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CONTROL DEVICES

5 GHz CMOS VCO for 802.11a WLANs

Measurement-based Model for I/Q Modulators

2002 Editorial Index

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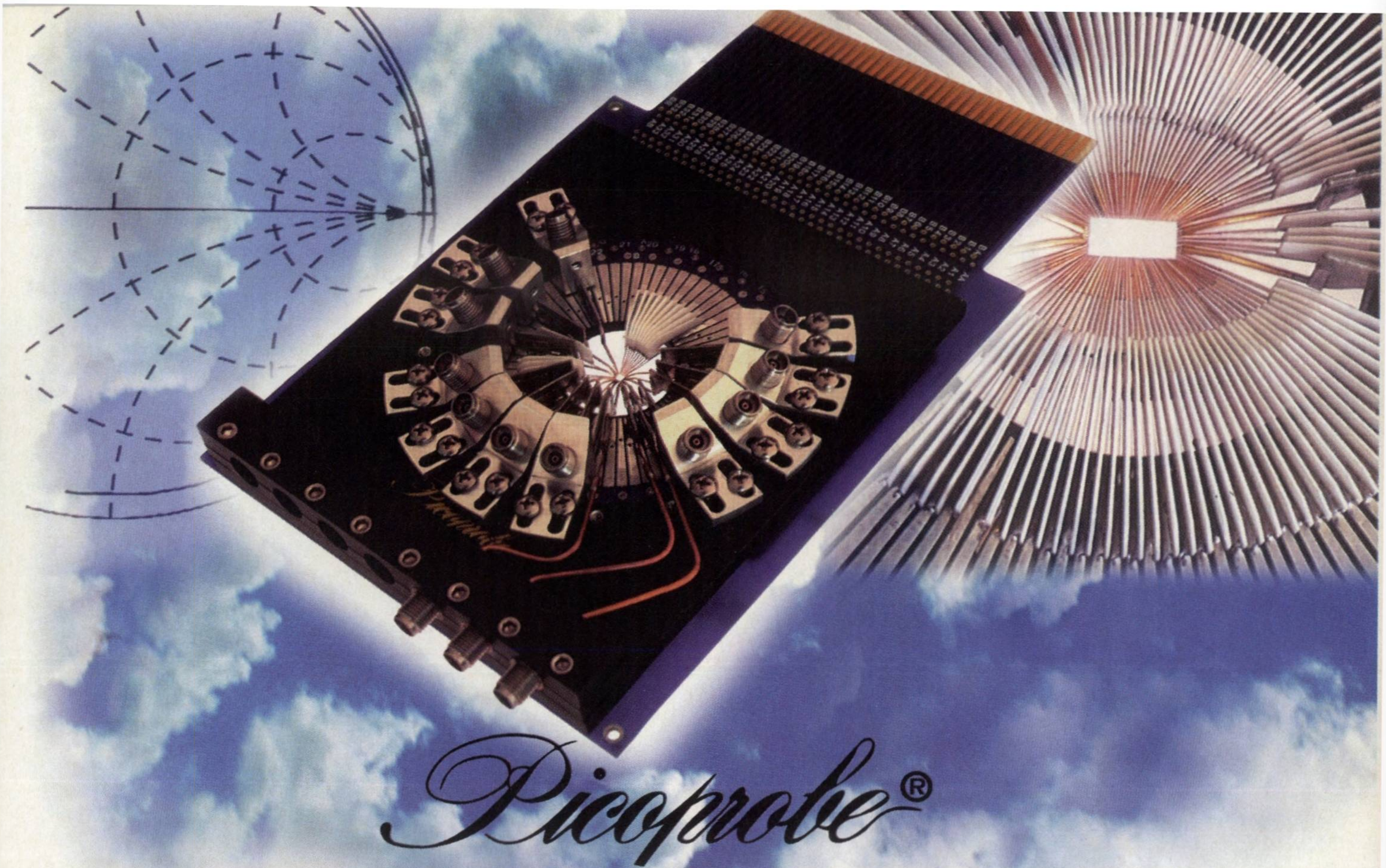
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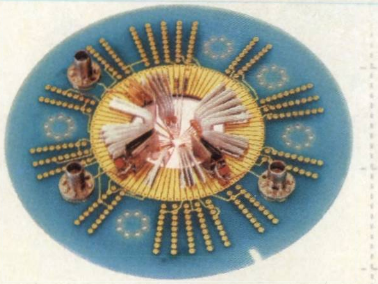

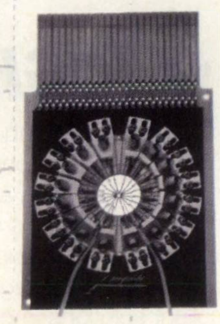

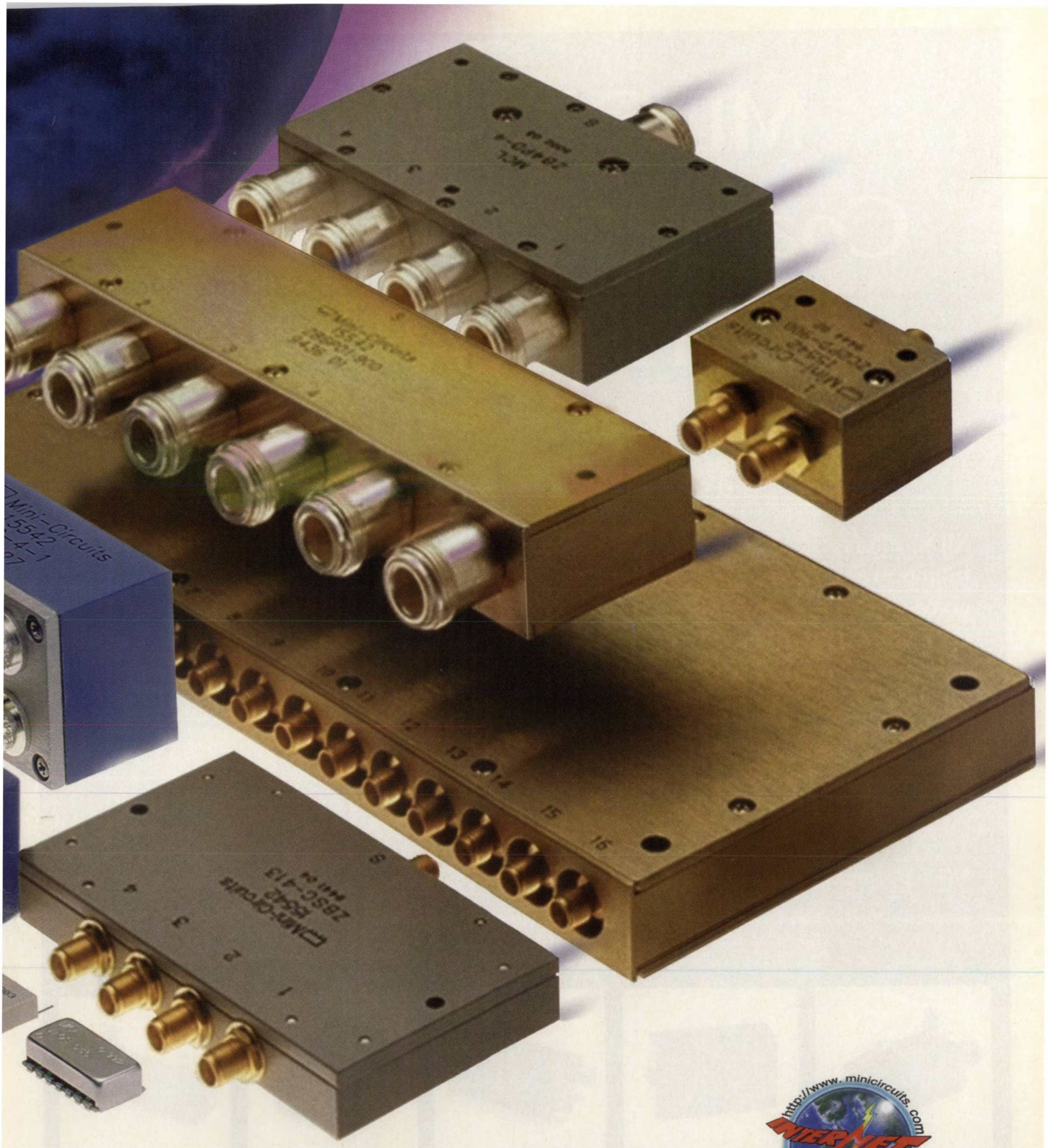


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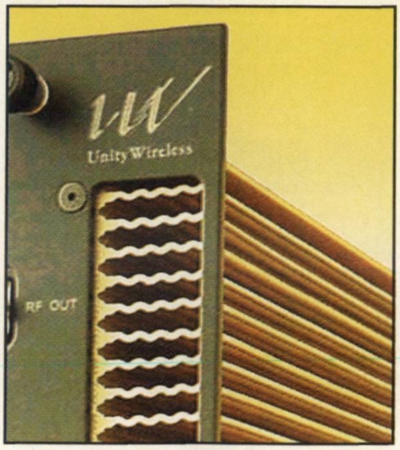

ON THE COVER

A feedforward multi-carrier linear power amplifier with 60 W maximum average output is featured on this month's cover

Cover art courtesy of Unity Wireless Systems Corp.

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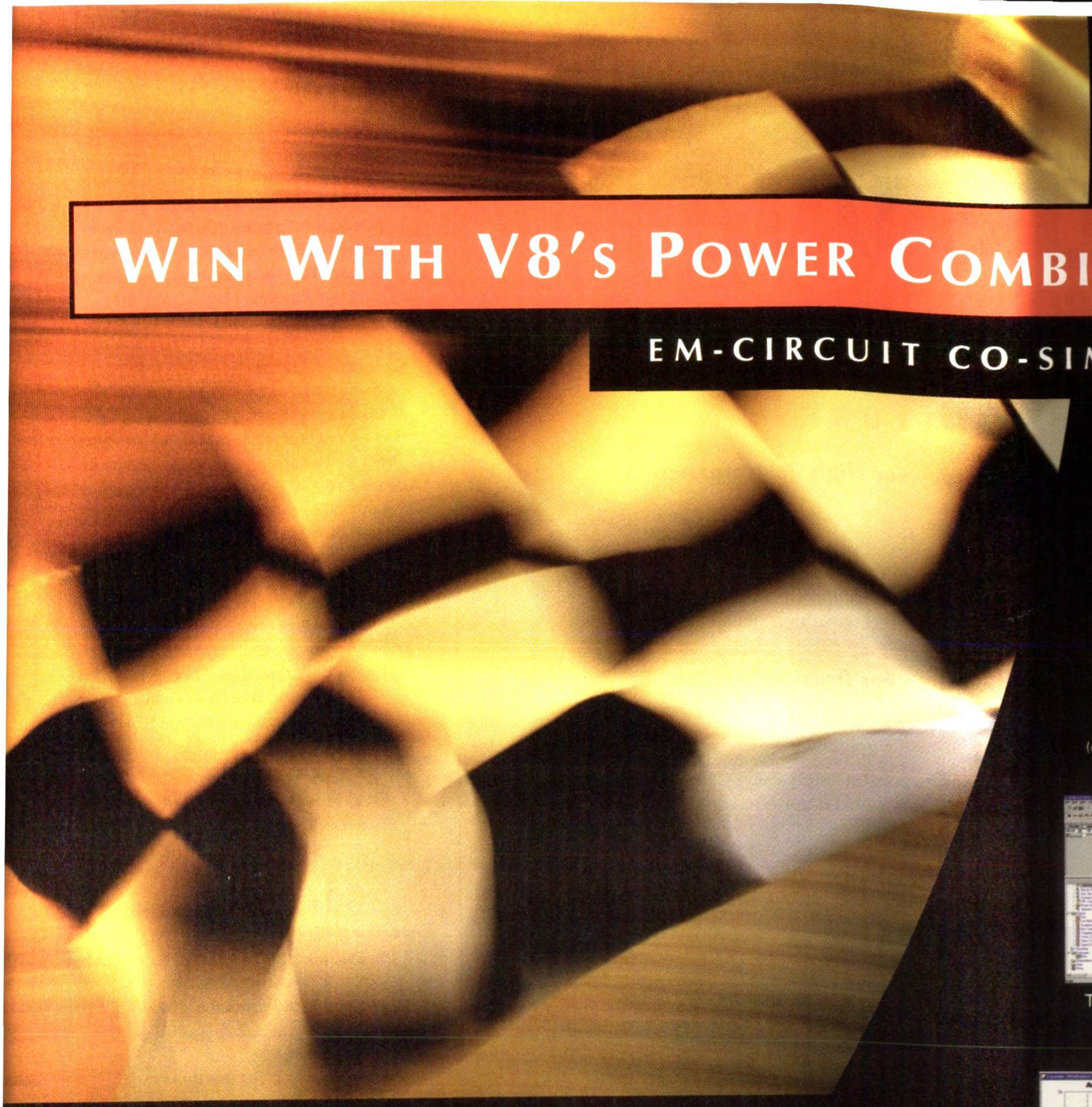
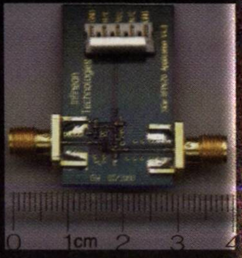
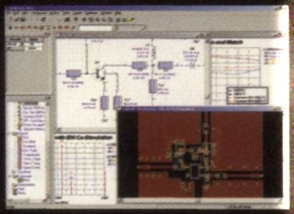
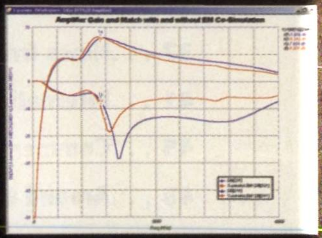




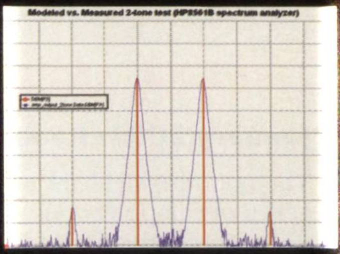
A 1930–1990 MHz LNA (courtesy: Infineon Technologies)



The schematic and layout of a LNA circuit



S-parameters shift slightly when electromagnetic effects are considered



TEST LINK reads measured data and compares results with your model

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FEATURES

PRODUCT FEATURES

DEPARTMENTS

LOOKING AHEAD TO NEXT MONTH

January 2003: Radar/Antennas

The editorial highlight next month is radar and antennas. With the emergence of compact wireless local area networks and other miniature high frequency applications, innovative new antenna designs have become a necessity. The January issue will feature some of these new trends and highlight some specific antenna designs aimed at the wireless market. A summary of the upcoming events at the Wireless System Design show to be held in San Jose in February will also appear.

Press run for this issue is 52,512 copies

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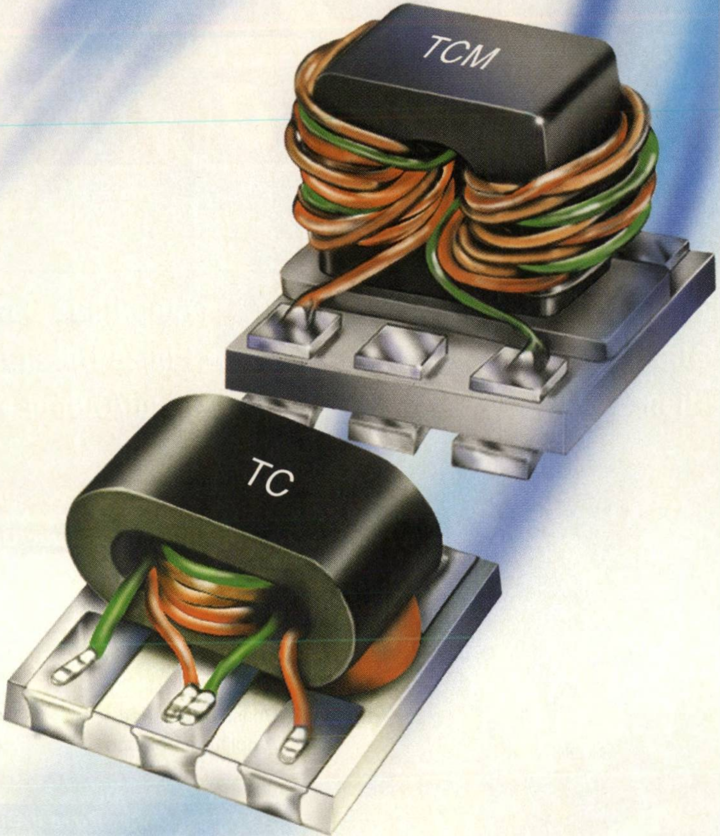
RF TRANSFORMERS



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Detailed Performance Data & Specs Online at: **www.minicircuits.com/model**

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TC1-1	1C	1.5-500	5-350	1.19
TC1-15	1C	800-1500	800-1500	1.29
TC1.5-1	1.5D	.5-2200	2-1100	1.59
TC2-1T	2A	3-300	3-300	1.29
TC3-1T	3A	5-300	5-300	1.29
TC4-1T	4A	.5-300	1.5-100	1.19
TC4-1W	4A	3-800	10-100	1.19
TC4-14	4A	200-1400	800-1100	1.29
TC8-1	8A	2-500	10-100	1.19
TC9-1	9A	2-200	5-40	1.29
TC16-1T	16A	20-300	50-150	1.59
TC4-11	50/12.5D	2-1100	5-700	1.59
TC9-1-75	75/8D	0.3-475	0.9-370	1.59

LEADS Plastic Base (actual size)

MODEL	Ω Ratio & Config.	Freq. (MHz)	Ins. Loss❖ 1dB (MHz)	Price $ea. (qty. 100)
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TCML1-11	1G	600-1100	700-1000	1.09
TCML1-19	1G	800-1900	900-1400	1.09
TCM2-1T	2A	3-300	3-300	1.09
TCM3-1T	3A	2-500	5-300	1.09
TTCM4-4	4B	0.5-400	5-100	1.29
TCM4-1W	4A	3-800	10-100	.99
TCM4-6T	4A	1.5-600	3-350	1.19
TCM4-14	4A	200-1400	800-1000	1.09
TCM4-19	4H	10-1900	30-700	1.09
TCM4-25	4H	500-2500	750-1200	1.09
TCM8-1	8A	2-500	10-100	.99
TCM9-1	9A	2-280	5-100	1.19

Dimensions (LxW): TC .15" x .15" TCM .15" x .16" ❖Referenced to midband loss.

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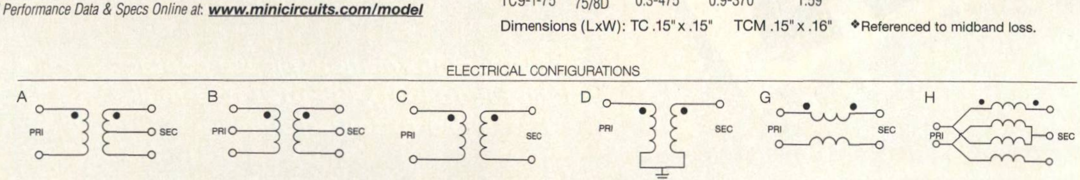


COMING EVENTS

Wireless Communications Association Technical Symposium
January 13–15, 2003
San Jose, CA

This ninth annual event will convene more than 1000 broadband wireless experts from 20 nations, collocated for the first time with the plenary meeting of the IEEE 802.16 Working Group on BWA. For more information, visit: www.wcai.com or contact: Colleen O'Reilly at colleen@wcai.com.

7th International Commercialization of Military and Space Electronics Conference and Exhibition (CMSE)
February 10–13, 2003
Los Angeles, CA

This conference is organized by Components Technology Institute Inc. in cooperation with EIA/ECA, IEEE/CPMT and IMAPS. It will specialize in COTS systems, subsystems, circuit boards and components while also emphasizing new technology, processes and design practices. Emphasis will be placed on practical solutions, new techniques and how to assess the risks of COTS and make cost-effective decisions that meet the mission requirements. Working groups and discussion sessions are planned on specific topics of concern to the industry. New issues identified by the delegates to the previous year's conference will also be addressed. Topics include: design practices, technology trends, applications, case studies/history, obsolescence management, radiation hardness, risk mitigation, selecting COTS and commercial suppliers, testing requirements and results, and constructive and destructive physical analysis. For further information, contact: Dale Stamps or Leon Hamiter at (256) 536-1304 or e-mail: dale@cti-us.com or lhamiter@cti.us.com. Information can also be accessed on-line at www.cti.us.com.

SATELLITE 2003
February 26–28, 2003
Washington, DC

This satellite conference and trade show features satellite operators, end-users, manufacturers, service providers, launch vehicle operators, teleports, consumer service providers and Wall Street financiers. For more information, contact: Cory Butler (301) 354-1669 or visit www.satellite2003.com.

International Conference on Subsurface and Surface Sensing and Imaging IV
March 2–6, 2003
San Diego, CA

This conference reports advances and progress in the research and development of subsurface and surface sensing and imaging techniques, sensors and applications, and addresses the technical barriers encountered in multiple domains of subsurface and surface sensing and imaging. Topics include: surface and ground penetrating sensors, signal and data processing and propagation and modeling, material properties and characterizations, and cross-cutting commonalities across subsurface and surface sensing applications. Additional information is available at http://ee.tamu.edu/subsurface-sensing-conference. For further information, contact: Cam Nguyen, Department of Electrical Engineering, Texas A&M University, College Station, TX 77843 (979) 845-6259 or e-mail: cam@ee.tamu.edu.

International Wireless Communications Expo (IWCE)
March 9–15, 2003
Las Vegas, NV

This show plays host to more than 350 exhibiting companies and 10,000 attendees in the two-way mobile communications industry. Along with base station workshops, the IWCE conference program features the latest developments in business, regulatory, public safety

and homeland security. For more information visit: www.iwceexpo.com.

IEEE Sarnoff Symposium
March 12, 2003
Trenton, NJ

The conference includes an exhibition of components, technologies, systems and services, and also features tutorials. Topics: broadband wireless systems, network security, satellite communications, signal processing for communications, microwave device technology, modeling and simulations, optical networking, ultrawideband systems, VoIP and QoS, military communications, 3G mobile systems and wireless LANs, smart antennas and phase arrays, microwave photonics, and software radio. For additional program and registration information, visit http://ewh.ieee.org/r1/princeton-centraljersey/Sarnoff_Symposium.htm or contact: Peter Zalud, symposium chair, Sarnoff Corp. at pzalud@sarnoff.com.

CTIA Wireless 2003
March 17–19, 2003
New Orleans, LA

With over 900 exhibitors, 500,000+ square-feet of space and nearly 40,000 attendees, this show is one of the largest and highly attended wireless shows in the telecommunication and computing industries. This event draws not only a traditional wireless audience of network providers, carriers and manufacturers but also brings in the users of wireless such as health care, government, military and automotive. Live Well, Work Smart, Play Hard... Wireless Makes it Possible. For more information, visit the show Web site at www.CTIAshow.com, or e-mail: conventions@ctia.org.

IEEE International Symposium on Electromagnetic Compatibility
May 11–16, 2003
Istanbul, Turkey

Sponsors: IEEE EMC Society, URSI Commission E, IEE, EOARD, AEAI. This symposium will provide opportunities for EMC researchers, scientists, engineers and vendors to present the latest research results, discuss problems of current and mutual interest and exchange views and experience related to new EMC components, materials and equipment. Topics: research, development and applications on EMC and related disciplines. Main themes include designing for EMC, signal integrity, RF compatibility and spectrum engineering, test and measurement methods, numerical modeling, and lightning and EMP interactions. For further information, visit www.ortra.com/emc2003. In addition, the symposium will be accompanied by a technical exhibition related to EMC. For exhibition information, contact: Eddie Rosen, ORTRA Ltd., 1 Nirim Street, PO Box 9352, 61092 Tel-Aviv, Israel +972-3-6384444, fax +972-3-6384455, e-mail: emc2003@ortra.co.il or Elya B. Joffe, general chairman, eb.joffe@ieee.org.

IEEE MTT-S International Microwave Symposium and Exhibition
June 8–13, 2003
Philadelphia, PA

This symposium will serve as the centerpiece of Microwave Week 2003. Topics: research, development and application of RF and microwave theory and techniques. In addition to IMS2003, a microwave exhibition, a historical exhibit, the RFIC symposium and the ARFTG conference will be held during Microwave Week 2003. The technical sessions will run Tuesday through Thursday of Microwave Week. Workshops will be held Sunday through Tuesday, and the ARFTG Microwave Measurements Conference will be held on Thursday and Friday. For further information, contact: Richard V. Snyder, general chair, RS Microwave Co. Inc., (973) 492-1207, e-mail: r.snyder@ieee.org. For exhibition information, contact: Kristen Dednah, Horizon House Publications, 685 Canton St., Norwood, MA 02062 (781) 769-9750 or e-mail: kdednah@mwjournal.com.

WORKSHOPS & COURSES

RF Wireless Engineering

■ **Topics:** Designed to give electrical engineers the specialized training that they need to achieve competence in RF and wireless engineering. Students learn practical skills, such as component selection and impedance matching network design.
■ **Site:** Atlanta, GA
■ **Dates:** January 27–31, 2003
■ **Contact:** Georgia Institue of Technology, 613 Cherry Street, Swann Bldg., 3rd Floor, Atlanta, GA 30332 (404) 385-3541.

RF Wireless System Design Fundamentals

■ **Topics:** Digital wireless communication systems concepts and performance limitations, system degradation due to RF components, wireless communication system budget profiles, propagation losses and link budgets, cost vs. performance issues, and performance of differing RF wireless system architecture.
■ **Site:** Sunnyvale, CA
■ **Dates:** February 3–5, 2003
■ **Contact:** Besser Associates, 201 San Antonio Circle, Building E, Suite 280, Mountain View, CA 94040 (650) 949-3300.

RF Wireless System Design Fundamentals

■ **Topics:** Combines theory with real-life examples to provide participants with a complete foundation in digital communication techniques and their effects on RF circuit parameters. Fee: $1145.
■ **Site:** Phoenix, AZ
■ **Dates:** March 10–12, 2003
■ **Contact:** Besser Associates, 201 San Antonio Circle, Building E, Suite 280, Mountain View, CA 94040 (650) 949-3300.

Phased Array Antennas for Communications and Radar

■ **Topics:** The presentation of the necessary theory, basic principles of operation, components, and important design parameters of phased array antennas.
■ **Site:** Davos, Switzerland
■ **Dates:** March 17–21, 2003
■ **Contact:** CEI-Europe AB, PO Box 910, S-612 25 Finspong, Sweden +46-122-175 70, fax +46-122-143 47.

Applied RF Techniques in Wireless Systems

■ **Topics:** Introduction to RF, single-ended and balanced S-parameters, impedance matching, graphical and analytical design methods, discrete and monolithic RF component models, Smith chart techniques, transmission lines and RF CAE, PCB materials.
■ **Site:** Nice, France
■ **Dates:** April 7–11, 2003
■ **Contact:** CEI-Europe AB, PO Box 910, S-612 25 Finspong, Sweden +46-122-175 70, fax +46-122-143 47.

Antenna Engineering

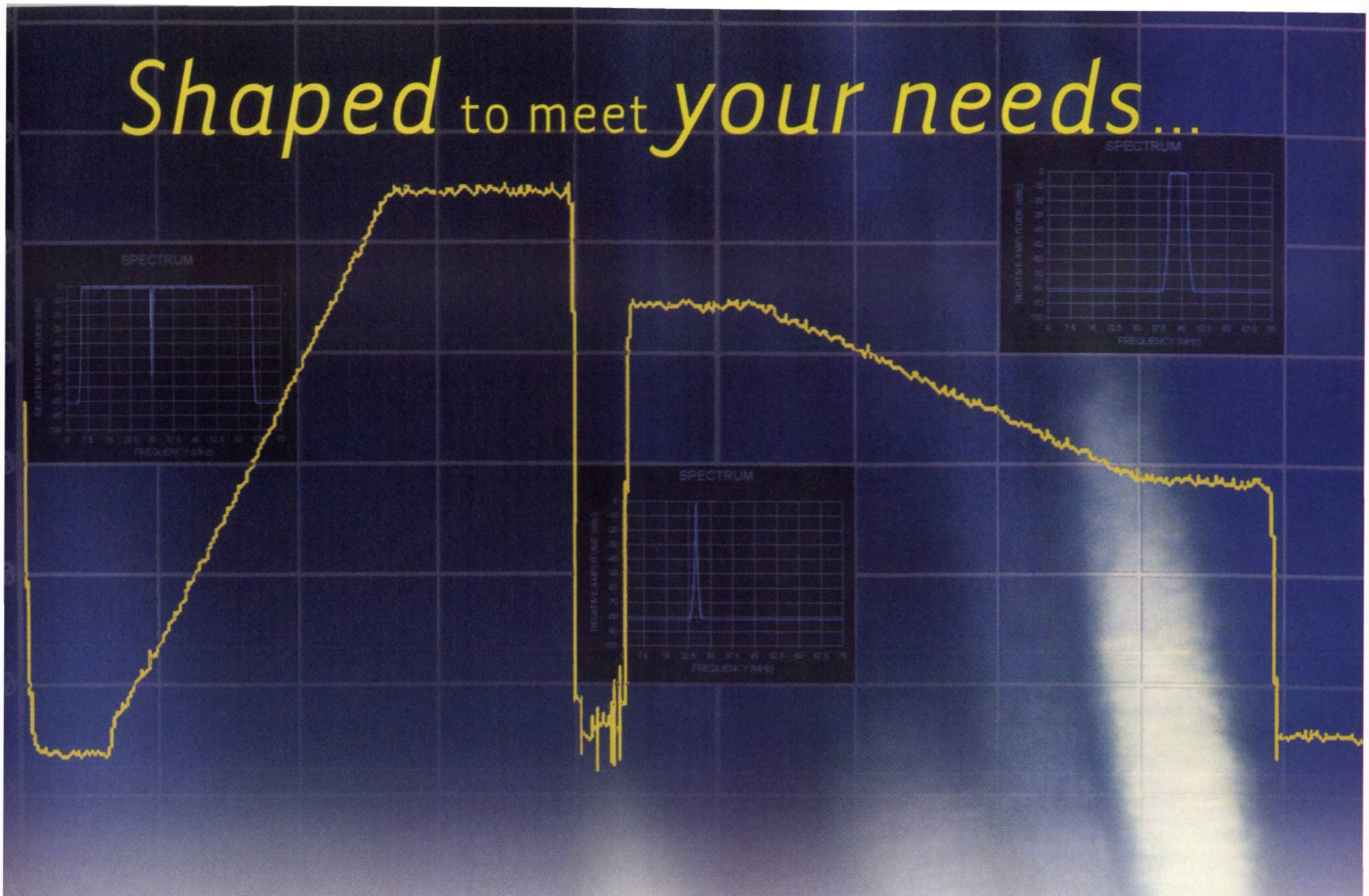
■ **Topics:** Presents the theory and practice of antenna engineering covering the range of antenna properties and types from basic to state-of-the-art. The antennas presented in the course cover a wide spectrum of frequencies.
■ **Site:** Atlanta, GA
■ **Dates:** April 28-May 2, 2003
■ **Contact:** Georgia Institute of Technology, Continuing Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3501.

Introduction to Electromagnetic Compatibility Design Practices

■ **Topics:** Fundamentals of electromagnetic compatibility (EMC/EMI), and focus on the methodology of how to minimize EMC problems. Attendees will be offered a hands-on personal consultation.
■ **Site:** Northbrook, IL
■ **Dates:** May 5–6, 2003
■ **Contact:** DLS Electronic Systems Inc. (847) 537-6400.

RF/Microwave Circuit Design: Linear/Nonlinear Theory and Applications

■ **Topics:** Enhance the design capability of the RF or microwave engineer by introducing modern linear and nonlinear design techniques. Seeks to combine the theory and practice of modern, computer-aided high frequency circuit design with greater intuition and increased insight.
■ **Site:** Cambridge, UK
■ **Dates:** May 12–16, 2003
■ **Contact:** CEI-Europe AB, PO Box 910, S-612 25 Finspong, Sweden +46-122-175 70, fax +46-122-143 47.



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High Efficiency Class B, E and F Power Amplifiers: The Magic of Parallel Circuits

Modern commercial and military communication systems require high efficiency, long term operating conditions. For this purpose, the power amplifiers, as final and highly current-consuming transmitter elements, are developed using the high efficiency class B, F or E modes of operation, depending on the technical requirements. In class B operation, which is a special case of class C with a conduction angle of half a period, the collector voltage waveform is pure sinusoidal and harmonics are present in the collector current only. In class F power amplifiers, the fundamental and harmonic load impedances are optimized by using short-circuit termination and open-circuit peaking, in order to control the collector voltage and current waveforms to obtain maximum efficiency. In class E amplifiers, an efficiency improvement is achieved by realizing the on/off switching operation with special current and voltage waveforms so that high voltage and high current do not exist at the same time. And if both collector voltage and current waveforms in an idealized class E mode contain all of the harmonics, then in class F only a certain amount of harmonic content is needed for either collector voltage or current waveforms. For example, only odd harmonic components are necessary to realize the ideal collector voltage form, and even harmonics components to form the ideal current one. As a result, the impedance conditions are different when, for class F operation, there is need to create zero or infinite impedance at any harmonic component, whereas for class E operation, all reactances at the harmonics should be negative.

At first glance, it looks like these high efficiency operation modes do not have anything in common with each other since it is necessary to provide different impedance conditions as well as to apply different circuit design approaches. However, to approximate class F or E modes, it is enough to realize the required impedance conditions only for several harmonics[1] and, more importantly, to apply the same circuit design technique — one or several harmonically tuned parallel circuits or only one parallel circuit mistuned at the fundamental frequency. All that is needed to design a high efficiency RF power amplifier is the proper choice of the parameters of the load network parallel circuit.

All that is needed to design a high efficiency RF power amplifier is the proper choice of the parameters of the load network parallel circuit.

[Continued on page 22]

Andrei Grebennikov
M/A-COM Eurotec Operations
Cork, Ireland

CLASS B

The equivalent circuit of a class B power amplifier with a parallel resonant circuit is shown in ***Figure 1***, where C_b is the blocking capacitance. The voltage and current waveforms for the active device operating in active and cut-off modes are also shown. The presence of an ideal parallel circuit, tuned at the fundamental frequency, leads to a sinusoidal collector voltage giving a sinusoidal current flowing into the load resistor R, while all harmonic current components are flowing through this parallel circuit having an infinite impedance at the fundamental and zero impedance at all harmonics. If the output device impedance at the required output power level is different from a 50 Ω load, then it is necessary to incorporate a matching circuit with the appropriate impedance ratio between the parallel circuit and the load.

Analytically, class B operation can be written as

$$i_c = \begin{cases} I_q + I\cos\omega t, & -\theta \le \omega t < \theta \\ 0, & \theta \le \omega t < 2\pi - \theta \end{cases} \quad (1)$$

where

I_q = quiescent current
I = fundamental current amplitude
θ = conduction angle part of the RF current cycle, for which the device conduction occurs and determines the point in time when the collector current i_c takes a zero value

At this moment

$$i_c = 0 = I_q + I\cos\theta \quad (2)$$

and the conduction angle θ can be calculated from

$$\cos\theta = -\frac{I_q}{I} \quad (3)$$

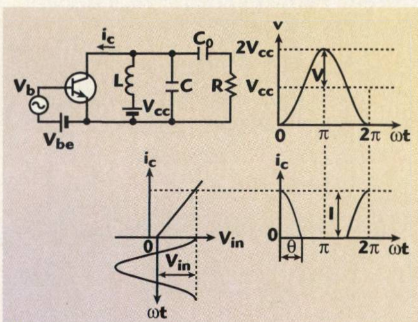


Fig. 1 Equivalent circuit of a class B power amplifier.

Consequently, in a common case

$$i_c = I(\cos\omega t - \cos\theta) \quad (4)$$

When ωt = 0, the collector current has a maximum amplitude of

$$i_c = I_{max} = I(1 - \cos\theta) \quad (5)$$

From Equation 3 one can obtain the following basic definitions: when θ > 90°, then cosθ < 0, $I_q > 0$ corresponding to class AB operation; when θ = 90°, then cosθ = 0, $I_q = 0$ corresponding to class B operation; when θ < 90°, then cosθ > 0, $I_q < 0$ corresponding to class C operation.

As a result, the periodic half-cosinusoidal output current i_c could be represented as a Fourier series expansion

$$i_c = I_0 + I_1\cos\omega t + I_2\cos 2\omega t + I_3\cos 3\omega t + \ldots \quad (6)$$

where the DC, fundamental and harmonic components can be obtained from

$$I_0 = \frac{1}{2\pi}\int_{-\theta}^{\theta} I(\cos\omega t - \cos\theta)\,d(\omega t) = I\gamma_0 \quad (7)$$

$$I_1 = \frac{1}{\pi}\int_{-\theta}^{\theta} I(\cos\omega t - \cos\theta)\cos\omega t\,d(\omega t) = I\gamma_1 \quad (8)$$

$$I_n = \frac{1}{\pi}\int_{-\theta}^{\theta} I(\cos\omega t - \cos\theta) \bullet \cos(n\omega t)\,d(\omega t) = I\gamma_n(\theta) \quad (9)$$

where

$$\gamma_0(\theta) = \frac{1}{\pi}(\sin\theta - \theta\cos\theta)$$

$$\gamma_1(\theta) = \frac{1}{\pi}(\theta - \sin\theta\cos\theta)$$

$$\gamma_n(\theta) = \frac{2}{\pi}\frac{\sin n\theta\cos\theta - n\cos n\theta\sin\theta}{n(n^2-1)},$$

$$n = 2, 3, \ldots$$

Consequently, in contrast to the class A operation mode where θ = 180° and the DC current is equal to the quiescent current during the whole period, for the other above-mentioned operating modes with θ <

[Continued on page 24]

180°, the DC current component is a function of the conduction angle θ.

The collector efficiency of a class B power amplifier, with an output power P_1, can be obtained from

$$\eta + \frac{P_1}{P_o} = \frac{1}{2}\frac{I_1}{I_o}\xi = \frac{1}{2}\frac{\gamma_1}{\gamma_o}\xi \qquad (10)$$

where

$\xi = V/V_{cc}$ is the collector voltage peak factor

If $\xi = 1$ and $\theta = 90°$, then from Equation 8 it follows that the maximum collector efficiency in class B operation is

$$\eta = \frac{\pi}{4} \cong 0.785 \qquad (11)$$

CLASS F

As can be seen from class B operation, only one parallel circuit tuned at the fundamental frequency results in insufficient high efficiency operating conditions. Additionally, Equation 11 represents the maximum ideal value, which is unrealizable in practice. Therefore, it is advisable to consider more efficient operation modes, which can ideally provide 100 percent collector efficiency.

First, consider the idealized load network harmonic conditions for class F operation[2]

$$Z_1 = R = \frac{8}{\pi}\frac{V_{cc}}{I_{max}}$$

$$Z_n = 0\Omega \text{ for even n}$$

$$Z_n = \infty\Omega \text{ for odd n} \qquad (12)$$

where

R = load
n = harmonic component

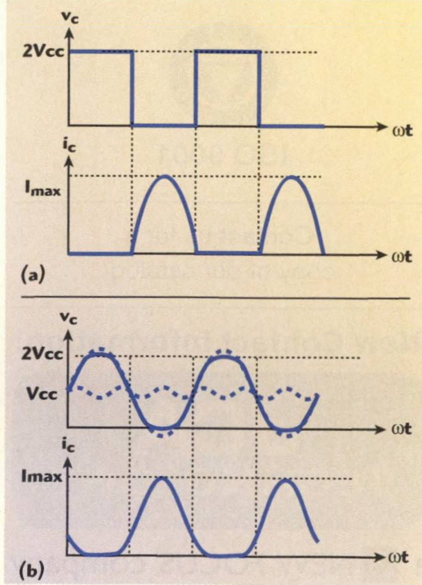
The ideal voltage and current shapes corresponding to the impedance conditions given by Equation 12 are shown in ***Figure 2***. Here, a sum of odd harmonics gives a square voltage waveform and a sum of even harmonics approximates a half-sinusoidal current shape. Based on the analysis of the square voltage and half-sinusoidal current waveforms, it is necessary to provide a peaking of several current and voltage harmonic components in order to achieve a high value of power amplifier efficiency. The better flattening of the voltage waveform provided by high order harmonic components, the less power dissipation is due to the flow of output current when the output voltage is extremely small. To understand the common design principles and to calculate numerically the power amplifier efficiency depending on the appropriate number of the frequency harmonic components of voltage and current waveforms, it is advisable to use a design technique applied to class F approximation with maximally flat waveforms.[3,4]

For example, an ideal class F amplifier with only the second harmonic voltage short-circuited and one third-harmonic current peaked realizes a maximum drain efficiency of 75 percent. In this case, for maximum voltage waveform flatness, the fundamental and third-harmonic voltages should be out-of-phase as shown, and the optimum ratios between voltage and DC current and appropriate harmonic components must be

$$V_1 = \frac{9}{8}V_{cc} \qquad V_3 = \frac{1}{8}V_{cc} \qquad (13)$$

$$I_1 = \frac{4}{3}I_0 \qquad I_2 = \frac{1}{3}I_0 \qquad (14)$$

However, as follows from Equation 9, the current coefficient $\gamma_3\theta$ becomes negative only for conductance angles of θ > 90°, which means class AB operation for a power amplifier with more than 50 percent duty cycle. There are also several other possibilities, like us-



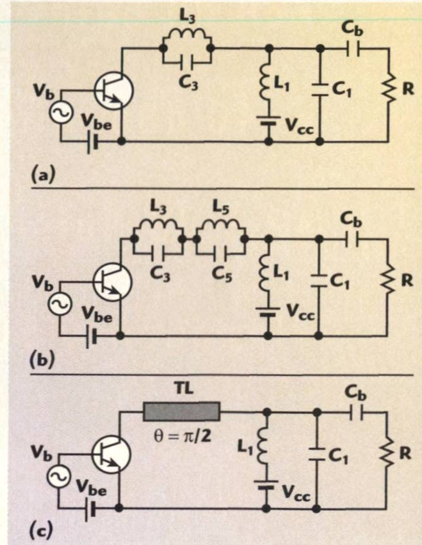
▲ *Fig. 2 Voltage and current waveforms corresponding to class F mode; (a) ideal conditions and (b) with third harmonics out of phase with the fundamental.*

[Continued on page 26]

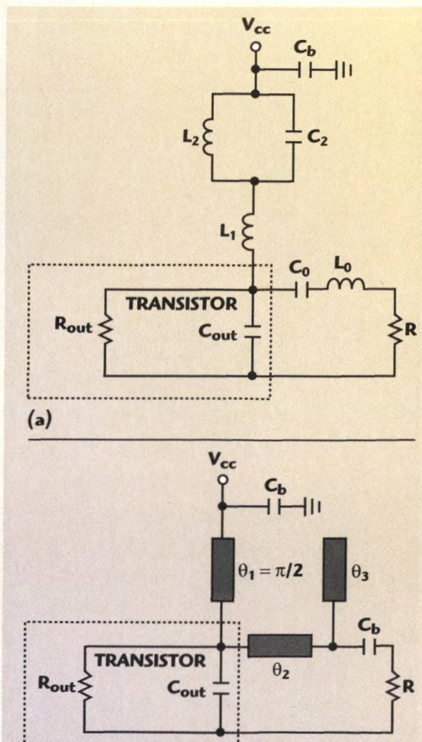
ing a slightly overdriven operation with a non-sinusoidal collector current waveform, including an out-of-phase third-harmonic, or using a non-sinusoidal driving signal containing the third-harmonic at the required amplitude. Nevertheless, in practice, due to the inherent active device nonlinearity, it is enough to choose a class AB mode with a small quiescent current, which is a compromise between power amplifier high efficiency and high gain operation.

The load network design approach for a high efficiency power amplifier can be based completely on using parallel resonant circuits tuned at the required harmonic frequency component. For example, to realize an idealized collector efficiency of 88.4 percent, it is necessary to incorporate an additional parallel circuit L_3C_3 realizing the infinite impedance at the third-harmonic current component, as shown in ***Figure 3***. In this case, a zero impedance at the second, fourth and higher harmonic components is assumed. The harmonic currents are flowing through the resonant circuit L_1C_1 tuned at the fundamental. Further efficiency improvement up to 92 percent can be made with the additional resonant circuit L_5C_5 connected in series to the collector terminal and tuned at the fifth current harmonic component. At microwave frequencies, all these lumped parallel circuits connected in series should be replaced by a quarter-wave transmission line short-circuited at the output. Such a circuit can ideally provide 100 percent collector efficiency, due to zero impedance at even harmonics and infinite impedance at odd harmonics. By having its characteristic impedance differ from the load, this transmission line can also realize the impedance transformation.

In reality, both extrinsic and intrinsic transistor parasitic elements have a substantial effect on the efficiency, especially at high frequencies. First, it is necessary to take into account the main influence of the device output capacitance C_{out}, the collector capacitance C_c for a bipolar device, or drain-source capacitance C_{ds} for an FET device. For a lumped-circuit power amplifier, in order to approximate the ideal class F with harmonic impedance conditions of $Z_1 = Z_3 = \infty$ Ω and $Z_2 = 0$ Ω at the device output terminal by compensating the influence of C_{out}, it is also advisable to use an additional parallel circuit L_2C_2 connected in parallel, as shown in ***Figure 4***, where the series resonant

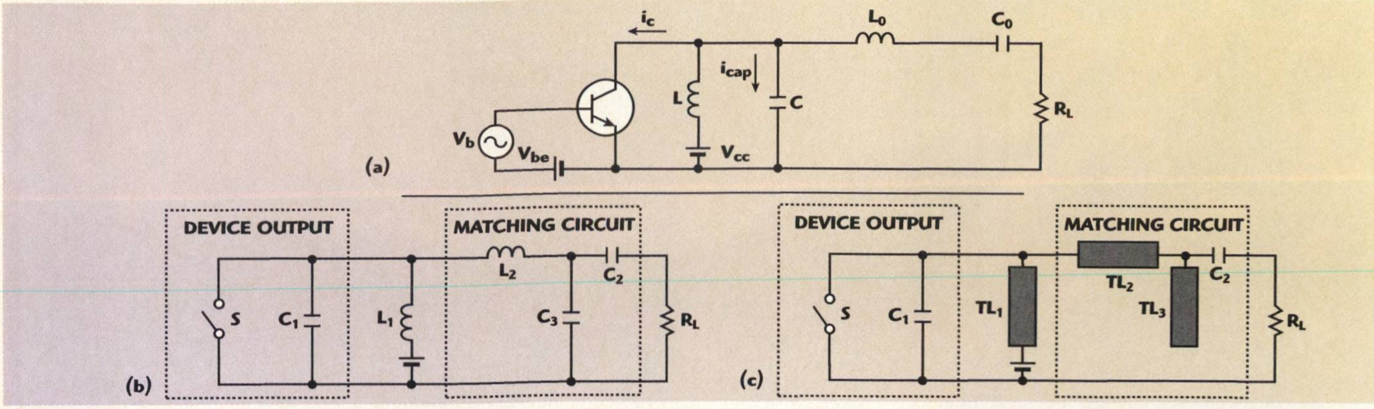


▲ *Fig. 3 Class F power amplifiers with different circuit realization (a), lumped parallel circuits (b) and quarter-wave transmission line (c).*



▲ *Fig. 4 Different load networks for class F power amplifiers; (a) lumped elements and (b) transmission line elements.*

[Continued on page 28]



▲ *Fig. 5 Equivalent circuit of a class E power amplifier with (a) a basic load network, (b) lumped resonant circuit and (c) transmission line elements.*

circuit L_0C_0 is tuned at the fundamental. As a result, the optimum ratios between the circuit elements can be calculated from[4,5]

$$L_1 = \frac{1}{6\omega_o^2 C_{out}},$$

$$L_2 = \frac{5}{3}L_1, \quad C_2 = \frac{12}{5}C_{out} \qquad (15)$$

In order to increase maximum efficiency up to 88.4 percent, it is necessary to provide a short-circuit termination for all even harmonic voltage and an open-circuit impedance for the third-harmonic current. Such a class F operation mode is easy to realize by using transmission lines in the output circuit when one of them is connected in parallel to the active device between the output device terminal and voltage supply. Such a circuit schematic is the dual to the one shown in the previous figure, when the transmission line is connected in series, but is more acceptable for practical implementation since no additional losses are due to the RF current at the fundamental frequency. Thus, for such a microstrip power amplifier, it is quite enough to provide the following electrical lengths of the transmission lines at the fundamental frequency[4,5]

$$\theta_1 = \frac{\pi}{2}, \quad \theta_2 = \frac{1}{3}\tan^{-1}\left(\frac{1}{3Z_o\omega_o C_{out}}\right),$$

$$\theta_3 = \frac{\pi}{6} \qquad (16)$$

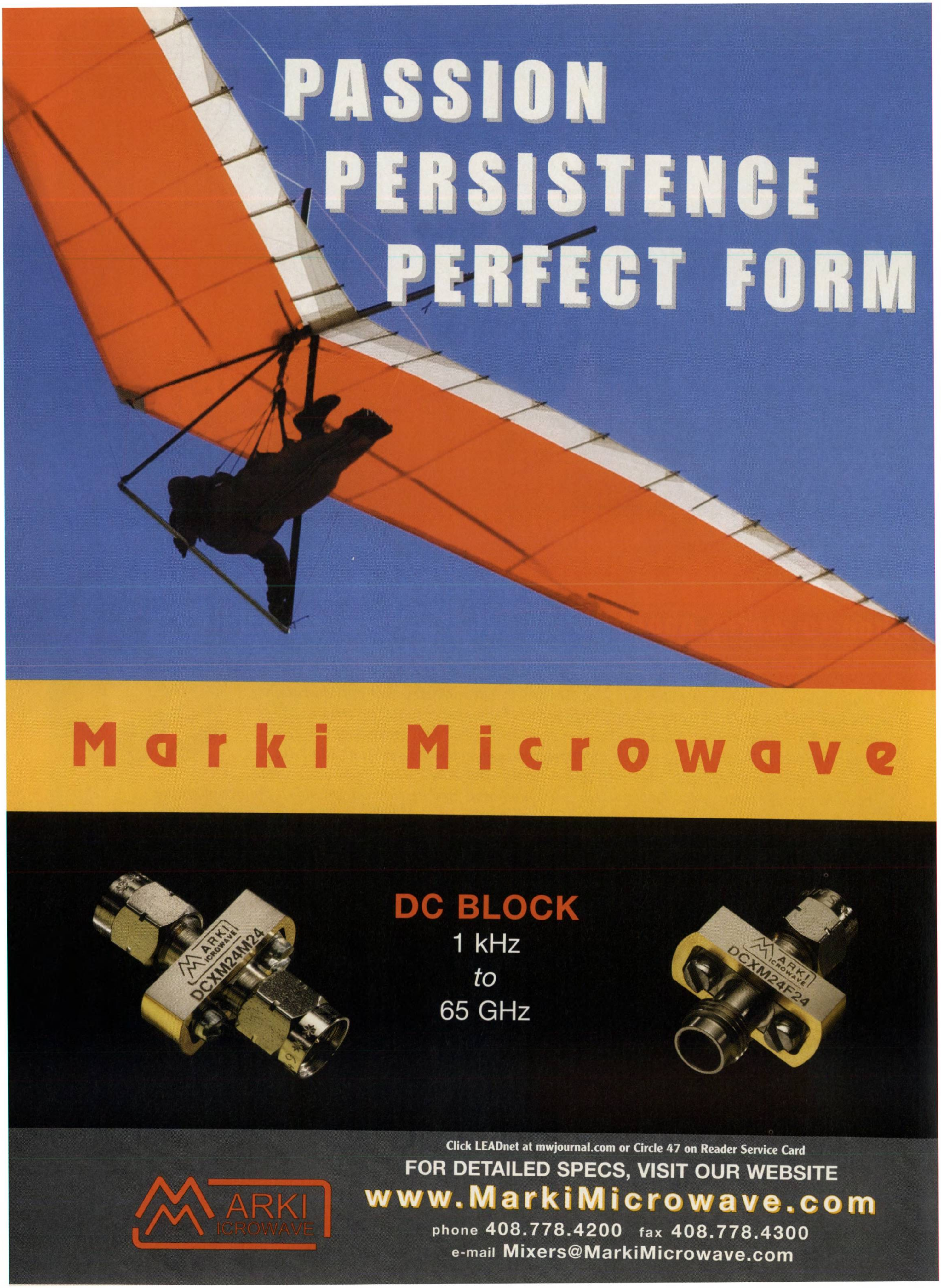
where

Z_0 = characteristic impedance of each microstrip line

CLASS E

Switched-mode class E tuned power amplifiers are widely used in different frequency ranges and output power levels beginning from several kilowatts at low RF frequencies to approximately one watt at microwave frequencies. In such class E power amplifiers, the load network usually consists of a shunt capacitance and a series inductance, which allow operating the transistor as an on-off switch under optimum values of load network elements.[6] The ideal shapes of the collector current and voltage waveforms demonstrate a condition when the high current and high voltage do not overlap simultaneously, that minimize the power dissipation and maximize the power amplifier efficiency up to 100 percent. However, such a load network configuration is not unique. For example, the switched-mode class E tuned power amplifiers with a parallel circuit, shown in ***Figure 5***, can be an alternative to the class E tuned power amplifiers with a shunt capacitance,

[Continued on page 31]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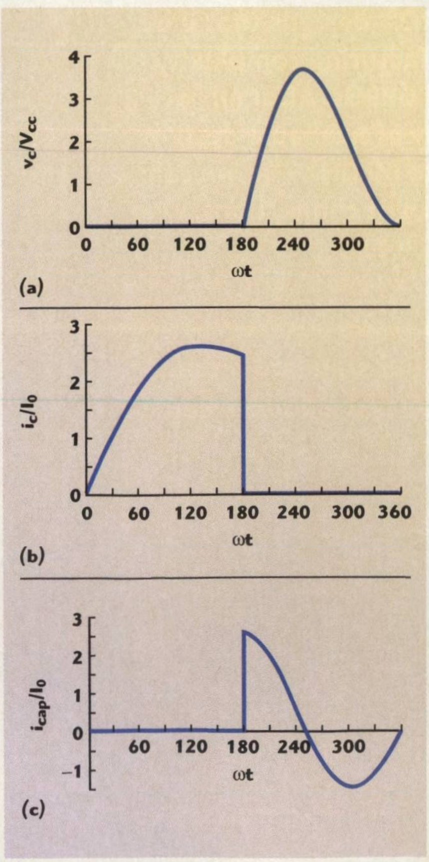
also realizing the high efficiency operation mode.[4,7] The load network with a parallel circuit consists of a parallel capacitance and a parallel inductance with an additional series filtering circuit to provide a high level of harmonic suppression.

The basic circuit of a switched-mode tuned parallel-circuit class E power amplifier is shown in the diagram. The load network consists of a parallel inductance L, a parallel capacitance C, a series L_0C_0 resonant circuit tuned at the fundamental frequency $\omega_0 = 1/\sqrt{L_0C_0}$ and a load R. In a common case, a parallel capacitance C can represent the intrinsic device output capacitance and the external circuit capacitance added by the load network. The active device is considered to be an ideal switch that is driven in such a way as to provide the device switching between its on- and off-state operating conditions. The loaded quality factor Q_L of the series resonant L_0 C_0 circuit should be high enough for the output current to be sinusoidal.



▲ *Fig. 6 Normalized collector voltage (a) and current (b) waveforms and (c) current through the load network capacitance for an idealized optimum class E amplifier.*

The normalized collector (a) current and (b) voltage waveforms for an idealized optimum parallel-circuit class E operating mode are shown in ***Figure 6***. From the collector voltage and current waveforms, it follows that, when the transistor is turned on, there is no voltage across the switch and the current i_c consisting of the load sinusoidal current and an inductive current flows through the device. However, when the transistor is turned off, this current now flows through the parallel capacitance C. As a result, there is no nonzero voltage and current simultaneously, which means a lack of power losses and gives an idealized collector efficiency of 100 percent.

The optimum load network parameters can be obtained from[4,7]

[Continued on page 33]

$$L = 0.732\frac{R}{\omega} \quad (17)$$

$$C = \frac{0.685}{\omega R} \quad (18)$$

whereas the optimum load resistance for the specified values of supply voltage V_{cc} and output power P_{out}, taking into account that $R = V_R^2/2P_{out}$, can be calculated from

$$R = 1.365\frac{V_{cc}^2}{P_{out}} \quad (19)$$

The phase angle between the fundamental frequency voltage and current seen by the switch terminal is equal to

$$\phi = 34.244° \quad (20)$$

which means that the load network is slightly mistuned with respect to the fundamental frequency and the values of the load network parameters should be chosen to create an inductive reactance at the fundamental frequency and capacitive reactances at the harmonic components.

For high power or low voltage power amplifiers, it is very important to know how small the value of the required load resistance is, since the higher its value, the easier to provide impedance matching to a conventional 50 Ω load. Thus, for the same output power with the same supply voltage, the ratio between load resistances $R^{(B)}$ in class B, $R^{(F)}$ in class F and $R^{(E)}$ in parallel-circuit class E can be written as[4]

$$R^{(F)} = \frac{4}{\pi}R^{(B)} \quad (21)$$

$$R^{(E)} = 2.729R^{(B)} \quad (22)$$

which clearly shows that, for parallel-circuit class E power amplifiers, the design output matching procedure can be significantly simplified. If the calculated value of the resistance R for the optimum parallel-circuit class E power amplifier is too small or differs from the required load resistance R_L significantly, it is necessary to use an additional matching circuit to provide maximum output power to the load. In this case, the first series element of such matching circuits should be an inductance to provide high impedance conditions for harmonics.

For a microwave power amplifier, usually all the inductances in the output matching circuit should be realized with transmission lines, in order to reduce the power losses. Therefore, for a parallel-circuit class E power amplifier, the parallel inductance L should be replaced by the short-length transmission line TL_1 with the optimum parameters obtained from

$$\tan\theta = 0.732\frac{R}{Z_0} \quad (23)$$

where

Z_0 = characteristic impedance of the transmission line TL_1

θ = electrical length of the tramission line TL_1[8]

[Continued on page 34]

Thus, a parallel circuit, being a very simple electrical structure, in reality represents a powerful means for increasing power amplifier efficiency operation. Therefore, in class B, the load network contains a parallel circuit tuned to the fundamental frequency providing also sufficient harmonic suppression. In class F, to approximate a 100 percent collector efficiency, one or several parallel circuits tuned at the harmonic components or a quarter-wave transmission line are used as the parallel circuit single-frequency equivalent. In class E, it is enough to use a slightly mistuned parallel circuit having an inductive reactance at the fundamental frequency and capacitive reactances at the harmonic components. ■

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Andrei Grebennikov *received his Dipl. Ing. degree in radioelectronics from the Moscow Institute of Physics and Technology, and his PhD degree in radio engineering from the Moscow Technical University of Communications and Informatics in 1980 and 1991, respectively. He joined the scientific and research department of the Moscow Technical University of Communications and Informatics as a research assistant in 1983. His scientific and research interests include the design and development of power RF and microwave radio transmitters for base station and handset applications, hybrid integrated circuits and MMICs of narrow- and wide-band, low and high power, high efficiency and linear microwave and RF amplifiers, and single-frequency and voltage-controlled oscillators using any type of bipolar and field-effect transistor. From 1998 to 2001, Grebennikov was a member of the technical staff at the Institute of Microelectronics, Singapore, responsible for the design and development of the LDMOS FET high power amplifier module. Since January 2001, he has been with M/A-COM Eurotec (Cork, Ireland), where he is involved in the design and development of 3G handset InGaP HBT power amplifiers and low noise VCOs.*

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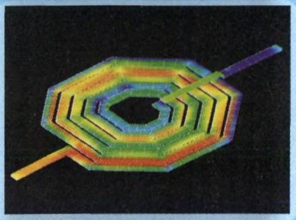

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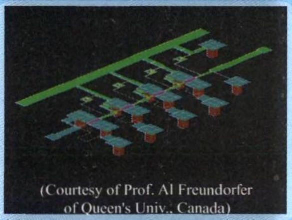

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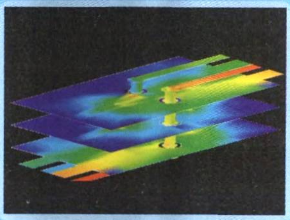

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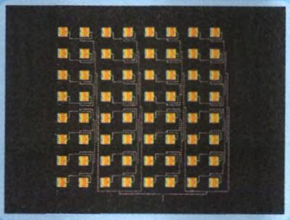

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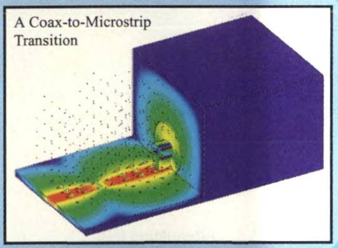

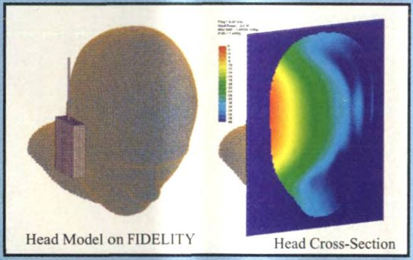

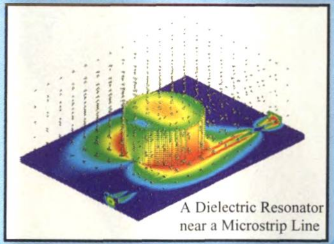

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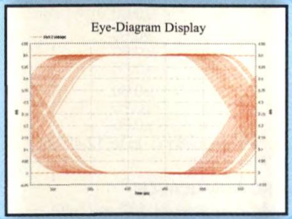

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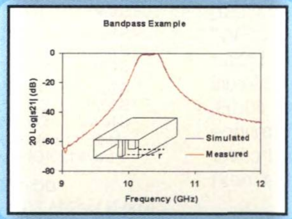

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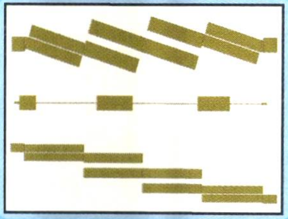

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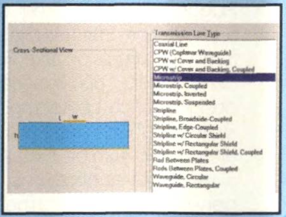

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Raytheon Delivers First Production Evolved SEASPARROW to US Navy

Raytheon Co. delivered the first production Evolved SEASPARROW Missile (ESSM) to the US Navy, defining the future of ship defense. "ESSM provides improved ship self-defense capabilities against faster, lower, smaller and more maneuverable anti-ship missile threats as well as increased firepower," said Capt. Ken Graber, the NATO SEASPARROW project manager.

ESSM is an international cooperative upgrade of the RIM-7 NATO SEASPARROW Missile. SEASPARROW is already the most widely deployed ship-defense missile system in the world. The new missile will provide the primary air defense for the capital ships of the 10 participating NATO navies. Discussions are under way to outfit the ships of at least six other navies as well. The program is managed by the NATO SEASPARROW Consortium, a 32-year-old organization described as "NATO's largest and most successful cooperative weapons project." Raytheon's Missile Systems business unit in Tucson, AZ, is leading the team of 18 companies from 10 countries in developing and producing this next generation SEASPARROW ship self-defense system. The other nations participating in ESSM's development include Australia, Canada, Denmark, Germany, Greece, the Netherlands, Norway, Spain and Turkey. ESSM has the speed, agility and accuracy to engage threats to the launching vessel at maximum range and in the most challenging of conditions. The final phase of the missile's flight test program is scheduled for the early spring of 2003 when performance with the AEGIS Fire Control System of the US Navy's Arleigh Burke class of guided missile destroyers will be verified.

Airborne Surveillance System Keeps Security Forces Safe

Air Force Security Forces personnel supporting Operation Enduring Freedom have been equipped with the latest in Unmanned Aerial Vehicle (UAV) technology, the Force Protection Airborne Surveillance System (FPASS). The system allows security forces to see beyond base perimeters and can provide a rapid visual assessment of detected threats.

The Electronic Systems Center's Force Protection System Program Office recently completed delivery of the initial Force Protection Airborne Surveillance System to deployed security forces personnel supporting Operation Enduring Freedom. "This system adds an enhanced layer of protection for bases around the world by allowing forces personnel to see beyond base perimeters," said Colonel Howard Borst, director, Force Protection System Program Office.

Each system consists of a ground station — computer, displays, recorder and communication equipment; six UAVs; a remote imagery viewing terminal; interchangeable payloads of color cameras and thermal imagers for day and night time imagery; in addition to transportation cases and launch equipment. "The system is not intended to be 'backpackable' but it is easily transported by a general purpose vehicle," said Major John Crennan, Delay Denial Systems Division Chief. The UAV, dubbed "Desert Hawk" by Lt. General T. Michael Moseley, commander, 9th Air Force and US Central Command Air Forces, is small in size, light weight and very simple to operate. The airframe is manufactured from damage resistant molded material that is designed for limited field repair. Desert Hawk is able to operate from a 100 × 100 m clearing without a runway. "FPASS was specifically designed to be used by cops," said Major Mike Giger, FPASS program manager. "It extends the range that security forces can monitor without putting troops into harms way," he said. "This system is not intended to replace troops, it is a critical surveillance tool that will protect and save lives by providing essential real time information on potential threats," said Borst. A two-man crew operates the system. To launch the UAV, operators use a bungee cord catapult. The system is powered by rechargeable batteries that have a one-hour life span or if available, can also be operated by using commercial AC power. The UAV is designed to fly primarily at altitudes of 300-500 feet and sends back to the operators' real time overhead video data.

Space System/Loral Selected for Navy's Communication System

Loral Space and Communications announced that the US Navy's Space and Naval Warfare Systems Command (SPAWAR) has awarded a Space Systems/Loral (SS/L) team, led by Raytheon, a $40 M Component Advanced Development (CAD) contract to develop the US Navy's $6 B, next-generation, satellite-based mobile communications system, the Mobile User Objective System (MUOS).

CAD is a 14-month effort aimed at reducing risk and advancing system design concepts that stem from MUOS' recently completed 1999-to-2002 Concept Exploration Phase (CEP). SPAWAR tapped the Raytheon-SS/L team for CAD based on the team performance during the earlier CEP program. The latest award reflects SPAWAR's selection of two teams, which will work in parallel until 2004, when one team will be selected to lead future MUOS efforts.

SS/L is part of a Raytheon-led team that also includes TRW Astro Aerospace and Honeywell. The two teams have been funded by SPAWAR to compete for a system design and development contract to be awarded in January 2004, for construction of the first MUOS satellite, which will be launched in 2008. Subsequently, the MUOS Program Production and Deployment contract will be awarded in mid-2006 and continue through 2023. As part of the newly awarded development program, SS/L will be adapting its highly successful commercial 1300 spacecraft platform for the MUOS narrowband tactical communications System.

"The combination of SS/L's heritage satellite bus with the payload technology and expertise of our team members provides our government with cost-effective improvements in its satellite communications Systems," said C. Patrick DeWitt, president of SS/L. "MUOS will ensure its users an uninterrupted communication link, without concern for the location, weather or local geography."

MUOS will be a narrow band satellite communication (SATCOM) system that supports a worldwide, multi-service/multi-national population of mobile and fixed-site war fighter terminals. Its capabilities will provide a considerable increase in throughput over the current Ultra High Frequency (UHF) Follow-on (UFO) narrow band satellite communications system. It will also provide greater flexibility through improved link performance for users such as Navy Seals and other special forces to operate in difficult environments. SS/L MUOS design is based on the company's space-proven 1300 geostationary satellite platform, which has an excellent record of reliable operation and is highly adaptable to a wide variety of payloads. Over the past 45 years, SS/L satellites have amassed well over 900 years of on-orbit services.

BAE Systems Demonstrate Guided Rocket

BAE Systems successfully launched a 2.75" laser guided rocket using a unique mid-body, fin-mounted, guidance system, scoring a "bull's-eye" hit on a small target more than three miles away from its launch point. The control test vehicle (CTV) was fired Sept. 29 at the Army's Yuma Proving Ground in Arizona for the Army's low cost precision kill (LCPK) program.

During the rocket's flight, the CTV completed a series of preprogrammed flight maneuvers, demonstrating real-time aerodynamic control by the autopilot and inertial sensor. The test vehicle was launched with a fully integrated guidance and control system and semi-active laser seeker to evaluate subsystem performance in flight. The shot followed extensive hardware in the loop testing at the Army's Missile Research and Development Engineering Center facility, Huntsville, AL. The LCPK program is an advanced technology development program to develop prototype laser-based 2.75" guidance sections. BAE Systems Information and Electronic Warfare Systems, Nashua, NH, is working under a $5 M contract to design and develop the guided rocket. ■

Martin Streetly, International Correspondent

BAE Systems C4ISR Delivers First Skynet 5 Terminals

UK contractor BAE Systems Command, Control, Communications, Computing, Intelligence, Surveillance and Reconnaissance (C4ISR) has delivered the first batch of six Talon satellite communications terminals to Paradigm Secure Communications for eventual use in the UK's Skynet 5 military communications satellite system. In all, 15 such terminals will be acquired, with second and third tranches being scheduled for delivery during December 2002 and August 2003, respectively. Skynet 5 (scheduled for introduction by 2010) is being procured via the UK's Private Finance Initiative and will see (as a beginning) the transfer of the existing Skynet 4 from UK Ministry of Defence control to that of Paradigm. This transfer is scheduled to take place during mid-2003.

BAE Systems C4ISR describes Talon as being a lightweight, deployable terminal that is man-portable, makes use of carbon fibre in its construction and can be configured to operate in the C- (4 to 8 GHz), X- (8 to 12.5 GHz), Ku- (12.5 to 18 GHz) and Ka- (26.5 to 40 GHz) bands. Here, the necessary changes are described as being simple and involving the introduction of frequency specific feed arms and some key electronic components. Talon is further noted as being fitted with either a 1.2, 1.9 or 2.4 m antenna dish, with an X-band 1.9 m configuration noted as being able to deliver a G/T value of better than 21 dB/k. The standard terminal includes all the functionality needed to support the required communications link (including antenna control and tracking, frequency conversion and the requisite modem functions) and is packed in four modular cases that can include heaters and cooling elements as required. Again using the 1.9 m dish configuration as an example, the equipment can be set-up in wind speeds of up to 15 m/s, can be operated in winds of up to 16 m/s and will survive gusts of up to 27 m/s.

ESA Launches Most Sensitive Gamma Ray Observatory Ever Built

Billed as the most sensitive gamma ray observatory ever built, the European Space Agency's (ESA) INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL) was launched into an eccentric, 72-hour, 9000 to 155,000 km orbit around the Earth on 17 October 2002. Designed to provide new insights into celestial objects such as black holes, neutron stars, active galactic nuclei and supernovae, the 2 tonne INTEGRAL vehicle is equipped with a payload that includes a spectrometer (known as the SPectrometer on INTEGRAL — SPI), an imager (the Imager on Board the INTEGRAL Satellite — IBIS), an X-Ray monitor (the Joint European X-ray Monitor — JEM-X), an Optical Monitoring Camera (OMC) and an Integral Radiation Environment Monitor (IREM).

Of these, the SPI is designed to perform spectral analysis of gamma-ray point sources and extended regions in the 20 keV to 8 MeV energy range, with a resolution of 2.2 keV at 1.33 MeV. As such, the SPI device incorporates an array of 19 hexagonal, high purity, germanium detectors that are cooled to an operating temperature of 85 K by a Stirling engine. A hexagonal coded aperture mask is located 1.7 m above the detection plane in order to image a 16° section of the sky with 2° angular resolution. In order to reduce background radiation, the detector assembly is shielded by an anti-coincidence system that includes limiting the aperture to approximately 30° and the provision of a plastic veto below the mask to further reduce the 511 keV background. For its part, the IBIS provides fine imaging, source identification and spectral sensitivity to both continuum and broad lines over the 15 keV to 10 MeV energy range. Within the device, a tungsten coded-aperture mask is located 3.2 m above its detection plane and is optimised for high angular resolution. The IBIS detector uses two planes, namely a 2600 cm^2 front layer (made up of 4 × 4 × 2 mm pixels) and a 3100 cm^2 back layer (9 × 9 × 30 mm pixels) that are 90 mm apart. The use of a two-layer detector allows photon paths to be tracked in 3-D as they scatter and interact with more than one element of the array. Events can be categorised and the device's signal-to-noise ratio is improved by rejecting those responses (usually towards the high end of the energy range) that are unlikely to correspond to real celestial photons. The IBIS aperture is restricted by a lead shielding tube and is shielded in all other directions by an active scintillation veto system.

The JEM-X X-ray monitor supplements the SPI and IBIS instruments and is used to detect and identify gamma-ray sources and in the analysis and interpretation of acquired gamma-ray data. Accordingly, JEM-X takes readings simultaneously with those of the SPI and IBIS devices and provides imagery with arcminute angular resolutions within the 3 to 35 keV prime energy band. Its baseline photon detection system consists of two identical high pressure imaging microstrip gas chambers (1.5 bar pressure and made up of 90 percent xenon and 10 percent methane), at a nominal gas gain of 1500. Each detector views the sky through a coded-aperture mask that is located approximately 3.2 m above the detection plane.

JEM-X itself is supported by the OMC which is used to observe optical emissions from INTEGRAL's prime targets at the same time as those targets are being observed by the SPI, IBIS and JEM-X. The remaining instrument — the IREM — is described as performing a wide range of in-orbit radiation monitoring functions and downloading the acquired data via the INTEGRAL vehicle's telemetry system. Overall, the satellite's orbit is designed in such a way as to keep it at an altitude of 40,000 km or above for as long as possible in order to minimise background radiation effects from the Earth's own radiation belts. INTEGRAL's unit cost is put at ¤ 330 million in year 2000 values.

Philips Launches TPMS Chip Solution

In order to meet upcoming US 2004 legislation and a wider perceived global market, Netherlands contractor Royal Philips Electronics has launched a chip-based Tire Pressure Monitoring System (TPMS) that provides the automobile driver with measurements of individual tire pressures and notification of pressure/inflation problems as they arise. TPMS applications have major safety and cost implications in terms of tire-related accidents, levels of tire wear and fuel consumption values. Goodyear calculates that at any given time, one in five vehicular tires is under-inflated by as much as 40 percent. Such irregularities lead to significant alterations in road-holding and braking characteristics, a significant shortening of tire life and an increase in fuel consumption of roughly one percent for every three pounds/in^2 of under-inflation.

The Philips TPMS uses a direct monitoring approach and takes the form of a Tire Module (TM) that broadcasts RF data to a central receiver. Each TM typically comprises an analogue piezo-resistive pressure sensor, a pressure sensor signal conditioning chip and an RF transmitter unit. As applied to the tire, the TM has to withstand a temperature range of from as low as –40° to as high as +150°C and acceleration rates of up to 2000 G. Functionally, the signal from the pressure sensor is amplified and digitised and the full device calibrated and initialised. A P2SC signal processing chip picks up the signal from a sensor bridge, digitises it, measures chip temperature and performs all the required calibration and initialisation. The P2SC chip includes a field proven Reduced Instruction Set Computer (RISC) microcontroller core, minimum power consumption and a wheel identification feature to solve issues of auto-rotation.

After calibration and initialisation, each tire sends its pressure data to the automobile's dashboard and a controller recognises which tire the signal is coming from. A low frequency wake-up approach has been used for tire location and is described as providing immediate and reliable identification. Small, 125 kHz wheel arch antennas are used to send the wake-up signal to the specific TM, which responds via the RF link. Each tire is woken up each time the ignition is switched on. Thereafter, tire pressure is checked at regular intervals and in the event of a sudden pressure drop, a warning is relayed to the driver without the need to wake the system up. Looking to the future, Philips notes that Bluetooth™ technology could have a TPMS application, as could inductive coupling on passive GHz technologies to overcome the need for internal batteries. ■

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■ SWMA-2-50DR	DC-4.5	65	0.7	25	5.30

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Bluetooth to Ramp Up in Market Outside of Mobile Handsets

While mobile handsets are expected to account for approximately two-thirds of the Bluetooth devices that will ship in 2002, and cordless headsets will also be a growing category, Allied Business Intelligence's (ABI) new Bluetooth report notes that there are significant opportunities for Bluetooth semiconductor vendors in other markets, especially computing.

ABI projects that computing devices will account for 21 percent of all Bluetooth-enabled devices that will ship in 2003, with a 27 percent share by 2007. The coming wave of Bluetooth cordless input devices including mice and keyboards will be an important factor in driving PC OEMs to embed Bluetooth functionality. Cordless computing peripherals have shown tremendous growth in recent years and Bluetooth will increasingly displace IrDA and proprietary RF technologies as Bluetooth chipsets continue to drive down the cost curve and exhibit improved power efficiency.

The Wireless Home Network: Room for Multiple Wireless Technologies?

According to a report by In-Stat/MDR, over the last three years, a very rapid wireless evolution has occurred in the home. In 1999 and 2000, the question was whether HomeRF or 802.11 would win in the home. In 2001, the main issue was whether 802.11a (5 GHz Wi-Fi) or 802.11g (2.4 GHz Wi-Fi, higher speed version of 802.11b) would be the technology of choice for the connected home of the future. In 2002, the wireless home landscape has broadened, with a handful of solid wireless technologies showing significant potential for specific applications in the home.

The vision of wireless home networking in the future involves the PC cluster of devices (broadband modem, router/AP device, desktops, laptops, PDAs, Web tablets) becoming wirelessly connected to the entertainment cluster of devices, i.e. audio and visual equipment such as TVs, DVD players, MP3 players, gaming devices and home theater devices such as high end displays and DVRs. Another step in networking the home is home automation, i.e. being able to monitor temperature, security and white goods from a central location. Promising home wireless technologies include Wi-Fi, UWB (Ultra-Wideband), Zigbee (the core technology behind IEEE 802.15.4), wireless 1394, and mesh networking technology.

For the purpose of rapid data transmission across LANs, IEEE 802.11b has gained the hearts and minds of many residential end-users. 802.11b, now in its third year of market shipments, has wowed the home market, pushing HomeRF squarely out of the picture. Low end networking vendors were quick to enter the 802.11b market, bringing with their efforts the two most important features of a home networking technology: (1) low cost and (2) easy configuration. Although the easy configuration feature may be arguable in some cases, most of the low end networking equipment vendors are in their second or third generation of 802.11b products and, after being blasted in many user reviews for configuration difficulties, have improved on their software significantly. Also, now Microsoft, the software giant himself, has entered the home 802.11b hardware fray, citing its user-friendly software configuration layer as its main differentiator.

For the latest coverage of the dynamic home networking market from In-Stat/MDR, check out: http://www.instat.com/catalog/Ncatalog.asp?id=99.

MEMS Offer a Possible Silver Lining for Semiconductor Equipment Suppliers

Given the down turn in the semiconductor equipment market, suppliers are now focusing more intently on the compelling opportunity MEMS fabrication is presenting, according to In-Stat/MDR. There are some 60 MEMS fab/foundries, several hundred start-ups (many of which have their own in-house prototyping and/or fabrication facilities), as well as countless universities and government labs worldwide researching MEMS technology. The high tech market research firm reports that continued unit growth and device diversity, as well as this large potential customer base, is making the MEMS sector a progressively more attractive market for semiconductor equipment manufacturers.

"Equipment for MEMS fabrication is now more available than ever before, ranging from dual purpose (for both semiconductor and MEMS processing steps) to purely MEMS-specific," says Marlene Bourne, a senior analyst with In-Stat/MDR.

One of the biggest competitive factors in the MEMS fabrication equipment market will come from the suppliers themselves — in the form of used equipment. While many start-ups may have funds to install in-house facilities, they often purchase used, rather than new, equipment. As a result, equipment suppliers are finding themselves buying their own old equipment to re-sell it to this particular market sector.

More semiconductor equipment manufacturers are involved in MEMS-specific equipment than would be expected. Several of the top suppliers now have divisions focused solely on MEMS solutions, and no doubt more will emerge in time. There are even several start-ups who have developed and are offering equipment specifically for the MEMS market. Toolsets range from those for deposition, lithography and etching, to wafer bonders, dryers and other equipment.

THE COMMERCIAL MARKET

Cellular Infrastructure Manufacturers to Face Tough 18 Months

The total worldwide count of analog, CDMA, TDMA, GSM, PDC, PHS and UMT base stations will grow at a compound annual growth rate (CAGR) of a mere 13.7 percent through 2006, according to In-Stat/MDR. The high tech market research firm finds that, during this same period, UMTS will lead the growth with 110 percent, with CDMA and GSM expected to come in at a not so very close second and third. All other air links will experience either flat or negative growth.

According to Ray Jodoin, director of In-Stat/MDR's wireless research group, "Over the next 18 months, there might be significant short term delays due to equipment shortages and problems, as well as a significant lack of funding. In addition, a considerable infrastructure manufacturer retrenchment will also occur, and could lead to additional delays because of the necessity to renegotiate contracts." In Stat/MDR also reports that, one year from now, a minimum of two infrastructure manufacturers, in each major market, will no longer be in business and that significant carrier consolidation will also occur during this period. "While the forecast indicates year-to-year growth, 2002 and 2003 should be viewed as extremely volatile," says Jodoin. "If the carrier CAPEX continues to slip, 2002 and 2003 new base station deployment will be down considerably from initial forecasts."

In-Stat/MDR has also found that:

- In 2006, there will be only two major air links deployed on a worldwide basis; CDMA at 20.8 percent share of the market (SOM) and GSM at 69.2 percent SOM. UMTS will have only a 4 percent SOM at that time.
- GSM will dominate with almost 94 percent of deployed European base stations in 2006. However, previous rapid growth is beginning to ebb as subscriber growth diminishes.
- Base station developments in the US will experience a dramatic decline in 2003 as a result of not only the new order downturn that occurred in 2002, but also an anticipated delay in the change over from TDMA to GSM. While activity will occur throughout 2003, systems will not be operational until early 2004.
- Unlike North America, Latin America is expected to continue to depend heavily upon analog and TDMA through 2006. Unless there is a radical transitioning of TDMA to GSM-850, CDMA will be the primary air link at the end of the forecast period in Latin America.
- While PDC will still dominate the Japanese landscape in 2006, NTT DoCoMo and J-Phone will be making rapid market advances with UMTS. Based on current plans, all CDMA deployments will be upgraded to at least 1xEV-DO in order to offer direct competition to UMTS data speeds. ■

INDUSTRY NEWS

■ **Endwave Corp.** has acquired certain wireless infrastructure assets of **Signal Technology Corp.**'s Wireless Group. The acquisition includes customer contracts, equipment, inventory, product designs and other intellectual property, and key personnel needed for the ongoing operation of the business unit. The purchase is expected to enhance Endwave's focus on the commercial wireless infrastructure market.

■ **Sirenza Microdevices** has completed the acquisition of **Xemod**, a designer and supplier of RF amplifier modules for the wireless communication market. Xemod technology extends Sirenza's power component product line to significantly higher power levels and operating voltages for wireless network equipment applications.

■ **M-tron Industries Inc.** has reached an agreement in principle to acquire the assets of **Champion Technologies Inc.**, a manufacturer of crystals and crystal oscillators, from US Bank. The financial details of the agreement were not disclosed.

■ **Superconductor Technologies Inc.** and **Conductus Inc.** have signed a definitive agreement to merge the two companies. The new company will retain the Superconductor Technologies name, and will combine the talent, technologies and assets of the two companies. In addition the companies have secured firm commitments through existing shareholders and affiliated entities for a $15 M investment through a private placement in the combined company, contingent upon the close of the merger.

■ **Yokogawa Corp. of America** has acquired all of the outstanding shares of stock of **Measurementation Inc.** from its affiliated holding company, **Yokogawa USA Inc.** The Yokogawa Group began a relationship with Measurementation in 1997 by purchasing an interest in the analytical systems integrator. Measurementation will operate as a separate division of Yokogawa Corp. of America.

■ **Amphenol Corp.'s Industrial Operations Division** has completed the acquisition of the RADSOK® business unit of **K&K Stamping**. RADSOK technology allows higher amperages to be used in electrical connectors with lower insertion forces, which helps to alleviate millivolt drop and associated temperature rise.

■ **Sensors Unlimited** will purchase certain assets and accept certain liabilities from **Finisar Corp.**'s Sensors Unlimited subsidiary for $6.1 M in cash. The new company will assume the name Sensors Unlimited and the existing management team and employees will remain in place.

■ **Anaren Microwave** has opened an all-new facility in the Suzhou Industrial Park in Suzhou, China, near Shanghai. Called **Anaren Communciations Suzhou Co. Ltd.**, the operation will be staffed by both local talent and personnel relocating from the company's headquarters in East Syracuse, NY. In related news, the company's recently acquired Almelo, Netherlands-based subsidiary **Anaren Europe BV** (formerly 5m Co.) has returned to full-scale operation following a fire in July of 2001. The completely renovated plant features nearly $8 M in leading-edge circuit board production equipment.

■ **Mimix Broadband Inc.** has relocated its corporate headquarters to a new facility in Houston, TX, where it will continue to operate an ISO 9001 certified manufacturing, assembly, test and management facility. The 15,000-square foot facility includes a newly constructed Clean Room used for wafer probe testing of MMICs, die attaching and wire bonding.

■ **K&L Microwave Inc.**, a subsidiary of the **Dover Corp.**, has opened a production facility in Nanjing, China. The facility is located in the Nanjing Economic & Technological Development Zone, one of China's major high technology industrial parks. The location allows for rapid movement of products to all parts of China.

■ **Lamina Ceramics** has opened a state-of-the-art manufacturing facility in Westampton, NJ, to increase production of components, modules, circuit boards and packages utilizing the company's proprietary LTCC-M technology. The 50,000-square foot facility will initially include two production lines.

■ **Chipcon Group AS** has opened a fully-owned subsidiary, **Chipcon Inc.**, in Cupertino, CA. The primary goal of Chipcon Inc. is to expand the presence of the Chipcon Group in the US and to intensify the sales and marketing of Chipcon products in North America.

■ **RF Micro Devices Inc.** and **Jazz Semiconductor** have agreed to enter into a strategic relationship for silicon manufacturing and development. Under the agreement, RF Micro Devices will obtain a guaranteed, lower cost source of supply for wafers fabricated utilizing Jazz Semiconductor's manufacturing processes, including SiGe, BiCMOS and RF CMOS. In related news, RF Micro Devices has begun high volume production shipments of two power amplifiers and a triple-band LNA/mixer to **Sanyo** for use in the new Sanyo SCP-4900 CDMA 2000 1X handset. Shipments began in the June quarter and have reached a multi-million dollar level.

■ **Dow-Key Microwave**, a subsidiary of the **Dover Corp.**, has entered into a strategic marketing and distribution alliance with **Teravicta Technologies** to offer Teravicta's RF MEMS switches worldwide.

■ **Xanoptix** and **Tyco Electronics** announced a multi-year, multi-million dollar joint strategic business agreement to promote Xanoptix's XTM Series of optical transceiver products. The alliance enables the companies to provide the next generation of parallel optics transceiver modules, utilizing optically integrated circuit technology with fused silicon chips and high performance active optics.

[Continued on page 50]

■ **Spectrum Control** and **Littelfuse Inc.** have entered into a teaming agreement. This agreement will create a synergism of the two organizations in the development of a series of integrated passive electromechanical solutions.

■ **Anritsu Co.** has formed a partnership with **Centro de Tecnologia de las Comunicaciones SA** that creates a complete Bluetooth test solution incorporating Anritsu's model ME7865A Bluetooth pre-qualification test system and a discounted qualification process through **CETECOM**, a Bluetooth Qualification Test Facility. In related news, Anritsu's model ME7808A broadband vector network analyzer (VNA) has earned two marketing engineering awards from Frost & Sullivan. The awards recognized the product as the year's most innovative test instrument overall as well as the top VNA, according to independent analysts who conducted extensive evaluations and research on leading measurement instruments.

■ **Advanced Analogic Technologies Inc. (AnalogicTech)** has entered into a distribution agreement with **Future Electronics**. Under terms of the new agreement, Future Electronics will sell and support AnalogicTech's entire Total Power Management product line, including its PowerManager,™ PowerLinear™ and SmartSwitch™ product families.

■ **Ansoft Corp.** has formed an educational partnership with **Carnegie Mellon University's Center for Wireless and Broadband Networking** by donating advanced software for the virtual design of high frequency technology. The in-kind contribution, which begins a three-year partnership between the two, includes an initial donation of Ansoft's HFSS™ and Ansoft Designer™ packages as well as support. In related news, Ansoft launched a campaign to expand the use of its electromagnetic and electrostatic simulation software by offering a free subset of the company's commercially available Maxwell 2D. The software, marketed at Maxwell SV, can be downloaded at www.ansoft.com/maxwellsv.

■ **Texas Instruments Inc. (TI)** has been appointed to the board of directors of the Wi-Fi Alliance as the organization's latest sponsor member helping to promote and expand the global Wi-Fi market. TI has been a contributing general member of the Wi-Fi Alliance since its acquisition of Alantro Communications in September 2000.

■ The microwave antenna products formerly produced by **TriPoint Global Communications'** Mark Antenna business will be manufactured under the Prodelin brand. The company will discontinue the use of the Mark Antenna name and brand.

■ **AMI Semiconductor** announced that its operation in Belgium achieved ISO/TS 16949 certification. ISO/TS 16949, coupled with customer-specific requirements, defines quality system requirements for use in the automotive supply chain.

■ **Sprague-Goodman Electronics Inc.** recently commemorated its 30th anniversary with a celebration ceremony at the company's Westbury, NY, headquarters.

■ **Cole Tubes Ltd.** is offering to help customers of the precision drawn products manufacturer **H Rollet** and subsidiary **Blackheath Tube**, which went into receivership on September 5, 2002.

FINANCIAL NEWS

■ **Linear Technology Corp.** reports sales of $142.01 M for the first quarter ended September 29, 2002, compared to $120.10 M for the same period in FY 2002. Net income was $53.8 M (17¢/diluted share), compared to $45.2 M (14¢/diluted share) for the first quarter of last fiscal year.

■ **RF Micro Devices Inc.** reports sales of $119.7 M for the second quarter ended September 30, 2002, compared to $98.3 M for the same period in 2001. Net income was $6.5 M (4¢/diluted share), compared to $1.5 M (1¢/diluted share) for the second quarter of last year.

■ **TESSCO Technologies Inc.** reports sales of $70.4 M for the second quarter ended September 29, 2002, compared to $62.0 M for the same period in 2001. Net income was $1.2 M (26¢/diluted share), compared to $900 K (20¢/diluted share) for the second quarter of last year.

■ **REMEC Inc.** reports sales of $53.5 M for the second quarter ended August 3, 2002, compared to $60.4 M for the same period in 2001. Net loss was $16 M (35¢/diluted share), compared to a net loss of $15.4 M (34¢/diluted share) for the second quarter of last year.

[Continued on page 52]

■ **Stratex Networks Inc.** reports sales of $52.6 M for the second quarter ended September 30, 2002, compared to $60.9 M for the same period in FY 2002. Net loss was $4.4 M (5¢/share), compared to $56.5 M (72¢/share) for the second quarter of last fiscal year.

■ **Cree Inc.** reports sales of $48.8 M for the first quarter ended September 29, 2002, compared to $43.2 M for the same period in FY 2002. Net income was $3.9 M (5¢/share), compared to $6.5 M (9¢/share) for the first quarter of last fiscal year.

CONTRACTS


▲ Harry Cunningham & Jim Zanello

■ **Harry Cunningham** and **Jim Zanello** have accepted consulting contracts with Thunderline-Z. After selling the co-owned Thunderline-Z business to the Fusite Division of Emerson in 2000, Cunningham and Zanello will be working in consultative VP of sales and engineering roles. The two started Thunderline-Z in 1984. Terms and financial details of the contracts were not disclosed.

■ **Boonton Electronics**, a wholly-owned subsidiary of **Wireless Telecom Group Inc.**, has been awarded an additional contract with the Federal Aviation Administration (FAA) for Boonton's 4530 series RF peak power meter, supporting the FAA's latest projects on air traffic control. The power meter is utilized by the FAA for its newest beacon system, ATCBI-6, for transponder queries in airplanes.

■ **Nurad Technologies** has been awarded a contract by Lockheed Martin to provide antennas and radomes for the Peace Marble V F-16 program. Nurad, part of the Chelton Microwave Group, will design and develop this antenna suite, which will interface with the electronic warfare system.

PERSONNEL

■ **Terry Nisbet** joined United Monolithic Semiconductors (UMS) as chief operating officer. He will be a member of the management board of UMS and his main tasks will be to help the company adapt to the challenges of the market place, strengthen its position and to improve the support UMS gives to customers.

■ Modelithics Inc. has named **Jerry Schappacher** to its company board of directors. Shappacher brings more than 20 years of engineering and entrepreneurial experience. He is the founder and current president of J-micro Technologies.

■ RF Micro Devices Inc. has appointed **Frederick J. Leonberger** to its board of directors. Leonberger is a senior VP and chief technology officer of JDS Uniphase Corp.

■ StratEdge announced that **Ralph Nilsson** has been appointed the new president of the company's Taunton, MA, division. The Taunton Division designs and manufactures hermetic glass-to-metal seal, flatpack, plastic equivalent packages and metal packages for telecommunications. Nilsson has 20 years of experience working in engineering, manufacturing and assembly, sales and marketing, operations, and quality control for microwave products.

■ MEMGen Corp. has appointed **Kang Sun** as VP, business development. With 15 years of experience growing companies and building strategic alliances worldwide, Sun will lead the company's sales and strategic partnership efforts.


▲ Paul Leo

■ **Paul Leo** has joined Spectrum Control as director of new business development for the new Spectrum FSY Microwave line of products. In this position he is responsible for all sales activities and business growth related to the company's microwave product line. Prior to joining Spectrum, Leo was employed for over 17 years at K&L Microwave, most recently holding the position of director of new business development.

■ Analog Devices Inc. has appointed **Serge Recoules** as managing director of European sales and marketing. Re-

[Continued on page 55]

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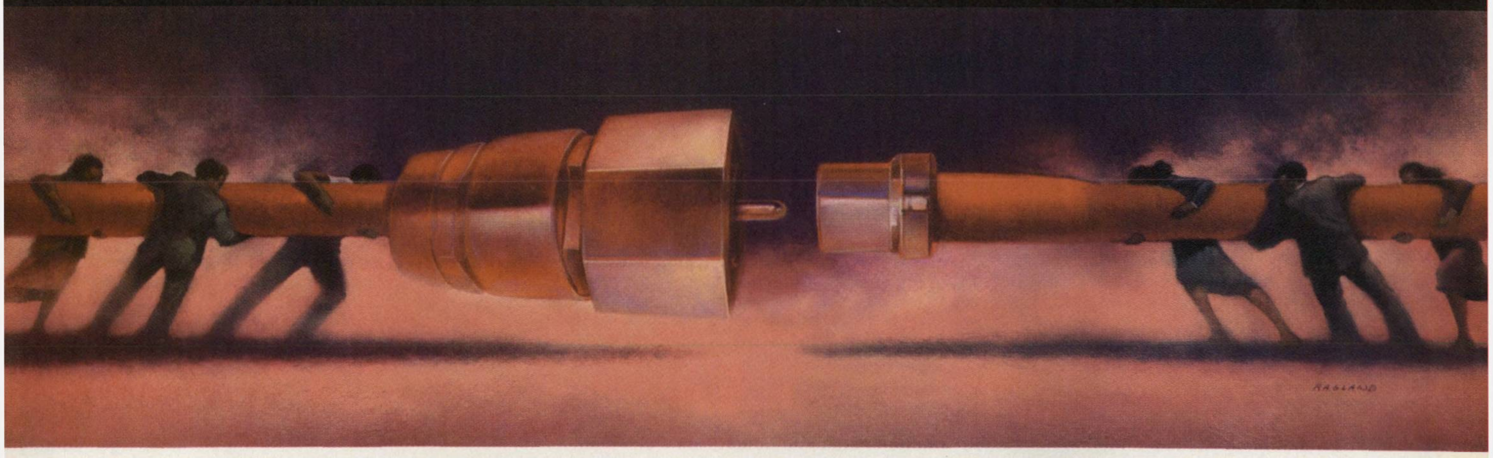

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coules will be responsible for leading the company's European sales effort, managing an experienced team of sales people across the region.


▲ Stuart Hendry

■ Link Microtek has promoted **Stuart Hendry** to the position of sales manager. Hendry joined the company in 1996 as sales manager for the North and Midlands.

■ Ceramaseal has named **Grant Schrag** its product development engineer at the New Lebanon, NY,-based facility. Previously, Schrag worked 12 years with MDC Vacuum Products Corp. and more specifically the Insulator Seal Division.

REP APPOINTMENTS

■ **MICRO-COAX**, Pottstown, PA, has appointed **Promark Electronics Inc.** as its exclusive distributor for Canada. Promark will represent MICRO-COAX's full line of semi-rigid products.

■ **Phase One Microwave Inc.**, Rocklin, CA, has made a series of rep appointments. **Technology Marketing Associates** will handle the Carolinas, Tennessee, Mississippi, Alabama, Georgia and general accounts in Florida, while **Microwave Component Sources** will handle specific target accounts in Florida. **TriTex Technical Sales** will cover Texas, Oklahoma, Arkansas and Louisiana, and **Calin-Southwest** will be responsible for Arizona, New Mexico and El Paso. **Rep Sales** will handle Utah, Colorado, Wyoming and eastern Idaho.

■ **Plextek Ltd.** has signed a UK distribution agreement with **Admiral Microwave Ltd.** Admiral will be promoting Plextek's wide ranging electronics to microwaves design expertise and will now be in a position to offer a complete service to customers looking for system and RF subsystem solutions or an extended component characterization.

■ **AMCOM Communications Inc.** has made a series of representative appointments. **E-Squared Marketing Inc.** will handle New York/Long Island, northern New Jersey and southern Connecticut. Internationally, **Nexos Electronic Systems Srl** will be the exclusive representative for Italy and **Matec Electronique** for France.

WEB SITE

■ **PolarFab** has launched a new, fully upgraded Web site at www.polarfab.com. Designed to provide technical and real-time manufacturing information to fab-lite, fables and independent device manufacturers, the site features an easy-to-use, secure customer access center for customers to view current inventory status and testing data. The site also provides extensive technical information such as application notes for each of the company's bipolar and BiCMOS process technologies.

UNDERSTANDING W-CDMA MODULATION QUALITY MEASUREMENTS

There are many ways of characterizing W-CDMA transmitter performance. However, the Third Generation Partnership Project (3GPP) specifications require two measurements to verify the in-channel modulation quality of W-CDMA transmitters — error vector magnitude (EVM) and peak code domain power (peak CDE). This article explores the purpose behind these key transmitter modulation quality conformance measurements for W-CDMA user equipment, why they are important and the relationship between them.

In constant-amplitude modulation schemes such as Gaussian minimum shift keying (GMSK), phase and frequency error are the metrics for modulation quality. However, this metric is not very effective for non-constant amplitude modulation formats that can also have errors in amplitude. The accuracy of non-constant amplitude modulation schemes such as quadrature amplitude modulation (QAM) and quadrature phase-shift keying (QPSK) can be assessed effectively by looking at the constellation of the signal. Signal impairment can be objectively evaluated by taking the displacement of each measured symbol from the reference position as an error vector (or phasor). The error vector is the vector difference between the measured and reference vectors, and the reference position is determined from a reference signal that is synthesized by demodulating the data bits from the received signal and remodulating these bits "perfectly."

The EVM is defined as the square root of the ratio of the mean error vector power to the mean reference power, expressed as a percentage:

$$\mathrm{EVM} = \sqrt{\frac{\sum_{n=0}^{N-1} \left| \overrightarrow{\mathrm{error\_vector}(n)} \right|^2}{\sum_{n=0}^{N-1} \left| \overrightarrow{\mathrm{reference\_vector}(n)} \right|^2}} \bullet 100\%$$

When evaluating the modulation accuracy of W-CDMA signals, it becomes evident that this definition of EVM, while sufficient for ordinary QPSK or QAM, needs further elaboration. Questions arise such as whether EVM should be measured at the chip or at the symbol level, whether it should be measured for a signal with a single dedicated physical data channel (DPDCH) or with another channel configuration, and how the reference should be calculated. As a result, there are three types of EVM measurements — QPSK EVM, composite EVM and symbol EVM.

The EVM measurement described in the 3GPP specifications corresponds to a composite EVM measurement. Although QPSK EVM and symbol EVM are not required, they can be useful when designing and troubleshooting a W-CDMA transmitter. The differences and benefits of each EVM measurement are explained below.

QPSK EVM

A W-CDMA uplink signal can consist of one dedicated physical control channel (DPCCH) and several DPDCHs. Each channel is binary

[Continued on page 59]

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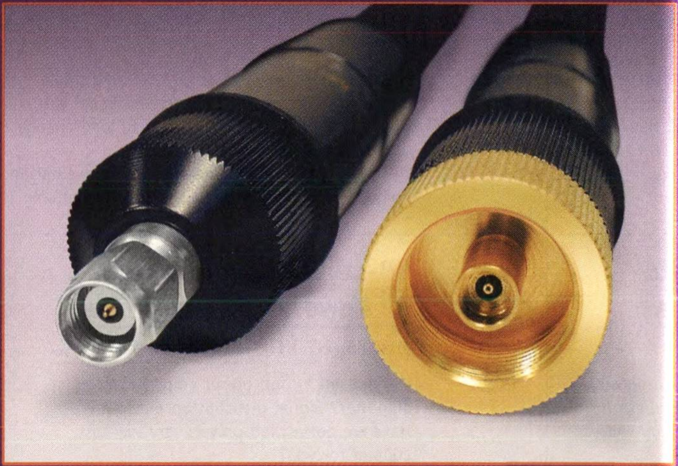

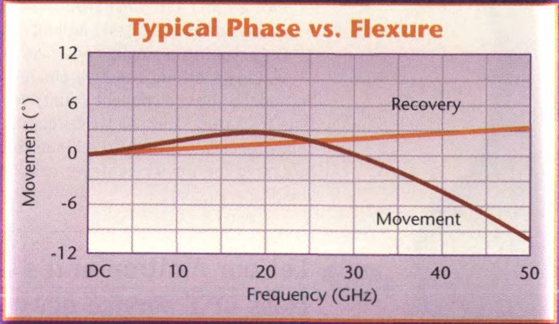

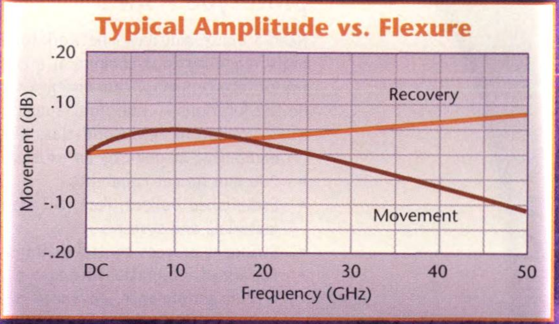

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phase-shift keying (BPSK) encoded, assigned to either the I or the Q paths, and spread with an orthogonal variable spreading factor (OVSF) code. The individual BPSK channels for each path are typically added at this point, and the complex-valued chip sequence is hybrid phase-shift keying (HPSK) scrambled. The resulting chip sequence is then root raised cosine (RRC) filtered, and the result is applied to the QPSK modulator. Since multiple amplitude levels are applied to the I and Q paths of the modulator, the final constellation does not usually look like QPSK or any other known constellation.

However, there are a few channel configurations that map onto a QPSK constellation. A single DPCCH (or DPDCH), for example, results in a QPSK constellation after the HPSK scrambling. A signal with a DPCCH and a DPDCH at the same power level maps onto a 45° rotated QPSK constellation. The rotation is caused by the complex scrambling. Since the receiver does not care about the absolute phase rotation, it effectively sees a QPSK constellation. The modulation quality of a single-channel signal (or other simple channel configurations) can be evaluated at the scrambled chip level with a QPSK EVM measurement.

The QPSK EVM actually compares the measured filtered samples with the filtered samples for an ideal QPSK reference. The filtered sample reference signal is calculated by obtaining the ideal scrambled chips. The QPSK EVM measurement does not descramble and despread the signal into symbols and back into chips to calculate the reference. Consequently, the ideal scrambled chips that are obtained are really uncoded chips.

The signal under test is downconverted (the baseband I and Q signals are recovered and sampled), and passed through an RRC receiver filter. In order to calculate what the ideal chips are, the measurement algorithm assumes that they are going to map onto a QPSK constellation, so the measured samples go through a decision process that can be considered a QPSK decoder. This process samples the chip timing and decides to which QPSK state they correspond. This is equivalent to obtaining the "ideal" chips. Like any other QPSK decoder, the algorithm assumes that the error will be small enough for the sample to fall onto the correct quadrant. Once the ideal uncoded chips are obtained, they are QPSK encoded again (assigned to the reference QPSK states), and passed through a raised cosine (RC) filter that is equivalent to the filtering experienced by the measured signal.

The QPSK EVM measurement is the starting point for the RF engineer. Before all the baseband algorithms are ready, the RF designer can evaluate the performance of the RF section by analyzing the trajectory of the baseband samples. Errors such as phase modulation or in-channel spurious content can be detected by looking at displays such as the constellation, phase error versus time, or error vector spectrum. The QPSK EVM measurement can also identify I/Q errors and linear impairments in the baseband filtering.

The QPSK EVM measurement can also be used by the system integrator to

[Continued on page 61]

troubleshoot the design when other measurements are failing. This may occur, for example, if the spreading and scrambling algorithms or the synchronization algorithms are not working properly. A correct QPSK EVM measurement will confirm that the problem does not occur in the RF section, so it must lie somewhere in the spreading or scrambling algorithms.

COMPOSITE EVM

Although measuring EVM for a signal with a single DPCCH (or other simple channel configuration) may be useful, in general the overall modulation quality of the transmitter for any channel configuration is the point of interest. The constellation of this signal will vary depending on its channel configuration. The composite EVM measurement evaluates the modulation quality of the signal regardless of its channel configuration. To synthesize a reference signal for the uplink signal, the active channels must be identified and despread to the encoded bit level, and EVM is calculated only for the scrambled chip samples.

After the baseband I and Q signals are recovered and filtered, the signal is descrambled and the active channels are identified, despread and BPSK-decoded to bits. The BPSK decoding refers to the assignment of "0"s and "1"s for either the I or Q path depending on the symbol amplitude values obtained for that path after the despreading. It actually corresponds to a bit detection process. The composite EVM measurement algorithm does not perform the complete decoding (deinterleaving, etc.) of the encoded bits. Instead, the reference signal is built from those encoded bits assumed to be correct. So if errors occur during the signal coding and interleaving, they will not be reflected in the measurement result.

In order for the measurement to identify the active channels and despread the channels correctly, it must synchronize to the DPCCH pilot sequence. A correct DPCCH pilot bit pattern is essential to make accurate measurements. As required by the W-CDMA 3GPP specifications, "the square root of the ratio of the mean power of the error signal to the mean power of the reference signal" is computed and expressed as a percentage EVM. In other words, EVM is defined as the ratio of the RMS power of the error vector to the RMS power of the reference signal. The error vectors are calculated only for the samples at the chip times. The algorithm described in the specifications includes descrambling and despreading of the signal, so it is suitable for measuring composite signals, and the specifications require an EVM measurement interval of one time slot.

The 3GPP specifications also describe the channel configuration to perform the modulation quality conformance test (EVM). The channel configuration is the 12.2 kbps uplink reference measurement channel, which consists of a DPDCH and a DPCCH. The DPCCH is –5.46 dB lower than the DPDCH. The specifications require an EVM better than 17.5 percent. The modulation quality test of the 12.2 kbps uplink reference measurement channel, as required by the specifications, is shown in

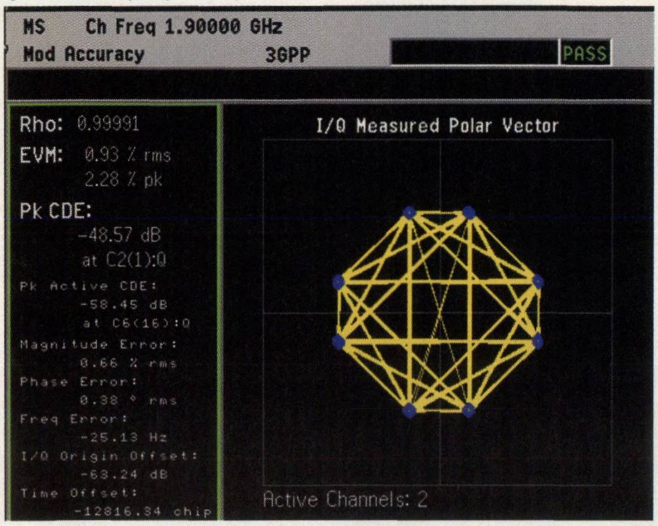
[Continued on page 63]

Figure 1. In addition to conformance testing, there are several main applications for which the composite EVM measurement (and its related displays and metrics) would be used instead of a QPSK EVM measurement.

EVALUATION OF THE QUALITY OF THE TRANSMITTER FOR A MULTI-CHANNEL SIGNAL

This is particularly important for RF designers, who need to test the RF section (or components) of the transmitter using realistic signals with correct statistics. In general, the peak-to-average power ratio of the signal increases as the number of channels increases. By measuring modulation quality on a multi-channel signal, the performance of the RF design for W-CDMA uplink signals with different loading can be evaluated. An example of a composite EVM measurement on a signal with the DPCCH and three DPDCHs is shown in ***Figure 2***.

Fig. 1 Modulation quality test of the 12.2 kbps uplink reference measurement channel.



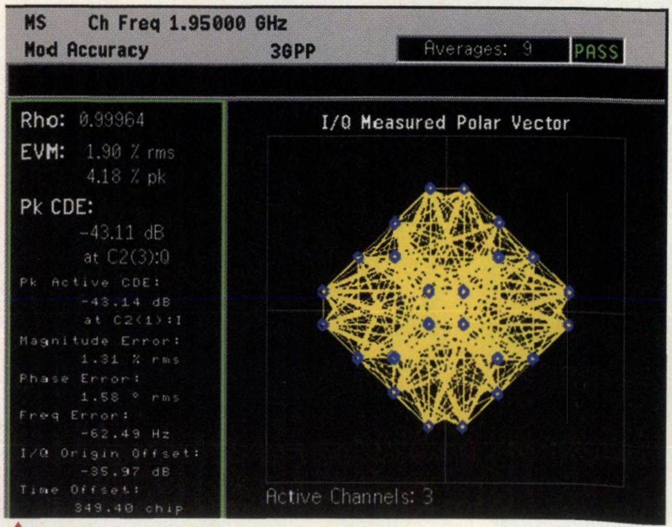


Fig. 2 Example of a composite EVM measurement on a signal with the DPCCH and three DPDCHs.

[Continued on page 65]

ANALYZING ERRORS THAT CAUSE A HIGH INTERFERENCE LEVEL IN THE SIGNAL

If the interference level is too high, the QPSK EVM algorithm may not be able to determine the ideal reference. In this case, QPSK EVM is not accurate. The composite EVM measurement descrambles and de-spreads the signal, so it takes advantage of its spreading gain. The true reference is recovered even when the signal is well beyond the interference level that will cause multiple chip errors. This allows system integrators to verify the minimum allowable modulation quality of the transmitter in order for the BTS (signal analyzer) to demodulate the signal in realistic field environments.

DETECTING SPREADING OR SCRAMBLING ERRORS

Depending on the degree of the spreading or scrambling error, the test equipment may show an intermittent or permanent unlocked condition for the composite EVM measurement. When this problem occurs, the QPSK EVM measurement can be used to confirm that the rest of the transmitter is working as expected. If the scrambling or spreading error does not cause an unlocked composite EVM measurement condition, the error vector versus time display can be used to find the problematic chip. This is mainly useful to baseband engineers and system integrators.

SYMBOL EVM

Symbol EVM provides the constellation and EVM for a specific code channel at the symbol level, even in the presence of multiple codes. An impairment that affects symbol EVM will also affect the composite EVM. For example, an amplifier compression problem will appear both in the composite EVM and in the symbol EVM measurement. However, because of the spreading gain, symbol EVM will attenuate the impairment. Symbol EVM is used because it provides the bridge between RF and the demodulated bits. Since it includes the spreading gain, it provides a measure of modulation quality that determines the error rate for that code channel.

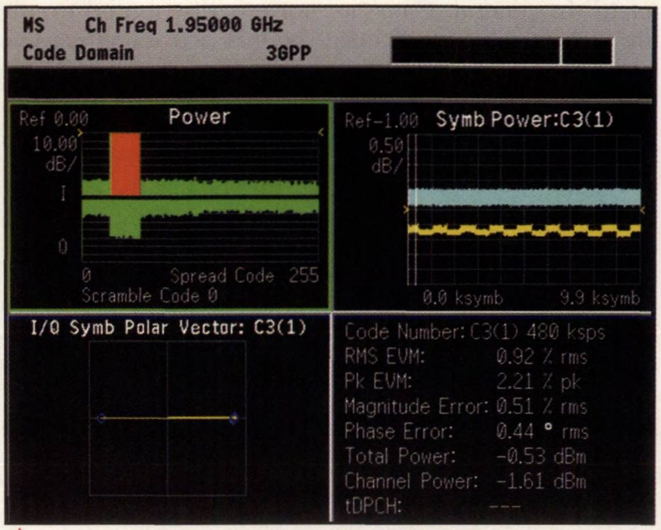
The relationship between symbol EVM and EVM at the chip level depends on the spreading factor. At low spreading factors (high data rates), chip modulation errors have a significant effect on symbol EVM, but at high spreading factors, chip modulation errors have very little effect on symbol EVM. In that sense, symbol EVM is particularly useful for baseband engineers for evaluating symbol quality and analyzing how specific impairments affect the quality of dedicated physical channels at different data rates.

Another advantage of symbol EVM versus composite EVM is that the former typically provides analysis over longer periods of time. For the same amount of measurement points, the symbol EVM measurement covers longer periods of time than the single slot composite EVM conformance measurement. In the case of symbol EVM, the measurement in-

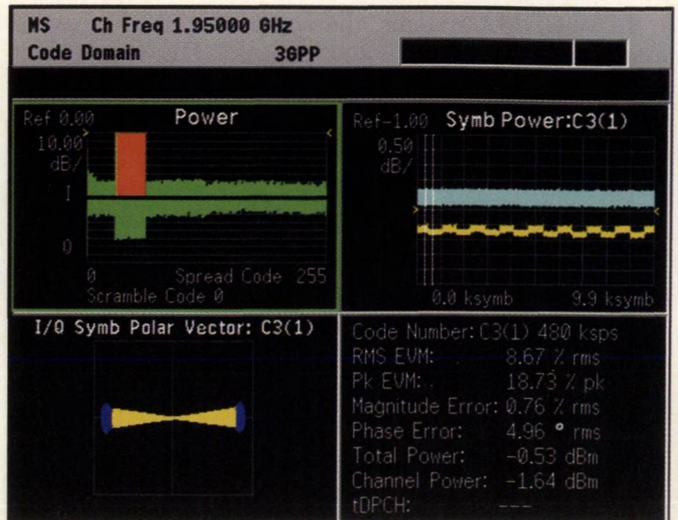
[Continued on page 67]

terval can usually be selected from 1 time slot to 30 or 60, depending on the number of frames captured. The time slot offset can also be selected.

For example, ***Figure 3*** shows the code domain power and symbol EVM for a W-CDMA uplink signal with a DPDCH and a DPCCH and with a periodic phase instability problem. The symbol EVM measurement is performed on the DPDCH for one time slot. ***Figure 4*** shows the symbol EVM measurement for the following time slot. In this case, the symbol EVM result varies a lot from time slot to time slot (0.92 versus 8.67 percent), an indication that the signal should be analyzed over a longer peri-



▲ *Fig. 3 Code domain power for a W-CDMA uplink signal with a DPDCH and a DPCCH and a periodic phase instability problem.*



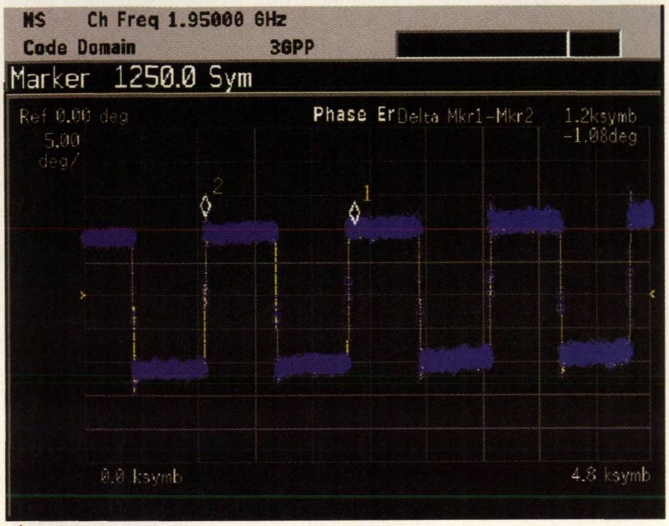
▲ *Fig. 4 The symbol EVM measurement for the succeeding time slot.*

[Continued on page 68]

od of time. ***Figure 5*** shows the phase error versus time display for the DPDCH over 15 time slots. The period of the interfering signal that is causing the phase problem can be calculated from this display. In this case, the interfering signal is a square wave and its frequency is 400 Hz.

PEAK CDE

In W-CDMA systems, the composite EVM measurement has been supplemented by peak CDE, which specifies a limit for the error power in any one code. In the case of phone conformance testing, this test is only required when multi-code transmission is provided. The phone must be configured with the UL 768 kbps reference measurement channel (which is the only UL reference measurement channel with two DPDCHs).

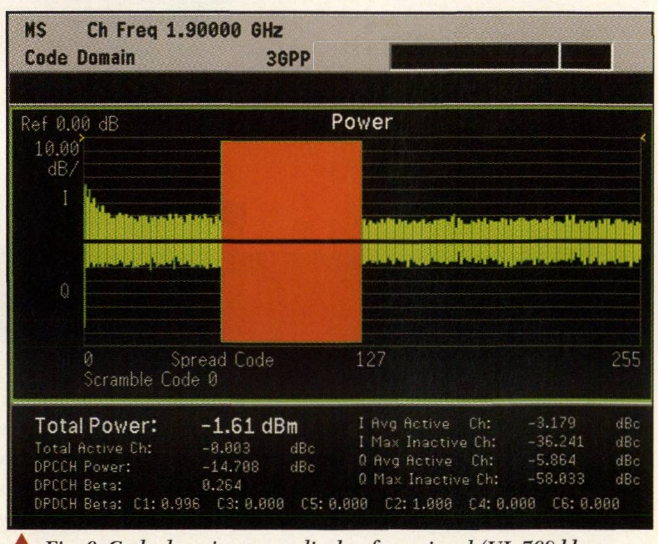


▲ *Fig. 5 Phase error vs. time for the DPDCH over 15 time slots.*

CDE is a projection of the error vector in the code domain. The projection of the error is interesting because it shows how the error power is distributed in the code domain. In general, Gaussian noise is distributed evenly throughout the code domain (both in active and inactive channels). Instead, transmitter impairments cause an uneven CDE distribution, where the larger errors concentrate on active channels, or in the case of a few specific impairments, in certain inactive channels. The error power should be evenly distributed throughout the code domain (as Gaussian noise), rather than concentrated in a few codes to avoid code-dependent channel quality variations.

One cause of unequal distribution of error power is LO instability. In essence, energy is lost from the active channels and appears in those channels with codes that are closely related to the active channel codes. In the case of OVSF codes, LO instability results in higher code domain noise for channels with the same codes as the active code channels but with different I/Q path. The error energy may also fall in channels consecutive to the active code channels, whether at the same or different I/Q paths, as shown in ***Figure 6*** for a UL 768 kbps reference measurement channel (one DPCCH and two DPDCHs) signal with an LO phase instability problem.

The algorithm to calculate the CDE first goes through the composite EVM measurement. As part of this measurement, the error vector at the scrambled chip level is generated. This error vector is a composite error, so in order to obtain the error energy for each code channel, the composite error must be projected onto the code domain. As requested by the W-CDMA user equipment (UE) conformance test specifications for the peak CDE test, the projection is only performed for a spreading factor SF = 4. The error will thus be projected onto the four code chan-



▲ *Fig. 6 Code domain power display for a signal (UL 768 kbps reference measurement channel) with a phase instability problem.*

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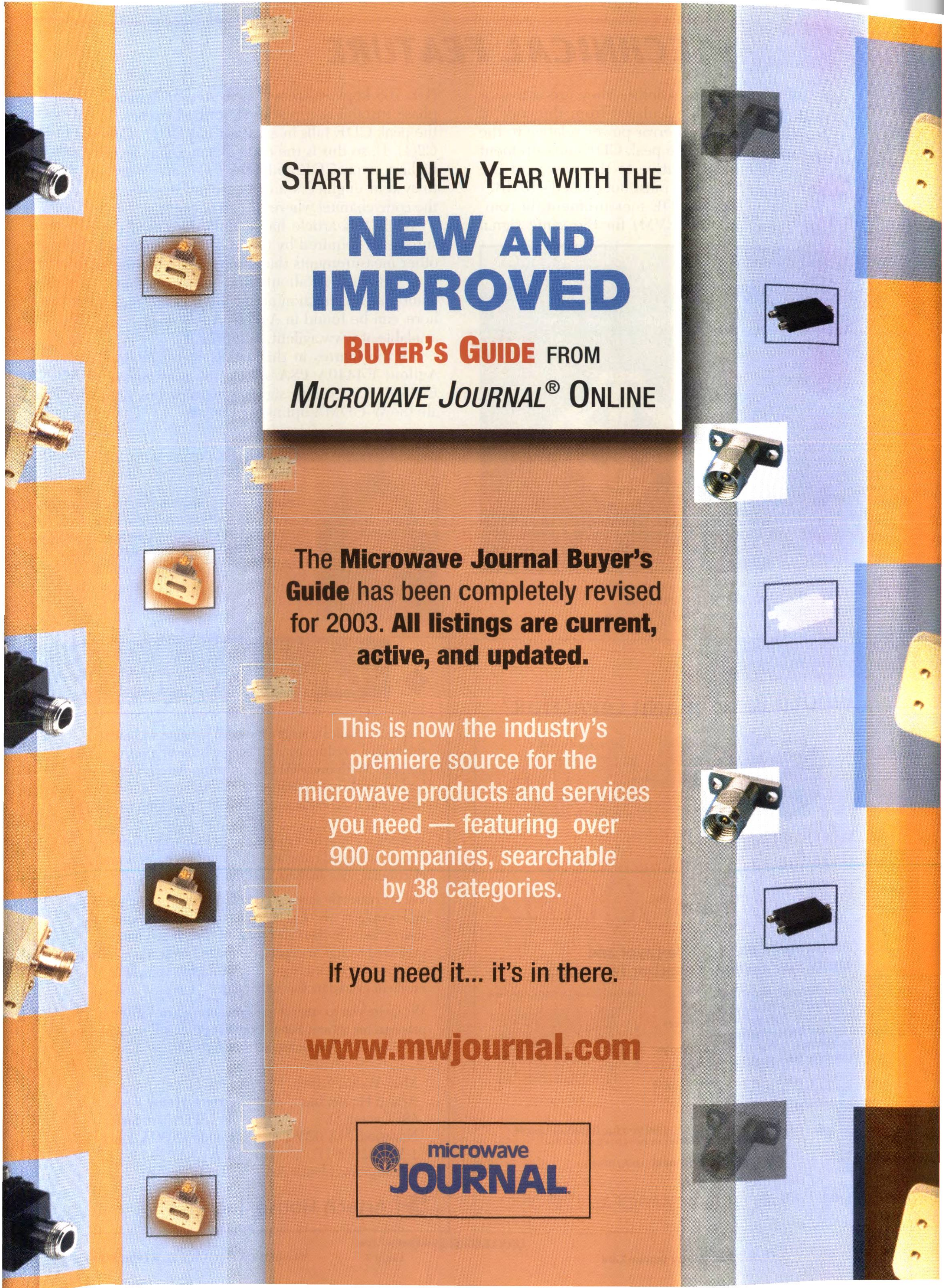
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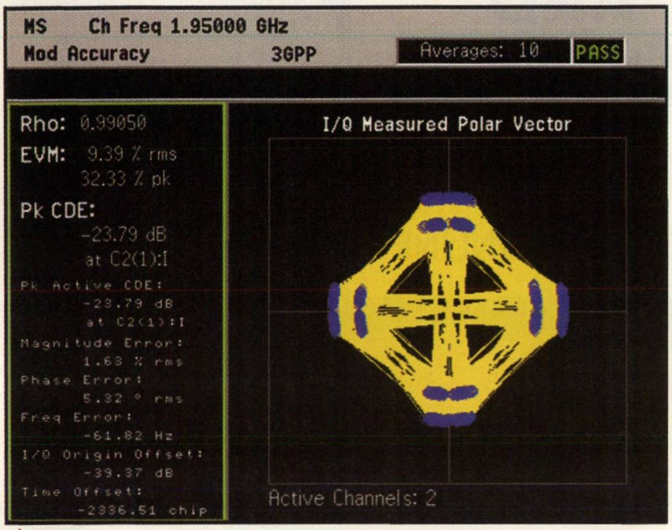
nels at SF = 4, regardless of whether they are active or not. The peak CDE is then calculated from the code at SF = 4 that returns the largest error power relative to the composite reference signal. The peak CDE measurement is expressed (in decibels) relative to the power of the composite reference. The error must not exceed –15 dB.

Figure 7 shows the peak CDE measurement (in combination with the composite EVM) for the same signal (UL 768 kbps reference measurement channel) with the phase instability problem described earlier. In this case, the peak CDE falls in an active DPDCH (Cch, 4,1 in I or C2(1): I), so this is the code channel that accumulates the highest error. CDE and peak CDE are mainly of interest to system engineers and baseband engineers to identify the code channel where the error occurs.

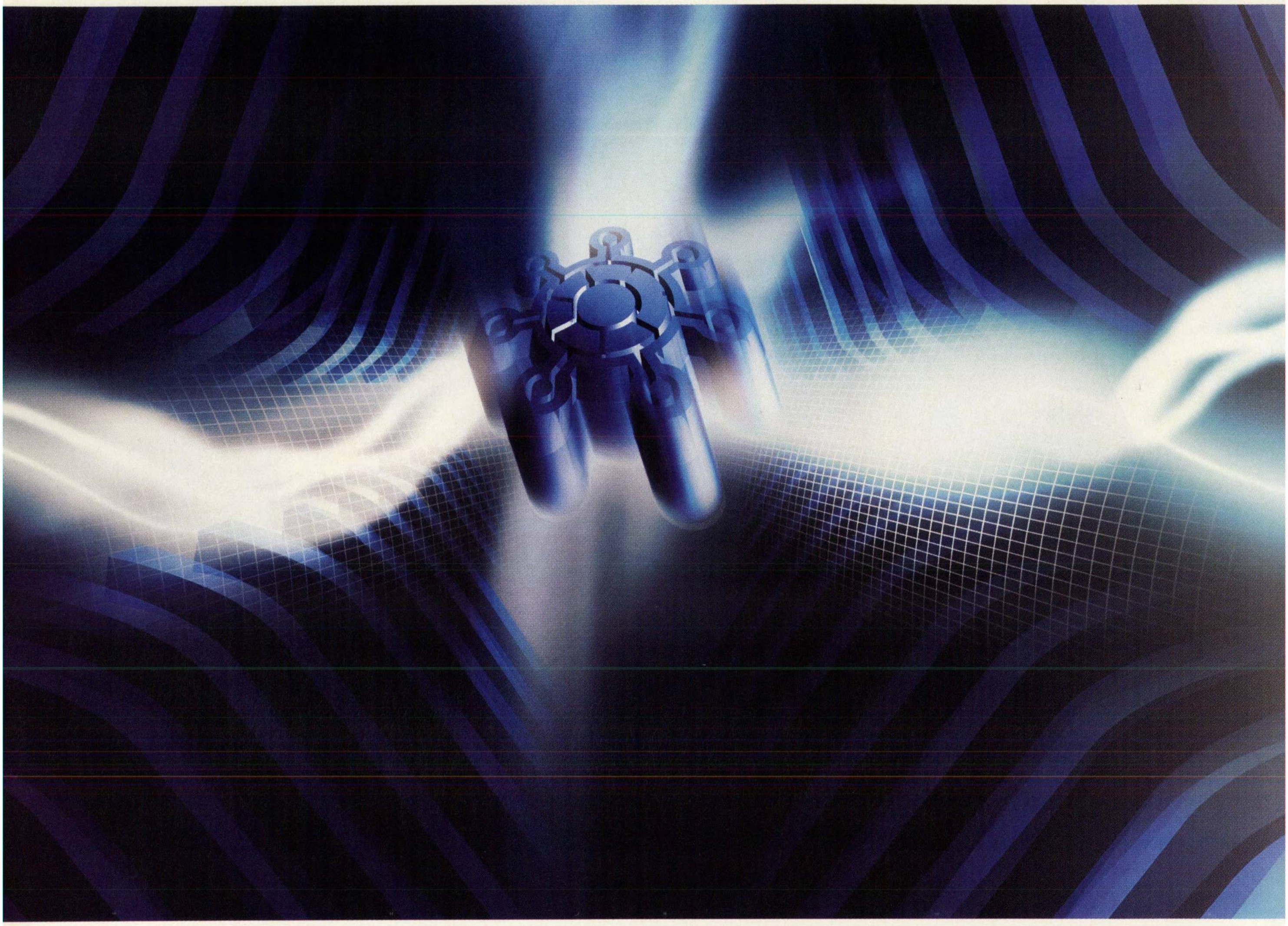


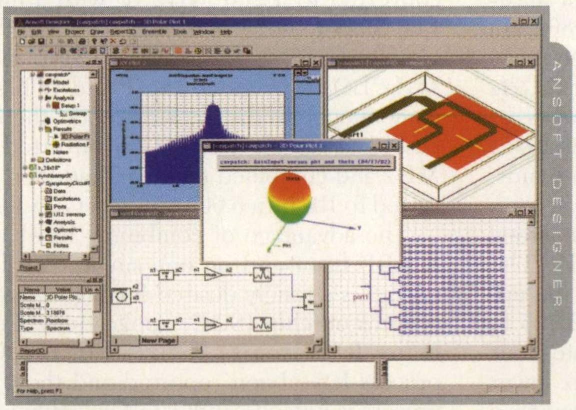
▲ *Fig. 7 Peak CDE measurement (in combination with the composite EVM) for the UL 768 kbps reference measurement channel signal of Figure 6.*

While this article has mainly described the two measurements required by the 3GPP specifications, there are other measurements that also can provide useful information. Information about these measurements, as well as additional information about the measurements discussed here, can be found in Agilent Application Note AN-1356, available at www.agilent.com/find/3G.

All the figures in this article were obtained from the Agilent E4440A PSA spectrum analyzer. The Agilent E4438C ESG vector signal generator was used to generate the W-CDMA uplink signals. ■

Marta Iglesias *holds her BSEE degree from the Universitat Politecnica de Catalunya, Spain. She has performed technical support for RF and microwave spectrum analyzers, and is currently a wireless industry marketing engineer for Agilent Technologies, where she is responsible for understanding the test needs of the wireless communications industry.*





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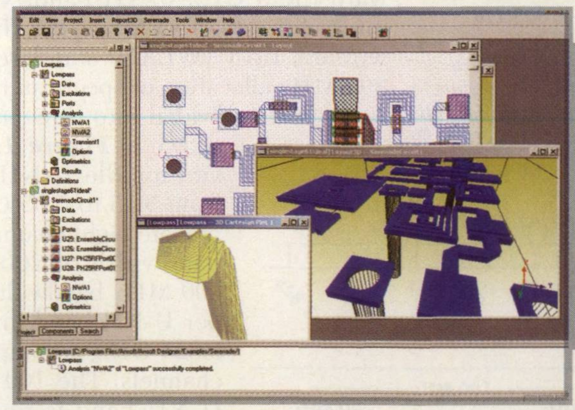

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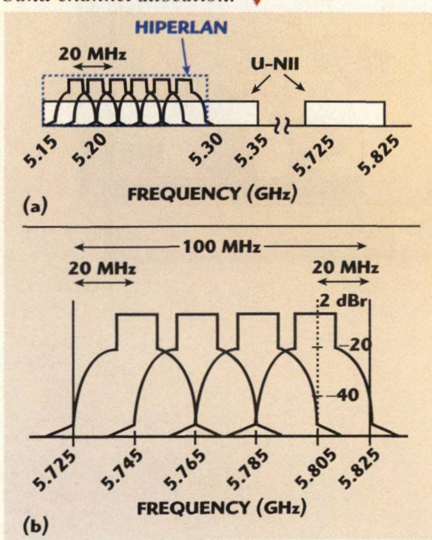
A Fully-Integrated 5 GHz 0.18 μm CMOS VCO for 802.11a WLAN Applications

This article presents a fully-integrated 5 GHz CMOS voltage-controlled oscillator (VCO) for a U-NII band 802.11a WLAN application. The VCO core circuit uses only PMOS fabricated with the 0.18 μm 1P6M standard CMOS process to obtain better phase noise performance since PMOS has a lower 1/f noise level than NMOS. The circuit measurement is performed using an FR-4 PCB test fixture. The power consumption of the VCO, excluding buffer amplifiers, is 8.1 mW at V_{DD} = 1.8 V. The output frequency of the VCO varies from 5860 to 6026 MHz giving a 166 MHz tuning range. The phase noise is -95.6 dBc/Hz at a 300 kHz offset.

Due to the fast growing demand for broadband wireless communications, the operating frequency is moving toward the 5 GHz U-NII band. With a maximum data rate of 54 Mbps, the IEEE 802.11a wireless LAN (WLAN) standard specifies a 300 MHz allocation of spectrum in the 5 GHz range that is divided into three sub-bands, as shown in **Figure 1**.[1] The lower and middle U-NII sub-bands, from 5.15 to 5.35 GHz, accommodate eight channels in a total bandwidth of 200 MHz. The 100 MHz bandwidth of the upper U-NII band, from 5.725 to 5.825 GHz, accommodates four channels. The 100 MHz lower U-NII band is restricted to a maximum power output of 40 mW, and the middle and upper sub-bands are restricted to 200 and 800 mW, respectively. The 802.11a WLAN frequency allocation overlaps with HIPERLAN from 5.15 to 5.3 GHz.

Fig. 1 IEEE 802.11a and HIPERLAN frequency allocations; (a) 802.11a and HIPERLAN overlap, and (b) 802.11a upper sub-band channel allocation.



The proposed heterodyne transceiver architecture for an 802.11a WLAN application (5.725 to 5.825 GHz) is shown in **Figure 2**. In the receive mode, the RF (5.725 to 5.825 GHz) is downconverted to a 200 MHz IF with a high side LO (5925 to 6025 MHz). In addition, the center frequency is translated to zero by a 200 MHz LO to produce the I and Q baseband components. In the transmit mode, the I and Q baseband signals are first upconverted to 280 MHz and combined together, and then upconverted to RF by a 6.005 to 6.105 GHz LO.

The advantage of combining baseband and the RF front-end on one single chip for cost savings is strongly desired for highly integrated systems-on-chip (SOC) applications. Recently, many RF circuits realized in the CMOS process have been reported and the 0.18 μm process is a good candidate for highly integrated SOC applications. The requirements of low power and low cost push the trend toward a single radio chip. A fully-integrated voltage-

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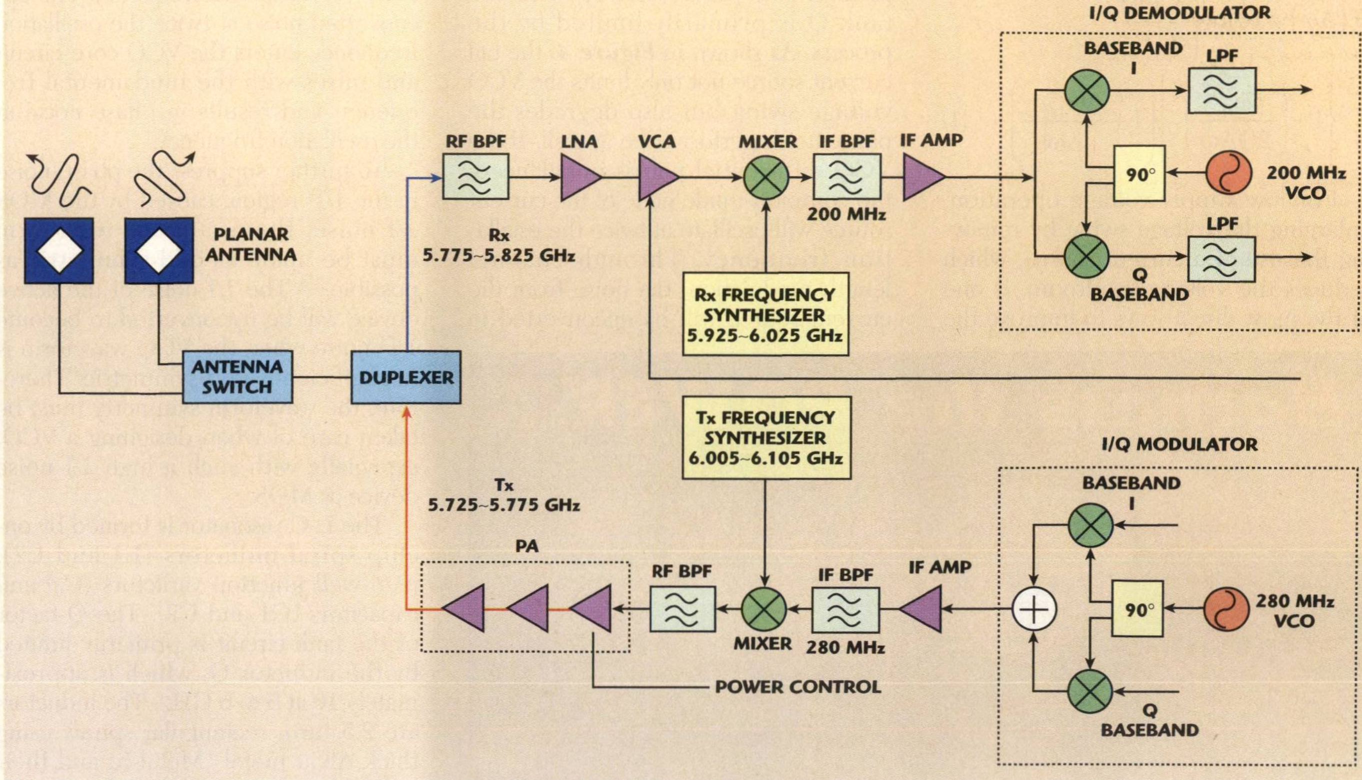
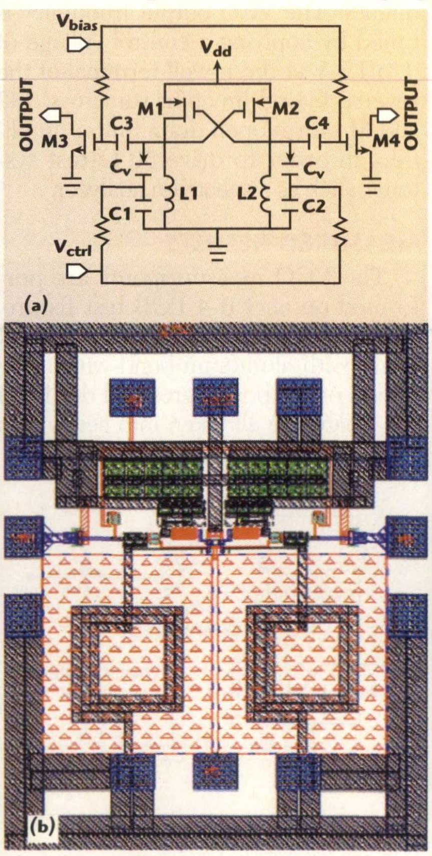
and Huey-Ru Chuang
National Cheng Kung University
Taiwan, ROC



▲ *Fig. 2 Transceiver architecture for an 802.11a WLAN upper sub-band application.*

controlled oscillator (VCO) is one of the most important and challenging building blocks in an RF transceiver. With the demand for low power and low cost, an on-chip VCO with no external components is the best choice. However, the low Q on-chip passive components such as inductors will degrade the VCO phase noise performance.

This article presents a fully-integrated 5 GHz VCO fabricated by a TSMC 0.18 μm standard CMOS process. The VCO output frequency covers the 5925 to 6025 MHz range and is applicable to the front-end receiver with an IF of 200 MHz with a high side LO.



▲ *Fig. 3 A 5 GHz L-C tank CMOS VCO's (a) circuit schematic and (b) layout.*

CIRCUIT DESIGN

The transistor's flicker noise (1/f) is the cause of the phase noise near the carrier with a $1/f^3$ shape. In the CMOS process, the transistor's 1/f noise is generally high, causing serious degradation of VCO phase noise performance. However, the PMOS 1/f noise is usually lower than for the NMOS by one order of magnitude. A low 1/f noise active port reduces not only the magnitude of phase noise in the $1/f^3$ and $1/f^2$ regions, but also lowers the corner frequency between the $1/f^3$ and $1/f^2$ regions. To obtain better phase noise performance, PMOS transistors were used in the VCO core.[2] The circuit and layout of the VCO, fabricated by the 0.18 μm CMOS process with a chip area of 790 × 1020 μm^2 including pads, is shown in ***Figure 3.*** The Agilent Advanced Design System (ADS) is used for design simulation of the VCO. The cross-coupled connection of the PMOS transistors M_1 and M_2 form a positive feedback loop to provide negative resistance to compensate for the loss in the L-C tank circuit. The source and gate voltages of M_1 and M_2 are 0 V and V_{DD} (1.8 V), respectively, without any extra current source. This bias scheme reduces the transistor width requirement for the oscillation to start and maximizes the oscillator signal peak-to-peak amplitude. The supply voltage for the 0.18 μm standard CMOS process is 1.8 V, which is fairly small. If the cross-coupled pair is biased via a current source, the allowable oscillator voltage swing will be further restricted and cause a poorer phase noise performance. According to the Leeson-Cutler phase noise model, the phase noise, which is the ratio of single-sideband-noise to carrier, is inversely proportional to the signal power.[2]

[Continued on page 76]

$$\mathcal{L}(\Delta\omega) = 10\log\left[\frac{1}{2}\frac{FkT}{P_2}\left\{1+\left(\frac{\omega_0}{2Q\Delta\omega}\right)^2\right\}\left(1+\frac{\Delta\omega_{1/f^3}}{|\Delta\omega|}\right)\right] \qquad (1)$$

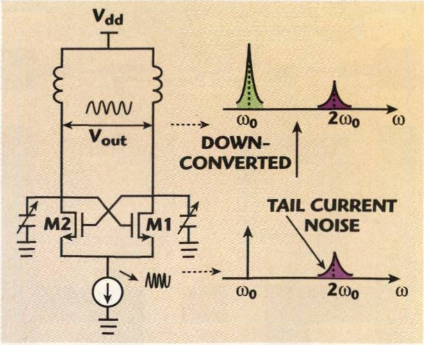
For low supply voltage operation, enlarging the voltage swing by removing the use of a current source, which reduces the voltage headroom, is one of the most direct ways to improve the phase noise performance, since the tank Q is primarily limited by the process. As shown in ***Figure 4***, the tail current source not only limits the VCO voltage swing but also degrades the phase noise performance as well. If the VCO differential pair is unbalanced, the common-mode node of the current source will oscillate at twice the oscillation frequency. Through channel length modulation, the noise from the current source will be upconverted to twice the oscillation frequency. The upconverted noise at twice the oscillation frequency enters the VCO core circuit and mixes with the fundamental frequency, and results in phase noise at the oscillation frequency.

To further suppress the phase noise in the $1/f^3$ region, caused by the MOS 1/f noise, the oscillation waveform must be made as odd-symmetric as possible.[3,4] The 1/f noise of the active device will be upconverted to become $1/f^3$ noise when the VCO waveform is not sufficiently odd-symmetric. Therefore, the waveform symmetry must be taken care of when designing a VCO, especially with such a high 1/f noise device as MOS.

The L-C resonator is formed by on-chip spiral inductors (L1 and L2), p^+/n-well junction varactors (C_v) and capacitors (C1 and C2). The Q-factor of the tank circuit is primarily limited by the inductor Q, which is approximately 10 at 5 to 6 GHz. The inductors are 2.5 turn, rectangular spirals using thick AlCu metal (Metal-6) and their inductance is approximately 2.3 nH. The series connections, C1-C_v and C2-C_v, resonate with L1 and L2, respectively, to determine oscillation frequency. The VCO output frequency is tuned by applying a control voltage of 0 to 1.8 V at the n-well terminal of the reverse biased junction varactors. M3 and M4 form open drain buffer amplifiers in order to drive 50 Ω test systems, such as a spectrum analyzer.

MEASURED RESULTS

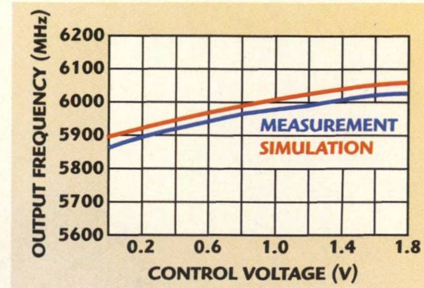
The VCO measurements are performed on an FR-4 PCB test fixture. The VCO chip is connected to the test board with aluminum bond-wires. The effects of the bond-wires and the FR-4 test board are all taken into account in



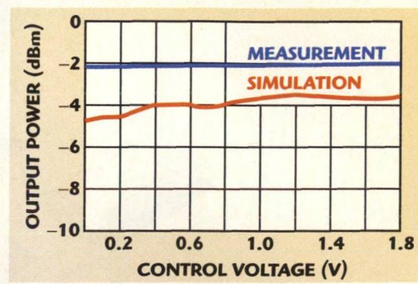
▲ *Fig. 4 Phase noise generated from the tail current noise.*

[Continued on page 78]

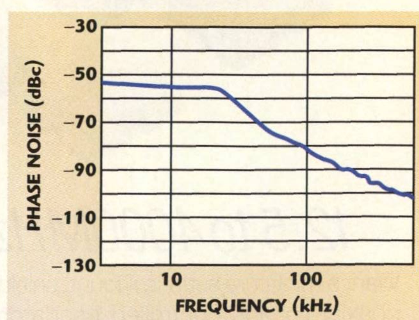
the simulations. The bond-wires and the FR-4 test board do not affect the oscillation frequency and phase noise performance; they only lower the output signal amplitude. The VCO core and each buffer amplifier dissipate 8.1 mW and 22.5 mW from a 1.8 V supply, respectively. The measured oscillation frequency of the VCO is 5860 to 6026 MHz when the control voltage varies from 0 to 1.8 V. The VCO tuning range measurement and simulation results are shown in ***Figure 5***. The measured output power is approximately –4 dBm, as shown in ***Figure 6***. The phase noise at a 300 kHz offset from the carrier is measured to be -95.6 dBc/Hz, as shown in ***Figure 7***. The VCO phase noise measurement is performed when the applied control voltage is 0 V, which is when the VCO has its highest tuning sensitivity K_{vo} (approximately 180 MHz/V) and therefore where the measured phase noise is the worst. The free running measured phase noise performance proves that the fully-integrated VCO is adequate for wireless communications. When the VCO is used in future 5 GHz frequency synthesizer applications, the phase noise can be further suppressed by the loop filter of the PLL frequency synthesizer. The output spectrum of the VCO is shown in ***Figure 8***. The second harmonic is lower than the fundamental by 41.6 dBc,



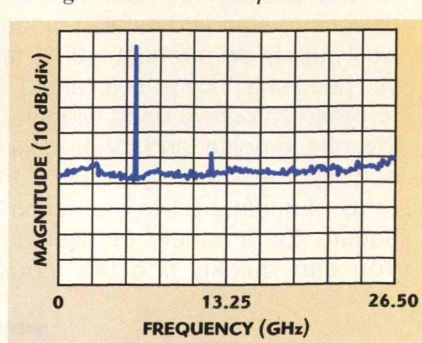
▲ *Fig. 5 VCO output frequency vs. control voltage.*



▲ *Fig. 6 VCO output power vs. control voltage.*



▲ *Fig. 7 Measured VCO phase noise.*



▲ *Fig. 8 VCO output spectrum.*

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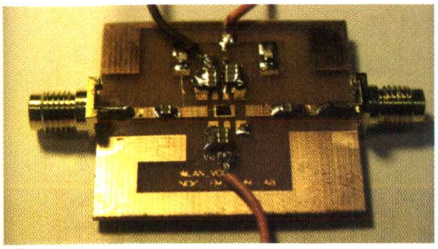

Fig. 9 The VCO test board.

TABLE I

MEASURED PERFORMANCE OF A 5 GHz 0.18 μm CMOS VCO

Control voltage/bias current	0 V to 1.8 V/4.5 mA
Buffer amp bias current (each) (mA)	12.5
Tuning range (MHz)	5860 to 6026
Tuning sensitivity (MHz/V)	50 to 180
Phase noise (with buffer amp) (dBc/Hz)	–95.6 @ 300 kHz
Output power (dBm)	–4
Chip area (including pads) (μm^2)	790 × 1020

which implies that the VCO pull up and pull down waveform is highly odd-symmetric. The photograph of the FR-4 PCB test fixture is shown in ***Figure 9***. ***Table 1*** summarizes the measured performance of the designed 5 GHz CMOS VCO.

CONCLUSION

A fully-integrated 5 GHz L-C tank VCO, fabricated in a TSMC 0.18 μm standard CMOS process, is presented. Made for an IEEE 802.11a WLAN application (5.725 to 5.825 GHz), the VCO output frequency covers 5925 to 6025 MHz and is adequate for the front-end receiver application, with an IF of 200 MHz and a high side LO. The VCO core circuit uses only PMOS to achieve better phase noise performance. The VCO output frequency is tuned by on-chip p^+/n-well junction varactors. The measurements are performed using an FR-4 PCB test fixture. The output frequency of the VCO is from 5860 to 6026 MHz with a 166 MHz tuning range, and the phase noise is -95.6 dBc/Hz at a 300 kHz offset. The VCO, excluding buffer amplifiers, consumes 8.1 mW at V_{DD} = 1.8 V. The low power consumption of the VCO suggests that the 0.18 μm CMOS process is useful for 5 GHz WLAN applications.

ACKNOWLEDGEMENT

The authors would like to thank the Chip Implementation Center (CIC) of the National Science Council, Taiwan, ROC, for supporting the TSMC CMOS process. ■

Reference:

1. IEEE Standard 802.11a: High Speed Physical Layer in the 5 GHz Band, 1999.
2. C.M. Hung, B.A. Floyd, N. Park and K.K. O, "Fully-integrated 5.35 GHz CMOS VCOs and Prescalers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 49, No. 1, January 2000, pp. 17–22.
3. A. Hajimiri and T.H. Lee, "Oscillator Phase Noise: A Tutorial," *IEEE Journal of Solid-State Circuits*, Vol. 32, No. 3, March 2000, pp. 326–336.
4. T.H. Lee, *The Design of CMOS Radio-frequency Integrated Circuits*, Cambridge University Press, New York, NY 1998.

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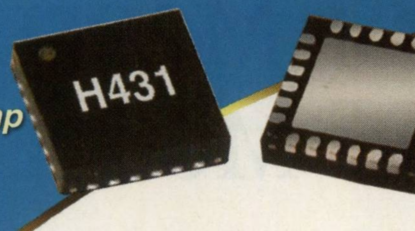

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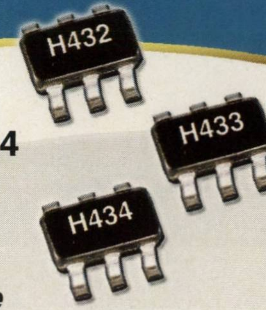

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HMC365S8G	DC - 13.0	4	-151 dBc/Hz	$5.25
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TECHNICAL NOTE

A Measurement-based Behavioral Model for I/Q RF Modulators

This article describes a nonlinear behavioral modeling technique for application to I/Q modulated communication channels. The model data was gathered by independent measurements of an I/Q modulator and amplifier, using vector signal generators and analyzers. Concatenating the models in simulation and verifying by measurement validated the technique. The method was applied to a W-CDMA transmit chain. The resulting error vector magnitude (EVM) and adjacent channel leakage ratio (ACLR) levels predicted by simulation closely matched the measurements.

The W-CDMA standard expresses transmit quality in terms of EVM and ACLR, and receive quality in bit error ratio (BER). These quality measurements are simple scalar numbers representing a very complicated system. Modern communications channels (still) consist of a number of concatenated functions such as baseband (BB) processor, DAC, modulator and amplifier. Each function contributes to the global figure of merit. A method needs to be found to capture the performance of each block in a behavioral model that, when concatenated, gives useful and accurate information on the overall system performance. The behavioral model of each block may be generated either from precise (circuit-based) simulation or by measurement.

An advantage of a behavioral model is the more compact representation it provides for a circuit, allowing the circuit to be simulated much more quickly, using less memory. This makes it more desirable for doing higher level circuit or system design. Since a component can be treated as a block and an equivalent circuit structure does not need to be known, it is potentially easier to generate a behavioral model than a circuit model. Another advantage is that a component vendor can supply a behavior model to designers without giving away any information about the details of the device.

Behavioral models based on circuit simulation are limited to the accuracy of the underlying circuit model. However, a behavioral model may be based on measurements of the component, and has the advantage of capturing the actual nonlinear performance of the device. In order to get models that are of more general purpose, the devices need to be measured with a more complex stimulus to more fully characterize their nonlinear behavior. Electronic signal generators (ESG) and vector signal analyzers (VSA) can be used to generate these complex test signals, and capture the complex modulated response, from which the data to populate a behavioral model may be obtained.

This article extends the concept of behavioral modeling by creating a model structure for baseband I/Q-to-RF modulators, along with using real-world measurements as a method for filling in the data for such a model.

[Continued on page 84]

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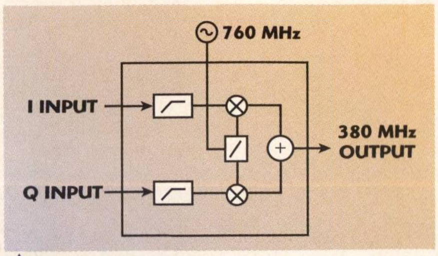
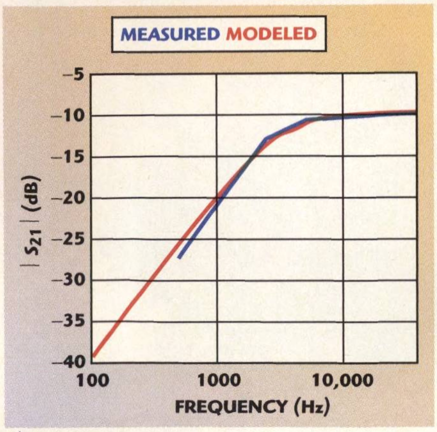
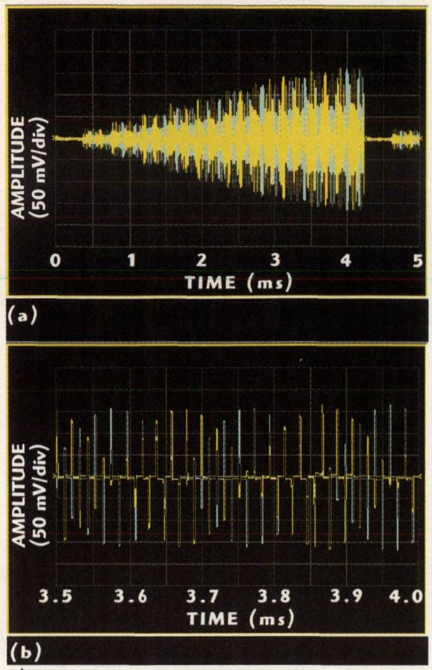


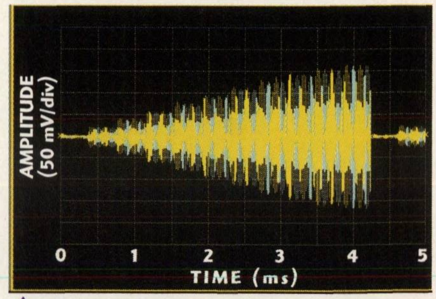
▲ *Fig. 1 Block diagram of the I/Q modulator model.*



▲ *Fig. 2 Frequency transfer function of I input to RF power out.*



▲ *Fig. 3 Total I/Q input waveform showing steps in I/Q magnitude; (a) total range and (b) close up of the last 10 percent of the waveform.*



▲ *Fig. 4 Output response showing compression at higher I/Q drive levels.*

GRAY BOX MODELING

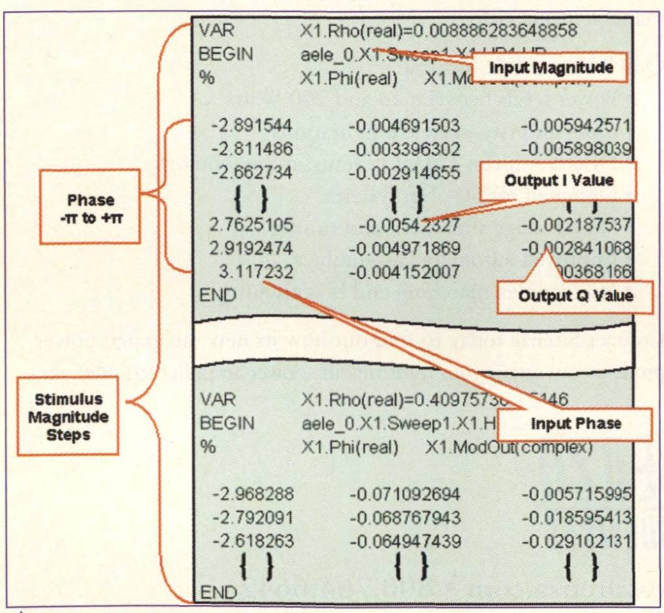
The term "gray box" is used to describe a model whose structure is known, but the details are not. In this case, it is assumed that the model maps I/Q inputs to modulated RF outputs, and the model details the transfer function. In this model, the linear distortion effects (such as filtering) are separated from the nonlinear distortion effects. Thus, the behavioral model for the nonlinear effects is required to be memory-less. A memory-less assumption also implies a flat frequency response, and no PM-to-AM conversion. The frequency response effects of the input I/Q filtering will be represented by a linear frequency dependent element before the nonlinear element.

Figure 1 shows the behavioral model for the modulator. The I/Q input filters (which are caused by DC blocks and baluns in the test fixture) were evaluated using an ESG that has an arbitrary waveform generator (AWG) for the baseband I/Q signals. A stepped sine wave was created for each of the I/Q inputs, and the output RF power measured on a VSA. ***Figure 2*** shows the frequency response of the I input (Q is similar) as well as the modeled response for a filter function used in the behavioral model.

What is desired for the nonlinear transfer function is a function that describes the RF output amplitude and phase as a function of the I and Q voltages. A simple way of doing this might be to drive a DC voltage into I, and measure the RF output (magnitude and phase) for various input levels, then repeat the same measurement for Q. However, I and Q may have some interaction, so the next level of stimulus to consider is setting I to a particular level, then vary Q over a range of values, while measuring the RF output; this would be repeated for a variety of I values. Unfortunately, from the I and Q input response, it is clear that the response goes to zero at DC (the I and Q are DC blocked).

A specialized drive of I and Q to measure the transfer function is required. After much experimentation, a pulsed DC signal was determined to be the best-suited drive. The magnitude of I and Q, ($M = \sqrt{(I^2 + Q^2)}$), is held constant and the phase is changed in 170° increments until 36 data points (every 10°) is obtained. By changing the phase 170°, any charging of the blocking capacitor is nearly removed by the next pulse. ***Figure 3*** shows the input signal, as measured on a VSA using the I/Q baseband inputs. The pulse was filtered to maintain a frequency content consistent with a W-CDMA signal, using a low pass filter of 2 MHz bandwidth. The spacing between pulses was set to allow any residual charge to leak off before the next pulse arrived. The last part of the stimulus is shown expanded, with I in yellow and Q in blue.

Figure 4 shows the output of the modulator, measured on a VSA using the RF input. The output modulated I/Q is compared to the input, and a transfer function is determined. This transfer function is used to populate a behavioral model that relates the input I/Q (magnitude and phase) to the output RF envelope. ***Figure 5*** shows the behavioral model data used as an input to the simulation. A behavioral



▲ *Fig. 5 The behavioral model data.*

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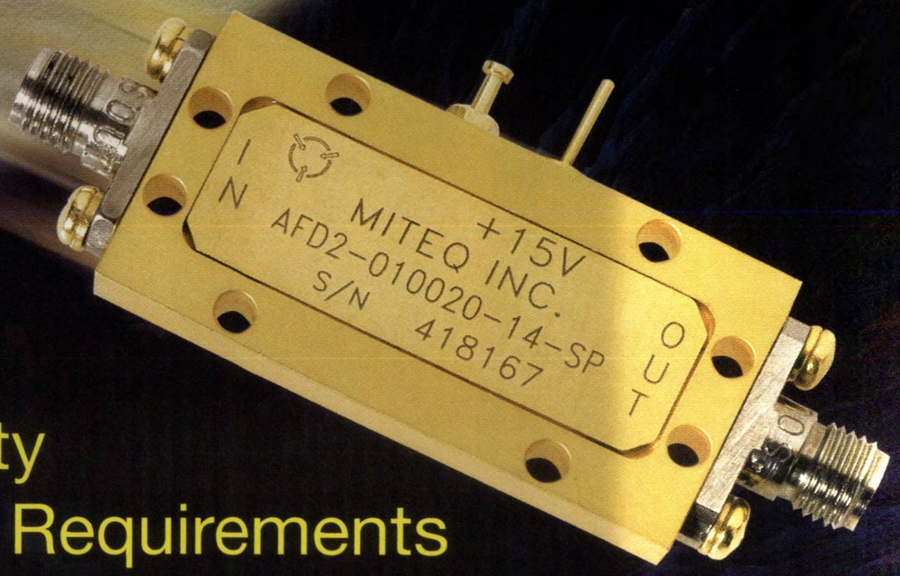
Moderate & Octave Band Amplifiers



Amplifiers for a Variety of System Requirements

MODEL NUMBER	FREQ. (GHz)	GAIN (dB, Min.)	GAIN FLATNESS (±dB, Max.)	NOISE FIGURE (dB, Max.)	IN/OUT VSWR	POWER OUT (dBm, Min.)	CURRENT (mA, Typ.)
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AFD3-010020-14-SP	1–2	34	1.25	1.4	2.0:1	+10	120
AFD3-022023-12-SP	2.2–2.3	30	0.50	1.2	1.5:1	+10	100
AFD3-023027-12-SP	2.3–2.7	30	0.50	1.2	1.5:1	+10	125
AFD3-027031-12-SP	2.7–3.1	30	0.50	1.2	1.5:1	+10	125
AFD3-031035-12-SP	3.1–3.5	30	0.50	1.2	1.5:1	+10	125
AFD3-037042-12-SP	3.7–4.2	30	0.50	1.2	1.5:1	+10	125
AFD3-040080-35-SP	4–8	24	1.25	3.5	2.0:1	+10	150
AFD3-020080-40-SP	2–8	23	1.50	4.0	2.0:1	+10	160
AFD3-040120-55-SP	4–12	18	1.50	5.5	2.0:1	+10	150
AFD3-080120-50-SP	8–12	18	1.25	5.0	2.0:1	+10	150
AFD1-010020-23P-SP	1–2	11	1.00	4.0	2.0:1	+23	200
AFD2-010020-23P-SP	1–2	25	1.50	3.5	2.0:1	+23	325
AFD3-020027-23P-SP	2.0–2.7	22	1.25	4.5	2.0:1	+23	350
AFD3-027031-23P-SP	2.7–3.1	22	1.25	4.5	2.0:1	+23	400
AFD3-031042-23P-SP	3.1–4.2	22	1.25	4.5	2.0:1	+23	350
AFD3-040080-23P-SP	4–8	20	1.25	5.5	2.0:1	+23	350
AFD3-020080-20P-SP	2–8	18	1.50	6.0	2.0:1	+20	350
AFD3-080120-20P-SP	8–12	15	1.25	5.0	2.0:1	+20	350
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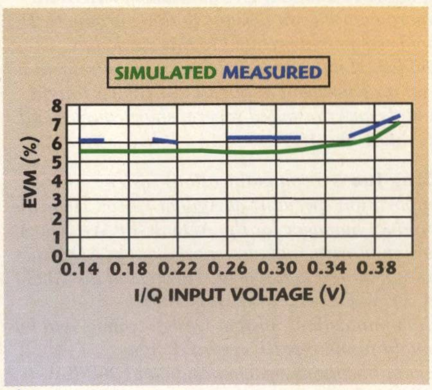
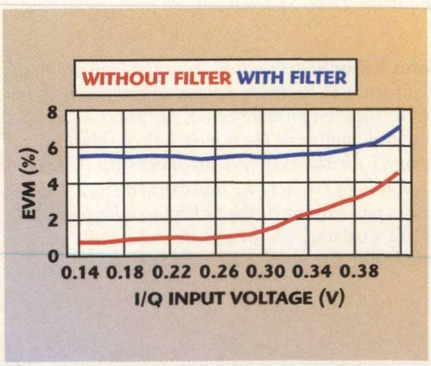
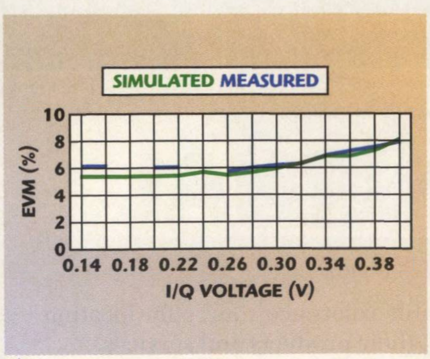
model simulation was created and the original pulsed input was used as a simulation stimulus. The response produced an output nearly identical to the measured output. Next, the model was stimulated with a W-CDMA signal, and the EVM response was obtained. As shown in ***Figure 6***, there was remarkable agreement with an actual measurement of EVM on the modulator. A similar process was used to characterize an RF amplifier, with the characterization consisting of measuring the amplitude and phase compression from which a behavioral model of the amplifier was created.



▲ *Fig. 6 EVM comparison between measured and simulated data.*



▲ *Fig. 7 Simulated EVM with and without filter.*



▲ *Fig. 8 EVM of modulator and amplifier cascade.*

The DC blocking of the I/Q is a result of the test fixturing. The goal was to determine the response of the modulator without the DC block, but such a measurement was not possible. However, the filtering function in the simulator could be de-embedded, and a complex modulation signal applied to the resulting model. ***Figure 7*** shows the result of this experiment. The DC block has a strong effect on EVM, and it can be clearly seen that the degradation of EVM of the modulator, although small, occurs at a much lower input drive that the preceding figure would indicate.

Finally, the modulator and amplifier were cascaded, both physically and in the simulation, and the measured and simulated EVM of the cascaded pair was compared. ***Figure 8*** shows

[Continued on page 88]

this result. Similar comparisons were done for other modulated characteristics such as adjacent channel power ratio (ACPR) and alternate channel power ratio, with good results.

CONCLUSION

For the first time, a method for creating measurement-based behavioral models has been presented as related to I/Q modulators. The model was validated using measurements of W-CDMA signals. Furthermore, the cascading of behavioral models was tested against a modulator and amplifier combination, and found to correctly predict the response to a complex modulated signal. ■

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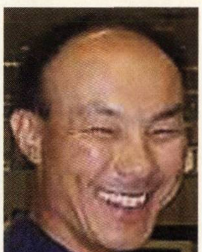
Greg Jue *is a communications system application specialist at Agilent EEsof. He is the product manager for the ADS 3GPP W-CDMA design library, and also specializes in ADS links to Agilent test equipment. He created the ADS 3GPP W-CDMA course and ADS Communications System Design course, and has taught numerous RF circuit design, communications system design and 3GPP W-CDMA design courses using ADS. He has been with Agilent EEsof for six years, and was at the Jet Propulsion Laboratory/Caltech University working on system design for the Deep Space Network prior to joining Agilent Technologies.*



John Kikuchi *graduated from the University of California at Berkeley School of Engineering in 1979. He then joined the US Air Force as a research engineer. He is currently a solution planner for the Wireless Business Unit of Agilent Technologies, where he has worked since 1983. His experience at Agilent also includes work in R&D, QA, and, most recently, sales and marketing for Agilent EEsof EDA.*

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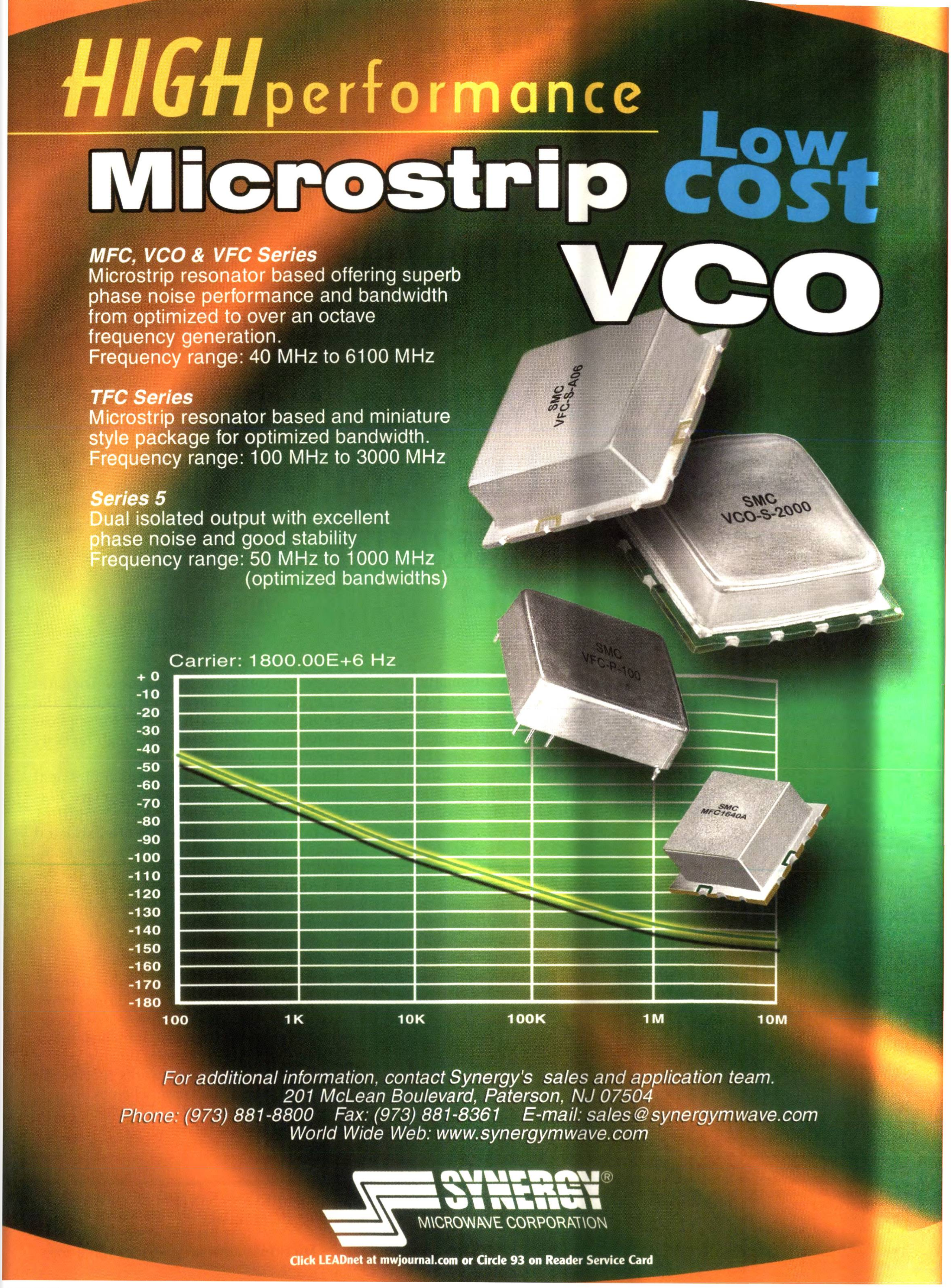
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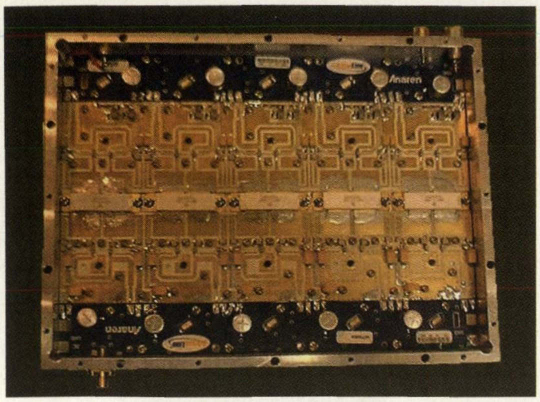
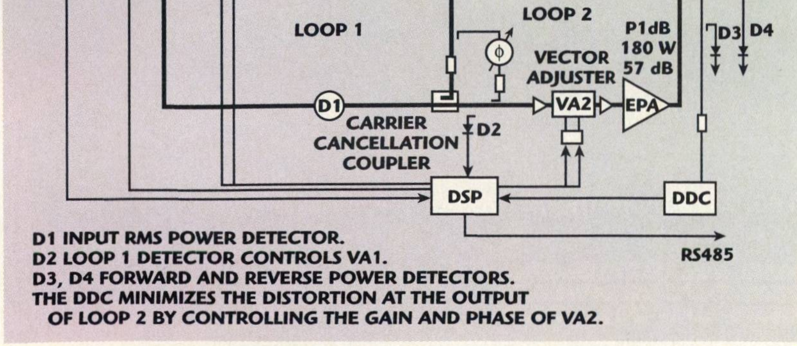
A Minimalist Approach to Feedforward Multi-carrier Linear Power Amplifiers



Atmospheric propagation attenuation is known to be higher in the 2.1 GHz band than in the cellular band. Thus, to overcome this performance disadvantage and to maximize cell coverage and capacity, Unity Wireless System's first feedforward multi-carrier linear power amplifier (MCLPA) product has been designed with a high 60 W maximum average output power. The new Tornado MCLPA has been developed to satisfy the emerging 3G W-CDMA market for applications requiring high power and high linearity at a relatively low cost.

Fig. 1 The Tornado feedforward MCLPA's block diagram.



The Tornado amplifier uses a classical adaptive control feedforward design (see ***Figure 1***), where the main power amplifier (MPA) distortion components are extracted using carrier cancellation in Loop 1 and amplified by the error power amplifier (EPA). The output distortion is then cancelled at the error cancellation coupler in Loop 2 (the error loop).

Direct Distortion Control

The distinguishing features of the Tornado design include a patent-pending direct distortion control (DDC) technology to control Loop 2. This technique is a low cost, ultra high selectivity, high linearity frequency tunable power detector. The DDC circuit works specifically with CDMA-type modulation schemes, including W-CDMA, cdma2000 and IS-95, and provides a number of useful advantages.

[Continued on page 96]

Unity Wireless Systems Corp.
Burnaby, BC, Canada

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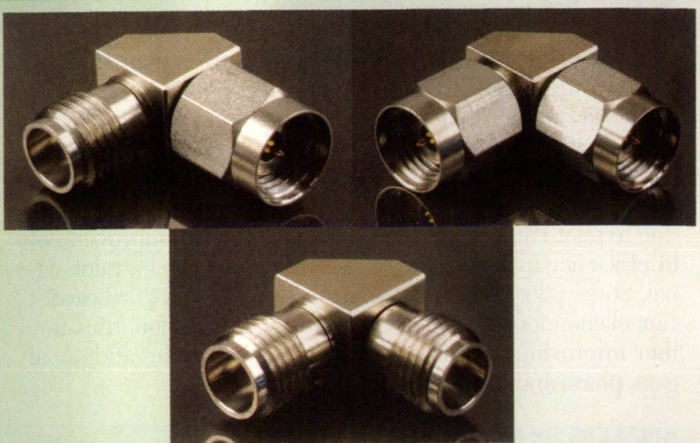
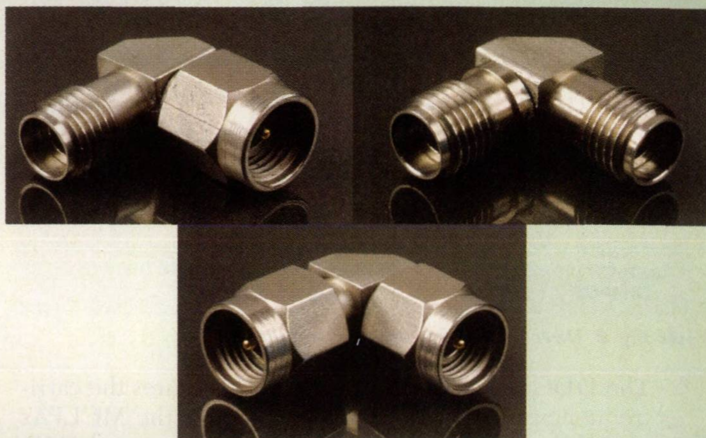
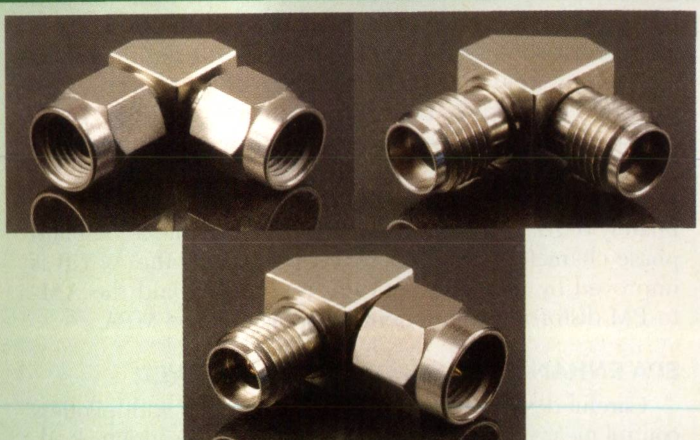


2.9mm, DC to 40 GHz



3.5mm, DC to 33 GHz



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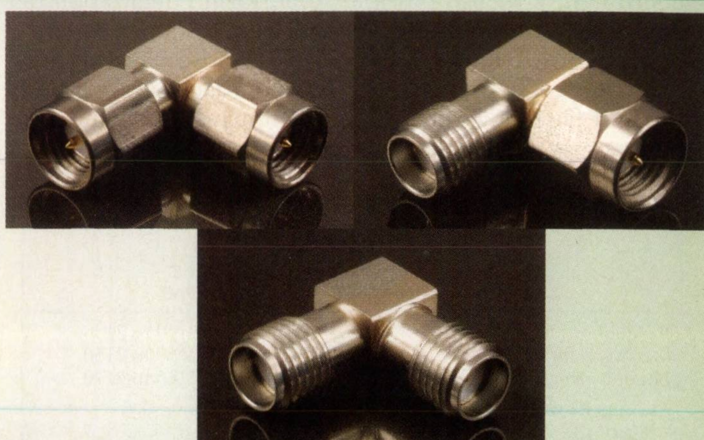

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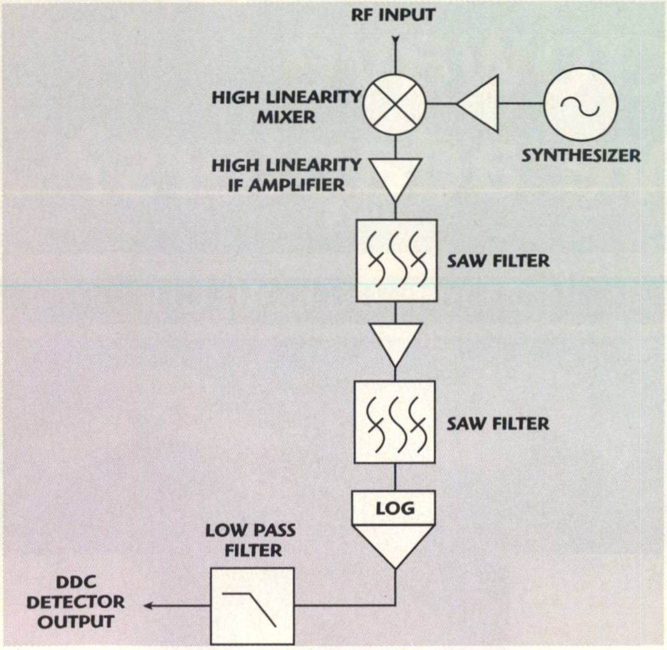


▲ *Fig. 2 Direct distortion control assembly.*

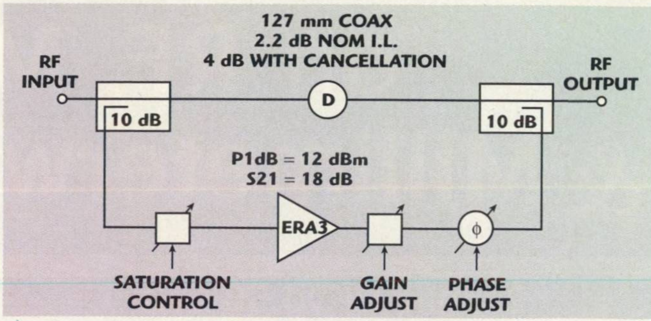
The DDC, shown in ***Figure 2***, first measures the carrier frequencies and then directly minimizes the MCLPA's intermodulation distortion (IMD) at the expected IMD frequencies. In addition to allowing the cancellation to be controlled, it is also possible to perform equalization of any asymmetric IMD components from the MPA, together with any asymmetric cancellation performance in the error loop. Therefore, the DDC approach ensures that the best possible level of IMD performance is obtained at all times and under all conditions.

The DDC is able to select the frequencies that are to be minimized, which means the error loop's instantaneous cancellation bandwidth requirements are lower than that required with a fixed frequency pilot injection system, which improves produceability. The DDC method also does not require a pilot injection system, meaning there is no possibility of leakage or spurious at the MCLPA output. Having no pilot injection also means that there are no error loop offsets due to pilot RF leakage. There is also marginal improvement in efficiency by not having to amplify and cancel a pilot signal. Some pilot recovery schemes also require a third carrier cancellation loop that is not required in this design, thus further improving produceability by eliminating the additional gain, phase and delay matching.

TABLE I

KEY PERFORMANCE SPECIFICATIONS

Frequency range (MHz) (any MCLPA can be used in any band, but only over 20 MHz instantaneously)	2110 to 2130 2130 to 2150 2150 to 2170
Average RF power output (dBm)	47.8
Multi-carrier intermodulation distortion (dBc) with 1 to 4 W-CDMA carriers and 5 MHz spacing (measured with rms detector, 30 kHz R/b, 100 kHz V/b, 0.5s sweep time)	–60 (Test Model 1 with 64 DPCH)
RF gain (includes variation due to frequency, power supply, temperature and unit-to-unit) (dB)	58 ±0.5
Input power supply range (V DC)	26 to 30 (800 W)
Power supply efficiency (%) (at maximum average RF output power and using Test Model 1 with 64 channels)	8
Operational ambient temperature range (°C)	0 to +50
RF connectors (front panel)	Input SMA-F Output SMA-F
External monitoring and control	RS 485
Alarms	over power, over temp, loop control fail, output, VSWR, power supply
Mechanical dimensions Height Width	 8 rack-units 4 units per 19" rack



▲ *Fig. 3 Peak predistortion block diagram.*

ANALOG PEAK PREDISTORTION

The analog peak predistortion method, shown in ***Figure 3***, works by cancelling the main path RF with the output from a limiting amplifier and provides both gain and phase correction of the MPA LDMOS soft limiting characteristics near P1dB. The effect of this correction method is that the MPA output power capability is increased by as much as 20 percent for the same level of adjacent channel leakage ratio (ACLR) or, alternatively, for the same output power, the ACLR is improved by approximately 3 dB. By compensating for the nonlinear gain and phase characteristics of the MPA in this way the ACLR is improved by reducing both the AM-to-AM and the AM-to-PM distortion components produced in the MPA.

EPA ENHANCED OUTPUT CARRIER POWER

Careful design of Loop 1 lined up together with pilotless control means that there is minimal noise and spurious loading on the EPA, and the total MPA distortion at the EPA output is only approximately 0.5 W rms. This allows the output power capability of the EPA to be put to good use by supplying carrier power in phase with the MPA output. The technique is similar to cross cancellation, but the implementation is simple and non-adaptive because the carrier power being supplied is only around 10 percent of the total MCLPA output power. The output contribution of around 5 W is approximately equal to the level of MPA carrier power that is typically lost into the 50 Ω load of the 10 dB error coupler.

KEY PERFORMANCE TARGETS

Table 1 lists the key performance specifications of the Tornado MCLPA. To improve propagation in the 2.1 GHz frequency band and maximize cellular communications coverage, the amplifier was designed with a high 60 W (47.8 dBm) maximum average output power.

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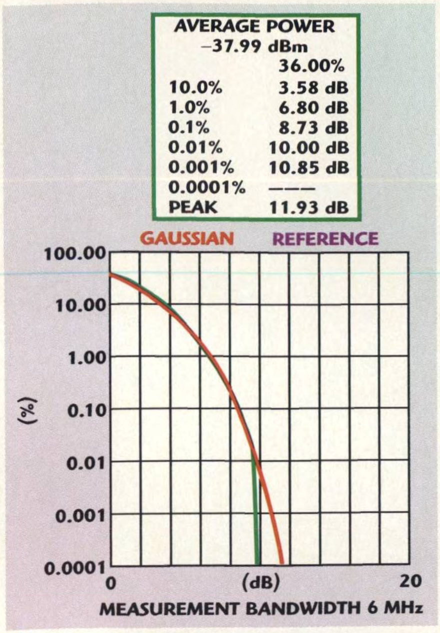
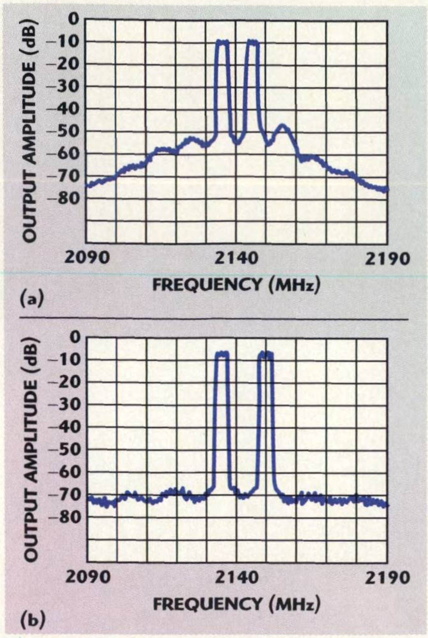


▲ *Fig. 4 CCDF of a single W-CDMA carrier using Test Model 1 with 64 channels.*



▲ *Fig. 5 MPA ACLR performance at 47.8 dBm (60 W) and 25°C (a) without and (b) with feedforward cancellation.*

The Tornado MCLPA is specified to operate with one to four W-CDMA carriers using Test Model 1 with 64 channels and no preclipping. By measuring the complementary cumulative distribution function (CCDF) for a single carrier (see **Figure 4**) it can be seen that the peak-to-average ratio at 0.01 percent probability is as high as 10 dB.

The peak-to-average ratio or crest factor (CF) is defined as the quotient of peak envelope power (PEP) to average power ($CF = PEP/P_{av}$), where PEP is defined as the power of the carrier sinusoid taken over one carrier period when its amplitude is at maximum and P_{av} is proportional to the mean value of the squares of the signal voltage over a long period of time. The required maximum average output power and the CF of 10 dB together determine the peak power capability and dimensions of the MPA, which for Tornado is 900 W P1dB.

LINEARITY PERFORMANCE

Using feedforward techniques the ACLR of the MPA output is typically improved by approximately 25 dB to 60 dBc at the MCLPA output, as shown in **Figure 5**. Higher than 60 W output power levels would make satisfying the absolute power level requirements of the spectral emissions mask more problematic and further linearization would very likely have been necessary unless the peak-to-average requirements of the input signal were relaxed.

EFFICIENCY

Efficiency has probably become the most important characteristic of an MCLPA as operators seek to reduce fixed operating costs, and governments and corporations seek to satisfy the Kyoto accord on greenhouse emissions. Just five years ago, before the advent of LDMOS and other efficiency enhancements, a bipolar feedforward MCLPA might have had an efficiency of just two to three percent. Using LDMOS transistors and using the worst-case W-CDMA carriers and Test Model 1 with 64 channels, Tornado achieves an efficiency of eight percent. However, using carriers with a more typical peak-to-average power of 8 dB, the MCLPA can be operated at 80 W average output power where the efficiency is close to 10 percent.

Further efficiency improvements, yielding up to 12 percent efficiency, may be obtained by accepting a reduction in ACLR performance of 5 dB and using the pre-feedforward architecture known as advanced cross cancellation. In this special case, the EPA has the same output power capability and characteristics as the MPA, and is used to supply half of the output carrier power. The efficiency improvements are the result of 0.5 dB lower loss after the EPA compared to the MPA. Also, since the MPA and EPA are closely matched, the MPA provides very good predistortion of the EPA, which further improves the overall efficiency of the EPA and MCLPA.

COST

It is a fact that today's competitive economic environment calls for the minimum possible dollars per watt. This need has been addressed by using three techniques that maximize the output power for a given set of transistors. These techniques include peak power predistortion, a high power, low loss filter delay line, and the use of the EPA to provide additional output carrier power in a similar fashion to cross cancellation. Feedforward amplifiers are also more cost-effective and more efficient at higher output power levels.

The cost of the bill of materials (BOM) was minimised by omitting any non-essential components. The design was also simplified by reducing a DSP board to just a single chip 8051-based microcontroller. A common design for the EPA and driver power amplifier (DPA) was also used, and even something as small as the total number of high Q capacitors was minimised to reduce overall cost.

CONCLUSION

A minimalist approach in the Tornado MCLPA's unique design has yielded an amplifier that has achieved high power output, excellent linearity performance and low cost to satisfy today's tough requirements for the emerging 3G W-CDMA market. The Tornado MCLPA is available for demonstration on request, and the company's efficient and flexible design and manufacturing capabilities are available to undertake custom designs for similar sophisticated requirements.

Unity Wireless Systems Corp., Burnaby, BC, Canada (604) 267-2712, www.unitywireless.com, sales@unitywireless.com.

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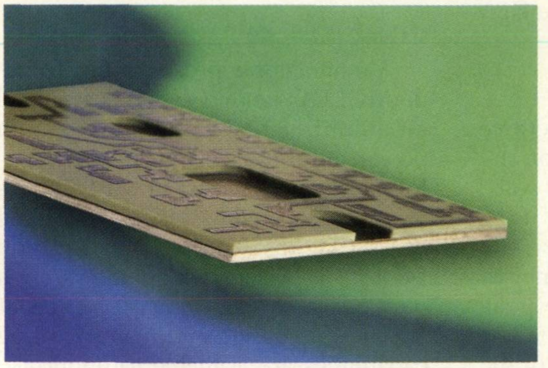
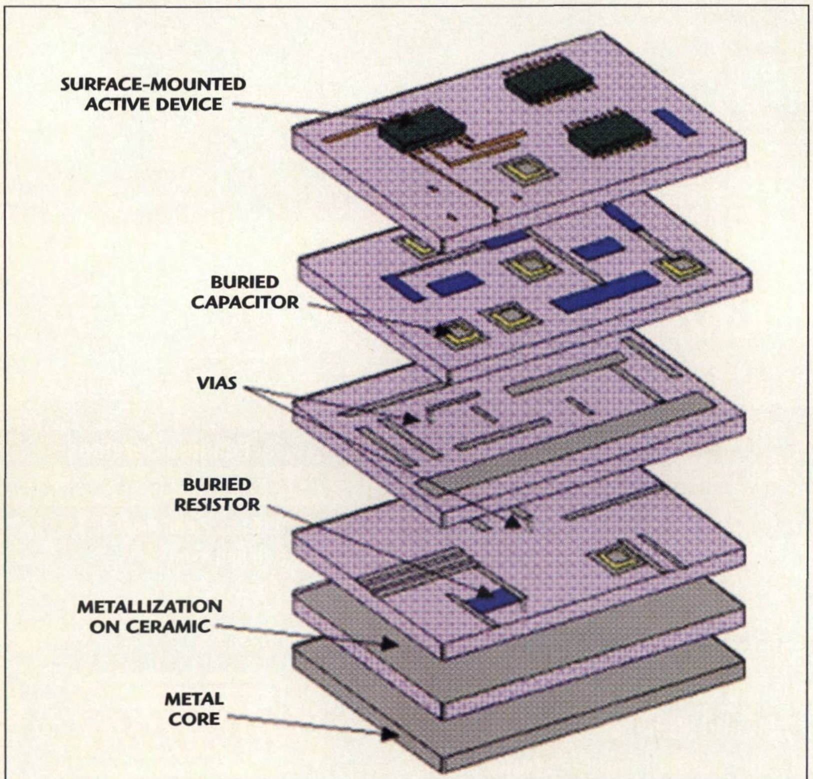


New Substrate Technology for High Performance Circuits and Systems

A new substrate technology has been developed that addresses the dense component placement, high heat dissipation, harsh environments and high frequencies associated with high performance devices such as microwave amplifiers for base stations, broadband amplifiers designed into multi-media networks, and high power microwave power combiners with on-board terminations. The new technology — low temperature co-fired ceramic on metal (LTCC-M) — utilizes a patented process that bonds ceramic to metal to deliver improved performance and reliability at lower cost. An example of LTCC-M is shown in ***Figure 1***.

Fig. 1 Multi-layer LTCC-M construction.



The LTCC-M process shares some similarities to LTCC. However, LTCC-M bonds a multi-layer "green tape" board to a Kovar or CuMoCu metal base using special materials and a 900°C firing process. The addition of the bonded metal base provides several advantages. For example, open cavities that extend down to the metal base can be created with LTCC-M to allow direct component die mounting on the base (or one or two layers above). This eliminates the need to attach a fully packaged high power component on a large substrate-mounted heat sink, which requires machining of both the substrate and sink in conventional LTCC processing. The metal core in an LTCC-M substrate allows heat to be carried away from hundreds of watts of power dissipation with a thermal con-

[Continued on page 106]

Lamina Ceramics
Westampton, NJ

TABLE I

SUBSTRATE PROPERTY COMPARISON

Material Property**	Lamina Ceramics LTCC-M: Kovar	Lamina Ceramics LTCC-M: CuMoCu (13/74/13)	Typical LTCC	Typical HTCC Alumina (96%)	Ceramic-filled PTFE	Typical FR4 Fiberglass
Range of part dimensions (inches)	up to 16 × 16	up to 16 × 16	up to 6 × 6	up to 6 × 6	up to 24 × 24 typically	up to 24 × 24 typically
Buried passives	yes	yes	yes	no	no*	no*
Buried resistor tolerance (%)	±10	±10	±10 to 30	n/a	n/a	n/a
High K tape	yes	yes	no	no	no	no
Ferrite tape	yes	no	no	no	no	no
Hermetic cavities	yes	yes	yes	yes	no	no
x-y shrinkage (%)	~±0.1	~±0.1	~12.7 to 14.8	~15	n/a	n/a
Thermal conductivity (W/m°C)	40	170	2 to 3	24.7	0.61	1.7
Expansion coefficient (TCE) (ppm/°C)	6.7 (up to 300°C)	5.5 (up to 400°C)	5.8 (up to 400°C)	8.2 (up to 400°C)	~1.7 to 24 (up to 400°C)	13 (up to 400°C)
Dielectric constant (ε_r)	6.0 at 15 GHz	5.5 at 15 GHz	7.8 at 2 GHz	9 at 15 GHz	6.15 at 15 GHz	5.4 at 15 GHz
Loss tangent, 25°C	0.0015 at 15 GHz	0.0005 at 15 GHz	~0.002 at 16 GHz	0.001 at 15 GHz	0.0025 at 15 GHz	0.032 at 15 GHz
Microstripline loss	0.3 at 12 GHz	0.17 at 12 GHz	~0.2 to 0.5 at 12 GHz	0.25 at 12 GHz	0.4 at 12 GHz	1.5 at 12 GHz

*Some manufacturers offer buried resistors. See www.ohmega.com

**Data compiled from measurements, manufacturers product data and web sites

ductivity of 170 W/m°C. Furthermore, high frequency loss as low as 0.5 dB per inch of transmission line at 40 GHz is possible.

There are a number of other benefits associated with LTCC-M. Shrinkage in the x-y plane during firing is typically 0.1 percent, a significant improvement over LTCC, which has a typical shrinkage of 12.7 to 14.8 percent. LTCC-M boards can be as large as 16" × 16" and have greater component density than LTCC boards, which are limited to 6" × 6" wafer sizes. The larger wafers allow multiple populated circuits to be created in one pass through the furnace, which can then be cut from the finished wafer. This capability lowers production costs because it reduces parts handling and other repetitive steps.

Production costs can also be saved in other ways using LTCC-M. To protect against environmental exposure, LTCC substrates often are placed in costly leaded Kovar packages. With LTCC-M, a hermetic package with lid can be produced for a savings of as much as 50 percent. LTCC-M also allows a variety of optical and electrical connection options that simplify integration and reduce assembly costs.

LTCC-M PROCESS

All of this is made possible by an LTCC-M process that greatly reduces the number of production steps compared to standard LTCC. The first part of the process, production of a populated substrate, is similar to the one used for LTCC parts, except that LTCC-M parts have a bonded metal base. Both LTCC and LTCC-M start with a roll of "green tape" however LTCC-M bonds that tape to Kovar or CuMoCu. The populated multiplayer board is formed in a similar fashion to LTCC:

- Cutting the dielectric substrate into blanks for each layer
- Punching via holes for connections between layers
- Applying metallization, insulation and resistive pastes to each layer
- Bonding the layers
- Co-firing the "green" multiplayer assembly and metal base

Although both substrates share many of the same processing steps, the LTCC-M technology has advantages. One is that up to 24, 0.004" thick layers for traces and buried passives are possible at a price as low as $2 per square inch per layer. For a given circuit design, such layering allows shrinkage in overall package dimensions. This combination of characteristics cannot be duplicated with conventional LTCC technology. A complete comparison of LTCC-M to LTCC and other substrates can be seen in ***Table 1***.

CONCLUSION

High performance systems pose difficult design problems, including circuit and system packaging. Conventional substrate technologies have been shown to either lack the performance or price point to meet the trend towards higher bandwidth and more feature-laden products in smaller packages. The new LTCC-M technology serves as a solution for these high performance circuits and systems.

Lamina Ceramics, Westampton, NJ 800-808-LTCC (5822), www.laminaceramics.com.

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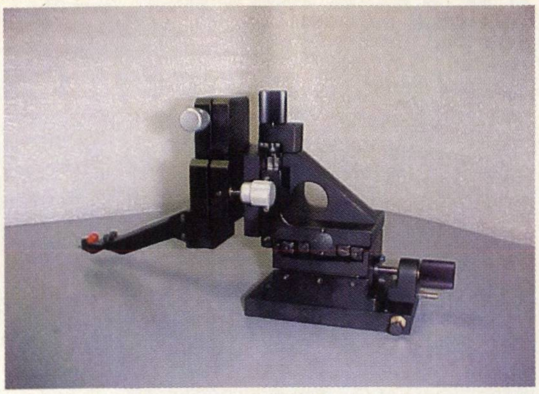
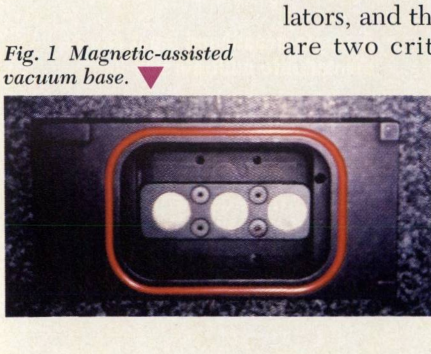


RF/MICROWAVE MANIPULATORS FOR PRECISE TEST PROBE MEASUREMENTS

In today's fast paced semiconductor industry making accurate and reliable measurements at microwave frequencies is critical to successful product development operations. Microwave measurements enable engineers to characterize both the linear and nonlinear behavior of devices, providing critical performance information. Precise probe contact is a necessity to obtain accurate test data. Precision microwave manipulators must be employed to properly position the probe contacts.

A series of new RF/microwave manipulators has been introduced that feature direct leadnut coupled drives and a number of base choices including a magnetic-assisted vacuum base. The WAVE100 and WAVE200 manipulators, and the PLF/PLS probe head link arms are two critical elements that assure microwave system stability and probe planarity required for sensitive microwave circuit measurements. These rugged rectilinear manipulators have a lead screw pitch of 40 threads-per-inch and feature secure massive mounts to provide stability, even with semi-rigid coaxial cables attached to the probes. The rigid probe head link arms are available in two styles to permit simultaneous use of four probes, and theta and planarity adjustments of the probes are standard.

Fig. 1 Magnetic-assisted vacuum base. ▼



FIVE DEGREES OF FREEDOM

The WAVE100 (left-handed) and WAVE200 (right-handed) manipulators are engineered with five degrees of freedom. The new manipulators feature five controls that are readily available for fingertip adjustment to obtain the precise probe contact required. The controls are up/down, forward/backward, side-to-side, planarity and 4° of theta control. Probing RF/microwave test structures is now easier than ever. In addition to maximum position control, the large 4.8" × 2.3" base is available in magnetic, magnetic-assisted vacuum, vacuum and mechanical lock mounts. The mechanical lock configuration is easy to use, requiring no tools for setup. ***Figure 1*** shows the manipulator's magnetic-assisted vacuum base

[Continued on page 110]

MICROMANIPULATOR CO.
Carson City, NV

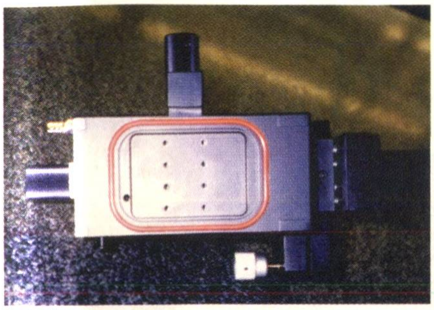


Fig. 2 *Vacuum base.*

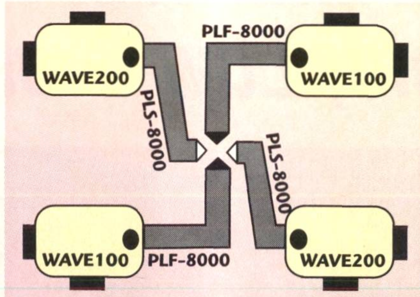


Fig. 3 *Manipulator/link arm possibilities.*

configuration. This base style is an excellent choice for occasional use on stations not designed for microwave work, as the magnetic base secures the manipulator from tipping and the addition of vacuum gives it rock-solid stability. ***Figure 2*** shows the vacuum base. The manipulator assembly weighs four pounds and provides a secure foundation for the semi-rigid cables used in most applications. Each WAVE100/200 manipulator requires a link arm to hold and extend the probe head to the device under test. These link arms accommodate probe stations where the chuck is below the platen or where the chuck is above the platen simply by using different mounting holes on the planarity face plate.

When combined with the rugged PLS (straight) and PLF (right angle) probe head support arms the fixture can easily probe pad sizes of 2 μm with precision planarity and theta alignment, and no probe vibration. ***Figure 3*** shows a possible four-probe test configuration using both WAVE100 and WAVE200 manipulators with PLS and PLF arms.

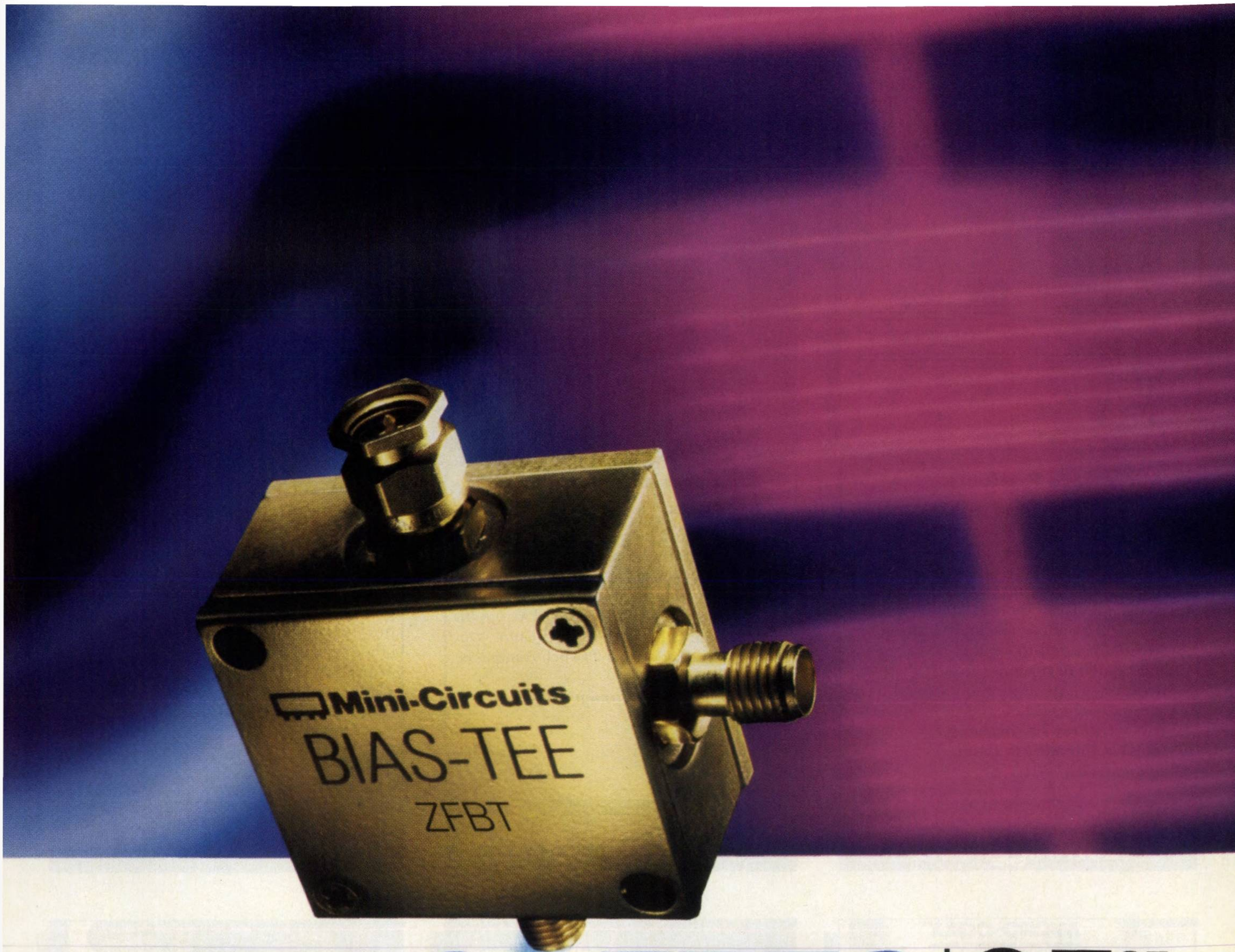
The WAVE100/200 manipulators are compatible with most manufacturer's probing stations, including Micromanipulator's 9000 series with the RF option for 12" wafers, 4000 Tech Series, 6500 or 8000 series for 4", 6" and 8" wafers. With the proper manipulator base choice they can work with probe stations with or without the RF option.

The WAVE100/200 manipulators can support all manufacturer's microwave probe heads, including the industry leading Picoprobe® microwave probe head that can be used at frequencies up to 220 GHz, and features excellent insertion and return loss performance.

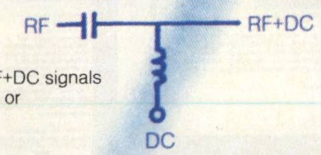
WAVE100 and WAVE200 manipulators are currently available with delivery times ranging from six to eight weeks. Additional information may be obtained by visiting the company's Web site at www.micromanipulator.com or by contacting the company's sales staff.

Micromanipulator Co.,
Carson City, NV
(775) 882-2400,
info@micromanipulator.com.

Circle No. 303



BIAS TEES From $25.95



Easily combines RF+DC signals for your modulation or test requirements.

Now up to 500mA DC current 100kHz-6GHz

With Mini-Circuits Bias-Tees, you can DC connect to the RF port of an active device without effecting its RF properties...modulate a laser, apply DC to an amplifier output, and more! Using statistical process control plus combining magnetics and microstrip, large DC currents may pass through the Bias-Tee without saturation and degradation of performance. At 1/3 to 1/4 the price of competitive units, these new Bias-Tees are available in surface mount, pin, and connectorized models. So why wait, solve your connection problems with Mini-Circuits Bias-Tees.

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

Model	Freq (MHz)	Insertion Loss (dB Typ.)			Isolation (dB Typ.)			VSWR (Typ.)	Price $ ea
	F_L-F_U	L	M	U	L	M	U	U	1-9 qty.
▲ZFBT-4R2G	10-4200	0.15	0.6	0.6	32	40	50	1.13:1	59.95
▲ZFBT-6G	10-6000	0.15	0.6	1.0	32	40	30	1.13:1	79.95
▲ZFBT-4R2GW	0.1-4200	0.15	0.6	0.6	25	40	50	1.13:1	79.95
▲ZFBT-6GW	0.1-6000	0.15	0.6	1.0	25	40	30	1.13:1	89.95
▲ZFBT-4R2G-FT	10-4200	0.15	0.6	0.6	N/A	N/A	N/A	1.13:1	59.95
▲ZFBT-6G-FT	10-6000	0.15	0.6	1.0	N/A	N/A	N/A	1.13:1	79.95
▲ZFBT-4R2GW-FT	0.1-4200	0.15	0.6	0.6	N/A	N/A	N/A	1.13:1	79.95
▲ZFBT-6GW-FT	0.1-6000	0.15	0.6	1.0	N/A	N/A	N/A	1.13:1	89.95
★ZNBT-60-1W	2.5-6000	0.2	0.6	1.6	75	45	35	1.35:1	82.95
■PBTC-1G	10-1000	0.15	0.3	0.3	27	33	30	1.10:1	25.95
■PBTC-3G	10-3000	0.15	0.3	1.0	27	30	35	1.60:1	35.95
■PBTC-1GW	0.1-1000	0.15	0.3	0.3	25	33	30	1.10:1	35.95
■PBTC-3GW	0.1-3000	0.15	0.3	1.0	25	30	35	1.60:1	46.95
•JEBT-4R2G	10-4200	0.15	0.6	0.6	32	40	40	-	39.95
•JEBT-6G	10-6000	0.15	0.7	1.3	32	40	40	-	59.95
•JEBT-4R2GW	0.1-4200	0.15	0.6	0.6	25	40	40	-	59.95
•JEBT-6GW	0.1-6000	0.15	0.7	1.3	25	40	30	-	69.95

L = Low Range M = Mid Range U = Upper Range

NOTE: Isolation dB applies to DC to (RF) and DC to (RF+DC) ports.

▲SMA Models, FT Models Have Feedthrough Terminal ★Type N, BNC Female at DC

■Pin Models •Surface Mount Models

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Microwave Products

This Web site enables customers to efficiently gather information from the company's products catalog. Visitors can easily access detailed part descriptions, images and drawings of all the company's GPO™ and GPPO™ standard products. It also features product information, assembly instructions and recommended tools. Pull-down menus provide quick navigation through the company overview, literature requests and technical information sections.

Corning Gilbert Engineering,
5310 West Camelback Road,
Glendale, AZ 85301

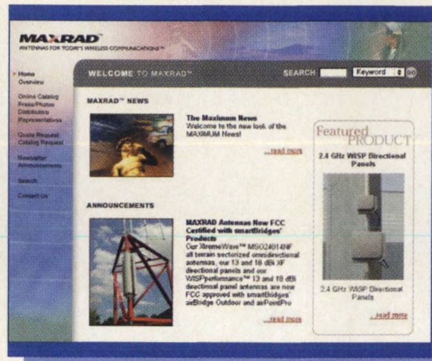
www.corning.com/corninggilbert

Commercial and Defense Products

This Web site details the company's design and manufacturing capabilities for commercial and defense products from 100 MHz to 100 GHz. Product information and downloadable data sheets for LNAs, PAs, multipliers, up/down converters, oscillators, synthesizers, transceivers and switch combiners.

Endwave Corp.,
990 Almanor Ave., Sunnyvale, CA 94085

www.endwave.com

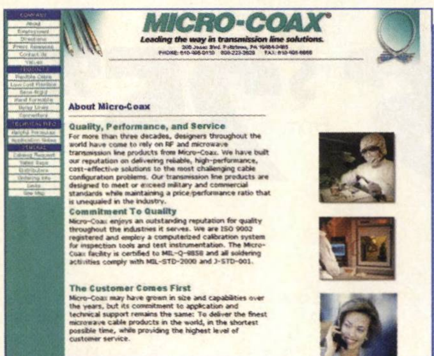


Antennas

In an effort to optimize marketing communications and shorten its new product launch cycle, the company has launched a new Web site. The site is now the central point for the company's marketing activities, including public relations, direct mail, up-to-date product catalogs, on-line advertising and other key supporting activities.

MAXRAD Inc.,
4350 Chandler Drive,
Hanover Park, IL 60133

www.maxrad.com

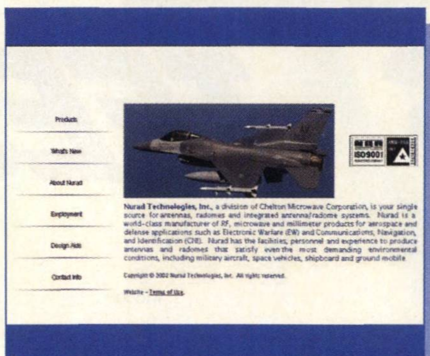


Microwave Transmission Line Products

This Web site makes it easier to locate and download information on the company's full line of microwave transmission line products designed for use in commercial, military and space applications. The site has been redesigned with improved functionality features and increased literature download capability so visitors can now easily download data sheets, application notes and other literature in PDF format.

MICRO-COAX,
206 Jones Blvd., Pottstown, PA 19464

www.micro-coax.com



Antenna and Radome Products

This updated and expanded Web site provides detailed information on antenna and radome products, technology and capabilities. Specific technical information is provided for airborne antennas for electronic warfare and communication, navigation and identification applications. The site also provides antenna and radome design aids and engineering data.

Nurad Technologies Inc.,
a division of Chelton Microwave Corp.,
3310 Carlins Park Drive,
Baltimore, MD 21215

www.nurad.org

RF Microwave Substrate Materials

This Web site features a new, faster-loading and easier to navigate look. Featured are product data tables, brochures, processing guides, technical bulletins and comparative tables. Information on all of the company's comprehensive substrate materials is available in the products section of the site, including the model N9000 RF microwave substrate material.

Park/Nelco–Neltec,
1420 West 12th Place, Tempe, AZ 85281

www.parknelco.com

RFICs for Wireless Communications Applications

This redesigned Web site focuses on enhancing customers' Web experiences. The site features an on-line product guide providing customers access to the company's extensive product portfolio and support documentation, such as data sheets, application notes, block diagrams, packaging types and performance details. It also includes a search engine that enables customers to search the product guide by product family, application, standard or part number.

RF Micro Devices Inc.,
7628 Thorndike Rd.,
Greensboro, NC 27409

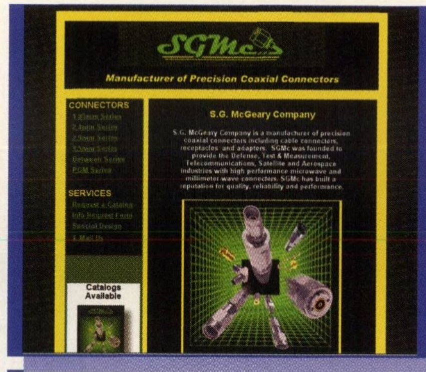
www.rfmd.com

Antenna Products

This web site provides information on the company's full range of products and services, including: antenna development, standard antenna products, EM modeling, antenna feeds, consulting, microwave components, antenna subsystems and test facilities.

Seavey Engineering Associates Inc.,
North River Commerce Park,
28 Riverside Dr., Pembroke, MA 02359

www.SeaveyAntenna.com



Precision Coaxial Connectors

This site has recently been upgraded and features descriptions, specifications and drawings of the company's full line of precision coaxial connectors. Included are 1.85, 2.4, 2.9 and 3.5 mm series. Products are available for cable connectors, receptacles and adapters (both in-series and between series). A form requesting custom designs is also available.

S.G. McGeary Co.,
525 Gus Hipp Blvd., Suite A,
Rockledge, FL 32955

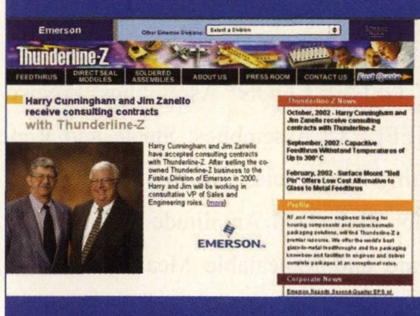
www.sgmcgeary.com

Programmable DC Power Supplies

This Web site features enhanced user-friendly features, providing visitors with greater technical content and graphic presentation. The home page features a product of the month, along with a breakdown of information available on the site. Users will find direct links to products, company news and information, sales and service support, and the company's new system outsourcing service. A complete section on articles, application notes and manuals is also available.

Sorensen, a division of Elgar,
9250 Brown Deer Road,
San Diego, CA 92121

www.sorenson.com



RF Feedthrus and Packaging Solutions

This new Web site features a monthly product release of advanced feedthrus and direct seal and soldered assembly packaging solutions. It is set up for electrical and mechanical engineers looking for the latest housing components and modular packaging solutions. The site also offers a complete overview of the company's glass-to-metal RF feedthrus and packaging solutions and offers an easy Fast Quote form for submitting applications.

Thunderline-Z,
11 Hazel Dr., Hampstead, NH 03841

www.Thunderlinez.com

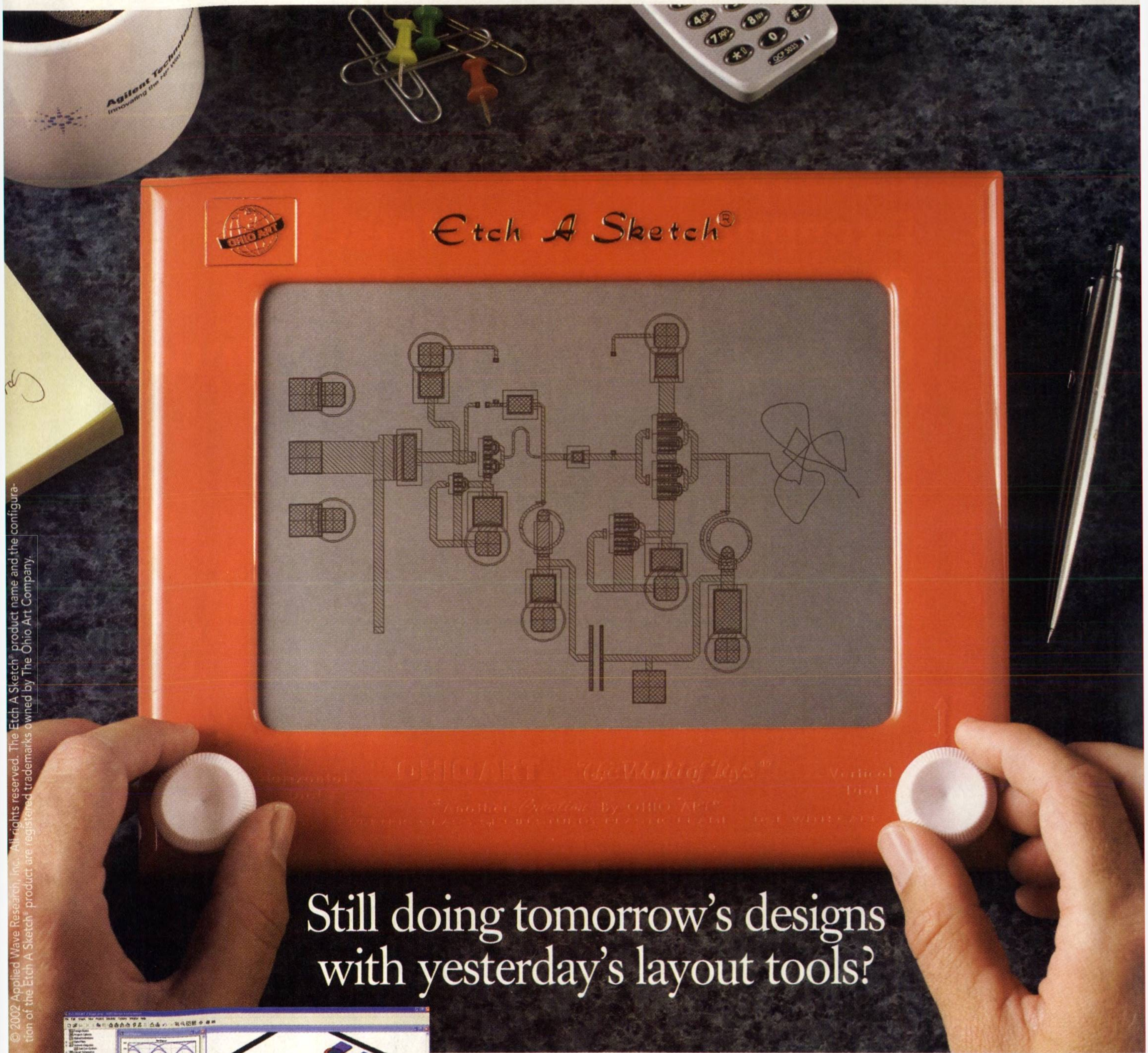
Test Solutions

This Web site features the company's test solutions, which can help customers get to market with next generation wireless devices. The company supports a broad range of innovative test solutions, services and support for components, devices and base stations. The wireless industry Web site features more informaiton on accelerating the delivery of users' wireless products.

Agilent Technologies,
295 Page Mill Rd., Palo Alto, CA 94306

www.agilent.com/find/wireless

AWR



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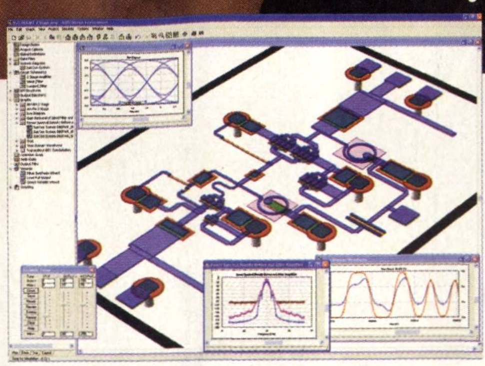

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IMI Printed Circuit Boards
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StratEdge Corp.
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Sumitomo Metal (SMI) Electronics
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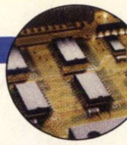


NEW PRODUCTS

COMPONENTS

■ Surface-mount Balun

This miniaturized version of the company's 2.4 GHz Xinger-brand surface-mount balun has an

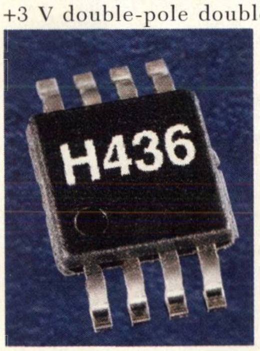
insertion loss of 0.35 dB (max), making it an ideal companion for 802.11b and 802.11g access point and embedded WLAN chipsets. Other advantages include optimization for impedance matching and guaranteed phase and amplitude performance.

Anaren Microwave Inc.,
East Syracuse, NY (315) 432-8909.

Circle No. 216

■ DPDT Switch

The model HMC436MS8G low insertion loss, +3 V double-pole double throw (DPDT)



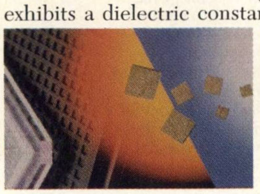
switch is designed for 802.11a/HiperLAN WLAN and UNII point-to-point/multipoint 5.1 to 5.9 GHz applications. It is an integrated antenna diversity and transmit/receive switch that provides 1 dB insertion loss while handling up to +30 dBm RF input power from 0/+3 V DC control inputs. Port-to-port isolation is over 20 dB with better than 20 dB return loss on any port. Packaged in a low profile, 1 mm high 8 lead MSOP surface-mount package, the switch is ideally suited for 802.11a and access point front-end switching.

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

Circle No. 218

■ Single Layer Capacitors

The Maxi-Plus Series of single layer capacitors exhibits a dielectric constant of 30,000. They



feature X7R temperature characteristics and are ideal for decoupling around electro-optical amplifiers and trans-impedance amplifiers. The series is also designed to operate in the millimeter bands with an ultra low equivalent series resistance specifically for the RF/microwave, optical and cellular market. Exhibiting a very high or non-definable self-resonant frequency, these capacitors feature ultra-wide band capabilities. The high dielectric constant featured in the Maxi-Plus Series allows for a compact package that is 60 percent smaller than previously offered packages. The series features capacitance values from 100 to 10,000 pF. Typical measurement coefficient for these capacitors is ±15 percent over the operating temperature range from –55° to +125°C. Rated from 50 V, the series is offered in length and width size ranges from 0.010" to 0.100" with custom sizes available.

AVX Corp.,
Myrtle Beach, SC (843) 946-0414.

Circle No. 217

■ TETRA Hybrid Combiners

The model WSC2-00015 and WSC4-00014 TETRA band high power transmit hybrid combiners allow either two carriers to be combined onto a single transmission line with the WSC2-00015 or four carriers with the WSC4-00014.

With an operating frequency band of 380 to 430 MHz, these combiners offer low insertion loss of 3.7 dB (max) (WSC2-00015) and 7.2 dB (max) (WSC4-00014) and high transmit input to input isolation of 40 dB (min) for the WSC2-00015 and 60 dB (min) for the WSC4-00014. Minimum power handling is specified as 25 W CW TETRA carriers per input for either 2:1 or 4:1 models. Passband return loss is specified at 15 dB (min) at all ports. Operating temperature range is –30° to +50°C.

K&L Microwave Inc.,
Salisbury, MD (410) 749-2424.

Circle No. 219

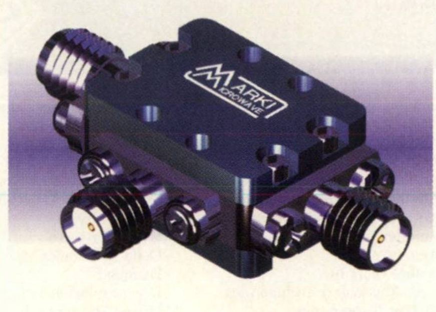
■ Capacitive Feedthrus

These feedthrus are designed for eliminating noise and frequency interference in discoidal capacitance filtering applications such as in modulators, switches, amplifiers, filters, multifunction assemblies and other active devices. Utilizing premium glass and proprietary soldering techniques, the series of single pin design styles can be custom manufactured for unique applications up to 300°C. These hermetic capacitive feedthrus are designed to meet or exceed MIL-F-28861 by providing a guaranteed hermeticity of 1×E^{-8} cc/sec at 1 atm or better. Capacitance values range from 5 to 27,000 pF with tolerances as tight as ±10 percent. They are ideal for designers seeking ultra-pure DC signals at higher frequencies. They eliminate the need for externally mounted capacitor chips, freeing board and/or package space.

Thunderline-Z,
Hampstead, NH (603) 329-4050.

Circle No. 225

■ Mixer



The model M2-0243 mixer covers 2 to 43 GHz with a 400 MHz to 43 GHz IF. Designed for fiber-optic clock-recover/acquisition applications requiring an ultra-broadband IF, the unit is a unique triple-balanced mixer design, available in 2.92 mm connectorized outline. Local oscillator drive levels are +12 to +15 dBm. Typical conversion loss is 10 to 20 dB.

Marki Microwave Inc.,
Morgan Hill, CA (408) 778-4200.

Circle No. 221

■ Semi-rigid Cable Connectors

These 2.8 mm male and female connectors are designed for RG-405 (0.085) semi-rigid cable.

Available in both direct solder or solder clamp attachment, these designs exhibit low SWR and perform to 40 GHz. Other 2.9 mm connectors are available for 0.085 low loss, 0.118 and 0.141 diameter semi-rigid cable. The connectors feature a DC to 40 GHz frequency range and SWR of 1.25 (max), and are air dielectric and mechanically compatible with SMA and 3.5 mm connector series.

S.G. McGeary Co.,
Rockledge, FL (321) 636-0909.

Circle No. 223

■ BMA Connectors

The BMA Series connectors feature a high integrity push-on SMA interface that is suitable

for dense modular connector arrays requiring fast and reliable connections. This line of high frequency BMA connectors has been expanded to fit many types of cables including semi-rigid sizes from 0.0865" to 0.1410" and flexible cables from 0.190" to .240" with crimp and solder attachment. The connectors accommo-

[Continued on page 122]

NEW PRODUCTS

date a maximum of 0.60" (0.120" custom) axial- and ±0.020" radial misalignment. Designed for DC to 22 GHz applications, these 50 Ω connectors have a 1000 Vrms dielectric withstanding voltage and 5000 megohms insulation resistance. Price: from $12.45 each.
TRU Corp., Peabody, MA (800) 262-9878.
Circle No. 226

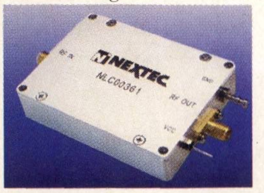
AMPLIFIERS

■ Power Thin Film Amplifier

The model AML618P3301 low noise, 1 W wide band amplifier operates in the 6 to 18 GHz frequency range and provides 33 dB (min) gain with an output power at 1 dB gain compression of +30 dBm (min). Noise figure is below 3 dB across the entire bandwidth. Input and output SWR is 1.8 nominal. Operating at +15 V DC this amplifier draws 1050 mA (typ) current. Internal DC regulator, reverse voltage protection and field removable SMA (f) connector shells are standard. Modules are also available as carrier mounted substrates. Size: 2.00" × 0.75". Delivery: 10 days (ARO).
AML Communications Inc., Camarillo, CA (805) 388-1345.
Circle No. 227

■ Low Noise Amplifier

The model NLC00361 low noise power amplifier is designed for mobile communications systems operating from 1920 to 1990 GHz. The gain at room temperature is 25 dB with noise figure over operating temperature range of 1.2 dB (max). The output third order intercept point at 10 dBm output power/tone at room temperature is 35 dBm (min). 1 dB compression point at room temperature is 18 dBm (typ).



Nextec Microwave & RF Inc., Santa Clara, CA (408) 727-1189.
Circle No. 229

■ Broadband Laboratory Amplifier

The model TPT5001200-6 broadband laboratory amplifier is a linear, class A lab unit covering 500 to 1200 MHz, producing a typical power of 38 dBm at 1 dB compression with 25 dB of gain. The 6 W amplifier offers typical IP3 of 48 dBm, input and output SWR < 2 and prime power of 110 V AC. Size: 6.00" × 5.50" × 3.25".
Transistor Power Technology Inc., Huntington, NY (631) 491-0265.
Circle No. 231

ANTENNA

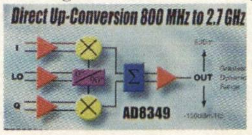
■ Broadband Dual Linear Antenna

This broadband dual linear antenna was designed for polarization diverse applications. High power handling and good isolation help with power on target and good polarization purity. The antenna is capable of functioning in airborne environments without degradation. It features SWR of 2.5 (max), port-to-port isolation of 25 dB (min) and operates over the 6 to 18 GHz frequency range.
Nurad Technologies Inc., a division of Chelton Microwave, Baltimore, MD (410) 542-1700.
Circle No. 233

INTEGRATED CIRCUIT

■ Quadrature Modulator

The model AD8349 I/Q quadrature modulator is designed to enable a single-stage upconversion for wireless infrastructure equipment. The device covers the 800 MHz to 2.7 GHz band, allowing designers to specify the AD8349, and to standardize on it across multiple operating bands and cellular standards. It is designed to ease direct upconversion for CDMA, WCDMA, GSM EDGE and TDMA transmitters. A direct upconversion architecture significantly reduces the cost compared to traditional multistage IF approach. The noise floor is specified at –156 dBm/Hz and the P1dB output compression point is specified at +5 dBm, thereby allowing the user to attain a higher output for a given adjacent channel power. With improved quadrature accuracy of 0.2 dB and phase balance of 0.5°, this component achieves a sideband rejection of –42 dBc. Price: $4.50 (10,000).



Analog Devices Inc., Norwood, MA (800) 262-5643.
Circle No. 234

MATERIALS

■ High Reliability, FR-4 Epoxy Material

The N4000-11 series of laminate and prepreg materials are being introduced to provide printed circuit board fabricators with a next-generation, high Tg FR-4 product that is designed to meet the difficult performance specifications currently being proposed by a variety of multinational OEMs. The N4000-11 is designed to provide a conductive anodic filament resistant, dimensionally stable material with superior thermal performance. With a Tg of 175°C, these materials are designed for use in a broad range of printed circuit board applications requiring very low Z-axis expansion, outstanding thermal stability and superior hole-wall integrity. The material also features improved process latitude when compared to similar high Tg dielectric materials currently under investigation for their thermal superiority. This material set is recommended for high density designs in the network storage, telecommunications infrastructure, enterprise server, and Internet connectivity segments.
Park Electrochemical Corp., Lake Success, NY (516) 354-4100.
Circle No. 235

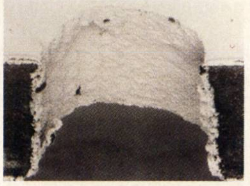
■ Copper-manganese-nickel Alloy

Wieland-LV7 is a copper-manganese-nickel alloy with an almost silvery color. Its chemical composition is Ni 20 percent, Mn 20 percent and Cu balance. The material has a good corrosion resistance (comparable to lead-free nickel-silvers) and excellent formability, joining (brazing, soldering) and plating characteristics. High strength and outstanding spring properties are achieved by special heat treatment. Stress relaxation at 150°C is less than 20 percent. It is also cost-effective, and ideal for special electrical applications such as high frequency connectors.
Wieland Werke AG, Ulm, Germany +49 (0) 741 9440.
Circle No. 236

SERVICE

■ Aluminum Nitride Clean Via Technology

This newly developed process renders laser drilled vias in aluminum nitride (AlN) slag-free. Clean Via Technology (CVT™) creates a perfectly clean AlN grain structure on laser drilled via walls. Exposing this virgin grain structure provides strong mechanical footholds as well as a chemically active surface for chemical bonds. This proprietary process makes it possible for both thick and thin film circuit manufacturers to use laser drilled AlN with a degree of success previously not possible.



P/M Industries, Portland, OR (800) 462-0439.
Circle No. 237

SOFTWARE

■ Simulation Software

Version 1.1 of APLAC Simulation Builder (ASB) is designed for the Mentor Graphics design frameworks. It enables seamless cooperation of the APLAC Simulator and Mentor Graphics Design Architect, RF Architect and PowerLogic. ASB connects directly to frame-

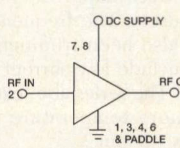
[Continued on page 124]

MNA AMPLIFIERS

MMICs from 500MHz to 5.9GHz $1.35

as low as $1.35 ea. (qty. 1000)

Biasing Configuration



Built-In RF Choke, Resistors, Bypass & Coupling Capacitors

Simplify your 500MHz to 5.9GHz designs with Mini-Circuits easy to use MNA amplifiers. With DC blocking capacitors and a biasing network built-in, all you do is drop the amplifier in place on your PC board, connect, and the job is done! There's no biasing to figure out and no external components to connect. Broadband, low and high power models offer 10 to 23dB (typ) gain, 7 to 18dBm (typ) power output, and more than 40dB isolation, which makes them terrific for use as an isolator. But these amplifiers go on to feature a minuscule ***3x3mm MCLP™ SM package with exposed metal bottom for excellent grounding and heat dissipation.*** If you're looking for versatility, MNAs operate from a +5V to 2.8V DC supply, making them indispensable for use in today's miniature battery operated hand-held devices. And if you're looking for value, prices start ***from only $1.60 ea.*** (qty. 30). *So simplify your design, your manufacturing, and your life with Mini-Circuits all-in-one MNAs!*

MODEL	Freq. (GHz)	DC Volts (V)	Gain Midband (dB) Typ.	Pwr. Out 1dB Comp. (dBm) Typ.	Price $ea. (qty.30)
MNA-2	0.5-2.5	5.0 2.8	12.8 11.5	17.7 12.9	1.90
MNA-3	0.5-2.5	5.0 2.8	16.2 15.2	11.4 9.7	1.60
MNA-4	0.5-2.5	5.0 2.8	16.6 14.6	17.0 13.4	1.90
MNA-5	0.5-2.5	5.0 2.8	22.8 21.4	12.2 10.1	1.60
MNA-6	0.5-2.5	5.0 2.8	23.5 21.5	18.0 14.1	2.25
MNA-7	1.5-5.9	5.0 2.8	17.2 15.4	15.6 12.7	2.25

Amplifier Designer's Kits **IN STOCK**

K1-MNA: 10 of ea. MNA-2, 3, 5, 6...$69.95

K2-MNA: 10 of ea. MNA-2, 3, 4, 5, 6, 7...$99.95

Application note for PCB layout included.

Detailed Performance Data Online at: ***www.minicircuits.com/amplifier.html***

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ISO 9001 ISO 14001 CERTIFIED

371 rev. A

works schematic database, and reads out netlist information that can be completely tailored to create a specific netlist. The software features multiple mapping library support, better mapping error reporting, support for measurement templates and an online help system. With its foundation on proven PCB design systems, ASB eliminates additional interfaces, database conversion and error prone manual re-design of RF blocks.

APLAC Solutions Corp., Helsinki, Finland +358-9-54045000.

Circle No. 238

SOURCES

OCXO

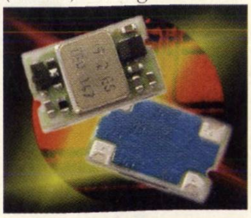
The model FTS501AH oven compensated crystal oscillator (OCXO) meets stratum level accuracy requirements for telecommunications applications, making it ideal for use in base stations, telecom switching, GPS and LAN/WAN applications as well as in test and satellite equipment. It offers a frequency stability of ±250 ppb over the 0° to 70°C temperature range and an overall accuracy of ±4.6 ppm for all conditions over 10 years. The frequency range of the new OCXO is 10 to 40 MHz. Supply voltage is 5.0 V, with 3.3 V available, and control voltage is 0.5 to 5.0 V. Storage tmperature range is –40° to +85°C. Price: $68 (1000). Delivery: eight weeks (ARO).

Fox Electronics, Fort Myers, FL (888) 438-2369.

Circle No. 240

TCXO

The VC-TCXO HFX series temperature-compensated crystal oscillator (TCXO) is designed to increase performance for GSM and CDMA products. The small size, coupled with several new features, enables engineers to produce high performance compact designs for GSM and CDMA products, such as mobile phones and handheld devices. The series also employs analog transistors to reduce phase noise, which improves effective data rates on handsets. The frequency in production has also been trimmed, yielding high accuracy rates. Additional benefits include low current consumptions and a built-in DC blocking capacitor. The series also features measurement technology that guarantees more temperature points for greater frequency stability. Size: 3.2 × 2.5 × 1.2 mm.



Murata Electronics, Smyrna, GA (770) 436-1300.

Circle No. 242

S-band VCO

The model V844ME02 S-band VCO is designed for the point-to-point radio market. This device covers from 3430 to 3610 MHz within 0.5 to 4.5 V DC of control voltage while covering 180 MHz bandwidth with an average tuning sensitivity of 87 MHz/V. The VCO also realizes spectral purity of –88 dBc/Hz (typ) at 10 kHz from the carrier. It will strengthen any phase-locked loop (PLL) with its 1.1:1 linearity over frequency and temperature and suppresses the second harmonic to better than –15 dBc. The V844ME02 draws 18 mA off a 5 V DC supply and furnishes the end user with 2.25±1.25 dBm of output power into a 50 Ω load and is guaranteed to operate over the extended commercial temperature range of –40° to +85°C. It is further heightened by pushing less than 1 MHz within 5 percent of the nominal supply voltage and pulls less than 8 MHz with a 14 dB return loss, any phase. Size: 0.50" × 0.50" × 0.13". Price: $15.95 each.

Z-Communications, San Diego, CA (858) 621-2700.

Circle No. 244

Phase-locked Oscillator

This 20 GHz phase-locked oscillator locks to a 5 MHz reference input in a single loop. Its low power consumption, along with its compact size, sturdy structure and low phase noise offer an attractive solution for various defense applications. The unit offers 20 GHz output frequency, +12 dBm (min) output power, an operating temperature range from –45° to +75°C, +12 to +24 V DC, < 400 mA power consumption and < –120 dBc phase noise at 100 kHz offset. Size: 2.25" × 2.25" × 0.62".

Elcom Technologies Inc.,
Rockleigh, NJ (201) 767-8030.

Circle No. 239

SUBSYSTEMS

Solid-state Power Supply

The PowerMod™ high voltage, solid-state power supply combines reliable switching technology at high voltage and high power in a rack-mount unit for use in manufacturing and laboratory applications. It features up to 200 kHz switching speeds with < 1 percent voltage regulation, < 1 percent ripple and maintains regulation when the load is changing. Capable of operating in constant voltage mode, constant current mode, or constant power mode, this switching power supply is offered in 30 and 40 kW 19" units. Providing full over-voltage and over-current protection and high immunity for operation near pulse discharges, the PowerMod supports demanding applications such as magnet control, ion implantation, magnetron heating, lasers, electron beams and RF transmitters. Price: $36,000 (30 kW) and $50,000 (40 kW).

Diversified Technologies Inc.,
Bedford, MA (781) 275-9444.

Circle No. 245

Low Profile Power Supply

This new series of the company's PowerBank family of low profile power supplies adds power-factor correction capability. From inputs of 115/230 V AC, it provides up to six configurable main outputs and two low power auxiliary outputs. Designated PowerBank PB15056PFC, output power is 1200 W at 110 V AC and 1500 W at 220 V AC. This unit is designed with 19" rack applications in mind, but it can also be used as a stand-alone box. Many mounting options make it suitable for a variety of applications. Internal fans provide cooling. Size: 16.84" × 12.60" × 1.75". Price: $1.42/W (100). Delivery: one to eight weeks.

Northwest Power Integrations (NPI),
a Vicor Integrations Architect,
Milwaukie, OR (503) 652-6161.

Circle No. 247

NEW LITERATURE

DC/DC Converter Guide

This 29-page catalog is completely user/applications-oriented. Each of 425 standard products is listed according to its output configuration (single, dual, triple, etc.), its output voltage (from 1 to 48 V), its output current (up to 40 A), its input voltage range (typically centered around 3.3, 5.0, 12.0, 24.0 or 48.0 V) and then its package.
DATEL Inc.,
Mansfield, MA (508) 339-3000.
Circle No. 200

Product Brochure

This brochure features the company's model ELCO-MPR-208/408-00 wideband VCO. The VCO tunes a 2000 to 4000 MHz octave from 0 to 24 V. Product information including common instrumentation/telecommunications specifications, packaging information and performance characteristics are included.
Emhiser Micro-Tech,
Reno, NV (775) 345-0461.
Circle No. 201

RFIC/MMIC Product Selection Guide

This selection guide contains a reorganization of over 190 products by market segments, broadband DC-6 GHz, cellular/PCS/3G, microwave/millimeter-wave and fiber optics. Application block diagrams, package information and a new section entitled "Specialty Products" are also included.
Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343.
Circle No. 202

Power Supply Catalog and Handbook

This 164-page power supply catalog features a revised and updated applications handbook and glossary, as well as full specifications on the company's current products. Included are specifications of many new products, including bipolar, four quadrant power supplies.
Kepco Inc., Flushing, NY (718) 461-7000.
Circle No. 203

Millimeter-wave Technology and Solutions

This 41-page catalog features the company's millimeter-wave products and services, such as: antennas and quasioptical products, mixers and detectors, oscillator and amplifier products, multiplier products, control components, filters and ferrite products, passive waveguide products, and test and measurement products.
Millitech LLC,
Northampton, MA (800) 664-5548.
Circle No. 204

CD-ROM Catalog

This CD-ROM catalog includes new products, updated datasheets with more comprehensive information and measurement curves, application notes, and a complete listing of the company's international sales representative network.
Mimix Broadband Inc.,
Webster, TX (281) 526-0536.
Circle No. 205

LC and Crystal Filters Brochure

This brochure features an extensive line of cost-effective crystal filters in all polynomials from 100 kHz to 300 MHz with fractional bandwidths of 0.002 to 3 percent, LC RF filters in all polynomials from 1 kHz to 2.5 GHz, and crystal-based frequency discriminators from 100 kHz to 80 MHz.
Network Sciences, c/o Sierra Microwave Marketing Technology,
Citrus Heights, CA (916) 339-0170.
Circle No. 206

Analog/Mixed Signal Foundry Services Brochure

This four-page brochure is an easy reference guide for companies that are evaluating outsourced foundry services to reduce the time-to-market volume to bring new products to market. The company's history and core competencies are also included as well as a brief overview of the bipolar and BiCMOS wafer fabrication technologies.
PolarFab, Bloomington, MN 55425.
Circle No. 207

Broadband Wireless Components

This 132-page product catalog for microwave components provides information on the company's products, including detailed data sheets on mixers, VCOs and microwave frequency sources for commercial telecommunications, instrumentation, defense and space applications.
REMEC Broadband Wireless,
Milpitas, CA (408) 432-9898.
Circle No. 208

Specialty Materials Brochure

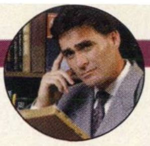
This new product capabilities brochure offers an array of specialty materials including high frequency circuit materials, laminates, photoimageable covercoats, high performance foams, busbars, EL lamps and drivers, elastomer components, nitrile floats, nonwoven materials, and moldable composite materials.
Rogers Corp., Rogers, CT (860) 774-9605.
Circle No. 209

Connectors Catalog

The connectors featured in this catalog offer a high contact reliability due to their design and the selection of materials as well as their surface treatment, providing excellent corrosion resistance. For all connector sizes listed the company supplies measuring equipment, including directional couplers, terminations, attenuators, high power loads as well as switches.
Spinner GmbH,
Munich, Germany +49 89 126 01 257.
Circle No. 210

Engineering Bulletin

The engineering bulletin (SG-207F) describes the company's line of microwave Sapphire PISTONCAP® trimmer capacitors. It adds data for a new wide lead version of the vertical surface-mount series. The other series include two configurations and five more mounting styles to suit all RF structures.
Sprague-Goodman Electronics Inc.,
Westbury, NY (516) 334-8700.
Circle No. 211



Wireless Communications — Principles and Practice, Second Edition

Theodore S. Rappaport
Prentice Hall PTR
707 pages; $92
ISBN: 0-13-042232-0

The second edition of this book has been written to initiate the newcomer to wireless personal communications, one of the fastest growing fields in the engineering world. Technical concepts which are at the core of design, implementation, research and invention of wireless communication systems are presented in an order that is conducive to understanding general concepts, as well as those specific to current and evolving wireless communication systems and standards. The text continues to evolve and has been updated and modified since its first edition, making it a useful book for practicing engineers, as well as for researchers, and graduate and undergraduate students. The second edition contains dozens of new homework problems and examples, as well as up to the minute technical details of the many emerging wireless standards throughout the world.

> ***"...this book has been written to initiate the newcomer to wireless personal communications..."***

Chapter 1 demonstrates the historic evolution of the wireless communication industry and documents the rapid growth of cellular radio. Chapter 2 provides an overview of the major modern wireless communication systems of the 21st century. Chapter 3 covers the fundamental cellular radio concepts and demonstrates the principle of trunking efficiency. Chapter 4 presents radio propagation path loss, link budgets and log-normal shadowing. Chapter 5 covers small-scale propagation effects such as fading, time delay spread and Doppler spread. Chapter 6 provides extensive coverage of the most common analog and digital modulation techniques used in wireless communications and demonstrates tradeoffs that must be made in selecting a method. Channel coding, adaptive equalization and antenna diversity concepts are presented in Chapter 7. Chapter 8 provides an introduction to speech coding. Chapter 9 introduces time, frequency and code division multiple access as well as more recent multiple access techniques such as packet reservation and space division multiple access. Chapter 10 describes networking considerations for wide area wireless communication systems. Chapter 11 unites all the material from the first nine chapters by describing and comparing the major existing, second generation cellular, cordless and personal communication systems throughout the world.

To order this book, contact: Prentice Hall PTR, Upper Saddle River, NJ 07458 (800) 922-0579.

Feedforward Linear Power Amplifiers

Nick Pothecary
Artech House Inc.
204 pages; $99, £73
ISBN: 1-58053-022-2

With the evolution of existing and new standards for mobile communication systems and wireless multimedia services, the quantity and complexity of the signals to be transmitted from a single location is increasing. There is a growing need for amplifiers that amplify all types of signals without adding significant distortion and are capable of operating over a wide bandwidth at potentially high levels of output power.

The general subject of this book is linear amplification for radio frequency transmitters. Specifically, the book is concerned with the use of feedforward as a linearization technique for radio frequency power amplifiers and is primarily aimed at engineers and technicians but is suitable for anyone wishing to learn about linear amplifiers in general, and feedforward in particular.

Chapter 1 begins with an overview of feedforward techniques and includes an introduction to a typical radio system for cellular, PCS, or IMT-2000/UMTS systems. Some concepts specific to operation at radio frequencies are also discussed. In Chapter 2, a mathematical-based approach is used to discuss amplifier input-output characteristics, signal modulation formats, signal envelopes, peak-to-average ratios and statistical analysis. Power amplifiers and system design are discussed in Chapter 3; topics include transistors for RF power amplifiers, amplifier efficiency and class of operation, intermodulation performance and system design issues such as combining RF signals. The concept of a linear amplifier is introduced and practical examples are given for different system configurations. Chapter 4 reviews different linearization techniques including feedback (RF feedback, envelope feedback, Cartesian loop and polar loop feedback), RF synthesis, envelope elimination and restoration, predistortion and feedforward. The discussion on feedforward includes the principles of operation, signal cancellation and loop control; dual-loop feedforward is also described. In Chapter 5, a detailed analysis of feedforward performance is given, with topics such as gain, input/output match, noise figure, broadband signal cancellation, error amplifier performance and system efficiency.

> ***"The general subject of this book is linear amplification for radio frequency transmitters."***

To order this book, contact: Artech House Inc., 685 Canton St., Norwood, MA 02062 (781) 769-9750 ext. 4002; or 46 Gilligham St., London SW1V 1HH, UK +44 (0) 207 596-8750.

Dan Massé

Dan Massé is a member of the Microwave Journal *staff.*

ADVERTISING INDEX

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3	Amplifier Research	44	215-723-8181	215-723-5688	www.amplifiers.com
4	Anaren Microwave	57	800-411-6596	315-432-9121	www.anaren.com
5	Ansoft Corp.	71,72–73	412-261-3200	412-471-9427	www.ansoft.com
6	Applied Wave Research Inc.	116	310-726-3000		www.appwave.com
7,8	Artech House	70,98	800-225-9977	781-769-6334	www.artechhouse.com
9	Atlantic Microwave Ltd.	88	44-1376-550220	44-1376-552145	e-mail: sales@ atlanticmicrowave.co.uk
10	BroadWave Technologies	40	317-346-6101	317-346-6995	www. BroadWaveTechnologies.com
11,12	Cascade Microtech	COV 4	503-601-1000	503-601-1002	www.cascademicrotech.com
13	Chin Nan	54	886-6-2678303	886-6-2678337	www.chinnan.com.tw
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16	CTIA WIRELESS	129	202-736-3664	202-785-0721	www.ctiashow.com
17	CTT Inc.	46	408-988-2999	408-986-9097	www.cttinc.com
18	DBP Microwave (formerly DB Products Inc.)	17	626-449-3790	626-449-7169	www.dbp4switches.com
19,20	Delta Microwave	31,33	805-240-1044	805-240-9544	www.deltamicrowave.com
21	Ducommun Technologies Inc.	86	310-513-7200	310-513-7298	www.ductech.com
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