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September 2006

Microwave Journal

Wireless Communications and Applications

State of the Technology in Wireless Communications

Low Voltage Operation of GaAs Power Amplifiers

Measuring WiMAX Signals

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FEATURES

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STAFF

Executive Editorial Office:

685 Canton Street, Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
e-mail: mwj@mwjournal.com

European Editorial Office:

46 Gillingham Street, London SW1V 1HH, England
Tel: Editorial: +44 207 596 8730 Sales: +44 207 596 8740
FAX: +44 207 596 8749

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Ask Harlan

"Ask Harlan," a technical question and answer session with Harlan Howe, Jr., an industry veteran and long-time *Microwave Journal* editor, has been a regular part of our web site (www.mwjournal.com) for almost two years now. In an effort to better combine the editorial content of our magazine with our newly developed and retooled on-line presence, we have decided to develop Harlan's RF and microwave engineering advice into a monthly feature.

How it works: Harlan has selected one question from his "Ask Harlan" column to be featured in the magazine. Please visit www.mwjournal.com/askharlan to provide an answer to this month's featured question (see below). Harlan will be monitoring the responses and will ultimately choose the best answer to the question. Although all of the responses to the featured question will be posted on our web site, we plan to publish the winning answer in the November issue. All responses must be submitted by **October 6, 2006**, to be eligible for the participation of the September question.

The winning response will win a free book from Artech House, along with an "I Asked Harlan!" t-shirt. In addition, everyone who submits a legitimate response will be sent an "I Asked Harlan!" t-shirt.

July Question and Winning Response

The July question was submitted by Jayesh Nath from Harris Corp.:

Dear Harlan,

What is the proper usage of diplexer and duplexer?

The winning response to the July question is from Simon Zhou of Mitec Telecom Inc.:

Diplexer is a network that splits a signal to two or more loads, dependent on frequency. Often a diplexer is used to route signals, based on frequency, to two different receivers. A diplexer can also be used to create a "matched" filter that is non-reflective outside of the intended passband. It can also be used as a bias tee, to feed your favorite active device with DC power. Duplexer is a three-port network that allows the transmitter and receiver in a radar or communications system to use the same antenna. The duplexer can be as simple as a circulator in low power applications, or it may be a radioactive gas-discharge T/R tube for megawatt radars.

Harlan's response:

A diplexer separates two signals based on frequency, while a duplexer separates based on power level or direction of signal flow. A typical diplexer consists of two bandpass filters with a common junction. A radar duplexer is generally made with two 90 degree hybrids separated by T/R tubes. A common duplexer for a simple transceiver can be made with a ferrite circulator to connect the transmitter to the antenna and the antenna to the receiver. Single pole-double throw switches are also sometimes used as duplexers.

This Month's Question of the Month

(answer on-line at www.mwjournal.com/askharlan)

Edson Wander from Electrolux has submitted this month's question:

Dear Harlan,

I am looking for information about measuring microwave oven cavity reflexion (SWR). I am having difficulty finding the correct probe to simulate the magnetron with the network analyzer. Could you provide any direction?

If your response is selected as the winner,
you'll receive a free book of your choice from Artech House.
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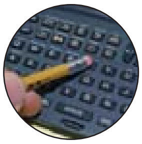

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Broomfield, CO
www.arftg.org

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December 4–5, 2006 • Clearwater Beach, FL
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Asia-Pacific Microwave Conference
December 12–15, 2006 • Yokohama, Japan
www.apmc2006.org

JANUARY

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January 9–11, 2007 • Long Beach, CA
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IEEE Topical Workshop on Power Amplifiers for Wireless Communications (PA Workshop)
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Long Beach, CA
http://paworkshop.ucsd.edu

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THE CURRENT STATE OF TECHNOLOGY AND FUTURE TRENDS IN WIRELESS COMMUNICATIONS AND APPLICATIONS

Tremendous changes are occurring in the area of wireless communications, so much so that the mobile phone of yesterday is rapidly turning into a sophisticated mobile device capable of more applications than PCs were capable of only a few years ago. For example, the data rates provided by the initial High Speed Downlink Packet Access (HSDPA) extension to 3G networks enable a user to wirelessly access the Internet at speeds up to 1.8 MBits/second. Further enhancements in HSDPA modulation schemes will soon increase this speed to greater than 10MBits/second. So downloading your latest e-mails with a 5 MB Powerpoint™ attachment outside of the office is no longer a frustrating and time-consuming exercise. In fact, it is just as fast as when you are in the office.

It is the need and desire of people to access the Internet from anywhere in the world that is driving many of the new changes that are occurring in the largest consumer market ever — the wireless mobile device market. In ***Figure 1*** we look at the mobile device view and see that there are three main routes to wirelessly access the Internet. Voice is still the main use of mobile devices and the GSM and CDMA networks around the world now connect over 2.3 billion wireless subscribers. The cellular standards are evolving to add high speed data connections, and cellular remains the way we connect from remote locations many miles away from a base station.

For local connections Bluetooth® is rapidly becoming a common feature in mobile devices with almost 30 percent attachment rate expected in 2006. This attachment rate is expected to grow to more than 50 percent over the next three years. Today we are seeing other radios being combined with Bluetooth, such as WiFi, FM

Fig. 1 Wireless access to the Internet everywhere and entertaining functions will lead to highly usable and fun mobile devices.

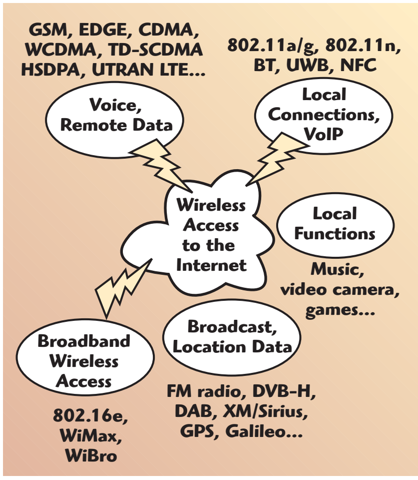

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TABLE I

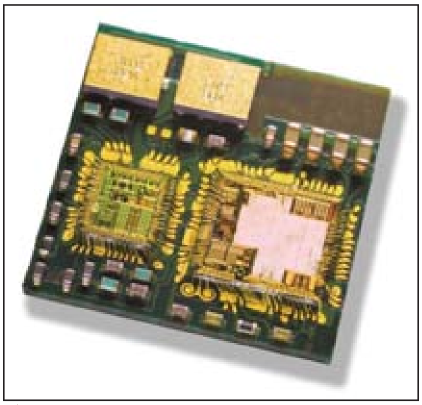
MAJOR CHANGES IN MOBILE DEVICE TRENDS 2003 TO 2008

Handset Feature	2003	2008
Number of radios	dual-band GSM or CDMA	quad-band GSM/ EDGE, tri-band WCDMA, Bluetooth, WiFi, FM, GPS, UWB
Number of simultaneous operating radios	1	3 or more
Number of antennas	1	5 or more
Board area available for main cellular radios	600 mm^2	300 mm^2
Form factors	flip-phone and candy bar phones with thickness of > 20 mm	flip, candy bar and tablet devices with thickness of 10–15 mm
Radio architecture	mainly analog RF transceiver with analog interfaces	mixed-signal RF transceivers with digital interfaces
Baseband processor technology node	0.18 μm CMOS	65 nm CMOS
Wireless connectivity speeds	70–80 KBit/s (cdma2000 1X RTT)	100–480 MBit/s (WiFi or UWB)
Memory storage	none	several Gigabytes

radio and Near Field Communications (NFC). Soon we will see combination Bluetooth and Ultra-wideband (UWB) devices to further enhance the wireless distribution of multimedia content. It will not be long before that 5 MB presentation will be beamed to an UWB-enabled plasma monitor in the conference room or displayed directly in real time onto your colleagues' mobile device at the table.

The third area being developed for wireless access to the Internet is the evolution of mobile broadband. Worldwide Interoperability for Microwave Access (WiMAX) is an industrial organization that promotes the 802.16 standard for both fixed and mobile devices. WiMax uses frequency bands between 2 and 11 GHz and does not require a line of sight between base stations. Each WiMax base station will theoretically have a range of about 30 miles. It is likely that WiMax will be used initially as a wireless alternative to DSL cable, especially in rural areas where the cable infrastructure is not very well developed. In 2007 it is likely that mobile WiMax will be built into laptops, similar to WiFi today, shortly followed by implementation into smart phones. Sprint is already preparing networks, and Motorola is planning to supply the devices.[1]

In addition to the ability to wirelessly access the Internet the mobile device of tomorrow will also be capable of viewing TV programs, watching videos, storing and playing music as well as providing location-based services using GPS or Galileo satellite navigation systems.



▲ *Fig. 2 A typical example of module integration showing a single RF transceiver die, SAW filters and matching components inside a single package.*

MAJOR CHANGES IN MOBILE DEVICE TRENDS

The More Radios the Better

Major changes are occurring in the mobile device arena in terms of radio complexity, as illustrated in ***Table 1***. Firstly, the number of radios being designed into mobile devices is increasing. Just a few years ago the only radios needed were dual-band (800/1900 or 900/1800 MHz) GSM or CDMA. We project that in 2008 it will be common to have as many as seven radios inside mobile devices. The major shift is the addition of HSDPA as more 3G phones become available. In order to satisfy the requirements of global networks, it is likely that the 3G radio will be at least tri-band covering regions 1, 2 and 5, followed by the need for several other regions. Adding different regions for WCDMA or HSPDA is more complicated than previously because each frequency pair needs a duplexer to separate the transmit and receive signals that are active at the same time. Bluetooth, WiFi, FM, GPS and DVB-H are the other five radios that are expected to be added in the next two years. Looking at the usage models suggests that many of these radios need to be capable of simultaneous operation, so interference and co-existence must be considered early in the design. For example, the US band of 800 MHz has a second harmonic that is right on top of the 1600 MHz broadcast TV channel used by Modeo for DVB-H (Digital Video Broadcast-Handhelds). Therefore, filtering must be designed so as not to block the TV viewing experience when you are talking on the phone, something that will soon be a common use of mobile devices.

Antennas Everywhere

All these radios will have different antennas requiring careful partitioning of the radios so that the antennas can be placed in optimal locations inside the mobile device and positioned such that interference is minimized. Another significant factor affecting mobile devices is that as the antennas become more broadband their impedance match degrades and the cellular power amplifier has to deliver power into a higher VSWR load. The antenna VSWR also changes significantly as the mobile device is placed near objects such as the body, metallic objects, inside briefcases, etc., and the power amplifier has to accommodate the changing environment to maintain the expected performance of total radiated power (TRP). Developing load insensitive power amplifiers and adaptive matching networks are key to maintaining the best user experience.

Shrinking Real Estate

Another trend happening inside a mobile phone is the reduction of space available for the radio. Phones are being designed that are thinner, slimmer and narrower than ever before. Only a few years ago the space available for the total RF section in a dual-band GSM or CDMA phone was close to 600 mm^2. Now the space available for a 3G phone with multiple GSM, EDGE, HSDPA radios is half that at only 300 mm^2. This trend has led to more and more integration of components both at the silicon level and at the module level. For example, nowadays VCOs, synthesizers loop filters and voltage regulations are all integrated into the transceiver die. Additionally, SAW filters (see ***Figure 2***) and in the future, crystal reference oscillators, are being incorporated into the transceiver module to realize a complete, self-contained system module in a small package.

The trend now is for very thin phones, with some now less than 10 mm thick. This implies that phone manufacturers desire to use only one side of the printed circuit board whereas before both sides were utilized. This also puts pressure on component manufacturers to shrink the size of the solutions. In the future we predict that mobile devices will be designed with more interesting form factors, including flexible materials for clothing and other applications. So making the components as small as possible is a key requirement for realizing almost all new devices.

Going Digital

Traditional RF architectures have usually been implemented using mainly analog approaches for down-conversion, modulation and filtering. In recent years there have been advances in design and process technologies that have allowed the conversion from RF to digital to occur within the radio before the baseband. For example, in RFMD's POLARIS™ TOTAL RADIO™ the transceiver uses a fractional-N synthesizer-based digital GMSK and 8PSK modulator all implemented in digital CMOS. This has also helped realize digital interfaces between the RF and baseband sections of the radio that allows the baseband chip to migrate to smaller and smaller CMOS geometries and segments the analog and mixed-signal elements into the front-end.[2]

In other developments even more integration of the RF functionality has been implemented in a digital fashion, an example of which is the Bluetooth® chip from Texas Instruments.[3] It remains to be seen how widespread this type of architecture will be adopted in the cellular handsets. Already similar ICs are available for the low end GSM standards but it will likely be several years until it is seen in 3G handsets. However, the trend is definitely towards more digital content in the radio.

CELLULAR HANDSET FUNCTIONAL BLOCKS

Whereas there are always some differences between standards and tiers, in general the semiconductor-based functional blocks of a mobile device are as shown in ***Figures 3*** and ***4***, with representative technologies shown. Of course, many other technologies can be used, but these shown are the most common. These are generally categorized into the following:

- Front-end components
  a) T/R and Mode Switch
  b) Power Amplifier
  c) RF Transceiver
  d) Filters, both Rx and Tx
- Communications Processor (baseband)
- Applications Processor

- Power Management and Analog Baseband
- Peripherals

Many excellent choices exist today for high performance semiconductors used in consumer devices. Computer and memory markets tend to drive the state-of-the-art for deep submicron digital CMOS, while the mobile phone market is the volume driver for mixed-mode and analog semiconductor processes. Historically, the RF and analog front-end has been optimized by function, with very little integration. The RF and analog front-end components are defined herein as all semiconductor blocks between the antenna and the digital baseband, non-inclusive. These functions were initially implemented as discrete solutions, on the phone board. In recent years the discrete solutions have been replaced with more integrated solutions — on-chip integration in some cases, module integration in others. Either way, the goal was to reduce the component count on the phone board and to enable new, lower cost and higher performance "super-components."

The trend toward module integration has allowed each function to continue to be optimized by semiconductor technology. For example, a GSM transmit module today consists of a PA, matching components, bandpass/low pass filter and transmit/receive switch. Generally speaking, the PA is either GaAs HBT or Si LDMOS, the match and filters are implemented as discrete SMD components and in some cases microstrip lines on the module substrate, and the transceiver switch is GaAs pHEMT. An example is shown in ***Figure 5***. These choices of technologies allow the function to be implemented with minimal performance compromise.

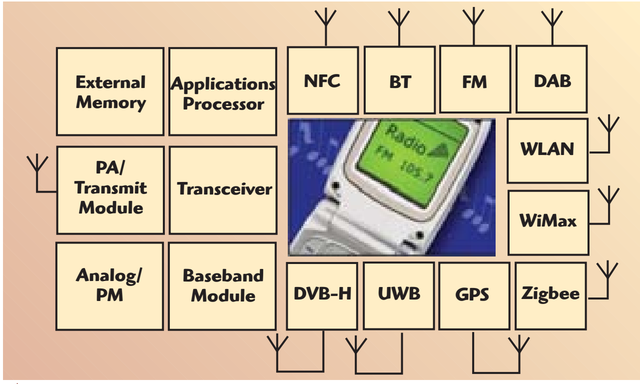


Fig. 3 Various radios and functional blocks in a mobile phone.

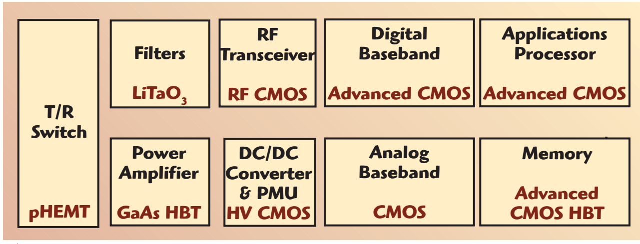


Fig. 4 Typical semiconductor blocks for cellular radio in a mobile phone.

Transceivers are also moving toward integrated solutions, with CMOS clearly becoming the preferred technology. Performance is very competitive, and the cost roadmap for CMOS is unparalleled due to the economies of scale driven by the digital markets. Solutions for the front-end of a GSM/EDGE phone combine on-chip integration and module integration for the optimum tradeoff between cost and performance. Today, a two-module solution exists for the entire cellular front-end, as shown in ***Figure 6***. This allows the phone manufacturer much simpler and lower cost design and manufacturing while shifting the burden of designing these components to the component supplier.

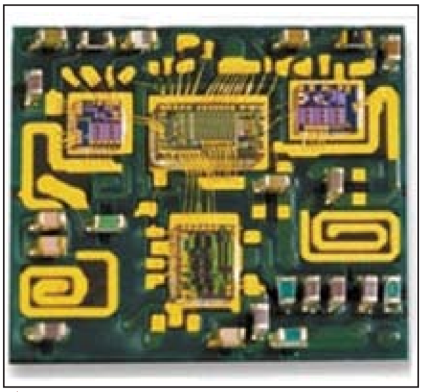


Fig. 5 A GSM/EDGE transmit module.

Technology Partitioning

As was mentioned earlier, some suppliers are integrating the RF transceiver together with the digital baseband as a system-on-chip (SoC). This allows the transceiver, which is migrating toward more digital processing techniques, to take advantage of the digital CMOS "platform." In this case, the remainder of the front-end is left to discrete or module-implemented solutions.

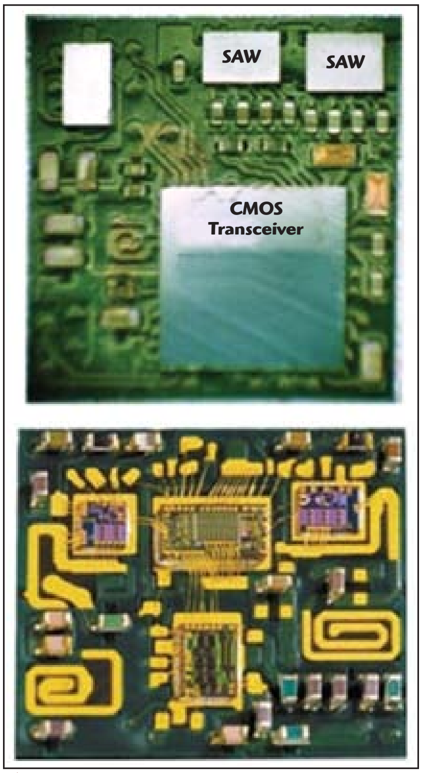
These solutions merge RF, analog and digital circuitry on a single CMOS process, which provides a single low cost platform to build upon. The trend is interesting, but as the advanced CMOS geometries continue to shrink, it will be difficult to maintain due to two reasons:

1. Analog voltages such as those needed for I/Os, LDO regulators, DC-DC converters, charge pumps for micro-electromechanical systems (MEMS) and other power management functions will not be supported. This will drive the power management into a separate technology, and will be required as part of the chipset.
2. As integration in the front-end occurs, technology will drive the partitioning toward digital-only in deep submicron CMOS and RF/analog in a higher voltage CMOS process. MEMS will reside here as well, to complete the front-end integration. This front-end integration platform will be a key for reducing cost and size, and enabling adaptability.

Integration drives cost and performance, so ultimately a highly integrated single-chip solution will be the most cost-effective means to produce the front-end. Technologies are being developed to address this need, and within the next few years, we will see new technologies drive new architectures, most likely on a CMOS-based technology platform.

Battery Technology Trends

Power requirements for mobile phones continue to increase due to larger color displays, additional radios, new standards for high speed data, etc. This places a greater de-



▲ *Fig. 6 A two-module GSM/EDGE quad-band front-end.*

mand on the battery, requiring ever-increasing energy densities. One way battery manufacturers are responding is by defining new materials to extend the useful life, but to the component manufacturer this typically means a greater range of supply voltage. For example, ***Figure 7*** shows the typical discharge curve for Li-Ion technology. Newer technologies allow extended talk time, but require operation to a lower voltage — as low as 2.5 V.

Most components are driven by voltage regulators or DC-DC converters contained within the power management IC. Digital chips require typically 1.8 to 1.3 V, which must be efficiently converted from the 4.2–2.7 V battery. RF transceivers typically do not consume a significant amount of current; thus, their power consumption is minimal over the discharge curve and their voltage can be supplied with a low dropout regulator (LDO). The power amplifier is typically the largest consumer of power, next to the baseband and/or display, so various means to improve power amplifier efficiency are employed.

INCREASES IN POWER AMPLIFIER EFFICIENCY

The DC power used by the power amplifier (PA) is converted either into RF power and transmitted to the antenna, or dissipated into the phone board and converted to heat. Efforts are made to minimize the wasted power, and to optimize the percentage converted to RF energy. Several techniques include:

Optimizing the Semiconductor Technology Used for the PA

The core efficiency of the PA is limited by the knee voltage (sometimes referred to as saturation voltage) of the semiconductor device. In order of decreasing efficiency, GaAs pHEMT, GaAs HBT, SiGe HBT and Si LDMOS are the technologies currently in use for mobile phone applications, with GaAs HBT having the largest share by far.

The load impedance, which defines the amount of power available and the efficiency of the PA, is set both by the knee voltage and the supply voltage (V_{bat}), as shown in Equation 1. For a varying supply voltage such as a battery, the load must be set to provide the required power at the minimum voltage available. Then for a fixed load, whenever the battery is not at its minimum voltage level (fully discharged), the additional voltage headroom is wasted as heat

$$R_L = \frac{\left(V_{bat} - V_{knee}\right)}{2P_{out}} \qquad (1)$$

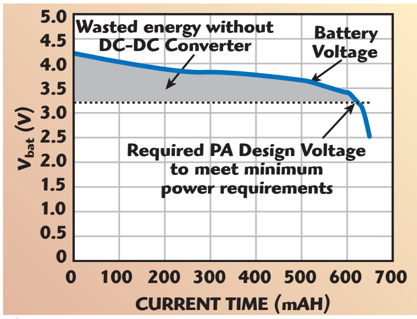
In some applications the load impedance is modified at a reduced power level to re-optimize the PA at that lower power. This has the effect of improving efficiency at that power. For a system such as IS-98 (US-CDMA), this can have a dramatic effect on the total talk time of the phone, as the power level from the phone is typically centered around 0 to 5 dBm (see ***Figure 8***).

Reducing the Post-PA Losses, Which in Turn Minimizes the Amount of Power Required From the PA Device Itself

These losses arise from the matching network for the amplifier as well as the switching network required at the antenna. Clever architectural choices can help reduce losses, but options are somewhat limited in multimode environments where multiple signals must be switched to the antenna(s).

Recovering Lost Power

As shown in Equation 1, the minimum battery voltage determines the load impedance to provide a given power. Lower minimum voltages means more wasted power when operating at any point above the minimum. As can be seen from the figure, this can mean a significant amount of wasted power. If the voltage can be efficiently converted from the battery voltage to

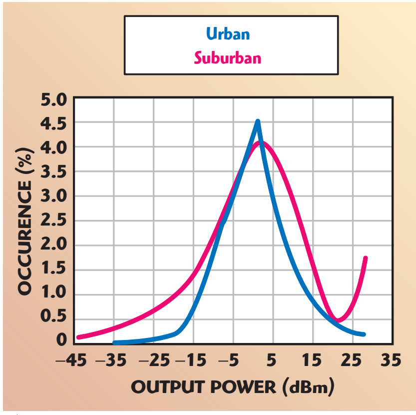


▲ *Fig. 7 Battery discharge curve for a Li-Ion battery.*

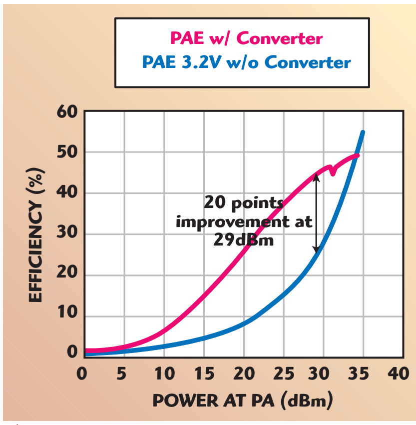
the required operating voltage for the PA, then that wasted power can be recovered. DC-DC buck converters perform this task, although they are just being developed for some higher power PAs, such as for GSM systems. The advantage is shown in ***Figure 9***, where the efficiency of the system is improved at reduced power levels by the DC-DC converter.

New trends in battery technologies are driving toward greater voltage range to achieve longer talk times, with minimum voltages as low as 2.5 V. Referring to Equation 1, as V_{bat} is reduced so is R_L, impacting total efficiency. Some technologies are better optimized for low voltage operation, such as GaAs HBT and GaAs pHEMT due to their lower V_{knee}. Ultimately, a boost DC-DC converter for the PA should provide the best talk times, as the PA is optimized for a higher RL and the total energy from the battery is conserved even at higher voltages.

The improvement shown in Figure 9 can be seen for a constant-envelope modulation system like GSM/GPRS. For a linear system, such as EDGE, the transmitter must support higher peak powers due to the amplitude modulation involved. Generally, these systems are implemented with an I/Q modulator and a linear transmitter, but this requires the PA to be backed off from saturated power, which reduces efficiency. A PA will typically achieve > 55 percent peak efficiency in GSM, but only ~20 to 25 percent in linear EDGE mode. This places severe constraints on the phone, not just from a talk time perspective, but also from heat dissipation. Some EDGE systems are implemented using polar modulation, which uses phase and amplitude modulation directly on the PA. In this system, the PA operates in saturation, just as in a constant envelope system like GSM. The phase modulation is applied to the RF input while the



▲ *Fig. 8 Probability density function (PDF) for CDMA.*



▲ *Fig. 9 Power amplifier efficiency with and without a DC-DC converter.*

amplitude modulation is applied to the voltage supply to the PA. If the amplitude is modulated with a high speed DC-DC converter (which can support the required EDGE bandwidth), the transmitter can operate with efficiency close to a GSM transmitter while maintaining the linear operation needed for EDGE. These innovations will continue with new systems (OFDM-based schemes being considered for 4G, for example).

Other techniques for preserving efficiency at backed-off powers include phased power combining approaches like Doherty and Chirex, and these are being implemented in some forms today. However, they do not address improved efficiency versus battery voltage.

COPING WITH ANTENNA MISMATCH

As mobile phones have shrunk in form factor, so have the antennas. What used to be a nice (from a RF design perspective), long, retractable dipole antenna is now a very small patch antenna supporting multiple bands and standards, and incorporating acoustic cavities and speakers. The susceptibility of these antennas to proximity effects is much higher, and this translates to higher VSWR at the transmitter. For linear systems, isolators used to be common to maintain a constant PA load impedance into a VSWR, but are no longer used. Nonlinear systems such as GSM suffered power and gain variation, translating to significant efficiency reductions with VSWR. Techniques to maintain performance, both for linear and nonlinear systems, are now in place, and more innovative solutions are being developed. These can be passive using phased power combining networks, or active using digitally controlled tuned load networks.

Passive phased networks work by combining the forward power from two PAs in phase, but canceling reflected power by combining out-of-phase. New techniques are in development to allow dynamic tunability of the load impedance, which can adapt to VSWR as well as changes in power level and/or battery voltage as well. Adaptive tuning requires some kind of structure that can modify the elements in the matching network, typically capacitors. Examples include barium strontium titanate (BST) capacitors that can be varied through an analog DC voltage, and MEMS-based switched capacitors that offer digital tuning capability for the load network.

RF MEMS

RF MEMS offers the potential to revolutionize the multimode radio front-end. The lower loss associated with above-IC MEMS switches and the possibility of tunable resonators can be used to integrate much of the functions currently performed by external, specialized substrates and technologies. In addition, they should provide improved functionality and performance, including tunability to enable operation in a multi-standard environment, leading to a truly cognitive radio.

RF MEMS switches have begun appearing on the market with reported reliability > 1E10 switching cycles and switching speeds < 10 µs, and carrying losses of < 0.2 dB with isolation > 40 dB at 2 GHz. This level of performance is sufficient to enable use in a multitude of applications, beginning with transmit/receive switching for GSM. The inherent linearity of a mechanical switch allows for WCDMA mode switching without distortion and with very low losses. Additional modes and/or radios sharing antennas can be switched very easily using MEMS switches. Above IC processing allows the MEMS devices to be built directly on CMOS, allowing control for the switch to be integrated in silicon (Si), but also to allow the MEMS devices to be integrated with other analog functions in CMOS.

Other applications for MEMS devices include crystal replacements for reference frequency generation. Some commercial products are beginning to emerge; however, the stability required to meet GSM phase noise is not yet available. These products are improving, using state-of-the-art silicon-on-insulator (SOI) technologies and/or above-IC beam resonators, and will soon be capable for all standards. Once integrated, opportunities for multiple frequencies exist, selectable with onboard MEMS switches, or perhaps by a bias voltage directly.

Using RF MEMS resonators for RF filtering can provide very compact, tunable, front-end filtering for multiple standards and/or frequencies. These resonators have been plagued by high motional resistance, limiting the capability to couple energy and thus causing very high losses in 50 Ω systems. Research is ongoing, however, to reduce the motional resistance, and to keep the quality factor (Q) high in the resonators. These devices will ultimately provide the front-end for a multi-standard, multi-band radio; the tunability will allow a feasible software-defined radio (SDR), with some amount of channel selection at the front-end.

CONCLUSION

The tremendous changes occurring in wireless communications are driving the mobile device to incorporate more radios inside the handset, while shrinking the physical size. This dynamic leads to innovative solutions to maintain electrical integrity while more than one radio is operating simultaneously, and to integrate more functionality into smaller packages while maintaining good thermal properties. But these are challenges that engineers thrive upon. Because we are creating the mobile phone of the future, or more correctly, the mobile device of the future, that will have more functionality than even some laptop computers have today. ■

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Alastair Upton *holds a BSc (Hons) degree in electrical engineering from the University of Leeds (UK) and an executive master's degree in technology management (EMTM) from the University of Pennsylvania/Wharton School of Business. He is managing director of strategic marketing for the cellular business at RFMD. Prior to this role, he was general manager of the digital cellular product line, responsible for initiating the Polaris™ TOTAL RADIO™ chipset products. He has been with RFMD since 1997 and has held product line director and product manager positions within the company. Prior to joining RFMD, he was with Lockheed Martin/GE Aerospace for 14 years as program manager, engineering manager and GaAs integrated circuit designer. He started his career with Philips in 1980.*

Victor Steel *received his MSEE degree from the University of Illinois in 1987. He is RFMD's vice president of corporate research & development (R&D). Previously, he served as director of RFMD's power amplifier product line from its inception until May 2000, when he formed the R&D group. Prior to the formation of product lines, he served as engineering manager for all of RFMD's power amplifier product development. Before joining RFMD in 1993, he was employed by ITT GaAs Technology Center in Roanoke, VA, as a senior design engineer, developing commercial power amplifier products as well as managing the test lab for the wafer fab.*

Raytheon Wins Homeland Security Contract

Raytheon Co. has been selected by the Department of Homeland Security to develop and produce the next generation of Advanced Spectroscopic Portal (ASP) nuclear detection capability. The ASP contract, with an initial value of $18.2 M, places Raytheon Integrated Defense Systems (IDS) at the forefront of border security and national defense, preventing the smuggling of nuclear materials through ports of entry. The domestic market for these portals is estimated to be greater than $1 B. Raytheon IDS is leading a team that includes Bubble Technology Industries (BTI) to produce a medium resolution Advanced Spectroscopic Portal system. "This contract represents the opening of a significant new market for Raytheon and our partners," said Dan Smith, president of Raytheon IDS. "We are committed to providing the best solutions with our core expertise in system engineering and integration, manufacturing, program management and breakthrough technologies to protect the homeland. We look forward to providing a reliable, affordable and highly effective portal screening system that will guard our nation against illicit threats." Raytheon will provide prime program management, engineering development, manufacturing, field support and research and development for future systems improvements. BTI is a company with a global reputation in nuclear physics. All work on the portals will be performed at IDS' SHINGO award-winning Integrated Air Defense Center, Andover, MA. Advanced spectroscopic portals are panel-like devices that contain detectors used to screen people, cars, trucks and containers for illicit radioactive materials at some of the more than 600 ports of entry into the United States. This new generation of portals is needed to improve discrimination between innocent and threat materials, which will reduce the number of false alarms compared to the first generation of screening portals currently in place. The ASP program will join Project Athena as a key element of IDS homeland security initiatives. Project Athena, an open architecture information fusion system that enables multi-domain situational awareness, has been successfully fielded and demonstrated in operational environments.

Harris Corp. Receives $169 M Contract for Multi-band Vehicular Systems

Harris Corp. announced that it has received a $169 M contract from the US Army Communications and Electronics Command (CECOM) for Falcon® III dual Vehicular Adapter Amplifier systems (VAA). The vehicular system, nomenclatured the AN/VRC-110, includes the NSA-certified AN/PRC-152(C) handheld radio. "This contract award reaffirms the success of the Falcon III product family and Harris' ongoing partnership with the US Army. The AN/VRC-110 ensures that our Army customers have the SINCGARS 50 W vehicular radio functionality that they rely on for long range communications and the portability of a handheld that is lighter and easier to carry in tactical, quick-dismount scenarios," said Dana Mehnert, president, Harris RF Communications Division. "In addition, the AN/PRC-152-based systems can easily be upgraded to provide additional capabilities in the future utilizing the JTRS Software Communications Architecture (SCA) and the Harris™ II programmable encryption module which will facilitate the Army's transition to JTRS." The AN/VCR-110 is a fully integrated, high performance multi-band vehicular radio system that includes the AN/PRC-152 SCA-based handheld, a power amplifier and an integrated handheld battery charger. The system provides 50 W output in the VHF (30 to 90 MHz) band — the typical configuration for SINCGARS units in use today — to provide the reliability to close long-range communications links required on the battlefield. In order to facilitate integration with the customer's existing mobile platforms, Harris designed the AN/VRC-110 radio systems to be compatible with the Army's existing vehicular mounts and cables. In addition, the AN/VRC-110 provides two antenna ports with automatic switching for true multi-mission capability, as well as built-in collocation filtering for dual installations. Operators need only to select the required net on the radio to switch between ground communications and ground-to-air or SATCOM communications. The first antenna port provides 50 W output from 30 to 90 MHz, while the second antenna port provides VHF high band and UHF operation. The AN/PCR-152 Handheld — the basis for the AN/VRC-110 — provides SINCGARS, Havequick II, VHF/UHF AN & FM and MIL-STD-188-181B UHF SATCOM, which includes ANDVT voice and up to 56 kbps data. It also uses the Harris Sierra II software-programmable encryption module to ensure support of future waveforms.

Northrop Grumman Flight Test New Radar Antenna for B-2 Bomber

Northrop Grumman, working closely with Raytheon, has begun flight-testing a new radar antenna on the B-2 stealth bomber that, combined with other upgrades, will enhance the aircraft's ability to respond to emerging worldwide threats. Testing of the active, electronically scanned array (AESA) antenna on the B-2 represents a milestone for this radar modernization program because it allows engineers to determine, for the first time, how the radar performs under actual conditions. Northrop Grumman is the prime contractor for the B-2, which remains the only long-range, large-payload aircraft that can penetrate deep into protected airspace. Combined with superior airspace control to be provided by the F-22 raptor and global mobility provided by tanker aircraft, the B-2 will ensure an effective US response to threats anywhere in the world. "The radar modernization program is one improvement the Air Force and Northrop Grumman are working on to enhance the B-2's capabilities," said Dave Mazur, vice president of Long Range Strike and B-2 program manager for Northrop Grumman's Integrated Systems sector. "The B-2's combination of long range, large payload and survivability makes it a unique strike asset and the upgrades will ensure the aircraft remains just as effective in the future."

"Raytheon's B-2 AESA radar system is performing well so far during the flight test phase," said Erv Grau, vice president for the Air Combat Avionics Group of Raytheon Space and Airborne Systems. "Integrating our advanced technology onto the platform is critical to ensure the B-2 is not only equipped to deal effectively with a variety of future threats but also has the capability to act as a critical node on the network as the battlespace continues to evolve." The B-2 radar work is part of a $382 M system development and demonstration contract awarded by the Air Force in 2004. During this phase, Northrop Grumman and Raytheon are developing and testing the radar and will install additional systems on operational B-2 aircraft of the 509th Bomb Wing at Whiteman Air Force Base, MO. This phase will be followed by production to field the new radar and install the antenna into the B-2 fleet.

Lockheed Martin Signs CRADA to Demonstrate Airborne Networking

Lockheed Martin and the US Air Force's Electronic Systems Center (ESC) have signed a Cooperative Research and Development Agreement (CRADA) to develop advanced tactical and airborne network communications capabilities. Lockheed Martin, in cooperation with ESC and the Air Force Research Laboratory (AFRL) in Rome, NY, will independently validate airborne network architecture for joint tactical networks. The airborne network CRADA will also reduce risk for the government and accelerate fielding of airborne network capabilities. "The Airborne Network CRADA offers Lockheed Martin and all the Services an opportunity to jointly accelerate needed capabilities for the warfighter," said Dom Costa, vice president of Lockheed Martin's Joint Tactical Radio System. "Airborne network communications are essential for mission success and this research, along with the other independent research Lockheed Martin is conducting, will allow the military to employ new capabilities at a lower cost and with reduced risk. We look forward to working with ESC and AFRL on this critical capability." ■

EU Speeds Towards Embedded Systems Design

As part of the European Union's 6th Framework Programme for funding technology and scientific projects, a new embedded systems initiative called Speculative and Exploratory Design in Systems Engineering (SPEEDS) has been established. The initiative is a concerted effort to define a standard, end-to-end framework for the implementation of innovative, next generation concepts, methodologies, processes, technologies and tools for the design of embedded systems.

Its aim is also to provide an environment that will not only foster greater collaboration between European companies of all sizes involved in the embedded systems arena but also significantly widen access for smaller companies to leading edge tools and techniques. The initiative will enable the European embedded systems industry to seamlessly evolve from model-based design of hardware/software systems towards an integrated component-based construction of complete, virtual system models.

SPEEDS is intended to significantly improve Europe's performance and competitiveness in embedded systems design in key, safety-critical industry sectors such as automotive, avionics, space and industrial control. Hence, the initiative is targeting a 60 percent reduction in development costs and 40 percent reduction in the development time of safety-critical embedded systems, whilst maintaining and improving the necessarily high quality standards demanded and managing the increasing design complexity involved.

The SPEEDS consortium is: Airbus Deutschland, Airbus France, Daimler Chrysler, Esterel Technologies, Extessy, I-Logix, Institut National de Récherche en Informatique et en Automatique, Israel Aircraft Industries, Knorr Bremse Fekrendszerek, Kuratorium OFFIS, Magna Powertrain, Parades Geie, Robert Bosch, Saab, TNI-Software and Université Joseph Fourier Grenoble.

MEMS Initiative Centres on Scotland

The institute for System Level Integration (iSLI) has been awarded £1.12 M of funding by Scottish Enterprise to assist UK industry with the adoption of cutting-edge microelectromechanical systems (MEMS) technology. The award will establish a publicly accessible centre of design excellence, providing the commercial sector with access to expertise and knowledge transfer for the rapid development of product prototypes.

The centre, based in Livingston, Scotland, will focus on the field of silicon-based MEMS technology and a key element is the significant support of Coventor Inc., which provides the cutting-edge toolset that will be used to perform the complex design and analysis tasks needed to develop new products.

For this initiative, iSLI has teamed up with its partners, Heriot Watt University and Strathclyde University, and the SemeMEMS open access facility. The partnership of the Centre for Microsystems and Photonics (CMP) at Strathclyde brings extensive experience in design for foundry manufacture together with a significant test and characterisation facility. The Micro-Engineering group of Heriot Watt complements this with world-class expertise in reliability and lifetime prediction of microsystems. Linking these research capabilities to the customer, through the market facing iSLI, will ensure that technology push and market pull are quickly and successfully married.

Mark Begbie, MEMS group manager at iSLI, comments, "I believe the partnership we have brought together presents a uniquely powerful value proposition to the technology sector within UK Plc. The centre's smooth integration of research capability with market focus and commercial foundry will be a real step forward in bridging the exploitation gap that so often hinders new technology uptake. By maintaining a market pull focus we expect to have a real impact on new product development."

Group Discussion on Information Society

The United Nations Group on the Information Society (UNGIS) has been launched to serve as an interagency coordinating mechanism within the UN system to implement the outcomes of the recently concluded World Summit on the Information Society (WSIS). The Summit set critical targets for global connectivity and ICT for development to be reached by 2015 and established 11 action lines to achieve the objectives of the Information Society. The outcome outlines a detailed blueprint involving governments, the private sector, civil society, the United Nations and other international organizations for implementation and follow-up at national, regional and international levels.

UNGIS will enable synergies aimed at resolving substantive and policy issues, avoiding redundancies and enhancing effectiveness of the system while raising public awareness about the goals and objectives of the global Information Society. The Group will also work to highlight the importance of ICTs in meeting the Millennium Development Goals.

To maximize its efficiency, UNGIS agreed on a work plan in which it would concentrate its collective efforts each year on one or two cross-cutting themes and on a few selected countries. In the coming period, the Group will focus on bringing the efforts of the UN system to bear on expanding access to communications and during the first year, it will be chaired by the International Telecommunication Union (ITU), with UNESCO, UNDP and WHO acting as vice-chairs.

EPCOS Joins MOBILIS

Alongside leading semiconductor companies and research institutes EPCOS is participating in a new European Union programme known as Mixed SIP and SOC Integration of Power BAW Filters for Digital Wireless Transmissions (MOBILIS). The objective of the program is to develop miniaturized RF filters for the latest mobile phone standards and digital radio reception with mobile phones. In particular, EPCOS will contribute its know-how in BAW technology in the project.

The MOBILIS participants expect to develop bulk acoustic wave solidly mounted resonators (BAW SMR) on a silicon basis, which on a single chip cover all mobile communications standards and frequency bands as well as additional services. The challenge is to develop a process that combines low insertion loss with high power compatibility as well as high linearity, low costs and a minimum form factor. Over the long term, this solution will be integrated into mobile phone chipsets as a system-on-chip (SOC) in order to achieve an even higher level of miniaturization.

New European Centre for AIDC

The European Centre for Automatic Identification and Data Capture (AIDC) technologies, in Halifax, UK, is expected to become operational later this year, and is due for completion in Spring 2007. Yorkshire Forward is investing more than £5 M in the centre, with additional funding from the UK Department of Trade and Industry, the European Regional Development fund and AIM UK.

AIDC technologies cover a range of products, including Radio Frequency Identification (RFID), smart cards, barcodes, biometrics and magnetic strips. The new European centre for AIDC will not only play a world role in promoting the development and uptake of all automatic identification technologies, but will also contribute to the setting of globally accepted standards for their application.

Managed by AIDC UK, the centre will have a multi-purpose theatre with accommodation for 70 delegates, plus a state-of-the-art technology demonstration area capable of showing practical uses of the technology. This area will be themed to show possible applications within a range of industries. An on-site laboratory will provide testing and research services for application research and student training. ■

802.20 Working Group Suspension a Minor Setback for Qualcomm

On June 18, 2006, the IEEE-SA Standards Board directed that all activities of the 802.20 (mobile broadband) Working Group be temporarily suspended with immediate effect, citing "irregularities" in its activities. What effect will this action have on the major stockholders in the mobile broadband market and on its vendors committed to mobile WiMAX? In particular, what are the implications for Qualcomm? According to ABI Research senior analyst Philip Solis, the IEEE's action forms something of an obstacle for the company. "This development removes — at least for the time being — one potential competitor to mobile WiMAX, whose backers can concentrate more on competing with 3G cellular technologies," concludes Solis. "It represents a minor setback for Qualcomm in its efforts to future-proof itself and to develop a roadmap for further technology developments."

The bald statement from the IEEE just skimmed the surface of the industry-political storm that has been brewing within the 802.20 working group. WiMAX, which meets the same communication needs and has an established standard, is moving towards a certification process. "A number of companies such as Motorola and Navini are focusing closely on mobile WiMAX and Intel has been a strong WiMAX proponent. They do not want to see 802.20 dilute the market," says Solis.

Qualcomm, however, has focused on 802.20 to the exclusion of WiMAX and, it is suggested, has attempted to stack the Working Group with consultants loyal to its cause. Employees of Intel and Motorola filed statements and appeals alleging that a number of consultants had been improperly voting as a block in favor of Qualcomm and that the group's chairman, Jerry Upton, was biased in the company's favor. Upton has since acknowledged that he is a consultant for the firm. The Working Group's suspension is scheduled to last until October 1. After that? According to Solis, it remains to be seen whether the 802.20 Working Group can or will be revived.

Bluetooth in 30 Percent of New Vehicles by 2012

Bluetooth will feature in a third of new vehicles in 2012, increasing from just three percent in 2005, according to a new report from technology and consulting firm Strategy Analytics. This report, "Automotive Communications Market: Bluetooth in 30 Percent of New Vehicles by 2012," predicts that five key influencing factors have led to a surge in automotive Bluetooth applications and cautions car makers not to leave this opportunity to aftermarket vendors. Five key factors have led to an increase in integration of Bluetooth technology in automotive applications over the last 12 months: growing customer awareness of BT; a rapid adoption of BT in cellular phones; strong automotive consumer demand for hands-free solutions; increasing availability of BT solutions in the OE and aftermarket; and legislative measures. "Automotive pricing, promotion and product positioning of Bluetooth versus other in-vehicle features will be critical to how take rates develop over the next two years," says Clare Hughes, Strategy Analytics Automotive Practice analyst. "As we have already seen with portable navigation, poor competitiveness from car makers and automotive system suppliers will result in aftermarket vendors taking a greater share of the growing consumer demand for Bluetooth."

GPS Handsets Playing a Larger Role in Commercial Telematics

According to ABI Research, one of the faster-growing areas in the commercial telematics market is the use of GPS-enabled mobile handsets for mobile resource management. Basic driver and load status information is actively sent via mobile phone to a centralized server, so fleet managers may better organize their field workers and make their operations more efficient. "Just a couple of years ago, handset-based commercial telematics services were a niche application offered in North America by only one major carrier, but they are now becoming an increasingly popular and lucrative business for wireless carriers and ASPs alike," says Frank Viquez, ABI Research's director of transportation research. Many of these services are offered as an add-on component to an existing voice and data plan through such carriers as Rogers Wireless, Spring Nextel, T-Mobile and Verizon Wireless. GPS-enabled handsets are ideal for small to mid-sized fleets looking for a simple and lower-cost means of communicating with drivers and to determine their status for dispatching, time sheet reporting, navigation and exception-based alerts. However, Viquez cautions, "Fleet management services delivered by way of the handset are by no means a comprehensive solution and can never replace embedded hardware." Integrated in-cab hardware offers a deeper level of functionality for fleets, partially including remote diagnostics, driver hours-of-service report, cargo monitoring and additional choices in wireless communications links.

The handset-based market for commercial telematics is not as well-established in Europe as it is in North America; this should not be a surprise, since only a handful of GPS-enabled GSM phones are currently available in Europe. Instead, many commercial fleet services in the region, from vendors such as TomTom, GPS-Buddy (Garmin) and Navman Wireless, focus on a dashtop navigation device as the main user interface, with an integrated wireless modem and black box for wireless connectivity and some major integration. For local fleets centered

around a major geographic center and offering local delivery, utilities and field services, this is an optimum solution and capitalizes on the popularity of portable navigation devices in the region. ABI Research's Commercial Telematics Research Service examines these issues, surveys the entire commercial telematics industry and provides insight into other major market developments.

Bluetooth Chips Get Big Boost from Mobile Phone Market

Fueled by the rapid uptake of Bluetooth in mobile phones, Bluetooth chip shipments have been on the rise, reports In-Stat. The rising Bluetooth chip shipments have had a cascading effect, leading to falling chip prices. This has led, in turn, to greater Bluetooth penetration of mobile phones and the emergence of Bluetooth in other product segments.

"The primary driver for Bluetooth handsets is the desire to connect to Bluetooth mono headsets, nearly 33 million of which were shipped in 2005," says Brian O'Rourke, In-Stat analyst. "This figure is expected to increase to over 55 million in 2006."

Recent research by In-Stat found the following:

- GSM phones have adopted Bluetooth most rapidly, with one-third of GSM handsets in 2005 shipping with Bluetooth.
- European and Japanese automakers made Bluetooth capability available in a greater variety of higher-end cars in 2005.
- According to results from In-Stat's 2006 Residential Technology Survey, 50 percent of average US consumers claimed to be "extremely familiar" with Bluetooth technology, compared to a mere two percent of respondents in a 2005 survey.

The research, "Bluetooth 2006: Mobile Phones & Headsets Driving the Market to New Heights," covers the worldwide market for Bluetooth ICs and applications. It includes forecasts for numerous Bluetooth-enabled products, and unit, revenue and ASP forecasts by Bluetooth type through 2010. It also analyzes Bluetooth standards and other competitive issues including comparison with competing technologies.

In related research, In-Stat found that prospective ultrawideband (UWB) silicon manufacturers will begin shipping UWB chipsets in 2006 and shipments are expected to ramp up with a total of 289 million chipsets shipping in the year 2010. PCs will be the initial and largest volume market for UWB wireless chipsets, with PC vendors shipping over 125 million desktop and laptop PCs with UWB capability by 2010. ■

INDUSTRY NEWS

■ **Agilent Technologies Inc.** and **Xpedion Design Systems Inc.** announced they have signed a definitive agreement for Agilent to acquire Xpedion, a privately held company that provides software for wireless and high speed digital circuit and systems design in the communications industry. The transaction is subject to standard closing conditions. Financial details were not disclosed.

■ **e2v technologies plc**'s subsidiary, e2v technologies S.A.S., has conditionally agreed to acquire **Atmel Grenoble S.A.S.** The acquisition is seen as an opportunity to strengthen the Group's position as a major global provider of specialized electronic components and subsystems.

■ **EFJ Inc.** announced that it acquired **3e Technologies International** (3eTI), a privately held, Maryland-based company. 3eTI is a technology-based company that offers security solutions for wireless platforms such as WiFi, mesh networking and Bluetooth. 3eTI also develops and sells secure wireless infrastructure that meet Federal Information Processing Standards, FIPS 140-2 validated 802.11i-compliant wireless networking standards.

■ **EADS Test & Services** has acquired **Get Electronique**, Castres, France. This small-size company specializes in services in industrial electronics and brings EADS Test & Services additional competencies in electronics repair, maintenance and sustainability in particular for activities aimed at prolonging the service life of systems and installations in such industries as aeronautics, defense, transport and energy. Get Electronique will become a 100 percent subsidiary of EADS Test & Services.

■ **Tech-Etch Inc.**, Plymouth, MA, has acquired the business, facility and assets of the Metals Division of **Innovex Inc.**, located in Litchfield, MN. This business was formerly known as Litchfield Precision Components. Tech-Etch will continue to operate the business in Litchfield and retain the experienced and talented team of managers and employees.

■ **Flomerics Group plc** announced that it has reached an agreement on the proposed acquisition of the entire share capital of **NIKA GmbH**, the Engineering Fluid Dynamics software company based in Frankfurt, Germany, and specializing in simulation tools for the prediction of fluid flow and heat transfer. NIKA's computational fluid dynamics technology is derived from €8.5 M of product development investment, primarily in Russia where scientific expertise is excellent and costs are low. NIKA's technology enhances Flomerics' existing product range and gives access to a much wider potential customer base of design engineers outside Flomerics' existing core market.

■ **Axiom Microdevices Inc.**, a provider of fully integrated complementary metal oxide semiconductor power amplifiers, has formed **Axiom Microdevices Europe Ltd.** and appointed Alex Lloyd as the director of business development for Europe. In addition, Axiom Microdevices has engaged **MJL Technology Ltd.**, a supplier of semiconductor and IT solutions, to represent and distribute its products in the South Korean region.

■ **Nu Horizons Electronics Corp.** announced the opening of the company's first office in Australia, located in Melbourne, Victoria. This location provides local sales and engineering support within Australia and was established as part of the company's ongoing Asia Pacific expansion plans.

■ **Anaren Inc.** announced that its board of directors has approved the expansion of Anaren's design and manufacturing facilities in East Syracuse, NY and Suzhou, China. The East Syracuse, NY expansion includes the construction of a 54,000 square foot addition to the company's 105,000 square foot headquarters, and will more than double the company's existing Space and Defense Group operations. Anaren requested and received a grant from New York's Empire State Development to help fund the expansion. The project is expected to be completed in the second quarter of calendar year 2007.

■ **LTX Corp.**, a provider of semiconductor test solutions, announced that it has completed the relocation of its Westwood, MA corporate headquarters to a new facility in Norwood, MA. LTX's new 56,000 square foot facility is located in a 49 acre research and development office park less than two miles from its previous facility.

■ **Sirific Wireless Ltd.** announced the launch of its operations in Korea. The new office will house sales and applications engineering teams to provide immediate support for domestic handset manufacturers and multinational OEMs with offices in Korea.

■ **picoChip** announced that it is expanding its technical support network with the establishment of a new office in Boston, MA. The company already has a sales office in San Jose, CA, and the new Boston office will act as a technical support center for North America.

■ **D2 Technologies** announced that it has opened a design center in Hsinchu City, Taiwan. The center will be responsible for a variety of R&D projects aimed at advancing the state of the art of VoIP technology.

■ **Ansoft Corp.** has collaborated with **Novas Software Inc.** to integrate Nexxim,® Ansoft's circuit simulation software for high performance IC design, with Novas' Verdi™ Automated Debug System to create an enhanced verification solution. The integration ensures that Nexxim circuit simulation results are readily available in Novas' open Fast Signal Database format, linking Nexxim's high capacity, high accuracy, circuit simulations with Verdi's comprehensive debug platform.

■ **Radio Waves Inc.** announced that they are partnering with **Eupen Cable** to supply their customers with Eupen

Elliptical Waveguide. Radio Waves customers can source microwave antennas and elliptical waveguide as a single package from Radio Waves and have one source for ordering and support.

■ **Wavesat** announced they are working with **Texas Instruments** to develop a 5.8 GHz mini-PCI module and reference design. The product will be commercially available by Q4 of 2006 from Wavesat.

■ **Applied Wave Research Inc.** (AWR®) and **Peregrine Semiconductor** announced the availability of a process design kit for Peregrine's UltraCMOS complimentary metal oxide semiconductor silicon-on-sapphire process in AWR's Analog Office® design suite, a software product developed specifically for analog and radio frequency integrated circuit design.

■ **Kepco Inc.**, a designer and manufacturer of well-regulated DC power supplies and associated electronics equipment, announced a new partnership agreement with **TestMart Inc.**, a marketplace operator and service provider for the IT, network maintenance, and test and measurement industry, who will provide a product catalog and government marketplace services to better serve and expand Kepco's federal customer channel.

■ **Modelithics** and **Johanson Technology** announced the immediate availability of high accuracy models for Johanson Technology's inductor and capacitor products. Complimentary use of these models for qualified designers can be arranged by request at www.modelithics.com/mvp/johanson/. In addition, Johanson Technology has contracted Modelithics to expand its offering of high accuracy substrate-scalable and parts-value-scalable Global Models for several other capacitors, ceramic chip inductors and wire wound inductors.

■ **Avago Technologies** announced that it has extended its agreement with **TSMC** to include the two next generations of its enhanced-performance image sensor products.

■ **Antenna Development Corp.** (AntDevCo) is a New Mexico custom spacecraft and missile antenna design and manufacturing company. While employed at the New Mexico State University Physical Science Laboratory, AntDevCo's principal engineers, Bruce Blevins and Thomas Greenling, developed a miniature X-band quadrifilar helix for the NASA Goddard Space Flight Center's Space Technology 5 (ST-5) spacecraft. This quadrifilar helix antenna — mounted as the primary antenna on three satellites — was launched into an Earth orbit on March 22nd, 2006, and completed the mission on June 30th.

■ **K&L Microwave Inc.** has received ISO 14001 certification for its Environmental Management System (EMS). Implementing an ISO-certified EMS greatly improves the company's ability to manage environmental issues and demonstrates sound environmental management.

■ **Amphenol RF** announced that it is now authorized to market the QMA interface as a member of the Quick Lock Formula® Alliance. Amphenol RF signed a QMA and QN license agreement with Huber + Suhner AG and Radiall SA earlier this year and is now QLF® certified on the QMA interface with the QN to shortly follow.

■ **The Micromanipulator Co. Inc.** announced that it has received notification of the issue of US Patent number 7,043,848 B2. This patent is for control of drift of a probe's position under conditions of stress and special environments.

■ **Pulse®**, a Technitrol company, announced it has joined the Multimedia over Coax Alliance (MoCA®) and will introduce a series of RF diplexers, filters and network interface devices to help enable home networking of digital entertainment between MoCA devices.

■ **Northrop Grumman Corp.** honored six suppliers who have demonstrated exceptional performance and teamwork on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program. The company presented NPOESS Outstanding Supplier Awards to ITT, Raytheon Intelligence and Information Systems, Maxwell Technologies, ABB Bomem, RT Logic and Earth Resources Technology Inc. during its third annual NPOESS Supplier Conference.

■ **RFMD®** announced that the company has commenced mass production shipments of its RF3159 linear EDGE power amplifier to **Samsung Electronics** for use in at least 15 EDGE-enabled handsets.

CONTRACTS

■ **Raytheon Co.** has won an initial $38 M contract from the Global Positioning System Joint Program Office at the US Air Force Space and Missile Systems Center to design next-generation global positioning receivers. An additional award to complete development and fabricate pre-production receiver cards for test and integration in host systems could follow.

■ **L-3 Communications** announced that its Interstate Electronics Corp. subsidiary was awarded $37 M for the first phase of the US Air Force Modernized USER Equipment Program by the US Air Force NAVSTAR Global Positioning System Joint Program Office. The total potential contract value for IEC, including future options, is $90.6 M.

■ **Ducommun Inc.** announced that its Ducommun Technologies Inc. (DTI) subsidiary has been awarded a $3.8 M contract from **Raytheon** for the manufacture and subsystem integration of electromechanical enclosures for the 63V1 and 63V3 radar systems used on the F-15 aircraft. This contract consists of 63V1 radars for Japan and 63V3 radars for multiple customers. The period of performance is through 2007 and the work will be performed at DTI's Phoenix, AZ facility.

■ **TriQuint Semiconductor** announced that the Office of Naval Research has awarded TriQuint a 20-month, $3.1 M contract to improve manufacturing methods of producing high power, high voltage, S-band GaAs amplifiers.

■ **Electron Energy Corp.** (EEC), a producer of rare earth magnets and magnet systems, has been awarded a Small Business Innovation Research (SBIR) Phase II contract by NASA to continue researching high temperature magnetic bearings technology. NASA's Glenn Research Center, Cleveland, OH, selected EEC to receive the $600,000 contract for development through November 2007. EEC will team with Texas A&M University to complete the project.

■ **TRAK Microwave Corp.** announced that it has been selected by **Harris Government Communications Systems**, Melbourne, FL, to be a supplier for its AN/GSC-52 Modernization (52MOD) Program. The AN/GSC-52 terminal is one in a family of Defense Satellite Communication Systems Network Terminals operated by the Army, Navy and Air Force throughout the world. The primary program function of 52MOD is to modernize and extend the life of AN/GSC-52 terminals. TRAK will supply Harris with frequency up/down block converters to support the upgrade activity. The complete modernization program is scheduled to be completed over a multi-year period of performance.

■ **Gennum Corp.**, a volume manufacturer of barium strontium titanate (BST) capacitor chips, announced that **Paratek Microwave Inc.**, a designer of radio frequency solutions, has selected Gennum's manufacturing process for its proprietary products geared towards the RF markets. The primary application for the products will be in the cell phone market where they will be used to increase the performance of handsets and reduce component size thus allowing incremental form factor reduction and/or feature adds.

■ **RF Engines**, a designer of signal processing solutions for FPGA, has been awarded a contract by **Thales**' Land and Joint Systems Division for the supply of a complex channelizer design. Building on the successful launch of the ChannelCore product line in December of 2005, this contract calls for a modified version of that product to meet a specific channel plan and FPGA resource availability. Use of the ChannelCore design has enabled Thales to utilize a small FPGA in the project, therefore meeting both space and power consumption targets.

■ **Symmetricom Inc.** announced that the company was chosen to supply its master reference oscillator for the Mobile User Objective System (MUOS) satellite led by **Lockheed Martin** for a US Navy customer. MUOS is a next-generation narrowband tactical satellite communications system designed to significantly improve communications for US forces on the move. Symmetricom's ultra stable frequency reference was selected based on the program's cost, performance and schedule requirements.

■ **Unity Wireless Corp.** has received purchase orders for its integrated wireless subsystem product from a North American-based wireless network customer. These integrated wireless subsystems form a substantial component of a rapidly deployable, compact base station being readied for deployment by the customer in preparation for use during the present hurricane season.

FINANCIAL NEWS

■ **Andrew Corp.** reports sales of $551 M for the third quarter of fiscal 2006 ended June 30, 2006, compared to $487 M for the same period in 2005. Net income for the quarter was $7 M ($0.04/per share), compared to a net income of $13 M ($0.08/per share) for the third quarter of last year.

■ **Fairchild Semiconductor** reports sales of $409.5 M for the first quarter ended April 2, 2006, compared to $362.8 M for the same period in 2005. Net income for the quarter was $26.6 M ($0.21/per diluted share), compared to a net loss of $10.4 M ($0.09/per diluted share) for the first quarter of last year.

■ **Provigent**, a provider of system-on-a-chip solutions for the broadband wireless transmission market, announced it has secured a credit line of $5 M from Plenus Venture Lending.

NEW MARKET ENTRIES

■ Founded in October 2005, **Centerline Technologies** has been established to meet the changing needs of advanced materials processing. The company's goal is to provide a world-class resource to develop sophisticated manufacturing processes to produce materials with exceptional quality, delivery and value. Services include lapping, polishing, dicing, laser machining and polarizing of filled vias. For more information, visit www.centerlinetech-usa.com or e-mail: sales@centerlinetech-usa.com.

■ **Bradford RF Sales** has been formed as a manufacturer's representative firm for New England. Mike Crittenden, owner, was the former director of sales for Microwave Development Co. and had over eighteen years with the company selling to military and commercial customers. He can be reached at (978) 521-1701 or via e-mail at mike_bradfordrfsales@comcast.net.

■ **Coaxial Precision Assemblies Inc.** (CPA) designs and manufactures semi-rigid, hand-formable and flexible cable assemblies as well as connectors. Cable assemblies can be phase, delay or amplitude matched. The quality of workmanship shows in both good electrical performance and tight tolerance of dimensions from unit to unit. The company can be contacted at 7439 La Palma Avenue #228, Buena Park, CA 90620 (562) 472-0083 or fax: (562) 684-4545.

PERSONNEL

■ Jacket Micro Devices (JMD) Inc. announced that **Joseph A. Crupi** has been named to the JMD board of directors. Crupi has had a distinguished career in the electronics and communications industry. Most recently, he was the vice president, Broadband Communications Group at Texas Instruments.


▲ John H. Warner, Jr.

■ Mimix Broadband Inc. announced that its shareholders have elected **John H. Warner, Jr.** to its board of directors, increasing the number of directors to eight. Warner is currently executive vice president of Science Applications International Corp. (SAIC). He joined SAIC as a member of the technical staff in 1973 and served on its board of directors for nearly twenty years.

■ WJ Communications Inc. announced the appointment of **Patrice Daniels** to its board of directors. She was elected to WJ's board and appointed as a member of its Audit Committee, effective immediately. The company also announced that **Dag Wittusen** has resigned from his position as a member of the board of directors of WJ for personal reasons. Daniels is currently chief operating officer of International Education Corp., a private post-secondary education company.

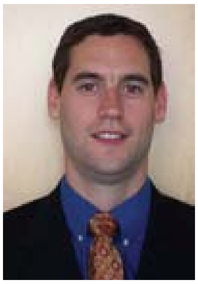
■ EMS Technologies Inc. has reported that **Francis J. Erbrick** and **Bradford W. Parkinson** were elected to join its board of directors at the Annual Meeting of Shareholders. Erbrick and Parkinson join the six directors who had been previously serving, and who were also re-elected to additional one-year terms at the Annual Meeting. Erbrick has worked since 1997 as a consultant with the Business Technology Office of McKinsey & Co., Stamford, CT (since 1997), providing information technology consulting services, typically to large companies. Parkinson holds the title of Professor Emeritus at Stanford University, where he continues to have substantially full-time research and student advisory responsibilities.

■ Peregrine Semiconductor announced that **Craig H. Ensley** has joined its executive team as president and chief operating officer, and has been elected to the board of directors. Ensley has 30 years of broad experience in the semiconductor and systems technology industries, spanning venture capital start-ups to multi-hundred-million dollar public corporations. Most recently, Ensley was with Cirrus Logic, where he led repositioning of the firm to be a highly profitable mixed-signal analog IC company.


▲ Casey Krawiec

■ StratEdge announced that **Casey Krawiec** has been promoted to vice president of North American sales. Krawiec joined StratEdge in August 2002 as senior account manager. His experience includes engineering and sales in the microelectronics and telecommunications industries, especially with high frequency semiconductor packaging and assembly. Prior to joining StratEdge, Krawiec spent seven years at Kyocera America, San Diego, CA, where he held the positions of offshore sales manager and sales engineer.

■ Aeroflex/KDI Resistors announced the appointment of **Richard Galgano** as general manager of Aeroflex/KDI-Resistor Products. Galgano succeeds Robert Hathaway who recently announced his retirement as Aeroflex/KDI-Resistor Products general manager. Hathaway will continue working with resistor products in a consulting capacity. Prior to re-joining Aeroflex, Galgano held various product, process and manufacturing engineering management positions at SGS-Thomson, L-3 and EMC Technologies. Since 2002 he has managed his own business, providing consulting services to a wide variety of top-tier companies, including Aeroflex.



▲ *Alexander Duesener*

■ Cadence Design Systems has appointed **Alexander Duesener** as group director of marketing for the company's activities in Europe, the Middle East and Africa (EMEA). He will hold overall responsibility for platform, product, kits and corporate marketing in EMEA. In his previous role as technical advisor, Duesener was instrumental in helping to define and drive implementation of innovative marketing strategies around core products and new strategic initiatives such as Cadence kits for vertical markets and product segmentation.

▲ *Steve Humphries*

■ Sabritec, a custom connecting devices manufacturer, has strengthened its operations within Europe with the appointment of **Steve Humphries** as European sales manager. In this position, Humphries will be responsible for building on the relationships and partnerships already established throughout Europe by providing commercial and technical product support locally. Prior to joining Sabritec, Humphries was the European sales manager for Florida RF Labs and EMC Technology, where he was responsible for all sales within Europe, the Middle East and Africa.

▲ *Twyla Veal*

■ Dow-Key® Microwave Corp. announced that **Twyla Veal** has been named regional sales manager. In her new position, Veal will manage all sales activity in southern California, New England, upstate New York and Canada. In addition, she will oversee service and technical support for customers in these regions. Prior to joining Dow-Key Microwave, Veal spent 10 years at Relcomm Technologies Inc., where, most recently, she served as sales and marketing services manager.

■ NEC Corp. of America Inc. announced the appointment of **James Limanowski** as the central regional sales manager for NEC's Radio Communications Systems Division. Limanowski will oversee sales, networking and promotional activities required to grow NEC's microwave presence in the Midwest.

▲ *Ian Gresham*

■ M/A-COM Inc. announced that **Ian Gresham**, senior principal engineer at the company's Lowell, MA headquarters, has been awarded the 2006 Outstanding Young Engineer Award from the Institute of Electrical and Electronic Engineers (IEEE) Microwave Theory and Techniques Society (MTT-S). Gresham was given the award in recognition of his leadership in the research and development of technological advances in millimeter-wave silicon and gallium arsenide-based circuits including system-on-chip applications for commercial and defense applications.

■ Cascade Microtech announced that **Eric Strid** and **Reed Gleason**, co-founders of Cascade Microtech, have received the Southwest Test Workshop Lifetime Achievement Award for more than 25 years of outstanding technical contributions to the field of RF wafer level measurements, including the development of the Pyramid probe, a unique production probe card technology that enables highly accurate and reliable at-speed production tests on high performance, high speed and high density semiconductor and related devices. Strid and Gleason were recognized at SWTW 2006, a research forum sponsored by the IEEE Computer Society that focuses on all aspects associated with microelectronic wafer and die level testing.

REP APPOINTMENTS

■ **DesignAdvance™ Systems Inc.**, a developer of design automation software for users of EDA and MCAD tools, announced its entrance into the European PCB design market with the appointment of **CADLOG** as its distribution partner. CADLOG, based in Rome, Italy, is a supplier of design tools and services for the PCB and electronics industries in Italy and southern Europe.

■ **Mica Microwave** announced the appointment of **Brennan Associates** as its exclusive sales representative in Florida, Georgia, Tennessee, Mississippi, North Carolina and South Carolina. Brennan Associates' main office is located at 1428A Gulf to Bay Blvd., Clearwater, FL 33758 (727) 446-5006, fax: (407) 239-6229 or e-mail: sales@brennanassoc.net.

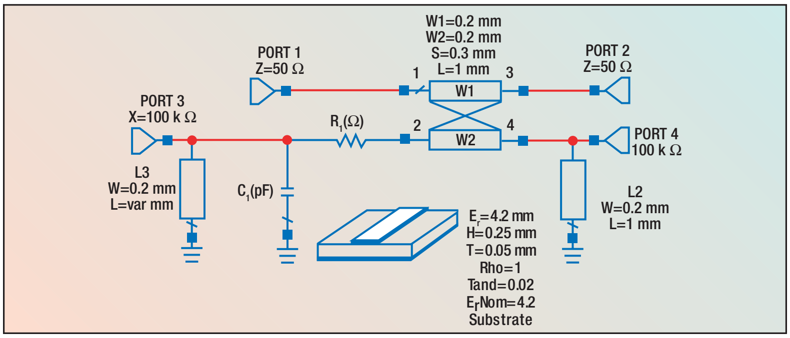
■ **Renaissance Electronics** announced the appointment of the company's newest sales representative servicing the country of Israel — **RST Reut-Systems and Advanced Technologies** for its waveguide product line. Moshe Shani of RST can be contacted via e-mail: moshe@rst-tech.co.il or phone: 972-(0) 52-6545000.

■ **Panasonic Industrial Co.** announced the appointment of **Digi-Key** as an authorized distributor for its line of RF modules including the PAN802154 wireless communication module supporting the 802.15.4 radio standard and the ZigBee™ specification.

COUPLED LINE NOISE IN HIGH SENSITIVITY RF RECEIVER CIRCUITS

Current trends in modern wireless communications systems require advanced digital signals to handle high data throughput. The wider frequency bandwidth of a data-containing signal channel, along with sophisticated digital modulation, result in stringent signal-to-noise ratio (SNR) requirements to maintain affordable data loss (bit error rate (BER), packet/frame error rate (PER/FER), etc.). For instance, digital video broadcasting (DVB) and wireless local area network (WLAN) systems utilize orthogonal frequency division multiplexing (OFDM) wideband signals with multiple sub-carriers, each of which is modulated at a rate much less than the original data-containing signal.[1,2] Although inter-symbol interference due to multi-pass propagation is neglected at a certain level, the communication link is limited by distance, depending on the transmitter output power and the receiver sensitivity. Government authorities are closely monitoring transmitter power emission levels and all existing wireless communication standards require upper power limits. As a result, receiver sensitivity enhancement and antenna gain (directivity) remain the only choices to extend communication link distance for a particular standard.

Fig. 1 Coupled line circuit used in simulations.



There are many noise sources defining receiver sensitivity.[3] The most important are the RF front-end loss between the antenna and the signal demodulator and the noise figure (NF) of the low noise amplifier (LNA). However, there is another, not so obvious noise source in an antenna to demodulator chain — the coupled line loss, which is important when a high signal-to-noise ratio (SNR) is required. This type of loss, as an additional noise source in a receiver chain, is investigated in this article, based on WLAN and DVB-Handheld (DVB-H) systems examples.

SHORT COUPLED LINES IN THE RF FRONT-END

Portable devices are getting smaller and the components positions and their interconnecting lines need to be designed correctly to avoid unexpected system performance degradation. Consider two microstrip lines, somewhere in the RF front-end circuit, coupled over a short 1 mm length (see ***Figure 1***). A laminate substrate (such as FR4, GETEK, BT) is chosen with a typical thickness of 0.25 mm with microstrip line widths of 0.2 mm and a pitch of 0.3 mm. These

OLEKSANDR GORBACHOV
STMicroelectronics
Taipei, Taiwan, ROC

dimensions are typical for WLAN Mini-PCI cards, CardBus32, etc. The positioning of the traces is not as dense as for the already "standard" multi-chip/multi-die modules. Suppose that the useful RF signal is passing through from port 1 to port 2. The line associated with ports 3 and 4 does not necessarily contain an RF signal; it can be some biasing or another line used in the whole circuit. When ports 3 and 4 are simply loaded with 50 Ω (which is pertinent to RF lines), this short coupling area does not usually create problems in an RF system since the coupled power is 50 to 60 dB lower than in the first line at frequencies up to several gigahertz. Just positioning transmit and receive chains not too close to each other is enough for "normal" system operation.

However, if the coupled line is directly connected to ground, capacitors, inductors or resistors, it may create resonances in the line and the coupling with the RF line can be dramatically changed. Such a resonant circuit can be modeled at 2.4 and 5 GHz (WLAN) as well as DVB-H high end frequencies by grounding port 4 through a 1 mm length line and connecting port 3 to an appropriate grounded capacitor. The well-known resonance "killer" is the resistor R_1 shown in the circuit. ***Figure 2*** shows the simulated insertion loss in the RF line (between ports 1 and 2), with L_2 = 1 mm, C_1 = 1.05 pF at 5.26 GHz, C_1 = 5.05 pF at 2.45 GHz and C_1 = 42.0 pF at 0.85 GHz. The Microwave Office circuit simulator[4] was used for the calculations. For simplicity, the capacitance is chosen to be frequency independent and loss less. One can see a large increase in the insertion loss of the RF line, if the resistive loss in the coupled line is small, especially at elevated frequencies. The usual resistive loss of a surface-mount technology (SMT) capacitor is 0.2 to 0.5 Ω at the frequencies considered and one can expect 0.2 to 0.3 dB insertion loss for the 2.4 GHz WLAN receiver, and up to 1 dB for the 5 GHz one. It can be neglected for DVB-H applications. The use of high Q capacitors, associated with coupled lines in RF front-end circuitry, is not suggested in this case. Such behavior is not easily observed if one is monitoring just narrow-band S-parameters and other component characteristics are not tested (or known) separately. The best approach is to avoid resonances near the operating frequencies by an appropriate choice of the trace length and capacitor value. An additional resistor (series or parallel) can be inserted if necessary. This phenomenon has to be understood correctly and differs from the well-known method of noise reduction in digital circuits by introducing a small resistor into a long digital control line.

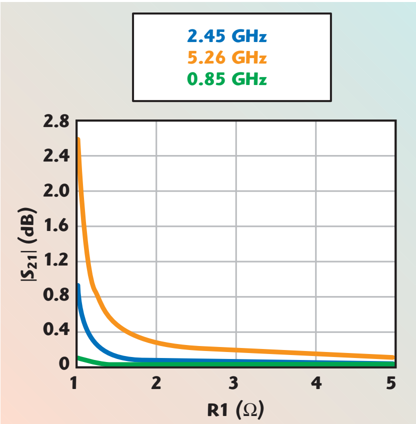


Fig. 2 Insertion loss between Port 1 and 2 for different resonant frequencies in line 3 to 4.

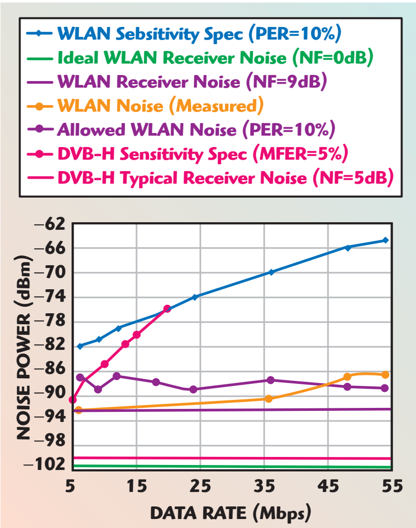


Fig. 3 Noise power in 802.11a WLAN and DVB-H receivers.

The phenomenon of an increased insertion loss in an RF line coupled with another resonating line is not only one of the consequences limiting receiver sensitivity. An RF signal created in a resonating line is coupled back to the "original" RF line. This signal is phase-shifted with respect to the "original" RF signal and appears as noise in the main line. Consider the simplified situation when the RF signal P_{IN} is passing through port 1 to port 2. Suppose this signal is coupled from port 1 to port 3 with a coupling coefficient L_1, creating a power $P_2 = P_{IN}/L_1$ in the coupled line. This attenuated signal is then resonating and coming back to the first line through port 4 to port 2 with a coupling coefficient L_2 and a phase change. The returned power is equal to $P_2 = P_{IN}/(L_1L_2)$. If the coupling area is small and homogeneous, $L_1 = L_2 = L$. The total power at port 2 consisting of the useful signal and noise is given by

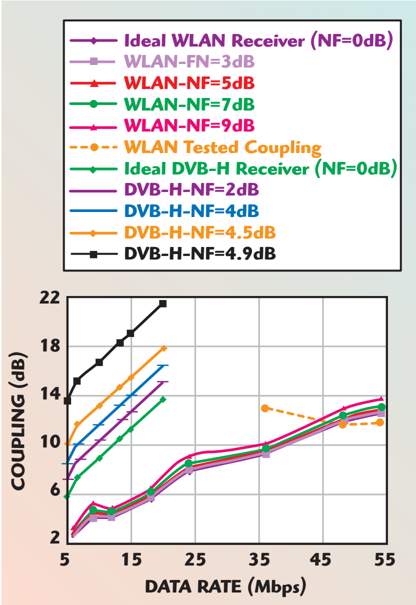
$$P_2'' = P_{IN} - P_2 + P_2' = P_{IN} - \left(\frac{P_{IN}}{L_1}\right) + \left(\frac{P_{IN}}{(L_1L_2)}\right) = \left(1 - \frac{1}{L_1} + \frac{1}{L_1L_2}\right)P_{IN} = \left(\frac{L^2 - L + 1}{L^2}\right)P_{IN}\left[\text{Watt}\right] \qquad (1)$$

Then the SNR can be defined as (all other noise sources being neglected)

$$SNR = \frac{P_{SIGNAL}}{P_{NOISE}} = \frac{(P_{IN} - P_2)}{P_2''} = \frac{\left(P_{IN} - \left(\frac{P_{IN}}{L}\right)\right)}{\left(\frac{P_{IN}}{L^2}\right)} = L^2\left(1 - \frac{1}{L}\right) = L^2 - L \qquad (2)$$

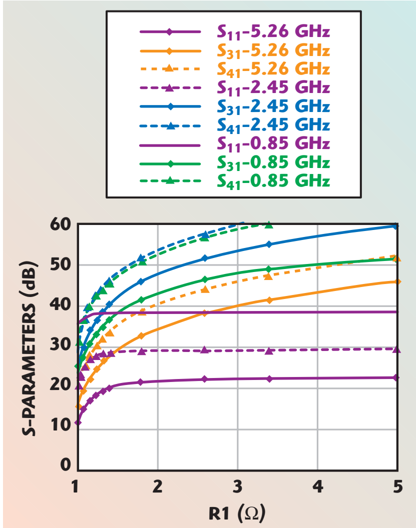
Equation 2 represents the effect of a coupling coefficient between the receiver RF chain line and some neighboring circuit line, the proximity of which can dramatically degrade the sensitivity of a receiver in addition to the "pure" insertion loss increase under the resonating line condition considered above.

Consider as an example the 802.11a WLAN standard requirements regarding the receiver sensitivity. ***Figure 3*** shows a standard noise floor of a receiver for 10 percent PER and the allowed coupling noise, calculated according to Equation 2 for a particular noise figure of the receiver and not taking into account the insertion loss in the coupled lines. It means that, with this coupling noise,



▲ *Fig. 4 Allowed trace coupling in receivers to pass WLAN (PER = 10%) and DVB-H (MFER = 5%) standard specifications.*

the receiver reaches a 10 percent PER with a 3 dB implementation margin for SNR. The figure also shows the receiver noise characteristics for DVB-H mobile (Raleigh fading is taken into account) for multiprotocol frame FER (MFER = 5 percent) and no implementation margin in this case. ***Figure 4*** shows the allowed coupling coefficient between two short lines to pass a standard specification (again without insertion loss consideration). It has to be noted that, although today's implementation of DVB-H is limited to just 13 Mbps data rate compared to 54 Mbps for WLAN, both system's receiver noise requirements are severe. Moreover, a 5 dB "typical" receiver noise figure for DVB-H, as stated in the standard, is more difficult to achieve than for the WLAN one (even a 9 dB noise figure could easily pass this specification). The last two figures also show some test data that will be explained later. One can see that a coupling coefficient of approximately 13 dB between the RF receiver line and another line is already detrimental for the high data rate signals of 802.11a systems. The same coupling coefficient has even a severe impact on the noise coupling in DVB-H receivers at high and mid data rates. It has to be noted that DVB-H receivers require a much lower noise figure. Consequently, this coupling has to be taken care of as well during system noise considerations.

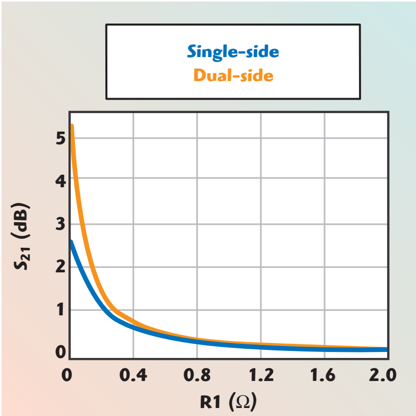


▲ *Fig. 5 Coupling between lines 1–2 and 3–4 for different resonant frequencies in line 3–4.*

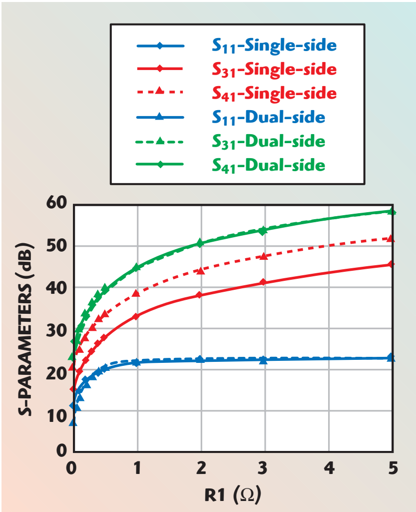
The coupling parameters of the circuit shown previously, with the same circuit element values used to calculate the insertion loss, are shown in ***Figure 5***. One can see that the coupling coefficient is reaching 15 dB in the 5 GHz band for a low series resistance value in the coupled line that, in conjunction with the line insertion loss, can create problems for the receiver sensitivity. The 2.4 GHz band is more resistant to the coupled lines' noise. The DVB-H high frequency couplings have similar levels as the 2.4 GHz ones and the coupling noise can become bothersome only for the 20 Mbps data rate of future applications.

When the resonance in a coupled line is created by two capacitors at the "left" and "right" sides of the 1 mm length coupled area (L2 is disconnected), the insertion loss is slightly higher than for the previous case for reasonable capacitor resistive loss values (0.2 to 0.5 Ω), although it is almost twice as high for very high Q components. ***Figure 6*** shows a comparison of the insertion loss at 5.25 GHz for the cases of a single capacitor, C1 = 1.05 pF, and dual-side capacitors, $C_1 = C_2 = 4.42$ pF with L_2 and L_3 disconnected. At the same time, the coupled noise is considerably lower (see coupling coefficients S_{31} and S_{41} in ***Figure 7***).

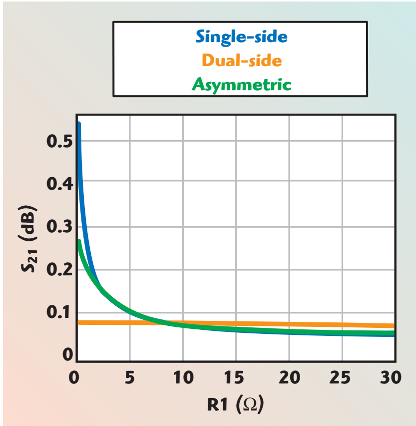
If the resonance is based on distributed transmission lines (microstrip in this case), one can see a considerably lower level of insertion



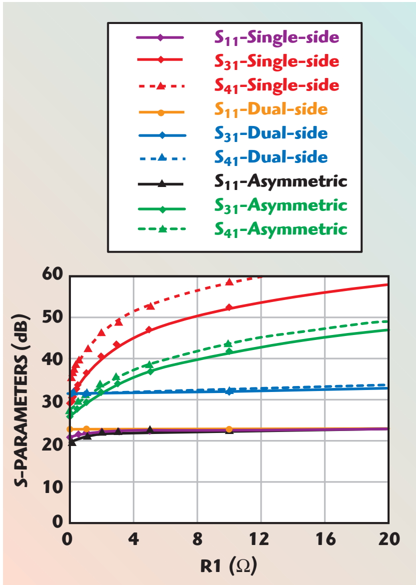
▲ *Fig. 6 Insertion loss in line 1–2 for different capacitor positioning and resonance in line 3–4.*



▲ *Fig. 7 Coupling between lines 1–2 and 3–4 for different capacitor positioning and resonance in line 3–4.*



▲ *Fig. 8 Insertion loss in line 1–2 for different microstrip line lengths creating resonance in line 3–4.*



▲ *Fig. 9 Coupling between lines 1–2 and 3–4 for different microstrip line lengths creating resonance in line 3–4.*

loss in the "main" RF line, compared to the lumped-element resonance of the previous cases (see ***Figure 8***). The greatest influence on insertion loss is noticeable when the coupling area is placed close to the grounded edge of a microstrip line, where the current density is the largest (coupling through magnetic field). Throughout all versions of a coupling area positioning, the coupling coefficients S_{31} and S_{41} are well below –25 dB and the noise level increase in the "main" RF line due to the signal coupled back from the resonating line is very small (see ***Figure 9***).

PACKAGED DEVICES IN RF RECEIVER CIRCUITS

The placement of components and transmission lines on a PCB is flexible and a PCB board designer can choose the correct layout needed. However, there is not too much freedom in packaged device choices. The package leads can create problems similar to those considered in the previous paragraphs. Consider the plastic LQFP lead-frame package often used in mobile RF circuits (transceivers, front-ends, etc.). A schematic of this package, used in the following simulations, is shown in ***Figure 10***. The balanced receiver LNA inputs have been chosen and one chain of a differential signal is coupled with a neighboring line, resonating at the operating frequencies (upper line in figure). Those lines are coupled through the chip package leads as well as through some short coupled lines placed on the PCB. Four microstrip coupled line sections in the middle, along with inductors, represent the RFIC package leads with bonding wires to the receiver chip. The balanced signal chains passing through the package leads are "screened" by the center lead grounded at the PCB side and as well at a package side. For simplicity, the upper-coupled line, inside the chip, is modeled as a grounded 10 pF capacitor (a reasonable approximation of the biasing decoupling circuit). The external part of this line is modeled either as a microstrip line of an appropriate length (to create a resonance at the frequencies considered) or as a grounded capacitor. The series resistance represents the loss in this line. 3 dB power dividers/combiners, along with 180° phase shifters have been chosen to convert the single-ended signal to a balanced one and vice versa.

Figures 11 and ***12*** present the simulated insertion loss and coupling coefficients for the LQPF leadframe package circuit. One can observe a high insertion loss, even in the 2.4 GHz WLAN frequency band, if the biasing coupled line parameters create resonance and the resistive loss in this line is small. It is obvious that a lumped-element resonance elevates the noise level more than a transmission line-based one. One can suggest inserting an artificial loss (series resistor) into this line to increase the sensitivity of a receiver. It has to be noted that the 5 GHz operation is not as good for this package due to fairly long lead traces, even with an appropriate series resistor. The "residual" insertion loss for a receiver is 0.65 to 0.7 dB. At the same time, a series resistor is mandatory in this line to avoid an additional "coupling back" noise from the biasing line to the receiver RF line (see Figures 12 and 4); even a small parasitic external capacitance with a value of 0.3 pF will create a resonance.

A low profile, leadless, QFN plastic molded package is preferred at high frequencies. ***Figure 13*** shows the dramatically decreased insertion loss simulated for the QFN package circuit (similar to the one for the LQFP package and for simplicity TL1 = TL2 = 0). However, the "coupling back" noise is still pertinent to this package and the insertion of at least a small series resistor into the biasing line is suggested (see ***Figure 14***) when the resonance in the neighboring line is close to the operating frequencies.

The simulations show that the LQFP package is not suitable for DVB-H applications due to increased insertion loss with coupled lines. The QFN package has no problems in DVB-H applications. At the same time, the "coupling back" noise is not a problem for both packages with reasonable component losses of 0.2 to 0.5 Ω. The differential signals considered create less coupling than single-ended signals (by approximately 3 dB). Thus, with single-ended RF lines, the coupling has to be verified more carefully. Certainly, the simulations shown have some estimated character due to the circuit simulator used. A 3D simulator used for electro-magnetic structures, however, shows good agreement within 1 dB. Notice that the coupling coefficients are somewhat dependent on the coupled line active resistors modeled in ports 3 and 4.

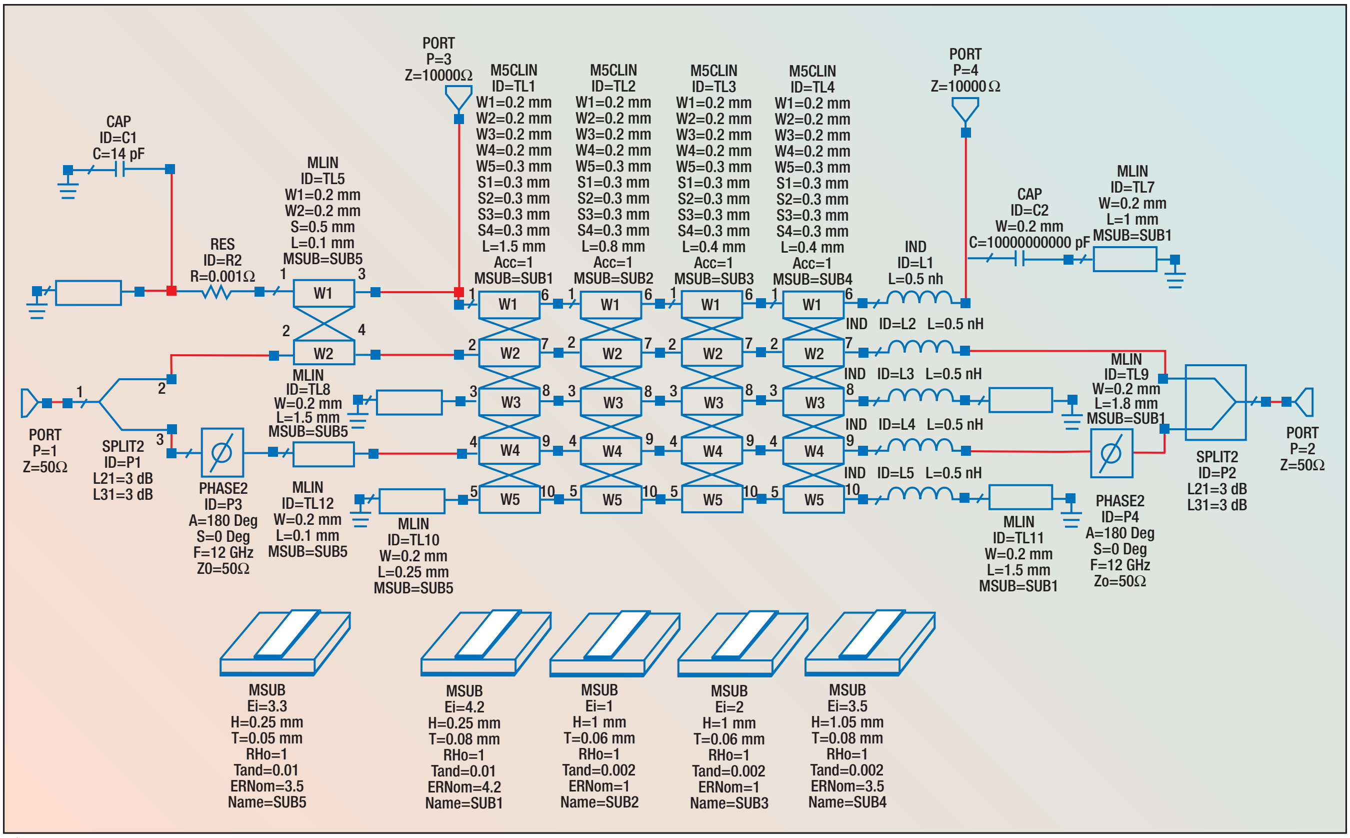


Fig. 10 LQFP lead-frame package example schematic used in simulation.

TEST RESULTS

An LQFP-48 lead-frame plastic package with an 802.11a WLAN transceiver placed on a Mini-PCI card has been tested. The equivalent circuit of the receiver section is similar to the one simulated. One of balanced input lines of the receiver is placed near to a control line, modeled as a capacitance of 10 pF at the semiconductor die side and as a 29 mm-long microstrip line and 1 kΩ resistors at ports 3 and 4. The simulation results for this circuit are presented in ***Figure 15***, without a series resistor in the control line. One can see that the long length of the control line creates multiple resonances, one of which is falling into the 5 GHz frequency band. The multiple lines neighboring to the control line can

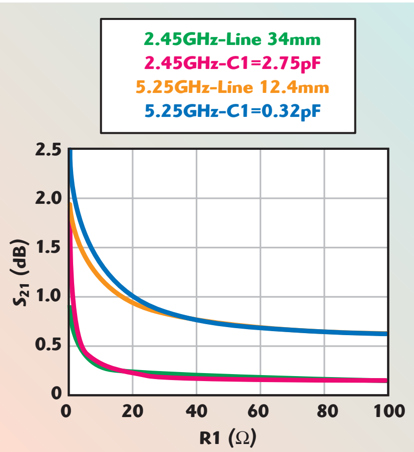


Fig. 11 Simulated LQFP package insertion loss in line 1–2 for different microstrip line lengths and capacitors, creating resonances in line 3–4.

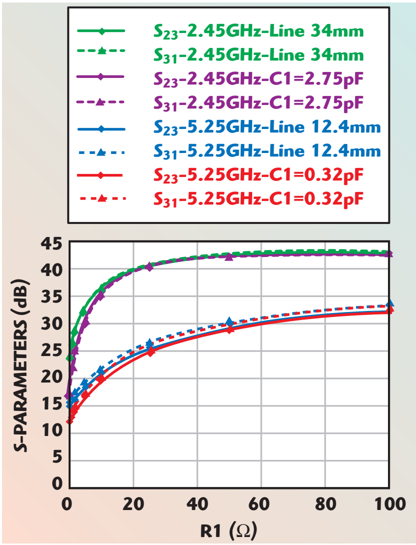
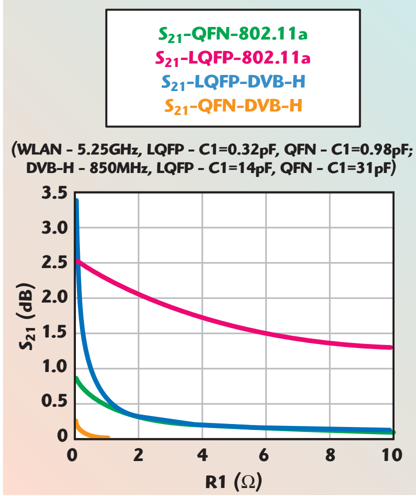


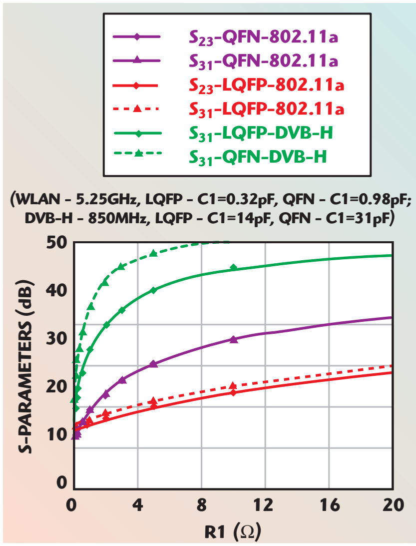
Fig. 12 Simulated LQFP package coupling coefficients between lines 1–2 and 3–4 for different microstrip line lengths and capacitors, creating resonances in line 3–4.

worsen the situation with coupling and resonances distribution.

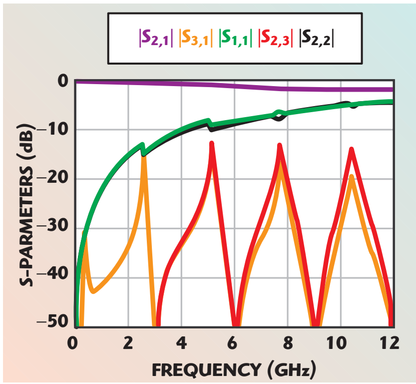
The noise floor of a receiver, measured at the baseband outputs, was shown earlier. One could see a rise in the noise floor at high signal data rates. The simulated results for the RF input line coupling with the neighboring line necessary to get the noise floor rise was also shown. The coupling coefficient between port 1 and port 4 as well as between port 4 and port 2 shown in the package simulation is approximately 12 dB, the same level as before. One can guess that this coupling results in an additional noise. A 50 Ω series resistor has been inserted into the control line that resulted in a 1 dB noise floor improvement. PER has been tested before and after this procedure for fixed input power levels (see ***Figure 16***). It is obvious that, without a series resistor, the PER test data variation is much higher than when a 50 Ω resistor is inserted. The absolute value of



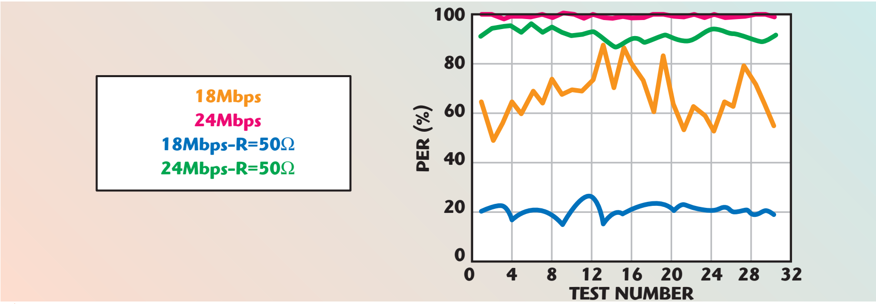
▲ *Fig. 13 Simulated 802.11a WLAN and DVB-H receiver line 1–2 insertion loss for LQFP and QFN packages for resonant circuits created by capacitors in line 3–4.*



▲ *Fig. 14 Simulated 802.11a WLAN and DVB-H receiver coupling between lines 1–2 and 3–4 for resonant circuits created by capacitors in line 3–4.*



▲ *Fig. 15 Simulation of real 802.11a WLAN receiver circuit used for test.*



▲ *Fig. 16 Measured 802.11a WLAN receiver (LQFP package) PER improvement by insertion of a 50 Ω resistor in the control line.*

PER becomes more than three times lower (from 65 percent average to 20 percent average) at an 18 Mbps data rate. At 24 Mbps, without a series resistor, the PER is always higher than 99 percent. However, inserting a 50 Ω resistor has resulted in a PER of 90 percent. This result provides approximately a 1 dB improvement in the noise figure of a receiver, which has been confirmed by a sensitivity test.

CONCLUSION

Coupled line loss is pertinent to all RF circuits. This loss becomes obvious, even for short lines, one of which creates a resonant circuit at the operating frequencies. This resonance occurs not necessarily in the RF line. The insertion loss increase and the "coming back" noise decrease the sensitivity of different RF receivers, even at quite low DVB-H frequencies. High-Q SMT components are more difficult to use in RF front-ends. The insertion of an appropriate resistor into the biasing or control line may increase the sensitivity of the RF receivers. High frequencies are more prone to the losses mentioned above. Long-lead packages are one of the possible reasons for the system noise degradation. Wideband frequency measurements of S-parameters are needed to discover possible noise degradation. The extensive simulation data presented in this article may be useful for different RF receiver circuits. The 5 GHz WLAN test example described validates one approach considered. ■

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4. *Microwave Office*, Applied Wave Research, 2002.

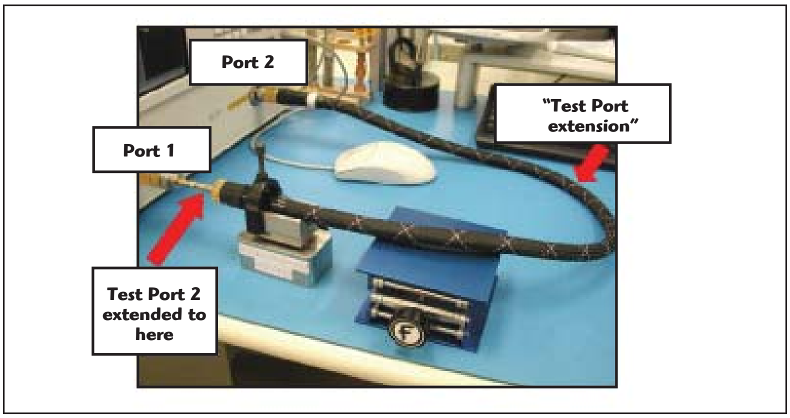
Oleksandr Gorbachov *received his PhD degree in electrical engineering from the Kiev Polytechnic Institute, Kiev, Ukraine, in 1990. He has more than twenty years experience in product research and development from RF through millimeter-waves in different R&D and application engineering positions. He is currently the RF applications manager at STMicroelectronics, Taipei, Taiwan. His engineering and scientific interests include RF components and modules for wireless communications.*

DISTORTION INHERENT TO VNA TEST PORT CABLE ASSEMBLIES

Today's modern vector network analyzers (VNA) are the product of evolutionary advances in technology that literally span decades — a marrying of the latest developments in microwave, integrated circuit and software technologies. To a great extent, the precise nature of vector network analysis results from its highly developed calibration algorithms and methodologies. In many VNA applications, a flexible test port cable assembly or "test port extension" may be required. The test port extension is used to establish a through connection for calibration purposes and for making measurements of the device under test (DUT). Generally, a single port extension is used, but this is by no means the rule. Port extensions may be employed on Port 1, Port 2, or both VNA ports as well. Capable of very precise and accurate results, a VNA's performance is predicated upon the stability and repeatability of the measurement system, that is, the DUT-to-VNA interface, which includes the test port extension, if used.

A test configuration using a flexible test port extension on Port 2 is illustrated in ***Figure 1***. The resulting calibrated measurements of a given DUT will contain notable inconsistencies. When observing the analyzer display, S_{22} return loss will differ from S_{11} return loss, appearing somewhat "noisy" in nature. If the test port extension is flexed, changes in both S_{22} and S_{11} return loss data will be observed. If measuring a low loss DUT, the aforementioned behavior is exaggerated. The intent of this article is to offer a qualitative explanation for this behavior and its underlying mechanisms.

Fig. 1 VNA shown with a flexible test port cable assembly on Port 2.

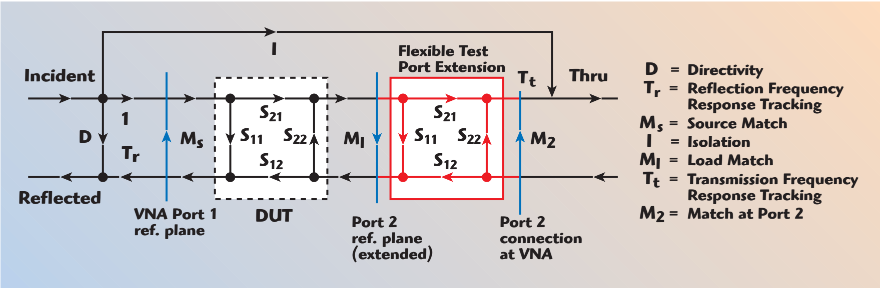


UNDERSTANDING HOW A VNA WORKS: VNA MEASUREMENT ERROR TYPES

Directivity Error

A vector network analyzer utilizes directional couplers for measuring forward and reverse propagating signals. Directivity is a mea-

PAUL PINO
W.L. Gore & Associates Inc.
Elkton, MD



▲ *Fig. 2 Forward (S_{21}) two-port error model showing port reference planes (blue) and flexible test port extension model (red).*

sure of a coupler's ability to discriminate against a signal that is propagating against the "coupled direction."

Reflection Response/Transmission Response Tracking Error

These errors represent the differences between reference signal paths and signal measurement paths.

Source Match Error

Error generated as a result of the mismatch between the source test port and the measurement system (this includes any device connected to the source test port).

Isolation Error

Error generated as a result of signal leakage between reference and measurement channels within the vector network analyzer.

Load Match Error

Error generated as a result of the mismatch between the load test port and the measurement system (this includes any device connected to the load test port).

Port 2 Match Error

Error generated as a result of the mismatch between the VNA test port and the test port extension.

The flow chart shown in ***Figure 2*** is a popular format for describing both the desired signal flow and error signal flow associated with VNA measurements. Specifically, the diagram describes a "forward" S_{21} transmission measurement where the intended signal flow is left to right, from Port 1, through the DUT, and into Port 2. A representation of the flexible test port extension used in this study is highlighted in red. This error model represents the test configuration depicted in Figure 1.

The diagram can be applied to S_{11} return loss measurements as well. The various errors listed previously are corrected for during the calibration process. A mirror image of the diagram would apply to "reverse" S_{12} transmission data and S_{22} return loss data, port reference planes are highlighted in blue.

SUMMARY OF FINDINGS

Through the calibration process, the VNA corrects for the phase and amplitude characteristics of the measurement system using a process known as "error correction." A test port cable extension, if used, is considered part of the VNA measurement system. The error correction operation is static in nature. The correction algorithm "assumes" the test port extension's phase and amplitude response remain constant. In short, the error correction algorithm is unable to compensate for future system changes.

The "noisy" quality noted primarily in, but not limited to, the DUT's S_{22} return loss data stems from minute physical changes within the test port cable assembly — physical changes that occur during flexure. As a result, the measurement system has been altered from its original calibration state; the VNA's error correction algorithms cannot compensate for this change.

These now-uncorrected changes are manifested as properties of the DUT, and are visible within the associated S-parameter data — most noticeably, in the return loss/VSWR data of the port equipped with the test port cable assembly. As the frequency increases, adverse effects resulting from changes in phase and amplitude response become more pronounced. This is especially true with phase, following the relationship

$$\text{degrees} = t\ (\text{ns}) \bullet 360 \bullet f\ (\text{GHz})$$

where a time period, t is expressed in degrees at a frequency, f. This formula can be used to describe a particular cable assembly feature, with the feature in question having a time delay measured in nanoseconds, whose electrical length in degrees increases with respect to wavelength. As the frequency increases, the wavelength decreases. Although constant in its time delay, the feature size can cover multiple wavelengths or a fraction of a wavelength, depending upon the frequency of interest.

An unstable, flexible test port cable assembly will have a profoundly negative impact on a VNA's measurement accuracy. By selecting a high quality cable assembly having long-term stability, coupled with proper measurement practices, one can significantly augment the capabilities of any VNA.

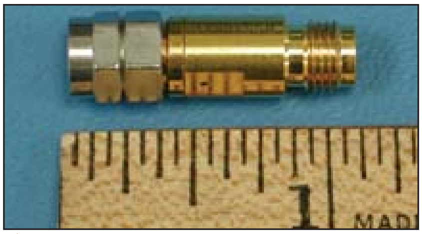
DESCRIPTION OF TEST PROCEDURE AND EQUIPMENT

The following equipment and procedures were used in this study. Data was captured using GORE proprietary software.

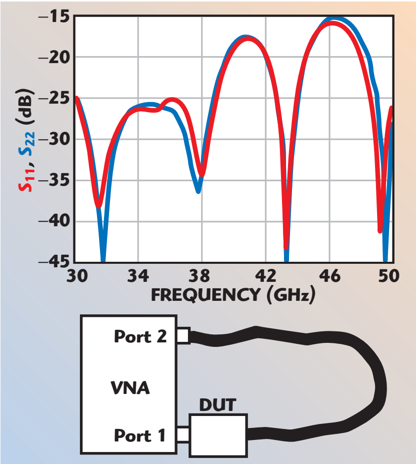
- Agilent Technologies PNA, model E8364B, swept frequency range: 0.010 to 67 GHz
- Flexible test port cable assembly, 2.4 mm socket to 2.4 mm ruggedized, NMD-style socket, GORE FE0BN0-BL038.0, length: 38 inches
- Calibration standard: Agilent Technologies E-CAL unit, 0.010 to 67 GHz, equipped with 1.85 mm interfaces

The ambient test conditions were 23° with relative humidity controlled at 20 percent. A full two-port calibration, omitting isolation, was applied over a frequency range of 0.0625 to 50 GHz, 800 points with an IF bandwidth of 100 Hz. No smoothing or averaging was used.

The low loss "insertable" DUT consists of an Anritsu 1.85 mm pin to



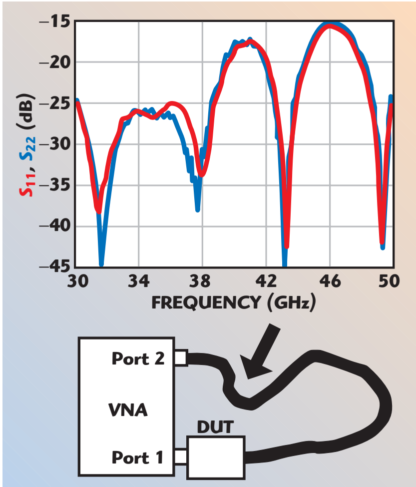
▲ *Fig. 3 The 1.85 mm pin to 1.85 mm socket adapter used as a low loss DUT.*



▲ *Fig. 4 S_{11} and S_{22} data for the low loss DUT with flexible test port extension in "not flexed" position.*

1.85 mm socket adapter, commonly known as a "connector-saver" (see ***Figure 3***). This adapter is considered to be a stable and sufficiently precise device for the purposes of this study. After inserting the DUT and carefully tightening the interfaces to the proper torque specification, the test port cable assembly was examined to ensure it was routed in a wide arc with no undue stress placed upon it. Support fixtures were used to hold the DUT side of the test port cable assembly (see Figure 1). At this point, a base-line data set comprising all four S-parameters was recorded.

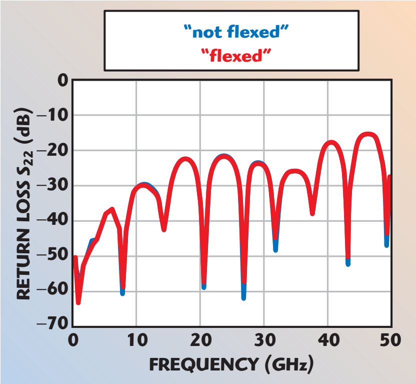
After recording base-line data, the test port cable assembly was bent sharply at a point just after the Port 2 connection. A data set consisting of all four S-parameters was collected with the cable assembly held in this bent or flexed position. Phase and amplitude characteristics of the DUT in the "flexed" and "not flexed" states were compared.



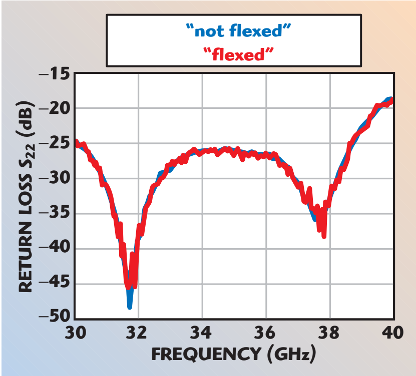
▲ *Fig. 5 S_{11} and S_{22} data for the low loss DUT with flexible test port extension in "flexed" position.*

S-PARAMETER ANALYSIS

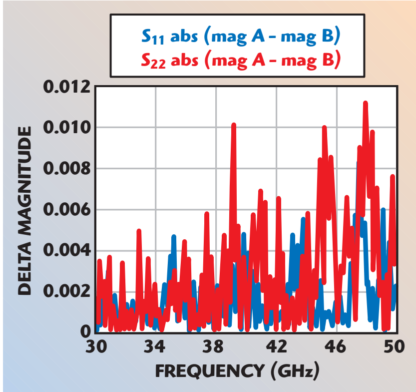
Although very slight, ***Figure 4*** demonstrates the differences between S_{11} and S_{22} data when a test port assembly is used. In ***Figure 5***, the test port assembly is flexed, as described in the test procedure. In this case, the differences are more prominent — S_{22} data differs noticeably from S_{11}, especially in terms of trace smoothness. Observe that the "not



▲ *Fig. 6 S_{22} return loss of the low loss DUT using the flexible test port extension; S_{22} "flexed" and "not flexed" data are overlaid.*



▲ *Fig. 7 Enlarged view showing S_{22} return loss of the "flexed" vs. "not flexed" states.*



▲ *Fig. 8 S_{11} and S_{22} difference magnitude of low loss DUT with the flexible port extension, as measured before "B" and after "A" the test port cable assembly flexure.*

flexed" S_{11} data differs from "flexed" S_{11} even though the distortion-inducing flexure occurred on the Port 2 side of the measurement system.

Figure 6 illustrates S_{22} return loss data for the low loss DUT using a test port extension in both the "flexed" and "not flexed" positions — note the behavior at and around nulls. ***Figure 7*** is a detailed view concentrating on performance between 30 and 40 GHz. Differences are due to phase/amplitude changes in test port assembly affecting error correction.

A more revealing representation for the change in return loss involves applying a subtraction operation to the "flexed" and "not-flexed" data sets, as seen in ***Figures 8*** and ***9***. In this case, the change in S_{11}, that is, a port not fitted with a port extension, is compared to the change in S_{22}, a port fitted with a port extension. The assumption being that S_{11} will change little, if not at all during flexure.

Figures 8 and 9 are comparisons between "flexed" and "not flexed" states on Ports 1 and 2. To gain a better understanding of the magnitude of change on Port 1 compared to Port 2, refer to Figure 8. For an idea as to how changes in magnitude compare to key VNA calibration error criteria such as source match, load match, reflection tracking and directivity (all expressed in dB), refer to Figure 9.

As the change between the "flexed" vs. "not flexed" condition approaches –45 dB, anomalies appear in the S_{22} return loss data. This behavior can be verified by examining Figures 4 and 5. In general, desirable corrected error levels for source match, load match, reflection tracking and directivity are in the realm of –45 dB. Measurement system distortion approaching this level will have a detectable influence upon the S-parameter data of the DUT. Distortion levels less than –50 dB are generally beyond the system's ability to distinguish such detail.

In Figures 6 and 7, a change in both S_{11} and S_{22} return loss is recorded. During calibration, the test port extension connected to Port 2 acts as the load match measurement path for Port 1. When the cable assembly is in the "flexed" state, any consequent distortion will affect the load match correction for Port 1. This explains the small change in S_{11} return loss even though the test port cable assembly was flexed very close to Port 2. If the DUT had possessed a significant amount of insertion loss, the change in S_{11} return loss between "flexed" vs. "not flexed" states would have been less pronounced. A high insertion loss DUT would isolate the two ports from one another, effectively reducing the influence of Port 2-related distortion on Port 1. ***Appendix A*** provides detailed explanations and examples of the basics of vector error correction.

INSERTION LOSS AND PHASE ANALYSIS OF LOW LOSS DUT

Figures 10 and ***11*** display the resulting apparent changes in insertion loss and insertion phase of the low loss DUT used in this experiment. The data clearly indicates a difference in phase and amplitude performance between the "not flexed" vs. "flexed" states of the test port cable assembly. To further emphasize an important point, these changes in phase and amplitude should not be confused with DUT performance; they are solely the result of changes within the measurement system that cannot be accounted for by the VNA

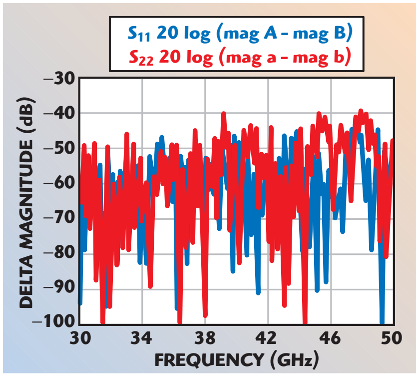


Fig. 9 S_{11} and S_{22} difference magnitude in dB, as measured before "B" and after "A" the test port cable assembly flexure.

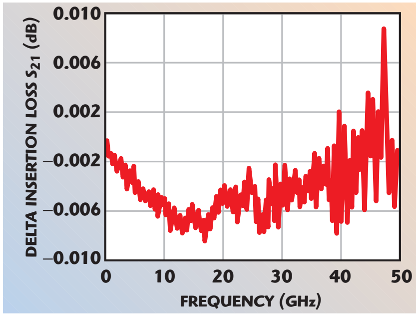


Fig. 10 Apparent change in S_{21} insertion loss of the low loss DUT with the flexible test port extension in "flexed" vs. "not flexed" states.

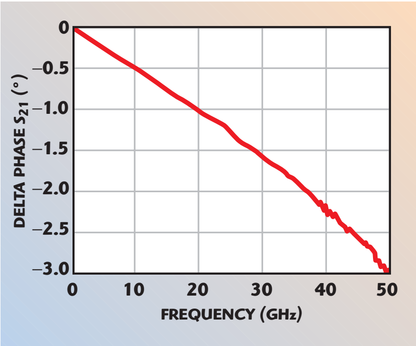


Fig. 11 Apparent change in S_{21} phase of the low loss DUT with the flexible test port extension in "flexed" vs. "not flexed" states.

error correction algorithm. As stated earlier, changes in the measurement system can easily be misinterpreted as changes in DUT performance.

CONCLUSION

The intent of this article was to explain the basic principles of VNA error correction and how VNA measurement system effects can be confused with DUT performance. This topic was deliberately approached in a qualitative manner so as not to burden the reader with the complexity of error correction algorithms. In closing, the following practices can be used to minimize the changes in phase/amplitude response associated with test port cable assemblies:

- For measurements requiring a high degree of precision and accuracy, limit test port assembly movement during the calibration and measurement processes
- Before using any cable assembly as a test port extension, measure its phase/amplitude response with flexure in two orthogonal planes of motion, noting which plane of motion yields the smallest change in phase/amplitude response. When attaching the assembly to a VNA, orient the cable so that its movement is in the plane of motion yielding the least amount of phase/amplitude distortion
- To track performance degradation, periodically check the phase/amplitude stability of the flexible test port cable assembly by using the manufacturer's advertised test method
- Ensure that all VNA and DUT connections are clean and the specified connector tightening torque is observed. Inspect all DUT and test system connectors for damage; inspect all DUT and test system connectors for proper pin/socket height specifications before connecting to mating connectors
- Perform VNA measurements in a temperature-controlled environment, ensuring instrumentation is positioned well away for heating/cooling ducts. Avoid placing instrumentation near exit/entrance ways, as these areas can experience intermittent fluctuations in temperature

When considering the purchase of a test port cable assembly, carefully review and compare manufacturers' claims of stability and repeatability with flexure. To realize optimal VNA performance, a high quality cable assembly with consistent long-term performance is required. ■

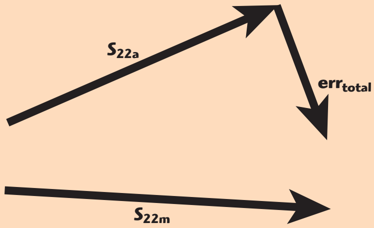
ACKNOWLEDGMENT

The author would like to thank Harmon Banning — mentor, teacher and friend — for his guidance in the preparation of this paper.

Paul Pino *received his BS degree in electrical engineering from the University of Delaware in 2000 after leaving a long career in the automotive industry. He joined W.L. Gore & Associates Inc. in 1999 and has worked with various groups, including Gore's Signal Integrity Lab, the Planar Cable Team and the Fiber Optic Transceiver Team. For the past four years he has worked within the ATE Microwave Group.*

APPENDIX A

SIMPLIFIED EXPLANATION FOR THE ILLUSTRATED BEHAVIOR IN FIGURES 4 THROUGH 7



Condition is for stable calibration – ideal

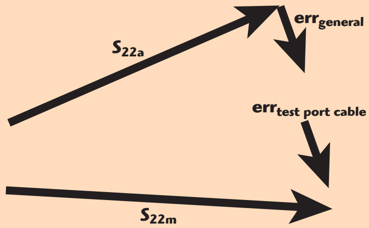
$$S_{22m} = S_{22a} + err_{total}$$

To arrive at corrected reading:

$$S_{22a} = S_{22m} - err_{total}$$

The S_{22m} vector represents a measured or uncorrected S_{22} data point. The S_{22a} vector is an actual or corrected data point. When making a calibrated measurement, corrected data is displayed on the VNA screen. The err_{total} vector is the sum of all error correction associated with a particular calibrated VNA measurement at a specific data point.

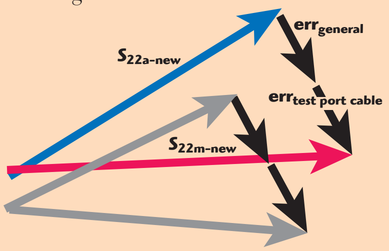
In reality, the err_{total} vector is comprised of several error correction vectors, including correction for the error associated with the calibration standards, as well as error associated with Port 2 of the VNA — hereafter referred to as $err_{general}$. In this example, a test port cable assembly connected to Port 2 is used as part of the calibrated measurement system. A portion of the error associated with Port 2 of the VNA is related to the test port cable assembly.



For this example, total error is:

$$err_{total} = err_{general} + err_{test\ port\ cable}$$

Once the test port cable assembly is flexed (after a calibration is completed), the following occurs:



Grey vectors represent initial S_{22a} and S_{22m} results under ideal conditions
Colored vectors represent S_{22a} and S_{22m} results with test port cable flexed

Error correction vectors are fixed (in magnitude and phase) for a given calibration, therefore all measurements subsequent to calibration have correction applied that assumes the measurement system is static.

With the test port cable assembly flexed, phase/amplitude distortion occurs. This distortion is manifested as a property of the DUT, not the test port cable assembly. The effect is $S_{22m\text{-}new}$.

The result: S_{22m} has changed in magnitude and phase, thus S_{22a} must change since it is calculated from S_{22m}. The outcome — $S_{22a\text{-}new}$ — results from a calibration correction based upon having the test port cable in its original "calibration position" (shown in grey).

RF POWER DETECTION: MEASURING WIMAX SIGNALS

WiMAX, which offers high speed data access to large geographical areas — covering distances up to 30 km — is defined by the IEEE 802.16 family of standards. It uses orthogonal frequency division multiplexing (OFDM) to attain the high data rates. Consequently, the composite signal envelopes of the data bursts have significant peaks, which cause large modulation crest factors. Accurate measurement and control of WiMAX signals is challenging, due to the typically high WiMAX crest factors of 12 dB and to its susceptibility to the varying modulation patterns. As WiMAX users move towards or away from the base station, the transmitter changes the waveform composition (or modulation) to optimize data speed and reception reliability. As the waveform changes, the corresponding crest factor variation introduces RF power measurement errors.

This article describes several methods to accurately measure and control the power of WiMAX transmitters. WiMAX transmit signal paths can employ high dynamic range logarithmic amplifiers and accurate rms detectors to ensure accurate control of the transmitted signal across changing modulation types and over temperature. Some of the highlighted topics will cover the difficulties in dealing with changing crest factors and rapid envelope changes.

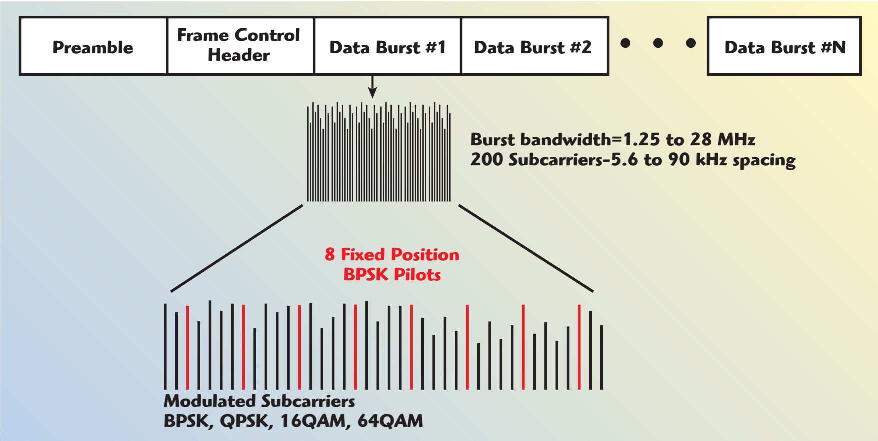
WIMAX STANDARDS

IEEE 802.16, the formal specification of WiMAX, is targeted at providing broadband wireless access beyond that which is currently available using IEEE 802.11x (WLAN). 802.16-2004 (sometimes called 802.16d), the latest full revision of the WiMAX standard, focuses primarily on fixed position point-to-point or point-to-multipoint networks. The standard defines OFDM modulation, a frequency range of 2 to 11 GHz, and data rates up to 70 Mbps. OFDM modulation in 802.16d utilizes up to 256 subcarriers with bandwidths from 1.25 to 28 MHz. The subcarriers are spaced such that they are orthogonal to each other, thus reducing signal interference. The choice of signal bandwidth can be determined in multiple ways. The base station can change the signal bandwidth based on transmission distance and signal environment, or network providers may determine the bandwidth available to a user, based on various pricing plans. ***Figure 1*** shows a basic diagram of the signal structure for an 802.16d network.

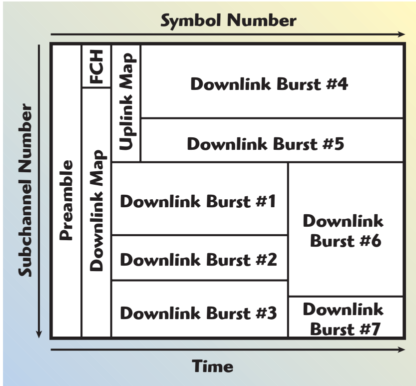
CARLOS CALVO
AND MATTHEW PILOTTE
Analog Devices Inc.
Norwood, MA

A recent amendment to 802.16-2004 focuses on the OFDMA physical layer. This updated standard, 802.16e-2005 (or Mobile WiMAX), introduces specifications that allow for mobility in a WiMAX network at speeds up to 75 MPH (120 kPH). In order to accomplish this, 802.16e increases the number of available carriers from 256 to 2048, with the BPSK pilot tones no longer at fixed intervals during each data burst. The bandwidth for each data burst includes 1.25, 5, 10 and 20 MHz. It is also possible that additional bands at 3.5, 5.5 and 7 MHz will be made available for use in Europe. While the 802.16d standard includes specifications for the entire 2 to 11 GHz band, 802.16e focuses on licensed bands below 4 GHz. ***Figure 2*** shows how the data bursts for an OFDMA network overlap in time, as opposed to the individual bursts of OFDM. This added complexity allows for a larger number of users and handles the necessary complexity for a multi-path mobile environment. 802.16e also merges WiBro under this IEEE standard. WiBro, a Korean system for wireless broadband access, was introduced in February 2002 when the Korean government allocated 100 MHz of spectrum from 2.3 to 2.4 GHz. This band was then standardized by the Korean Telecommunications Technology Association (TTA) in late 2004. WiBro base stations offer a theoretical data rate up to 50 Mbps and cover a radius of 1 to 5 km, allowing the use of portable and mobile Internet devices within the range of a base station. Under 802.16e, WiBro is defined as one of the available system profiles and consists of 1024 subcarriers within an 8.75 MHz bandwidth.

As shown in the figures, WiMAX is transmitted using OFDM and is made up of 256 to 2048 subcarriers, each of which is modulated using BPSK, QPSK, 16QAM or 64QAM. The combination of all these subcarriers and different modulation schemes results in the potential for large peaks and troughs during each signal burst. In theory, it is possible for these extremes to fall on top of each other causing a large peak-to-average ratio (PAR) or crest factor (CF). Variations in data rate and burst length will affect the overall signal crest factor. This can cause issues even in the simplest of WiMAX systems. For example, a system which utilizes 256 subcarriers will have a theoretical crest factor of 10 log(256) = 24 dB. In practice, it is more likely to only have a peak crest factor of 12 dB because the probability that the phase of every subcarrier will add together is very low. A crest factor of 12 dB still poses significant design considerations with regards to the selection of high linearity devices (mixers, modulators, power amplifiers, etc.) in the RF signal chain. Because WiMAX systems can be used for non-line-of-sight applications, gain control of the transmitter is necessary to adjust the output TX level depending on the channel quality. It is also necessary to accurately control the power amplifier's output in order to avoid signal clipping and increased distortion. Some systems employ crest factor reduction schemes, typically in the digital baseband processing, to minimize these effects.



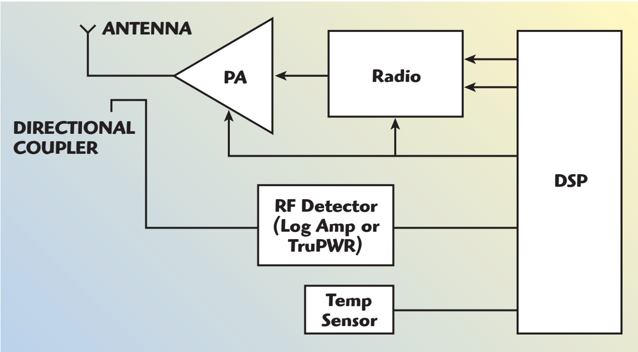
▲ *Fig. 1 806.16d OFDM data burst and signal spectrum.*



▲ *Fig. 2 806.16e OFDMA data burst.*

RF POWER DETECTION IN THE TRANSMIT SIGNAL CHAIN

Figure 3 shows the block diagram of a typical WiMAX transmit signal chain. The transmit signal path consists of three consecutive stages: digital baseband processor or digital signal processor, radio and power amplifier. A portion of the transmitted signal is sampled by the directional coupler before it reaches the antenna. The sampled RF power is delivered to the power detector where it is converted to a DC voltage. The output voltage of the power detector is digitized and fed to the digital signal processor (DSP). Once the power measurement is available as a digital level, a decision is made based on the measured output power versus the desired output power. The DSP will adjust the output power using a digital-to-analog converter to drive the signal path power control, either at the baseband, radio or power amplifier. The RF power management loop will reach a steady-state once the measured output power and the desired output power are balanced. A temperature sensor can also be introduced as an input to the DSP to add temperature compensation capabilities. This RF power management configuration is not limited to a particular application. Both base stations and subscriber stations alike may incorporate variations of this same RF power control system.



▲ *Fig. 3 WiMAX transit signal chain with RF power management.*

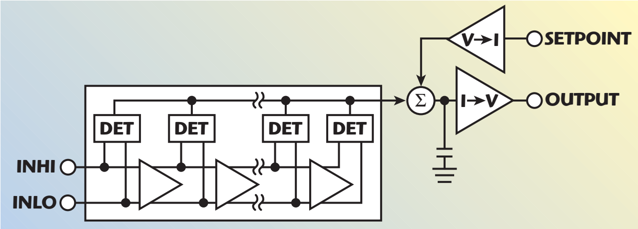
There are two basic methods by which the RF power detector and the DSP can interact to control the power of the WiMAX burst. The first method, which is similar to the technique used in envelope ramping in GSM applications, shapes the RF burst instantaneously. It uses the feedback of the detector to shape the envelope of the RF burst, made up of the preamble, frame control header and data. This envelope shaping method requires high speed detectors and fast feedback paths. A more commonly adopted method is that of output power monitoring. This method takes a power measurement during a burst and adjusts the RF power accordingly during the subsequent burst. The power adjustments are highly dependent on the linearity of the radio components to scale and shape the RF burst. A single measurement of RF output power can be affected by the high frequency components in the measured signal, which can manifest themselves as noise or AC-residual on the detector's DC output. To mitigate this effect, multiple measurement points can be taken throughout the burst to average out the AC-residual error.

DETECTOR BACKGROUND

Historically, diode detectors have been used in RF power control circuitry to regulate transmitted power. The simple diode circuitry offers a small dynamic range with poor temperature stability. Even with temperature compensation circuitry, a diode detector can only offer a small detection range with worsening temperature performance at low input powers.

A popular alternative to the diode detector is the demodulating logarithmic amplifier (log amp). The log amp offers an easy to use linear-in-dB RF power detection response, a wide dynamic range, temperature stability and nanosecond response times. The newest RF power measurement alternative is the TruPWR rms-responding detector, which offers wide dynamic ranges and temperature stability. In addition, rms detectors are insensitive to changes in the peak-to-average ratios, whereas diodes and log amps are both waveform dependent.

Each WiMAX application has diverse power control and RF detection needs. Subscriber stations can be designed with dynamic ranges as small as 30 dB, but are susceptible to supply power consumption. Base sta-



▲ *Fig. 4 Basic block diagram of a logarithmic amplifier.*

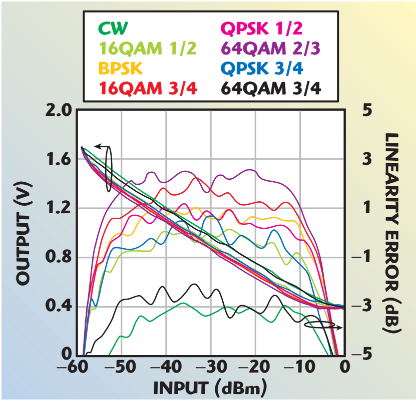
tions have more allowance for power consumption, but need to control dynamic ranges of up to 60 dB. Both, similarly, require temperature stability for improved accuracy. Only log amps and rms detectors are able to meet those needs.

LOGARITHMIC AMPLIFIERS

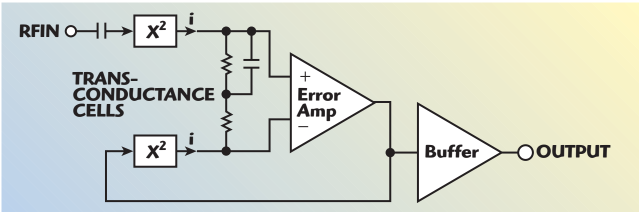
The first detection method to be looked at is a peak-detecting device, the logarithmic amplifier. A wide variety of log amps is available with detection ranges from 40 to 100 dB, and frequencies from DC to 10 GHz. A typical block diagram of a log amp is shown in ***Figure 4***.

The core architecture of a log amp is a cascaded chain of linear amplifiers. Each amplifier has a gain of 5 to 20 dB. The combination of gain and number of amplifiers determines the detection range of the log amp. The output of each amplifier stage is fed into a full wave rectifier (marked DET). The outputs of each rectifier are summed together, and the summer's output is applied to a low pass filter to remove the ripple of the rectified signal. This yields the logarithmic output (often referred to as the "video" output), which will be a steady-state DC output for a steady-state AC input signal. It is the bandwidth of this video output that is particularly important in a WiMAX system. The wider the video bandwidth, the faster the log amp is able to respond to changes in the peak voltage, or amplitude, of the input signal. This makes the log amp particularly suited to accurately keep up with the envelope of the WiMAX burst. With response times as low as 8 ns, log amps can easily keep up and measure small periods of the RF burst, such as the preamble, which last about 26 µs.

Using a peak-detecting device like a log amp is advantageous when measuring the signal power of a waveform at an exact point in time. Because the log amp is able to track the envelope of its input, provided the modulation rate is lower than the video bandwidth of the log amp, the DC output will be an instant-by-instant measurement of the peak amplitude of the input signal. This kind of measurement is useful in a WiMAX system to detect high crest factor signals during a burst and make the appropriate adjustments in power amplifier biasing or implement a crest factor reduction scheme in the next burst. ***Figure 5*** shows the output voltage and linearity error of a log amp at various 2.35 GHz OFDM modulations, 256 subcarrier signals with 10 MHz bandwidth. The error, normalized to QPSK with 3/4 encoding rate, is graphed on the secondary y-axis, scaled in dB. While the log amp is



▲ *Fig. 5 Log amp output voltage and linearity error at various 2.35 GHz OFDM modulations.*



▲ *Fig. 6 Block diagram of a TruPWR rms detector with 3 dB linear-in-volts response.*

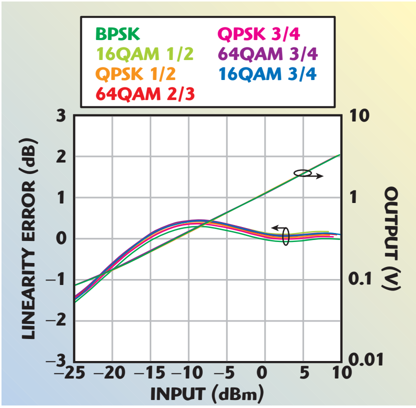
able to maintain approximately 50 dB of measurement range within ±1 dB or error for each modulation, there is an obvious shift in the intercept of the transfer function. The intercept is the point on the x-axis through which the transfer function would pass if the output voltage could go to 0 V. This intercept shift is a byproduct of the successive detection architecture of a log amp. The amount of intercept shift is based on the crest factor of the signal. Because the log amp behavior is repeatable over manufacturing process variations, the intercept shift of the log amp for a sine wave versus a modulated input signal can be easily characterized. The DSP can then use an offset correction to compensate for the detector's output voltage and yield accurate RF power measurement.

The low power consumption, of the order of 15 to 30 mA, makes log amps viable in both base stations and subscriber stations alike. The well-established log amp architecture offers excellent temperature stability across large dynamic ranges as well as fast response times for burst tracking and peak sampling. However, as the peak-to-average ratio of the RF signal varies, the output response of a log amp will also vary. This introduces an uncertainty that in many cases must be compensated for by the DSP.

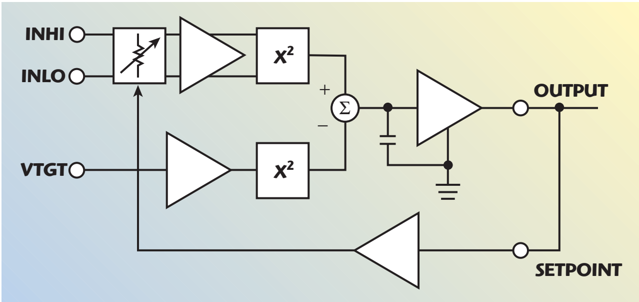
RMS-RESPONDING DETECTORS

Unlike diodes and log amps, mean power detectors (or rms detectors) have responses which are independent of waveform. The waveform-independence is particularly useful as WiMAX systems optimize the quality of the link by dynamically adjusting the signal modulation. The composite signal envelopes of the data bursts may have significant peaks that can drastically change over time and throw off measurement accuracy. Using log amps in the RF power control system require some method of compensation; however, rms detectors simplify the complexity of the system by reducing and in some cases eliminating compensation schemes.

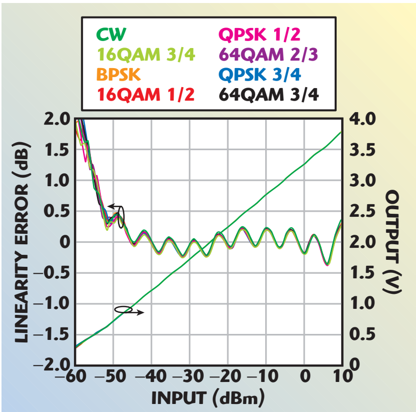
Figure 6 shows the block diagram of a 30 dB rms detector. It achieves independence from peak-to-average ratios by computing the square, mean and root functions of an rms calculation. The RF input is fed to one of two identical squaring-cells. The squared signal is then averaged through a low pass filter network. The signal is fed to a high gain error amplifier that has the second squaring-cell in its feedback path. This feedback loop performs the square-root function, thus completing the rms calculation. The output is a linear-responding DC voltage whose conversion gain has units of V_{DC}/V_{rms}. The linear-in-volts rms detector is able to operate at frequencies as high as 6 GHz. The rms-responding detector allows the RF power control system to monitor and dynamically adjust the transmitter's output power even as the peak-to-average ratio of the transmitted signal changes. ***Figure 7*** illustrates the accuracy in measuring various OFDM waveform types. The method used to calculate the error is similar in nature to that used in the log amp error calculation. The linearity error of the detector is within ±0.5 dB across the dynamic range of the device. The various waveforms lie on top of each other with a deviation of a couple tenths of a dB. This 30 dB dynamic range and low 1 mA power consumption is useful for subscriber applica-



▲ *Fig. 7 Linear-in-volts rms detector output voltage and linearity error at various 2.35 GHz OFDM modulations.*



▲ *Fig. 8 Block diagram of a linear-in-dB TruPWR rms detector with 60 dB dynamic range.*



▲ *Fig. 9 Linear-in-dB rms detector output voltage and linearity error at various 2.35 GHz OFDM modulations.*

tions. The slower response time, in the range of 25 µs, limits the rms detector use to output power monitoring. **Figure 8** shows the block diagram of a 60 dB rms detector, which is appropriate for wider dynamic range base station applications. The input signal is applied to a 12-step, continuously variable gain amplifier, which is controlled by the setpoint, a logarithmic control voltage. The output of the VGA is fed to an accurate squaring-cell. The fluctuating output is filtered and compared with the output of an identical squarer. At this point, the square and mean operations of the rms calculation are complete. The output is fed back to the VGA setpoint, making the output proportional to the logarithm of the rms value of the input. The detector response is linear-in-dB, allowing the device to measure RF signals in a 60 dB dynamic range. The final step of performing the square-root function is not needed for accurate rms detection. **Figure 9** shows the performance of the 60 dB rms detector when measuring various OFDM modulated input signals. Again, the various waveforms lie on top of each other with negligible deviation. The humps in the linearity error curve correspond to the steps of the logarithmic VGA. Still, the linearity error across the dynamic range stays well within ±0.5 dB. As in the case of the linear-in-volts detector, the 70 µs response time of this 60 dB detector also limits this detector application to output power monitoring.

CONCLUSION

The emerging WiMAX standard has great potential to offer wide area coverage and mobile access to high speed networks. The large crest factors associated with the OFDM modulation scheme require accurate transmit power measurements for PA control and the implementation of crest factor reduction algorithms. Designs requiring fast response to the OFDM envelope should consider the accuracy of log amps. The waveform-independence provided by rms detectors can reduce, or even eliminate, the need for compensation schemes in these networks, simplifying the overall design of the transmit chain. ■

Carlos Calvo *received his BS and MS degrees in electrical engineering from Worcester Polytechnic Institute. He is an applications engineer in the Advanced Linear Products Division at Analog Devices Inc.*

Matthew Pilotte *received his BS degree in electrical engineering from Worcester Polytechnic Institute. He is an applications engineer in the Advanced Linear Products Division at Analog Devices Inc.*

NOVEL LOW PASS FILTERS USING A DEFECTED MICROSTRIP STRUCTURE

In this article, the stop-band characteristics of a novel defected microstrip structure (DMS) are studied and its application to a low pass filter is proposed. The equivalent circuit model of the unit defected microstrip structure is used to explain the stop-band characteristic at a certain frequency and the parameters of the circuit model are extracted from EM simulation and circuit theory. Two types of three-pole low pass filters and a type of five-pole low pass filter are proposed and optimized as applications of DMS. The measured results on the five-pole low pass filter are in good agreement with the simulated ones.

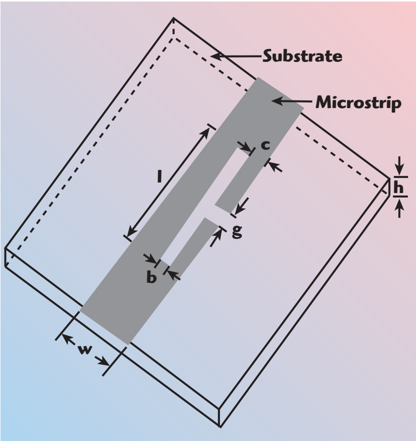
A novel defected microstrip structure (DMS), which behaves in a way similar to the known defected ground structure (DGS) unit cell,[1–10] is studied in this article. The unit DMS[3,4] is made by etching slots in the microstrip line, which then exhibits the property of rejecting microwaves at certain frequencies. Due to its simple planar structure and ease of fabrication by a photolithographic process, DGS is widely used in microwave passive circuits, such as filters,[2,5,6] antennas[4,7,8] and oscillators.[9,10] Because of the leakage through the ground plane, the problems of enclosure should be considered when DGS is used to design microwave circuits. In the DMS case, the defected cell is etched in the center conductor and there is no leakage through the ground plane. This structure can be integrated more easily with other microwave circuits and the filter and antenna dimensions can be effectively reduced by using DMS.[4]

Based on EM simulation results, a circuit model of the DMS is established and the lumped elements of this model are extracted according to circuit theory. The stop-band effect of the presented DMS can be explained by employing the extracted parameters and circuit theory. In order to show the effectiveness of the proposed scheme, two types of three-pole low pass filters and a five-pole low pass filter (LPF) are designed using DMS to improve their stop-band characteristics. The results measured on the five-pole LPF agree well with the simulation.

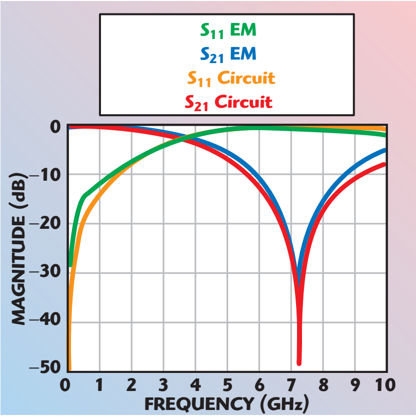
FREQUENCY CHARACTERISTICS OF THE DEFECTED MICROSTRIP STRUCTURE

The novel defected microstrip structure (DMS), which consists of a rectangular slot of length l and width b etched in the middle of the center conductor and a small slot of width g perpendicular and in the center of the main slot, is

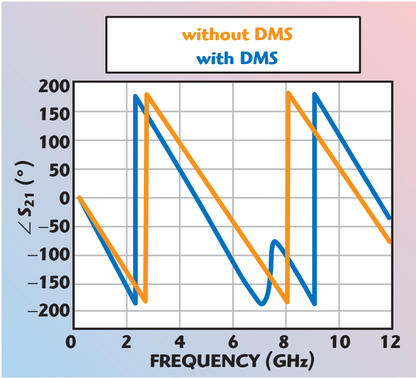
SHENG ZHANG, JIAN-KANG XIAO, ZI-HUA WANG AND YING LI
Shanghai University
Shanghai, China



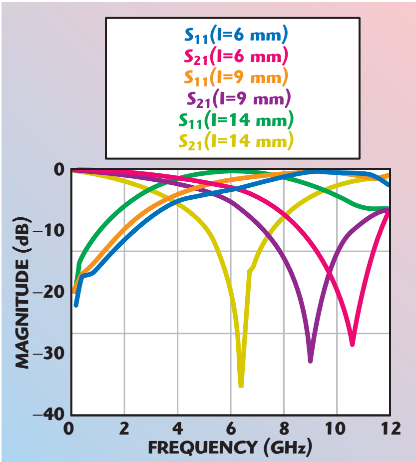
▲ *Fig. 1 Defected microstrip structure.*



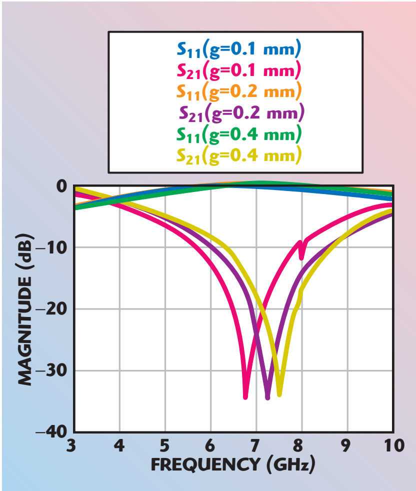
▲ *Fig. 2 Simulated S-parameters for a 50 Ω microstrip with a unit DMS.*



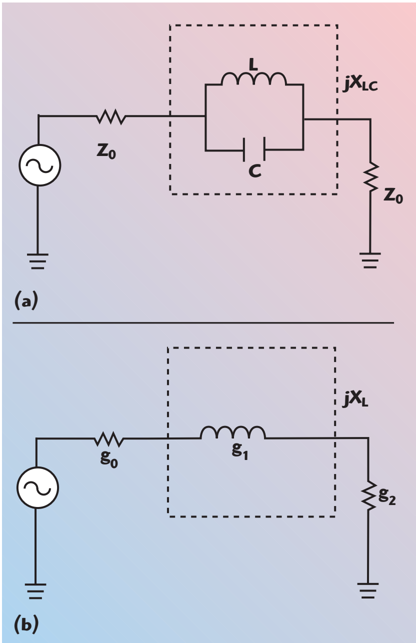
▲ *Fig. 3 Simulated S_{21} phase for a microstrip with and without DMS.*



▲ *Fig. 4 Simulated S-parameters for different slot lengths.*



▲ *Fig. 5 Simulated S-parameters for different gap widths.*



▲ *Fig. 6 Equivalent circuits of the microstrip line with unit DMS; (a) with unit DMS and (b) a Butterworth prototype.*

shown in ***Figure 1***. The width of the microstrip line is then $W = b + 2c$. Similarly to DGS, the DMS increases the electric length of microstrip and disturbs the current distribution. The effective capacitance and inductance of the microstrip line increase. Accordingly, a microstrip with a unit DMS has a stop-band and slow-wave characteristics. Novel compact microwave components can be designed by using these characteristics. It can be seen from ***Figures 2*** and ***3*** that for a 50 Ω microstrip line with $l = 13$ mm, $b = 1$ mm, $c = 0.8$ mm and $g = 0.2$ mm, the cut-off frequency f_c and the attenuation pole frequency f_0 are 3.57 and 7.25 GHz, respectively.

In order to probe the relationships between the etched slot dimensions and the characteristics of the stop-band, a 50 Ω microstrip, with a substrate relative dielectric constant of $\varepsilon_r = 2.2$ and $h = 0.762$ mm, is chosen for all simulations. Considering the limited width of the center conductor, the parameters $b = 1$ and $c = 0.8$ mm are fixed in the following calculations. Thus, the proposed DMS can be fully described by the length l and the slot width g.

The influence of the length l on the frequency characteristics is simulated with an electromagnetic (EM) simulator while the gap g is kept constant and equal to 0.2 mm. ***Figure 4*** shows the simulation results for three different lengths l. The stop-band frequency decreases when the length l increases. The reason is that the large slot area is directly related to the effective inductance. As the length l is increased, the effective inductance increases, and the increasing inductance gives rise to a lower stop-band. At the same time, the width g of the etched gap also influences the stop-band frequency.[2] To investigate the influence of the gap g, the length l is kept constant and equal to 13 mm. ***Figure 5*** shows the simulated results for three different gaps. It can be seen that as the width of the etched gap increases, the location of the attenuation pole increases. The reason is that the gap affects the effective capacitance. The increased gap width leads to a lower capacitance and the lower capacitance results in a higher resonance frequency f_0. Different stop-bands can be obtained by adjusting the length l and gap width g of the DMS and the length l affects the location of stop-band more effectively. The DGS has similar stop-band characteristics to the unit cell DMS, so the equivalent circuit model of DGS2 can be used to extract the equivalent circuit parameters of DMS.

MODELING AND PARAMETER EXTRACTION OF DMS

The electrical characteristics of the DMS stop-band are simulated as

TABLE I
STOP-BAND CHARACTERISTICS AND EXTRACTED EQUIVALENT CIRCUIT PARAMETERS OF DMS USING A 50 Ω MICROSTRIP (ε_r = 2.2, h = 0.762 mm)

DMS Dimensions	b = 1 mm, c = 0.8 mm					
	g = 0.2 mm			l = 13 mm		
	l = 6 mm	l = 9 mm	l = 14 mm	g = 0.1 mm	g = 0.2 mm	g = 0.4 mm
f_0 (GHz)	10.61	9.02	6.43	6.84	7.25	7.50
f_c (GHz)	6.02	4.62	2.98	3.49	3.57	3.65
S_{21} max (dB)	–28.59	–31.26	–35.47	–35.47	–34.93	–34.26
L (nH)	1.7297	2.5412	4.1608	3.3731	3.3766	3.3277
C (pF)	0.1225	0.1225	0.1515	0.1605	0.1428	0.1353

a parallel LC resonance circuit,[2,5,6] as shown in ***Figure 6***. The equivalent parameters of the parallel LC circuit of the DMS can be extracted from the EM simulation results. The equivalent circuit of the DMS is matched to the one-pole Butterworth LPF response. The reactance of the DMS can be expressed as

$$X_{LC} = \left[\omega_0 c\left(\frac{\omega_0}{\omega} + \frac{\omega}{\omega_0}\right)\right]^{-1} \tag{1}$$

where

ω_0 = resonance angular frequency of the parallel LC resonator

The series inductance of the one-pole Butterworth LPF can be written as

$$X_L = \omega' Z_0 g_1 \tag{2}$$

where

ω' = normalized angular frequency
Z_0 = characteristic impedance
g_1 = normalized parameter of one-pole Butterworth LPF

According to circuit theory, the two reactance values must be equal at ω_c, that is

$$X_{LC}\Big|_{\omega=\omega_c} = X_L\Big|_{\omega'=1} \tag{3}$$

where

ω_c = cut-off angular frequency of the parallel LC resonator

From Equations 1, 2 and 3, the inductance L and the capacitance C can be obtained as

$$C = \frac{\omega_c}{Z_0 g_1}\frac{1}{\omega_0^2 - \omega_c^2} \tag{4}$$

$$L = \frac{1}{4\pi^2 f_0^2 C} \tag{5}$$

where f_0 is the resonant frequency, which can be obtained from the EM simulation results. The equivalent-circuit parameters can be calculated from Equations 4 and 5. The values of the lumped-element parameters for the proposed DMS are shown in ***Table 1***.

The simulated frequency response of the extracted equivalent circuit parameters for a 50 Ω microstrip with

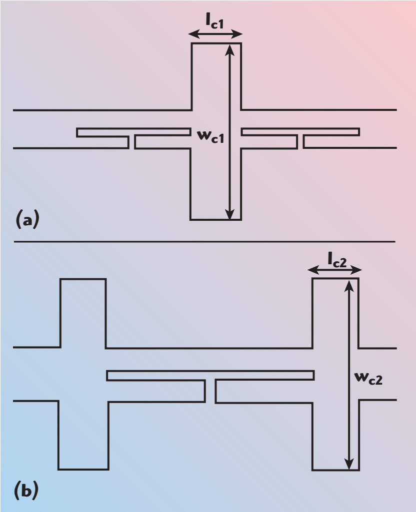


Fig. 7 Two types of three-pole low pass filters; (a) with two DMSs and (b) with one DMS.

unit DMS have been shown previously and compared with the EM simulation. It shows an excellent agreement between the EM simulation and the calculated circuit simulation. The calculated equivalent circuit parameters of the unit DMS are C = 0.1428 pF and L = 3.3766 nH. A small discrepancy still exists between the two simulations because the LC parallel circuit is an ideal model and the loss of the resistor and radiation are not considered.

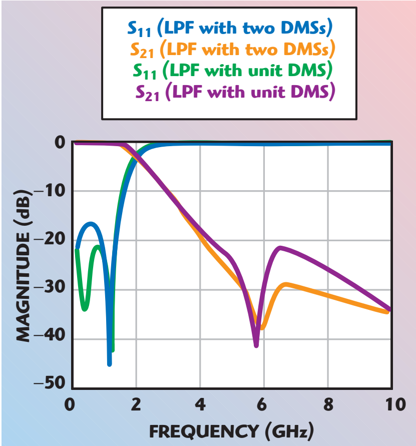
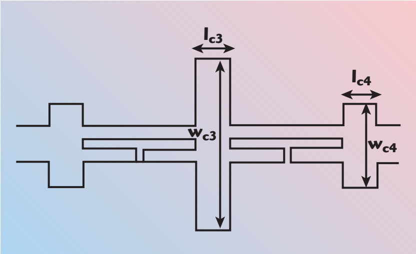


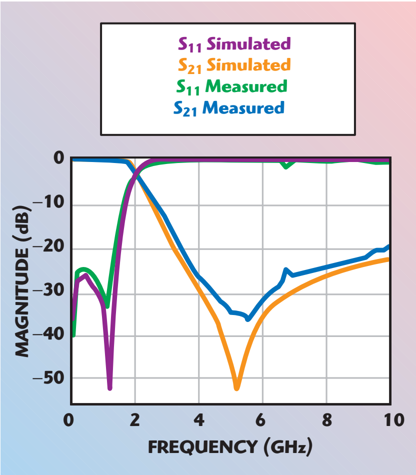
Fig. 8 Simulated S-parameters for two types of three-pole low pass filters.

DESIGN OF A THREE-POLE LPF AND FIVE-POLE LPF USING DMS

In order to verify the stop-band validity of the DMS, two types of three-pole low pass filters are designed and shown in ***Figure 7***. The dimensions of the DMS are the same as before. According to transmission line theory, if an open stub, with a characteristic impedance Z_0, is shorter than $\lambda_g/4$, it can be used to realize a shunt capacitance.[11,12] In an LPF with two DMSs, the shunt capacitor can be realized by using a crossed open stub. The width of the stub is w_{c1} and its length is l_{c1}. Two series inductances are realized by using two DMSs, on both sides of the stub. In another LPF with unit DMS, two identical stubs with a width w_{c2} and length l_{c2} are used as series inductances on both sides of a unit DMS. The optimized dimensions of the stubs that are calculated with the EM simulator are l_{c1} = 3.3 mm, w_{c1} = 14.54 mm, l_{c2} = 2.9 mm, w_{c2} = 16.2 mm. The simulated S-parameters of the two low pass filters are shown in ***Figure 8***. It can be seen that in the low pass-band, the maximum ripple level is –0.08 dB; the S_{21} parameters are less than –15 dB. In the whole stop-band, the maximum insertion losses of both fil-



▲ *Fig. 9 Five-pole low pass filter.*



▲ *Fig. 10 Simulated and measured S-parameters of a five-pole low pass filter.*

ters are better than –20 dB. The excellent band-gap performance of DMS is demonstrated.

In order to improve the insertion loss performance of the LPF, a five-pole LPF is designed using two DMSs, as shown in ***Figure 9***. This filter is realized by setting two higher impedance identical open stubs on each sides of the three-pole LPF with two DMSs. The optimized dimensions of two different stubs can be obtained with the help of an EM simulator. They are $l_{c3} = l_{c4} = 2.9$ mm, $w_{c3} = 18.7$ mm, $w_{c4} = 7.9$ mm. The EM simulated and measured results of a five-pole low pass filter are shown in ***Figure 10***. The measurements are taken with a HP8510 vector network analyzer. There is only a slight difference between the two results. It can be seen from the measured results that there is an attenuation pole at 5.5 GHz, and the insertion loss characteristics are improved in the whole stop-band while the return losses are more than 25 dB in the low passband.

CONCLUSION

In this article, a novel defected microstrip structure (DMS) and its equivalent circuit are studied. In comparison with a defected grounded structure (DGS), there is no increment of leakage from the ground plane by using DMS. There is also no enclosure problem for this novel defect structure, because it is etched on the center conductor. In order to show the validity of DMS and its characteristics, three types of low pass filters are designed with DMS. Due to the DMS resonance, the three LPFs have wider and deeper stop-band performances than that of conventional LPFs. Finally, the response of a five-pole LPF has been measured, which shows an excellent insertion loss characteristic. ■

ACKNOWLEDGMENT

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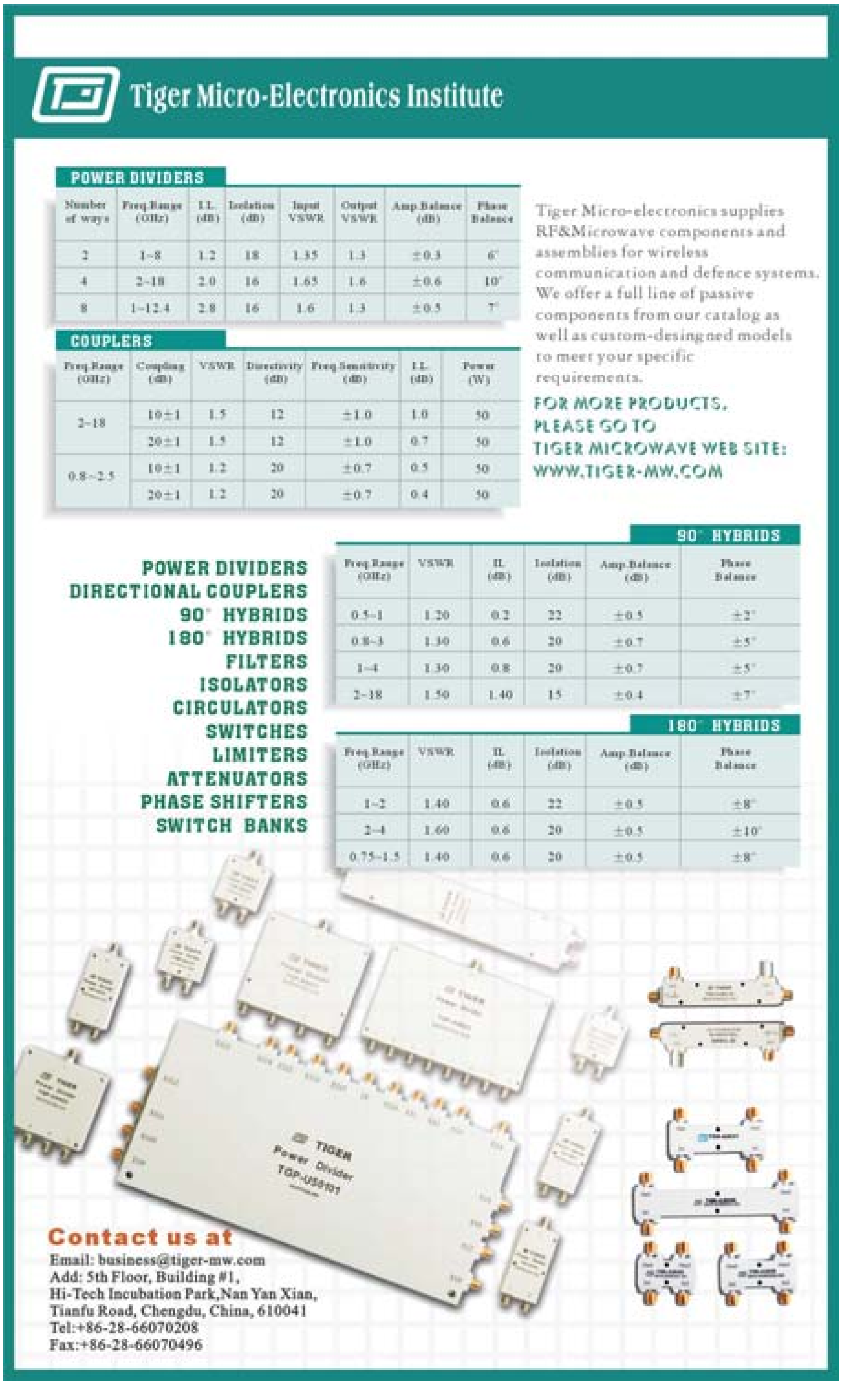
Sheng Zhang *received his BS degree from Anhui Normal University, China, in 2000, and his MS degree from the Hefei University of Technology, China, in 2004. He is currently working toward his PhD degree at Shanghai University, China. His research interests include electromagnetic band gaps, substrate integrated waveguides and passive microwave components.*

Jian-Kang Xiao *received his BS degree in electronics in 1996 and his MS degree in radio physics from Lanzhou University in 2004. Since then, he has been an electrical engineer at the Institute of Modern Physics, Chinese Academy of Sciences. He is currently working toward his PhD degree at Shanghai University, China. His research interests include microwave and millimeter-wave theory and technologies.*

Zi-Hua Wang *received his BS degree from the Harbin Institute of Technology, China, in 1968, and his MS degree from the Shanghai University of Science and Technology, China, in 1981. He is now a professor at the school of Communication and Information Engineering, Shanghai University. His research interests include fiber and integrated optics, microwave theory and technology, and antennas.*

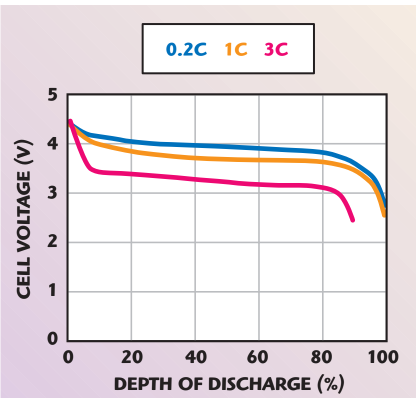
Ying Li *is currently a professor at Shanghai University. His research interests include electromagnetic theory, microwave and millimeter-wave techniques and their applications.*



LOW VOLTAGE OPERATION OF GaAs POWER AMPLIFIERS

Next-generation mobile phones are capable of downloading music and video programming, displaying global positioning system (GPS) mapping and sharing high resolution photographs. These new applications are becoming increasingly popular as teenagers and others learn to manipulate photo and music files. Applications involving heavy display usage (such as mobile television) will significantly affect the overall power budget in a mobile phone. As consumers evolve their phone usage habits to include these more data-intensive applications, total battery storage requirements will dramatically change. Battery life reserved for handset talk time is no longer sufficient.

Fig. 1 Lithium-ion battery discharge characteristics.

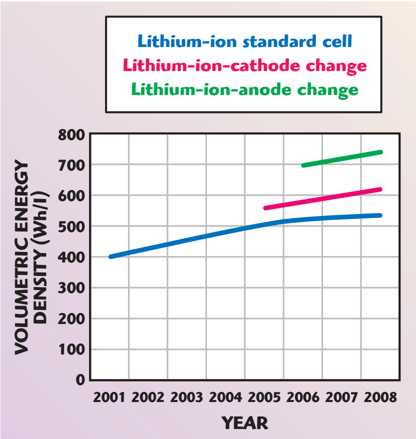


BATTERY TECHNOLOGY

In order to stretch battery technology to permit higher energy density and longer battery life, the world's leading battery suppliers are looking at alternative chemistry and fabrication techniques which will result in lower discharge voltages. Today's mobile phones are designed to use batteries at discharge voltages above 3.0 to 3.5 V, where lithium-ion batteries have an excellent discharge characteristic. ***Figure 1*** illustrates the voltage profile for a variety of discharge conditions. (1C refers to the current draw required to drain the nominal battery capacity in one hour; for example, for a 650 mAh battery the current level at 1C would be 650 mA.) Note that as a battery is drained more quickly, its capacity is reduced. At 3C the lithium-ion battery is effectively depleted at 90 percent of its rated capacity. The point at which the voltage drops off near complete discharge is often referred to as the "cut-off voltage."

In particular, battery suppliers have developed alternative cathode and anode materials that improve volumetric energy density (energy per liter) or gravimetric energy density (energy per kilogram or specific energy) of a cell. Lithium-ion cells are currently best for size-critical applications such as mobile phones, so much of the recent development focus has been on the addition of new metals for additional cathode chemistry complexity. By sub-

JOE MADDEN
Avago Technologies
San Jose, CA

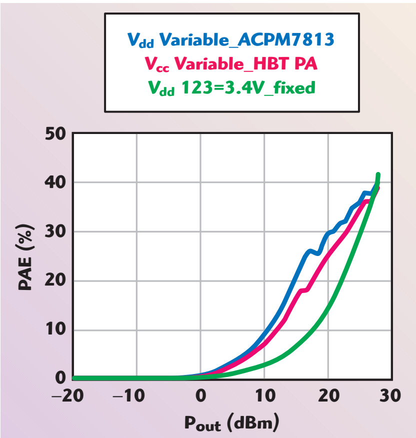


▲ *Fig. 2 Volumetric energy density progress (source: Nikkei Electronics).*

TABLE I

TRADEOFFS IN DISCHARGE VOLTAGE FOR ALTERNATIVE CHEMISTRIES

	Cathode	Anode	Initial Voltage	Cut-off Voltage
Standard cell	$LiCoO_2$	C	4.2 V	3.1 ~ 3.3 V
New cathode	$LiMnCoO_2$ $LiCoNiO_2$	C	4.4 V 4.2 V	3.0 ~ 3.3 V 2.7 ~ 3.0 V
New anode	$LiCoNiO_2$	Si	4.2 V	2.5 ~ 2.7 V



▲ *Fig. 3 Variable bias voltage for W-CDMA amplifiers (at 25°C and V_{cntl} = 2.5 V).*

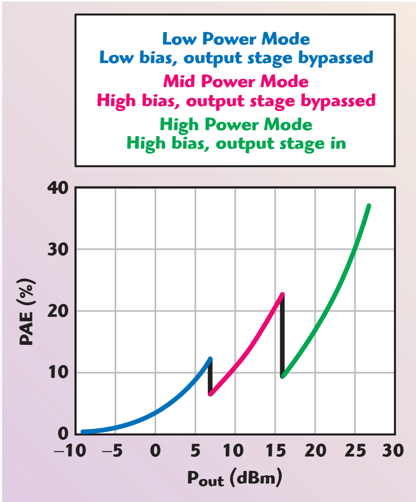
stituting manganese or nickel in the cathode, volumetric density can be dramatically increased, but at the expense of discharge voltage. This has been followed up by the substitution of silicon for the graphite (carbon) anode in order to extend the performance of the cell as much as possible. The anode change causes the discharge characteristic to slope even more, resulting in a more dramatic decline in available voltage and a more dramatic leap forward in volumetric energy density. ***Figure 2*** and ***Table 1*** describe the impact: By giving up as much as 0.6 V of discharge voltage, the new batteries can improve energy density by as much as 40 percent.

Note: another alternative to lithium-ion batteries, especially for weight-critical applications, is lithium sulfur cell technology. Lithium sulfur batteries, since they use no heavy metals, are lighter and more environmentally friendly than lithium-ion batteries. With its liquid cathode construction, the lithium sulfur system can deliver high current readily and can reportedly reach gravimetric densities of over 300 Wh/kg and volumetric density of roughly 450 Wh/liter. Lithium sulfur cells currently operate nominally at 2.1 V, with a cut-off voltage at less than 2.0 V. The "green" nature of this approach makes lithium sulfur a possible candidate for high volume applications such as mobile phones.

THE PROBLEM

Why haven't mobile phones already taken advantage of the benefits that are possible with changes to the battery? The limitation comes down to a short list of components that have not been scrutinized for their ability to cope with lower voltage. In particular, many system designers believe that RF power amplifiers need to be supplied with 3 V or higher, due to the heavy use of HBT amplifier technology in the marketplace at present.

Today, the majority of the mobile handset market uses heterojunction bipolar transistors (HBT) for the RF power amplifiers in handsets. For HBT amplifiers, a forward bias is applied to the emitter-base junction, and a reverse bias is applied to the base-collector junction. The sandwich structure of the HBT device requires an overall voltage supply of 3.0 V to cause the device to "turn on" for high power amplification (at low RF power levels, the bias voltage can be a bit lower with acceptable degradation in linearity). As the market considers the use of low voltage battery cells, some HBT amplifier users are now considering the addition of a buck/boost DC/DC voltage converter in order to maintain adequate bias voltage. This would obviously add cost and reduce efficiency of the overall amplifier solution.



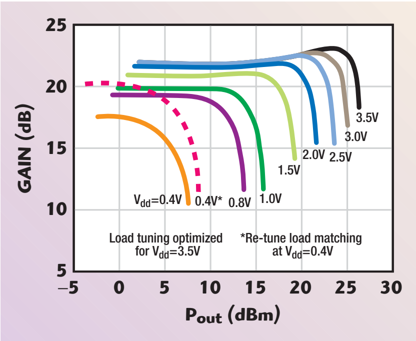
▲ *Fig. 4 Increased PAE through a switched PA architecture.*

COMPLEXITY WITH BIAS CONTROL SCHEMES

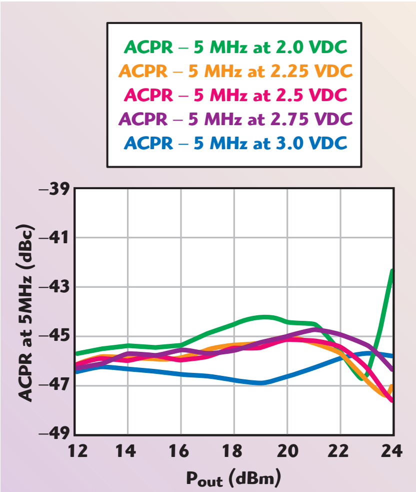
DC/DC converters are often used in the design of mobile handsets today, stepping down the bias voltage for a power amplifier during transmissions that only require low RF power output. ***Figure 3*** illustrates the benefit derived from adjusting the bias voltage to be lower in the case of both E-pHEMT and HBT amplifiers. For optimal efficiency at all power levels, the voltage was adjusted continuously according to a preset profile. Note that in both cases, the same bias voltage profile was used, demonstrating that the E-pHEMT amplifier inherently performs at higher efficiency than its HBT counterpart.

Amplifiers are also often switched into different states in order to save power. Many amplifiers have been introduced to the market in which the output section may be switched out of the signal path, allowing the driver section of the amplifier to supply the output power at much higher power-added efficiency (PAE). The most efficient of these designs make use of a patented "switchless" technology developed by Avago Technologies.

Figure 4 shows the impact of switched amplifiers. In this case, a



▲ *Fig. 5 The impact of bias voltage on a standard E-pHEMT PA.*



▲ *Fig. 6 ACPR performance for W-CDMA operation at 1950 MHz.*

"switchless" architecture was used, meaning that the bias voltage was simply set to zero for the bypass condition, with a specialized matching network that enabled a low loss bypass network to direct the signal from the driver stage to the antenna port. To simplify the demonstration, in the mid-power and high power ranges the bias voltage was simply set to 3.4 V, while at low power the bias was set to a lower constant voltage. In the end, a combination of continuously variable bias voltage and switched amplifiers can realize a power amplifier for W-CDMA or CDMA operation with a PAE in the 20 to 40 percent range throughout the entire dynamic operating range of the system.

THE SOLUTION

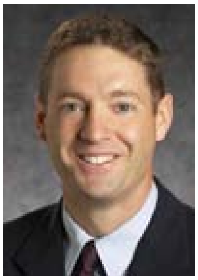
In contrast with HBTs, FET devices operate on a different principle, allowing them to operate at much lower bias voltages. E-pHEMT (enhancement mode pseudomorphic high electron mobility transistor) technology offers an excellent alternative. With the highest efficiency in the industry at high voltages, E-pHEMT devices become even more compelling at low bias voltages. Because E-pHEMT devices can maintain linearity and gain at low bias voltages, below 2 V, the cost and electrical loss in the buck/boost converter can be avoided. Efficiency and handset talk time can be maximized while avoiding unnecessary components.

Figure 5 illustrates the point that E-pHEMT amplifiers can maintain predictable and useful performance as low as 1.5 V, and possibly lower. In the plot, a standard E-pHEMT amplifier was subjected to a variety of bias conditions using a standard load matching network and test waveform. At extremely low voltage (0.4 V), engineers were able to re-tune the load matching network in order to re-optimize the amplifier's performance and achieve a level of 20 dB gain for low power levels.

Many handset manufacturers already adjust the output power of the RFIC to compensate for changes in amplifier gain at varying bias voltages. Often this is done at the low power or mid-power transmitter levels, where linearity performance is not critical for the amplifier. In other words, when the mobile handset is fairly close to the base station (within a mile or so), the transmitter power from the handset can be backed off. This relaxes the performance requirements for the amplifier in terms of intermodulation distortion and other forms of nonlinear behavior. However, in the case of a new battery cell technology, the voltage will be set at a lower level for high output power levels as well, creating a more critical need for high linearity performance up to 24 dBm output power and higher. Note that the actual output power required from the amplifier varies depending on the output duplexer or switch technologies chosen; bulk acoustic wave (BAW) filters such as film bulk acoustic resonator (FBAR) filters can reduce the output loss, reducing the amplifier's output power rating. A combination of E-pHEMT amplifiers and low loss filters can address the requirements for high antenna output power and high linearity simultaneously with low supply voltage.

Figure 6 demonstrates the linear performance of the E-pHEMT amplifier over a wide range of bias voltage conditions. Typical specifications call for −35 dBc adjacent channel power ratio (ACPR) performance for a W-CDMA signal. The E-pHEMT amplifier easily exceeds this requirement, with margin for mass production up to a transmitter power of 24 dBm. In fact, below 24 dBm the impact of the bias voltage on linearity is not measurable by a typical test set. Only at high power does the linearity degrade slightly as the bias voltage is turned down to 2.0 V. Based on these simple tests, it is clear that E-pHEMT technology can maintain high linearity and flat, predictable AM/AM and AM/PM performance at low bias levels.

Dozens of innovative ideas have certainly been employed to squeeze the maximum linear RF power out of the smallest possible amount of DC power. As a new generation of mobile phones is born with lower battery cell voltage, RF power amplifiers must also change directions. The end result will be incredible levels of efficiency and autonomous operation time for a typical handset. With new battery and PA techniques, consumers will be able to talk on their mobile phones for extended periods and still enjoy the latest offerings in multimedia content. ■



Joe Madden *holds a BS degree in physics from UCLA. He is responsible for corporate business development at Avago Technologies, a spinout of Agilent Technologies Inc. He has been involved in wireless product marketing for over fifteen years, with a few years in the lab designing filters and other RF devices. Before joining Avago, he served as president of STI-Sunnyvale and as vice president of marketing at Spectrian Corp. He has published papers ranging from molecular-beam epitaxy to digital amplifier predistortion.*

ACCURATE SIMULATION OF AN X-BAND FREQUENCY SYNTHESIZER

This article describes the simulation and design of an X-band frequency synthesizer that can be applied to a micro-satellite transmitter system. The effects of the sideband's spurious noise on the adjacent channels and the phase noise in each component in the circuit on the noise performance of the system are discussed. The effect of the carrier recovery PLL in demodulation on the level of the single-sideband (SSB) phase noise is also included in the analysis. An accurate estimation of the loop filter is used, which guarantees the precision of the design. In the simulation, the characteristics of commercially available components are considered.

Today's transmitters for earth imaging micro-satellite systems demand higher communication quality and higher data rates to be capable of transmitting pictures or data with an appropriate quality, a higher frequency of operation and more channels per unit bandwidth. Low power consumption and small size are also required for this equipment. All of these constraints combine to make the whole design, including component selection and evaluation, quite challenging. One portion of this design that is very critical with regard to all of the requirements mentioned above is the synthesized oscillator.[1] This article describes the design of an X-band frequency synthesizer that can be used in micro-satellite transmitters. It discusses the design of the phase-locked loop (PLL) and the phase noise in each component of the circuit (voltage-controlled oscillator (VCO), phase detector, temperature-compensated crystal oscillator (TCXO), dividers and loop filter). In the simulation, the reference spurs and their effect on the noise performance of the PLL frequency synthesizer are also included. The accuracy of the values calculated for the loop filter is crucial to the success of this design. In the present case, the loop filter is accurately evaluated by using an efficient estimation technique.

This article describes the design of an X-band frequency synthesizer that can be used in micro-satellite transmitters.

An X-band VCO requires a low noise, high frequency prescaler to bring its output frequency into the range of the existing PLL for phase locking. Frequency multipliers and dividers are now available to simplify the design and implementation of X- and Ku-band synthesizers. In the simulation, the characteristics

MOHAMED KAMECHE
Centre National des Techniques Spatiales (CNTS), Algeria

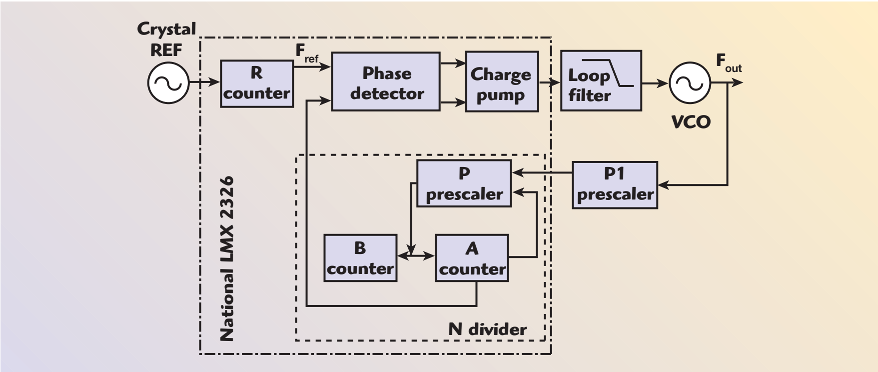


Fig. 1 Block diagram of the frequency synthesizer.

of commercially available components are considered. The high stability crystal reference oscillator is a 10 MHz TCXO from Voltronics; the phase-locked loop is a National Semiconductor 2326 component, capable of phase locking a VCO between 500 MHz and 3 GHz. For this reason, a Hittite (12 GHz, 1/8) prescaler was used to extend the frequency into X-band.

DESIGN AND THEORY

Figure 1 shows the PLL's linear model with feedback. This PLL is called an integer-N system, which means that the VCO frequency and the crystal reference are some integer multiple of the reference frequency. The PLL consists of a high stability crystal reference oscillator, a frequency synthesizer, a voltage-controlled oscillator and a passive loop filter. The frequency synthesizer includes a phase detector, a current mode charge pump and programmable frequency dividers. The passive filter is desirable for its simplicity, low cost and low phase noise. If the input signal to the PLL is

$$r(t) = A\sin(\omega_r t + \theta_r) \qquad (1)$$

and the output signal for the VCO is assumed to be

$$y(t) = B\cos(\omega_y t + \theta_y) \qquad (2)$$

Assuming that $\omega_y = \omega_r$, the output from the phase detector is expressed as

$$e(t) = K_p\left(\theta_r - \frac{\theta_y}{N \bullet P_1}\right) = K_p \bullet \theta_e \qquad (3)$$

where

θ_r = input phase
θ_y = output phase
θ_e = phase error
K_p = phase-detector/charge-pump gain factor

The VCO is assumed to be a linear device whose output frequency varies proportionally to the loop filter voltage $V_f(t)$, and is expressed by

$$f_{VCO} = f_0 + K_{VCO}V_f(t) \qquad (4)$$

where

f_0 = free-running frequency
K_{VCO} = VCO's gain factor or tuning coefficient expressed in MHz/V

Since the phase is the integral of the angular velocity, the VCO is modeled as

$$VCO(s) = \frac{K_{VCO}}{s} \qquad (5)$$

Figure 2 shows the third-order low pass filter introduced in this model by its transfer function F(s) described by Equation 6 and applicable to this system, which requires a third pole for additional reference suppression

$$F(s) = \frac{V_f}{e} = \frac{Z(s)\frac{1}{sC3}}{Z(s) + R3 + \frac{1}{sC3}} \qquad (6)$$

where Z(s) describes the transfer function of the second order loop filter given by

$$Z(s) = \frac{1 + sR2C2}{s(C1 + C2 + s \bullet R2 \bullet C1 \bullet C2)} \qquad (7)$$

Combining these transfer functions gives the open loop gain

$$T(s) = \frac{K_p F(s) K_{VCO}}{(N + P_1)s} \qquad (8)$$

To achieve optimal circuit performance, the phase noise should be evaluated for proper loop design. It will impact many critical operating characteristics of the synthesized oscillator, including adjacent channel power. Phase noise in a PLL can originate from a number of sources. The well-known noise sources are specifically the crystal reference (TCXO) noise, the phase detector noise and the VCO phase noise. If a TCXO is used, its phase noise data should be obtained from the manufacturer so that the reference values can be used in the model. A simple approximation for this noise source due to the crystal reference itself, as with any oscillator, is that it is inversely proportional to the offset frequency.[2] Higher order approximations are required for more accuracy, but the 1/f approximation is a good starting point for this study.

The VCO noise can be modeled as a simple approximation inversely proportional to the offset frequency from the carrier. The noise of the VCO is effectively high pass filtered by the PLL, providing rejection of phase noise or phase error within the bandwidth, but leaving the VCO noise well outside of the loop bandwidth unaffected. The VCO noise is given by[3]

$$S_{\theta VCO}(f) = K_{VCO0} + \frac{K_{VCO2}}{f^2} + \frac{K_{VCO3}}{f^3} \qquad (9)$$

where the three coefficients in the VCO noise equation were determined to yield the specific noise at the particular offsets from the carrier.

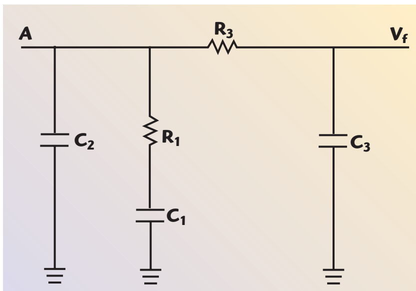


Fig. 2 Loop filter circuit design.

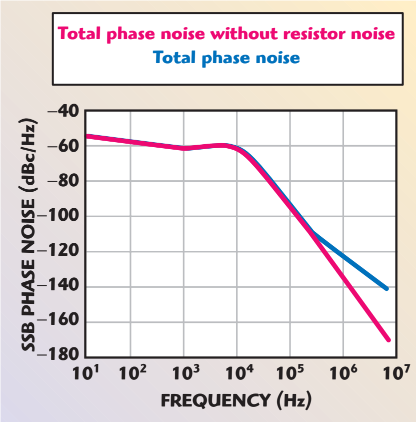


Fig. 3 Single-sideband phase noise with and without resistor noise.

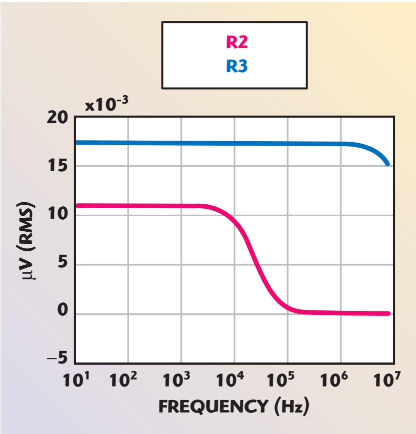


Fig. 4 Resistor's noise versus frequency.

The phase detector noise represents the internal noise floor of the phase/frequency detector and frequency dividers within the PLL. For the National Semiconductor synthesizer used in this work, the phase detector noise floor is given for an effective reference frequency of 1 Hz. This noise is shaped by the closed loop transfer function G(f) of the synthesizer as[4]

$$S_{\theta pd}(f) = 10^{\frac{S_{\theta pdref}+10\log\left(\frac{f_{ref}}{1\mathrm{Hz}}\right)}{20}}\, G(f) \qquad (10)$$

It is well known that the reference sidebands and spurious outputs play a major role in determining the noise properties of a PLL frequency synthesizer. Reference spurs are unwanted noise sidebands that can occur at multiples of the comparison frequency, and can be translated in the transmitter subsystem by the mixer to the desired signal frequency. The power of the reference spur is expressed by[2]

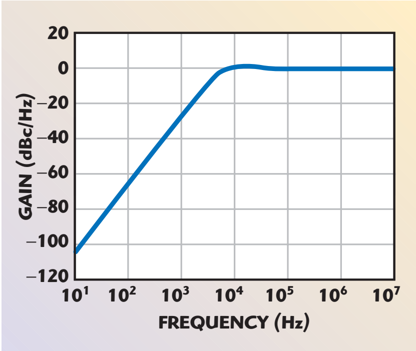


Fig. 5 Loop error response.

$$\mathrm{SpurGain}\left(F_{spur}\right) = 20\log\left[\frac{K_{VCO}F(s)\bullet K_p}{s}\right] \qquad (11)$$

where F_{spur} will be assumed to be a multiple of the comparison frequency.

Aside from spur gain, the spur's noise is also caused by mismatches and leakages in the charge pump of the PLL. These two factors in the charge pump can cause an AC modulation on the tuning line of the VCO, which can be viewed as FM modulation. This FM modulation gives rise to reference spurs. The spur level is given by[2]

$$\mathrm{Spur} = 10\log\left[10^{\frac{\mathrm{LeakageSpur}}{10}} + 10^{\frac{\mathrm{Pulsespur}}{10}}\right] \qquad (12)$$

where the leakage spur is the dominant term of the reference spurs caused by the leakage effects at lower comparison frequencies. However, the mismatch is the dominant factor at high comparison frequencies.

RESULTS AND DISCUSSIONS

For the design described in this article, a Matlab program was used to simulate the circuit. In the simulation, the characteristics of a National Semiconductor model LMX2326 programmable frequency synthesizer and a VCO with a 50 V/MHz sensitivity were used. The VCO is from General Microwave, which utilizes a high performance transistor operating at the fundamental, rather than the doubling push-push mode. A commercial 10 MHz temperature-compensated crystal oscillator from Voltronics with a specified noise of approximately –110

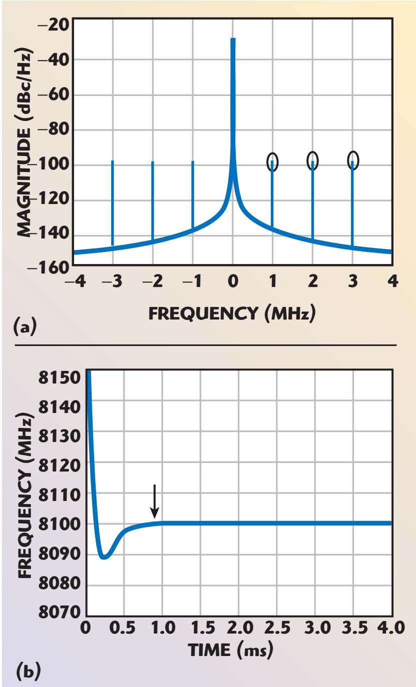


Fig. 6 Low loop filter cut-off frequency; (a) PLL output spectrum and (b) PLL transient response.

dB/Hz at an offset frequency of 10 kHz is used. The PLL using the LMX2326 component is capable of phase locking a VCO between 500 MHz and 3 GHz. For this reason, to extend the frequency range in the X-band frequencies, a (12 GHz, 1/8) prescaler from Hittite was used. The HMC363 prescaler is a low noise divide-by-8 static divider using an InGaP/GaAs heterojunction bipolar transistor (HBT) technology and has a phase noise of –153 dBc/Hz at an offset frequency of 100 kHz, which helps the user maintain good system noise performance. In practice, the PLL can be programmed via a laptop computer and parallel port cable. The frequency changes were done using software provided by National Semiconductor, in which the PLL serial-control data are controlled by three inputs (data, LE and clock). For regulating the channel frequency, the serial data input is designed to control the 15 b of the R counter and 18 b of the N counter (which includes 7 b from the A counter and 11 b from the B counter). In this example, a frequency range of 8025 to 8175 MHz and a channel spacing of 1 MHz are required. So, for the reference divider (R counter) equal to 10 (000000000001010)b and the N counter equal to 1010 : (A counter = 18 (0010010) and B counter = 31

(00000011111)), the output frequency resulting (P1 × (32 × B + A) × reference frequency) is equal to 8080 MHz.

Figure 3 shows the total phase noise with and without the resistor noise sources. Note that the reference spurs are not included in the total phase noise. The results show that within the loop bandwidth (10 Hz to 10 kHz) of the synthesizer, the level of the reference oscillator is higher because the closed loop transfer function is very large in magnitude and it drops off rapidly when it reaches the loop bandwidth. The results also show that the resistor noise contribution is very small at the synthesizer output. The R_2 and R_3 noise versus frequency is shown in ***Figure 4***. To demonstrate that the noise of the VCO is high pass filtered by the PLL, providing rejection of the phase noise or phase error within the bandwidth, ***Figure 5*** shows the loop error response, which is obtained by the connection between the open and closed loop responses.

In this approach, the loop filter design is a very critical part of the PLL synthesizer. In general, a low loop filter cut-off frequency does not suppress the phase noise at close-in frequencies because the closed loop negative feedback region is narrowed. In addition, it makes the PLL response slower and the settling time of the frequency switching (PLL lockup time) longer and, as a result, the PLL spurious is suppressed. Conversely, increasing the cut-off frequency provides a faster PLL response and a shorter PLL lockup time. However,

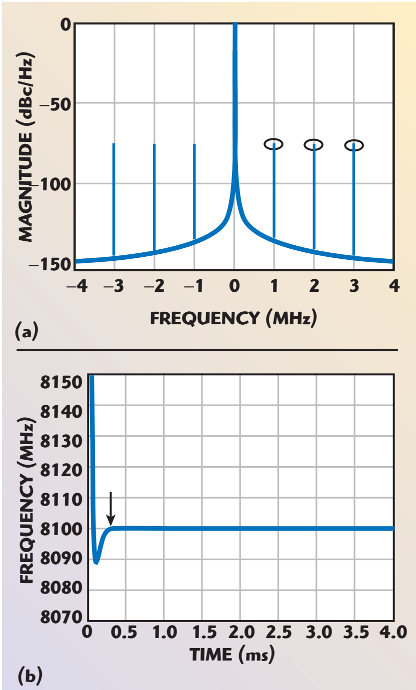


Fig. 7 Performed loop filter with higher cut-off frequency; (a) PLL output spectrum and (b) PLL transient response.

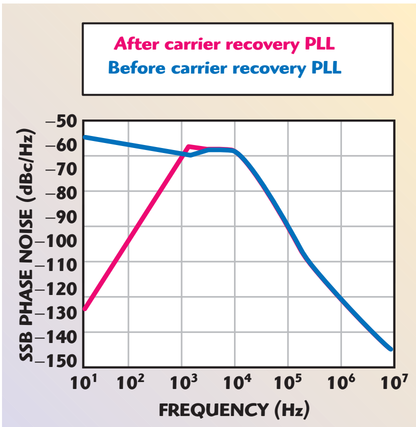


Fig. 8 Noise before and after carrier recovery in demodulation.

the PLL output signal is frequency-modulated and contains high level spurs. Since the sideband's spurious noise affects the adjacent channels, the unwanted spurs can be suppressed by narrowing the loop filter bandwidth.[5] An accurate estimation of the loop filter is used, which guarantees the precision of the design. The output spectrum and the transient response plots for two low loop filters with different cut-off frequencies are shown in ***Figures 6*** and ***7***, where the spurious level, phase noise and frequency transient are evaluated under various conditions.

Figure 8 shows the effect of the carrier recovery PLL in demodulation on the level of the single-sideband (SSB) phase noise and demonstrates the phase noise rejection properties of the carrier recovery PLL. The carrier recovery PLL suppresses the 100° deviation at 100 Hz down to a level that eliminates crossings of the decision boundaries. Integration of this curve on both sides of the carrier results in an rms phase noise of 0.008 radians, and a margin of signal-to-noise ratio (S/N) of 22.36 dB.

CONCLUSION

A simple design of an X-band frequency synthesizer that can be applied to micro-satellite transmitter systems has been presented. This article has discussed the phase noise from different sources in the PLL and their effects on the noise performance of the system and has demonstrated that the loop filter cut-off frequency choice is very important to achieve the performed PLL's spurious level, phase noise and frequency transient. To guarantee the precision of the design, an accurate estimation of the loop filter was used. The results indicate that for a frequency range of 8025 to 8175 MHz and with a carrier recovery of 0.6 kHz, the PLL gives an rms of 0.008 radians and a signal-to-noise ratio of 22.36 dB. ■

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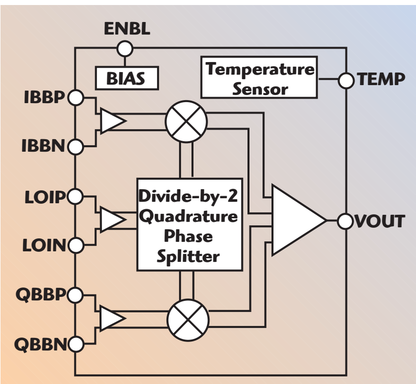
Mohamed Kameche *received his diploma in electrical engineering and his master's degree in signal and systems from the University of Tlemcen, Algeria, in 1998 and 2001, respectively. From 1998 to 2001, he was a teaching member in the department of electronics at the University of Tlemcen. He is currently with the National Center of Space Techniques (CNTS) at Arzew, Oran, Algeria. His research interests include temperature effects on RF and microwave devices and package modeling for microwave circuit applications.*

A BROADBAND I/Q MODULATOR FOR BROADBAND RADIO DESIGNS

Modern digital radio transmitter design poses increasing challenges for equipment designers. The ongoing trend towards increased throughput of data is increasing the modulation density and carrier bandwidths of transmitted signals. Peak-to-average ratios increase with higher order modulation schemes and to maintain good adjacent channel power ratio (ACPR) while transmitting the same rms power level, components with lower intermodulation distortion and lower noise must be used.

Baseband, IF and RF bandwidth must be flat across the channel to maintain the spectral shape of the modulated carrier. Furthermore, if digital pre-distortion techniques are being used then the higher order harmonics need to be passed through the baseband inputs and gain flatness must be maintained up to the higher order harmonics of the baseband signal. When a radio transmitter design calls for operation over a very wide range of RF frequencies the RF gain flatness of the overall signal chain becomes critical. Minimizing gain variations in the signal chain over frequency eases the burden of signal chain planning and budgeting. This article focuses on I/Q modulators, which are a critical component in modern transmitters.

Fig. 1 The ADL5385 I/Q modulator's basic block diagram.



A BROADBAND I/Q MODULATOR

I/Q modulators perform the frequency translation that mixes the baseband signal to the desired location in the RF spectrum. An I/Q modulator consists of a local oscillator (LO) input that is split into in-phase (I) and quadrature (Q) components that are separated by 90°. These two signals drive separate mixers that are also driven by I and Q baseband signals. The outputs from both mixers are then summed to provide a modulated carrier either at RF or IF. The ADL5385 contains these basic blocks (see ***Figure 1***) and is able to achieve a wide tuning range that spans five octaves (50 MHz to 2.2 GHz) through the use of an active divide-by-two LO splitter instead of the more traditional passive polyphase filter. Its wideband performance can be seen in

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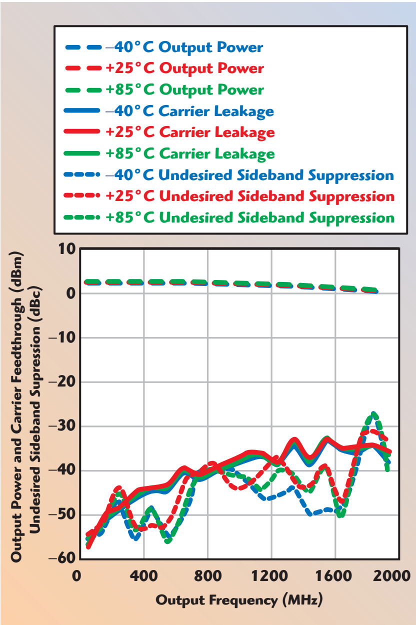
Norwood, MA

Figure 2, where the output power has a very flat response over the entire output frequency range, with a 1 dB bandwidth of 1300 MHz. This new modulator is designed to directly drive a 50 Ω load and also includes an integrated temperature sensor.

GAUGING SIGNAL QUALITY USING ERROR VECTOR MAGNITUDE

Error vector magnitude (EVM) is a measure of the quality of modulation of a signal and it is directly affected by the quadrature and amplitude errors within the modulator. The amount of quadrature and amplitude errors can be gauged by observing the level of sideband suppression in a single-sideband spectrum. Figure 2 shows that the native uncompensated sideband suppression of the ADL5385 I/Q modulator is better than –38 dBc out to 900 MHz. This level of sideband suppression typically yields EVM performance that is more than acceptable for most communication standards. If higher performance is required, sideband suppression can be optimized by adjusting the relative gain and phase of the baseband signals.

The 64QAM constellation, eye-diagram and spectrum, shown in ***Figure 3***, was generated using random data at 5.056941 MSym/s with a filter alpha of 0.18. This closely mimics the data rate and modulation for a typical cable modem head end application. It can be seen that the EVM for this signal is 0.33 percent rms with a quadrature error of 0.27° and a gain error of 0.003 dB.

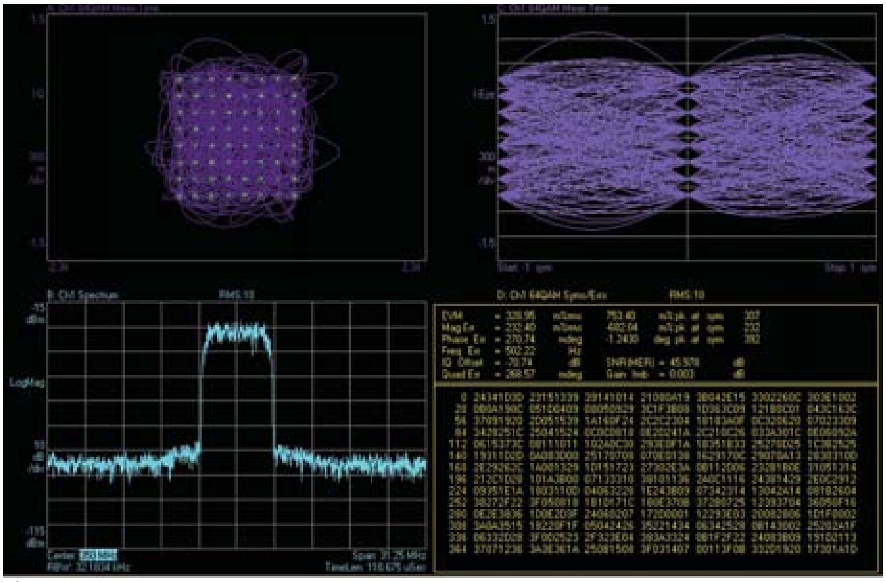


▲ *Fig. 2 Single-sideband performance vs. output frequency from –40° to +85°C.*

SIGNAL QUALITY VS. POWER LEVEL

Figure 4 shows how ACPR varies with output power for the same 64QAM modulated carrier. The high OIP3 of the ADL5385 I/Q modulator enables it to achieve high output power levels with minimal adjacent channel leakage. This results in less gain required in the subsequent stages of the radio.

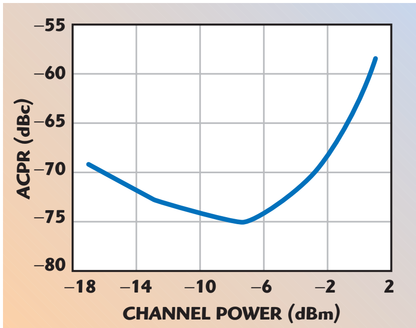
The displayed performance was obtained without digital compensation of the baseband data. This, along with the wide RF tuning range, allows the modulator to be used without factory calibration. This can significantly reduce the time and effort required for design and manufacturing.



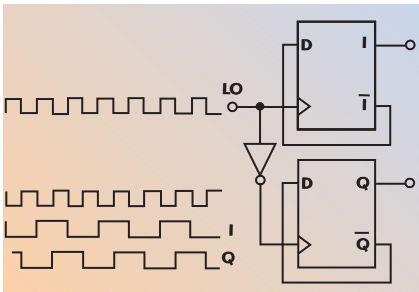
▲ *Fig. 3 The spectrum, constellation and eye-diagram of a 64QAM carrier at 350 MHz.*

DIVIDE-BY-TWO SPLITTER ENABLES BROADBAND OPERATION

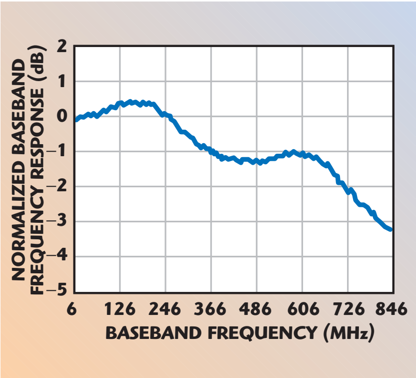
Systems such as cable modem head end equipment must be able to dynamically place carriers anywhere in the the 40 to 900 MHz range. Traditional modulators that use a passive resistor-capacitor polyphase network to split the LO into quadrature components have generally been unable to span such a wide frequency range. This is because the resistor-capacitor networks are tuned for a particular center frequency and typically have a useful range of just over two octaves. Traditional cable modem headend equipment designs use a two-stage upconversion. The baseband signal is upconverted using an I/Q modulator to an IF frequency above the cable band, typically around 1100 MHz. This IF signal is then mixed down into the cable band using a mixer. These solutions require more components and the complexity associated with such de-



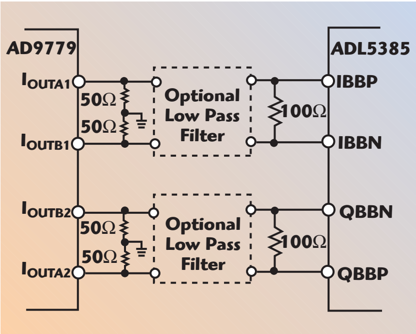
▲ *Fig. 4 64QAM ACPR vs. output power (symbol rate = 5.056941 MSym/s with a filter alpha of 0.18, adjacent channel bandwidth = 5.25 MHz).*



▲ *Fig. 5 The ADL5385 modulator's divide-by-two phase splitter showing the applied LO at twice that of the desired LO frequency in the mixer.*



▲ *Fig. 6 The ADL5385 baseband section's normalized frequency response.*



▲ *Fig. 7 AD9779 and ADL5385 interface schematic.*

signs increases the design time and effort. System cost and complexity can clearly be reduced if this signal chain could be simplified to a single-stage direct launch architecture.

The ADL5385 overcomes the two-octave limitation of traditional I/Q modulators by utilizing a divide-by-two LO splitter. This architecture is illustrated in ***Figure 5***, where two D-flip-flops are clocked by an LO signal and its inversion. In the ADL5385 the inversion is achieved by crossing the polarities of the inputs on one of the differential D-flip-flops. The I and Q signals that drive the mixer cores shown in the ADL5385 block diagram are generated through the alternate clocking of the D-flip-flops by the two LO input signals. Close inspection of the timing diagram on the left of the figure will reveal that it is imperative that the applied LO signal be at twice the desired RF output frequency and that the duty-cycle of that LO signal be exactly 50 percent. Any deviation from 50 percent will degrade the 90° split and this will in turn degrade sideband suppression.

WIDE BASEBAND BANDWIDTH INCREASES DATA CAPACITY

In single-channel modulation systems, data capacity can be increased by either using a higher order modulation scheme or by using more bandwidth. ***Figure 6*** shows the normalized baseband frequency response of the ADL5385. With wider carrier bandwidths, the challenge is to maintain a flat gain across the bandwidth of the carrier. This ensures that the spectrum is not distorted by gain ripple. If the gain ripple is too great then precompensation might be required in the digital domain. This process will require the characterization of the frequency response of every radio and will increase the complexity of the design and drive up the cost to manufacture the radio. The ADL5385 offers a 0.1 dB baseband gain flatness out to 85 MHz. This means that for most applications, there should be no need to perform any sort of precompensation.

A SEAMLESS INTERFACE TO BASEBAND I/Q DACS

The ADL5385 is designed to interface seamlessly with Analog Devices' family of transmit digital-to-analog converters (TxDAC). The interface between the two devices typically involves six resistors and a simple LC filter (see ***Figure 7***). The four 50 Ω resistors shunting to ground from each of the DAC outputs provide the 500 mV DC bias for the ADL5385 baseband inputs while the 100 Ω resistor in shunt between each differential pair sets the AC swing of the baseband inputs. With this simple interface the need for single-ended-to-differential or level-shifting amplifiers is eliminated.

PACKAGE, AVAILABILITY, EVALUATION BOARDS

The ADL5385 is packaged in a RoHS-compliant 24-lead LFCSP with exposed paddle. Samples and evaluation boards are currently available and may be ordered on the company's web site.

**Analog Devices Inc.,
Norwood, MA
(781) 329-4700,
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RS No. 300

HIGH PERFORMANCE 28 V INGAP HBT POWER AMPLIFIERS

A new 28 V InGaP HBT technology has been developed for mobile infrastructure power amplifier applications that provides significant advantages in power output and efficiency compared to other technologies currently used for these devices. This 28 V process was developed from WJ Communications' highly successful 5 V InGaP HBT process that has demonstrated very high reliability for mobile infrastructure applications. Three new power amplifiers have been developed using this new process.

The +28 V InGaP HBT process is state-of-the-art with exceptional breakdown voltage and power handling capabilities. The high breakdown voltage of the HBT was achieved with a thicker collector structure. Multiple fingers are arranged into a single building block with an emitter area around 1500 μm^2. Multiple building blocks are then arrayed into a large size power HBT. Each building block has the capability to deliver 2 W of RF power in the 1 to 3 GHz frequency band. The f_T and f_{max} of the basic HBT finger are 6.4 and 25 GHz, respectively. Lifetime tests have already been run for over 4000 hours at 315°C junction temperature with minimal beta degradation. The process has also proven to be capable of handling up to 6 dB input overdrive without failure.

In addition, a new surface mountable power DFN (Dual Flat-pack No-lead) package has been developed for these InGaP HBT devices that incorporates a eutectic die attach for the semiconductor die to minimize thermal resistance and ensure highly reliable operation.

THE NEW +28 V InGaP AMPLIFIERS RAISE THE BAR FOR PERFORMANCE AND EFFICIENCY

Currently, three new amplifiers have been developed using this 28 V InGaP HBT process. They all feature high dynamic range and broad frequency range of operation in a surface-mount configuration.

The AP601 device is a single-stage 1.8 W amplifier featuring 13.5 dB gain and high performance over the 800 to 2200 MHz frequency range with up to +32.5 dBm of output power at the 1 dB compression point (P1dB). ***Figure 1*** shows the AP601 amplifier's power-added ef-

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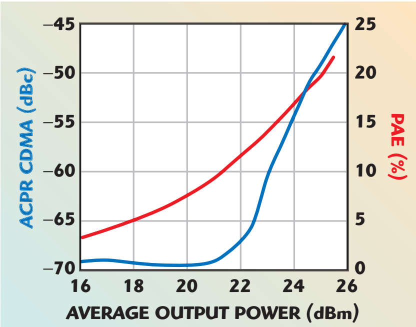
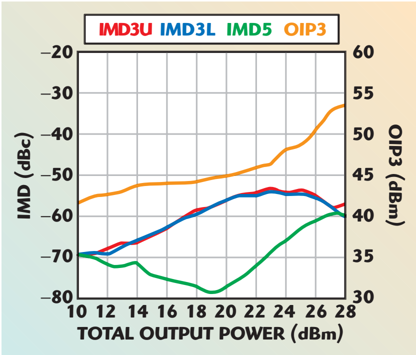
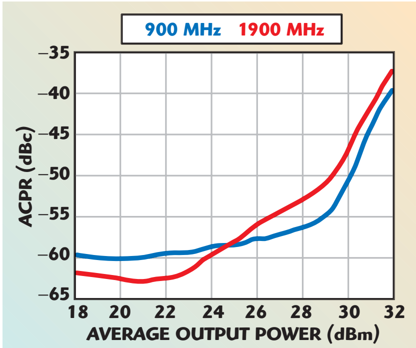


▲ *Fig. 1 The AP601 amplifier's PAE and ACPR performance (using an IS-95A signal) vs. average output power at 900 MHz.*



▲ *Fig. 2 The AP602 amplifier's IMD and OIP3 performance at 900 MHz with a two-tone spacing of 1 MHz.*



▲ *Fig. 3 The AP603 amplifier's ACPR performance at 900 and 1900 MHz.*

ficiency (PAE) and ACPR performance vs. average output power.

In addition to using the +28 V InGaP HBT process technology, the device incorporates proprietary bias circuitry to compensate for variations in linearity and current draw over temperature. The module does not require any negative bias voltage. An internal active bias allows the AP601 amplifier to operate directly off of a commonly used single 24 to 28 V DC supply. An added feature allows the quiescent bias to be adjusted to meet specific system requirements.

The AP601 is housed in a RoHS compliant 5 × 6 mm power DFN package and typically draws 65 mA operating at +23 dBm output and 40 mA quiescent current. Input and output return losses are 10 and 8 dB, respectively. Its PAE is typically 15 percent at +23 dBm output and its output third-order intercept (OIP3) is +46 dBm for a two-tone output of +27 dBm/tone and a spacing of 1 MHz. The AP601 amplifier's typical applications are mainly in wireless mobile infrastructure and as final stage amplifiers in repeaters.

The AP602 high dynamic range 4 W amplifier is also a single-stage amplifier that operates from 800 to 2200 MHz but features a gain of 13.7 dB and up to +36 dBm of P1dB power. Its basic configuration is similar to the AP601; however, it draws 120 mA operating at +27 dBm output and 80 mA quiescent. Its OIP3 is +49 dBm and its PAE is 15 percent at +27 dBm output. ***Figure 2*** shows the AP602 amplifier's IMD and OIP3 characteristics.

The third amplifier in the family is the AP603 7 W device. This amplifier is also a single-stage device that operates from 800 to 2200 MHz. The AP603 features 12 dB of gain with up to +37.5 dBm of P1dB output power.

The AP603 amplifier has a 14 percent PAE at +30 dBm output and a +49 dBm OIP3. It draws 255 mA at +28 V at a power output of +30 dBm and 160 mA quiescent current. Its input and output return losses are 10 and 6 dB, respectively. ***Figure 3*** shows the AP603 amplifier's ACPR performance vs. its average output power.

All three new amplifiers are targeted for use as pre-driver and driver stage amplifiers in wireless infrastructure applications where high linearity and high power is required. This combination makes these devices an excellent choice for next generation multi-carrier 3G mobile infrastructure applications. Additional information may be obtained by contacting sales@wj.com.

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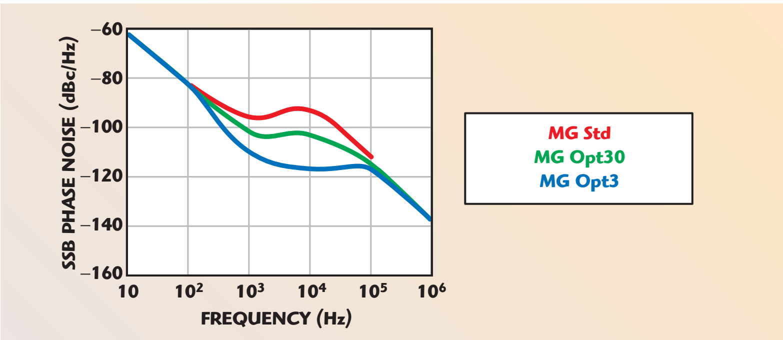
RS No. 301

SIGNAL GENERATOR FAMILY ENHANCED WITH LOW PHASE NOISE, HIGH POWER AND 70 GHZ COVERAGE

Anritsu Co. is introducing a 70 GHz model to its MG3690B family of RF/microwave signal generators that not only extends the frequency range but also offers flexibility and cost of ownership advantages. The new model incorporates an enhanced design that makes it the only signal generator on the market that can perform a 0.1 Hz to 70 GHz continuous sweep, helping to improve accuracy and overall efficiency.

Fig. 1 Specified phase noise at 10 GHz.



The 70 GHz model has been developed with flexibility in mind. In addition to the standard phase noise, there is an ultra-low phase noise option of –110 dBc/Hz (typically) at 1 kHz offset at 10 GHz and a new low phase noise option that provides an intermediate level of performance. ***Figure 1*** shows the phase noise performance of the MG3690B generator. The variety of phase noise choices allows engineers to customize the instrument for specific applications. This ability is critical because phase noise is becoming increasingly important for both commercial and defense communications systems, as it is directly related to component, filtering and shielding expense.

Achieving low phase noise over the full frequency spectrum is achieved due to the de-

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sign of the MG3690B. For applications above 2.2 GHz, patented techniques, which add additional phase-locked loops, are utilized. This approach helps deliver excellent SSB phase noise. A digital down converter (DDC), which produces frequencies by successive binary division, is used for 10 MHz to 2.2 GHz applications. This approach eliminates the addition of nonharmonic spurious common with mixer-based down conversion schemes. Below 10 MHz, the signal generators utilize direct digital synthesis (DDS) techniques to achieve a frequency resolution of 0.01 Hz, in addition to the low phase noise.

The design does more than provide improved phase noise and increase the frequency range. It also helps the MG3690B achieve continuous coverage from 0.1 Hz to 50 GHz with a specified +8 dBm output power at 50 GHz, with +9 dBm specified at 67 GHz with an option. It also has a typical switching speed of 5 ms in < 1 GHz steps for improved accuracy.

The MG3690B delivers comprehensive, high performance signal generation. Its internal pulse generator has swept delay capability for moving target simulation, including singlet, doublet, triplet and quadruple pulses. The signal generator has 100 ns leveled pulse width, synchronized pulse with AM/FM/ΦM for complex EW signals, and phase modulation up to 400 radians deviation at 1 MHz rates.

A wide variety of signal simulation applications are improved due to the MG3690B's enhanced performance. For example, the 70 GHz MG3690B can be used as a clock source for bit error rate testing (BERT) and its low single-sideband (SSB) phase noise translates to precise clocks with edges that are consistent period after period. It offers traditional master/slave capability to drive a mixer's RF and LO at offset frequencies with two tracking synthesizers for mixer measurements. An external power meter leveling mode is available, so the MG3690B can be used for TWTA measurements as well.

The 70 GHz model's base price of $65,200 is less than comparable models. Pricing of the options include $2500 for the low phase noise, $6500 for the ultra low phase noise and $9000 for 67 GHz high power output.

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RS No. 302

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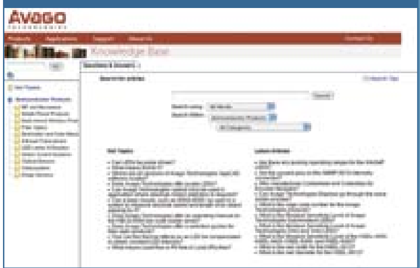

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The company's site now incorporates a new application that enables users to retrieve instant answers to technical questions. This knowledge-base tool can be accessed directly at http://knowledgebase.avagotech.com and provides easy access to a repository of answers for a wide variety of technical and applications questions collected from the company's customers and distribution partners over many years. The result is a self-service technical support 24 hours a day, seven days a week.

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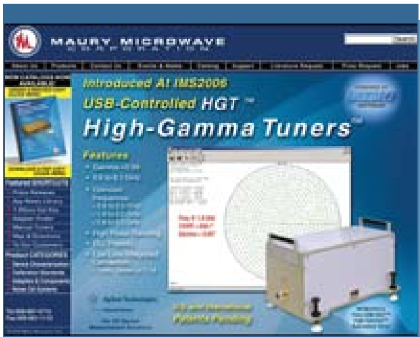
Presteigne, Powys LD8 2UH UK

www.labtechmicrowave.com



Interactive Adapter Finder

The interactive adapter finder is a tool that allows users to define the transition they need (coax-to-coax or waveguide-to-coax) and by selecting the connector type and gender (if applicable) for each side of the adapter, a search of the company's database returns a set of Maury adapters that matches the users' parameters. From this set of adapters, the user can select the model needed, and by clicking on its link, a data sheet page with detailed specifications, model number, dimensions and photo will result.

Maury Microwave Corp.,
2900 Inland Empire Blvd.,
Ontario, CA 91764

www.maurymw.com

Microwave Components

New additions to the web site include new products in all categories for commercial communications and military applications. In addition, engineers have the ability to place on-line orders for coaxial isolators, MICA*PAC isolators, and drop-in isolators and circulators. Frequency ranges include 0.5 to 40 GHz. Price and delivery quotes are within 48 hours on most on-line products. Have special requirements? This web site makes it easy to request those custom, hard to find solutions.

MICA Microwave Corp.,
1096 Mellon Avenue,
Manteca, CA 95337

www.mica-mw.com

High Performance Connectors

This site allows engineers to get high quality, high performance blind mate and threaded connectors quickly. The site features 360° product views along with data sheets and real time inventory. Account details are only a few clicks away and allow customers to easily check order status and download invoices safely and securely. The company stocks thousands of SMP, SMPM and MSSS connectors along with cable assemblies and tooling.

Micro-Mode,
1870 John Towers Avenue,
El Cajon, CA 92020

www.smpconnectors.com

Product Portfolio

This enhanced and redesigned web site features a searchable product database that allows users to sort by category or application, as well as search for specific parts and product types. The site's new design reflects the company's expanded product offerings, worldwide sales coverage, application tools to support customers and technology development. Highlights include: an emphasis on applications; products displayed by application and category; and a resources section.

Mimix Broadband Inc., 10795 Rockley Road, Houston, TX 77099

www.mimixbroadband.com

China Web Site

The company has created a new web site for the Chinese market. The site can be accessed on the company's home page by clicking on the Chinese Welcome message. Features include: product offerings in four segments – printed circuit materials, high performance foams, custom electrical components and other polymer products. The menus and entry pages have been translated into simplified Chinese that will help guide visitors to pages that will mostly remain in English.

Rogers Corp., One Technology Drive, Rogers, CT 06203

www.rogerscorporation.com

Hermetic Products and Services

This recently updated web site features the company's standard line of products and services, and related information including the Product Highlight. Newly added is the Technical Library, which includes design and process guidelines offering customers assistance in product application and troubleshooting based on many years of hands-on experience. The Technical Library and Product Highlights provide new information on a regular basis.

Special Hermetic Products Inc., 39 Souhegan Street, Wilton, NH 03086

www.shp-seals.com

Signal Analysis Platform

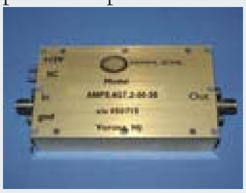
The MXA signal analysis platform provides measurement speeds that can be 30 to 300 percent faster than other analyzers. This enables dramatic improvement in throughput and yields in manufacturing. This platform provides high performance in a midrange analyzer that enables engineers to solve design challenges for current and emerging applications faster and with fewer iterations. ≤ 14 ms WCDMA ACLR with 78 dB dynamic range is typical. The platform allows flexible signal and spectrum analysis measurements for the design and manufacture of wireless communication devices to current and emerging standards. It seamlessly integrates a broad range of standards-based measurements, such as WiMAX, or the company's 89601A vector signal analysis software — all in one instrument.

Agilent Technologies Inc.,
Palo Alto, CA (800) 829-4444,
www.agilent.com.

RS No. 216

High Power Amplifier

The model AMP5.4G7.2-30-38 is a C-band high power amplifier ideal for wireless, defense and satellite communications.



This model operates in a frequency range from 5.4 to 7.2 GHz. The output power at 1 dB compression is at least 38 dBm and gain is greater than 30 dB. Input voltage is +12 V and current draw is less than 5A. Additionally, the unit is equipped with an integral isolator at the output. This model is supplied with SMA(f) input and output connectors. Size: 3" × 5" (including connectors) × 1".

Amplical Corp.,
Verona, NJ (201) 919-2088,
www.amplical.com.

RS No. 217

Power Amplifiers

These power amplifiers are designed for applications such as CDMA, HDTV and WiMAX.

This new family of solid-state amplifier modules for wireless communications includes four modules for CDMA applications, one module for HDTV applications, one module that meets WiMAX 802.16 specifications and can be modified to meet various OFDM and NPR requirements, and one module that covers most of UHF, L and S bands for general applications requiring instantaneous ultra broadband.

AR Worldwide Modular RF,
Bothell, WA (425) 485-9000,
www.ar-worldwide.com.

RS No. 218

Low Noise Amplifier MMIC

The model HMC548LP3 (E) is a low noise amplifier that operates in a frequency range from 1200 to 3000 MHz and is comprised of two internally matched SiGe HBT MMIC LNA stages, housed in a single 3 ×3 mm leadless SMT package, and optimized for GPS applications. The unique topology of the HMC548LP3 (E) allows the designer to place a bandpass filter between the two amplifier stages, enabling the receiver to reject nearby blocking signals without incurring the noise figure degradation associated with a high rejection pre-filter.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.

RS No. 219

High Power Circulators

The CT-1740-S series of 1-5/8 EIA high power circulators covers up to 10 percent bandwidth

in the frequency range from 120 to 250 MHz. Rated at 2.5 kW average power and 10 kW peak. Typical specifications are 20 dB minimum isolation, 0.25 dB loss and 1.25 maximum VSWR. This series operates in a temperature range from 0° to 65°C. Other UHF units are also available. Applications include: TV, scientific, industrial and communications.

UTE Microwave Inc.,
Asbury Park, NJ (732) 922-1009,
www.utemicrowave.com.

RS No. 225

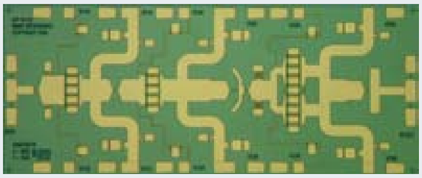
Reactive Splitters

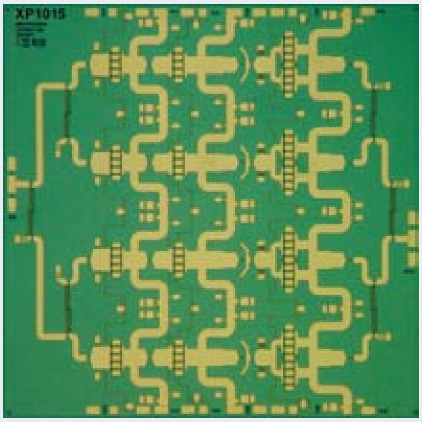
These reactive splitters feature rugged construction and good performance across all wireless bands from 0.8 to 2.7 GHz, which makes them ideal for in-building or tower top systems. Installation is easy with unobstructed access to connector ports for even the largest coaxial cables with no additional mounting hardware. These splitters are available from stock in two- and three-way, 7/16 DIN, Type N or SMA female configurations. Rated for 200 W (maximum). Weatherproof (IP65 rated). Made in the USA.

MECA Electronics,
Denville, NJ (973) 625-0661,
www.e-meca.com.

RS No. 220

Amplifier Chip Set





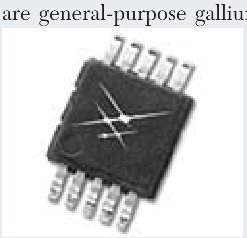
This gallium arsenide monolithic microwave integrated circuit three-stage balanced power amplifier and complementary three-stage driver amplifier are identified as XP1015 and XP1016, respectively. The power amplifier has a balanced design to achieve good output match, operates in a frequency range from 43.5 to 46 GHz, and has a small-signal gain of 12 dB with +31 dBm P1dB compression point. The driver amplifier covers this same frequency band and achieves a small-signal gain of 14 dB with +24 dBm P1dB compression point. Used as a driver and final stage cascade, the chip set achieves 26 dB gain and 2 W saturated output power.

Mimix Broadband Inc.,
Houston, TX (281) 988-4600,
www.mimixbroadband.com.

RS No. 221

GaAs Attenuators

Models SKY12322, SKY12323 and SKY12325 are general-purpose gallium arsenide (GaAs)



attenuators that feature excellent distortion performance for various types of linear applications including UMTS, WCDMA, WiMAX and WLAN.

These GaAs digital single-positive-control step attenuators are also designed for base station transmitter and receivers, and can be used in radio frequency identification (RFID) transceivers. Targeted at original equipment manufacturers (OEM) building any type of receiver or modem, these broadband, low insertion loss attenuators are built in small packages of only 3 × 3 mm. The bilateral radio frequency (RF) ports allow input and output.
Skyworks Solutions Inc., Woburn, MA (781) 376-3000, www.skyworksinc.com.

RS No. 224

X-band Antenna

The model RPS2P2-80-S is a lightweight and highly portable transmit/receive 2' diameter Cassegrain X-band antenna.

This antenna is designed for military satellite communications that operate in the 7.25 to 8.4 GHz frequency band. The antenna can transmit and receive on each port for either LHCP or RHCP senses of polarization without having to rotate the OMT or a polarizer. The only three components requiring field assembly are the Cassegrain feed, the two-piece precision reflector and the mount, which folds flat for storage. All assembly hardware is captive and no tools are required for assembly.
mWAVE Industries LLC, Gorham, ME (207) 857-3083, www.mwavellc.com.

RS No. 222

Surface-mount Isolators/Circulators

The SLE series of redesigned and improved surface-mount isolators operates in a frequency range from 380 to 2200 MHz and is ideal for low power applications.

This device is low cost and miniaturized in size making it a perfect fit for tomorrow's telecom applications. This device is also available in a circulator version. Both are available in tape and reel format for high speed automated assembly. Models available in typical bandwidths of 5 percent with isolation > 17 dB and insertion loss < 0.8 dB.
Renaissance Electronics Corp., Harvard, MA (978) 772-7774, www.rec-usa.com.

RS No. 223

COMPONENTS

SP8T Broadband Switch

The model MSR-8DT-07-AKG-STANDARD option 0120 is an absorptive/non-reflective SP8T, broadband switch that is surface mountable

and miniature in size. This model operates from 0.1 to 20 GHz, provides an insertion loss of 6 dB maximum and isolation of 110 dB minimum. The unit offers a rise/fall time of 300 ns typical. Supply voltages are +5 V at 500 mA maximum, –12 V at 100 mA maximum. RF phase tracking is 0.2° per °C all ports with respect to common with temperature. Size: 1.5" diameter circle point to point × 0.4". Weight: < 2.5 ounces typical.

American Microwave Corp., Frederick, MD (301) 662-4700, www.americanmicrowavecorp.com.

RS No. 226

Low Intermod Termination

The 50T-453 RF load is specially designed for intermodulation testing and measurements of –165 dBc at 1950 MHz (with two 20 W tones).

Perfect for lab use, this model boasts a 50 W input power rating and a low VSWR of 1.20 maximum at 3000 MHz. Available with 7/16 or N connectors.

JFW Industries, Indianapolis, IN (317) 887-1340, www.jfwindustries.com.

RS No. 229

Coaxial Cable Assembly

These low cost flexible/semi-flex coaxial cable assemblies utilize RG and LMR type cables that meet MIL-17-C specification. All the cable assem-

blies are 100 percent tested for standard electrical performance and additional testing is possible per a customer's requirement. Currently, the company offers cable assemblies that use various high quality connectors such as SMA, N, MMCX, MCX, SMB, TNC and BNC. Customer specified connectors are also used upon request.

Electronika International Inc., Cleveland, OH (440) 743-7034, www.electronikainc.com.

RS No. 227

I&Q Vector Modulator

The model SA-69-GB is a 2 to 18 GHz, PIN diode, amplified I&Q vector modulator. This device simultaneously controls phase and amplitude

with 360° and 15 dB of dynamic range. The phase and amplitude flatness is ±20° and ±3 dB. VSWR is less than 2.0 and with the amplifier there is no loss in signal power. It is capable of non-degraded performance at 0 dBm CW and can handle +20 dBm maximum. It is digitally controlled via two sets (I&Q) of monotonic 12 bit TTL compatible binary logic and switches in 500 ns. The device offers an input control slope characteristic that is linear with output voltage. Size: 4.25" × 3.5" × 0.75".

G.T. Microwave Inc., Randolph, NJ (973) 361-5700, www.gtmicrowave.com.

RS No. 228

SMA Female Connectors

These SMA female connectors operate in a frequency range from DC to 18 GHz. The connectors are housed in passivated stainless steel with an

assembly that provides for minimum leakage. Type N connectors are also available for immediate delivery. All connectors and terminations meet environmental MIL-STD-202 standards and are RoHS compliant. MCLI maintains stock on large quantities of connectors and terminations, and is able to offer immediate delivery on large quantities at volume discounted prices.

Microwave Communications Laboratories Inc., Saint Petersburg, FL (727) 344-6254, www.mcli.com.

RS No. 230

Quick-Connect Cable Assemblies

These Quick-Connect cable assemblies utilize Emerson connectivity solutions partner Johnson components SMA Quick-Connect system. These

assemblies operate in a frequency range up to 12.4 GHz and are ideal for test and system applications where rapid mating to a standard SMA female is desirable. The assemblies are currently available on the Midwest triple screened M42 cable in the standard finish or armoured. Customized cable assembly options are available on request.

Midwest Microwave, Saline, MI (734) 429-4773, www.midwest-microwave.com.

RS No. 231

Power Splitters/Combiners

The ZX10-4 family of four-way 0° power splitters/combiners operates in a frequency range from 800 to 3000 MHz. These devices are ideal for

panel mount, conserving space on a panel maintaining high isolation (20 dB typical) and low insertion loss (0.6 dB typical). These splitters/combiners are ideal for antenna arrays, signal distribution and test bench use. Price: $38.95 each (1–24).

Mini-Circuits, Brooklyn, NY (718) 934-4500, www.minicircuits.com.

RS No. 232

75 Ω RF Switch

The RoHS-compliant PE42742 high performance RF switch is targeted for broadband applications. Designed to exceed the strict FCC 15.115 regulations, this 75 Ω single-pole, double-throw (SPDT) device offers high isolation of 88 dB at 216 MHz and 78 dB at 806 MHz. A unique design feature allows the device to maintain its isolation levels even in the unpowered state, which is one of the more stringent requirements of FCC compliance for CATV-to-antenna isolation. Size: 4 ×4 mm 20-lead QFN package. Price: $1.67 each (10 K).

Peregrine Semiconductor,
San Diego, CA (858) 731-9400,
www.psemi.com.

RS No. 233

Threshold Detector

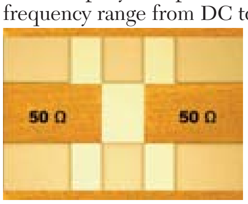
The model TD-A-42T-818 is a hermetically sealed threshold detector that is optimized for the 8 to 18 GHz frequency range (other frequency ranges are available). It offers an internally fixed threshold level that provides a minimum signal level of –42 dBm with a maximum input VSWR of 2.5. The threshold stability is a constant ±3 dB over the operating temperature and frequency range.

Planar Monolithics Industries,
Frederick, MD (301) 662-4700,
www.planarmonolithics.com.

RS No. 234

Attenuator Design Kits

The company's chip attenuators operate in a frequency range from DC to 26.5 GHz and are available in engineering design kits. An assortment of common values are prepackaged in waffle pack form with delivery from stock. Price: $250.00 (1 to 5 kits).



Ion Beam Milling Inc.,
Manchester, NH (877) 644-2326,
www.ionbeammilling.com.

RS No. 252

High Power Splitter/Combiner

The P/N PP4-50-452/2N is a four-way high power splitter/combiner that enables the user to either split an input signal of 400 W into four equal outputs or combine four inputs of 100 W each for a total output of 400 W minus the insertion loss of 0.6 dB. Specifications include a frequency range of 20 to 400 MHz, amplitude and phase balance of 0.5 dB and 6 degrees, respectively, isolation of 20 dB and 1.3 VSWR. Size: 4" × 3.4" × 1" and connectors are type N female.

Pulsar Microwave Corp.,
Clifton, NJ (973) 779-6262,
www.pulsarmicrowave.com.

RS No. 235

Narrowband Cavity Filter

The part number 7C9-2656.39-5.11S11 is a narrowband, highly selective cavity filter. This unit is centered at 2656.39 MHz and offers a 3 dB bandwidth of 5.11 MHz. The filter has a rejection of greater than 45 dB at CF ± 6 MHz. Insertion loss measures less than 4 dB and VSWR is less than 1.25.

Reactel Inc.,
Gaithersburg, MD (301) 519-3660,
www.reactel.com.

RS No. 236

Attenuator Relay

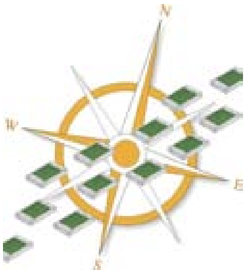
The A152 attenuator relay is designed to be used in 50 and 75 Ω systems that operate from DC to 5 GHz. It offers a low loss bypass and a 20 dB attenuated path in "Pi" configuration. Other attenuation values are available on request. Gold-plated contacts provide good intermodulation performance and repeatability (±0.1 dB). Additional features include high isolation, resistance to shock, vibration and electrostatic discharge, a stable value over frequency and temperature range, and excellent phase linearity.

Teledyne Electronics and Communications,
Cumbernauld, Scotland +44 1236 453 124,
www.teledyne-europe.com.

RS No. 238

Non-magnetic Resistors

These non-magnetic chip resistors are ideal for use in medical and sensor applications. The new components are available in 13 standard case sizes: 0402 (0.040" × 0.020") thru 3838 (0.380" × 0.380"). These thick-film non-magnetic resistors are available with wrap around terminations suitable for solder mount. The devices eliminate materials that would disturb magnetic field applications such as in magnetic resonance imaging machines. Resistors range with tolerances from 1 percent, and power ratings from 40 mW to 5 W.



State of the Art Inc.,
State College, PA (800) 458-3401,
www.resistor.com.

RS No. 237

Dual Directional Coupler

The model C7711 is a low loss, 30:1 bandwidth coupler that operates in a frequency range from 100 to 3000 MHz, making it ideal for multi-band military and commercial applications. This model rates at 100 W CW, with an insertion loss of 0.35 dB, VSWR (ML) of 1.25, coupling flatness of 40 dB ±1 dB and directivity of 18 dB. Size: 3" × 2.2" × 0.7".

Werlatone Inc.,
Brewster, NY (845) 279-6187,
www.werlatone.com.

RS No. 239

Coaxial Attenuator

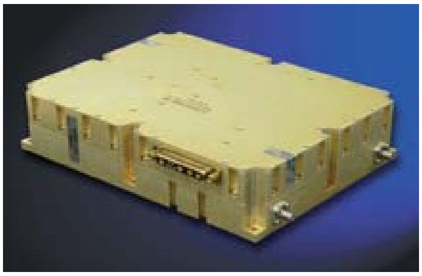
The commercial grade, model 3082-6156-XX is a 2 W, type N fixed coaxial attenuator that operates from DC to 6 GHz. This product offers the durability of XMA products, featuring a lightweight, nickel plated brass body and gold plated beryllium copper center contact. This, coupled with solid electrical performance and attractive prices, makes the attenuator an outstanding value. This product is ideal for in building applications as well as military and telecommunications volume production applications requiring good long-term performance and low cost.

XMA Corp.,
Manchester, NH (603) 222-2256,
www.xmacorp.com.

RS No. 240

AMPLIFIERS

High Power GaN RF Amplifier



The model SSPA 0.5-2.5-30 is a high power, broadband, gallium nitride (GaN) RF amplifier that operates in a frequency range from 0.5 to 2.5 GHz. This PA is ideal for broadband military platforms as well as commercial applications because it is robust and offers high power over a multi-octave bandwidth. The amplifier operates with a base plate temperature of 85°C with no degradation in the MTBF for the GaN devices inside. This amplifier offers a typical P1dB of 20 W at room temperature. Saturated output power across the band is typically 25 to 30 W. Noise figure at room temperature is 6 dB typical. Size: 4" × 6" × 2".

Aethercomm Inc.,
San Marcos, CA (760) 598-4340,
www.aethercomm.com.

RS No. 241

TWT Microwave Amplifiers

Models 70T18G26 and 70T26G40 are traveling wave tube (TWT) microwave amplifiers that nearly double the power available over the 18 to 40 GHz frequency range. Model 70T18G26 provides 75 W of CW power over 18 to 26.5 GHz and model 70T26G40 provides 70 W of CW power from 26.5 to 40 GHz. Previously, models 40T18G26 and 40T26G40, with a power output of 40 W, were the highest power offering over the 18 to 40 GHz band.

AR Worldwide RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.ar-worldwide.com.

RS No. 242

High Gain Amplifiers

The model PTB-50-0R118-6R5-18-120VAC-SFF-DVA and model PEC-50-0R118-6R5-18-120VAC-1U-SFF are high gain amplifiers with integrated digital attenuation control. These amplifiers operate in a frequency range from 100 MHz to 18 GHz and offer a gain of 50 dB minimum, gain flatness of ±2 dB (up to 55 dB attenuation), noise figure of 6 dB at 100 MHz, 3 dB at 18 GHz and an attenuation range of 0 to 60 dB (1 dB resolution).

Planar Electronics Technology,
Frederick, MD (301) 662-5019,
www.planarelec.com.

RS No. 243

Medium Power Amplifiers

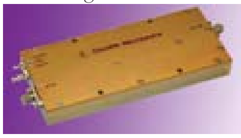
This line of medium power amplifiers yields 5 W minimum output power over the frequency range from 0.5 to 18 GHz. These amplifiers were developed for a custom application in a Flight Line Test Set and are available in bands that operate from 0.5 to 1.5 GHz, 1.5 to 3 GHz, 3 to 6 GHz and 6 to 18 GHz.

Rodelco Electronics Corp.,
Ronkonkoma, NY (631) 981-0900,
www.rodelcocorp.com.

RS No. 244

GaAs FET Amplifier

The model SM1727-37HS is a GaAs FET amplifier designed for various WiMAX products and device test applications. The unit operates from 1.7 to 2.7 GHz with a P1dB of +37 dBm. Small-signal gain is 20 to 33 dB with a flatness of ±0.5 dB across the band. Typical WiMAX performance (802.16d 64QAM OFDM) is –40 dB EVM at +30 dBm burst power. Standard features include a single +12 VDC supply and over/reverse voltage protection. Size: 4" × 2" × 0.54".

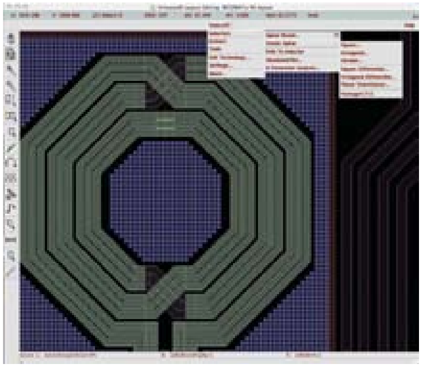


Stealth Microwave Inc.,
Trenton, NJ (609) 538-8586,
www.stealthmicrowave.com.

RS No. 245

SOFTWARE

Enhanced EDA Tool

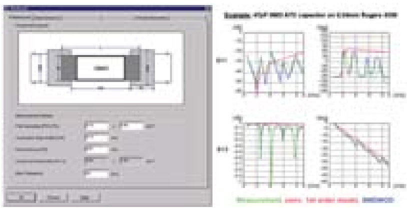


The VeloceRF™ v1.5 features an enhanced Spiral Wizard™ inductor synthesizer, several improvements in its rapid RLCK modeling engine and new features addressing Design for Manufacturability for 90 and 65 nm RFICs. The synthesis engine now supports the creation of patterned shields that enhance inductor Q-factor and improve substrate isolation. Version 1.5 efficiently addresses DFM requirements emerging for RF CMOS at the 90 nm process node and below. Features such as conductor track slotting to mitigate metal stress, geometry resizing under current density constraints and the use of dummy fill patterns are now programmed into the VeloceRF inductor library and are consistently supported by the Spiral Wizard, the modeling engine and the layout and LVS modules.

Helic,
Athens, Greece +30 210 9949390,
www.helic.com.

RS No. 246

Multi-port SMD Modeling



SMDMOD is a new tool for designers of hybrid microwave circuits using R, L, C surface-mount components and representing their electrical properties correctly in circuit simulations up to 10 or even 20 GHz and higher. Based on two-port S-parameter measurement results of a set of samples on one, two or three different substrates, SMDMOD allows the capability to extract super-scaleable realistic multi-port models. From that, SMDMOD allows the generation of two-, three- or four-port S-parameter files of intermediate component values mounted with varying pads on a different substrate, with one or two ports on each pad. These S-parameter files can then be included in standard circuit simulators to better represent SMD component parasitic effects than current commercial state-of-the-art equivalent circuits models do.

AC Microwave GmbH,
Aachen, Germany +49-241-879 3022,
www.linmic.com.

RS No. 247

SOURCES

Advanced Digital Synthesizer Technology

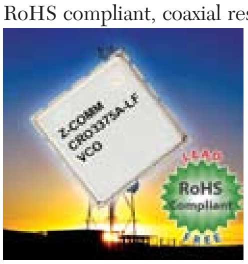
The WaveCor 2.50 is the newest addition to ITT's line of DDS-based frequency synthesizers. This synthesizer features an operating frequency range from 300 MHz to 2.5 GHz with step sizes of less than 1 Hz. This new product continues WaveCor's tradition of low phase noise and spurious levels combined with extremely fast switching speeds. At 2.4 GHz, the WaveCor provides phase noise levels of –136 dBc/Hz at a 10 kHz offset and spurious levels up to –70 dBc. Switching speeds are less than 250 ns at any operating frequency. The WaveCor 2.50's high reliability and performance is available in a lightweight 3U rack mount chassis.

ITT Corp. – AES Division,
Lowell, MA (978) 441-0200,
www.ittmicrowave.com.

RS No. 255

C-band Coaxial Resonator Oscillator

The model CRO3375A-LF is a lead-free, RoHS compliant, coaxial resonator oscillator in C-band (3370 to 3380 MHz) that features low phase noise performance of –115 dBc/Hz at 10 kHz offset from the carrier. This design offers tuning linearity with a typical tuning sensitivity of 7 MHz/V and covers the entire band between 0.5 to 4.5 V. It is designed to operate at 5 VDC supply while drawing 21 mA (typical) over the extended operating temperature range of –40° to 85°C. Size: 0.50" × 0.50" × 0.22". Price: $29.95/VCO (5). Delivery: four weeks.



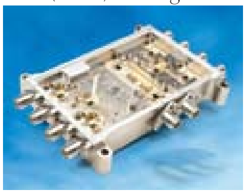
Z-Communications Inc.,
San Diego, CA (858) 621-2700,
www.zcomm.com.

RS No. 248

SUBSYSTEM

Custom Multi-function Assemblies

This series of custom multi-function assemblies (MFA) is designed for RF power distribution applications.



These particular MFAs provide input filtering, amplification using GaAs MMIC devices, digitally controlled attenuation, and temperature compensated power distribution of incoming RF signals amongst eight output ports. Limiters and equalizers are incorporated onto each signal path to provide flat output power response vs. frequency, and particular care has been taken in the design to provide stringent phase matching and tracking performance. Multiple models have been developed to accommodate multi-octave bandwidths within the 0.5 to 18 GHz range, making them ideally suited for electronic surveillance and signal intelligence (SIGINT) applications. Each model is hermetically sealed and works over the complete military operating range of –55° to +85°C.

Endwave Defense Systems,
Sunnyvale, CA (408) 522-3180,
www.endwave.com.

RS No. 249

TEST EQUIPMENT

Spectrum Analyzer

The 9100 spectrum analyzer series provide features such as a frequency range from 100 kHz to 4 GHz, RBW of 100 Hz to 1 MHz and VBW of 10 Hz to 1 MHz. With the displayed average noise level of –135 dBm (typ., RBW = 1 kHz, attn.= 0 dB), or additional power measurement capabilities like channel power, ACPR and OBW, this series can claim a leading position in the market of portable spectrum analyzers. A standard TCP/IP interface permits to not only exchange measured data ultra-fast, but also allows remote control of the spectrum analyzer from any place in the world over a domain network.

Boonton Electronics,
Parsippany, NJ (973) 386-9696,
www.boonton.com.

RS No. 250

EDA Products and Capabilities

This complete set of EDA products and capabilities enable the mainstreaming of System-in-Package (SiP) IC design. This solution addresses the limitations inherent in the current "expert engineering" approach to SiP design by providing an automated, integrated, reliable and repeatable process to meet the escalating demand for wireless and consumer products. New products include the Cadence® Radio Frequency SiP Methodology Kit, two new RF SiP products, Cadence SiP RF Architect and Cadence SiP RF Layout, and three new Digital SiP products, Cadence SiP Digital Architect, Cadence SiP Digital SI and Cadence SiP Digital Layout.

Cadence Design Systems Inc.,
San Jose, CA (408) 943-1234,
www.cadence.com.

RS No. 251

Noise Generator

The model NW2.7G-HP-MI is a manual high power output noise generator that features broadband frequency coverage from 10 MHz to 2.7 GHz. Power out is +30 dBm and the unit features a flatness of ±2.5 dB. This model operates from standard line voltages. Applications for the instrument include system and component wireless testing, signal simulation, CATV and VSAT testing as an economical source for bit error rate telecommunication testing. The high power output and broadband coverage allow the unit to be used in multiple applications, supplying high power levels into even narrow bandwidths.

NoiseWave Corp.,
East Hanover, NJ (973) 386-1119,
www.noisewave.com.

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Upgradeable Probe System

The BlueRay™ probe system, a high-throughput wafer prober capable of testing up to 70,000 dies per hour, can now be upgraded from a semiautomatic to a fully-automated probe station in the field. This is achieved by docking a wafer-handling robot, which then handles all wafers automatically. Docking and undocking is quick and done on site, reducing downtime to a minimum. In addition, the test platform can now remain constant from ramp-up to production, which minimizes changeover costs and capital investments.

SUSS MicroTec Test Systems GmbH,
Sacka bei Dresden, Germany
+49 35240 73-0, www.suss.com.

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NEW LITERATURE

PRODUCT DATA SHEET

This data sheet provides detailed information on the company's precision load pull system, the AU2000 series. This system provides digitally-controlled, precision electronic and mechanical tuner-based large signal characterization of semiconductor devices for the RF, microwave and millimeter-wave industry.

Auriga Measurement Systems LLC,
Lowell, MA (978) 441-1117,
www.auriga-ms.com.

RS No. 200

PRODUCT SELECTION GUIDE

This product selection guide summarizes over 430 products including 31 products new for June 2006. The guide organizes the company's portfolio by product line as well as by market applications including: automotive, broadband, cellular, microwave and mm-wave, test and measurement, fiber optic, military and space. Newly redesigned are dedicated sections for connectorized modules, designer's kits and application circuits. An updated version of the 2006 Designer's Guide CD-ROM is also available.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.

RS No. 201

CD COMPONENTS CATALOG

The Summer 2006 full-line CD components catalog offers a comprehensive display of the company's standard and custom capabilities. The CD includes product specifications, outline drawings, test data, manufacturing flow diagrams and a wide assortment of technical application notes.

MITEQ Inc.,
Hauppauge, NY (631) 436-7400,
www.miteq.com.

RS No. 202

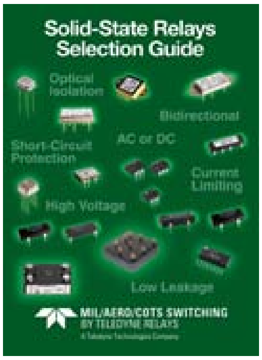
FILTER DATA SHEET

This data sheet highlights the company's newest filter products for use in microwave applications. These products include high performance, low profile, ceramic resonator filters suitable for both military and commercial markets. The data sheet is available for download on the company's site or contact the company for a hard copy.

Reactel Inc.,
Gaithersburg, MD (301) 519-3660,
www.reactel.com.

RS No. 203

SELECTION GUIDE



This selection guide is designed for military, aerospace and COTS applications. The catalog features 74 families in a tabular format designed in an easy to use format to quickly assist engineers in choosing a product. The digest provides detailed information about the relays, which include AC, DC and bi-directional relays with output ranging from 0.25 to 10 amps, and includes parameters such as load voltage, load current, ON-state voltage drop, isolation type, input voltage, operating temperature, mounting and dimensions.

Teledyne Relays,
Hawthorne, CA (800) 284-7007,
www.teledynerelays.com.

RS No. 204

TERMINAL BLOCK CATALOG

This edition of the BUCHANAN terminal block catalog consolidates information for six major terminal block types including: Eurostyle, barrier strips, card edge terminal blocks, interface modules, Europa and NEMA terminal blocks. This catalog combines a considerable amount of product information with helpful part number cross-references.

Tyco Electronics Corp.,
Harrisburg, PA (800) 522-6752,
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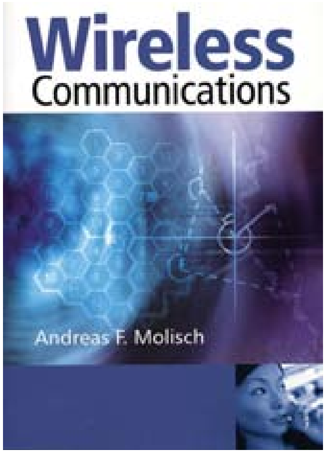
RS No. 205

Wireless Communications



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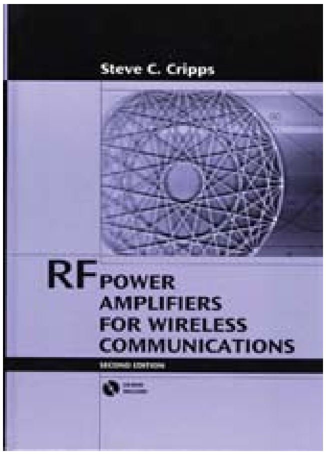
This book is written for advanced undergraduate and graduate students, as well as for practicing engineers and researchers. Readers are assumed to have an understanding of elementary communication theory, like modulation/demodulation as well as basic aspects of electromagnetic theory. The book is divided into five parts. The first part, the introduction, gives a high level overview of wireless communications. The second part describes the various aspects of wireless propagation channels. As the propagation channel is the medium over which communication happens, understanding it is vital to understanding the remainder of the book. The third part of the book deals with the structure and theory of wireless transceivers. After a short summary of the components of an RF transceiver, the different formats that are used for wireless applications are discussed. The fourth part then takes into account the desire to operate a number of wireless links simultaneously in a given area. This so-called 'multiple access' problem has a number of different solutions. The last part of the book describes standardized wireless systems. Standardization is critical so that devices from different manufacturers can work together and systems can work seamlessly across national borders. The book describes the most successful cellular wireless standards, namely GSM (Global System for Mobile Communications), IS-95 and its advanced form CDMA 2000, as well as Wideband CDMA (also known as UMTS). The most important standard for wireless LANs — namely IEEE 802.11 — is also described. A companion web site (www.wiley.com/go/molisch) contains some material which would have made the printed version overly bulky. In particular, the appendices of the various chapters, as well as supplementary material on the DECT (Digital Enhanced Cordless Telecommunications) system, the most important cordless phone standard, can be found there.

RF Power Amplifiers for Wireless Communications: Second Edition



Steve C. Cripps
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This is the second edition of this book, where the general flow of the original book has been kept. There are several new chapters and nearly all of the original material has been updated and extended as appropriate. A new Chapter 4 digs a bit deeper into all the things that make PA devices behave differently at gigahertz frequencies than at audio. Some of this analysis leads into another new chapter, Chapter 8, where an undisguised attempt is made to persuade RF designers that transistors do not behave as switches anymore and the classical 'switch' modes can be approximated using more conventional RF thinking on impedance and harmonic matching. Modulation and nonlinear effects in PAs are closely interwoven and both are covered in Chapter 9. The design of bias networks for PAs has been promoted to chapter status, Chapter 11. The problems of maintaining stability and simultaneously minimizing supply modulation effects can cause as much difficulty for a PA designer as does the design of the RF matching networks and hopefully this new chapter will provide some useful new insights for the PA practitioner. PA linearization has become a huge subject and several books have been devoted to it. Chapter 14 has therefore been carefully limited to an overview, as in the original edition. Efficiency enhancement techniques, as in the first edition, are considered as a separate subject from linearization and Chapter 10 is a much extended and updated treatment of this important topic. A feature of this second edition is the inclusion of a CD, which contains most of the simulation files and some of the Excel spreadsheets that are used in the text.

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Juergen Wissling
Wissling Marketing Services
Riedstrasse 5
72813 St. Johann-Wuertingen
Germany
Tel: +49 7122 828140
FAX: +49 7122 828145
jwissling@horizonhouse.com

Israel
Oreet Ben Yaacov
Oreet International Media
15 Kineret Street
51201 Bene-Berak, Israel
Tel: +972 3 570 6527
FAX: +972 3 570 6526
obenyaacov@horizonhouse.com

Korea
Young-Seoh Chinn
JES Media International
2nd Floor, ANA Bldg.
257-1, Myungil-Dong
Kangdong-Gu
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FAX: +82 2 481-3414
yschinn@horizonhouse.com

Singapore
Hoong-Mun Koo
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