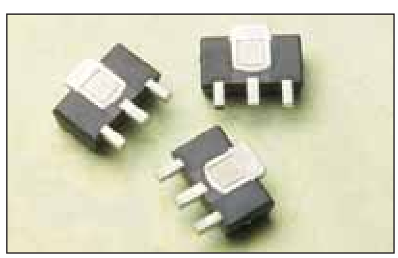
ANSYS, Inc. announced its Ansoft Designer® 5.0 and Nexxim® 5.0 products. This engineering simulation platform and integrated technology supports Simulation Driven Product Development™ of electronic products. New features have been added to these latest versions that compress the electronic design and analysis cycle. For example, links with ANSYS® DesignXplorer™ software enable design of experiments, sensitivity studies and six-sigma design. Additionally, a distributed-solve high-performance computing capability has been added that allows engineers to analyze process variations within a full signal integrity analysis across a network of computers. The new software packages, named DesignerSI™ and DesignerRF™, integrate technology from Ansoft Designer and Nexxim into application-specific engineering platforms that are easy to use and straightforward to acquire.

ANSYS, Inc.
www.ansys.com

IF Gain Block Amplifiers

Analog Devices, Inc. announced two new intermediate frequency (IF) gain block amplifiers. The ADL5535 and ADL5536 gain block amplifiers cover the 20 to 1000 MHz frequency range and are suitable for a variety of applications that require high performance specifications such as in cellular, satellite, CATV, military and instrumentation equipment. The ADL5535 gain block amplifier provides an extremely flat gain of 15 dB over frequency, noise figure of 3.3 dB, a P_{1dB} of 19.1 dBm and an OIP3 of 47.6 dBm at 190 MHz. The ADL5536 gain block amplifier provides a flat gain of 20 dB over frequency, noise figure of 2.8 dB, P_{1dB} of 19.8 dBm and an OIP3 of 46.5 dBm at 380 MHz. Both amplifiers are internally matched to 50 ohms at the input and output, making these amplifiers easy to implement in a wide variety of applications. Only input/output AC coupling capacitors, power supply decoupling capacitors, and an external inductor are required for operation. The ADL5535 and ADL5536 are available now in a 3-lead SOT-89 package and are priced at $1.75 in 1,000 unit quantities.

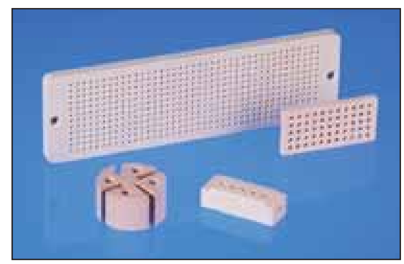
Analog Devices, Inc.
www.analog.com



High Linearity Gain Blocks

Avago Technologies announced the addition of three new innovative flat gain, high linearity low noise, gain blocks that can be used as a broadband gain block or radio frequency (RF) driver amplifier MMIC. Housed in an industry standard SOT-89 package measuring 4.5 × 4.1 × 1.5 mm, Avago's MGA-30x89 series now covers frequency bands from 40 to 6000 MHz and only requires a simple DC biasing match. Moreover, no additional RF matching components are required to achieve wide bandwidth performance. The ease-of-use and extended broadband performance of Avago's MGA-30x89 series makes these gain blocks an ideal choice for designers of cellular devices, WiMAX wireless base stations, satellite and cable TV set-top boxes, and a variety of other wireless applications. Avago's MGA-30789 and MGA-30889/30989 flat gain, high linearity gain blocks are available now with pricing starting from $1.69 and $1.25, respectively, in 10,000 unit volumes.

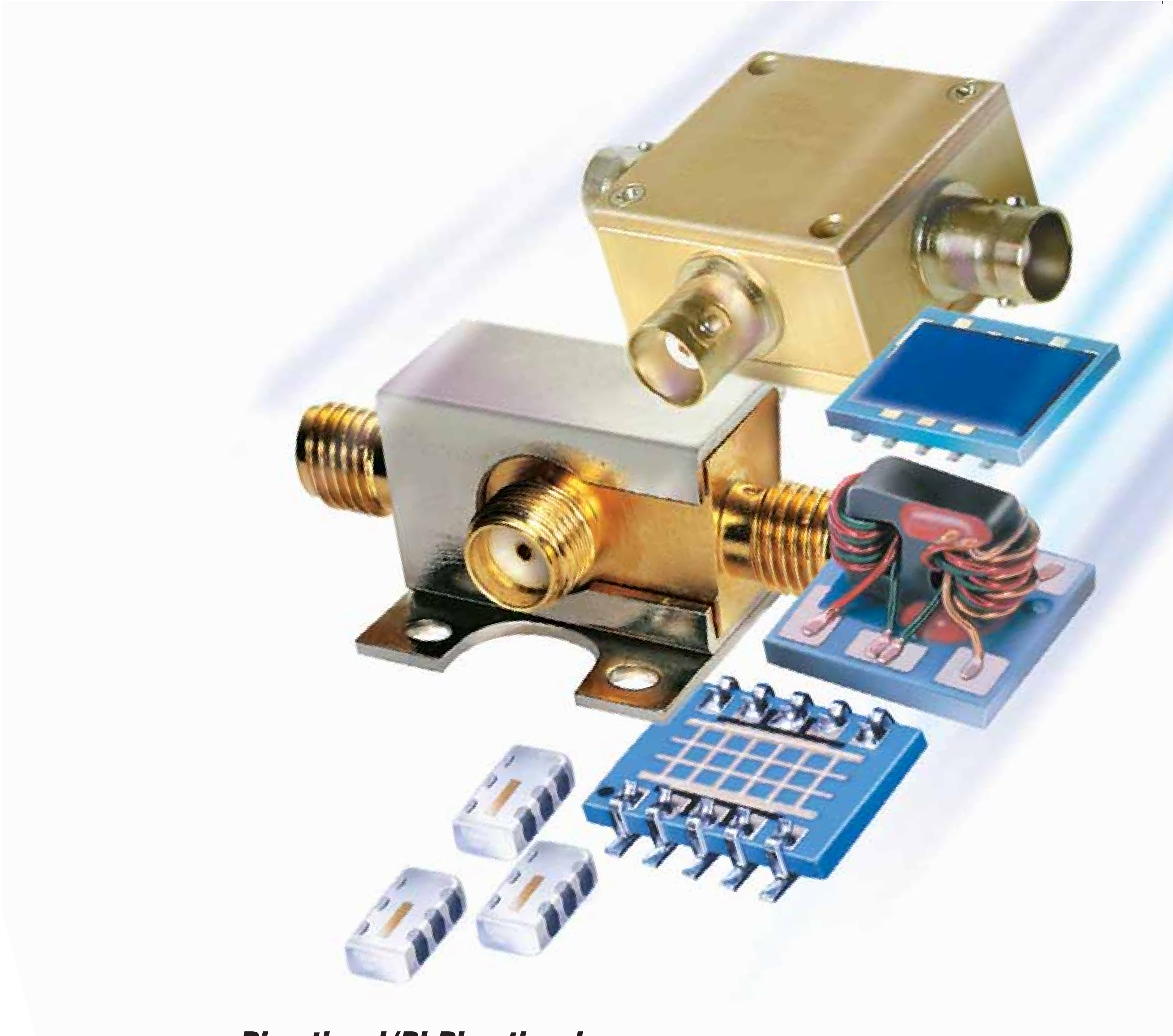
Avago Technologies
www.avagotechwireless.com

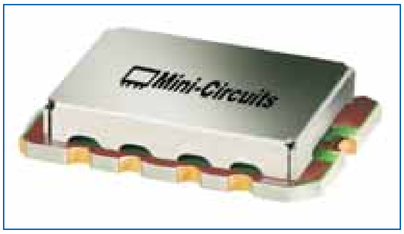


Fixtures for High Temperature Brazing

Morgan Technical Ceramics' Wesgo/Duramic business offers custom made alumina fixtures used to isolate and insulate metal components during high temperature brazing processes. MTC–Wesgo/Duramic fixtures have proven to be excellent options when brazing medical and laser industry components, high electrical field devices and magnetic resonance imaging (MRI) equipment. Design and configuration of MTC–Wesgo/Duramic Alumina fixtures are highly flexible. Both simple and intricate features, including small diameter holes, can be machined to tight tolerances to meet customer requirements. Cleanliness is ensured through a specially designed air firing process. Also, during the brazing process, thermal expansion of the fixture is matched to that of the Alumina insulator used for ceramic-to-metal seals.

Morgan Technical Ceramics
www.morgantechnicalceramics.com

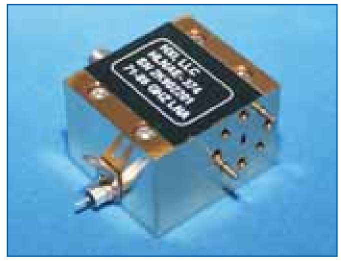




Low Noise Amplifier

Mini-Circuits offers the TAMP-1521GLN+ low noise amplifier, covering 1380 to 1520 MHz with these typical specifications: ultra-low noise figure of 0.75 dB, high IP3 of 27 dBm, high gain of 35 dB, and power output of +14 dBm. The device uses advanced E-PHEMT technology in a two-stage, unconditionally stable design. The amplifier is RoHS compliant, provided in a shielded module that is smaller than equivalent discrete designs. Pricing in 5-49 quantity is $14.95.

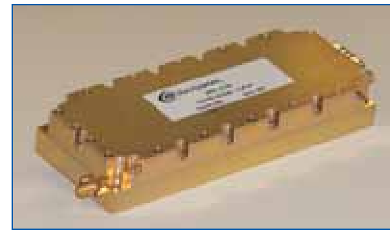
www.minicircuits.com



Low Noise Amplifiers

Renaissance Electronics Corporation/HXI announces the HLNA Series of Low Noise Amplifiers, covering the frequency ranges from 18 to 110 GHz. A wide variety of gain and bandwidth combinations are available to provide the designer with a solution for most applications. Custom designs are available and in most cases NRE is not required. MMIC technology is employed for high reliability and repeatability.

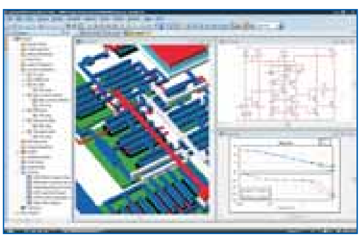
sales@hxi.com
www.hxi.com



GaN Power Amplifier

Aethercomm announces the release of a highly efficient Gallium Nitride (GaN) power amplifier, model number SSPA 0.8-2.5-40. This high efficient GaN power amplifier was designed for CW or Pulsed applications and can be used in commercial, military and satellite communication platforms. This unit was built to sustain the most stringent operating environments. P_{3dB} is 40 watts RF power (typ.) with Power Added Efficiency of 30% to 40%.

sales@aethercomm.com
www.aethercomm.com



Analog Office 2009

AWR has released Version 2009 of its Analog Office high-frequency analog and RFIC design software. This latest release includes AWR's patent-pending multi-rate harmonic balance (MRHB™) technology, which dramatically increases the speed and reduces the computer memory required for analysis of complex multi-tone designs. It also offers AXIEM™ 3D planar EM technology.

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Sage Laboratories, Inc. offers a standard line of coaxial rotary joints suitable for use in commercial, military, and medical equipment applications. All of the standard products are available from stock. Also, an extensive library of custom and modified designs exists at Sage from years of solving customer needs. The catalog product family features units covering DC to 40 GHz in a variety of configurations.

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New Application Notes

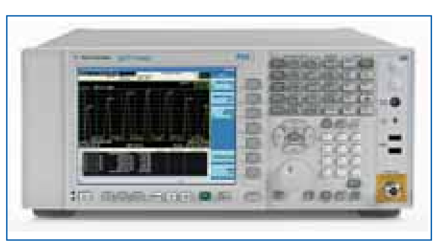
Agilent Technologies offers application notes on X-Parameters, Baseband IQ Analysis, SDR Design, Amplifier Test and Migrating Legacy Analyzers using its X-Series test products. The free application notes provide insight into solving tough measurement problems in a unique way; in both the manufacturing and design environments. Offering a combination of speed and scalability, and created and supported by renowned worldwide measurement experts, Agilent's X products help engineers bring innovative, higher-performing products to emerging markets around the globe. Application note topics include accurate baseband IQ analysis at a lower cost of test, developing optimal software defined radios, ensuring accurate ACPR measurements of LTE power amplifiers. The notes are available online at:

www.agilent.com/find/powerofx

2-Way 90° Power Splitter

A new power splitter from Mini-Circuits offers high power handling of 8 watts over nearly an octave bandwidth; 4000 to 7200 MHz. Very low unbalance specifications are 0.2 dB amplitude and 2 degrees phase (typical). The Model QCS-722+ is offered in a miniature 0805 form factor LTCC package, enabling smaller implementation of image reject mixers, SSB modulators, phase shifters, variable attenuators and balanced amplifiers. The splitter is priced at $3.99 in 10-49 quantity.

www.minicircuits.com



PXA Signal Analyzer

Agilent Technologies Inc. offers an LTE test solution that combines the market-leading Agilent 89600 VSA LTE FDD and LTE TDD analysis software with the highest-performance member of the Agilent X-Series, the Agilent N9030A PXA signal analyzer. The PXA provides industry-leading RF performance that supports both LTE FDD and LTE TDD. It delivers up to 140 MHz analysis bandwidth and up to 75 dB of spurious-free dynamic range with typical flatness of ±0.4 dB.

www.agilent.com/find/PXA

7900-8100 MHz Bandpass Filter

Mini-Circuits has introduced the BFCN-8000+ LTCC bandpass filter, constructed in a five-layer design to achieve miniatuization (3.2 mm × 1.6 mm). The electrical design includes rejection peaks close to the passband, for improved system performance. The unit covers 8000 MHz ±100 MHz, and insertion loss under 2 dB at the center frequency. The rugged package has wrap-around terminals for easy soldering and visual inspection. The device is priced at $3.95 in 10-49 quantity.

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Magnetic Materials in Transmission Line Transformers

This discussion is in regard to the required charactersitics of magnetic materials used in transmission line transformers. Figure 1 shows the comparison of K5 and Q1 ferrite cores operating at a 50:12.5 ohm using Ruthroff's 1:4 design. These are in turn compared to an autotransformer using the Q1 core. As can be seen, the autotransformer is vastly inferior and the TLTs have similar efficiencies at this impedance level. Also the K5 transformer has a better low frequency response because of the higher permeability of this material.

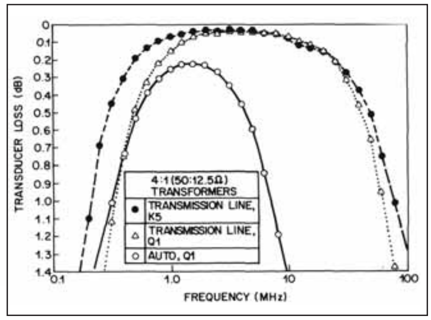

Figure 1 · Loss and bandwidth performance of 4:1 transformers operating at the 50:12.5 ohm level.

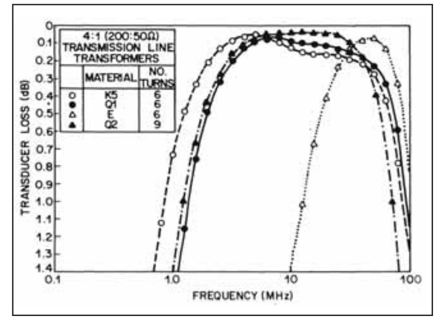

Figure 2 · Loss vs frequency of four 4:1 transformers at the 200:50 ohm level.

Figure 2 includes a comparison of the two cores used in Figure 1, but at the higher impedance level of a 200:50 ohm ratio. A similar transformer using a Q2 core is also shown in the figure. The Q2 core shows that at a higher impedance level a higher bulk resistivity is required for optimum efficiency. Results for a fourth transformer using a powdered iron core (E material) are also included. Since this material has much lower permeability than the ferrite materials, its low frequency response suffers accordingly.

After consideration of the available information in these figures and other experiments, we can conclude:

1) Since very little flux occurs in the cores in the passband, the losses are basically due to the potential difference along the lengths of the transmission lines. The losses are due to the voltages and are therefore dielectric in nature. As was seen, the highest bulk resistivity yields the highest efficiency.

2) The other parameter that is important with transmission line transformers is the permeability. High permeability of core materials results in shorter transmission lines. This directly benefits Ruthroff's bootstrap approach, which adds a delayed voltage to a direct voltage. Further, with shorter transmission lines, their characteristic impedance is somewhat less critical. If a toroid is used for the core, the magnetizing inductance L_M (in henrys) is:

$$L_M = 0.4\pi N^2 \mu_0 \left(\frac{A_e(\text{cm}^2)}{L_e(\text{cm})} \right) \times 10^{-8}$$

where N is the number of turns, μ_0 is the permeability of the core, A_e is the effective cross-sectional area of the core, and L_e is the average magnetic path length.

We can see from the above equation that by increasing the permeability ten-fold, the number of turns is reduced by about one-third. Thus, for a Ruthroff transformer, which adds a delayed voltage to a direct voltage, the high frequency response is about three times greater.

3) When looking at the table [1] and the above figures, two properties of the core material stand out: permeability and bulk resistivity. In fact, a figure of merit can be defined in this case, which is permeability times bulk resistivity.

Also, powdered iron and manganese zinc (MnZn) ferrite are not recommended for the broadest bandwidth. Again, from the experimental results it is seen that the nickel zinc (NiZn) ferrite delivers best results.

Reference

1. Jerry Sevick, "Magnetic Materials for Broadband Transmission Line Transformers," *High Frequency Electronics*, January 2005, Table 1. Available in the Archives section at: www. highfrequencyelectronics.com

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This note is dedicated to, and adapted from the most recent publication of friend and colleague Jerry Sevick, who died this past November 29. A brief obituary is included here:

Sevick, Jerry, Ph.D., of Basking Ridge, NJ died peacefully on November 29, 2009, at the age of 90. Born in Detroit, he was a graduate of Wayne State University and a member of their Athletic Hall of Fame. He was drafted by both the Chicago Bears and Detroit Lions, but did not play professional football. He served as a pilot in the US Army Air Corps in WWII.

Jerry taught at Wayne State University and worked as the local weather forecaster at WXYZ TV in Detroit. After completing a doctorate in Applied Physics from Harvard University, he worked for Bell Laboratories, serving as the Director of Technical Relations prior to his retirement. An avid Ham radio operator (W2FMI), Jerry was renowned for his research and publications related to short vertical antennas and transmission line transformers.

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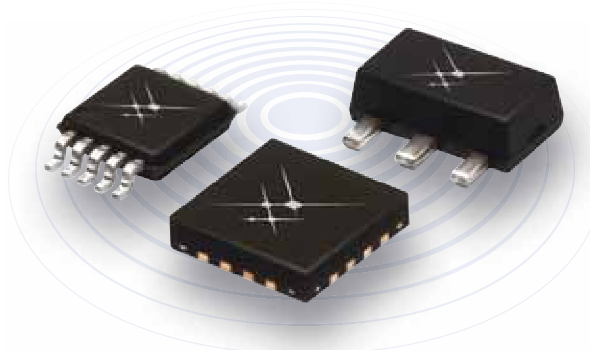

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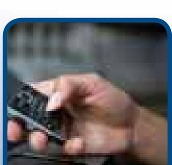

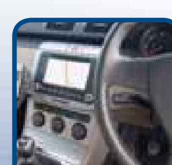

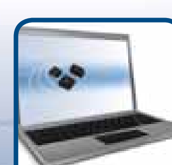

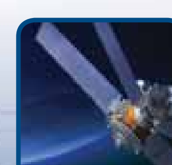

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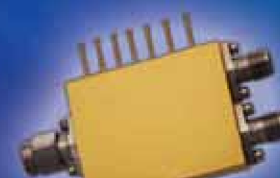

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