Vol. 49 • No. 4
April 2006

Microwave Journal

Amplifiers and Oscillators

Microwave Oscillators: State of the Technology

2 GHz CMOS Complementary VCO

Wideband Adaptive Linear Amplifier

horizon house
Founded in 1958

www.mwjournal.com

APRIL 2006 VOL. 49 • NO. 4

FEATURES

COVER FEATURE

TECHNICAL FEATURES

49 Years of Publishing Excellence

Microwave Journal (USPS 396-250) (ISSN 0192-6225) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

POSTMASTER: Send address corrections to *Microwave Journal*, PO Box 3256, Northbrook, IL 60065-3256 or e-mail mwj@omeda.com. Subscription information: (847) 291-5216. This journal is issued without charge upon written request to qualified persons working in that part of the electronics industry, including governmental and university installation, that deal with VHF through light frequencies. Other subscriptions are: domestic, $120.00 per year, two-year subscriptions, $185.00; foreign, $200.00 per year, two-year subscriptions, $370.00; back issues (if available) and single copies, $10.00 domestic and $20.00 foreign. Claims for missing issues must be filed within 90 days of date of issue for complimentary replacement.

Horizon House also publishes *Telecommunications®* and *Journal of Electronic Defense*

BPA WORLDWIDE

Posted under Canadian international publications mail agreement #0738654

Microwave® Journal

FEATURES

TECHNICAL FEATURE

SPECIAL REPORT

PRODUCT FEATURES

DEPARTMENTS

Cover design by Strand Marketing Inc.;
Graphic Designer: David Bush
(www.strandmarketing.com)

STAFF

Publisher: Carl Sheffres
Associate Publisher: Edward Johnson
Editor: Harlan Howe, Jr.
Managing Editor: Keith W. Moore
Technical Editor: Frank M. Bashore
Associate Technical Editor: Dan Massé
Staff Editor: Jennifer DiMarco
Editorial Assistant: Barbara Walsh
Consulting Editor: Howard I. Ellowitz
Consulting Editor: Theodore S. Saad
Consulting Editor: Peter Staecker
Assistant to the Publisher: Kristen Dednah
Traffic Manager: Edward Kiessling
Traffic Administrator: Ken Hernandez
Director of Production & Distribution: Robert Bass
DTP Coordinator: Janet A. MacDonald

EUROPE

Deputy Publisher: Michel Zoghob
European Editor: Richard Mumford
Office Manager: Eugenie Hardy

CORPORATE STAFF

Chairman: William Bazzy
President & CEO: Charles A. Ayotte
Executive Vice President: William M. Bazzy
Executive Vice President: Joan B. Egan
Senior Vice President & Group Publisher: David B. Egan

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

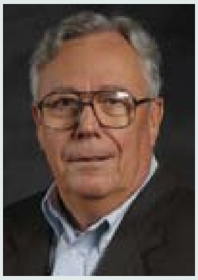
www.mwjournal.com

Printed in the USA

"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 June issue. All responses must be submitted by **May 5, 2006**, to be eligible for the participation of the April 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.



Harlan Howe, Jr. *received his BS degree in optics from the University of Rochester in 1957. He has been actively engaged in the microwave industry for 48 years, first as a design engineer and then as an engineering manager. In 1990, he became the publisher/editor of* Microwave Journal*. He retired as publisher in 2001, but remains the editor. He is a Life Fellow of IEEE, past president of MTT-S and the recipient of an IEEE Third Millennium Medal in 2000 and the MTT-S Distinguished Service Award in 2005.*

Renuka Wekhande from RF Arrays Systems India Pvt. Ltd. has submitted this month's question:

Dear Harlan,

1. What are the various parasitics that should be considered when designing a monolithic microwave integrated circuit (MMIC) for standard quad flat no-lead (QFN) packages?
2. What are the advantages of using a gallium arsenide (GaAs) heterojunction bipolar transistor (HBT) over a pseudomorphic high electron mobility transistor (pHEMT)?

If your response is selected as the winner,
you'll receive a free book of your choice from Artech House.
Visit the Artech House on-line bookstore at www.artechhouse.com
for details on hundreds of professional-level books
in microwave engineering and related areas
(maximum prize retail value $150).

CALL FOR PAPERS

28th Annual Symposium of the Antenna Measurement Techniques Association (AMTA 2006)
by May 8, 2006

IEEE Radio & Wireless Symposium (RWS 2007)
by July 5, 2006

7th Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF 2007)
by July 28, 2006

IEEE Topical Workshop on Power Amplifiers for Wireless Communications (PA Workshop)
by October 2, 2006

MAY

INTERNATIONAL WIRELESS COMMUNICATIONS EXPO (IWCE 2006)
May 17–19, 2006 • Las Vegas, NV
www.iwceexpo.com

JUNE

IEEE INTERNATIONAL FREQUENCY CONTROL SYMPOSIUM
June 4–7, 2006 • Miami, FL
www.ieee-uffc.org/2006fcs/

IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM (IMS 2006)
June 11–16, 2006 • San Francisco, CA
www.ims2006.org

IEEE RADIO FREQUENCY INTEGRATED CIRCUITS SYMPOSIUM (RFIC 2006)
June 11–13, 2006 • San Francisco, CA
www.rfic2006.org

AUGUST

IEEE EMC SYMPOSIUM
August 14–18, 2006 • Portland, OR
www.emc2006.org

18TH ANNUAL INTERNATIONAL MILITARY & AEROSPACE/AVIONICS COTS CONFERENCE, EXHIBITION AND SEMINARS
August 22–24, 2006 • Santa Clara, CA
http://cotsconference.home.att.net

SEPTEMBER

EUROPEAN MICROWAVE WEEK 2006 (EUMW 2006)
September 10–15, 2006 • Manchester, UK
www.eumw2006.com

IEEE INTERNATIONAL CONFERENCE ON ULTRA-WIDEBAND (ICUWB 2006)
September 24–27, 2006 • Waltham, MA
www.icuwb2006.org

OCTOBER

28TH ANNUAL SYMPOSIUM OF THE ANTENNA MEASUREMENT TECHNIQUES ASSOCIATION (AMTA 2006)
October 22–27, 2006 • Austin, TX
www.amta.org

JANUARY

IEEE RADIO AND WIRELESS SYMPOSIUM (RWS 2007)
January 9–11, 2007 • Long Beach, CA
www.radiowireless.org

IEEE TOPICAL WORKSHOP ON POWER AMPLIFIERS FOR WIRELESS COMMUNICATIONS (PA WORKSHOP)
January 8–9, 2007 • Long Beach, CA
http://paworkshop.ucsd.edu

7TH TOPICAL MEETING ON SILICON MONOLITHIC INTEGRATED CIRCUITS IN RF SYSTEMS (SIRF 2007)
January 10–12, 2007 • Long Beach, CA
www.ece.wisc.edu/sirf07

Workshops & Courses

Sonnet Training Class

■ **Topics:** This ½ day course is an introduction to the use of Sonnet's 3D planar electromagnetic simulation software. It will offer hands-on technical training that is designed to bring new users up to speed and highlight new features to experienced users in the area of high frequency design. For more information, visit www.sonnetsoftware.com/support/training.asp.
■ **Site:** For location information, please visit url.
■ **Dates:** For date information, please visit url.
■ **Contact:** Yun Chase, Sonnet Software Inc., 100 Elwood Davis Road, North Syracuse, NY 13212 (315) 453-3096 or e-mail: chase@sonnetsoftware.com.

OPERA-2d Software – Introductory Training Course

■ **Topics:** The OPERA-2d course will provide a short introduction to the workings of the pre- and post-processor and describes the type of problems that can be analyzed using the OPERA-2d solvers. Aspects of finite element modeling are also discussed. For more information, visit www.vectorfields.com.
■ **Site:** Oxford, UK
■ **Dates:** May 17–18, 2006
■ **Contact:** Vector Fields Ltd., Julie Shepherd, 24 Bankside, Kidlington, Oxford, OX5 1JE UK +44 (0)1865 370151 or e-mail: julie.shepherd@vectorfields.co.uk.

MEMSWAVE 2006

■ **Topics:** This EuMA and Italian Electromagnetics Society (SIEM) sponsored workshop will provide an international forum for scientists and industrialists to discuss the most recent advances and best achievements in the area of RF MEMS with the emphasis on European activities. It aims to cover, but is not limited to: design and simulation tools; fabrication, process and materials; packaging, assembling and 3D integration; components and circuits; antennas; MEMS and IC integration; reliability and testing; and application and system design.
■ **Site:** Orvieto, Italy
■ **Dates:** June 29–30, 2006
■ **Contact:** For more information, visit www.memswave2006.org.

Practical RF and Microwave Design

■ **Topics:** This intensive, five-day course provides acceleration through the RF design learning curve by presenting a comprehensive introduction to RF and microwave design theory, techniques and measurements. Although the course includes necessary theoretical aspects, great emphasis is placed upon the practicalities of RF engineering. For more information, visit www.conted.ox.ac.uk.
■ **Site:** Summertown, Oxford, UK
■ **Dates:** July 3–7, 2006
■ **Contact:** University of Oxford Continuing Education, 1 Wellington Square, Oxford, OX1 2JA UK +44 1865 270360 or e-mail: anthony.santiago@conted.ox.ac.uk.

Far-field, Anechoic Chamber, Compact and Near-field Antenna Measurements

■ **Topics:** This course presents the state-of-the-art in antenna measurements, including far-field, anechoic chamber, compact and near-field measurements. The course also includes range evaluation and compensation techniques and microwave holography. For more information, visit www.pe.gatech.edu.
■ **Site:** Atlanta, GA
■ **Dates:** November 6–10, 2006
■ **Contact:** Georgia Institute of Technology, Professional Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3500.

The Entrepreneurial Engineer

■ **Topics:** This short course is an efficient and memorable introduction to the personal, interpersonal, business and organizational skills necessary to help engineers of applied science and mathematics perform at high levels in today's increasingly opportunistic organizations and enterprises. For more information, visit http://online.engr.uiuc.edu/shortcourses/tee/index.html.
■ **Site:** Archived on-line course.
■ **Dates:** Archived on-line for anytime viewing.
■ **Contact:** University of Illinois at Urbana-Champaign, 117 Transportation Bldg., 104 S. Mathews Avenue, Urbana, IL 61801 (217) 333-0897 or e-mail: deg@uiuc.edu.

INVITED PAPER

MICROWAVE OSCILLATORS: THE STATE OF THE TECHNOLOGY

Demand for higher bandwidth and frequencies in wireless and wireline applications continues to climb. This is increasing the pressure on the RF industry to deliver higher performance, higher functionality, smaller size, lower power consumption, lower cost, and faster new designs of RF and microwave components. Oscillators are the key components for virtually any communications, navigation, surveillance or test and measurement system. They provide a critical clocking function for high speed digital systems, generate electromagnetic energy for radiation, enable frequency up and down conversion when used as local oscillators, and are used as a reference source for system synchronization. The market forces are motivating designers and developers to improve the performance of microwave components up to millimeter waves. This article reviews some of these developments in the field of microwave oscillators. A short recent history is presented. Present state-of-the-art is addressed and a brief look at the future is included.

Fig. 1 A 12.5 GHz GaAs FET dielectric resonator oscillator (1.6" × 1" × 0.6").

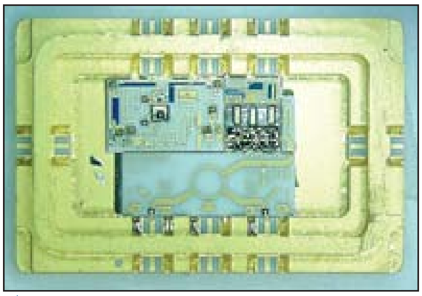
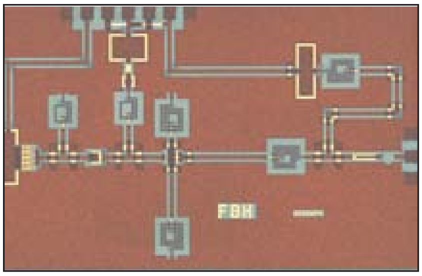


Fig. 2 A differential 43 GHz SMT source using a 10.75 GHz low noise Si-bipolar VCO (0.68" × 0.45" × 0.17").[12]

EVOLUTION

Microwave oscillators started with vacuum tubes and pretty much ruled this field for three decades starting from 1940. Reflex klystrons were a common way to generate low or moderate powers at X- or Ku-band right into the 1970s. The signal generation circuit, consisting of a klystron and its power supply itself used to be the size of some small test equipment of today, consumed greater than 20 W of DC power and used 800 V of power supply to provide 10 mW at X-band. However, it provided a clean signal due to the inherent high Q cavity used. By the late 1970s transistor dielectric resonator oscillators[1] could provide clean 10 mW of power at X-band using 5 V and 30 mA in about one cubic inch of volume (see ***Figure 1***). More recently, surface-mount hybrid oscillators (see ***Figure 2***) and complete MMIC solutions (see ***Figure 3***) are able to provide necessary performance occupying much less volume and at a fraction of the cost.

A.P.S. (PAUL) KHANNA
Phase Matrix Inc.
San Jose, CA



▲ *Fig. 3 A 36 GHz InGaP/GaAs HBT MMIC VCO (2.1 × 1.3 mm sq.).[21] (courtesy of FBH, Berlin, Germany)*

With the advent of solid-state devices, new devices started playing a role in signal generation solutions before 1970. Gunn and IMPATT diode oscillators dominated signal generation applications before the three-terminal devices took over in the mid-1970s. Gunn diodes generate microwave energy using the negative resistance characteristics of bulk semiconductor devices requiring standard, low impedance, constant voltage power supplies. Gunn diodes offer low phase noise, low power oscillators from 4 GHz to greater than 100 GHz. Gunn oscillators are still used at mm-wave frequencies and utilize GaAs or InP materials depending upon the frequencies and power required. Power output of greater than 20 dBm can be obtained at 40 GHz with efficiency in the range of 2 to 3 percent. Gunn diodes are still effectively playing at mm-wave frequencies where phase noise performance is difficult to achieve otherwise.

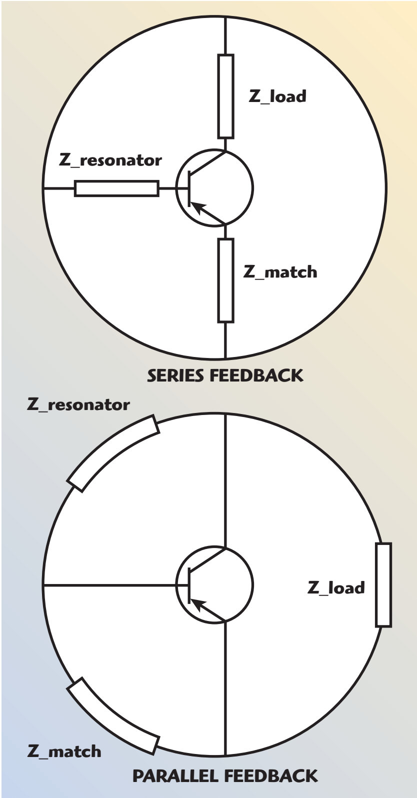
IMPATT diodes were another early form of solid-state device generating high power microwave energy with efficiencies of 10 to 20 percent and covering frequencies up to and beyond 100 GHz. IMPATT diode oscillators, however, have about 10 dB higher phase noise and offer a narrower tuning band than Gunn diode oscillators. IMPATTs find their application in higher powers at higher frequencies. Depending on the frequency and power needed, Si or GaAs IMPATT diodes are used. Greater than 1 W of power can be obtained at 40 GHz. The use of both Gunn and IMPATT diodes in microwave signal generation applications has been on the decline since three-terminal devices made their debut in microwave frequency ranges around 1975. From then on it was like a revolution the way junction bipolar transistors and field-effect transistors took over the microwave active circuits domain enabling many new applications. It is interesting to note, however, that even though newer technologies made great headway in microwave signal generation, even today two-terminal solid-state devices are being used effectively due to the performance edge these devices have in certain areas.

Transistor oscillators have made great strides in the last quarter of a century. Silicon bipolar junction transistors have dominated the oscillator field until recently. With low 1/f noise characteristics, Si BJT discrete devices have produced excellent results both in fixed tuned and tunable oscillators at frequencies exceeding 20 GHz. GaAs FET and HEMT devices on the other hand have been demonstrated to oscillate at frequencies beyond 100 GHz as fundamental oscillators. Typically, in an oscillator, Si BJT devices offer about 10 dB better phase noise close to the carrier compared to GaAs FET devices. Versatility and diversity of the three-terminal devices have produced a large number of techniques to optimize different parameters in various applications. Multi-frequency oscillators, push-push oscillators, quenchable oscillators, optically controlled oscillators, injection-locked oscillators, self-oscillating mixers and regenerative frequency dividers are some of the examples.

Oscillators provide the heartbeat of all RF and microwave systems irrespective of their application. In most cases performance of the oscillator determines key characteristics of the subsystem. At the low end of the microwave frequency spectrum, cellular and emerging wireless communications are the driving force behind the development of microwave oscillators. On the high end of the spectrum, automotive radars, broadband radios and high speed optical communications are fueling the need for volume. Special and very high performance oscillators are never lacking in demand to perform so called 'out of the ordinary' functions.

OSCILLATOR TOPOLOGIES AND TYPES

Oscillators are also regarded as DC-to-RF converters. A typical oscillator consists of an active device and a passive frequency-determining resonant element. The active device can be a two-terminal device like a Gunn or IMPATT diode or more commonly a three-terminal device including a junction bipolar transistor, metal semiconductor FET or more recent devices using newer semiconductor materials. In order to generate a high frequency signal an active device with sufficient gain to compensate for feedback loop losses is necessary. Oscillation conditions need to be satisfied for the circuit containing the active device and passive element. Two different topologies are used for this purpose, as shown in ***Figure 4*** in their generalized form. A parallel feedback oscillator is the one in which the frequency-determining element is used as a feedback element



▲ *Fig. 4 Generalized oscillator configurations using three-terminal devices.*

between the input and output in order to generate necessary instability and a negative resistance oscillator is the one in which reflection gain at a given terminal is used to satisfy the oscillation condition when connected to a frequency-determining element with the proper phase condition.[2]

While both techniques are commonly used for microwave signal generation, the parallel feedback approach is more suitable for narrowband, lower noise tunable oscillators and the negative resistance configuration is used for wideband tunable oscillators.

Microwave oscillators can be divided into many different types based on frequency bandwidth, type of resonator used or type of active device used. Resonators largely determine frequency tuning range, stability and noise performance of the oscillator, and are commonly used to define different types of oscillators.

FIXED TUNED OSCILLATORS

Fixed tuned oscillators are generally required for many applications including as reference sources, fixed local oscillators and radars. These oscillators are generally characterized by low frequency drift and low phase noise. A high Q resonator is the key element for this type of oscillator. A wide range of resonators with varying Q factors are presently available. From low Q planar transmission line resonators to the highest Q sapphire loaded resonators, there are a number of different types of resonators.

Metallic cavity resonators have long been used as high Q elements for filters and low noise oscillators. High temperature stabilities were achieved using Invar. The impractical size of these cavities, however, restricted their application in signal generation. Excellent phase noise performance of –180 dBc/Hz at 10 kHz has been reported at 10 GHz using an air dielectric resonator cavity for stabilization using a noise detection and suppression technique.[3]

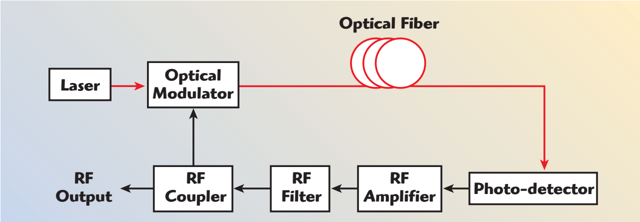
Dielectric resonators are made of low loss, temperature stable, high permittivity and high Q ceramic material in a regular geometric form. Common examples of the materials are $BaTi_4O_9$ and $ZrSnTiO_4$.[6] The material resonates in various modes determined by its dimensions and shielding conditions. $TE_{01\delta}$ mode is used for the optimum temperature stability and Q. The practical frequency range for these resonators lies between 2 and 40 GHz while the Q factor typically reduces linearly with increasing frequency. A Q of 10,000 at 4 GHz is representative of commonly used materials. Because of its small size, low price and excellent integrability in MICs, DRs are very commonly used in active and passive microwave components up to mm-wave frequencies. Development of temperature stable dielectric resonators dates back to the late 1970s, soon after the introduction of three-terminal devices in the main stream of microwaves. The marriage between these two elements has produced a wide variety of much needed microwave sources with excellent performance in terms of phase noise and temperature stability with desired compactness and cost. Dielectric resonator oscillators (DRO) are most commonly used for fixed tuned or narrowband tunable configurations to phase lock or frequency modulate for numerous applications. A well-known high volume application for these oscillators in recent history has been in the Ku-band DBS applications. Recently, when there was a large telecom demand ahead of availability of fully integrated ICs, these sources were employed in volume for the 10 Gb/s high speed optical communications market. With the increased bandwidth requirements of microwave communication systems today, complex modulation schemes using 64QAM or higher are commonly used. This order of complexity requires very low close-in phase noise in order to keep the bit error rate (BER) in the digital communication systems under check. Electronically tunable phase-locked DROs are today the backbone of the majority of microwave communication systems requiring very high performance in a small size and reasonable cost. DROs are now commercially available with better than ±1 ppm/°C and/or with a phase noise of better than –120 dBc/Hz at 100 kHz at X-band.[2]

The sapphire-loaded cavity resonator oscillator (SLCO) is another type of low noise oscillator that utilizes sapphire, a low loss dielectric material. Using whispering gallery modes with a Q factor > 200K, and noise detection and suppression circuits, phase noise as low as –160 dBc/Hz at 10 kHz offset at 10 GHz has been reported.[4,5]

Ceramic coaxial resonator oscillators are fixed or narrowband tunable oscillators based on high Q ceramic resonators. The resonator is a silver-plated length of temperature-stable ceramic shorted on one end. Using these resonators in a negative resistance oscillator configuration, phase noise of better than –120 dBc/Hz at 10 kHz is now commercially available up to 4 GHz. Coaxial resonator oscillators (CRO), however, offer a practical low cost solution for frequencies between 1 and 5 GHz.

Surface acoustic wave (SAW) oscillators utilizing high Q lithium niobate devices enable the circuit to achieve low phase jitter performance over a wide operating temperature range. SAW oscillators have long filled the need for very low noise oscillators at RF frequencies up to 2 GHz. These oscillators have been extensively used as clocks in wired applications including optical communications, Gigabit Ethernet communications, storage circuits, etc. Sonet applications at 622 Mb/s, 2.488 Gb/s use these oscillators extensively. Very low phase noise has been demonstrated using SAW devices and optimized active devices. A frequency multiplied SAWO at 8 GHz was reported using a high quality SAW resonator at 500 MHz in the parallel feedback of a low noise amplifier, with a phase noise of –140 dBc at 10 kHz.[6] The practical frequency range for a SAWO is typically between several hundred megahertz to about 2.5 GHz.

Bulk acoustic wave resonator (BAW) oscillators are a recent introduction in the field of fixed frequency oscillators. The resonator, more commonly known as FBAR, is a three-layer structure with the top and bottom electrodes of molybdenum sandwiching a middle



▲ *Fig. 5 Block diagram of an opto-electronic oscillator.*

layer of oriented piezoelectric aluminum nitride. These resonators are practical for use in the frequency range of 500 MHz to 5 GHz. An air interface is used on both outer surfaces to provide high Q reflectors at all frequencies. When RF signals are applied near the mechanical resonant frequency the piezoelectric transducer excites the fundamental bulk compression wave traveling perpendicular to the films. These tiny chips with a size of 40 × 40 mils possess a quality factor of greater than 500 at 2 GHz.

FBAR oscillators have demonstrated phase noise of better than –112 dBc/Hz at 10 kHz at 2 GHz.[7] Even though FBAR filters are already being used in large volume in cellular phones, improvements in the Q and temperature stability (5 to 10 ppm/°C presently) will be required before FBAR oscillators can be exploited commercially.

Optoelectronic oscillators (OEO) are a recent addition to achieve high frequency sources. These oscillators employ an elegant opto-electronic feedback loop approach to the generation of microwave frequencies. The OEO is a generic architecture consisting of a laser as the source of light energy. The laser radiation propagates through a modulator and an optical energy storage element, before it is converted to electrical energy with a photo-detector (see ***Figure 5***). The electrical signal at the output of the modulator is amplified using an RF amplifier and filtered before it is fed back to the modulator, thereby completing a feedback loop with gain, which generates sustained oscillation at a frequency determined by the filter. The OEO enjoys extremely high Q-factors of its optic resonator system suitable for the low phase noise RF signal generation. A 10 GHz oscillator with the phase noise of –160 dBc/Hz at 10 kHz offset has been reported.[3] The main advantage of the OEO is its phase noise frequency independence that enables the generation of a low phase noise signal from microwaves to upper millimeter-wave frequencies. A disadvantage in its simple form is its natural multimode operation resulting in gaps in the frequency coverage as well as relatively high spurs. A YIG filter has been used to extend the tunability of the OEO, while the spurious problem has been addressed in a multiloop design capable of undesired mode suppression.[8,9]

FREQUENCY TUNABLE OSCILLATORS

Wideband tunable oscillators are necessary components for ECM, ESM and test instrumentation, as well as many communication systems. These are characterized by the tuning bandwidth and linearity, phase noise, settling time and post tuning drift. The needs for the specific characteristics depend upon the application. Compromises are called for in view of the fact that all of these parameters cannot be achieved using a single technology or technique. In order to achieve oscillations over a wideband the active device needs to possess negative resistance over the band and the frequency tuning element needs to tune over the band. Design techniques are then used to satisfy oscillation conditions over the band while optimizing one or more desired parameters. Phase noise being a function of the carrier frequency and tuning bandwidth, care should be taken while comparing frequency tunable oscillators.

Varactor-tuned oscillators are voltage-tuned oscillators utilizing Si or GaAs varactors, typically a metal n-type schottky barrier, in association with the active device to generate signals over a wideband. With the available technology a little more than octave band oscillators have been reported up to Ku-band using multiple varactors.[10] At lower frequencies it is more practical to achieve an octave band. VCOs based on discrete devices have demonstrated more than octave bands with excellent phase noise up to 4 GHz. Silicon bipolar devices are the devices of choice due to their lower 1/f noise and corner frequency and are commonly used for VCOs up to X-band. Using a low noise silicon bipolar transistor with a 10 GHz f_t and 40 GHz f_{max} process and a silicon hyperabrupt varactor diode, a narrowband VCO was reported at 10 GHz with phase noise of –112 dBc/Hz at 100 kHz offset.[12] GaAs FET devices offer wideband oscillations up to mm-wave frequencies with degraded phase noise. Another technique to achieve low noise wideband signal generation at higher frequencies is the use of push-push oscillators. VCOs covering 9 to 18 GHz have been demonstrated using silicon bipolar devices.[10] VCOs exceeding octave bandwidth have been recently developed using coupled push-push technology. Phase noise of –118 dBc/Hz at 100 kHz offset was reported at 4 GHz in a 3 to 6 GHz VCO.[11]

Frequency settling time is another important characteristic required in certain military systems as well as in test instruments. This represents the speed and accuracy with which the oscillator frequency can be changed. Silicon devices once again shine in realizing fast settling VCOs. Using silicon bipolar transistors with silicon varactor diodes, settling times of better than 1 µs (for the frequency to be within 1 MHz) have been demonstrated at Ku-band.[13] In applications requiring fast on and off VCO switching, a technique of quenching the negative resistance instead of switching the bias on and off has demonstrated switching times of better than 1 µs.[14]

YIG-tuned oscillators (YTO) are used in test and measurements as well as in wideband military systems requiring multi-octave bands of tuning. YTOs are oscillators of choice when wideband tuning, high tuning linearity and good phase noise are simultaneously required. These oscillators utilize a yittrium iron garnet (YIG) ($Y_3Fe_5O_{11}$) spherical resonator placed between two poles of a cylindrically re-entrant electromagnet. The resonant frequency of the YIG resonator in a uniform magnetic field is a linear function of the magnetic field strength. YIG resonators offer a very high Q (> 4000 at 10 GHz), which linearly increases with frequency. The practical usable frequency range of YTO is between 2 and 50 GHz. While the higher frequency is limited by the magnet saturation and high power dissipation, the lower limit is governed by the saturation magnetization $4\pi Ms$.

In view of the wideband nature of these oscillators, active devices in the negative resistance configuration have been generally used. Using a low noise silicon bipolar transistor and a novel composite feedback architecture in which double coupling the YIG sphere as a series feedback for higher frequencies and as a parallel feedback for lower frequencies, a tuning range of 2 to 22 GHz has been achieved with a phase noise of better than –130 dBc/Hz at 100 kHz at 10 GHz.[15] At higher frequencies, using a single GaAs FET and a single YIG sphere frequency range coverage of 20 to 40 GHz was reported with a phase noise of better than –100 dBc/Hz at 100 kHz at 40 GHz.[16] YTOs have been commercially available up to 50 GHz. In practice it is becoming more common to achieve mm-wave frequencies by using MMIC frequency doublers with lower frequency YTOs or VCOs. YIG-tuned oscillators are still an attractive choice when their slower tuning speed, large size and high power consumption can be tolerated.

Permanent magnet YTOs are a narrowband tunable version of the YTO. These oscillators use a permanent magnet in place of an electromagnet significantly reducing the DC power consumption and size of the oscillator. Phase noise of –125 dBc/Hz at 100 kHz has been demonstrated using PMYTOs in X- and Ku-bands covering 20 percent bandwidth. These oscillators offer excellent tuning linearity, good frequency stability and phase lock/modulation capability as well.

MMIC-IZATION AND RECENT TECHNOLOGIES FOR MICROWAVE SIGNAL GENERATION

MMIC oscillators are now becoming more and more common. It is worth noting that microwave oscillators, due to their intrinsic mysterious nature, resisted getting converted from discrete to integrated form for much longer than their amplifier counterparts. While MMIC amplifiers started maturing in the early 1980s, the microwave industry had to wait much longer before having reliable commercially available MMIC oscillators. One of the reasons that oscillators continue using discrete devices in many applications is that the volume required for each potential model does not justify the investment for developing MMICs for each. However, once a volume application is identified, MMIC oscillators are developed systematically. In amplifiers it is easier to design wideband generic amplifiers and use them in multiple applications. Additionally, in any given system one can notice a much larger number of amplifiers compared to the number of oscillators. Volume applications of the microwave oscillators today have been converted or are in the process of being converted to stand alone integrated circuits or as a part of the complete system on a chip (SoC). As an example, the oscillator function in cellular phones today is fully integrated in the mixed signal IC.

Heterojuction bipolar transistors (HBT) inherently exhibit much lower

1/f noise levels than field-effect transistors due to their vertical current flow through the semiconductor interfaces, where the impact of surface states on the output signal is reduced. SiGe HBTs exhibits very good 1/f noise levels, but suffer from the limitation of high frequency performance as the emitter area is increased. A larger emitter area is normally required to reduce the current density, which leads to lower 1/f noise.

SiGe HBTs exhibit higher electron mobility, lower device thermal noise and lower device shot noise compared to traditional silicon bipolar transistors. These devices are very attractive for oscillators due to their wide potential bandwidths and low contributions to phase noise. Using SiGe HBTs, low noise DROs and YTOs have been reported. Recently, using a SiGe HBT device, a YTO covering 8 to 20 GHz was reported offering –130 dBc/Hz at 100 kHz offset up to 18 GHz.[17] A fixed frequency SiGe DRO at X-band is capable of providing phase noise of better than –125 dBc/Hz at 100 kHz.

With increased demand for higher frequency sources coupled with progress in MMIC technology and improved modeling and simulation techniques, significant progress on MMIC oscillators can be noticed. Silicon germanium technology devices are inherently highly linear, low phase noise and temperature stable. The key advantage of silicon germanium over many technologies is its compatibility and integrability with mainstream low cost CMOS processing. In addition, silicon germanium provides ultra high frequency capability up to and beyond 100 GHz. A fully integrated SiGe push-push VCO covering 64 to 72 GHz has shown phase noise of –103 dBc/Hz at 1 MHz at 70 GHz.[18] Using a SiGe HBT oscillator and integrated buffer amplifiers, an output power of greater than 16 dBm and a frequency range of 74 to 81 GHz was reported with phase noise of –99 dBc/Hz at 1 MHz offset at 77 GHz, intended for automotive applications.[19] Phase noise of –90 dBc/Hz was also demonstrated at 98 GHz for a VCO covering 94 to 100 GHz.

MMICs based on a GaAs InGaP HBT process have taken a performance lead in providing excellent phase noise X- and Ku-band MMIC oscillators. Using these devices, VCOs with greater than 10 percent bandwidth in X-band have been reported.[20] A Colpitts, push-push oscillator topology is selected for the VCO with a distributed tank circuit and on-chip collector-base junction varactors. The VCO draws approximately 160 mA from a 3 V supply at room temperature. The free running VCO achieves –110 dBc/Hz at a 100 kHz-offset frequency at X-band. The VCO's phase noise performance is excellent due to the use of high Q, low impedance distributed transmission lines and high power excitation. A fundamental 36 GHz VCO with 7 percent tuning bandwidth was recently reported using the InGaP/GaAs HBTs process. This VCO offers a phase noise of –85 dBc/Hz at 100 kHz.[21]

CMOS

Advances in CMOS processes are pushing low cost silicon into the signal generation turf at frequencies right into millimeter-wave applications. RF capabilities of the CMOS process were demonstrated at 1 GHz in 1995. Due to the very nature of the carrier transport in CMOS transistors taking place at the interface between the SiO_2 and Si, the 1/f corner frequency in CMOS transistors is much higher than the corner frequency for bipolar transistor typical verticle devices, with bulk carrier transport. Within a decade CMOS has proven to have useful properties up to 100 GHz. Innovative circuit and system architecture techniques have compensated intrinsic CMOS transistors' physical deficiencies by exploiting and advancing the understanding of fundamental mechanisms behind excess thermal noise and 1/f noise processes in semiconductor devices and how it affects circuit and system performance. CMOS provides a unique appeal for integration of multiple and mixed signal technologies, making it an ideal choice for radio and high speed wired applications of the future.[22] Power handling is another limitation of CMOS, and therefore long-range wireless links requiring transmitted power above 100 mW are definitely a challenge. Fortunately, trends towards higher capacity and smaller cells conspire to favor CMOS. Similarly, trends towards high data rates, large bandwidth, and package switched voice, data and video, favors CMOS by making its higher corner frequency (relative to bipolar devices) for 1/f noise become less of a problem. CMOS scaling enabled the technology to reach for higher gigahertz frequencies and higher speeds. Using a CMOS process with f_{max} of 110 GHz, 100 GHz oscillations were reported in 2004 with 0.4 Vp-p output using 1 V, 30 mA.[23] More recently a 192 GHz cross-coupled push-push VCO was reported using 0.13 µm CMOS with phase noise of –100 dBc/Hz at 10 MHz.[24] CMOS is very well poised to be the enabling technology for the merging of computing and communication functionality right up to foreseeable high frequencies and speeds.

Fully integrated CMOS oscillators are of great interest for use in single-chip wireless transceivers. In most oscillator circuits reported to date that operate in the 0.9 to 2 GHz frequency range, an integrated spiral inductor is used and the final oscillator displays much superior phase noise than a ring oscillator. For lack of a good varactor compatible with CMOS technology, the integrated LC oscillator uses MOS caps instead, as another innovative circuit technique. New tuning methods using digital capabilities and MOS analog switches have been successfully demonstrated.

GaN technologies were initially developed for solid-state source amplifiers. It is only recently that capability of AlGaN/GaN HEMT transistors has been demonstrated to be suitable for frequency generation in the microwave frequencies. The low frequency noise performance and the residual phase noise of AlGaN/GaN HEMT grown on SiC is expected to have interesting applications for designing low phase noise oscillators. These devices, designed for power applications, have the potential of directly generating power levels greater than 20 dBm at frequencies higher than 10 GHz removing the need for buffer amplifiers and improving the noise far from the carrier. A 10

GHz DRO using a GaN discrete device was reported offering –118 dBc/Hz at 100 kHz.[25] InP technology is another prime candidate for low noise oscillators at microwave and millimeter-wave oscillators.

IMPACT OF INCREASING SPEEDS IN THE DIGITAL WORLD

Speeds with which digital signals are processed have been increasing at a very fast pace requiring the clocks to move up in frequency to the microwave region. Optical communication systems are now operating at 2.5 Gb/s, 10 Gb/s and 40 Gb/s requiring clocks at 10, 20 and 40 GHz. 10 Gb Ethernet is already in the main stream and standardization work is likely to start on 100 Gb Ethernet this year. A number of digital communication systems and storage systems are operating at speeds higher than 1 Gb/s. CPUs are operating at microwave frequencies. Microwave broadband radios are already providing bandwidths exceeding 1 Gb/s. Microwave component developers need to get familiar with new requirements and terminologies in the digital world. Digital engineers are also becoming more tuned to RF/microwave techniques.

Oscillators perform a key "clock" function in the digital communication world in both wired as well as wireless applications. In the digital world the quality of the signal source is traditionally measured in the form of jitter instead of phase noise. In reality these clocks are microwave oscillators requiring certain features or characteristics. As an example, clocks typically require differential outputs requiring active or passive baluns in the output. We need to think in terms of p-p or rms voltage rather than dBm (see ***Table 1***). Oscillators like ring oscillators, I/Q oscillators, differential cross-coupled oscillators and multivibrators are now being used at microwave frequencies in a number of applications.

A low jitter clock source is a key requirement of modern low BER digital communication systems.[12] However, jitter and phase noise are related. Clock jitter is defined as the variation in timing of a critical instant in a periodic waveform with respect to a jitter-free reference. In interpreting the clock sources generally it is the phase jitter, which characterizes the clock.

At lower speeds oscilloscopes or communication analyzers can easily measure the jitter from the wave shape. However, at 10 Gb/s and above it is much harder to measure

TABLE I

RELATION BETWEEN Vp-p AND dBm INTO 50 Ω

dBm = 4 +20*log(Vp-p)		Vp-p = 0.637*10^(dBm/20)	
Vp-p	dBm	dBm	Vp-p
0.1	–16	–10	0.2
0.5	–2	0	0.64
1	4	6	1.27
5	18	15	3.58
10	24	20	6.37

the clock jitter using classical methods for lack of real time oscilloscopes at frequencies high enough to capture the third and fifth harmonic of the fundamental signal. A phase noise measurement capable of measuring extremely low level instabilities is a practical tool to interpret the source phase jitter at high frequencies.

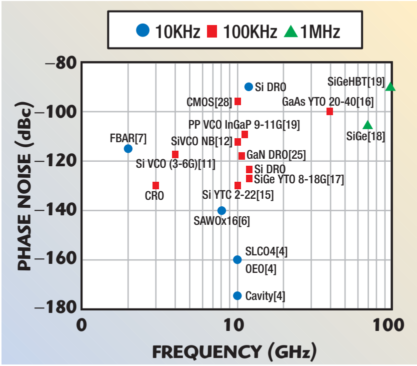
Jitter is calculated from the measurement of integrated phase noise over a fixed offset bandwidth (50 kHz to 80 MHz for OC-192, for example) and is represented in many units, including radians, degrees, time (seconds) and UI (unit interval).[2,26] Different forms of jitter including period jitter, cycle-to-cycle jitter and time interval error are in some ways related to the phase noise or frequency stability of the microwave oscillator. Oscillators required to clock analog-to-digital converters (ADC)/digitizers working at multi-gigahertz frequencies need a low noise floor in order to improve the signal-to-noise ratio (SNR) performance of the data converter. Noise generated by a clock source can add jitter to an ADC, which causes degradation of the SNR of the ADC.

CONCLUSION

Microwave oscillator technology continues to make strides in the availability of new active devices and resonator technologies. Circuit simulation and design techniques are advancing. Oscillator noise simulation techniques have matured over the last decade. One of the areas requiring more effort, however, is accurate noise modeling of the active devices. Oscillator noise simulation is only as good as the device model. It has now been shown that low frequency current noise sources are cyclostationary and are modulated not only by the DC current, but also by the time varying, large-signal RF current.[27] Significant progress has been made in the last decade on this subject but more challenges remain for the designers of the future. ***Figure 6*** is an attempt to show some examples of phase noise performance of microwave oscillators using different technologies and techniques.

On the measurement and specifications front, a number of issues need to be addressed. As an example, there is no standard technique for the measurement of oscillator output impedance or return loss. The quality factor of the oscillator continues to be an ambiguous term. Due to the lack of standard techniques it is sometimes difficult to correlate even measurements of modulation sensitivity and bandwidth. Similar comments can be heard about frequency settling measurements as well as jitter measurements. Oscillator packaging is another area where standardization can be valuable to both vendors and users. Even though partial standardization is happening due to market forces, a concerted effort will be beneficial. In general, standardization for specifications and measurement techniques related to microwave oscillators and high speed clocks requires attention.

The future of microwave solid-state signal generation is brilliant and full of new applications. The integration wave will continue absorbing discrete oscillators in most of the volume applications. In addition to InGaP and SiGe HBT we should see good results from newer technologies including InP and GaN devices for high frequency, low noise MMIC or discrete oscillators. The fundamental frequency of operation of transistor oscillators will continue moving up with the technology. GaAs metamorphic HEMT will be a candidate to provide power and efficiency at W-band and above. High volume and consumer applications will continue to see more and more signal generation functions absorbed in a small corner of the system-on-a-chip (SoC). Gunn and IMPATT diodes will continue to be used at higher mm-wave frequencies. In addition to potential improvements in FBAR oscillators, MEMS technology will make in-roads in signal generation by providing micro-machined resonators, inductors and switches for new applications. Finally, let us not underestimate the power of RF CMOS technology, which will not only solidify its position at low freqencies[28] but also produce exciting results at frequencies beyond 100 GHz. Special applications to support unusual requirements for defense, instrumentation and the higher end of communication systems will continue to use oscillators based on discrete devices where one or more parameters including power consumption, settling time, phase noise and bandwidth can be more easily optimized. ■



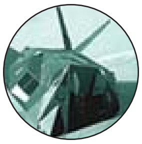
▲ *Fig. 6 Phase noise comparison of different technologies.*

References

1. A.P.S. Khanna, "Microwave Transistor Dielectric Resonator Oscillators," Thesis, Doctorate of Engineering, University of Limoges, France, September 1981.
2. Bahl and P. Bhartia, *Microwave Solid-state Circuit Design*, John Wiley & Sons Inc., 2003, Chapters 3 and 9.
3. C.W. Nelson, D.A. Howe and A. Gupta, "Ultra-low Noise Cavity-stabilized Microwave Reference Oscillator Using an Air-dielectric Resonator," *Proceedings of the 36th Annual PTTI Meeting*, December 2004, pp. 173–178.
4. D.A. Howe and A. Hati, "Low Noise X-band Oscillator and Amplifier Technologies: Comparison and Status," *Proc. IEEE Freq. Cont. Symposium*, 2005, pp. 481–486.
5. M. Tobar, E. Ivanove, P. Blondy, D. Cros and P.Guillon, "High Q Whispering Gallery Traveling Wave Resonators for Oscillator Frequency Stabilization," *IEEE Trans. on UFFC*, Vol. 47, pp. 421–426.
6. G. Montress, T. Parker, M. Loboda and M. Greer, "Extremely Low Phase-noise SAW Resonators and Oscillators: Design and Performance," *IEEE Trans. on Ultrasonics, Ferroelectrics and Frequency Control*, Vol. 35, No. 6, November 1988, pp. 657–667.

7. A.P.S. Khanna, E. Gane, T. Chong, H. Ko, P. Bradley, R. Ruby and J.D. Larson, "A Film Bulk Acoustic Resonator (FBAR) L-band Low Noise Oscillator for Digital Communications," *Proc. 32nd European Microwave Conference*, 2002.
8. D. Eliyahu and L.Maleki, "Tunable, Ultra-low Phase Noise YIG-based Opto-electronic Oscillator," *Proc. IEEE MTT-S Symposium*, Philadelpia, PA, 2003.
9. X.S. Yao and L. Maleki, "Multi-loop Optoelectronic Oscillator," *IEEE J. of Quant. Electron*, 2000, p. 79.
10. J. Anastassiades, D. Kaminsky, E. Perea and A. Poezevara, *Solid-state Microwave Generation*, Chapman and Hall, 1992.
11. U.L. Rohde, A.K. Poddar, J. Schoepf, R. Rebel and P. Patel, "Low Noise Low Cost Ultra Wideband N-push VCO," *2005 IEEE MTT-S International Microwave Symposium Digest*, June 2005, pp. 1171–1174.
12. A.P.S. Khanna, E. Topacio, E. Gane and D. Elad, "Low Jitter Silicon Bipolar-based VCOs for Applications in High Speed Optical Communication Systems," *2001 IEEE MTT-S International Microwave Symposium Digest*, 2001, pp. 1567–1570.
13. A.P.S. Khanna, "Fast-Settling, Low Noise Ku-band Fundamental Bipolar VCO," *1987 IEEE MTT-S International Microwave Symposium Digest*, June 1987, pp. 579–581.
14. A.P.S. Khanna, R.T. Oyafuso, R. Soohoo and J. Huynh, "Microwave Quenchable Oscillators — A New Class," *1989 IEEE MTT-S International Microwave Symposium Digest*, June 1989, pp. 515–518.
15. A.P.S. Khanna and J. Buenrostro, "2 to 22 GHz Low Phase Noise Silicon Bipolar YIG Tuned Oscillator Using Composite Feedback," *1992 IEEE MTT-S International Microwave Symposium Digest*, pp. 1297–1299.
16. A.P.S. Khanna and J. Hauptman "18 to 40 GHz 13 dBm GaAs FET YIG Tuned Oscillator," *1991 IEEE MTT-S International Microwave Symposium Digest*, pp. 209–212.
17. R. Leier, "SiGe Silences YIG Oscillator Phase Noise," *Microwaves & RF*, January 2006, pp. 79–82.
18. R. Wanner, H. Schäfer, R. Lachner, G. Olbrich and P. Russer, "A Fully Integrated 70 GHz SiGe Low Phase Noise Push-push Oscillator," *2005 IEEE MTT-S Microwave Symposium Digest*, June 2005.
19. H. Li, T. Suttorp and J. Böck, "Fully Integrated SiGe VCOs with Powerful Output Buffer for 77 GHz Automotive Radar Systems and Applications Around 100 GHz," *IEEE Journal of Solid-state Circuits*, Vol. 39, No. 10, October 2004, pp. 1650–1658.
20. X. Gao, M. Koechlin, C. Lyons, J. Chiesa, G. Guven and P. Katzin, "A Low Noise 9.95/10.66 GHz PLO for Optical Applications," *2003 IEEE MTT-S International Symposium Digest*, pp. 729–732.
21. F. Lenk, M. Schott, J. Hilsenbeck and W. Heinrich, "Optimizing MMIC Reflection-type Oscillators," *2004 IEEE MTT-S International Microwave Symposium Digest*, June 2004, pp. 1341–1344.
22. L.M. Frana-Neto, R. Eline and B. Balvinder, "Fully Integrated CMOS Radios From RF to Millimeter-wave Frequencies," *Intel Technology Journal*, August 2004.
23. L.M. Franca-Neto, et al., "64 GHz and 100 GHz VCOs in 90 nm CMOS Using Optimum Pumping Method," *Int. Solid-State Circ. Conf. (ISSCC)*, San Francisco, CA, Feb. 2004.
24. C. Cao, E. Seok and K.K. O, "192 GHz Push-Push VCO in 0.13 µm CMOS," *Electronics Letters*, Vol. 42, No. 4, Feb. 2006, pp. 208–210.
25. P.J. Rice, R. Sloan, M. Moore, A.R. Barnes, M.J. Uren, N. Malbert and N. Labat, "10 GHz Dielectric Resonator Oscillator Using GaN Technology," *2004 IEEE MTT-S International Microwave Symposium Digest*, June 2004, pp. 1497–1500.
26. http://www.phasematrix.com/Microwave_Components/jitter.html.
27. J.C. Nallatamby, M. Prigent, M. Camiade, A. Sion, C. Gourdon and J. Obregon, "An Advanced Low Frequency Noise Model of GaInP-GaAs HBT for Accurate Prediction of Phase Noise in Oscillators," *IEEE Trans. Microwave Theory & Tech.*, Vol. 53, No. 5, May 2005, pp. 1601–1612.
28. L. Perraud, J.L. Bonnet, N. Sornin and C. Pinatel, "Fully Integrated 10 GHz CMOS VCO for Multi-band WLAN Applications," *European Solid-state Circuits*, 2003.

A.P.S. (Paul) Khanna *received his BS degree in electronics from Punjab Engineering College, Chandigarh, India, and his doctorate in engineering from the University of Limoges, France. Prior to joining Phase Matrix, he held technical leadership positions at Celeritek, Agilent Technologies, Hewlett Packard, Avantek and Loral. In addition to his commitments in industry, he is an adjunct professor at Santa Clara University, where he teaches a graduate microwave and RF measurements course and actively participates in IEEE activities. He is technical co-chair for the IMS 2006 Symposium in San Francisco, CA. He is currently director of engineering at Phase Matrix Inc., San Jose, CA. His professional interests include RF, microwave and millimeter-wave components and sub-assemblies, broadband wireless access and high speed technologies.*



Lockheed Martin Applies Surveillance Technology for US Marines in Iraq

United States military forces stationed in Iraq will soon utilize surveillance technology and methods adapted from those used by police departments to track and investigate gang activity. Lockheed Martin, in conjunction with Chicago and Los Angeles police departments, is employing counter-insurgency (COIN) surveillance technology to support urban operations conducted by the US Marine Corps in Iraq. The COIN technology will allow the military units to utilize video surveillance and other police investigative methods to track and identify persons of interest to learn their patterns, characteristics and associates, as well as help them to better predict when and where insurgents might strike.

"The COIN technology will save the lives of US Marines in Iraq," said battalion commander lieutenant colonel Nick Marano. "The approach will enable our troops to target specific areas, observe people behaving in ways that they disguise when they see a marine and collect and link investigative data to identify patterns and key insurgent locations. This data will be available to the tactical unit in the field, as well as command and intelligence centers."

Lockheed Martin's COIN technology augments military procedures with proven police investigative methods and enables troops to act with greater accuracy and conduct round-the-clock surveillance from a safer distance. This police surveillance and investigative technology is modified and integrated to suit the needs of the US Marines who will employ the technology. By identifying potential insurgents and their networks, the COIN technology will also help protect Iraqis and US troops against suicide bombers and improvised explosive devices (IED).

In addition to deploying cameras and other devices to track suspicious activities, Lockheed Martin will create an investigative database that will store information about Iraqi insurgents collected by US military forces patrolling the area. The database is a customized version of a police investigative database developed by the Chicago Police Department for its anti-gang, counter-drug operations.

The effort will also include hands-free intelligent recorders developed by Lockheed Martin that automatically translate the Marines' spoken words into formatted text and precise location information which is then securely transmitted into the database.

"These devices will allow our military men and women to record information and location into a secure database by simply speaking aloud," said Gordy McElroy, Lockheed Martin vice president of Intelligence and Homeland Security Systems. "This enables our deployed Marines to collect the information they need while keeping their hands on their weapons and paying attention to their surroundings. With information in the database, our forces and analysts will be better able to search and retrieve information on persons of interest in specific areas." Currently, the COIN technology is a part of a pilot program that Lockheed Martin is testing to be used in Iraq. Following testing in desert situations, the corporation plans to deliver the surveillance architecture in early 2006.

"The technology helps extend what the individual Marine sees and senses," said lieutenant colonel Marano. "Using this police work model, we will be able to solve several problems earlier by surveillance."

The Chicago Police Department (PD), who developed the capabilities to investigate urban gangs, has used these methods and similar technology with great success. The Chicago PD is providing its expertise and lessons learned in an effort to help the Marines in Iraq.

"Our officers and detectives use Illinois Citizen Law Enforcement Analysis and Reporting (I-CLEAR) on a daily basis to track crime trends and check criminal backgrounds of wanted offenders," said Philip J. Cline, superintendent of the Chicago Police Department. "This technology has expanded as a model for law enforcement agencies across the country, and now, we look forward to sharing some of these same concepts with the military."

The Los Angeles PD is assisting by bringing their urban and counter-terrorism operations experience to the program, helping to coordinate how US Marines in Iraq will use the COIN technology.

"This is another step the LAPD is taking to help our military in any way possible," said Ralph Morten, LAPD detective supervisor. "Our LAPD SWAT and bomb disposal units are currently working with the Marines to prepare them to handle situations in Iraq that are similar to what our officers handle here."

The COIN contract is valued at an initial $2.5 M and may grow if adopted by other forces operating in Iraq. Lockheed Martin has additional counter-IED contracts underway across the corporation, primarily focused on capabilities to address specific aspects of the IED problem — such as area surveillance, prediction, convoy training and the explosive devices themselves.

Raytheon, ITT to Offer Early, Affordable Wideband Radios

Two military communication leaders, Raytheon Co. and ITT, are collaborating on two new, highly affordable software communication systems, the Microlight-3G and the Single Channel Ground and Airborne Radio Advanced Improvement Program-enhanced (SINCGARS ASIP-E). The new products share common modules, waveform capabilities and operating environments. Pre-production units for user evaluation will be available later this year.

Raytheon's Microlight-3G is a wearable, software-defined radio that will improve military communication by linking individual warfighters to a tactical Internet. ITT brings its Joint Tactical Radio System (JTRS) Soldier Radio Waveform (SRW) to Microlight-3G. The SRW upgrade complements the wearable radio's already available Enhanced Position Locating and Reporting System (EPLRS) waveform. The SWR's addition to Microlight means that soldiers can send and receive secure communication, information and intelligence from all locations, including urban 'canyons.' Microlight-3G is a derivative of the 2G model, now fielded as part of the Army's LandWarrior program.

ITT's SINCGARS ASIP-E adds 'Side Hat,' a small ultra high frequency (UHF) expansion module, to the current SINCGARS ASIP configuration. The expansion module also contains the SWR and ELPRS waveforms so that the resulting SINCGARS ASIP-E offers very high frequency voice and UHF data communication channels for vehicular and manpack operations. This allows mounted soldiers to conduct both voice and data communications simultaneously — a capability extension that gives them immediate updates to command and control information and improves their ability to make critical decisions on the battlefield.

"Microlight-3G, with Raytheon's EPLRS and ITT's new SRW, is a wideband capability that we can deliver on an accelerated schedule to our troops," said Jerry Powlen, Raytheon vice president of Integrated Communications Systems. "Additionally, the Microlight-3G will be capable of interoperating with future JTRS platforms and is designed to embrace new technology as it comes on line." "This is a watershed event for warfighters," said Lou Dollive, president of ITT Aerospace/Communications Division. "Microlight-3G and ASIP-E establish a migration strategy that can put emerging JTRS capabilities in the hands of deployed forces far sooner than we previously anticipated." Between them Raytheon and ITT have produced more than 75 percent of all the tactical radios that are currently fielded with the US armed forces. ITT's SINCGARS is the Army's combat net radio and — with more than 230,000 units fielded — is the most widely deployed military radio in the world. Raytheon's EPLRS and ITT's SINCGARS are the Tactical Internet's foundational communication systems. ■

Fine ARTS Contract for QinetiQ

As part of the Advanced Radar Targeting System (ARTS) programme, the UK Ministry of Defence has awarded a contract to QinetiQ to demonstrate the advanced targeting capability offered by Electronically Scanned (E-Scan) radar technology. The company has teamed with SELEX Sensors and Airborne Systems and BAE Systems Customer Solutions and Support to integrate an Active Electronically-Scanned Array (AESA) on a Tornado GR4A for assessment by the RAF in 2007.

With growing interest in extending the in-service life of the GR4, the project will explore the use of AESA and Synthetic Aperture Radar (SAR) in an air-to-surface role, including real-time target imaging, with a view to replacing the installed mechanically scanned terrain following/ground mapping radar system originally designed in the 1970s.

The contract was placed by the Defence Procurement Agency's (DPA) Sensors, Avionics, Navigation and Air Electronic Warfare Integrated Project Team on behalf of the MoD's Research Acquisition Organisation, as part of the Output 6 Research Programme sponsored by the DPA's Future Business Group. ARTS will also be supported by the Defence Logistic Organisation's Tornado IPT, while the Defence Science and Technology Laboratory will provide the MoD with independent technical advice on the programme.

ARTS benefits from a range of MoD and UK industry funded research programmes in the fields of AESA and SAR technologies, and will provide a continuing route for the rapid exploitation of future research and development. Furthermore, ARTS will run in parallel with the multi-national Advanced Multi-Mode Solid-State Airborne Radar (AMSAR) programmes and will focus on specific areas of capability development (SAR and Automatic Target Recognition). It will also focus on platform integration and aims to raise System Readiness Levels.

EADS Defence and Security Systems Division Restructures

The EADS Defence and Security Systems (DS) Division has been reorganised in order to further promote integration and increase efficiency, with the aim being for the Division to focus more intensively on its national customers and markets. In the new structure, there will be a balance between national tasks and operational units: in addition to their operational tasks, the DS Board members will also assume responsibility for divisional transversal tasks such as national key accounts or divisional central units like the System Design Centre, thus providing a respective central point of contact for national customers. Furthermore, by relocating the System Design Centre to division level, it will be more accessible for all the DS and EADS Business Units.

The organizational structures in the Defence and Communications Systems and Defence Electronics Business Units are also being streamlined. And following on from the considerable expansion of the Military Aircraft Business Unit portfolio in 2005, it is now being supplemented by an optimized structure and the new name — Military Air Systems. In the field of missiles, LFK will be integrated into MBDA in which EADS, together with BAE Systems and Finmeccanica, continues to be a shareholder, along with Eurofighter GmbH.

Explaining the rational behind the restructuring, Stefan Zoller, a member of the Executive Committee of EADS and CEO of Defence & Security Systems, stated, "We need to become more profitable and DS must generate more growth. At the same time, we are confronted with stagnant budgets in EADS' home markets, and the pressure from competitors in our export markets has risen sharply. In the future, we intend to grow in a profitable manner, both organisationally and by actively participating in the consolidation process of our industry. DS will thus be better prepared to make a significant contribution to EADS' results in the future."

UWB Moves a Step Closer to Mainstream

In a development that claims to bring UWB closer to mainstream use, NEC Corp. has announced that it has succeeded in developing the world's first reliable signal creation and processing technology in the wireless 3 to 9 GHz wide bandwidth range, enabling high speed wireless transmission of data from computers and digital home appliances.

To realize the wide spectrum of frequencies, the company developed an oscillator that can generate signals in the 3 to 9 GHz range. In addition, an ultra-high speed gain amplifier and bandpass filter have been added into the oscillator to change the gain in accordance with fast band hopping, achieving a flat characteristic output in the desired frequency range. Key to this new development is: the introduction of a new amplifier that achieves high performance for both large amplitude and noise rejection simultaneously; and the placing of just one voltage-adjustment circuit on a chip and using a bus to distribute compensation voltages, drastically reducing the amount of power needed for variation correction.

NEC is certain that its technology will significantly contribute to the realization of high speed wireless networks at home and in the office, and plans to strengthen its research toward the early commercialization of UWB products.

3G/WCDMA Products Increase

The Global Mobile Suppliers Association (GSA) survey — *3G/WCDMA-HSDPA Devices Variety and Availability* — confirms that the number of 3G/WCDMA devices announced in the market has reached 315, an increase of 129 products over the previous half-year period. The rapidly increasing variety, competitiveness and availability of user devices are key factors in driving 3G market acceptance and the survey states that 176 WCDMA products were launched in the past 12 months (a growth of 126 percent).

The figure of 315 includes 25 devices, which support HSDPA, more than double the figure of the previous six-month period. The GSA understands that over half of the number of commercial WCDMA operators is now moving to HSDPA as the new baseline for mobile broadband. The number of suppliers who have entered the WCDMA market by launching devices has increased by over 50 percent in 12 months, from 25 to 38. And the share of WCDMA devices targeted for the global 3G market has continued to rise to exceed 80 percent, with the remainder being focused on the Japanese FOMA™ market.

Moscow Institute Benefits from Cadence Expertise

Cadence Design Systems Inc. and the Moscow Institute of Electronic Technology (MIET) have successfully completed a three-year joint curriculum development project to provide engineering students with the skills and knowledge to work for international technology companies in Russia. However, its benefits will continue to be reaped, as the two-year graduate program is self-sustaining and will help train some of Russia's best and brightest minds in the future, supporting the strong emerging marketplace in Russia.

Under the project, Cadence provided design expertise and training, computer equipment and software, and funding for instructors and student scholarships. The program offers a master's degree in analogue/mixed signal engineering and includes 24 courses, accompanying laboratory projects and practical training. So far, 42 students have graduated and begun working for such companies as Angstrom, Cadence, Freescale Semiconductor, UNICOR and Unique ICs. ■

IEEE Task Group Advances Standard Process for 802.11™

The task group responsible for developing the IEEE 801.11n project has voted to accept, as a base line, a joint proposal to amend the IEEE 802.11™ wireless local area network (WLAN) standard by adding specifications for new technologies that will raise WLAN connection speeds to as much as 600 Mbps. The task group working on this amendment, the IEEE P802.11n™ "Wireless LAN Medium Access Control (MAC) and Physical Layer (PH) Specifications: Enhancement for Higher Throughput," voted unanimously (184/0/4) to confirm the joint proposal as a base line. The project to develop IEEE 802.11n began in 2003 to ensure the interoperability of the next generation of WLAN devices. A draft of the amendment is expected in late 2006, with publication slated for 2007. "The IEEE 802.11 Wireless LAN working group continues to improve this WLAN standard to meet the evolving needs of the public and industry," said Stuart J. Kerry, chair of the IEEE 802.11 Working Group on Wireless Area Networks. "Hundreds of technical experts from the world's leading technology companies, academic institutions and government agencies have collaborated to develop the foundation for new high throughput wireless LAN technology." Bruce Kraemer, chair of the IEEE 802.11n High Throughput Task Group, adds that "reaching this step is a significant milestone. It demonstrates the success of the IEEE consensus process in bringing together the diverse interests of enterprises and consumers. The technology to be incorporated into 802.11n will provide new capabilities to diverse industry sectors ranging from computers and consumer electronics to public access and mobile telephony."

Asia CEM Market is Now World's Largest

With an abundance of low cost labor and a vast technical workforce, Asia is now the world's largest Contract Electronic Manufacturing (CEM) market, reports In-Stat. The Asian CEM market was US $73.35 B in 2004, and is expected to reach US $161.90 B by 2009, the high tech market research firm says. "With China and Taiwan already strong in this field, other Asian countries such as India, Thailand and Vietnam are emerging as strong contenders for low cost manufacturing of electronic equipment," says Prakash Vaswani, In-Stat analyst. "The total CEM capacity in Asia will grow to 65 percent of the world's CEM capacity by 2009, with China leading the way." A recent report by In-Stat found the following:

- Many top and mid-tier contract manufacturers are forging closer ties with Asian suppliers and investing in enhanced software programs to improve material management.
- Asian CEM and assembly capacity was almost 52 percent of the global CEM capacity in terms of square footage in 2005.
- With rich technical talent available locally, electronic manufacturers in Asia have the potential to move in design services, thereby improving their margin considerably.

The report, "Asia CEM and Assembly Capacity by Country," covers the Contract Electronic Manufacturing market in Asia. The report includes a country-by-country breakdown of the CEM market and analysis and forecasts of CEM capacity in Asia. Factors responsible for attracting CEM players in the region, as well as the major application segments that Asia caters to, are also discussed. For more information on this report, visit: www.in-stat.com.

For Contactless Payments, Consistency is Key

2005 was notable in the United States for its demonstration — in the rollout of contactless payment capabilities to millions of people — of just how fast a major technology can be deployed. Issuers such as Chase Bank, HSBC, American Express and others have distributed contactless cards and key fobs to millions of their customers. Many constituents are involved: merchants, consumers, card issuers, associations and all the members of the contactless ecosystem — chip manufacturers, antenna designers, operating system developers, inlay makers and card plastic packagers. "Dozens of companies have swiftly changed gears to take advantage of this emerging opportunity," says ABI Research's director of RFID and M2M research, Erik Michielsen. "Many companies are trying to provide piecemeal solutions. There are many brands and co-brands, many form-factors. But one theme that has emerged time and time again from our research is the need for consistency. As this technology is being rolled out, it is incredibly important to develop a consistent industry-wide message that speaks to merchants, consumers and even component manufacturers. Some common technology standards have been put in place, but that consistency must extend all the way to the consumer who will understand that despite different form factors, modes of use and retailer adoption rates, contactless payment is one option, not two dozen." Similarly, it is beneficial if merchants, and all the players in the design and manufacturing chains that underpin the retail effort, fully understand the issuer's needs. "Market-wide coordination will ensure the best outcomes for all concerned," concludes Michielsen. ABI Research has just completed a comprehensive new service to assess the rapidly evolving global contactless commerce landscape. The "Contactless Commerce Research Service" is a subscription-based program of market intelligence that addresses the changing market drivers and technology choices that enable the contactless payment and commerce marketplace. It includes research reports, regular market updates, a forecast that is updated in real time, ABI insights and analyst inquiry time.

Bluetooth Automotive Markets a Good Bet for Continued Growth

Bluetooth automotive markets have historically been impeded by many issues that have slowed uptake and effectively stalled the market. In its recently published report entitled "Automotive Bluetooth — Handsets, Headsets, Telematics, OEM and Aftermarket Installed Devices," ABI Research has found the market grew significantly in 2005 and is showing healthy signs of this growth being a long-term prospect. Principal analyst of wireless connectivity Stuart Carlaw observes that "Several key factors have fallen into place and have driven the market to an unprecedented level: 141 percent growth in 2005, compared to 2004." Although a number of factors affect the uptake of Bluetooth in the automotive environment, three drivers are clearly head and shoulders above the rest. Awareness, familiarity and use of Bluetooth within the user consumer base have grown significantly and this has resulted in Bluetooth becoming a feature demanded by consumers, rather than pushed by manufacturers. Cellular handset penetration rates have continued to rocket and appear set to continue in the same direction. Finally, the growing trend for hands-free driving legislation has played directly into the hands of the Bluetooth community and can be seen as the most influential driver. All this may point to a rosy future for Bluetooth in the automotive market; however, Carlaw goes on to state that "There are still some significant barriers standing in the way of outright success for Bluetooth in this sector," adding: "Resolving the issues of interoperability, reducing silicon and equipment costs and penetration into consumer devices outside the cellular handset will all be crucial to securing a solid future for Bluetooth in the automotive environment." ABI Research's new study, "Automotive Bluetooth," examines the potential market for Bluetooth enabled OEM car kits, aftermarket car kits, speakerphones and headsets. The report includes detailed regional forecasts as well as a comprehensive profile of the Bluetooth-enabled cellular terminal market and all major products currently occupying the automotive Bluetooth supply chain. ■

INDUSTRY NEWS

■ **Smiths Group** announced that it has acquired the business and assets of **Lorch Microwave LLC**, adding microwave filter technology to its electronic components and subsystems Interconnect business. Smiths Group has acquired the business for $25 M from undisclosed private vendors, including $1 M payable after July 31, 2007, contingent on certain conditions being met.

■ **Sirenza Microdevices Inc.** announced a definitive agreement to acquire **Premier Devices Inc.** (PDI) for a combination of common stock, cash and debt valued at approximately $72.1 M. PDI designs, manufactures and markets complementary RF components featuring technologies common to existing and planned Sirenza products. With this acquisition, Sirenza, a designer and manufacturer of RF component solutions for global, diversified end markets, will expand both the depth and breadth of its products, extend its design and manufacturing capabilities into Asia and Europe, and continue its strategic mission to diversify and expand its end markets and applications.

■ **M/A-COM**, a business unit of Tyco Electronics, announced that the company has acquired an RF automotive antenna testing facility located in Belleville, MI. The facility includes three outdoor ranges, a screen room and an anechoic chamber. The use of the facility is not solely restricted to automotive companies or manufacturers, but is fully available for a complete range of RF testing to any and all interested parties.

■ **Unity Wireless Corp.** has signed a definitive agreement to acquire Israeli-based **Avantry Ltd.** Avantry develops and supplies wireless point-to-point microwave radio-for-broadband backhaul solutions for wireless and wireline communications networks. The acquisition, which is subject to certain standard terms and conditions, will broaden the Unity Wireless product line and customer base, and will allow for cross-selling opportunities that are expected to increase revenues.

■ **Advanced Power Technology Inc.** (APT) announced that the company has entered into a license agreement with the Electronic Systems' sector of **Northrop Grumman Corp.** to manufacture next-generation silicon carbide (SiC) microelectronic devices. The agreement forms an exclusive foundry supplier relationship whereby Northrop Grumman will license certain SiC technology to APT including relevant SiC patents and manufacturing methods to enable APT to manufacture proprietary high performance SiC microelectronic devices exclusively for Northrop Grumman. In related news, APT announced the planned closure of its facility in Montgomeryville, PA. The business management functions and remaining manufacturing activities currently located in Montgomeryville will be transferred to the company's facility in Santa Clara, CA.

■ **Kulicke & Soffa Industries Inc.** (K&S) announced a plan to tighten its focus on semiconductor assembly equipment and materials and create value for its shareholders. K&S has signed a definitive agreement to sell its wafer test assets to **SV Probe PTE Ltd.** K&S has also signed a definitive agreement to sell its package test assets to **Investcorp Technology Ventures II, L.P.**, which is managed by the Technology Investment Group of Investcorp, a global investment firm. In both cases, the transactions are subject to closing conditions.

■ **NEC Electronics Corp.** has announced that it will merge its wholly-owned subsidiary, **NEC Compound Semiconductor Devices Ltd.**, back into the parent company, effective as of April 1, 2006. NEC Compound Semiconductor Devices designs and manufactures RF and wireless semiconductors, components for fiber optic communications, optocouplers and solid-state relays. In the US and throughout the Western Hemisphere, **California Eastern Laboratories** (CEL) is NEC's exclusive sales and marketing partner for products manufactured by NEC Compound Semiconductor Devices. CEL maintains an extensive inventory, provides engineering and applications support, and participates in the design of the NEC Compound Semiconductor Devices' products that specifically target the company's domestic markets.

■ **Terabeam/HXI** has moved all of its operations to a new facility in the Ward Hill Industrial Park (East), Haverhill, MA. The new location provides increased manufacturing and office space to accommodate recent and projected sales growth in the millimeter-wave communications and radar markets. Terabeam/HXI is a division of Terabeam Inc., which also owns Proxim Wireless and Ricochet.

■ **STMicroelectronics**, a semiconductor manufacturer, inaugurated its new state-of-the-art design and development facility in Greater Noida, India. The company also announced its plans to invest US$30 M in local operations over the next two years and recruit 300 new engineers by the end of 2006.

■ **Trilithic Inc.** has formed the Quick Response Team™ to provide exceptional delivery on custom filters and RF/microwave components. The team has been formed as a result of the response to the high demand for prototype testing. This team of senior Trilithic engineers and manufacturing associates can in most situations provide a limited quantity (10 pieces or less) of new designs in a two-week delivery window. This is the ideal solution for prototype systems and/or proof of concept testing.

■ **Jacket Micro Devices Inc.** (JMD) announced that the US Patent and Trademark Office has issued US Patent No. 6,987,302 – "Stand Alone Organic-based Passive Devices." This patent was awarded to JMD's founders for the company's invention of a key technology used in JMD's multi-layer organic (MLO™) packaging process.

■ **Hittite Microwave Corp.** announced it has received its ISO/TS 16949:2002 certification for the design, manufacture and sale of plastic encapsulated analog and mixed-signal ICs for RF, microwave and millimeter-wave applications for the automotive industry. In addition to receiving this new certification, the company was recertified to the ISO 9001:2000 standard, which it has maintained since 1997.

■ **RF Micro Devices® Inc.** (RFMD®) announced that it has shipped its 20 millionth POLARIS™ TOTAL RADIO™ cellular transceiver. RFMD attributes its strength in cellular transceivers to the breadth of its GSM/GPRS and GSM/GPRS/EDGE transceiver product portfolio and the company's ability to expand its content within the world's leading handset manufacturers.

CONTRACTS

■ **Andrew Corp.** has won a strategic multiyear contract from a Tier 1 operator in the Middle East for a major geolocation system deployment. The agreement, valued in excess of $10 M for the first phase of deployment, calls for Andrew to install the first fully operational uplink time difference of arrival (U-TDOA) system outside of North America and the Caribbean. The Andrew Geometrix® U-TDOA will cover a network of thousands of cell sites, and initial shipments of product already are underway.

■ **Aeroflex** announced that its joint bid with **Centro de Tecnología de las Comunicaciones S.A.** (CETECOM Spain) has been successful in winning the contract from the WiMAX Forum to develop the protocol conformance test solution for the new WiMAX 802.16e technology standard. The contract win follows the recent open call for tenders initiated by the WiMAX Forum. In related news, **Agilent Technologies Inc.** announced that its wireless test equipment has been chosen by CETECOM Spain to be part of its WiMAX conformance test system. The WiMAX Forum, which promotes and certifies broadband wireless products, chose CETECOM Spain as its certification laboratory for WiMAX conformance and interoperability testing.

■ The **China Academy of Telecommunication Research** (CATR) has selected a system from **Rohde & Schwarz** for certification in the field of radio resource management (RRM). The protocol testers R&S CRTU-M and R&S CRTU-S and the spectrum analyzer R&S FSU are being added to the protocol tester R&S CRTU-W, which has already been put into operation by CATR. Rohde & Schwarz thus provides the Chinese regulatory authority with a complete RRM system for which worldwide the most RRM test cases defined in specification 34.121 chapter 8 are validated.

FINANCIAL NEWS

■ **Applied Wave Research Inc.** announced the completion of a Series C preferred stock financing totaling $6.4 M. The company's existing investors, including Synopsys Inc. and CMEA Ventures, were joined in this funding round by key new investors Intel Capital, Dow Pension Funds and the Southern Ute Growth Fund. The investment funds will be used to finance future acquisitions, broaden research and development efforts in new technologies, and continue the expansion of the company's worldwide sales and support networks.

■ **RF Industries Ltd.** reports sales of $3.4 M for the fourth quarter ended October 31, 2005, compared to $3.2 M for the same period in 2004. Net loss for the quarter was $101,000 ($0.04/per share), compared to a net income of $373,000 ($0.10/per diluted share) for the fourth quarter of the previous year.

■ **Ansoft Corp.** announced that its board of directors voted to amend its existing common stock repurchase program to permit the company to acquire an additional 1,000,000 shares of its common stock. Under the original program approved in 1998 and amended in 2002 and 2004, the company has purchased approximately 2,800,000 of the 3,000,000 shares authorized for repurchase.

PERSONNEL

■ WJ Communications Inc. announced the appointment of **Bob Whelton** to its board of directors. Whelton is currently an executive vice president of operations for Micrel Inc., a manufacturer of IC solutions for the worldwide analog, Ethernet and high bandwidth markets.

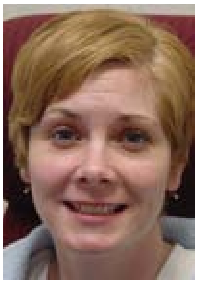
■ RF Monolithics Inc. (RFM) announced the appointment of **William L. Eversole** as an independent director to RFM's board of directors. Eversole will serve on the board's audit and compensation committees. Eversole is currently president and chief executive officer of Bandspeed Inc., a provider of combined silicon-software enterprise Wi-Fi Solutions, located in Austin, TX, and has over 30 years experience in the semiconductor business, specializing in product and business development.

■ QUALCOMM Inc. announced the appointment of **Andrew Gilbert** as president of QUALCOMM Europe. Gilbert, a native of England, will be responsible for the leadership of QUALCOMM's European business and will be based in the company's London office. Gilbert succeeds **Pertti Johansson** who has been appointed to a new position as president of QUALCOMM Middle East and Africa. Gilbert has spent the last 25 years in sales, marketing and general management roles for telecommunications vendors in both Europe and the United States.

■ Rogers Corp. announced that **Dennis Loughran** has joined the company as vice president of finance and chief financial officer. Loughran will be responsible for overseeing the company's financial operations worldwide and helping the company achieve its future strategic objectives. He brings to Rogers an extensive background in financial management, operations and international business. For the last five years, Loughran served as vice president of finance and supply chain at Alcoa Consumer Products.


▲ *Michael W. Murphy*

■ MI Technologies announced the appointment of **Michael W. Murphy** to the position of vice president of sales. In his new assignment, Murphy is responsible for the company's domestic and international sales. Prior to being named vice president of sales, Murphy served as vice president and business manager of MI Technologies' Commercial and Communications business.


▲ Elizabeth Roecker

■ Microwave Communications Laboratories Inc. has announced the appointment of **Elizabeth Roecker** to the company as its administrative coordinator. Her duties include management of customer service, accounts payable and receivable.

■ AR Worldwide Modular RF has expanded its sales force with the addition of **Jim Wilcox** as regional sales manager. Wilcox brings over 20 years of experience in high tech sales and marketing to his new position at AR Worldwide Modular RF.

REP APPOINTMENTS

■ **Anritsu Co.** announced the appointment of **East Coast Microwave** (ECM) as an authorized distributor for Anritsu's connector and component product lines. The appointment of ECM, which has offices in Massachusetts and Florida, will allow Anritsu to better serve its customers and is expected to help Anritsu increase its market share in components.

■ **Diamond Antenna and Microwave Corp.** announced it has selected two new rep appointments. **P2M** will be responsible for France and **RL Engineering** will cover Maryland and Virginia in the US. Guy Majcherczyk at P2M can be contacted at 01 30 62 64 64 or e-mail: gmajcherczyk@p2m.com. Ray Lopez at RL Engineering can be reached at (410) 760-5533 or e-mail: rlengri@aol.com.

■ **Eastern Wireless TeleComm Inc.** (EWT) recently announced the appointment of **G Squared Technologies**. G Squared Technologies will be responsible for the territory of Virginia, Maryland, District of Columbia, southern New Jersey and eastern Pennsylvania.

■ **Endwave Defense Systems** announced the signing of **Blackhart Sales**, Phoenix, AZ, to service the states of Arizona and New Mexico. Tim Martinelli will handle outside sales responsibilities while Kathy Martinelli will be responsible for inside sales activity. Endwave Defense Systems is a wholly-owned subsidiary of Endwave Corp. that designs and manufactures Hi-Rel, integrated RF subsystems and components for homeland security and defense applications.

■ **Sandvik Osprey Ltd.** has appointed **Dour Technical Sales** as its exclusive representative in the state of Florida. Peter Dour of Dour Technical Sales can be reached at (407) 854-7686 or e-mail: dourtechsales@earthlink.net.

■ **G.T. Microwave Inc.**, Randolph, NJ, announced the appointment of domestic representative, **Gruber & Associates Inc.**, to cover Georgia, Alabama, Mississippi, Tennessee and the Fort Walton Beach area (Florida). Gruber & Associates were allotted the task of covering prospective customers in the southeast region of the United States. Their headquarters is stationed at 241 Powers Cove, Marietta, GA 30057 or visit www.grubersales.com.

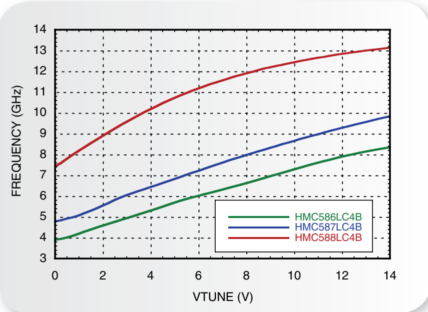
MMIC VC

Low Noise Sources For Automotive, Microw

Wideband VCO, 5 to 10 GHz

- HMC587LC4B
- Ultra Low SSB Phase Noise: -95 dBc/Hz @ 100 kHz
- Single Supply: +5V @ 55 mA
- RoHS Compliant 4x4 mm SMT Package
- Other Models Cover 4 to 12.5 GHz

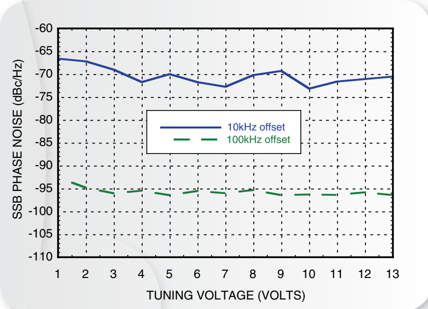
Frequency vs. Tuning Voltage



VCO with ÷16, 23.8 to 24.8 GHz

- HMC533LP4 (E)
- Pout: +12 dBm
- Low Phase Noise: -95 dBc/Hz @ 100 kHz Typ.
- RoHS Compliant 5x5 mm SMT "E" Package

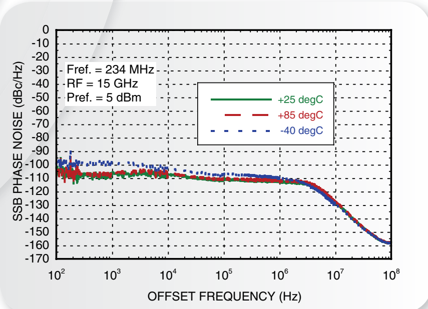
SSB Phase Noise vs. Tuning Voltage



Phase Locked Oscillator, 14.7 - 15.4 GHz

- HMC535LP4 (E)
- Pout: +9 dBm
- Low Phase Noise: -110 dBc/Hz @ 100 kHz Typ.
- RoHS Compliant 4x4 mm "E" SMT Package

Phase Noise Performance



Hittite MICROWAVE CORPORATION

ISO/TS 16949 TÜV SÜD ISO 9001

RoHS EARTH FRIENDLY

DESIGN AND TEMPERATURE COMPENSATION OF A KU-BAND CHANNEL AMPLIFIER WITH ALC FOR A SATELLITE TRANSPONDER

This article describes the design, development and test results of a Ku-band channel amplifier with an automatic level control (ALC) system for a satellite transponder. A systematic temperature characterization and optimization procedure depending upon the measured data of the channel amplifier is presented. This procedure takes into account the effect of parameter variations from one unit to another and eliminates the conventional trial and error method to determine the optimum component values of the temperature compensation circuits.

In tropical regions, satellite communication links at Ku-band frequencies face excess up- and downlink paths loss due to rainfall. The uplink rain attenuation causes a decrease in the signal level received at the satellite receiver, which leads to a decrease of the satellite transmitter power. This signal level is further reduced by the downlink rain attenuation. This may cause the signal level to fall below the sensitivity threshold level of the ground receiver a for specific BER performance. Adaptive power control systems in the satellite transmitter and ground receiver can solve this problem. This article describes the design, development and characterization of a Ku-band channel amplifier with an automatic level control (ALC) system for spacecraft applications to control the input of the final power amplifier (TWTA or SSPA) according to the signal level arriving at the channel amplifier input. Thus, the ALC system also protects the final power amplifier against any accidental high power from the uplink.[1] This channel amplifier can operate in an ALC mode as well as in a fixed gain mode (FGM). In the fixed gain mode, the gain is 44 dB and in the ALC mode, the gain varies automatically from 39 to 59 dB depending upon the input power level. This amplifier has an adjustable gain control (22 dB) system to operate the final power amplifier in different back-off conditions in both modes of operation.

The required gain of the amplifier is achieved by using three amplifier modules us-

S.C. BERA, R.V. SINGH
AND V.K. GARG
ISRO
Ahmedabad, India

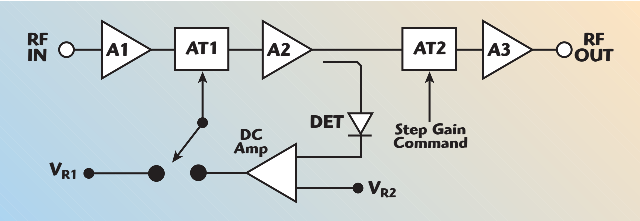


Fig. 1 Basic block diagram of the channel amplifier with ALC.

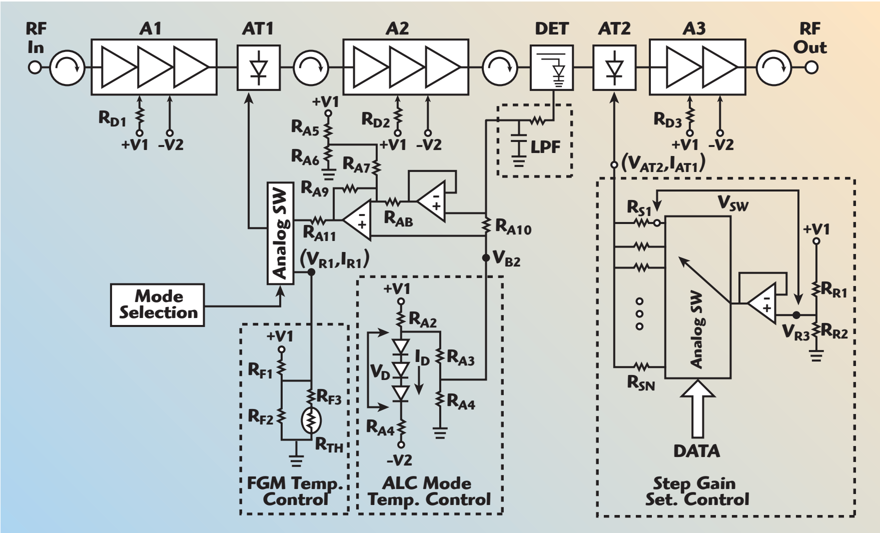


Fig. 2 Block diagram with control signals.

ing PHEMT devices (CFY67-08). In the ALC mode, the channel amplifier operates as a closed loop feedback system.[1] The amplifier contains a Schottky diode detector to detect the sampled RF power. This detected voltage is amplified by a differential DC amplifier and applied to the control input of a variable PIN diode attenuator. The attenuation of the attenuator varies according to the input power level so as to maintain the output power level of the channel amplifier constant. Another PIN diode attenuator is used for the adjustable step gain control.

It is known that the gain of the HEMT-based amplifier modules, the attenuation of the PIN diode attenuators and the detected power level of the Schottky diode detector are all functions of temperature. Thus, suitable compensation circuits[2–4] are included to compensate for the temperature variation of the channel amplifier's performance over the required temperature range for satellite applications. A practical systematic procedure based on the measurement data instead of the conventional trial and error method is presented to determine the component values of the compensation networks.

BLOCK SCHEMATIC OF THE CHANNEL AMPLIFIER

The basic block schematic of the channel amplifier with ALC is shown in ***Figure 1***. The amplifier modules A1, A2 and A3 are used to meet the total gain requirement of the channel amplifier. The voltage variable attenuator AT1 is for the automatic gain control of the amplifier, depending on the input power level. The range of gain control of this attenuator is +15 to –5 dB over the nominal gain of 44 dB. The attenuator AT2 is for adjusting the gain of the amplifier by up to –22 dB, in steps of –2 dB. For the ALC function, the RF power is sampled after the amplifier A2 and detected by the detector diode. This detected voltage is applied to one of the inputs of the differential DC amplifier. The other input of the differential amplifier is connected to the reference voltage V_{R2}, which determines the output power level of the channel amplifier. The output of the DC amplifier is connected to the ALC attenuator AT1 through an analog switch. The switch position determines the mode of operation of the channel amplifier. When the switch connects the attenuator AT1 to the other reference voltage V_{R1}, the channel amplifier operates in the fixed gain mode. The voltage V_{R1} level determines the gain of the channel amplifier in the fixed gain mode operation.

The gain of the microwave amplifier modules, the attenuation of the PIN diode attenuators and the detected power level of the Schottky diode detector are all functions of temperature. Thus, suitable compensation circuits are required to compensate for the temperature variation of the channel amplifier performance over the specified temperature range for satellite transponders.

The schematic circuit diagram of the channel amplifier with the different temperature dependent control signals is shown in ***Figure 2***. The temperature-controlled reference voltage V_{R1} is generated using a thermistor to compensate the gain in FGM operation. The temperature-controlled reference voltage V_{R2} is generated using P-N junction diodes to compensate the output power level variation in ALC mode operation.[1] To achieve a temperature invariant and accurate step attenuation, an improved control circuit is used for the PIN diode attenuator.[4]

REALIZATION OF INDIVIDUAL MODULES

Amplifier Modules

The amplifier modules A1, A2 and A3 are used to achieve the required channel amplifier gain. A1 and A2 are three-stage amplifiers and A3 is a two-stage amplifier. All the amplifier modules are made using PHEMT devices (CFY67-08) for the Ku-band downlink frequency of 11.45 to 11.70 GHz. The MIC assembly drawing of the three-stage amplifier is shown in ***Figure 3***. All the matching networks are fabricated on a 25 mil thick alumina (Al_2O_3) substrate ($\varepsilon_r = 9.9$), 0.25" × 0.5", and the required bias resistors are also accommodated on the alumina substrates in the RF tray. The two-stage amplifier A3 is realized with the same MIC cards used in the three-stage amplifier by eliminating one inter-stage matching network. These circuits were simulated and analyzed with the HP (EEsof) circuit simulator, series IV. To adjust the overall gain of the channel amplifier the resistors RD1, RD2 and RD3 are used in the +V1 supply lines of the amplifier A1, A2 and A3, respectively.

Variable Attenuators

The attenuators for step gain control (22 dB) and automatic level control (20 dB) are both two-stage, PIN diode-based, voltage variable analog attenuators. The MIC assembly drawing of the attenuator is shown in ***Figure 4***. D1, D2, D3 and D4 are beam lead PIN diodes (MPND-4005), connected with 3 dB Lange couplers designed at Ku-band frequencies. In this configuration, the circuit will provide maximum attenuation when the PIN diode resistances are 50 Ω, which will be determined by the current through the diode. The photograph of the integrated RF tray is shown in ***Figure 5***.

TEMPERATURE COMPENSATION OF THE CHANNEL AMPLIFIER

It is known that the gain of the PHEMT-based amplifier modules, the attenuation of the PIN diode attenuators and the detected power level of the Schottky diode detector are functions of temperature. Moreover, the temperature dependency of the on-resistance of the analog switch (CD4051) is influenced by the temperature characteristic of the channel amplifier. Thus, suitable temperature compensation circuits, with a suitable method to determine the component values, are required to compensate the temperature variation of the channel amplifier's performance over the required temperature range for satellite applications. There are two temperature-dependent control signals V_{R1} and V_{R2} generated to compensate the temperature variation of the channel amplifier's gain in the FGM and ALC modes, respectively. Another control signal, V_{R3}, is generated to achieve a temperature invariant step gain setting. The practical procedures to determine the component values of the control circuits for the different modes of operation are discussed in the following sections.

FIXED GAIN MODE (FGM)

In the fixed gain mode, it must be ensured that the gain of the channel amplifier is within the specified limit over the operating temperature range. The function of the control signal V_{R1} is to set the gain of the amplifier at 44 dB and to keep this gain within the specified limit (peak-to-peak < 0.8 dB) over the temperature range of –10° to +60°C. To generate the temperature-controlled reference signal V_{R1}, a thermistor R_{TH} is used with the resistors R_{F1}, R_{F2} and R_{F3}, as shown in the block diagram. The equivalent circuit of the V_{R1} signal generator with the attenuator and analog switch is shown in ***Figure 6***. Here, the reference point is taken before the analog switch to include its temperature variation. $V_{FO}(T)$ and $R_{FO}(T)$ are function of temperature due to their dependency on $R_{TH}(T)$ and are given by

$$V_{FO}(T) = \frac{V_1\left[R_{F2}\left(R_{F3}+R_{TH}(T)\right)\right]}{R_{F1}+\left[R_{F2}\left(R_{F3}+R_{TH}(T)\right)\right]} \quad (1)$$

$$R_{FO}(T) = R_{F1}\left[R_{F2}\left(R_{F3}+R_{TH}(T)\right)\right] \quad (2)$$

Suppose that, at a temperature T, the voltage at the reference point and the current to the attenuator is $V_{R1}(T)$ and $I_{R1}(T)$, respectively, to achieve the required gain (44 dB) setting of the channel amplifier. Then from the equivalent circuit

$$V_{FO}(T) - V_{R1}(T) = R_{FO}(T) \times I_{R1}(T) \quad (3)$$

To determine the circuit component values (R_{F1}, R_{F2} and R_{F3}) of this network, it is required to take three sets of voltage and current readings [{$V_{R1}(T_A)$, $I_{R1}(T_A)$}; {$V_{R1}(T_C)$, $I_R(T_C)$}; $V_{R1}(T_H)$, $I_{R1}(T_H)$}] at three different temperatures (T_A, T_C, T_H) by setting the amplifier's gain at the required value (44 dB). The optimum values of R_{F1}, R_{F2} and R_{F3} will be the ones that satisfy Equations 4, 5 and 6 simultaneously

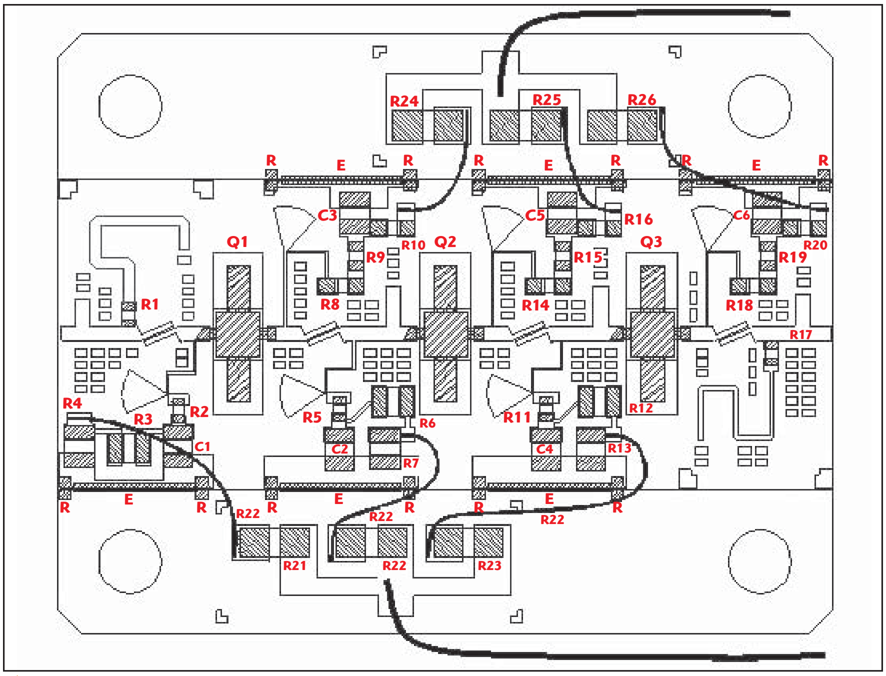


Fig. 3 *MIC assembly of the three-stage amplifier.*

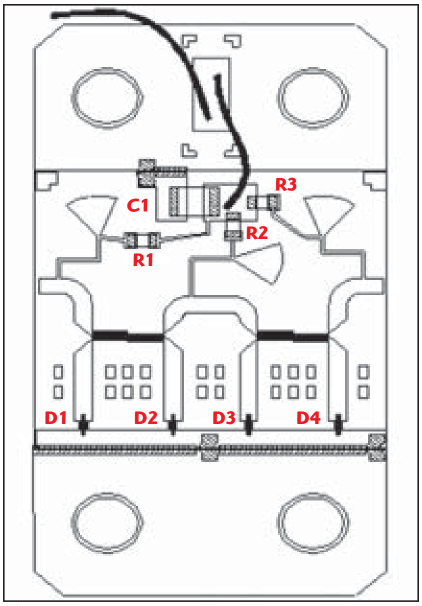


Fig. 4 *MIC assembly of the PIN diode attenuator.*

$$V_{FO}(T_A) - V_{R1}(T_A) = R_{FO}(T_A) \times I_{R1}(T_A) \quad (4)$$

$$V_{FO}(T_C) - V_{R1}(T_C) = R_{FO}(T_C) \times I_{R1}(T_C) \quad (5)$$

$$V_{FO}(T_H) - V_{R1}(T_H) = R_{FO}(T_H) \times I_{R1}(T_H) \quad (6)$$

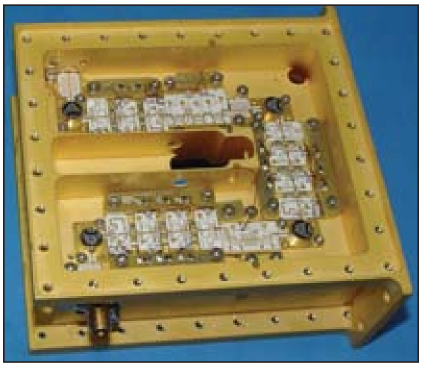


Fig. 5 *Photograph of the RF tray.*

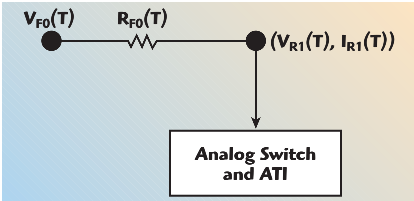
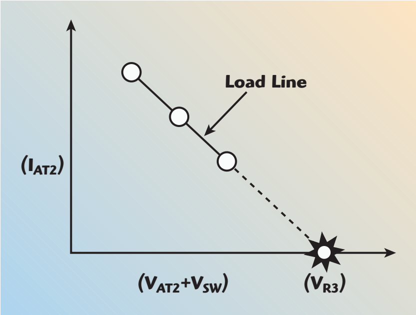


Fig. 6 *Equivalent circuit for V_{R1}.*

AUTOMATIC LEVEL CONTROL MODE

In the ALC mode, the detector circuit will detect the RF power, and there will be a voltage drop across the load resistor R_{A10}. This voltage will be amplified by the differential amplifier and fed to the attenuator AT1 through the analog switch. The reference voltage V_{R2} will determine the output of the channel amplifier in the ALC mode. The variation of the output power over the range of the input power variation will be determined by the overall gain of the ALC loop. The loop gain is determined by the resistor R_{A8},



▲ *Fig. 7 Plot to determine V_{R3}.*

R_{A9}, R_{A10} and R_{A11}. An offset current provided through the resistor R_{A7} ensures that the output of the differential amplifier is at a negative potential at very low RF power levels. The characteristics of the detector, amplifier modules and attenuators change with temperature. Thus, the reference voltage V_{R2} should be a temperature dependent voltage to achieve the required fixed output power level within the specified range over the operating temperature range.[1] To generate the temperature-controlled reference voltage V_{R2}, P-N junction diodes are used. The following equations determine the current (I_d) through the diodes and the voltage (V_d) across all the diodes

$$I_d(T) = f(V_d(T)) \tag{7}$$

$$I_d(T) = \frac{V_1 - V_D(T) - I_d(T) \times R_{A2} + V_2}{R_{A1}} - \frac{V_d(T) + I_d(T) \times R_{A2} - V_2}{R_{A3} + R_{A4}} \tag{8}$$

Assuming that there is no current drawn by the detector diode and the differential amplifier from the reference supply V_{R2}. Therefore, at a particular temperature T, if the reference voltage requirement is $V_{R2}(T)$, then one can write

$$V_{R2}(T) \times [R_{A3} + R_{A4}] = [V_D(T) + I_D(T) \times R_{A2} - V_2] \times R_{A4} \tag{9}$$

The circuit component values (R_{A1}, R_{A2}, R_{A3} and R_{A4}) of this network can be determined by taking three sets of voltage readings [$V_{R2}(T_A)$, $V_{R2}(T_C)$, $V_{R2}(T_H)$] at three different temperatures (T_A, T_C, T_H) by setting the amplifier's output power level at the required value (say 0 dBm). Then the optimum value of R_{A1}, R_{A2}, R_{A3} and R_{A4} will be the one which satisfies Equations 10, 11 and 12 simultaneously

$$V_{R2}(T_A) \times [R_{A3} + R_{A4}] = [V_D(T_A) + I_D(T_A) \times R_{A2} - V_2] \times R_{A4} \tag{10}$$

$$V_{R2}(T_C) \times [R_{A3} + R_{A4}] = [V_D(T_C) + I_D(T_C) \times R_{A2} - V_2] \times R_{A4} \tag{11}$$

$$V_{R2}(T_H) \times [R_{A3} + R_{A4}] = [V_D(T_H) + I_D(T_H) \times R_{A2} - V_2] \times R_{A4} \tag{12}$$

ADJUSTABLE GAIN SETTING

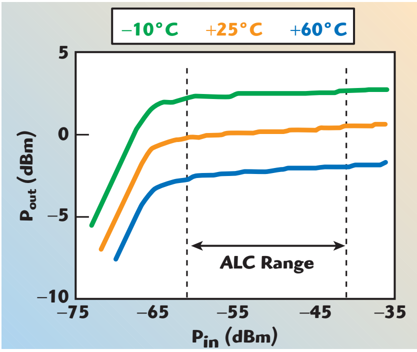
The step attenuator AT2 sets the gain of the channel amplifier. A proper load line selection technique is used to achieve a temperature invariant attenuation of the PIN diode based attenuator AT2.[4] An analog switch (CD4051), with a bank of resistors R_{S1} to R_{SN} and a reference voltage V_{R3}, is used for the control signal of the PIN diode attenuator circuit.[4] The reference voltage V_{R3} is the critical parameter to achieve a temperature invariant attenuation. The resistors R_{R1} and R_{R2} determine this reference voltage. To determine R_{R1} and R_{R2}, three sets of voltage and current readings are required [{$V_{AT2}(T_A)$, $I_{AT2}(T_A)$, $V_{SW}(T_A)$}; {$V_{AT2}(T_C)$, $I_{AT2}(T_C)$, $V_{SW}(T_C)$}; {$V_{AT2}(T_H)$, $I_{AT2}(T_H)$, $V_{SW}(T_H)$}] at three different temperatures (T_A, T_C, T_H) by setting the attenuation of the attenuator, preferably at the maximum required value (say 22 dB). Then, plotting these data as shown in ***Figure 7***, one can get the reference voltage V_{R3}, which is the intercept point of the load line with the voltage ($V_{AT2} + V_{SW}$) axis. R_{R1} and R_{R2} will then be determined by satisfying the following equation and putting the constraint on current drawn from the source V_1

$$V_{R3} = \frac{V_1 \times R_{R2}}{R_{R1} + R_{R2}} \qquad (13)$$

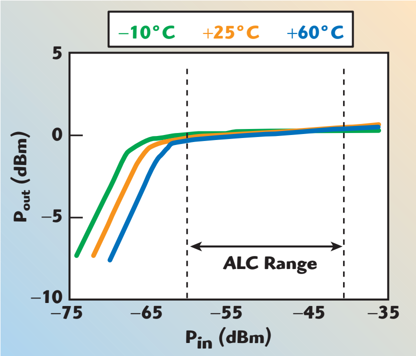
The resistance values R_{S1} to R_{SN} can be determined by setting the reference voltage V_{R3} and then adjusting these resistor values to achieve the different step attenuation required (2, 4, 6,… dB). This can be done at any temperature. In this method, the temperature variation of the 'analog switch resistance' has been taken into account by plotting the load line with respect to voltage ($V_{AT2} + V_{SW}$). Therefore, this procedure eliminates the separate temperature characterization of the 'analog switch resistance' over the temperature range.

TEST RESULTS

The integrated channel amplifier has been fabricated and tested over the Ku-band downlink frequency of 11.45 to 11.70 GHz. The output versus input power characteristics of the channel amplifier in the ALC mode are shown in ***Figure 8***. The measured output power variation is within 1 dB for an input power variation of –59 to –39 dB. As shown, without the temperature compensation circuit, the output power variation in the ALC mode over the temperature range of –10° to +60°C is nearly 4.5 dB. The required reference voltage (V_{R2}) was measured at cold, ambient and hot temperature to achieve a constant power (0 dBm) at the output of the channel amplifier. The optimum component values R_{A1}, R_{A2}, R_{A3} and R_{A4} are determined by satisfying Equations 9, 10 and 11 simultaneously. The power characteristics of the channel amplifier with the optimum components value for the temperature compensation circuit in the



▲ *Fig. 8 I-O characteristic without temperature compensation.*



▲ *Fig. 9 I-O characteristic with temperature compensation.*

ALC mode are shown in ***Figure 9*** at three different temperatures. With the temperature compensation circuit, the measured variation is reduced to less than 0.4 dB over the temperature range of –10° to +60°C.

In the fixed gain mode, without a compensation circuit, the gain variation of the channel amplifier is nearly 5 dB over the temperature range of –10° to +60°C. The three sets of voltage and current readings (V_{R1}, I_{R1}) at cold, ambient and hot temperatures are measured to obtain the same gain of 44 dB.

The optimum values of the resistors R_{F1}, R_{F2}, R_{F3} of the compensation network are determined for a thermistor of 5 kΩ by satisfying Equations 4, 5 and 6 simultaneously. With the optimum components value of the compensation network, the measured gain variation over the temperature range becomes 0.4 dB. The optimum reference voltage V_{R3} is determined by the optimum load line selection technique.[4] The three sets of voltage and current [($V_{AT2} + V_S$), (I_{AT2})] readings at cold, ambient and hot temperatures are measured to get the same attenuation of 22 dB. Plotting these data, the optimum voltage (V_{R3}) is 0.963 V. For this optimum reference voltage, the resistor values R_{R1}, R_{R2}, and R_{S1} to R_{S11} are determined. With this reference voltage, the achieved step attenuation accuracy is within ±0.4 dB for all the steps (–2, –4, ..., –22 dB) over the temperature range of –10° to +60°C.

CONCLUSION

This article discusses the design, temperature characterization and test results of a Ku-band channel amplifier with an automatic level control (ALC) system for spacecraft applications. The presented practical procedure to determine the component values of the compensation circuits will be very useful to optimize the performance of the channel amplifier without characterizing the individual modules. This systematic procedure takes into account the effect of parameter variation from one unit to another and eliminates the conventional trial and error method, leading to a reduction in labor time. ■

References

1. S.C. Bera and R.V. Singh, "A Temperature-compensated Closed Loop Overdrive Level Controller for Microwave Solid-state Power Amplifiers," *Microwave Journal*, Vol. 47, No. 4, April 2004, pp. 114-122; correction in *Microwave Journal*, Vol. 47, No. 6, June 2004, p. 156.
2. J.H. Shim, *Circuit for Compensating Temperature of Automatic Gain Control Circuit*, US Patent No. S 2002/0187766 A1.
3. Wey, et al., *Temperature Compensated Variable Attenuator*, US Patent No. 6 297 709 B1, 2001.
4. S.C. Bera and P.S. Bharadhwaj, "Insight into PIN Diode Behavior Leads to Improved Control Circuit," *IEEE Transactions on Circuits and Systems-II*, Vol. 52, No. 1, January 2005, pp. 1–4.

S.C. Bera *received his M. Tech degree in radio physics and electronics from the University of Calcutta, India, in 1994. He joined the Space Applications Center of the Indian Space Research Organization (ISRO), Ahmedabad, India, that same year, where he has been involved in many communication payload projects of ISRO, including the INSAT-2, INSAT-3, INSAT-4 and GSAT series of spacecraft.*

R.V. Singh *received his B. Tech (EE) degree from GB Pant University of Ag. and Technology, Pantnagar, Nainital, India, in 1972. He joined the Space Applications Center, ISRO, Ahmedabad, India, in October of that year. He has worked on various microwave components and subsystems including low noise amplifiers, receivers and SSPAs for communication satellite transponders. He has worked as associate project director for the communication payload for the INSAT-3A satellite of ISRO. He has contributed to various INSAT- 2, 3 and 4 series communication satellite projects of ISRO. He is presently working as group director of the power amplifier group in the Satcom Payload Technology Area of the Space Applications Center, ISRO.*

V.K. Garg *received his B. Tech. degree in electronics and communications from IIT, Madras, India, in 1970. He joined the Experimental Satellite Communication Earth Station (ESCES), Ahmedabad, India, in July 1971. Since then, he has been involved in all major communications satellite projects of ISRO, including the SITE, STEP, APPLE, INSAT-1, INSAT-2, INSAT-3 and INSAT-4 series of spacecraft. He was associate project director for the INSAT-2C and INSAT-2D communication payloads. He is currently deputy director, Satcom Payload Technology Area at the Space Applications Center, ISRO, Ahmedabad, India. He is guiding the design and development of regenerative payloads, special payloads and state-of-the-art technology subsystems.*

DESIGN OF AN AMPLIFIER USING A HARMONIC TERMINATION MATCHING TUNER AND HARMONIC BLOCKING BIAS LINE

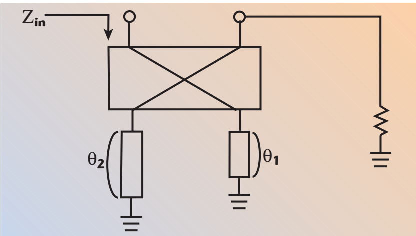
In this article, a new 3 dB branch line hybrid, using an asymmetric defected ground structure (DGS) microstrip, is proposed. The proposed branch line coupler suppresses the second and third harmonic components effectively. If transmission lines having an arbitrary electrical length are connected at the through and coupled ports of the DGS branch line hybrid, then the DGS branch line hybrid is operated as an impedance transforming tuner. A new DGS λ/4 bias line that can suppress high frequency harmonics as well as low frequency intermodulation is also proposed. With the harmonic termination tuner, using the proposed hybrid and the harmonic blocking bias line, the second and third harmonic components of the fabricated IMT-2000 band amplifier were suppressed by up to 25 and 27 dB, respectively. A harmonic load-pull measurement setup for an amplifier can easily be implemented with the proposed circuits.

Harmonic load-pull systems have gained importance recently, because such setups allow the appropriate harmonic terminations for a transistor to be determined in order to obtain high efficiency and high linearity. Harmonic load-pull can also make the verification of transistor models possible. However, the active load-pull systems that are presently used are very complicated and present many difficulties in the measurements.[1,2] An impedance tuner that transforms a 50 Ω termination impedance into an arbitrary impedance can be realized with a 3 dB hybrid coupler and open or shorted stubs in its coupled and through ports. When the isolated port is terminated in 50 Ω, the reflection coefficient at the input port is easily controlled by changing the stub lengths θ_1 and θ_2 in the coupled and the through port of the 3 dB hybrid, and can be expressed as[3]

JIN-KUK LEE, SU-TAE KIM AND YONG-CHAE JEONG
Chonbuk National University
Chonju, Korea
JONG-SIK LIM
Soonchunhyang University
Asan, Korea
CHUL-DONG KIM
Sewon Teletech Inc.
Anyan, Korea

$$S_{11} = \frac{e^{-j\theta_1} - e^{-j\theta_2}}{2} \qquad (1)$$

The impedance tuner is used to measure the optimum input/output impedance of a microwave circuit such as an amplifier, mixer and so forth. ***Figure 1*** shows a conventional impedance tuner using a 3 dB hybrid and shorted stubs for optimum input/output impedance transformation. A load-pull measurement is possible within the operating frequency band when the matching points for the device under test (DUT) are determined with impedance tuners, but the harmonic termination is almost impossible, due to the frequency characteristics of the 3 dB hybrid. Consequently, the operating conditions in the fundamental band can be changed due to the harmonics termination. A defected ground structure (DGS), which is realized by etching a dumbbell or spiral shaped pattern in the ground plane of a microstrip line, has been proposed.[4] Several applications using DGS to design a coupler, a filter and a power amplifier have already been presented.[5–8] Recently, a DGS microstrip line that can suppress the second and third harmonics by inserting an asymmetric defect in the ground plane has also been presented.[9] The DGS microstrip basically provides a slow-wave effect by increasing the effective inductance of the transmission line.

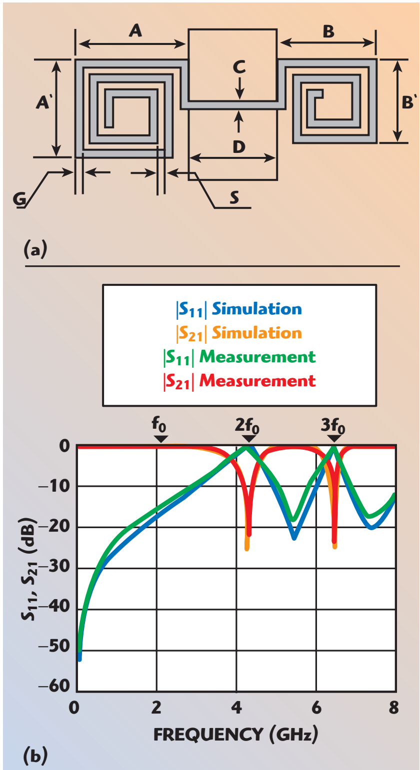


▲ *Fig. 1 Impedence tuner using a 3 dB hybrid and shorted stubs.*

In this article, an impedance tuner using a new 3 dB branch line hybrid is proposed. Since the proposed 3 dB branch line hybrid includes asymmetric DGS microstrip lines, the second and third harmonics can easily be suppressed. A λ/4 DGS bias microstrip is also used that effectively suppresses the third harmonic component as well as the second harmonic and low frequency intermodulation components.[8–10] An amplifier harmonic load-pull setup can be easily implemented by using an impedance tuner and a λ/4 bias line that suppress the second and third harmonics.

HARMONIC TERMINATION 3 dB BRANCH LINE HYBRID TUNER

Although there are several shapes used for the defects of DGS microstrip lines, dumbbell or spiral shapes are the most common. The spiral DGS microstrip lines have steeper band-rejection characteristics than dumbbell DGS lines, but their band-rejection bandwidth is narrower. Several stage dumbbell DGS lines also have steep and wide band-rejection characteristics, but a larger circuit size is required than for the spiral. Therefore, an asymmetric spiral DGS that has a dual band-rejection characteristic at the specified frequencies is effective for circuit size reduction. ***Figure 2*** shows the geometry of an asymmetric spiral DGS on the ground plane of the microstrip line, in which the dimensions of the spiral-shaped defects in the right- and the left-hand side are different (A = 3 mm, A' = 2.6 mm, B = 2.6



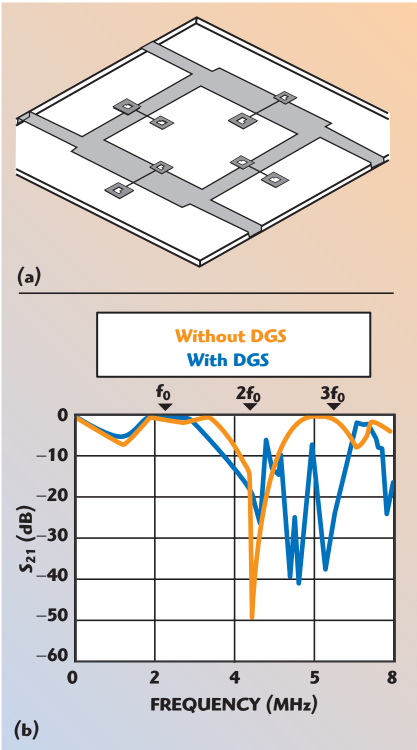
▲ *Fig. 2 The asymmetric DGS microstrip line (a), and its simulated and measured characteristics (b).*

mm, B' = 2.2 mm, C = G = S = 2.2 mm, D = 2.4 mm). The transfer and the reflected characteristics are also shown. The substrate used is RT/duroid 5880 with a dielectric constant of 2.2 and a thickness of 31 mils. The circuit was simulated with HFSS from Ansoft. The asymmetric spiral DGS microstrip line is designed for the IMT-2000 base station transmitting band, and the transfer characteristic around the second and third harmonic bands is suppressed. A harmonic termination 3 dB branch line hybrid coupler, using asymmetric DGS microstrip lines, was simulated and fabricated. The fabricated hybrid is of a slightly smaller size than the conventional hybrid because of the slow-wave effect of the DGS microstrip lines. In a conventional 3 dB branch hybrid, the length and width of the 35.35 and 50 Ω lines are 26.8, 3.9 and 26.4, 2.4 mm, respectively, but those of the proposed hybrid are 19.6, 5 and 25.6, 2.4 mm, respectively. ***Figure 3*** shows the geometry of the proposed branch line coupler where the center frequency is 2.14 GHz. The coupling and the transmit coefficient of the 3 dB hybrid are –3.1 and –3.4 dB, respectively. Also shown is the transfer characteristic in the case when the open stubs at the coupled and through ports have the same electrical length. For comparison, the transfer characteristics of the conventional 3 dB hybrid are also shown. The transfer losses for the proposed hybrid, within the operating band and at the second and third harmonics, are –0.3, –15.5 and –28.9 dB, respectively. The measured results in the operating band and at the second harmonic show very similar characteristics to the conventional hybrid. But the characteristics at the third harmonic are quite different. It is definitely observed that the second and third harmonics cannot pass in the proposed harmonic termination 3 dB branch line hybrid.

HARMONIC BLOCKING BIAS CIRCUIT

Small-signal amplifiers in the UHF band usually use chip inductors as RF chokes in their bias circuits. However, λ/4 long, high impedance transmission lines terminated with chip capacitors or radial stubs are usually used as bias lines at higher frequencies. When a capacitively terminated λ/4 bias line is connected to a signal line, even harmonic components that propagate on the signal line are blocked, while odd harmonic components pass through. In the signal amplifying process, an amplifier generates harmonics and intermodulation distortion components in addition to the amplified input signal. A proper harmonic termination is required to increase the efficiency and for active load-pull setup.

Figure 4 shows the layout of a harmonic blocking λ/4 bias line. Instead of a conventional microstrip line, a λ/4 DGS microstrip line is used. Due to the slow-wave effect of the DGS, the second passband is shifted down. As a result, the third harmonic of the amplifier can be reflected at the bias line junction point. A bypass LC series resonating circuit is also inserted in the bias pad of the λ/4 bias line, in addition to the bypass capacitor.[10] This LC tank makes the low frequency blocking range broader. The transfer characteristics of the conventional and the proposed bias line are also shown for the low frequency band. The low frequency



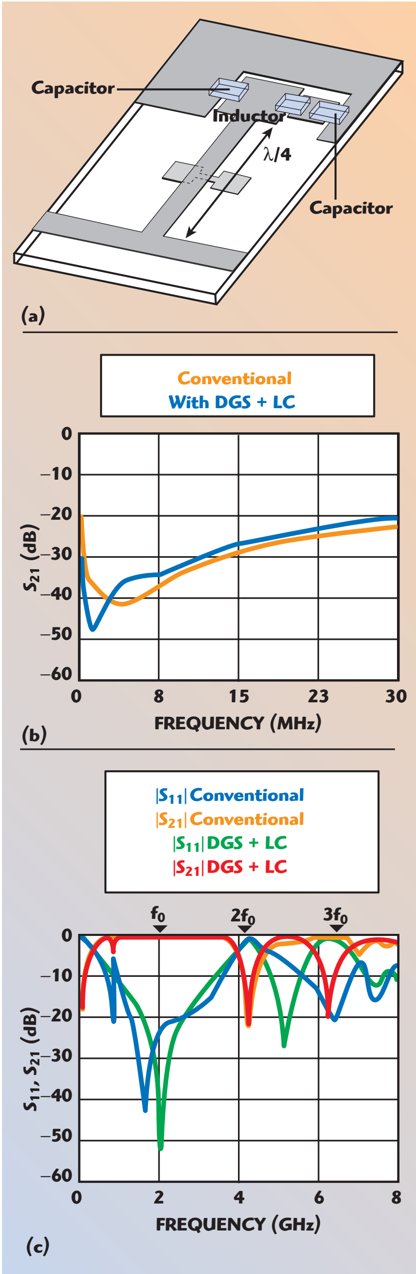
▲ *Fig. 3 Geometry of the harmonic termination 3 dB branch line hybrid (a) and the measured transfer characteristics of the conventional and proposed hybrids (b).*

band-rejection of the proposed bias line is shifted down, so that low intermodulation components can be reduced compared to the conventional bias line. The transfer characteristics of the conventional and the proposed bias line in the operating and harmonic bands are also shown in the figure. The operating and second harmonic frequency characteristics are almost similar to that of the conventional bias line, but the third harmonic band is shift down, so that the second and third harmonics are blocked by the proposed bias line.

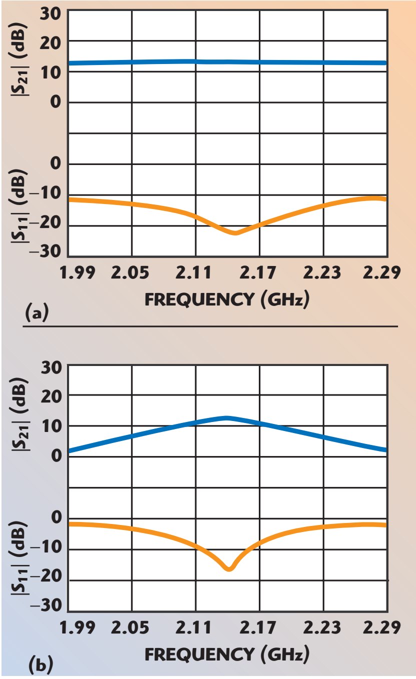
AMPLIFIER DESIGN USING HARMONIC TERMINATION TUNER AND HARMONIC BLOCKING BIAS LINE

To show the validity of the proposed harmonic termination impedance tuner and the harmonic blocking bias line, two kinds of amplifiers were fabricated and compared. One is realized with a conventional bias line and only in-band matching circuits. The other is made with the harmonic termination tuner and the harmonic blocking bias line. The operating frequency is 2.11 to 2.17 GHz and the transistor used is a FLL357ME device from Fujitsu.

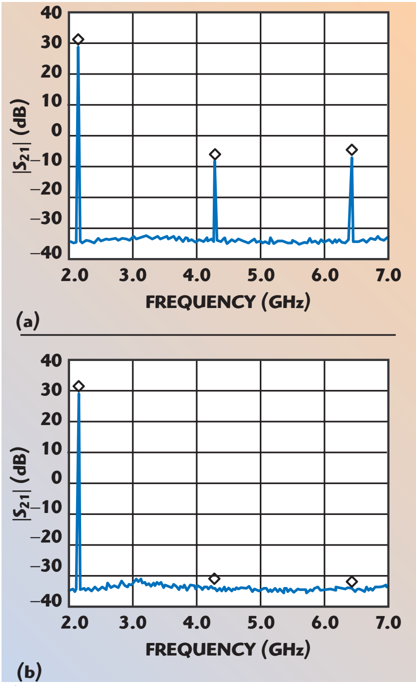
Figure 5 shows the transfer and reflected characteristics of the conventional and proposed amplifiers. The measured gain, the maximum return loss and 1 dB compression point (P1dB) of the conventional amplifier are 13.03 ± 0.1 dB, –23 dB and 35 dBm, while those of the proposed amplifier are 13.38 ± 0.07 dB, –17.75 dB and 34 dBm, respectively. These characteristics show similar electrical characteristics in operating band except for P1dB. Because the impedance tuners were fabricated on PCB, the matching networks of the proposed amplifier were much bigger than the conventional. Therefore, if the impedance tuner could be fabricated on a high Q and high dielectric constant material, the P1dB of the proposed amplifier would be similar with that of the conventional one. ***Figure 6*** shows the fundamental, the second and third harmonic characteristics for the two amplifiers. For the conventional amplifier, the second and third harmonics are 36.40 and 36.26 dB below the fundamental, while for the proposed amplifier they are 61.58 and 63.50 dB, respectively. It is evident that the second and third harmonic component levels in the proposed amplifier are much smaller than those of the conventional amplifier. This means that the proposed bias line and the proposed impedance tuner terminate the harmonic components properly.



▲ *Fig. 4 Layout of the harmonic blocking λ/4 bias line (a), its low frequency band transfer characteristics (b) and its wide frequency band transfer and reflection characteristics (c).*



▲ *Fig. 5 Transfer and reflection characteristics of (a) the conventional and (b) the proposed amplifier.*



▲ *Fig. 6 Measured harmonic characteristics of the fabricted amplifiers; (a) conventional and (b) proposed.*

CONCLUSION

In this article, a new harmonic termination impedance tuner using asymmetric DGS microstrips and a harmonic blocking λ/4 bias line are presented. These circuits suppress the harmonic components without affecting the electrical characteristics within the operating frequency band. By applying these circuits, a harmonic load-pull amplifier design can be easily performed. Since the fabricated harmonic termination impedance tuner was made with microstrip lines, its size is larger and its insertion loss higher. Consequently, the proposed amplifier has a smaller P1dB, compared with a conventional amplifier. If it was fabricated with low loss transmission lines, it would be possible to use it in a practical load-pull system. It is expected that the impedance tuner and bias line can be used in other microwave circuits. ■

References

1. R.B. Stancliff and D.D. Poulin, "Harmonic Load-pull," *1979 IEEE International Microwave Symposium Digest*, pp. 185–187.
2. J. Benedikt, R. Gaddi, P.J. Tasker and M. Goss, "High Power Time-domain Measurement System with Active Harmonic Load-pull for High Efficiency Base Station Amplifier Design," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 48, No. 12, December 2000, pp. 2617–2624.
3. Y.C. Jeong, "A Design of Predistortion Linearizer Controlling the Individual Order of Intermodulation," Sogang University Dissertation, 1996.
4. C.S. Kim, J.S. Park, D. Ahn and J.B. Lim, "A Novel 1-D Periodic Defected Ground Structure for Planar Circuits," *IEEE Microwave and Guided Wave Letters*, Vol. 10, April 2000, pp. 131–133.
5. J.S. Lim, C.S. Kim, J.S. Park, D. Ahn and S. Nam, "Design of 10 dB 90° Branch Line Coupler Using Microstrip Line with Defected Ground Structure," *Electronics Letters*, Vol. 36, No. 21, October 2000, pp. 1784–1785.
6. D. Ahn, J.S. Park, C.S. Kim, J. Kim, Y. Qian and T. Itoh, "A Design of the Low Pass Filter Using the Novel Microstrip Defected Ground Structure," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 49, No. 1, January 2001, pp. 86–93.
7. J.S. Lim, C.S. Kim, D. Ahn, Y.C. Jeong and S.W. Nam, "Design of Low Pass Filters Using Defected Ground Structure," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 8, August 2005, pp. 2539–2545.
8. Y.C. Jeong, S.G. Jeong, J.S. Lim and S.W. Nam, "A New Method to Suppress Harmonics Using λ/4 Bias Line Combined by Defected Ground Structure in Power Amplifier," *IEEE Microwave and Wireless Component Letters*, Vol. 13, No. 12, December 2003, pp. 538–540.
9. D. Woo and T. Lee, "Suppression of Harmonics in Wilkinson Power Divider by Using Asymmetric Spiral DGS," *2004 European Microwave Conference Proceedings*, Vol. 1, pp. 467–470.
10. K. Kimura and M. Seki, "Improvement in ADLR Asymmetry for W-CDMA InGaP/GaAs HBT Power Amplifier," *2004 European Microwave Conference Proceedings*, Vol. 1, pp. 333–336.

A 2 GHz, 0.25 μm CMOS Complementary VCO with Differentially Tuned MOS Varactors for Wireless Applications

This article describes a 2 GHz CMOS complementary voltage-controlled oscillator (VCO) with differentially tuned MOS varactors for ISM-band wireless communications applications. The VCO is fabricated using a 0.25 μm mixed-signal/RF CMOS process. This VCO, utilizing differentially tuned MOS varactors, can reduce the adverse effect of high varactor sensitivity by rejecting the common-mode noise. The measurements listed in ***Table 1*** are performed using an FR-4 PCB test fixture. The output power of the VCO is 8.2 dBm with a power consumption of 8 mA at V_{DD} = 2.5 V, excluding buffer amplifiers. The output frequency of the VCO varies from 1827 to 2136 MHz with a 309 MHz or 16 percent tuning range and its phase noise is –100.2 dBc/Hz at a 100 kHz offset.

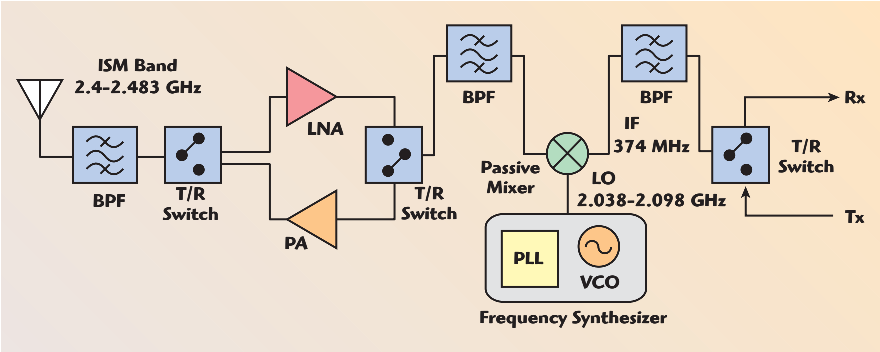
TABLE I

PERFORMANCE OF A 2 GHz CMOS COMPLEMENTARY VCO WITH DIFFERENTIALLY TUNED MOS VARACTORS

Control Voltage	–1.25 V to 1.25 V Simulation	Measurement
VCO bias current (with buffer amp) (mA)	25.7	24
Tuning range (MHz)	1899 to 2327	1827 to 2136
Phase noise @100 kHz offset (dBc/Hz)	–101.7	–100.2
Output power (dBm)	9.2	8.2
Pushing figure (±0.2 V) (MHz)	–	9
FOM (dBc/Hz)		–177
Die size (mm)	1.03 × 0.98	

For a mixed-signal and system on a chip (SoC) design, it is very important to reduce the effect of the common-mode noise coupled through the substrate. In general, differential circuits are preferred, in a single chip radio, to minimize the effects of common-mode noise from other circuits such as digital and analog baseband blocks. For the same reason, LC tank, voltage-controlled oscillators (LC-VCO) of inherent differential structures have been widely used to design a VCO with a low phase

H.T. Lin, Y.K. Chu and H.R. Chuang
National Cheng Kung University
Tainan, Taiwan, ROC

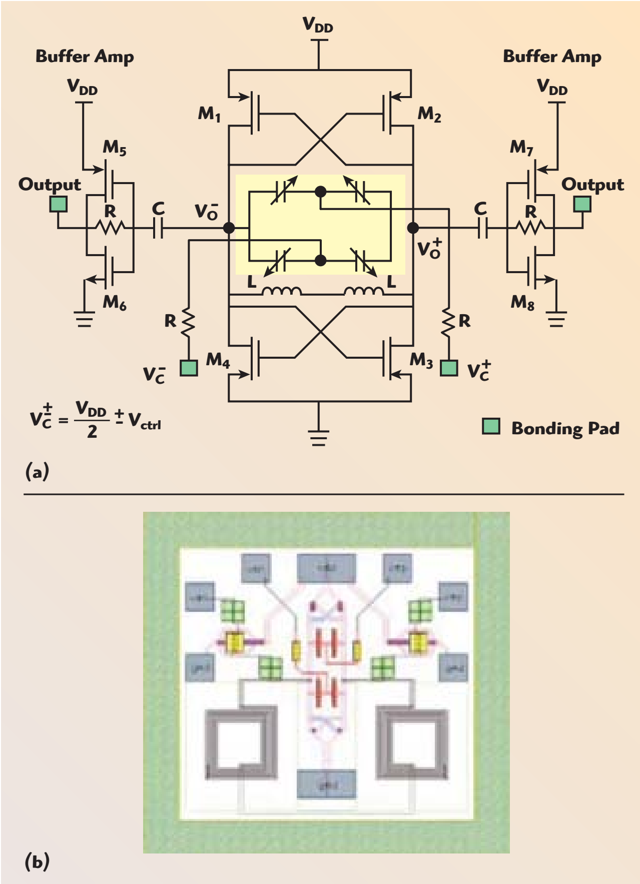


▲ *Fig. 1 Architecture of a 2.4 GHz CMOS single-mixer RF transceiver.*

noise. However, though the LC-VCO circuit has differential outputs, it does not have a differential control input. If the noise signals are coupled to the control input signal, the phase noise or jitter will be significantly degraded by the AM-to-PM conversion process. Therefore, a fully differential LC-VCO must not only have differential outputs, but also differential control voltage inputs. Its implementation is an important issue. As feature sizes are scaled down to deep sub-micrometer in modern CMOS process technology, a very thin gate oxide is required to maintain short-channel effects at an acceptable level. This leads to a low breakdown voltage of the device and, therefore, the supply voltage has to decrease proportionally. The lowering of the supply voltage, due to technology scaling, decreases the frequency tuning range. For example, the supply voltage drops from 3.3 to 2.5 V for a change in technology from 0.35 to 0.25 µm. The range of the varactor control voltage decreases accordingly, resulting in reduced frequency tuning range if the varactor gain remains the same. Therefore, for low voltage CMOS, a higher sensitivity varactor is required for the VCO to achieve a respectable performance. However, high varactor sensitivity is unfavorable to phase noise performance, as described by the modified Leeson's formula.[1] A band-switching topology can be employed to reduce the effect of varactor sensitivity while maintaining the required frequency tuning range,[2] but extra control circuitry is required for switching the varactors, which complicates the phase-locked loop (PLL) locking procedure. This article presents another method: differential tuning of the MOS varactors[3] to avoid the drawbacks of the effect of high sensitivity.

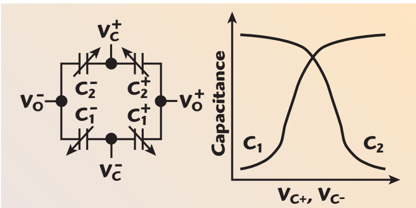
CIRCUIT DESIGN

Figure 1 shows a 2.4 GHz CMOS transceiver RF front-end, which uses a single mixer transceiver architecture for ISM-band wireless applications. A 2 GHz VCO designed for this CMOS transceiver is shown in ***Figure 2***. The VCO is fabricated with a 0.25 µm mixed-signal/RF CMOS process. The core circuit of the 2 GHz VCO is a complementary cross-coupled pair with both PMOS and NMOS, which generate a negative resistance to compensate for the losses in the LC resonator. There are several reasons for the advantage of the complementary structure used as the core circuit of the VCO. The complementary structure offers a higher transconductance for a given current, which results in faster switching of the cross-coupled differential pair. It also offers better rise- and fall-time symmetry, which results in less up-conversion of 1/f noise and other low frequency noise sources.[4] For the devices used in this oscillator, a minimum channel length of 0.25 µm is used and the appropriate channel widths are chosen to make the transconductance of NMOS equal to the transconductance of PMOS. Therefore, the DC level of the drain nodes in the complementary cross-coupled pair can be maintained as $V_{DD}/2$ in order to achieve a more symmetric waveform. The voltage source of M1, M2, M3 and M4 is directly connected to 0 V and V_{DD} (2.5 V), respectively, without any extra current source. For low supply voltage operation, enlarging the voltage swing by removing the use of a current source, which reduces the voltage headroom, is one of the most direct ways to improve the phase noise performance. This bias scheme maximizes the oscillator signal peak-to-



▲ *Fig. 2 Schematic (a) and RFIC layout (b) of a 2 GHz CMOS differentially tuned VCO.*

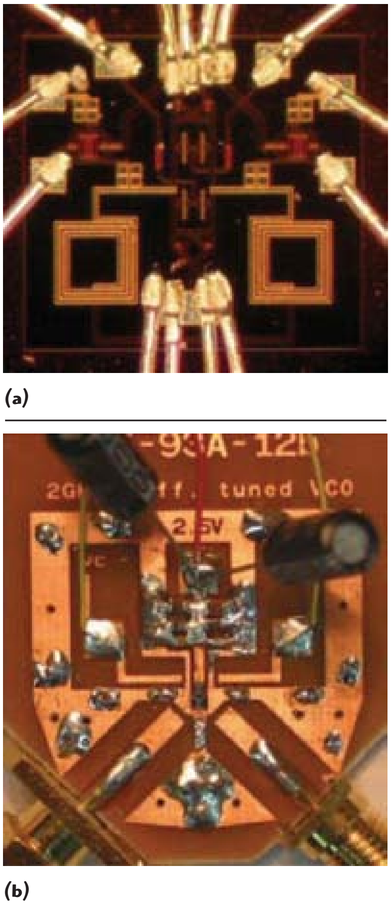
peak amplitude. The series combination of the two on-chip inductors constitutes the tank inductor. Because the layout of the inductor is asymmetric, two inductors in series, placed in a vertically symmetric way, ensure that the same structure could be seen by the drain nodes of the cross-coupled pair. This will result in a more symmetric waveform between the two drain nodes. In this design, one side of the MOS varactor is connected directly to the drain node of the cross-coupled pair, whose DC level is $V_{DD}/2$, and the other is connected to the positive (Vc^+) or negative (Vc^-) control voltage. The arrangement scheme of the MOS varactors is shown in ***Figure 3***. The equivalent capacitance between Vo+ and Vo– is determined by the differential control voltage $Vc = (Vc^+ – Vc^-)$ and is irrelevant to the common-mode voltage of VC.[2] Therefore, all common-mode noise can be rejected. In order to drive 50 Ω test systems such as a spectrum analyzer, an inverter-type buffer amplifier is used at each output. The effect of the buffer amplifiers on the phase noise can be reduced by careful design.



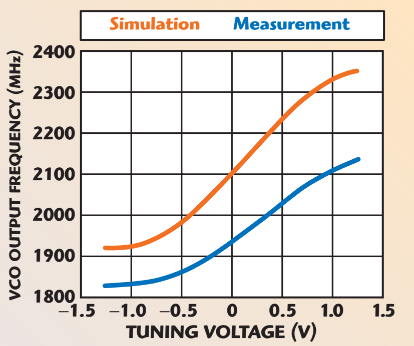
▲ *Fig. 3 The scheme and C-V curve of the differentially tuned MOS varactor.* [2]

MEASURED RESULTS

The VCO measurements were performed using an FR-4 PCB test fixture. ***Figure 4*** shows the chip micrograph and a photograph of the FR-4 PCB test fixture. The VCO chip is connected to the test board with aluminum bond-wires. The effects of the bond-wires and the FR-4 test board were all taken into account in the simulation. The bond-wires and the FR-4 test board do not affect the oscillation frequency and phase noise performance; they only reduce the output signal amplitude. The VCO core and each buffer amplifier dissipate 8 and 16 mA, respectively, from a 2.5 V supply. The measured oscillation frequency of the VCO varies from 1827 to 2136 MHz when the differential control voltage varies from –1.25 to +1.25 V. The simulated and measured tuning ranges are shown in ***Figure 5***. ***Figure 6*** shows the simulated and measured VCO output power versus control voltage. The measured output power is approximately 8.2 dBm. ***Figure 7*** shows a log plot of output phase noise measured with an Agilent E4440A spectrum analyzer with a phase noise utility program. The phase noise is approximately –100.2 dBc/Hz at 100 kHz offset from the

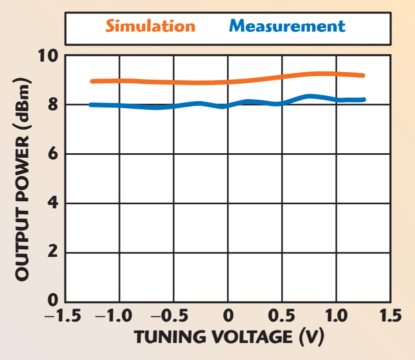


▲ *Fig. 4 Chip micrograph (a) and photograph of the VCO on an FR-4 PCB test fixture (b).*

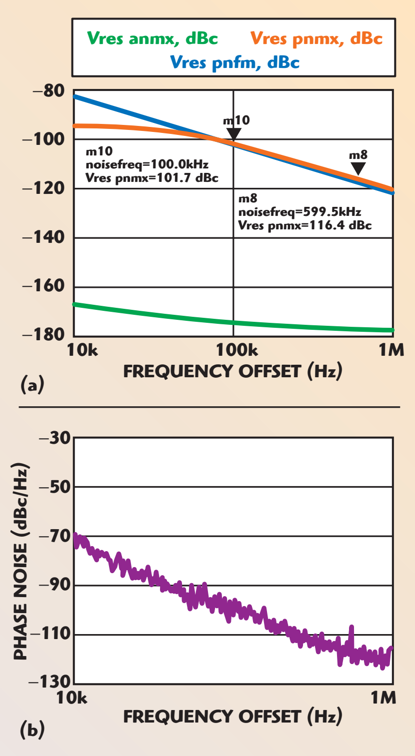


▲ *Fig. 5 Simulation and measurement of the VCO output frequency versus control voltage.*

carrier. The phase noise measurement was performed at the output frequency of 2050 MHz, where the VCO has the highest K_{vco} (~180 MHz/V) within the tuning range, which is for the worst case. ***Figure 8*** shows the measured VCO output spectrum. The power level difference between the fundamental and second harmonic is approximately –36 dBc. ***Figure 9*** shows the measured push-



▲ *Fig. 6 Simulation and measurement of the VCO output power versus control voltage.*



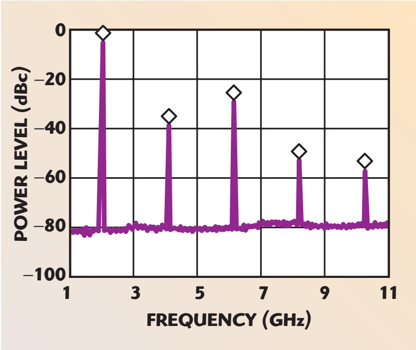
▲ *Fig. 7 Simulation (a) and measurement (b) of the VCO phase noise at $F_{carrier}$ = 2050 MHz.*

ing figure, which is 9 MHz for a 0.2 V change in V_{DD}. The figure of merit (FOM) of the VCO can be calculated from[5]

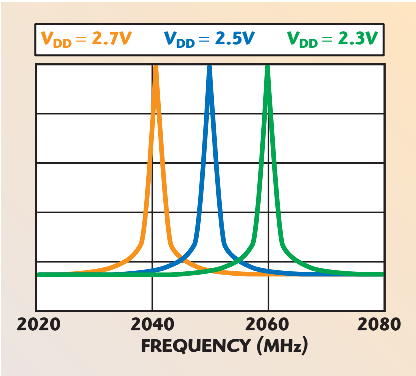
$$\text{FOM} = L(\Delta\omega) - 20\log\left[\left(\frac{\omega_0}{\Delta\omega}\right)\left(\frac{FTR}{10}\right)\right] + 10\log\left(\frac{P_{diss}}{1\text{mW}}\right)(\text{dBc/Hz}) \qquad (1)$$

CONCLUSION

A 2 GHz CMOS complementary VCO, with differentially tuned MOS varactors fabricated with a TSMC



▲ *Fig. 8 Measurement of the VCO output spectrum.*



▲ *Fig. 9 Measurement of the pushing figure.*

0.25 µm CMOS process, is presented. The VCO has demonstrated that differentially tuned varactors can provide a wide tuning range and reject the common-mode noise. The chip die size is 1.03×0.98 mm^2, including the pads. The measurements were performed using an FR-4 PCB test fixture. The tuning range is 1827 to 2136 MHz, which is approximately 16 percent, with the control voltage varying from –1.25 to +1.25 V. The VCO output power is approximately 8.2 dBm while the second harmonic level is approximately –36 dBc below the fundamental. The phase noise is -100.2 dBc/Hz at a 100 kHz offset. The phase noise measurement was performed at 2050 MHz, where the VCO has the highest K_{vco} (~180 MHz/V) within the tuning range. Therefore, the phase noise is measured for the worst case. The pushing figure is 9 MHz per 0.2 V change in V_{DD}. The power consumption is about 20 mW (without buffer) at V_{DD} = 2.5 V. ■

ACKNOWLEDGMENT

The authors would like to thank the Chip Implementation Center of the National Science Council, Taiwan, ROC, for its support of the TSMC CMOS process.

References

1. J. Rogers, J. Macedo and C. Plett, "The Effect of Varactor Nonlinearity on Phase Noise of Completely Integrated VCOs," *IEEE Journal of Solid-State Circuits*, Vol. 35, September 2001, pp. 1360–1367.
2. N. Fong, J.O. Plouchart, N. Zamdmer, D. Liu, L. Wagner, C. Plett and N.G. Tarr, "A Low Voltage Multi-GHz VCO with 58 Percent Tuning Range in SOI CMOS," *IEEE Custom Integrated Circuit Conference Digest*, May 2002, pp. 423–426.
3. N.H.W. Fong, J.O. Plouchart, N. Zamdmer, D. Liu, L.F. Wagner, C. Plett and N.G. Tarr, "A 1 V 3.8 to 5.7 GHz Wideband VCO with Differentially Tuned Accumulation MOS Varactors for Common-mode Noise Rejection in CMOS SOI Technology," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, No. 8, August 2003, pp. 1952–1959.
4. A. Hajimiri and T.H. Lee, "Design Issues in CMOS Differential LC Oscillators," *IEEE Journal of Solid-State Circuits*, Vol. 34, No. 5, May 1999, pp. 717–724.
5. T.J. Cho, S.Y. Oh, S.W Yoon, J. Laskar and R. Tummala, "Design of CMOS Voltage-controlled Oscillators using Package Inductor," *IEEE Electronic Components and Technology Conference Digest*, Vol. 2, June 2004, pp. 1682–1686.
6. C.C. Ho, C.W. Kuo, C.C. Chih Hsia and Y.J. Chan, "A 2.4 GHz Low Phase Noise VCO Fabricated by 0.18 µm PMOS Technologies," *IEEE International Symposium on VLSI Technology Digest*, October 2003, pp. 144–146.
7. A.M. Thiebout, "Low Power Low Phase Noise Differentially Tuned Quadrature VCO Design in Standard CMOS," *IEEE Journal of Solid-State Circuits*, Vol. 36, No. 7, July 2001, pp. 1018–1024.

Yuan-Kai Chu *received his MSEE degree from National Cheng Kung University, Tainan, Taiwan, in 2002, where he worked on 5 GHz CMOS RFICs for his master studies. He is currently with the HiMAX Opto-electronics Corp. as an R&D engineer. His research interests include RFIC/MMIC design for wireless communication systems.*

Huey-Ru Chuang *received his BSEE and MSEE degrees from National Taiwan University, Taipei, Taiwan, in 1977 and 1980, respectively, and his PhD degree in electrical engineering from Michigan State University, East Lansing, MI, in 1987. From 1987 to 1988, he was a post-doctoral research associate at the Engineering Research Center, Michigan State University. From 1988 to 1990, he was with the Portable Communication Division of Motorola Inc., Ft. Lauderdale, FL. He joined the department of electrical engineering at National Cheng Kung University, Tainan, Taiwan, in 1991, where he is currently a professor. His research interests include antenna and RFIC/microwave circuit design for wireless communications, computational electromagnetics and applications, EMI/EMC, microwave communication and detection systems.*

DESIGN OF A WIDEBAND ADAPTIVE LINEAR AMPLIFIER WITH A DSB PILOT AND COMPLEX COHERENT DETECTION METHOD

In this article, a novel adaptive linearization method, based on a double sideband (DSB) pilot in a feedforward power amplifier, is presented. The methods of generation and detection of the DSB pilot signal are described in detail. With this method, an ultra-linear, wideband adaptive feedforward amplifier for a WCDMA base station is successfully designed. The test results show that a greater than 25 dB improvement can be obtained for the IMD3 of the power amplifier and, correspondingly, a greater than 15 dB amelioration in ACPR is observed.

In third generation (3G) mobile communication systems, linear amplification is required for linear modulations. Nonlinear amplification yields inter-modulation distortion (IMD) products and results in unacceptable spectral regrowth in adjacent channels. To achieve linear amplification, linearization techniques are usually employed. Various techniques have been developed to reduce IMD products in high power amplifiers. Generally, three main linearization methods are used. They are the feedforward method, the feedback method and the predistortion method. Adaptive techniques are usually employed to improve the linearization performance.

ADAPTIVE FEEDFORWARD METHOD WITH DSB PILOT

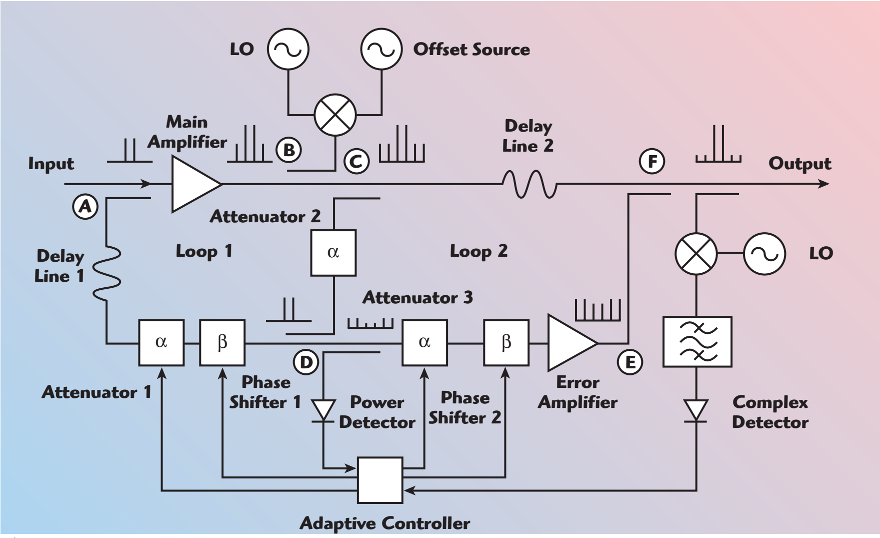
The feedforward method is a commonly used approach, which provides a significant improvement in the linearity of power amplifiers.[1–5] The mechanism used in a feedforward amplifier is to cancel the inter-modulation products produced by the main amplifier. The diagram of the feedforward amplifier with a DSB pilot is shown in ***Figure 1***. The purpose of the DSB pilot is to obtain a better adaptive cancellation.

A feedforward amplifier consists of two loops. The first one, Loop 1, is the carrier cancellation loop that is used to cancel the carriers and obtain the IMD products of the main amplifier (denoted as error signal). The second loop, Loop 2, is the IMD cancellation loop, which is used to reduce the output IMD products with the error

JIANYI ZHOU, LEI ZHANG, WEI HONG, JIANING ZHAO AND XIAOWEI ZHU
Southeast University
Nanjing, China

signal. For simplicity, assume that the amplifier is injected with a two-tone signal, as shown at node A. The output of the main amplifier will contain the IMD products in addition to the main amplified signals, as shown at node B. The DSB pilot signal is injected at the output of the main amplifier, as shown at node C. In Loop 1, an error signal that contains the IMD products generated in the PA and the DSB pilot signal is obtained, as shown at node D. This error signal is the result of the comparison of a sample of the PA output signal, appropriately attenuated, with a properly retarded sample of the input signal. This combination is usually carried out in a 180° combiner. In Loop 2, the error signal obtained in the previous circuit is appropriately amplified (as shown at node E) and injected in opposite-phase to the output in order to cancel the IMD introduced by the PA and the pilot signal, as shown at node F. Delay lines should be used in both loops for wideband operation. The amount of correction is limited by the ability of the two loops to match the gain and phase between the main signal and error path. In Loop 1, the main path consists of the main amplifier and Attenuator 2, while the error path consists of the Delay Line 1, Attenuator 1 and Phase Shifter 1. In Loop 2, the main path consists of the Delay Line 2, while the error path consists of the Delay Line 1, Attenuator 3, Phase Shifter 2 and the Error Amplifier.

The cancellation is very sensitive to the operating condition of the power amplifier, such as operating temperature, operating frequency and the power level of the input signal. Therefore, adaptive techniques are required in feedforward amplifiers. The purpose of the adaptive method is to achieve the best cancellation in both loops. The cri-



▲ *Fig. 1 Block diagram of a feedforward amplifier.*

terions for the optimal cancellation in the two loops are different. The purpose of the first loop is to cancel the main signal. As a result, the optimal cancellation of the first loop can be achieved by minimizing its output power. In the second loop, the situation is more complicated because it is very difficult to obtain an accurate power level of the distortion signals. Therefore, a pilot signal is generally injected at the output of the main amplifier to facilitate the adaptive cancellation of the second loop. With a pilot signal, the optimal cancellation of the second loop can be approximately achieved by minimizing the cancelled pilot signal power. The amount of correction of a feedforward amplifier is limited by the mismatch of the gain and phase between the main signal and the error signal. When only a small amount of gain and phase error is achieved, the correction is determined by[1–3]

$$\Delta IMD = -10\log \left|1 + 10^{\Delta G/10} - 2 \bullet 10^{\Delta G/20}\cos(\Delta\phi)\right| \quad (1)$$

where

ΔIMD = amount of IMD improvement in dB
ΔG = amplitude error between the main path and error path
$\Delta\phi$ = phase error between the main path and error path

Much research has been done on the analysis of the mismatches that affect the performance of feedforward amplifiers. This article focuses on the analysis of the second loop with a DSB pilot. It is known that the bandwidth of cancellation is mainly limited by the mismatch of the group delay, and the optimization of the phase error is more difficult than that of the amplitude error. To simplify the analysis, only the phase error and the group delay are considered, and the gain of the two paths is assumed to be perfectly matched. The selection of the pilot is very important for the feedforward amplifier. The chosen frequency of the pilot should be outside the operating frequency band so that it can be detected accurately without difficulties. Assuming that the center frequency of the amplifier is ω_0, the pilot signals are located at $\omega_0 - \Delta\omega$ and $\omega_0 + \Delta\omega$, where $\Delta\omega$ is the frequency of the offset source. The voltage of the output pilot signal after cancellation is

$$\begin{aligned} V = {} & A\cos\left[(\omega_0 - \Delta\omega)t\right] - \\ & A\cos\left[(\omega_0 - \Delta\omega)t + \Delta\phi + (\omega_0 - \Delta\omega)\Delta t\right] \\ & + A\cos\left[(\omega_0 + \Delta\omega)t\right] - \\ & A\cos\left[(\omega_0 + \Delta\omega)t + \Delta\phi + (\omega_0 + \Delta\omega)\Delta t\right] \end{aligned} \quad (2)$$

where

A = amplitude of the pilot in both the main path and the error path
Δt = delay error between the main and error paths
$\Delta\phi$ = phase error between the main and error paths

The total pilot signal power, after cancellation, is

$$P = A^2 \sin^2\left[\frac{\Delta\phi + (\omega_0 - \Delta\omega)\Delta t}{2}\right] + A^2 \sin^2\left[\frac{\Delta\phi + (\omega_0 + \Delta\omega)\Delta t}{2}\right] \quad (3)$$

For simplification, let $\Phi = \Delta\phi + \omega_0\Delta t$ and $\Phi_0 = \Delta\omega\Delta t$; Equation 3 can then be rewritten as

$$P = A^2 \sin^2\left[\frac{\Phi_0 - \Phi}{2}\right] + A^2 \sin^2\left[\frac{\Phi_0 + \Phi}{2}\right] \quad (4)$$

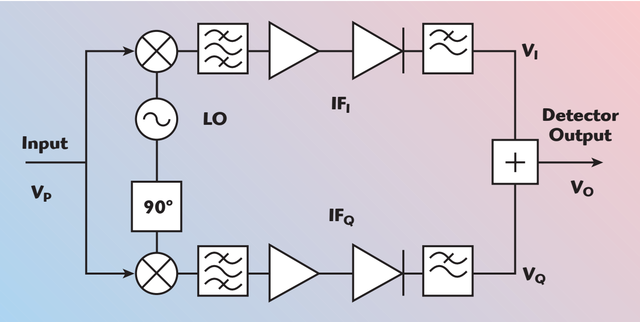
After calculating the derivative

$$\frac{dP}{d\Phi}$$

and let it equal to zero, the solution is

$$\sin(\Phi_0 - \Phi) - \sin(\Phi_0 + \Phi) = 0$$

For a wideband, feedforward amplifier, the delay error Δt should be as small as possible, generally less than 1 ns, and $\Delta\omega$ is approximately several tens of megahertz. The value of Φ_0 is very small, normally approximately several degrees. Thus, the total power of the pilot signal is minimal when $\Phi = 0$. For a feedforward amplifier, the best cancellation performance is generally obtained when $\Phi = 0$. Therefore, when the power of the cancelled pilot is minimized, it means that the optimal cancellation of the second loop is obtained. It is very clear that the DSB pilot method is more accurate and efficient for wideband linearization than the single sideband (SSB) pilot method.

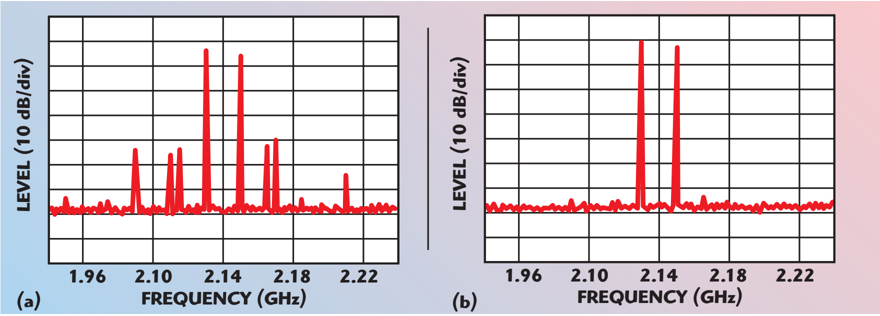


▲ *Fig. 2 Complex detection of the DSB pilot signal.*

GENERATION AND DETECTION OF THE DSB PILOT SIGNAL

The generation of the DSB pilot signal can be accomplished with a high carrier-suppression analog modulator. Here, the detection of the DSB pilot signal is accomplished with a complex coherent method, as shown in ***Figure 2***. The LO of the mixer is the same as that of the modulator; therefore, there is no frequency error in this system. The advantage of the complex detection method is that it can accurately determine the power of the DSB pilot signal by eliminating the phase error in the system. The pilot signal input to the detector can be written as

$$V_P = A_1 \cos[(\omega_0 - \Delta\omega)t + \Phi_1] + A_2 \cos[(\omega_0 + \Delta\omega)t + \Phi_2] \quad (5)$$



▲ *Fig. 3 IMD performance of the amplifier (a) before linearization and (b) after linearization.*

where

A_1, Φ_1 = amplitude and phase of the low sideband pilot signal

A_2, Φ_2 = amplitude and phase of the high sideband pilot signal

The LO for the mixers is $V_{LO} = \cos\omega_0 t$.

The IF output signals of the mixers are

$$IF_I = G_1\left[A_1\cos\left(\Delta\omega t - \Phi_1\right) + A_2\cos\left(\Delta\omega t + \Phi_2\right)\right] \quad (6)$$

$$IF_Q = G_1\left[A_1\sin\left(\Delta\omega t - \Phi_1\right) - A_2\sin\left(\Delta\omega t + \Phi_2\right)\right] \quad (7)$$

where

G_1 = cascaded gain of mixers, IF filters and IF amplifiers

The output voltages of the square-law detectors after the low pass filters are

$$V_I = G_1G_2\left[\frac{A_1^2}{2} + A_1A_2\cos\frac{\Phi_1+\Phi_2}{2} + \frac{A_2^2}{2}\right] \quad (8)$$

$$V_Q = G_1G_2\left[\frac{A_1^2}{2} - A_1A_2\cos\frac{\Phi_1+\Phi_2}{2} + \frac{A_2^2}{2}\right] \quad (9)$$

where

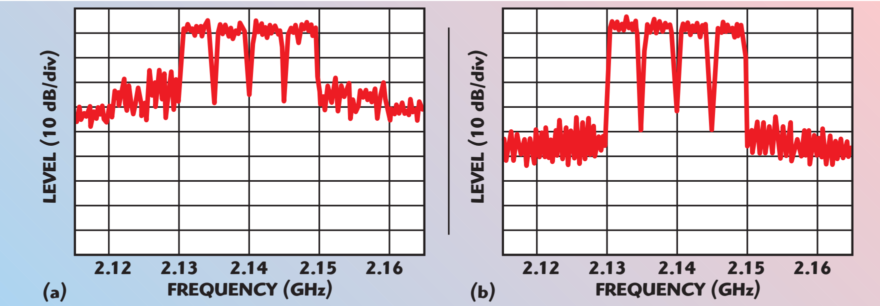
G_2 = conversion gain of the detectors

The output voltage of the complex detector is

$$V_o = G_1G_2\left[A_1^2 + A_2^2\right] \quad (10)$$

It is obvious that the output voltage is proportional to the total power of the DSB pilot signal and is independent to the phase difference between the pilot and the LO signals. Therefore, the total power of the DSB pilot signal is accurately detected by the complex detector. The output voltage of a simple detector, however, is dependent to the phase of the pilot, as shown in Equations 8 or 9. The advantage of the complex detection is very clear for the DSB pilot.

The adaptive controller is used to minimize the voltage of the power detector and the complex detector by adjusting the Attenuator 1 and Phase Shifter 1 in the first loop, and Attenu-



▲ *Fig. 4 ACPR performance of the amplifier (a) before linearization and (b) after linearization.*

ator 3 and Phase Shifter 2 in the second loop. As stated above, optimal cancellation is obtained when these voltages are minimized.

EXPERIMENTAL RESULTS

An adaptive feedforward amplifier was designed and fabricated for use in the WCDMA band. The output power of the amplifier is 10 W. ***Figure 3*** gives the two-tone IMD results of the power amplifier. The spacing between the two-tone input frequencies is 20 MHz. The original IMD3, before linearization, is approximately –35 dB. After linearization, the levels of the IMD components are less than –62 dB. The improvement in IMD performance is better than 27 dB. ***Figure 4*** gives the multi-carrier adjacent channel power ratio (ACPR) results for the power amplifier. The input of the amplifier is a four-carrier WCDMA downlink signal with 64 dedicated physical channels (DPCH) in each carrier. The multi-carrier ACPR performance before and after linearization is shown. The improvement in ACPR is better than 15 dB.

CONCLUSION

A wideband adaptive feedforward amplifier with high linearity is designed for a WCDMA base station using the DSB pilot method. The theoretical analysis and experimental results show that the DSB pilot method and the complex detection method are valid and effective for feedforward linearization. ■

References

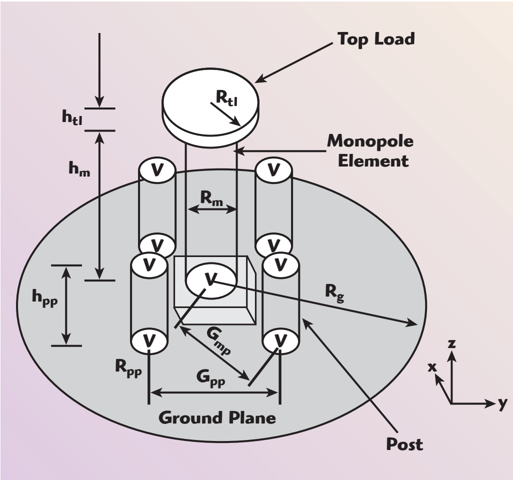
1. J.K. Cavers, "Adaptation Behavior of a feedforward Amplifier Linearizer," *IEEE Transactions on Vehicular Technology*, Vol. 44, No. 1, February 1995, pp. 31–40.
2. Y.K.G. Hau, V. Postoyalko and J.R. Richardson, "Sensitivity of Distortion Cancellation in feedforward Amplifiers to Loops Imbalances," *IEEE MTT-S 1997 International Microwave Symposium Digest*, Vol. III, June 1997, pp. 1695–1698.
3. S.G. Kang, I.K. Lee and K.S. Yoo, "Analysis and Design of feedforward Power Amplifiers," *IEEE MTT-S 1997 International Microwave Symposium Digest*, Vol. III, pp. 1519–1522.
4. J. Zhou, L. Feng, X. Zhu and W. Hong, "Design of an Ultra-linear Wideband feedforward Amplifier Using EDA Tools," *Microwave Journal*, Vol. 43, No. 1, January 2000, pp. 124-130.
5. M.G. Choi, Y.C. Jeong and I.H. Park, "*Method and Apparatus for Amplifying feedforward Linear Power Using Pilot Tone Hopping*," US Patent No. 081,156, 2000.

A Low Profile, Top-loaded Monopole Antenna with Four Small Posts

This article describes a low profile, wideband, top-loaded monopole antenna with four small posts. A post-type monopole is used to enhance the impedance matching. This provides a low radiation resistance within the usable band. Four small posts lead to a higher antenna gain and better omni-directional patterns. In addition, the top loading also permits the antenna height to be reduced (small antenna size). A bandwidth of 54.5 percent (1.62 to 2.82 GHz) was experimentally obtained for a VSWR less than 2:1. This antenna also offers a high gain characteristic. The proposed antenna can be applied to PCS, DCS, IMT-2000 and WLL.

Monopole antennas are used in mobile communications. A monopole antenna is a very simple and efficient radiating element.[1] The simple whip and monopole antenna are attractive for use in mobile handsets and repeater applications because of their omni-directional characteristics, simple structure and the inherent 2:1 size reduction over equivalent dipole designs.[2] However, these antennas suffer from a limited bandwidth and distorted radiation characteristics. In the coming generation of mobile communications, multimedia services will be provided by a mobile handset, which must therefore be equipped with a broadband antenna. The use of a single wideband antenna that covers a wide range of frequencies is very desirable for spectrum monitoring. It is well known that the smaller the size of the antenna, the lower the antenna efficiency and the narrower the bandwidth (a few percent).[3] A broadband sleeve monopole with an operational bandwidth of approximately 24 percent was investigated.[4] A bandwidth enhancement (36 percent) for a monopole antenna, using a parasitic normal-mode helix, was reported.[5] A planar monopole antenna with an operational bandwidth of 44 percent was described,[6] and a top-loaded monopole antenna was also reported.[7] This antenna had a small size, but its

Fig. 1 Antenna structure and design parameters.



YONG-WOONG JANG
Keukdong College
Chungbuk, Korea
HYUN-CHUL GO
Hankook Antenna Co. Ltd.
Gyeonggi-do, Korea
SANG-WOO LEE
Mokpo Maritime University
Jeonnam, Korea

operational frequency bandwidth was very narrow (a few percent).

In this article, a low profile, wideband, top-loaded monopole antenna with four small posts is described. It offers a low radiation resistance within the usable frequency band. The four posts also lead to better omni-directional patterns and higher gain than the conventional top-loaded monopole structures. The top loading also leads to a reduced antenna height (small antenna size). The impedance bandwidth for a VSWR less than 2:1 is adequate for DCS, PCS, IMT-2000 and WLL.

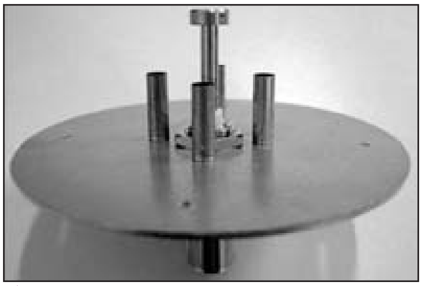
ANTENNA STRUCTURE AND EXPERIMENTAL RESULTS

The structure of the proposed low profile, wideband, top-loaded monopole antenna with a ring-shaped plate is shown in ***Figure 1***. It consists of the post-type monopole, a dielectric-layer, a top-load, four posts placed at 90° from each other, a circular ground plane and a 50 Ω, N-type connector. R_m is the radius of the monopole, h_m is the height of the monopole, h_{tl} is the height of the top-loading piece, h_{pp} is the height of the posts, R_{tl} and R_{pp} are the radii of the top-loading piece and the posts, respectively, and R_g is the radius of the circular ground plane (reflector). The 50 Ω, N-type connector is located at the center of the z-axis to feed the proposed antenna. A rectangular dielectric piece, 7 × 7 × 3 mm, is placed at the bottom of the monopole. The top loading is used to reduce the height of the monopole element and to enhance the omni-directional patterns. The additional four posts also lead to a wider bandwidth and higher gain than for the conventional top-loaded monopole structures. The top loading reduces the high angle radiation, which leads to a decrease in multi-path fading and increases the service area.[8] A photograph of the fabricated antenna is shown in ***Figure 2***.

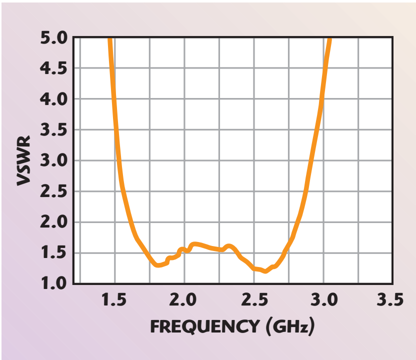
The characteristics of the antenna depend highly on the design parameters:

R_m = the radius of the monopole element.

H_m = the height of the monopole element.



▲ *Fig. 2 The fabricated antenna.*

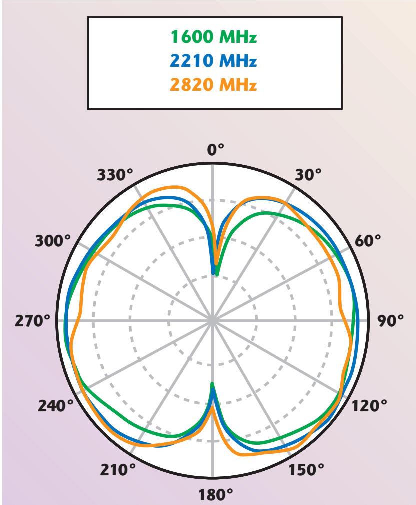


▲ *Fig. 3 Measured antenna VSWR.*

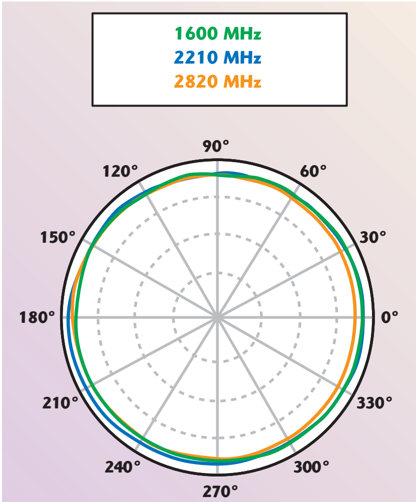
H_{tl} = the height of the top-loading piece.
H_{pp} = the height of the posts.
R_{tl} = the radius of the top-loading piece.
R_{pp} = the radius of the posts.
R_g = the radius of the ground plane (reflector).
G_{mp} = the gap between the monopole and the posts.
G_{pp} = the gap between posts.

The fabricated antenna dimensions are: R_{tl} = 5.5 mm, h_{tl} = 2.8 mm, R_m = 3 mm, h_m = 28 mm, R_{pp} = 3 mm, h_{pp} = 17 mm, R_g = 55 mm, G_{mp} = 15 mm and G_{pp} = 22 mm. The post-type monopole is used to enhance the impedance matching. In this study, the circular ground plane is made of aluminum, 1.0 mm thick, and the post-type monopole is also made of aluminum with a 3 mm radius.

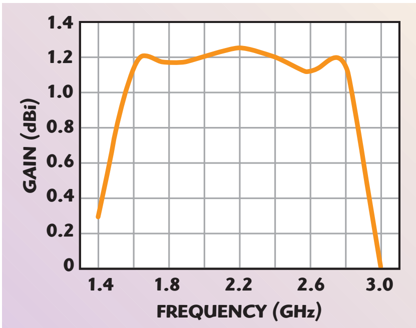
The measured VSWR versus frequency of the proposed antenna is shown in ***Figure 3***. The experimental impedance bandwidth is approximately 1.62 to 2.82 GHz (54.5 percent bandwidth for a center frequency of 2.2 GHz) for a VSWR less than 2:1. The aluminum weight is relative-



▲ *Fig. 4 Measured radiation patterns in the y-z plane.*



▲ *Fig. 5 Measured radiation patterns in the x-z plane.*



▲ *Fig. 6 Measured antenna gain versus frequency in the x-z plane.*

ly light and its conductivity is good. This material is not easily affected by rain or sunshine and permits a relatively low fabrication cost.

After calibration, using a horn antenna, the radiation patterns in the far field were measured. An investigation of the radiation pattern characteristic of this antenna shows them to be similar to those of a conventional monopole. In ***Figure 4***, the measured y-z plane radiation pattern of the proposed antenna is bi-conical at the center frequency f = 2.2 GHz. The x-z plane radiation pattern is omni-directional without distortions, as illustrated in ***Figure 5***.

Figure 6 shows the measured antenna gain in the x-z plane for operating frequencies across the PCS and IMT-2000 bands. The peak antenna gain is 1.2 dBi for DCS, PCS and IMT-2000 operations, but drops off rapidly past the band edges. This is due to impedance mismatch and pattern degradation, as the back radiation level increases rapidly at these frequencies.

CONCLUSION

In this article, a low profile, wideband, top-loaded monopole antenna with four small posts is described. A post-shaped monopole is used to enhance the impedance matching, which results in a low radiation resistance within the usable band. Four additional posts also lead to better omni-directional patterns and higher gain characteristics. Additionally, top loading also reduces the height of the antenna (smaller antenna size). A ring-shaped plate also leads to a wider bandwidth and higher gain than the conventional top-loaded monopole structures. The top loading reduces the high angle radiation, which leads to a decrease in the multi-path fading and to an increase in the size of the service area. An experimental bandwidth of 54.5 percent (1.62 to 2.82 GHz) was measured for a VSWR less than 2:1. This antenna provides a wide bandwidth and a high gain characteristic. The proposed antenna can be used in PCS, DCS, IMT-2000 and WLL applications. ■

References

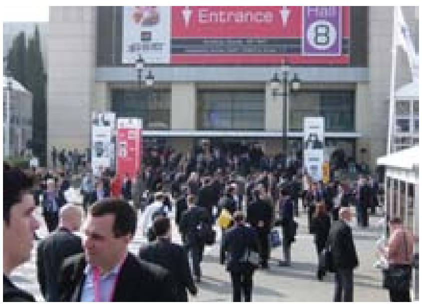
1. M. Weiner, S. Cruize, C.C. Lee and W. Wilson, *Monopole Elements on Circular Ground Plane*, Artech House Inc., Norwood, MA, 1987.
2. J. MacLean, H. Foltz and G. Crook, "Broadband, Robust, Low Profile Monopole Incorporating Dielectric Loading and a Distributed Capacitive Feed Mechanism," *1999 IEEE Antenna and Propagation Symposium Digest*, Vol. 3, pp. 1562–1565.
3. K. Fujimoto and J.R. James, *Mobile Antenna Systems Handbook*, Artech House Inc., Norwood, MA, 1994, pp. 65–70.
4. J.I. Moon, S.O. Park and K.Y. Park, "Broadband Sleeve Monopole Antenna for Dual-band PCS/IMT-2000," *Electronics Letters*, Vol. 36, 2000, pp. 1829–1830.
5. Y.W. Chow, E.K. N. Yung and H.T. Hui, "Bandwidth Enhancement of Monopole Antenna by Using a Parasitic Normal-mode Helix," *International Journal of Electronics*, Vol. 88, 2001, pp. 557–593.
6. J.A. Evans and M.J. Ammann, "Planar Monopole Design Consideration Based on TLM Estimation of Current Density," *Microwave and Optical Technology Letters*, Vol. 36, 2003, pp. 40–42.
7. H. Jiang and H. Arai, "FDTD Analysis of Low Profile Top-loaded Monopole Antenna," *IEICE Transactions on Communications*, Vol. E85-B(11), 2002, pp. 2468–2475.
8. C.A. Balanis, *Antenna Theory*, John Wiley & Sons Inc., Hoboken, NJ, 1997.

3GSM WORLD CONGRESS: MODERNISM AT ITS BEST

The 2006 3GSM World Congress could well have found a soul mate in its new home of Barcelona, where Modernisme — the movement that evoked change and development — emerged in the 19th century. Fittingly, it was that very 21st century phenomenon, communications technology that grabbed the headlines at the Fira de Barcelona conference and exhibition centre during the four-day event in February. The general consensus was that the event feted as ‘the biggest mobile show on Earth’ lived up to its billing. In fact, Barcelona’s famous artistic sons, Picasso and Gaudi are likely to have approved of a great deal of the innovation and design on display.

GOOD COMMUNICATION

Visitors may not have been readily conversant with the local Catalan and Castilian languages but communication in the common language of technological innovation was not a problem as the global mobile industry convened to network, exchange ideas and do business. The conference attracted high level keynote speakers who addressed the issues of today and tomorrow, including: the convergence of telecoms, media and entertainment; billing; the evolution of value-added services; strategies for growth in developing markets; and the evolution of 3G.



All of these themes were also reflected in the exhibition with all of the main players in the market making their presence felt with new launches and promotions. The result was record figures with a total audited attendance of 50,000 visitors (including all visitors, delegates, participants and staff) attracted to the site which provided double the floor space than in Cannes in 2005, accommodating a total of 962 companies — a 40 percent increase over last year. In today’s environment of fast technology change and increasing end-user expectations, 2006 shows all the signs of being a decisive year for new multimedia services and growing markets. This is a challenge that companies exhibiting at the 3GSM World Congress seemed more than happy to embrace and meet head on, targeting the event to make numerous product announcements.

NEW INNOVATIONS

Particularly active in the microwave and RF arena were the test and measurement, semiconductor and chipset manufacturers. Read on for a selection of the major new

RICHARD MUMFORD
Microwave Journal *European Editor*

product announcements from some of the leaders in our industry. Apologies to those companies that have not been mentioned due to space constraints.

Familiar names to *Microwave Journal* readers dominated the test and measurement sector, demonstrating their diversity as well as new products. For instance, a wealth of new products and initiatives were announced by Agilent Technologies that underline the company's commitment to the wireless communications market. Of particular interest was the announcement that the N4010A Wireless Connectivity Test Set supports the Bluetooth Enhanced Data Rate (EDR) test mode and offers new audio generation and analysis capabilities for Bluetooth audio test. Developers, integrators and manufacturers now have a single test set for ensuring devices adhere to the Bluetooth Special Interest Group's (SIG) version 1.2 and 2.0 standards. Also, to ensure adherence to the new standard, the N4010A now enables loopback testing of EDR transmitters and receivers. Six of the eight Bluetooth 2.0 EDR test cases are integrated into the test set and the remaining two can be made utilizing the N4010A and additional equipment.

Another significant introduction is the release of the GS-8800 RF, the first commercially available pre-conformance test system that supports High Speed Downlink Packet Access (HSDPA) test cases (3GPP TS 34.121). The test system enables cellular phone design engineers to perform early RF design verification to meet a wide range of development needs. In addition to HSDPA, it supports other cellular technologies, such as W-CDMA, GSM/GPRS, EGPRS, cdmaOne/CDMA2000 and 1xEV-DO.

These are just two products of note but Agilent also announced: new initiatives for WiMAX design and deployment and exhibited an extensive WiMAX product portfolio; a new IP UMTS Terrestrial Radio Access Network (IP UTRAN) signaling analyzer; the first commercially available base station test system compliant with the latest Common Public Radio Interface (CPRI) standards; new lab application features for the 8960 Wireless Test Set that provide real-life network emulation for GSM/GPRS and W-CDMA/HSDPA; a new Wireless Quality of Service Management solution; and collaboration with Freescale Semiconductor to create a test solution that can be used to efficiently test chipset platforms to the standards set by the ZigBee Alliance.

3GSM is also a major event for Rohde & Schwarz as witnessed by the plethora of new products launched and on display. The first to highlight is the expanded functionality of the R&S FSH3 handheld spectrum analyzer, with the introduction of the R&S FSH-K4 option, which adds the capability to perform code domain power measurements on 3GPP base stations. Test parameters include the overall power as well as the powers of the main code channels such as the Common Pilot Channel (CPICH), the Primary Common Control Physical Channel (P-CCPCH), the Primary Synchronization Channel (P-SCH) and the Secondary Synchronization Channel (S-SCH). The carrier frequency offset and the error vector magnitude are also measured and displayed. The option also includes an automatic level control function that allows users to quickly set the optimal reference level. For base stations equipped with two antennas, users can choose the antenna to which the spectrum analyzer is to synchronize (antenna diversity).

A second key announcement is that the company is now providing an option for Bluetooth V2.0 + EDR that complements the R&S CBT and the R&S CBT32. Fitted with the EDR option, these RF testers enable all measurements — with the exception of EDR C/I performance — to be performed without any external equipment or PCs. Significantly, with regard to EDR receiver tests, the option supports the loopback test mode in accordance with the specification. Like the basic versions, the R&S CBT and the R&S CBT32 with EDR option feature high measurement speed. Lab tasks can thus be handled quickly, reducing test times and costs in production.

Other announcements of note include: an all-in-one measurement solution for WiMAX applications — by combining the R&S SMU200A vector signal generator and R&S FSQ signal analyzer, the company offers a future-proof measurement solution for WiMAX applications; and the introduction of the R&S CMU-K72 HSDPA monitoring option to the R&S CMU300 universal radio communication tester. With this monitoring option it is possible to analyze the data flow on the high speed shared control channel (HS-SCCH), which enables the tester to simultaneously analyze four HS-SCCHs with up to 128 UEs altogether; similarly the HSDPA functionality of the R&S CMU200 mobile radio tester is enhanced when equipped with the R&S CMU-K64 software option. By using this new firmware upgrade, the tester is now able to set up a call to user equipment of classes up to 3.6 Mbit/s in the in signaling mode as well as the non-signaling mode.

Further testament to the prolific output of the test and measurement manufacturers was Anritsu Corp. who launched and showcased a variety of new products. An important announcement was that the successful MD8470A application tester now has the added functionality of UE-to-UE connectivity testing in one instrument. This 'network on the bench solution' allows the user to test the application connectivity of the UE without setting up a live call on the real network. The Couple-UE Network Simulator (CNS) software provides the necessary network simulation to realize voice call, video call and SMS/MMS exchange between two UE, including UEs from different operators.

Also, HSDPA testing capability has been added to the UMTS Master MT8220A analyzer, producing what is claimed to be the first truly portable handheld test instrument that can verify Node B transmitter performance. When equipped with this new HSDPA option, the tester can make all the measurements listed in the 3GPP specification for HSDPA base station performance testing.

Field technicians and wireless engineers can quickly check base station performance using any of the three options — RF measurement, demodulation and over the air (OTA). All key RF measurements, including band spectrum, channel spectrum, spectral emission mask and ACLR, can now be made on HSDPA signals. All standard WCDMA demodulation measurements can also be made.

And there was more as the company announced: the introduction of the MD8391A RNC Simulator, a compact, low price Node B test solution (mounted on a 19 inch rack and weighing less than 10 kg, the tester is aimed at infrastructure vendors wishing to efficiently test the Node Bs); the MS8911A DVB-T/H tester, a battery operated handheld tester for DVB-T and DVB-H analysis and the only tester in the market that performs DVB-H measurements; a WCDMA/HSDPA Modulation Quality Measurements option for the MS2781A Signature™ High Performance Signal Analyzer; and a next generation 3G SGSN Load Generator Test Tool for the market leading MD1230B Ethernet/IP test platform.

Not to be outdone, Aeroflex announced the launch of an Adaptive Multi-Rate (AMR) option for the 6113 base station tester to complement the company's existing GSM and GPRS/EDGE test capability. The AMR option extends the tester's coverage to enable testing of AMR-specific elements of the base station, in particular those parts that include AMR codecs in the signal path. Its A-bis control and decode capability allows both the transmitter and receiver paths to be fully tested. Unique receiver tests include bit error rate and frame erasure rate. Significantly, the AMR option also includes a 'live' mode that allows testing to be carried out without taking the base station out of service. Two key additional features of the 6113 AMR option include a rate adaptation test and a combined traffic/signaling channel BER test. The rate-adaptation test is not only used for checking that the base station is correctly measuring the carrier to interference ratio (C/I) but also as a tool for optimising the thresholds and hysterisis settings used to trigger rate-adaptation.

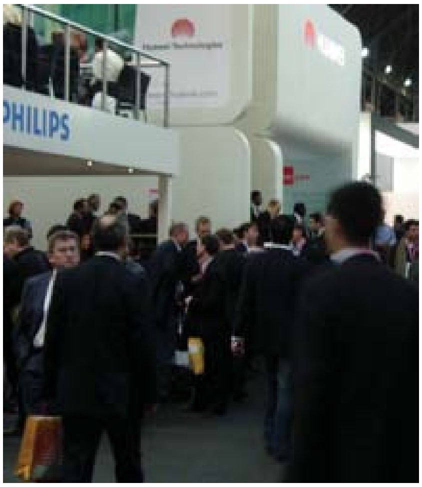
Other key announcements were the significant extension to the capability of the 6103 AIME/CT GSM, GPRS, EGPRS mobile terminal protocol test system to include the first Dual Transfer Mode (DTM) test cases, a comprehensive suite of Downlink Advanced Receiver Performance (DARP) test cases, including three that are unique to Aeroflex and the complete suite of 3GPP Release 4 and EGPRS test cases as defined by the Global Certification Forum and PTCRB; and the launch of a handset

trace capability for the SystemAT laboratory-based test system, which is used for regression testing new wireless network software and features prior to rollout and handset validation/interoperability testing as well as network load and capacity testing.

Demonstrating that the city of Barcelona had attracted the technological global village, the semiconductor and chipset manufacturers were an illustration of the international pull of the World Congress. For example, from the US, Triquint Semiconductor unveiled products that realise the promise of a truly integrated WCDMA and EDGE RF front end. First was the release of two new smaller form factor WCDMA and EDGE wireless phone receive modules designed to better meet the signal processing needs in next-generation, multi-mode slim-line (cellular) handsets that use both WCDMA and EDGE (WEDGE) networks. The new modules (numbered 890057 and 890060) are tri-band and quad-band, respectively. The 890057 covers the WCDMA-2100 band, plus the GSM 900/1800/1900 bands. The 890060 is ideal for phones requiring the WCDMA-2100 band, plus the GSM 850/900/1800/1900 bands. The modules offer a combination of WCDMA linearity (signal precision) that meets 3GPP out-of-band blocking requirements, low transmission path insertion loss — all in a small size (5.4 × 4.0 mm) with a height profile of 1.1 mm.

Important too is the release of the company's latest quad-band transmit module, the TQM6M5001 that provides full GSM/EDGE capability. It enables the higher EDGE bandwidth services sought by wireless phone users, and its high level integration allows phone designers to move from the GPRS of GSM service to full EDGE, which affords data rates up to three times faster than GPRS. The new module measures 6 × 6 × 1.1 mm.[3] This breakthrough product is an all-in-one RF transmit module with full Gaussian minimum shift keying (GMSK) and EDGE linear functionality, combining a quad-band EDGE PA, a linear transmit/receive switch, plus PA and switch control along with electrostatic discharge protection.

Other new products featured include: three new highly integrated WCDMA modules that reduce the RF front end complexity of 3G phones, each designed to provide key performance enhancements within a multi-band WCDMA handset (cellular (TQM616017), PCS (TQM666017) and IMT2100 (TQM676001)); the p/n



890047, the company's latest fully optimized WCDMA/GSM quad-band switch module for the RF front end of 3G handsets; and the TQM7M5003 quad-band GSM/EDGE-polar power amplifier module, for use in GSM/EDGE wireless handsets and data cards in the GSM 850/900/1800/1900 bands.

Compatriot company Skyworks made three major announcements. The first, one year on from launching the Helios™ Mini, the company unveiled Helios II, its next-generation EDGE radio. This highly integrated solution reduces the RF board space by condensing all required EDGE RF functionality into two compact devices. The SKY74137 RF transceiver is a highly integrated device for multi-band GSM, GPRS and EDGE applications. The receive path implements a direct down-conversion architecture, consisting of four integrated LNAs, a quadrature demodulator, selectable baseband filter bandwidths and low droop DC offset correction (DCOC) sequencer. The transceiver also implements the company's polar loop transmit architecture, autonomously splitting the amplitude and phase within the device using traditional analogue in-phase and quadrature (I/Q) signals. Secondly, the SKY77331 PA module (PAM) is designed in a compact form factor with integrated coupler for quad-band GSM, GPRS and EDGE mobile handsets. Features include high efficiency, an integrated coupler, wideband envelope control path, input/output matching and gold-plated lead-free contacts.

Next, two new ultra-compact and high efficiency EDGE front-end modules (FEM) for leading mobile handset suppliers were launched. The SKY77512 transmit FEM is designed in a compact form factor of 8 × 8 × 1.2 mm for quad-band mobile handsets supporting GMSK and linear enhanced data for EDGE modulation. The SKY77519 is a transmit and receive FEM designed in a very low profile compact form factor of 6 × 6 × 1.1 mm for quad-band WEDGE mobile handsets. It is said to be the industry's smallest module for open-polar EDGE. When combined with the company's FEMs for closed loop platforms, Skyworks supports all three EDGE architectures — closed loop, open loop and linear implementations.

Finally came the addition of a highly integrated transmit WCDMA FEM supporting HSDPA to the company's Intera™ portfolio. The SKY77427 is a fully matched, 22-pin surface-mount module that enables customers global support with band I, II and V coverage, which are anticipated to be the dominant frequency bands for 3G handsets. By integrating its next-generation, innovative load insensitive power amplifier (LIPA™), a duplexer, power detector and filters into a single 5 × 8 mm package, the company's Intera™ FEMs allow mobile handset designers to simplify RF design and reduce board space.

Not to be overshadowed by its transatlantic rivals, Philips highlighted several innovations in mobile, sound entertainment and near field communication. These included the technology foundation to power Unlicensed Mobile Access (UMA) enabled phones using the Nexperia™ cellular system solution 6120 for UMA, which will be available shortly in the US market from a major operator. The company has collaborated with Kineto Wireless (also an exhibitor at 3GSM) who provides the UMA-compliant handset software stack in the Nexperia cellular system solution. Requiring no additional setup by the consumer, UMA phones switch between cellular networks and WiFi hotspots, automatically detecting the fastest and most cost-effective network and reducing bills dramatically.

Additionally, the company displayed a single-package Bluetooth and FM Radio Solution (BGB260FM), which includes Bluetooth 2.0 + EDR functionality with an FM stereo radio and is said to deliver the smallest PCB area solution on the market today. Aimed at the designers and manufacturers of mobile phones and headsets, the product provides a simple solution offering advanced, yet cost effective, functionality.

The simplicity of near-field communication was demonstrated in an effective and novel way when Philips, together with Samsung and Telefonica Moviles, demonstrated an easy-to-use short-range wireless technology, by providing 200 attendees of the 3GSM World Congress with an NFC-enabled Samsung mobile phone that could be used for payment and access at the event. The company also showcased the next generation TV-on-mobile solution (BGT215) and debuted a new Nexperia™ cellular system solution that gives advanced 3G voice and data coverage across both 2G and 3G networks by integrating support for UMTS, EDGE and Dual Transfer Mode (DTM).

Alongside Philips in the busiest hall (Hall 8) and rubbing shoulders with the big names in the mobile phone market, RF Micro Devices decided to make some big announcements. First was the availability of the RF3159 quad-band power amplifier, specifically designed to support EDGE mobile devices utilizing linear transmit architectures. It will be available for general sampling this month, with mass production ramping in May. It is a high linearity quad-band GSM/GPRS/EDGE PA designed to support EDGE transceivers utilizing a linear transmit architecture. The RF3159 PA module is fully matched for easy implementation and is housed in a 6 × 6 mm package. It is designed to be the final amplification stage in a dual-mode GSM/GPRS/EDGE mobile transmit line up operating in the 824 to 915 MHz and 1710 to 1910 MHz bands.

The second significant announcement was the availability of a new high efficiency linear PA module — the RF5184. It is specifically designed to be the final RF amplifier in high performance WCDMA wireless handheld devices and is a dual-band product that supports Region 2 (1850 to 1910 MHz) and Region 5/6 (824 to 849 MHz). In conjunction with the RF5198 single-band PA for Region 1 (1920 to 1980 MHz), RFMD is positioned with RF solutions in industry-leading form factors for all three of the current WCDMA markets — Europe, the United States and Japan.

Chipping in with its latest development, Analog Devices Inc. demonstrated its first W-CDMA/EDGE (WEDGE) chipset. Based on the Blackfin® Processor and advanced analogue, mixed-signal and RF technologies, the highly integrated SoftFone® — W chipset comprises the AD6902 (Monza) digital baseband processor, AD6856 Stratos-W analogue baseband/audio/power-management IC and the AD6541/AD6547 Othello® — W radio. The chipset supports the features generally included in mid- to high-end feature phones without requiring an external co-processor. The AD6902 also includes programmable serial ports and a flexible audio subsystem, allowing handset designers to easily support additional features such as FM radio, mobile TV, voice over WiFi and other applications.

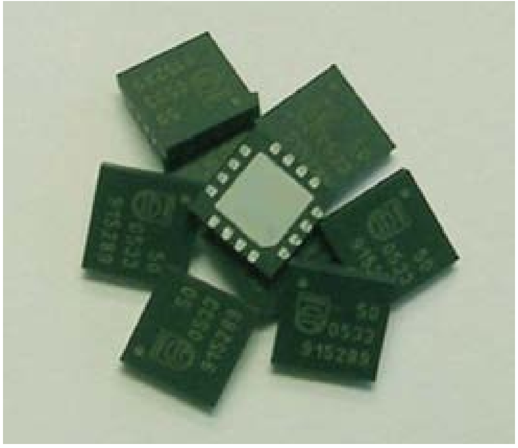
Finally, although the Avago Technologies name may have been new to some visitors the products and personnel were familiar, as the company was the result of the acquisition of Agilent Technologies Inc.'s Semiconductor Products Group at the end of 2005. They haven't wasted time in developing new products announcing two new film bulk acoustic resonator (FBAR) duplexers for handsets, PC data cards and other wireless products operating in the US PCS and UMTS frequency bands. Both duplexers are housed in the industry's smallest, ultra-thin packages featuring a height of 1.3 mm, with a 3.8 × 3.8 mm footprint.

These dimensions are achieved through the company's Microcap bonded-wafer chip scale packaging and enable miniature RF modules with increased functionality to be embedded into other portable consumer appliances. The ACMD-7402 duplexer is optimized for the US PCS band 1850.5 to 1909.5 MHz transmit, 1930.5 to 1989.5 MHz receive, and offers low TX insertion loss and excellent rejection that enhances sensitivity and dynamic range. Similarly, the ACMD-7601 is a high performance duplexer for UMTS Band I frequencies of 1920 to 1980 MHz transmit, 2110 to 2170 MHz receive — the frequency band is the most common version of the W-CDMA standard used in Europe and Asia. The device enhances sensitivity and dynamic range of UMTS receivers while extending handset battery life by minimizing the power amplifier's current drain.

Also introduced was the ADCC-3000, a one-quarter inch optical format, 1.3 megapixel CMOS image sensor featuring the company's enhanced-performance (EP) pixel architecture and image-pipe processing technology. The sensor is one of the few 1.3 megapixel sensors that fits easily into the industry's smallest (8 × 8 × 5 mm) low profile camera modules.

AN EVENT TO SAVOUR

So there you have it — the first 3GSM World Congress held in Barcelona and its home for the foreseeable future. Just like Spanish tapas, this report has been a taster of what was on offer and hopefully given a flavour of the wealth of technology and innovation that was on show. ■



AN ULTRA LOW NOISE, HIGH LINEARITY AMPLIFIER

With the introduction of wireless systems at ever-higher frequencies such as WCDMA at 2 GHz and WiMAX at 2.5 GHz and 3.5 GHz, the link budget becomes a significant problem if good coverage is to be achieved at a reasonable cost. Link budget is also an issue when new services that require a higher data rate are being introduced.

The link budget can be augmented by using features such as downlink diversity and multiple antenna diversity in the uplink, but the baseline is always set by the basic radio parameters of the system, such as radiated power and receiver sensitivity. These basic radio parameters can be improved by using high gain antennas, power amplifiers with better efficiency and lower noise low noise amplifiers (LNA) in the receiver chain.

For the latter case, the LNA is the key component in providing the overall sensitivity of the receiver chain as well as setting the dynamic range and linearity. This is a field where OMMIC (a part of the Philips Electronics Group of Companies) has been particularly active, resulting in the development of a family of LNAs to address this function for use in applications from GSM to WiMAX that provide not only low noise figures but at the same time very high linearity. The latest product to join the family is the CGY2109HV LNA.

Typical applications for the LNA are base stations, tower mounted amplifiers (TMA), tower mounted boosters, remote RF heads and base transceiver stations (BTS) for GSM, CDMA, DCS, PCS, WCDMA and WiMAX.

PHEMT TECHNOLOGY

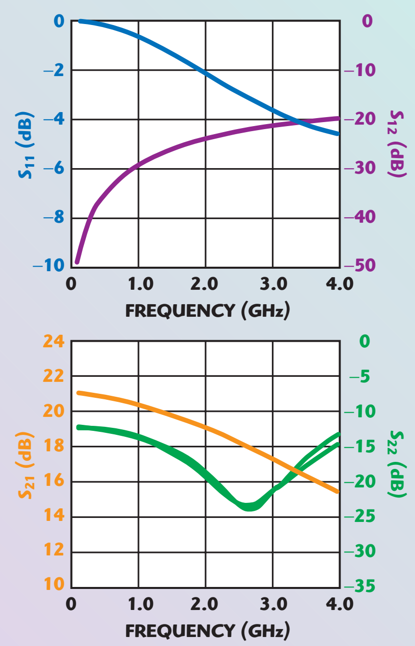
The company has developed a family of advanced GaAs MMIC technologies based on PHEMT and MHEMT structures; the technology used for the CGY2109HV amplifier is the ED02AH 0.18 µm PHEMT process. This technology is used in applications from fiber optic transimpedance amplifiers, fully integrated core chips to flight qualified components for the space industry. It lends itself ideally to being the main technology for these new ultra low noise, high linearity LNAs. Its

OMMIC
Paris, France

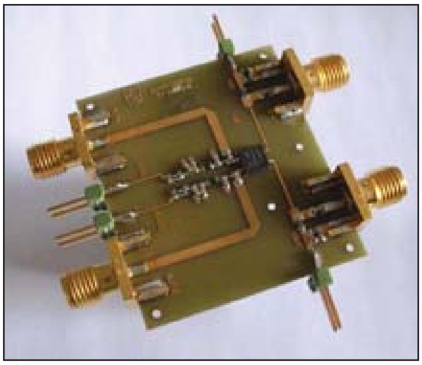
TABLE I

CGY2109HV PROCESS PERFORMANCE

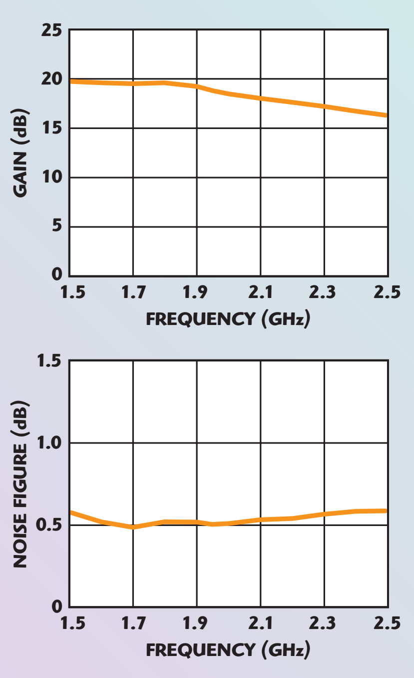
Transistor type	GaAs PHEMT
Gate length (µm)	0.18
F_t (GHz)	65
F_{max} (GHz)	125
V_t (V)	–0.9
I_{dss} (mA/mm)	250
V_{bgd} (V)	8
Passive components available	epitaxy resistors, NiCr resistors, MIM capacitors, inductors, air bridges, via holes



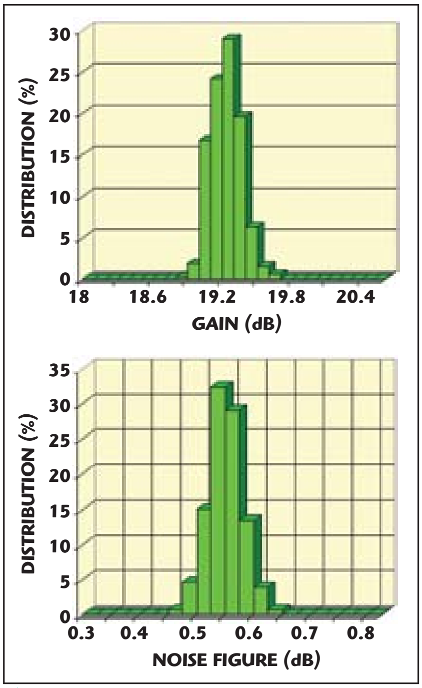
▲ *Fig. 1 Package level measured S-parameters.*



▲ *Fig. 2 The single-ended application board.*



▲ *Fig. 3 Measured gain and noise figure of the application board.*



▲ *Fig. 4 Histogram of gain and noise figure for over 900 LNAs.*

TABLE II

PERFORMANCE SUMMARY AT 1.95 GHz FOR 900 DEVICES

Parameter	*Measured Mean Value*	*Standard Deviation*
Gain	19.2 dB	0.13 dB
Noise figure	0.55 dB	0.03 dB
IP3 (input)	10.7 dBm	0.12 dBm
Vg	–0.42 V	0.07 V

performance is shown in ***Table 1***. This high RF performance also translates into an exceptional noise performance with a minimum noise figure of less than 0.1 dB at 900 MHz and only 0.18 dB at 3.5 GHz with a high associated gain.

A NEAT PACKAGE

Considering the product itself, the CGY2109HV is a dual-LNA MMIC mounted in a plastic 4 × 4 mm QFN 16 pin package. This package is both leadless and has an exposed die pad, making it very suitable for RF applications. It is also available fully RoHS compliant.

The MMIC mounted in the package is a dual-LNA using the ED02AH process. It has been designed to give both the lowest noise figure and a very high input IP3 with high gain. The measured S-parameters of the CGY2109HV (de-embedded to the pads of the plastic package) are shown in ***Figure 1***. Each graph includes the S-parameters for each of the channels of the dual-LNA and it can be seen that there is negligible difference between the two channels.

Typically, the new LNA is used with simple input and output matching circuits and is mounted on a low cost substrate such as FR4. The single-ended application board is shown in ***Figure 2*** and the measured performance in ***Figure 3***, with the latter showing the noise figure and gain measured at the board's connectors (including all the losses due to the connectors and on board matching circuit). At 1.9 GHz a noise figure of 0.5 dB, 19 dB of gain and an input IP3 of 11 dBm is measured with 50 mA per LNA.

The production test set up was used to measure more than 900 LNAs randomly selected from four wafers from three different production batches. From ***Figure 4*** it can be seen that there is very little variation between adjacent devices as well as very low wafer-to-wafer variations of the noise figure and gain.

The results are summarized in ***Table 2***, where V_g is the gate bias used to establish the required 50 mA drain current. The CGY2109HV can be used either with a constant current or constant gate voltage.

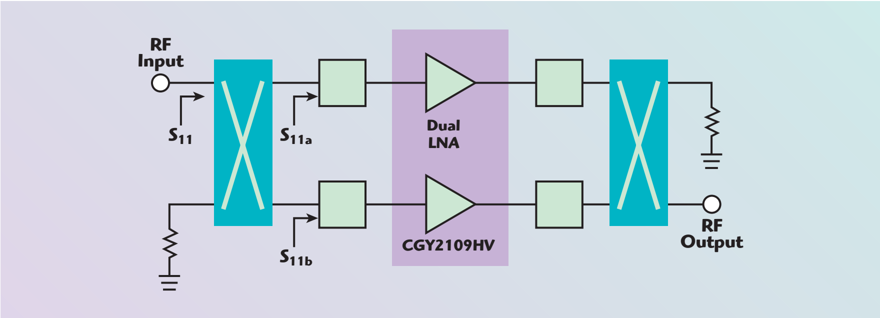


Fig. 5 Schematic of a balanced configuration.

BALANCED CONFIGURATIONS

An ideal LNA has a noise figure of 0 dB, perfect input match and generates no intermodulation products. Input match is important especially when a high Q mechanical filter is placed in front of the LNA, which is usually the case in the applications described earlier. Poor input match degrades the filter performance, but achieving a low noise figure and good input match at the same time is frequently contradictory as the GaAs field effect transistors that are usually used for such applications require a different match for low noise figure and low return loss.

The classic way to circumvent this contradiction is to use a balanced amplifier, as shown in ***Figure 5***. It utilizes two amplifiers of the same type that are placed between two 3 dB hybrid couplers. If the two amplifiers present exactly the same input impedance, all power that is reflected from the amplifiers will be absorbed in the 50 Ω load at the fourth port of the input hybrid 90° coupler. In this case the complete amplifier presents a perfect input match even if the two individual amplifiers are not matched to 50 Ω.

Under these conditions the input and output match is given by

$$S_{11} = 1/2(S_{11a} - S_{11b})$$

The noise figure will be increased by loss of the coupler but the amplifiers can then be matched for lowest noise figure and not for matching to 50 Ω. The overall gain is maintained and the IP3 increased by 3 dB since

TABLE III
CGY2109HV MEASURED PERFORMANCE IN A BALANCED CONFIGURATION WITH 90° HYBRID COUPLERS

Frequency (MHz)	850	1950
Noise figure (dB) Note (a)	0.7	0.7
Gain (dB)	23.5	20
Input IP3 (dBm) Note (b)	8.5	13.5
S_{11} (dB)	< –20	< –20
S_{22} (dB)	< –20	< –20
Reference conditions		
Vds (V)	3	3
Ids (mA)	50	50

the input power is divided equally between the two amplifier halves, resulting in the doubling of the power handling compared to using a single amplifier.

As has been demonstrated, the two LNAs that constitute the CY2109HV are in practice virtually identical, which makes this device an excellent candidate for use in a balanced configuration. The measured performance of the LNA in a balanced configuration with 90° hybrid couplers is given in ***Table 3***. Note that (a) the LNA performance is measured at the connectors of the boards and does not include any de-imbedding of losses on the circuit board itself; and (b) the IP3 is measured with two tones at 1949 and 1951 MHz and with two tones at 849 and 851 MHz.

At 850 MHz a noise figure of 0.7 dB and an output IP3 of 32 dBm is obtained and the input and output return loss is better than –20 dB from 700 to 1100 MHz. At 1950 MHz a noise figure of 0.7 dB and an output IP3 of 33 dBm is obtained and the input and output matching is better than -20 dB from 1.5 to 2.5 GHz.

YIELD AND RELIABILITY

The constraints in terms of production yield of the base station manufacturer and the long-term reliability of the device are very high. The first requirement is met by the use of a very stable technology with very low component-to-component dispersion and full RF testing (gain, noise figure, IP3) of 100 percent of the plastic-packaged devices.

The reliability of the LNA is achieved through design and the use of a very stable and reliable technology. This high level of long-term reliability has been validated by the use of accelerated aging tests. A total of 147 CGY2109HV coming from different wafers and batches have been subjected to the following tests:

- High temperature storage (150°C) for 1358 hours
- High temperature life testing (150°C) for 1006 hours
- High temperature, high humidity (85°C, 85 percent) for 1680 hours
- Thermal cycling from –55° to +150°C (200 cycles)

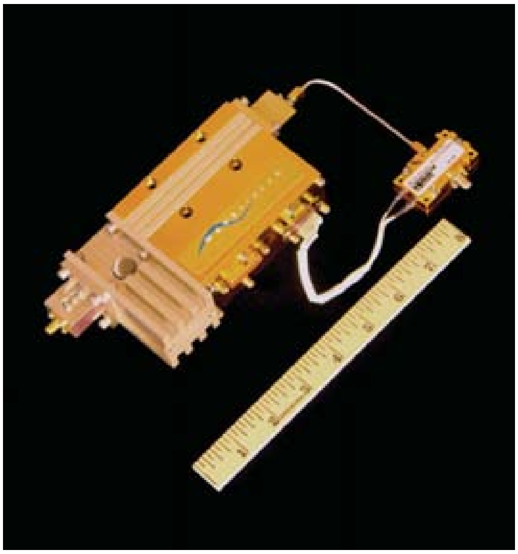
No failures were seen during these reliability tests.

CONCLUSION

By combining advanced technology, plastic packaging and careful design, a new product has been developed that is perfectly suited to, amongst others, the base station market. With an amplifier noise figure of 0.5 dB and an output IP3 of 30 dBm, the CGY2109HV is an extremely high performance amplifier.

OMMIC,
Paris, France, 33 1 45 10 67 31,
information@ommic.com,
www.ommic.com.

RS No. 300



A COMPACT, EFFICIENT 25 W KU-BAND POWER AMPLIFIER

Demand for higher data rates and greater mobility in satellite communications is driving the need for smaller, lighter, more efficient and less costly power amplifiers. Using its patented spatial power combining, Wavestream has introduced a 25 W P1dB Ku-band power amplifier that draws under 200 W DC and fits in a rugged, compact 2.5 lb package.

Intended to provide a solution for integrators developing satellite communications-on-the-move (COTM) and micro-flyaway terminals at the commercially available Ku-band frequencies, this product provides the high power desired in a small and efficient package that enables the terminal manufacturers to tightly integrate it into their systems. The specific power amplifier requirements for these terminals include:

- high output power – to meet new data rate requirements
- small footprint – to fit inside micro-flyaway single-box systems or on COTM antennas
- low profile – to maintain the low profile of a micro-flyaway box and allow placement near feed for COTM
- low power dissipation – to minimize thermal management issues and weight of heat sinks in these very compact systems
- lightweight – to enable placement on in-motion axes of COTM antennas and minimize weight of micro-flyaway systems
- low cost – to enable widespread adoption of these new and more mobile communication solutions

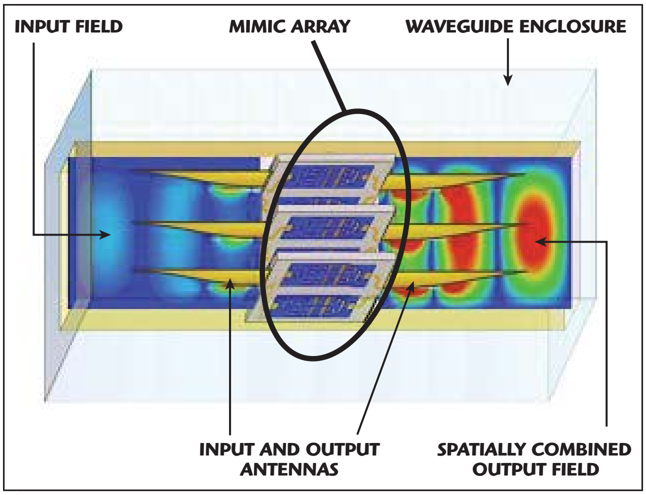
The 25 W PowerStream™ Deck Power Amplifier (DPA) provides impressive performance against all of these requirements with its spatial power advantage.

SPATIAL POWER ADVANTAGE

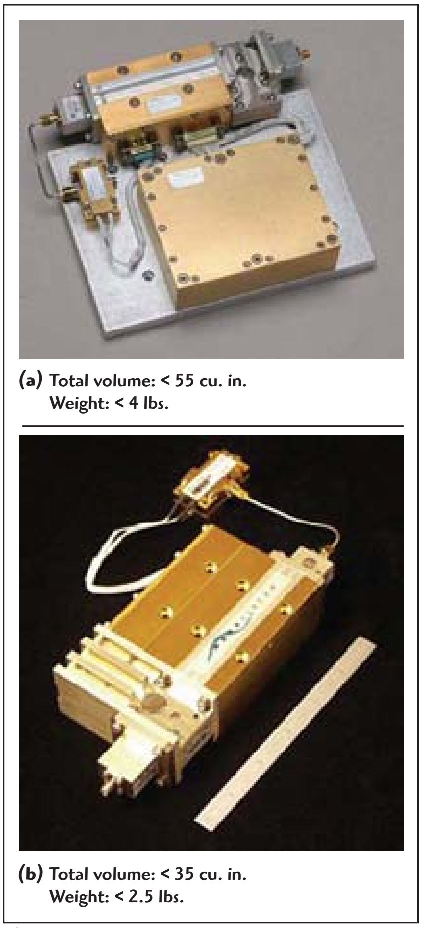
Solid-state power amplification has spread dramatically from cell phones to satellite terminals because of its high reliability, compact size and low cost. The use of SSPAs for satellite communications has been limited by the amount of power generated by individual transistors and the ability to efficiently combine the outputs of many transistors.

Binary microstrip combining efficiently combines only about 16 transistor outputs on a single chip. Binary combining efficiency deteriorates as the number of combined transistors increases, due to ohmic loss in each combining

WAVESTREAM
San Dimas, CA



▲ *Fig. 1 The PowerStream Deck Amplifier provides higher output power and higher efficiency by spacially combining outputs of cards stacked in waveguide.*



▲ *Fig. 2 Initially released 25 W Ku-band Deck Power Amplifier (a) and newly released 25 W Deck Power Amplifier (b).*

stage. Commercially available Ku-band MMICs currently reach maximum power of around 8 W.

Demand for higher power than individual MMICs provide has resulted in SSPA architectures that combine many MMIC outputs using microstrip and/or waveguide combining. These combining networks are lossy and bulky, and the resulting SSPAs are costly to manufacture, and too large and heavy for many portable applications.

Rather than combining in multiple steps, with increasing loss and size for each combining stage, the spatially power combined amplifier combines all transistor outputs in a single step. Many amplifying elements synchronously amplify the input signal, and their outputs are combined in free space for very high combining efficiency. The PowerStream Deck Amplifier stacks up cards containing traditional MMIC amplifier chips for spatial combining of their outputs to achieve high power density and high efficiency.

POWERSTREAM DECK AMPLIFIERS

The PowerStream Deck Amplifier module contains an array of solid-state MMIC amplifier chips mounted on cards stacked in a waveguide enclosure (see ***Figure 1***). Imprinted on each card are input antennas that receive a portion of the input signal and output antennas that radiate a portion of the amplified output. These outputs coherently combine within the waveguide, creating the high power output of the module.

The Deck Amplifier architecture provides significant advantages over traditional SSPAs in two ways:

- single-stage combining in air makes them highly efficient. The Deck Amplifier has demonstrated very close to 100 percent combining efficiency, independent of the number of devices combined.
- flexibility of the stacked card architecture reduces amplifier cost and improves efficiency. The number of cards and chips per card can be varied for optimum operating power with the fewest MMICs. Available chip-level power directly determines the number of chips to reach the desired output level, whereas in binary power combining the number of chips must be a power of two.

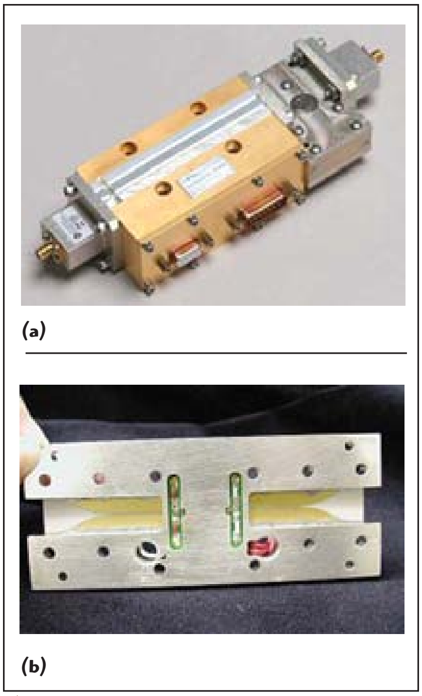
Based on this Deck Amplifier module, Wavestream has developed several power amplifier products aimed at the satcom industry. In addition to the Deck Power Amplifier featured here, the company has introduced a 25 W Ku-band Block Upconverter that is so small and light that it can be mounted on the feed of 1 m or larger antennas.

DECK POWER AMPLIFIER

When Wavestream introduced the first Deck Power Amplifier (DPA) product in 2005, it was considered to be the smallest, lightest and most efficient 25 W Ku-band power amplifier available. Several integrator's in the target market of COTM and fly-away terminals quickly saw that this was a component that could provide them with a competitive advantage at their system level.

The DPA consists of a Deck Amplifier module, a driver amplifier, a power supply, and the isolator and launches necessary for the configuration. In the original product release, the power supply was a separate module located near the Deck Amplifier module, as shown in ***Figure 2***. While this configuration was already compact, the company has now improved the product to incorporate the power supply inside the housing of the Deck Amplifier module, also shown, eliminating cabling and connectors and reducing the overall volume of the package significantly. Comparison photos also show the reduction in volume and weight for the two versions; the integration of the power supply into the Deck Amplifier module reduces both volume and weight by more than one third. For terminals already filled to capacity that are being looked at to provide additional features or functions, this space reduction is a real enabler.

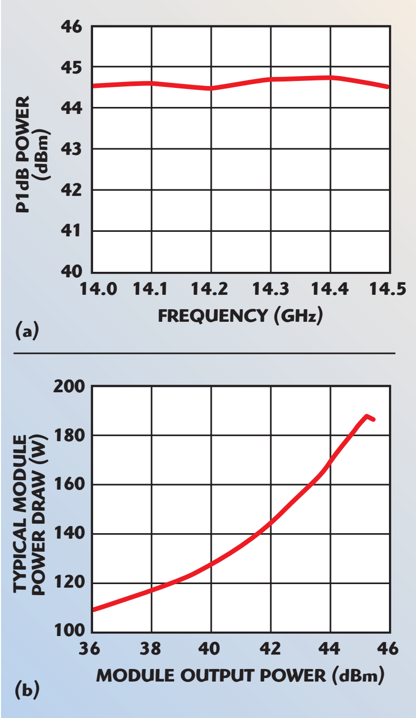
The Deck Amplifier module used in this product (see ***Figure 3***) uses three cards stacked to produce the 25 W P1dB output. The cards, also shown, each contribute a third of the total output power. By using only two active cards, a highly efficient 16 W P1dB module can also be built in the same form factor. Additional products based on the 16 W version of the



▲ *Fig. 3 Three-card Deck Amplifier module used in the DPA (a) and individual card used in the Deck Amplifier module (b).*

module are planned for release in 2006 as well. The maximum dimensions of the product are 7.5" L × 2.3" W × 1.5" H. This includes an output isolator and both input and output coaxial launches, which are required for some configurations. For configurations not requiring the output launch (WR-75 output), the total length is 6.55". Typical output power and DC draw curves for the three-card configuration are shown in ***Figure 4***. In addition to the 14.0 to 14.5 GHz performance shown, this product is also specified to cover the extended Ku-band from 13.75 to 14.5 GHz, with less than 1 dB reduction in rated output power below 14 GHz.

The line driver module, shown in ***Figure 5***, provides about 25 dB of additional gain necessary to take the typical output level of available L- to Ku-band upconverters up to the required input level for the Deck Amplifier module. This module was developed specifically for this product to be extremely compact, measuring just 2" L × 1.5" W × 0.75" H, including connectors. Later this year, this line driver will be available in a direct mount version, which attaches to the end of the Deck Amplifier module, replacing the current launch. This will reduce the overall size of the DPA slightly and simplify the already



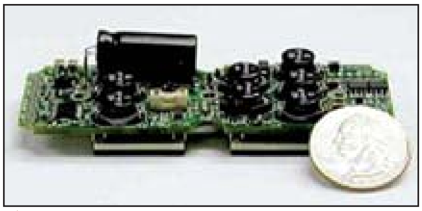
▲ *Fig. 4 Typical 1 dB compressed power (a) for the 25 W Ku-band Deck Power Amplifier and typical DC power consumption (b) for a Deck Amplifier module.*

straightforward installation of the product even further.

The key development that enabled the reduction in size and weight of the DPA is the integration of the power converter into the Deck Amplifier module itself. The power supply provides conversion of +48 V or +28 V prime DC supply to the individual bias levels required for each of the cards in the module and also for the line driver module. In addition, the power supply provides a set of discrete monitor and control interfaces to ensure proper power-up sequencing and provide status. Protective functions such as transmit enable required and overtemp auto shutdown are incorporated. The newly designed power supply card, which fits into the well of the new Deck Amplifier module, is shown in ***Figure 6***. This card provides all the required functionality in about 1.25" × 2.5" of floorplan space.

The Deck Power Amplifier's compactness is greatly enhanced relative to alternative SSPAs by the reduction in thermal management needed to cool it. The DPA's high efficiency enables the production of 25 W P1dB output power from a total DC power draw of under 200 W. Typical 14 to

▲ *Fig. 5 Compact line driver module used in the DPA.*



▲ *Fig. 6 New power supply card enabling integration into the Deck Amplifier module.*

14.5 GHz 25 W SSPA units consume over 300 W DC. This one-third reduction in power consumption reduces the heat sink and cooling system size and weight, and may enable a much smaller system package size.

BENEFITS OF THE DPA

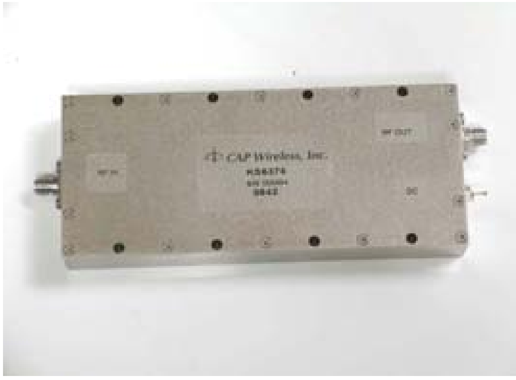
The PowerStream DPA provides system-level benefits over other solid-state approaches by improving on performance for the key requirements for mobile and transportable satcom terminals:

- high output power – generates over 25 W of 1 dB compressed output power
- small footprint – 6.55" × 3.5" footprint for Deck Amplifier module plus 2" × 1.5" footprint for line driver
- low profile – has 1.5" maximum height (driver 0.75-high)
- low power dissipation – draws less than 200 W DC draw
- lightweight – weighs less than 2.5 lb
- low cost – uses minimum number of MMICs to generate 25 W output

With these features, the new DPA enables integrators to offer the smallest, lightest and lowest cost high performance mobile satcom terminals available.

Wavestream,
San Dimas, CA (909) 599-9080,
www.wavestreamcorp.com.

RS No. 303



A BROADBAND MEDIUM POWER SOLID-STATE DRIVER AMPLIFIER

A solid-state driver amplifier has been introduced that operates from 2 to 18 GHz and offers 35 dB of gain and 31.5 dBm of output power at the 1 dB compression point. The model KS6378 SSPA operates from 15 V DC at 2.6 A, and is housed in a 5" × 2.1" × 0.7" package with SMA connectors. With its 2.7 dB typical noise figure, this new amplifier is ideally suited for a driver amplifier for VED amplifiers and higher power solid-state power amplifier applications, as well as in instrumentation, electronic warfare simulation and broadband, high dynamic range receive systems.

The KS6378 broadband amplifier combines the advantages of high frequency MMIC performance and reliability with state-of-the-art packaging to achieve outstanding broadband power amplification at an economical cost. The amplifier takes advantage of commercially available broadband MMICs to achieve moderate power amplification from 2 to 20 GHz. The package includes a copper heat spreader to optimize heat dissipation and enhance reliability. ***Table 1*** lists the KS6378 amplifier's typical performance. ***Figure 1*** shows its noise figure vs. frequency characteristics, ***Figure 2*** its gain and return loss, and ***Figure 3*** its power output performance.

DESIGN DETAILS

The challenge was to implement the MMICs in a configuration that was lower in cost than traditional microwave integrated circuit (MIC) hybrid circuitry. Hence, a cost-effective, high performance package was developed for MMICs that is compatible with current surface-mount processes and exhibits extremely low parasitic elements. To support the high power dissipation and high frequency performance, the package incorporates a CuW heatspreader with a leadless LTCC ringframe that provides nonresonant perfomance to greater than 20 GHz. This unique package has been labeled the CPM module by CAP Wireless.

The package interconnect is key to its ability to offer high performance. Compared with

CAP WIRELESS INC.
Newbury Park, CA

TABLE I

KS6378 TYPICAL PERFORMANCE SPECIFICATIONS

Frequency (GHz)	2 to 18
Gain (dB)	35
Gain variation 3–18 GHz (±dB)	2
Gain variation, over operating temperature (±dB)	1
Input VSWR (50 Ω)	2:1
Output VSWR (50 Ω)	2:1
Output power, saturated (W)	2
Output power, 1 dB compressed (W)	1.5
Third-order intercept point (dBm)	40
Second-order intercept point (dBm)	50
Harmonics (Pout<P1dB) (dBc)	–20
Spurious (dBc)	–70
Voltage (V)	14 to 16
Current (A)	2.6

other MMIC packages that offer leaded interconnects, the CPM module features a leadless interconnect that minimizes parasitic elements. This feature supports the highest frequencies of operation without degrading gain, VSWR or power loss. Additionally, the configuration of the CPM package supports multiple MMICs from various manufacturers.

The CuW heatspreader is designed to absorb some of the stresses due to mismatches of the cofficient of thermal expansion (CTE) of the GaAs MMIC die and the heatsink material (typically Cu), while providing a highly thermal conductive path to remove heat from the die. The LTCC package can be sealed using a low cost epoxy seal for commercial applications, or using a hermetic, solder seal for military applications. By sealing and protecting the MMIC circuit, the remaining circuitry can be processed and handled by normal surface-mount processes, and the entire package does not require hermetic sealing. Significant effort was expended to develop a solder seal ring structure for the hermetic lid attachment that was resonance free to greater than 20 GHz.

The LTCC package is designed to be directly soldered to both the

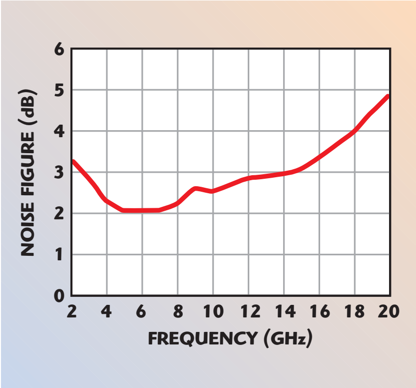


Fig. 1 Noise figure versus frequency.

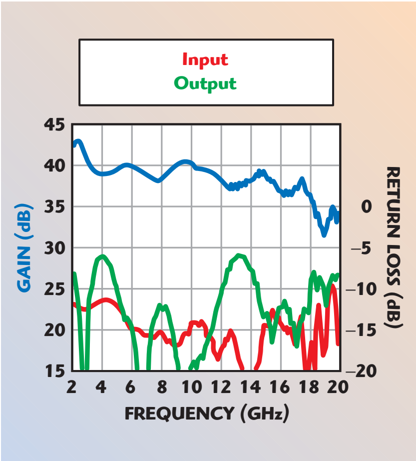


Fig. 2 Gain and return loss.

heatsink surface and the substrate. This implementation, while excelling in thermal and electrical characteristics, challenges the mechanical environment due to the potential stress imposed on the mating substrate. Rogers RT/duroid® was chosen as the inter-MMIC substrate for its compatibility with traditional circuit board processing, its high performance, low loss characteristics, and its ability to operate under multiple cycles of compressive and tensile stress imposed by a potential CTE mismatch without failing.

Figure 4 illustrates a typical implementation of a CPM module in a broadband, high thermal conductivity LTCC package. Once the implementation of the MMICs into the LTCC package is successfully completed, the implementation of a multi-chip line up to achieve required specification targets is relatively straightforward.

CONCLUSION

A broadband solid-state driver amplifier has been introduced that features low noise and high gain over the 2 to 20 GHz frequency range. This new driver amplifier can provide up to 31.5 dBm of output power by utilizing GaAs MMIC technology and state-of-the-art thermal packaging that offers enhanced reliability and consistency at an economical cost.

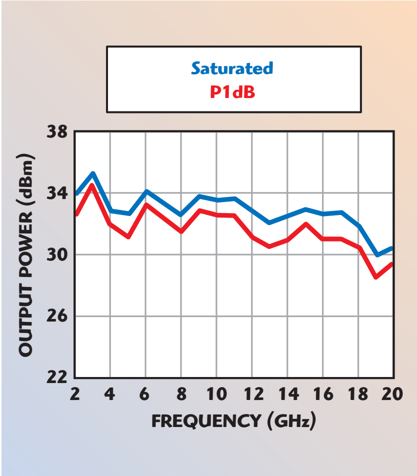


Fig. 3 Output power.

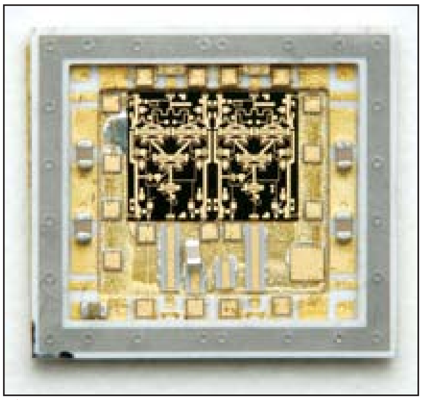
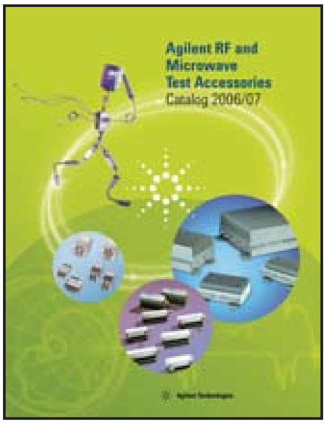


Fig. 4 A CPM module in an LTCC package.

CAP Wireless Inc.,
Newbury Park, CA
(805) 499-1818,
www.capwireless.com.

RS No. 301



Test Accessories Catalog

This RF and microwave test accessories catalog quickly and conveniently identifies RF and microwave test accessories such as switches, attenuators and adapters. The catalog features new product highlights and easy-to-read comparison tables to help a reader find the information needed to meet specific design and test requirements. To request a copy, visit www.agilent. com/find/catalogmta.

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

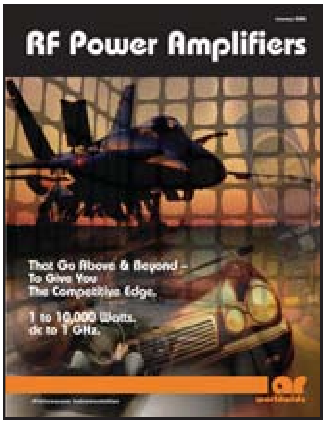
RS No. 310

Product Brochure

This brochure features the company's WAVE~X products that provide flexible, low profile EMI absorption that is readily conformable and easy to install in the area to be shielded. The WAVE~X family offers a frequency range from 10 MHz to 40 GHz, good near-field attenuation and mode suppression, space saving, thin materials and good mechanical conformability properties. The WAVE~X family includes the WX, WK, WD, WC and WS series product groups.

ARC Technologies Inc.,
Amesbury, MA (978) 388-2993, www.arc-tech.com.

RS No. 311



RF Power Amplifiers Brochure

This revised RF Power Amplifiers brochure features the company's wide range of RF power amplifiers that are currently available. The brochure highlights the "A" and "W" series amplifiers that cover 1 to 10,000 W and DC to 1 GHz. Product photographs, descriptions, specifications and performance graphs are included for each model.

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

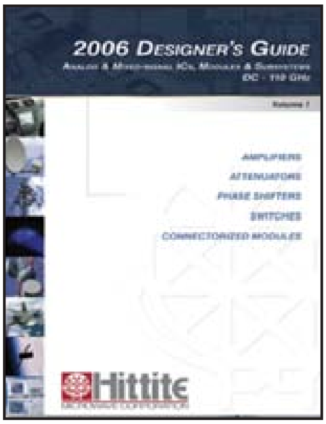
RS No. 312

Electromechanical Switch Catalog

This catalog presents the company's complete line of electromechanical switches with many options to suit any application from DC to 26.5 GHz. Models include single-pole, double-throw; double-pole, three-throw; single-pole, multi-throw and transfer switches. Options include a wide variety of connectors and actuator voltages. In addition, these switches may be ordered with indicators, TTL drive and internal terminations, as options.

EPX Microwave,
San Carlos, CA (650) 692-2198, www.epxmicrowave.com.

RS No. 313



Designer's Guide

The 11th edition Designer's Guide catalog for 2006 includes full specifications for 398 components, 80 new RFIC and MMIC product data sheets, quality/reliability, application and packaging/layout information. New for 2006 is a two catalog volume format: Volume 1 – Amplifiers and Control Devices; Volume 2 – Frequency Generation, Mixers and Modulators. To request a 2006 catalog two volume set, visit www.hittite.com and select the "Submit Inquiry" button.

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

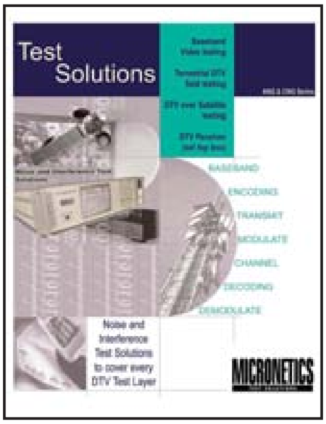
RS No. 314

Product Catalog

This product catalog highlights the company's attenuation, RF switching and test systems. The catalog features several product lines including fixed attenuators and terminations, rotary attenuators, programmable attenuators, RF switches, matrix switches, programmable attenuation systems, power dividers and RF test accessories.

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

RS No. 315



Test Solutions Brochure

This brochure details the company's noise and interference test solutions that cover virtually every DTV test layer. Flexible architecture options include: 50 Ω impedance, 75 Ω impedance, signal input and combiner for S+N or E_b/N_0, noise and output filters, front or rear panel output, remote control, interfaces: GPIB and optional RS/232, and attenuator characterization.

Micronetics Inc.,
Hudson, NH (603) 883-2900, www.micronetics.com.

RS No. 316

Product Catalog/ CD-ROM

This CD-ROM highlights the company's design, development and supply of high performance gallium arsenide (GaAs) semiconductors from DC to 50 GHz for microwave and millimeter-wave wireless communications applications. Due in part to its recent acquisition of Celeritek, Mimix offers a highly diversified product line that serves top tier telecom, satellite and defense companies.

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

RS No. 317

Product Catalog

This thin film catalog has been revised to be easier to navigate through by product groups. Now a reader can search by product groups such as chip resistors, microwave and RF resistors, chip attenuators, chip capacitors, networks and arrays, packaged resistors, jumpers/kits and substrates. The company can assist with any Hi-Rel or commercial thin film needs.

Mini-Systems Inc.,
North Attleboro, MA (508) 695-0203,
www.mini-systemsinc.com.

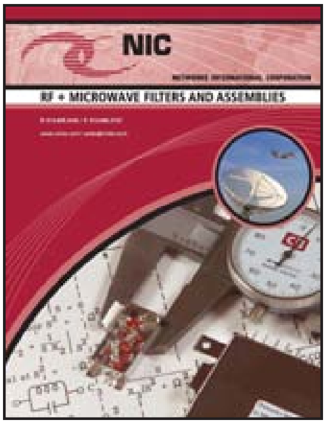
RS No. 318

Micro Brochure

This brochure highlights the company's design and manufacture of signal processing systems in the frequency range of DC to 26.5 GHz. Products include amplifiers, preamplifiers, antenna systems, filters, frequency converters, frequency translators, multiplexers, multicouplers, power panels, radar frequency generators, radar receiver synthesizers, RF distribution systems and RF switch matrix systems. Products are used in the telemetry, communication, surveillance, radar surveillance, cellular networks and CATV fields.

Mu-Del Electronics Inc.,
Manassas, VA (703) 368-8900, www.mu-del.com.

RS No. 319

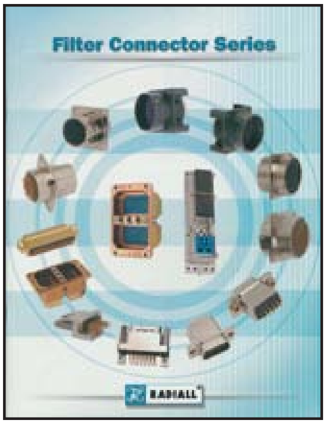


Products and Capabilities Brochure

This products and capabilities brochure is designed for advanced RF communications. Products include: lumped component, ceramic and crystal filters, switched filter banks, phase shifters, multiplexers and diplexers, TCXOs and VCTCXOs, and space qualified products. Advanced environmental testing capabilities and filter design considerations are also included.

Networks International Corp.,
Overland, KS (913) 685-3400, www.nickc.com.

RS No. 320

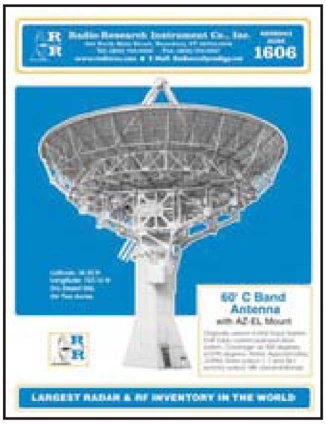


Filter Connector Catalog

This 44-page catalog presents the company's filter connectors, which are certified to ISO 9001:2000, AS9100 and other customer specific requirements. The devices featured include the MIL-DTL-38999, MIL-C-26482, MIL-DTL-24308 D-SUB and MIL-DTL-83513 MICRO-D products, together with the ARINC 404, ARINC 600 and EPX series. The catalog covers the filter connectors' performance and construction, including typical mechanical and environmental performance.

Radiall,
Paris, France + 33 1 49 35 35 35, www.radiall.com.

RS No. 321

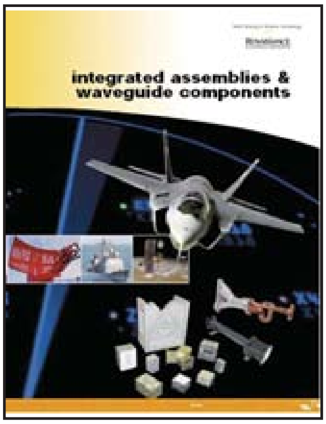


RF Research Tools Catalog

This 28-page catalog displays the company's radar systems, 10 kHz to 36 GHz RF sources, 1 kW to 25 MW modulators, microwave components, tracking pedestals, parabolic dishes to 60' diameter and microwave tubes. These products are available from stock and are completely tested. A high power RF test facility is available. Magnetron repair facility for magnetrons up to 5 MW is also highlighted.

Radio-Research Instrument Co. Inc., Waterbury, CT (203) 753-5840, www.radiores.com.

RS No. 322



Product Brochure

This brochure describes the company's high power capability for the design and manufacture of integrated waveguide subsystems and components. These components include ferrite circulators/isolators, bandpass filters/diplexers, power dividers/combiners, water loads, ceramic windows, arc sensors and orthomode tees. These products operate in frequency bands from 400 MHz through 50 GHz and from WR2100 to WR22 waveguide while achieving power levels from a few watts to megawatts of peak and average power levels.

Renaissance Electronics Corp., Harvard, MA (978) 772-7774, www.rec-usa.com.

RS No. 323

RF Product Selection Guide

This guide features the company's high performance RF components for the commercial communications and A&D equipment markets. The company's integrated circuit (IC) and multi-chip module (MCM) product lines include amplifiers, power amplifiers, transceivers, tuners, discrete devices, RF signal processing components, signal source components, government and military-specified components, and antennae and receivers for satellite radio.

Sirenza Microdevices, Broomfield, CO (303) 327-3030, www.sirenza.com.

RS No. 324

Product Brochure

This brochure highlights the company's design, development and manufacturing of microwave components and integrated subsystems. Recently, the company has developed a number of specific satellite communications products to suit both custom and common needs. Among the featured products includes the 9700 series synthesizers that operate from 700 MHz to 12.8 GHz. Also highlighted are the company's new LNB and BUC capabilities, for custom applications up to Ka-band.

Teledyne Microwave, Mountain View, CA (650) 962-6944, www.teledynemicrowave.com.

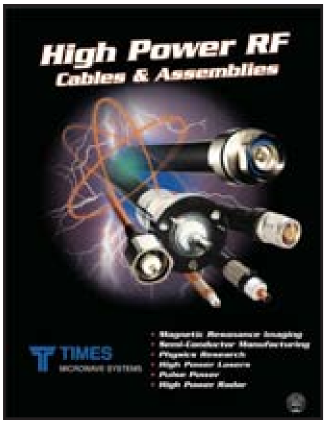
RS No. 325

Switch Catalog

This space-qualified microwave switch catalog features information about the company's high reliability electromechanical devices. This complete line of space-qualified switches is for high power applications in the L-, S-, C-, Ku- and Ka-bands. The product line consists of coaxial switches, waveguide switches, switch matrices and blocks. These products are typically custom-designed and manufactured according to specific performance requirements.

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

RS No. 326



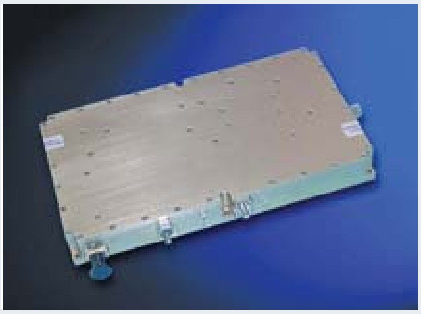
Coaxial Cables and Assemblies Brochure

This updated high power RF coaxial cables and assemblies brochure covers 50 Ω flexible cables for use in high power applications such as high power radar, pulse power, medical and semiconductor manufacturing. Cables are available for use at continuous operating temperatures up to 250°C. The product range includes MIL-C-17 cables, special Times-designed high power cables and LMR-LLPL® cables. Custom high power coaxial cable assemblies are also available.

Times Microwave Systems, Wallingford, CT (203) 949-8400, www.timesmicrowave.com.

RS No. 327

High Power RF Amplifier

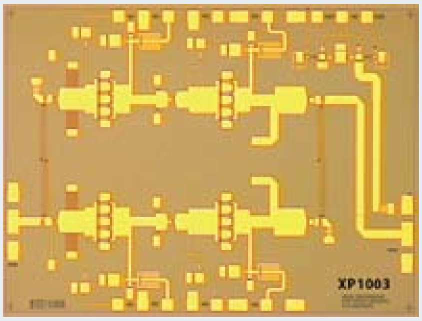


The model SSPA 0.020-0.520-100 is a high power, super broadband, RF amplifier that operates from 20 to 520 MHz. This power amplifier is ideal for broadband military platforms as well as commercial applications because it is robust and offers high power over a multi-octave bandwidth. This amplifier offers a typical P1dB of 100 W at room temperature. Saturated output power across the band is typically 125 W. Noise figure at room temperature is 8 dB typical. It is packaged in a modular housing that is approximately 4.5" × 8.5" × 1".

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

RS No. 216

MMIC Power Amplifier



The model XP1003 is a gallium arsenide (GaAs) monolithic microwave integrated circuit power amplifier optimized for linear operation. This two-stage power amplifier is good for modulation levels up to 64 QAM and offers a typical third-order intercept point of +34 dBm. The device also includes Lange couplers to achieve good input/output return loss and offers a small-signal gain of 16 dB across the band. Using 0.15 micron gate length GaAs pseudomorphic high electron mobility transistor device model technology, this chip covers the 27 to 35 GHz frequency band.

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

RS No. 224

Low Noise Amplifiers

The model SGL-0622Z and model SGL-0363Z are SiGe low noise amplifiers (LNA) that are targeted at high volume, power-sensitive applications. The model SGL-0622Z is a two-stage, fully matched RFIC offering good broadband performance from 5 to 4000 MHz. The model SGL-0363Z is a single-stage LNA optimized for high performance narrowband applications between 5 and 2000 MHz. Both models are available for immediate shipment.

Sirenza Microdevices,
Broomfield, CO (303) 327-3030,
www.sirenza.com.

RS No. 226

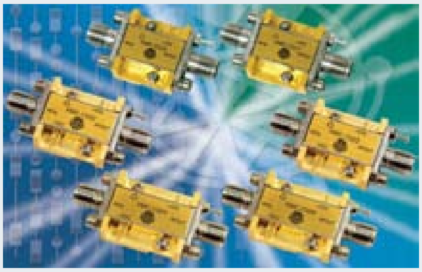
Bandwidth-upgradeable Oscilloscope

The Infiniium 80000B series is a low noise, bandwidth-upgradeable oscilloscope that features good integrity and probing. Each model of the Infiniium 80000B series offers a low noise floor at its particular bandwidth. Additional signal integrity advantages of the series include low jitter measurement floor, low trigger jitter and flat frequency response. The bandwidth upgradeability of this series allows engineers to select the appropriate bandwidth needed for a particular application and then upgrade oscilloscope performance as the next project moves on to more advanced technology.

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

RS No. 217

Connectorized Wideband Amplifiers



The model HMC-C023 and model HMC-C026 are wideband power amplifier modules that operate from 2 to 20 GHz and deliver +26 dBm of output P1dB. The model HMC-C016, model HMC-C017 and model HMC-C022 are wideband low noise amplifier modules with frequency coverage from 2 to 27 GHz. For applications, which require operation to lower frequencies, the model HMC-C024 wideband driver amplifier module is rated from 10 MHz to 20 GHz. These modules are ideal for military, space, test and measurement, telecom and microwave radio applications.

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

RS No. 222

X-band Power Amplifier

This 5 W (saturated) power amplifier operates with 25 dB gain from 9.75 to 10.25 GHz. Incorporating a –18 dB coupled monitor port, it features gain flatness of 0.5 dB and typical VSWR on all ports less than 1.5. Reverse voltage protection and internal voltage regulation ensure proper operation from a wide range of supply voltages. Alternate frequency bands are available.

CAP Wireless Inc.,
Newbury Park, CA (805) 499-1818,
www.capwireless.com.

RS No. 220

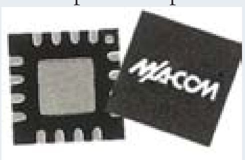
50 W TWTA Amplifier

The model 50T4G18 is a traveling wave tube microwave amplifier that operates over the 4.2 to 18 GHz frequency range. This model provides 50 W of CW power and is suitable for EMC and RF testing. Previously, model 20T4G18A, with a power output of 20 W, was the highest power offering for this frequency range.

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

RS No. 219

Power Amplifier



The model MAAPSS0076 is a RoHS compliant DECT power amplifier that operates from 1880 to 1930 MHz. It is designed for applications that require dual power modes, high gain and small size at a low cost. This model, with its wide voltage operating range, is a dual mode power amplifier that maximizes system performance while reducing DC power consumption. The MAAPSS0076 is a three-stage power amplifier designed for digitally enhanced cordless telephone applications and is available in a lead-free 3 mm 12-lead PQFN plastic package. Price: $0.54 (10,000).

M/A-COM Inc.,
Lowell, MA (800) 366-2266,
www.macom.com.

RS No. 223

Octave Band Amplifiers

The model B802 and model B1201 are modular amplifiers applicable to many applications

where small size driver or output amplifiers are needed. The B802 covers 4 to 8 GHz and offers a minimum gain of 20 dB while the B1201 spans the 8 to 12 GHz band and offers 11 dB minimum gain. Both models have a power output (P1dB) at +10 dBm. Typical noise figure for both models is 4 dB. These amplifiers operate from 5 to 10 V power and draw a typical 100 mA. Size: B802: 0.64" × 0.36" × 0.17"; B1201: 0.43" × 0.36" × 0.17". Price: $250.00; $350.00. Delivery: stock to eight weeks.

EPX Microwave Inc.,
San Carlos, CA (650) 692-2198,
www.epxmicrowave.com.

RS No. 221

Test Amplifier

The model PTB-0220 amplifier has been developed to provide additional gain in any test lab. This amplifier is completely portable and operates from a standard 120 VAC supply or an optional 230 VAC supply. Many options can be specified such as frequency range, gain level, OP1dB level, noise figure and variable gain. These amplifiers are available to suit any need. Sealed boxes and standard 19" racks are available for any amplifier.

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

RS No. 225

Multipurpose Power Amplifier

The model SM1822-44 is a GaAs FET amplifier designed for high performance military and commercial markets. The unit operates from 1800 to 2200 MHz with a P1dB of 44 dBm across the band and an OIP3 of 55+ dBm is typical. Small-signal gain is 45 dB with a flatness of ±0.5 dB across the band. Standard features include a thermal protection with auto reset, over/reverse voltage protection, TTL on/off, FWD and REV power detection, and level control.

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

RS No. 227

Enhanced Design TWTAs

The design of the PTC 6000 and 7000 series high power, commercial traveling wave tube amplifiers (TWTA) has been enhanced, covering 1 to 40 GHz, with power outputs ranging from 250 to 500 W CW or 1 to 40 kW pulsed. The TWTAs are now fully modular, with all functional boards manufactured separately and plugged together, allowing quick replacement of PCBs. This feature, combined with clear troubleshooting instructions and indicators, enables all routine operational problems to be solved easily on site. Potting of high voltage sections has been eliminated and other user benefits include improved reliability, faster on-site repair and easier maintainability.

TMD Technologies Ltd.,
Middlesex, UK +44 (0) 20 8573 5555,
www.tmd.co.uk.

RS No. 228

Coaxial Resonator VCO

The model CRO0412A-LF is a coaxial resonator-based voltage-controlled oscillator de-

signed for the VHF band (380 to 445 MHz). This model offers a phase noise performance of –117 dBc/Hz at 10 kHz offset from the carrier. This design offers good tuning linearity with a typical tuning sensitivity of 17 MHz/V and covers the entire band between 0.5 to 4.5 V. Size: 0.50" × 0.50" × 0.22". Price: $29.95/VCO (five piece minimum). Delivery: stock to four weeks.

Z-Communications Inc.,
San Diego, CA (619) 621-2700,
www.zcomm.com.

RS No. 229

COMPONENTS

SPST Switch

The model SWM-6000-1DTU option 011 is an absorptive/non-reflective SPST switch that operates from 10 MHz to 6 GHz (other frequencies are available). Insertion loss is ≤ 1.25 dB at 10 MHz and ≤3.5 dB at 6 GHz. Isolation is ≥100 dB at 10 MHz and ≥30 dB at 6 GHz. VSWR is 1.5. Speed is ≤12 ns delay on and ≤8 ns delay off. Video transient is ≤42 mV P-P at 300 MHz BW and 13 mV P-P at 20 MHz BW. Supply is +5 V at ≤3 mA and –5 V at 4 mA. Size: 1.4" × 0.8" × 0.4". Weight: < 1.0 ounce typical.

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

RS No. 230

Broadband Attenuators

The model 50MAP2G6-63SS is a broadband attenuator that covers the frequency range from 2 to 6 GHz. These attenuators are ideal for broadband wireless applications. Attenuation step size is 1 dB and maximum attenuation is 63 dB. Step sizes include 1, 2, 4, 8, 16 and 32 dB, and control is via TTL. Accuracy is ±0.3 or 3 percent of the attenuation setting. Insertion loss is 7 dB maximum. The 50MAP2G6G-63SS is supplied with SMA(f) input and output connectors and draws less than 50 mA in DC current from a –12 V supply.

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

RS No. 231

Elliptic Notch Filter

The model 8NSP-1305/UX230-O/O is a wideband elliptic notch filter for elimination of JTIDS frequency spectrum, from 1210 to 1400 MHz by 50 dB. With compact size, low loss and 100 W CW power handling, this unit supports all traffic communication between 933 and 1190 MHz and between 1420 and 1800 MHz. Through a combination of TEM, lumped elements and suspended-substrate technology, the RF performances per unit of volume are optimized.

K&L Microwave, Salisbury, MD (410) 749-2424, www.klmicrowave.com.

RS No. 237

Programmable Attenuator

The model 651-026-063 is an electromechanical programmable attenuator with an external TTL board. This attenuation solution provides low insertion loss and TTL control. The model is a 50 Ω unit with a frequency range of DC to 1000 MHz, dynamic range of 63 dB in 1 dB steps and SMA female RF connectors.

BroadWave Technologies Inc., Franklin, IN (317) 346-6101, www.broadwavetech.com.

RS No. 233

Dual Directional Couplers

This high power broadband 40 dB dual directional coupler is designed to support emerging needs for electronic countermeasures systems. Power handling capability is rated to 200 W (CW) and the frequency of operation spans from 20 to 1000 MHz. Insertion loss is 0.22 dB maximum.

Filtronic Signal Solutions, Hudson, NH (603) 459-1600, www.filss.com.

RS No. 234

I&Q Vector Modulator

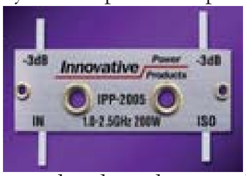
The model SA-39-AR is an integrated digitally controlled PIN diode I&Q vector modulator, amplifier and negative gain equalizer that operates from 500 MHz to 2 GHz. This device offers simultaneous 60 dB and 360° of dynamic attenuation and phase control with an accuracy of 0.06 dB and 0.1° at any CW frequency. Across the entire band, VSWR is 1.8 with +30 dB of RF gain held within a ±1 dB window to an output 1 dB compression point of +17 dBm. With two 12-bit (I&Q) TTL compatible logic, this device switches from state to state in 1.0 µsec.

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

RS No. 235

90° Hybrid Coupler

The model IPP-2005 is a high power, 3 dB, 90° hybrid coupler that operates in a frequency range from 1000 to 2500 MHz and will combine two signals with up to 200 W CW of total output power. This 3 dB hybrid is produced in a drop-in style package with solder tab connections and an overall size of 1.35" × 0.50" × 0.12". Insertion loss is less than 0.25 dB and phase balance is less than 3°. VSWR is less than 1.25, amplitude balance is ±0.65 dB and there is greater than 19 dB of isolation. Delivery: stock to four weeks.



Innovative Power Products Inc., Holbrook, NY (631) 563-0088, www.innovativepp.com.

RS No. 236

GPS Hybrid Band Reject Filter

The model 7BRX-1575/80-S is a GPS hybrid band reject filter with bi-directional inputs. This filter features a typical notch depth attenuation of 70 dB from 1565 to 1585. The maximum 3 dB bandwidth is 80 MHz. The VSWR is 2.0 from DC to 2200 MHz excluding the notch area. Size: 3.0 × 1.25 × 0.50 excluding SMA female connectors.

Lorch Microwave,
Salisbury, MD (410) 860-5100,
www.lorch.com.

RS No. 238

High Selectivity Cavity Filter

The model 8CX9-1621.35-X10.3S11 is a narrowband, highly selective cavity filter. This unit is centered at 1621.35 MHz and offers a 10.3 MHz passband. Insertion loss measures in at only 1.9 dB in the passband and passband VSWR is less than 1.5. This highly selective unit exhibits an out-of-band response of greater than 50 dB at 1605 MHz and an ultimate attenuation of greater than 30 dB out to 11.5 GHz.

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

RS No. 246

50 W Divider/Combiners

The 50 W M-series of Wilkinson power divider/combiners is ideally suited for systems applications from 0.800 to 2.200 GHz where increased power is used to extend system coverage. These divider/combiners are available from stock in two-way through eight-way configurations in both N-female and SMA-female connector styles with high isolation, low insertion loss and good VSWR.

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

RS No. 239

90° and 180° Hybrids

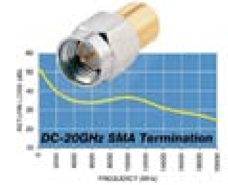
These 90° and 180° hybrids are designed utilizing either lumped element circuit synthesis or stripline technology and operate in a frequency range from 10 MHz to 26.5 GHz. The model HB-2 is 1.75" long and handles a frequency range of 1 to 2 GHz. SMA connectors are shown, but N type connectors are also available. A large stock of hybrids, available for immediate delivery, is also available.

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

RS No. 240

50 Ω Termination

The model ANNE-50X is a 50 Ω termination that offers wideband coverage of DC to 20 GHz. It features a return loss of 40 dB typical up to 4 GHz and 30 dB typical at 10 to 20 GHz. The ANNE-50X offers rugged construction and operates at –55° to 100°C. Applications include: cellular communications, satellite communications, test set-up, and defense and radar. Price: $13.95 each (1–9).



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

RS No. 241

I/Q Phase Detector

The model IQM8510L18R is an ultra accurate I/Q phase detector that operates in the 8.5 to 10 GHz band. This device utilizes an improved balun and better matched semiconductors. The phase and amplitude accuracy is typically ±3° and ±0.2 dB. Other frequencies and bandwidths are available.

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

RS No. 242

Two-way Power Divider

The model RFOC-811-QRC-2-PD is a 6 to 13 GHz two-way power divider. The insertion loss from 6 to 12 GHz and 12 to 13 GHz are 0.6 dB maximum and 0.9 dB maximum, respectively. The isolation in the entire frequency range is 18 dB minimum. Amplitude balance and phase balance are ±0.15 dB maximum and ±1.5° maximum, respectively. The input and output VSWRs are better than 1.4. Size: 0.8" × 1.04" × 0.42".

Planar Monolithics Industries Inc.,
Frederick, MD (301) 631-1579,
www.planarmonolithics.com.

RS No. 244

High Power RF Combiners

The model PP2-13-450/50N and model PPS2-14-1N are RF power combiners that operate in frequency ranges from 10 to 250 MHz and 5 to 500 MHz, with output combined power levels of 50 and 200 W, respectively. Insertion loss is 0.5 dB and isolation is 25 dB for both models.

Pulsar Microwave Corp., Clifton, NJ (800) 752-2790, www.pulsarmicrowave.com.

RS No. 245

Drop-in Isolators

The R series of Ku- and X-band drop-in isolators is ideal for military, SATCOM, space, intelligence and air surveillance radar systems. These flange-mount isolators operate in frequency ranges from 7.2 to 8.4 GHz, 9.5 to 10.5 GHz, 12.7 to 14.5 GHz and 14 to 15.5 GHz. These temperature stable devices offer a typical loss of < 0.4 dB, and return loss and isolation of > 20 dB in an industry standard footprint. Price: $24.95.

Renaissance Electronics Corp., Harvard, MA (978) 772-7774, www.recrseries.com.

RS No. 247

Solid-state Switches

This family of miniature solid-state switches offers form, fit and function replacements for popular mechanical outlines. These switches operate from 2 to 18 GHz and design options include SPST, SP2T, SP3T, SP4T and SP5T. Features include low loss, high isolation and fast switching in miniaturized, connectorized packages.

RH Laboratories, Nashua, NH (603) 459-5900, www.rh-labs.com.

RS No. 248

Device Controller

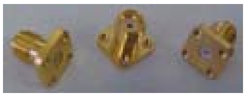
This CTL switchable device controller is an ideal solution for test bed configurations and test module design. It features a GPIB/IEEE-488, RS-232/RS-485 or Ethernet communication interface. The CTL provides control for the company's programmable attenuators, RF switches and other switchable components. Typical applications include test and verification lab environments with single components controlled with a PC to an integrated subsystem with 64 individual programmable attenuators and 32 switches configured in a communications RF simulation system.

Trilithic Inc., Indianapolis, IN (317) 895-3600, www.trilithic.com.

RS No. 251

Surface-mount Coaxial Connector

The model 32K443-800 is an SMA surface-mount coaxial connector (SMCC) that offers a four-hole flange mounting structure, with a separate center contact pin that is soldered to the signal via on the board. The connector is reusable and extra center contact pins are available. This device offers electrical performance up to 18 GHz. These SMCC products are designed to provide an impedance match if the signal trace or signal via on the board is 50 Ω.



Rosenberger of North America LLC, Lancaster, PA (717) 290-8000, www.rosenbergerna.com.

RS No. 249

Antenna Switch

The model TQP4M3019 is a high power antenna switch designed for CDMA applications. The part in single-pole, triple-throw (SP3T) configuration offers good cross-modulation and isolation performance while exhibiting low insertion loss in all frequency bands including PCS, cellular and GPS. The size of this switch satisfies customers' needs for phone board space as the industry drives toward slim-line handset design. Size: 2 × 2 mm, 12-lead STSLP package.

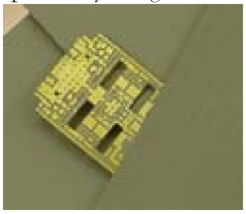
TriQuint Semiconductor Inc., Hillsboro, OR (503) 615-9000, www.triquint.com.

RS No. 252

MATERIAL

Microwave Laminate

The AD300A is a microwave laminate that is specifically designed to support base station antennas and power amplifiers where low loss and low PIM is critical. It is also well suited for RFID reader antennas, tower mounted amplifiers and multimedia transmission systems. AD300A is a woven fiberglass reinforced PTFE/microfine ceramic composite material that offers significant improvement in cost and performance. Other key performance attributes include low moisture absorption, low dissipation factor of 0.002 at 10 GHz and low insertion loss.



Arlon Inc., Bear, DE (302) 834-2100, www.arlon-med.com.

RS No. 218

SOURCES

Dual Bias Noise Source

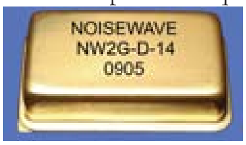
The model NMA2500 is a dual bias noise module that is ideal for applications in jamming, dithering, built-in test and calibration. The dual bias voltage of +12 and +5 V allows for greater flexibility in system integration and lower power consumption. Sealed housing eases the integration into a wide range of military and commercial applications.

Micronetics Noise Products Group,
Hudson, NH (603) 883-2900, www.micronetics.com.

RS No. 255

Amplified Noise Source

The model NW2G-D-14 is a dual-in-line packaged amplified noise source that provides frequency coverage from 10 MHz to 2 GHz. This model is an ideal choice when high levels of noise are required and the noise source must be mounted on a circuit board where space is at a premium. The NW2G-D-14 features –5 dBm of output power with flatness of ±2 dB or better. Standard operation is from +15 VDC with a 100 mA maximum current draw.



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

RS No. 256

SUBSYSTEM

Doppler Ranging Sensor Heads

The SRU series of ranging sensor heads is designed for long range distance detection where the sensitivity is essential. These ranging sensors are used for moving target distance detection. Four configurations are offered for special applications. The single channel versions are used for speed and distance sensing only while dual-channel versions are offered for speed, distance and direction sensing. In addition, dual antenna versions are offered for high power versions to eliminate the limited Tx/Rx isolation problems due to the diplexer. The single antenna versions are constructed with a high performance horn antenna or lens corrected antenna, a linear to circular polarizer and T/R diplexer, a single sideband upconverter or modulator, a balanced mixer or an I-Q mixer and an amplifier, and a high performance Gunn oscillator.

WiseWave Technologies Inc.,
Torrance, CA (310) 539-8882, www.wisewave-inc.com.

RS No. 253

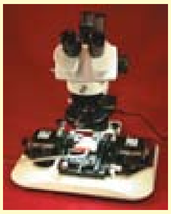
TEST EQUIPMENT

Mutli-function ATE System

The 5800 series multi-configuration, multi-function ATE system is a highly flexible, scalable and modular test environment designed to provide the true reconfigurability needed to meet the ever-changing requirements of the printed circuit board industry. This series features an open hardware and software architecture and reconfigurable pinface styles to give users the ability to combine analog in-circuit testing with a maximum of 3456 test points, high integrity functional testing and systems test all within a single test environment.

Aeroflex Inc.,
Plainview, NY (516) 694-6700, www.aeroflex.com.

RS No. 254



Laboratory (RF)MicroProbe Station

Extremely Low Cost
< $10,000 US
DC/RF/Microwave Test

A ultra compact, manually operated probe station for engineers, scientists and students. Measure Microwave, RF and IV parameters of Semiconductor Devices. Characterize MEMS, wireless, photonic and nanoelectronic components and assemblies.

•Benchtop Size(1ft²) • 2" Vacuum chuck with pump• 1" X-Y-Ø stage with z-lift• •2 ea. 0.5" X-Y-Z probe positioners, includes 2 ea. 18 GHz probes & DC needles• •10X/30X Stereo Zoom Trinocular Microscope • Flourescent Illuminator • •Compatible with additional Magnetic Mount Positioners(optional)• •Compatible with industry standard microwave probes(optional)•

•Cost effective for research projects•

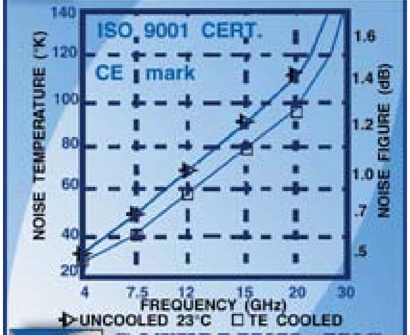
J microTechnology
3744 NW Bluegrass Pl
Portland, OR 97229
(503) 614-9509
(503) 531-9325 [FAX]
www.jmicrotechnology.com

Research Performance / Student Price

RS 53

LOW NOISE AMPLIFIERS

WWW.SATELLINK.COM



SATELLINK, INC.
3525 MILLER PARK DR.
GARLAND, TX 75042
CALL (972)487-1434
FAX (972)487-1204

RS 115

AST Advanced Switch Technology
694 Fortune Cr
Kingston, On
K7P 2T3
Canada
Tel:613 384 3939
Fax:613 384 5026
E-mail: info@astswitch.com

AST is the only company exclusively dedicated to the manufacturing of switches.
Our commitment to quality and performance is unmatched in the industry.

If it's switches you're looking for, your only choice is AST.

www.astswitch.com

RS 3

Applications Engineer
Lark Engineering Co.

COMPANY DESCRIPTION:
Lark Engineering is a leading manufacturer of RF & Microwave filters. Customers are leaders in wireless telecommunications and leading military contractors. Beautiful work environment, small office, congenial staff, located in San Juan Capistrano, California. Manufacturing located in Tijuana, Mexico.

POSITION DESCRIPTION:
Coordinate sales activity with commissioned Sales Representatives. Some travel required to visit customers.

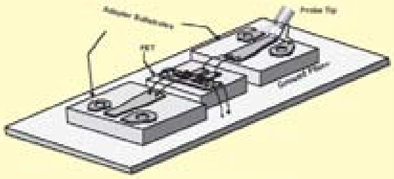
REQUIRED EXPERIENCE:
BSEE. Excellent verbal and written communication skills required. Knowledge of filters a plus. Compensation dependent upon qualifications.

CONTACT INFORMATION:
Human Resources: hr@larkengineering.com
FAX: 949-240-7910

Lark Engineering Co.
The Filter Source
27282 Calle Arroyo
San Juan Capistrano, CA 92675-2768
Telephone: 949-240-1233 • Fax: 949-240-7910
www.larkengineering.com

RS 57

ProbePoint™ CPW-μStrip Adapter Substrates



•Precision CPW to μStrip Adapter Substrates•
•Companion Calibration Substrates and Standards•
•Standard & custom Carriers•
•Accurate Electrical Data to Frequencies >50 GHz•

•5,10,& 15 mil thickness•
•Compatible with 40GHz+ probes•
•Standard and Custom Calibration Standards•

J microTechnology
3744 NW Bluegrass Pl
Portland, OR 97229
(503) 614-9509
(503) 531-9325 [FAX]
www.jmicrotechnology.com

Test Tooling for the Untestable

RS 54

REVOLUTIONARY HERMETIC SMP CONNECTORS

These SMPs meet the requirements of MIL-STD-348, but utilize unique housing interface features, which significantly improves reliability and production assembly yields. Proprietary techniques are used to independently control plating thickness on pin and housing.

For use with Aluminum, Kovar and other package materials

SPECIAL HERMETIC PRODUCTS, INC.
PO BOX 269 – WILTON – NH – 03086
(603) 654-2002 – Fax (603) 654-2533
E-mail: sales@shp-seals.com
Web: www.shp-seals.com

RS 123

Looking for an article?
Looking for an author?
Visit www.mwjournal.com to search our comprehensive on-line database for archived *Microwave Journal* articles dating as far back as 1997.

—Simply click—
"The Magazine,"
"Editorial Archives"
and then plug in
your search criteria

DUAL WAVEGUIDE & COAXIAL SWITCH SPECIALISTS

Highest reliability for non-redundant locations
in the majority of ground stations worldwide.
Request your "RF Switch Slide Guide" today!

SECTOR MICROWAVE INDUSTRIES, INC.
999 Grand Blvd., Deer Park, New York 11729
(631) 242-2300 • FAX: (631) 242-8158
Web: www.sectormicrowave.com

RS 117

Manual Probe Station

Very Low Cost
High Function
6" or 8" Chuck

A full featured, modestly priced, manually operated probe station developed for engineers and scientists.
Measure Microwave, RF and DC parameters of Semiconductor Devices, Packages and Assemblies with NIST traceability.

• Benchtop Size(<3ft²) • Vacuum chuck • Slide out X-Y-Ø stage• •X-Y-Z probe positioners •Top Plate Z-lift •Vacuum Accessory Manifold• •6.5X-112.5X Stereo Zoom Microscope • Adjustable Halogen Illuminator • •Vacuum Accessories • Compatible with 40GHz+ probes• • Accessories for Thermal Chucks and Probe Cards• •Compatible with Magnetic Mount Positioners•

•Test wafers, microstrip packages and surface mount components•

J microTechnology
3744 NW Bluegrass Pl
Portland, OR 97229
(503) 614-9509
(503) 531-9325 [FAX]
www.jmicrotechnology.com

A Precision Probe Station at a Utility Price

RS 55

Microwave Journal CALL FOR PAPERS

To see one's work in print is the rightful reward of every creative engineer and scientist. The editors of *Microwave Journal* invite you to submit your technical manuscripts for consideration to be published in one of our upcoming issues. Technical articles, application notes and tutorial articles based on the monthly editorial themes are encouraged. Editorial themes include wireless, radar and antennas; RF components and systems; test, measurement and CAD; amplifiers and oscillators; semiconductors, MMICs and RFICs; satellite and mm-wave applications; communications and wireless applications; passive components; and control devices and modulation.

Design features should contain new and innovative technical ideas of practical use and interest to our predominantly engineering readers. Papers should be 14 to 16 double-spaced pages and contain 8 to 12 visual aids in the form of sketches, graphs, photographs or tables.

Papers should be submitted to the attention of the Technical Editor and will be reviewed promptly by our Editorial Review Board prior to acceptance. Articles outside of the monthly themes also will be encouraged.

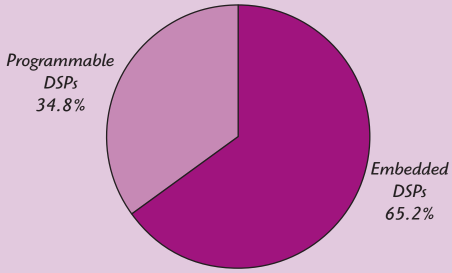
SEND ALL MATERIAL TO:

Microwave Journal
685 Canton Street
Norwood, MA 02062
(781) 769-9750
Fax (781) 769-5037
e-mail:
fbashore@mwjournal.com

MICROWAVE METRICS

DSP Strategies: The Embedded Chip Trend Continues

The market for general-purpose digital signal processor (DSP) chips dipped 2% last year to the $7.6 B level because of a severe drop in the China cellular market in the first half of 2005. According to a new market study from Forward Concepts, that market will resume growth to a healthier 15% level in 2006, driven primarily by the 3G and 2.5 cellular markets. But the new study emphasizes the even bigger market for DSP technology in the embedded DSP market that has grown to $14.3 B, or nearly twice that of general-purpose DSP chips.

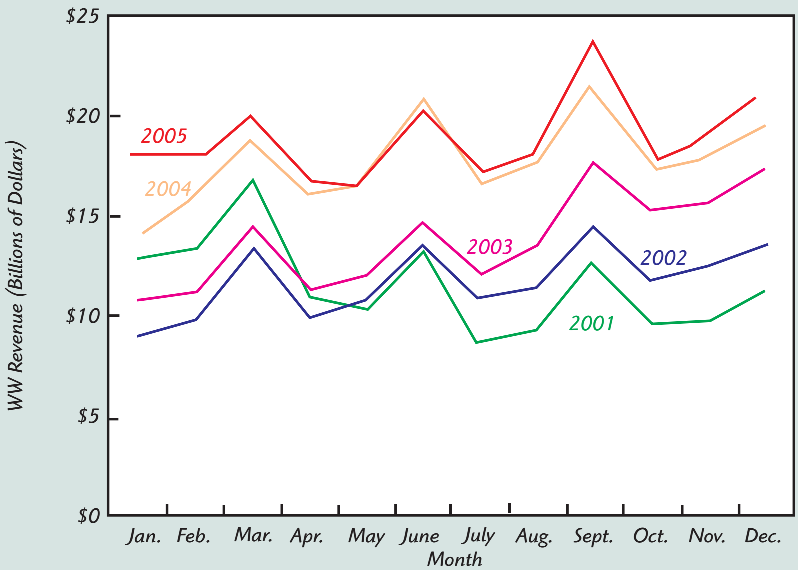


Source: Forward Concepts, 1575 W. University Dr., Suite 111, Tempe, AZ 85281-3283 (www.fwdconcepts.com)

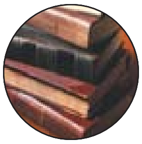
Monthly Worldwide Semiconductor Revenue

The Semiconductor Industry Association (SIA) has released revenue numbers for December 2005 of $21.85 B dollars (raw numbers not three month moving average). The December numbers are up from $19.40 B in December of 2004 and represent a 12.6% growth month over month. This is a continuation of November's pick up in growth.

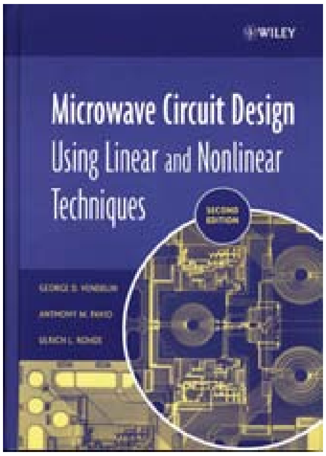
Year-to-date the growth over the same months from 2004 started the year very strong at 25.4%, then successively moderated until July before growing again for August and September. October moderated with November and December again showing good growth with the year ending at 7.1% year-over-year growth.



Source: IC Knowledge LLC, PO Box 20, Georgetown, MA 01833 (www.icknowledge.com)



Microwave Circuit Design Using Linear and Nonlinear Techniques: Second Edition

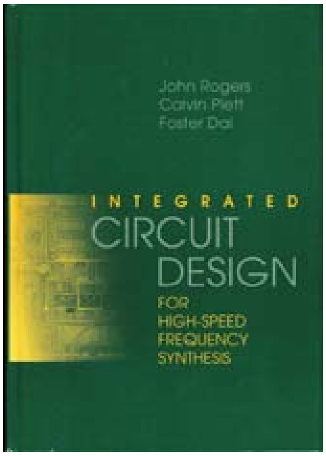


George D. Vendelin, Anthony Pavio and Ulrich L. Rohde
Wiley-Interscience · 1078 pages; $148
ISBN: 0-471-41479-4

To order this book, contact:
John Wiley & Sons Inc.
One Wiley Drive
Somerset, NJ 08875
(800) 225-5945

Approximately 15 years have passed since the first edition of this book. While the basic principles have not changed, today's technology provides huge opportunities to improve the circuit design by linear and nonlinear techniques. This second edition offers a thorough and vastly expanded revision of the original book. It has been streamlined by following the concepts of systems and their requirements at microwave frequencies, showing the transition between lumped and distributed elements and the new, exciting devices, particularly the silicon-germanium transistors and the low cost BiCMOS technology, which is competing heavily with gallium arsenide and seems to be winning in many wireless applications. A separate chapter is now offered on two-port networks and all their characteristics, followed by two new chapters, one on matching networks and an extensive one on RF microwave filters, including silicon-based filters for cellular telephone applications. The linear two-port chapter has been extended by showing the temperature-dependent noise and detailed derivations of noise figure for both bipolars and FETs. The small-signal amplifier and power amplifier chapters now include the latest design and circuit choices, as well as linearization. The oscillator chapter has been extended to include BiCMOS and SiGe HBT oscillators suitable for high integration and modern noise reduction circuits have been added. Time-domain analyses for starting conditions have also been incorporated. The microwave mixer section has been extended with a wealth of new designs. Consistent with the industry's needs, there is also a new chapter on RF switches and attenuators. The book ends by looking at and using modern design software, realizing that this field is constantly changing by offering better and faster software tools, although the basic capabilities remain the same.

Integrated Circuit Design for High-speed Frequency Synthesis



John Rogers, Calvin Plett and Foster Dai
Artech House · 491 pages; $129, £55
ISBN: 1-58053-982-3

To order this book, contact:
Artech House
685 Canton St.
Norwood, MA 02062
(781) 769-9750 ext. 4030; or
46 Gillingham St.
London SW1V 1HH UK
+44 (0) 207-8750

There are excellent books on integrated circuit design (IC) and excellent books on synthesizer design but none dealing exclusively with fully integrated synthesizer design. This book deals with frequency synthesizers and the circuits that are used to implement them in modern IC processes. It is devoted to discussing the details of frequency synthesizing design using IC technology. First, the system-level overview and 'big picture' is given, followed by circuit details. In Chapter 2, some synthesizer architectures are discussed. In Chapter 3, details of system-level design of PPL-based frequency synthesizers are described. Chapter 4 contains a summary of digital design techniques and issues. In Chapter 5, continuing with the digital theme of Chapter 4, CMOS logic and current mode logic are presented. Specific applications of these digital circuits, such as dividers and phase detectors are discussed in Chapter 6. This is followed in Chapter 7 by a discussion of the charge pump, a circuit with a digital input and an analog output. In Chapter 8, the RF design of oscillators, the final loop component, is presented. Sigma-delta modulators, which control the divider ratio in a PPL-based, fractional-N frequency synthesizer, are discussed in Chapter 9. A detailed discussion of direct digital synthesizers is given in Chapter 10. Finally, Chapter 11 contains a discussion of common digital modulations and direct modulations of frequency synthesizers. Two appendices are included. Appendix A is a review of control theory and Appendix B is an overview of IC technology from a circuit designer point of view.