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Microwave Journal

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THE FORWARD LOOK . . . in microwave plumbing fo

By TORE N. ANDERSON
AIRTRON INC.
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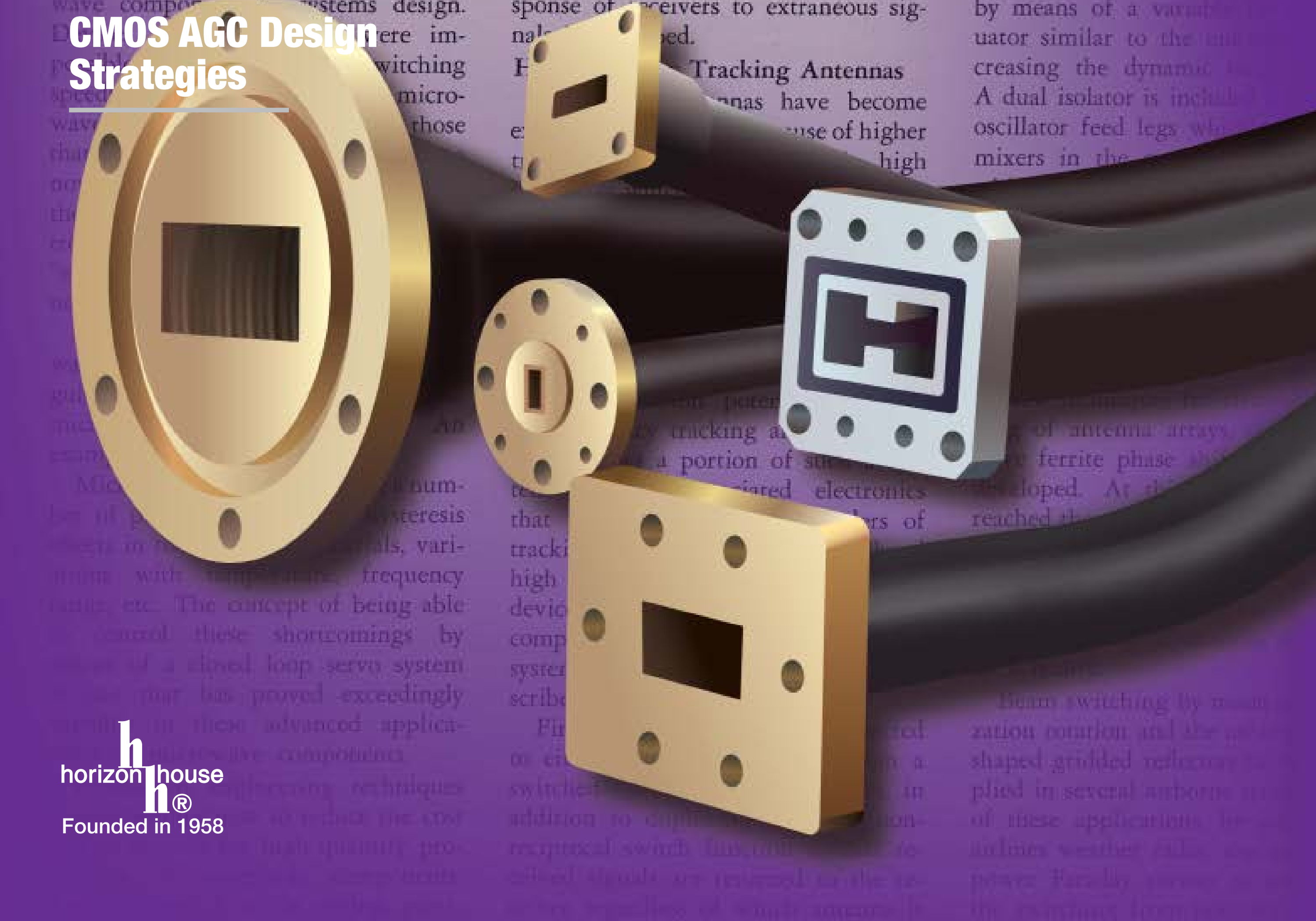

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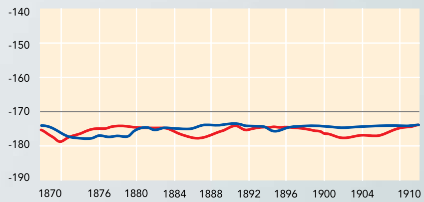

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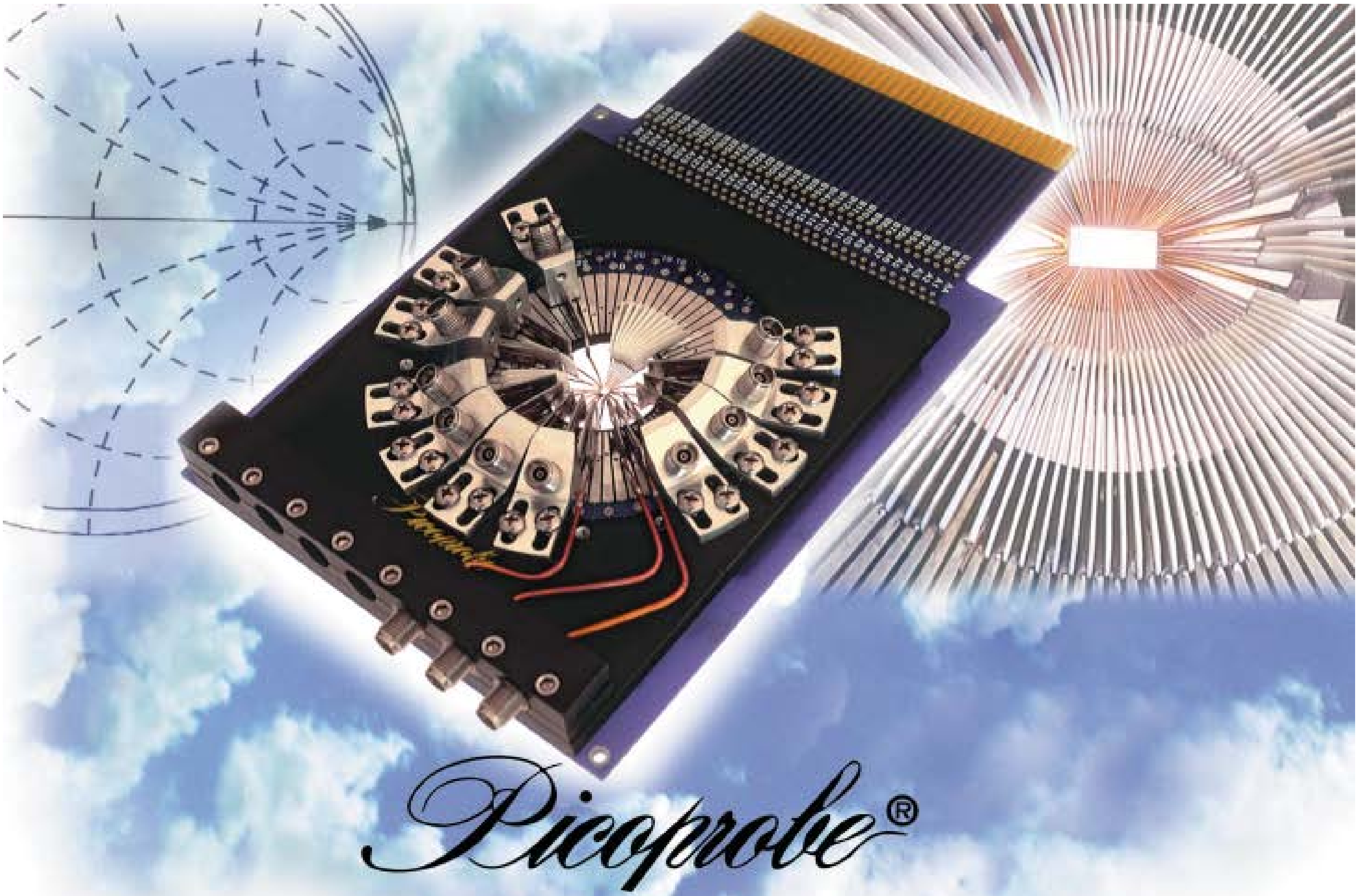

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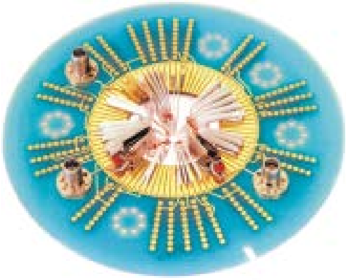

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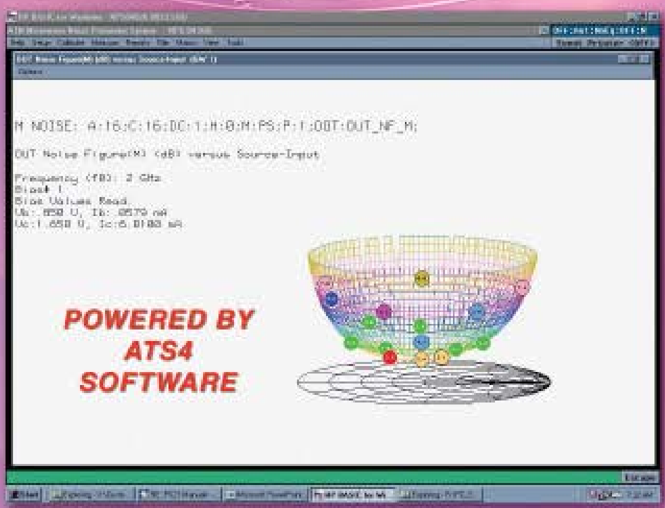

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FEBRUARY 2008 VOL. 51 • NO. 2

FEATURES

COVER FEATURE: THEN AND NOW

TECHNICAL FEATURES

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DEPARTMENTS

STAFF

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

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

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Impedance Matching in RF & Microwave Circuits

Les Besser returns to present this month's webinar demonstrating analytical and graphical (Smith Chart) impedance matching techniques. Methods for maximizing RF power transfer, conjugate matching, bandwidth considerations and impedance matching of balanced circuits will be discussed.

Presented by **Besser Associates** and *Microwave Journal*.

Live webcast: 2/19/2008, 11:00 AM (EST)

Online Technical Papers

White Paper: "Orthogonal Frequency Division Multiplexing"
Mark Elo, Marketing Director of RF Products, Keithley Instruments

White Paper: "Parallel Capacitance in High Power RF Resistors"
Florida RF Labs/EMC Technology Inc.

White Paper: "WiMAX Backhaul—No Longer Takes a Back Seat"
Aviv Ronai, CMO, Ceragon Networks

"Design, Development and Fabrication of Post-coupled Band Pass Waveguide Filter at 11.2 GHz for Radiometer"
Ravish R. Shah, Amit Patel, Ved Vyas Dwivedi and Hitesh B. Pandya

Expert Advice

Every month, *Microwave Journal*'s Expert Advice asks a noted industry expert to provide commentary related to the magazine's editorial theme. Readers are encouraged to respond with comments based on their own experience or opinions. Responses will be posted as part of an online dialog for all.

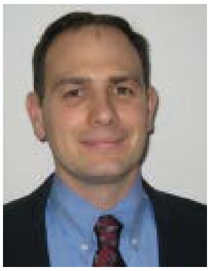
Win: The first five contributors are eligible to receive a complimentary copy of *Electrical Engineering: A Pocket Reference* from Artech House.

February: Rafi Herstig, VP of Advanced Engineering and R&D with K&L Microwave, discusses the benefits of the band-reject filter in eliminating undesired signals while maintaining an intact up/down link and why this lesser-known component is becoming the solution of choice in a growing number of cases.

Retrospective

Zoltan Cendes was among the early pioneers to bring Maxwell's equations to the computer. In this exclusive online retrospective, the IEEE fellow and founder of Ansoft Corp. takes us back to his experiences at McGill University and the General Electric Corporate R&D Center for a personal look at the early days of computational electromagnetics.

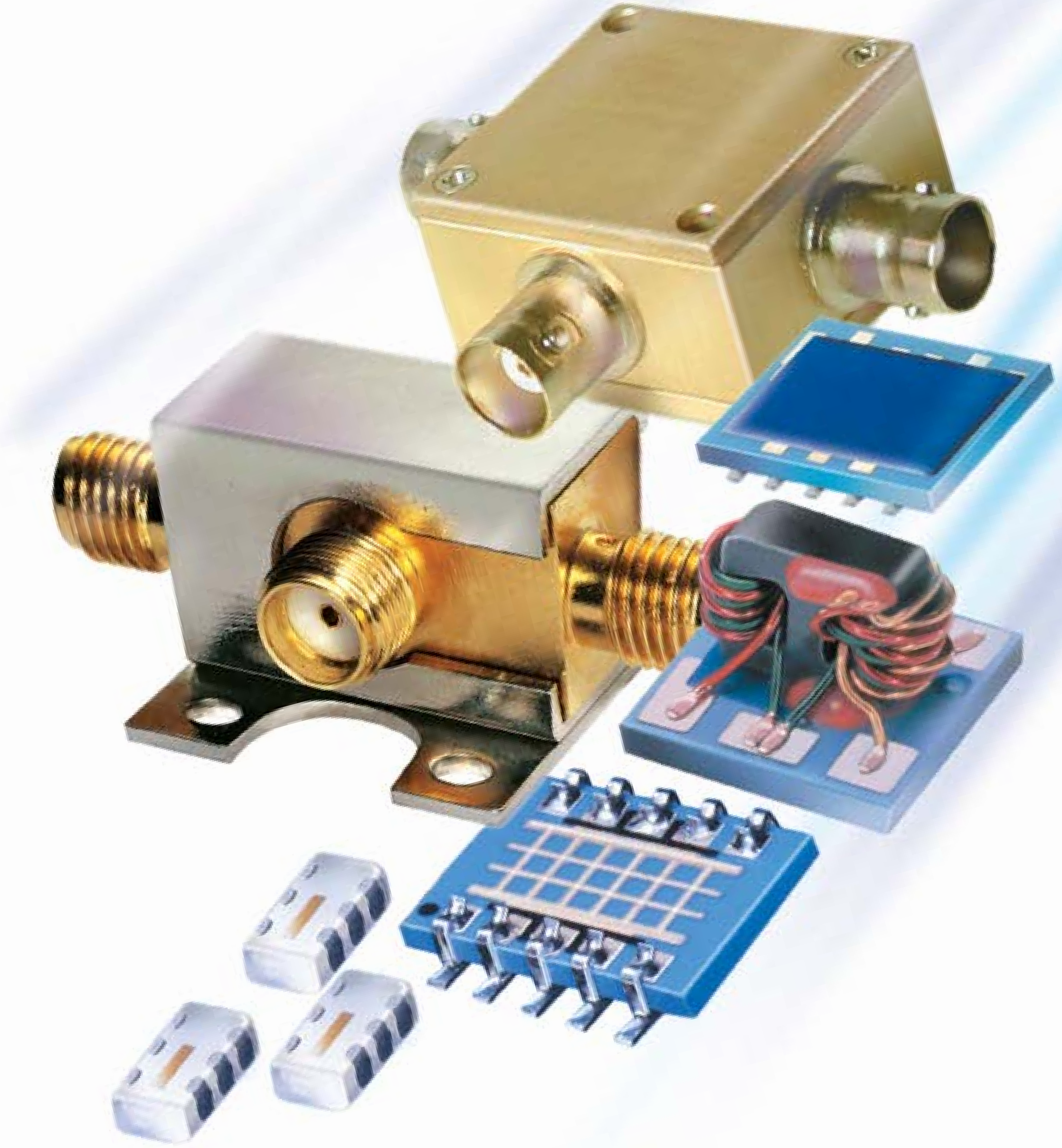
Executive Interview

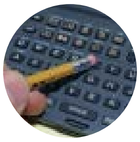


In this month's executive interview, *Microwave Journal* talks with **David Sherrer**, Director of Research and Product Development at Rohm and Haas, about the new PolyStrata™ microfabrication process that enables perfectly shielded, low-loss, broadband transmission line networks supporting complex, miniaturized and highly integrated component and system designs well into millimeter-wave frequencies.

Event

Radio & Wireless Symposium (RWS), January 20–25
Microwave Journal provides a wrap-up of conference highlights, news, information and product announcements at this year's RWS held in Orlando, FL.





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Washington, DC
www.satellite2008.com

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JUNE

IEEE RADIO FREQUENCY INTEGRATED CIRCUITS SYMPOSIUM (RFIC 2008)
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www.rfic2008.org

IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM AND EXHIBITION (IMS 2008)
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Workshops & Courses

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■ **Site:** London, England
■ **Dates:** February 19-20, 2008
■ **Contact:** For more information, visit www.iqpc.com/uk/DEW2008/MJ.

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■ **Topics:** The S600UX User Training Class has been designed to teach detailed information on how to use the S600 series Parametric Tester. During this hands-on session, students use Keithley tools to develop test programs for parametric devices within the Keithley Test Environment (version 5.1.x).
■ **Site:** Cleveland, OH
■ **Dates:** March 3–6, 2008
■ **Contact:** For more information, visit www.keithley.com.

Modern Wireless Data Communications

■ **Topics:** This course is tailored to end users, technology planners, decision makers and implementers who need an understanding of both how wireless works and what the technology can do. The information starts with an introductory level, and progresses into coverage of the more technical material at an intermediate depth. For more information, visit http://epdweb.engr.wisc.edu.
■ **Site:** Madison, WI
■ **Dates:** April 8–10, 2008
■ **Contact:** University of Wisconsin-Madison, Department of Engineering Professional Development, 432 North Lake Street, Madison, WI 53706 (800) 462-0876.

Antenna Engineering

■ **Topics:** This course provides an overview of the theory and practice of antenna engineering, including a range of antenna types, applications and electromagnetic properties from basic to state-of-the-art. Explore a wide spectrum of frequencies from 550 kHz to 550 GHz, with primary emphasis in the VHF, UHF and microwave regions. Examine communications and radar, commercial and military applications. Explore related topics, such as radomes, antenna materials, NEC computer analysis and antenna-measurement techniques.
■ **Site:** Atlanta, GA
■ **Dates:** April 21–25, 2008
■ **Contact:** Georgia Institute of Technology, Professional Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3500.

IEEE COMCAS 2008

■ **Topics:** This two-day technical program covers a variety of complementary subjects and a technology exhibition. The idea is to create a very diverse and multidisciplinary conference where engineers and scientists from various complementary electronics disciplines can meet and discuss subjects of common interest. Emphasis will be on applications oriented research and development, from antennas and device engineering to circuit applications to systems and software.
■ **Site:** Tel-Aviv, Israel
■ **Dates:** May 13–14, 2008
■ **Contact:** ORTRA Ltd., 1 Nirim Street, P.O. Box 61092, Israel +972-3-6384455, www.microwave.co.il.

Printed Circuit Board Design for Real-world EMI Control

■ **Topics:** The primary focus of this seminar is to help working engineers understand the causes of EMC problems so this knowledge can be applied to real world product design immediately. Formulas and equations are not required and are minimized throughout the seminar. Understanding the causes of EMC problems will allow engineers to make difficult design trade-off decisions.
■ **Site:** Oxford, UK
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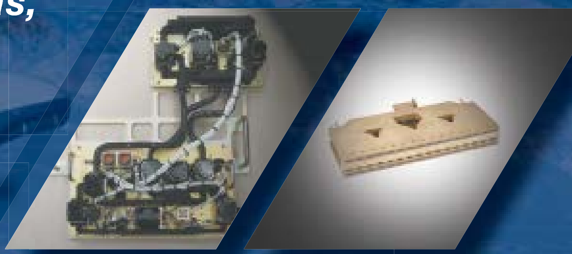

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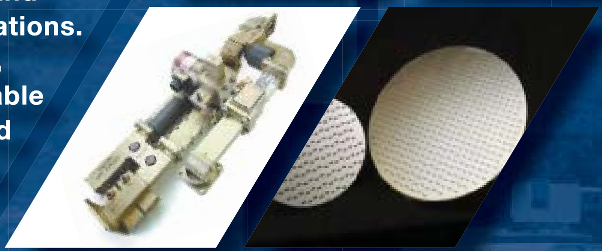

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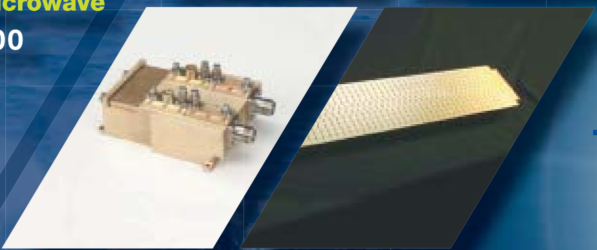

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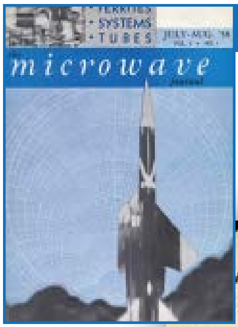


THE FORWARD LOOK . . .

in microwave plumbing for systems applications

By TORE N. ANDERSON
AIRTRON INC.
LINDEN, NEW JERSEY

THE ADVENT OF microwave ferrites and continued advances in microwave techniques have ushered a whole new era into the use of microwave components in systems design. Devices which heretofore were impossible are now realities; switching speeds, modulation rates in microwave components far exceeding those that were even dreamed of before are now simple and realistic. Because these new devices are essentially controllable by electronic means, the term "electronics" in the microwave component field has now come into its own.

The applications of the new microwave ferrite components to missile guidance radar, tracking antennas, microwave relays, are fabulous. An example is shown in Figure 1.

Microwave ferrites introduce a number of problems because of hysteresis effects in the magnetic materials, variations with temperature, frequency range, etc. The concept of being able to control these shortcomings by means of a closed loop servo system is one that has proved exceedingly valuable in these advanced applications of microwave components.

Production engineering techniques are succeeding now to reduce the cost and to provide for high quantity production of waveguide components. Techniques such as die casting, precision investment, and plaster casting, new constructional techniques for flexible waveguides, jacketing materials, the new epoxies and plastics plus some of the new low loss high temperature dielectric materials open the way to miniaturization and compact structures for missile applications.

An extremely important field in the microwave art is the problem of reducing interference in the now crowded microwave frequency spectrum. Years ago, the microwave region was considered virtually limitless as far as frequency allocation and use was concerned. Today, we face a number of serious problems in frequency allocation, spurious radiation, and harmonic reduction for microwave systems. A number of the techniques which are being developed to reduce spurious radiation and the response of receivers to extraneous signals is described.

High Accuracy Tracking Antennas

Monopulse antennas have become exceptionally popular because of higher tracking speeds and extremely high accuracies which the basic scheme provides. However, in trying to implement these systems into actual hardware, it turns out to be a real problem to provide the exact phase and amplitude balances required in the antenna plumbing to be able to realize the precision potential of large high accuracy tracking antennas. Figure 1 shows a portion of such a system with its associated electronics that yields extremely high orders of tracking accuracy with broadband high powered circuitry. Since this device embodies so many of the new components that are now available for systems use, it would be best to describe this in some detail.

First, the transmitter is connected to either of two antennas through a switched circulator which supplies, in addition to duplexing action, a nonreciprocal switch function so that received signals are returned to the receiver regardless of which antenna is connected.

In the receiver arm of the switched circulator is a built-in noise tube which, during the dead time between magnetron pulses, is fired to monitor constantly the receiver noise figure.

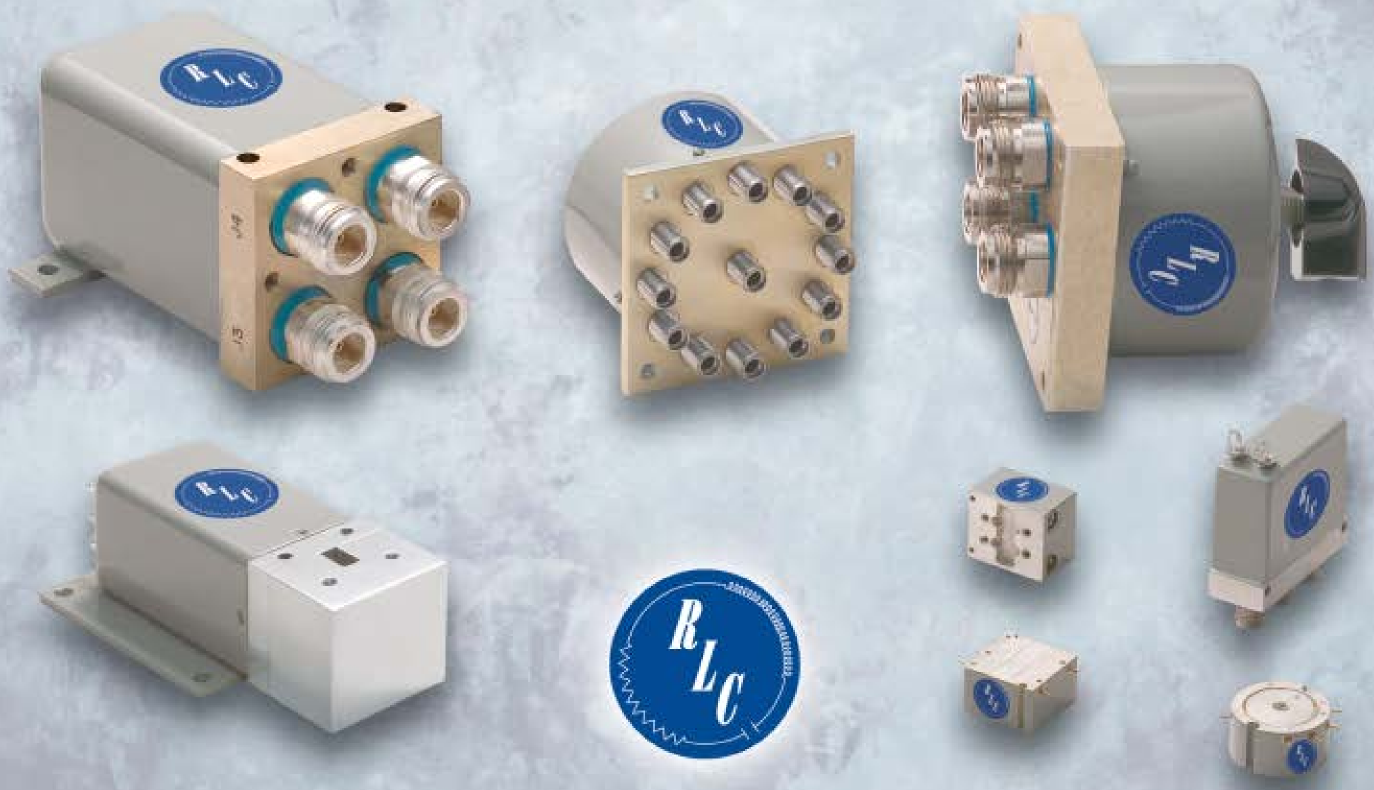
To enhance the dynamic range of the system, a variable microwave ferrite attenuator is also mounted in the receiver circuit to make 100 Db total dynamic range available.

For determining the frequency of operation a servo controlled wavemeter cavity using a remote indicating dial mechanism is used to monitor the frequency of the system. An isolator is included in the line leading to the wavemeter to avoid the wavemeter reaction from affecting the local oscillator power dividing circuits. The local oscillator itself is remotely tunable with a similar type of servo drive and the output level can be adjusted by means of a variable ferrite attenuator similar to the one used for increasing the dynamic receiver range. A dual isolator is included in the local oscillator feed legs which go to other mixers in the system; the phase for which can be controlled by means of ferrite phase shifters in a closed loop servo arrangement to exactly compensate for phase errors in the system. Amplitude errors are corrected for by AGC action in the IF strip and ferrite attenuator.

New techniques for electronic scanning of antenna arrays, using microwave ferrite phase shifters, are being developed. At this writing none has reached the stage where it can be satisfactorily employed in systems application, although from some of the new developments it is apparent that electronic scanning of antennas will soon be a reality.

Beam switching by means of polarization rotation and the use of specially shaped gridded reflectors has been applied in several airborne systems. One of these applications, for commercial airlines weather radar, uses a medium power Faraday rotator to accomplish the switching from horizontal to vertical polarization. With horizontal polarization, the parabolic reflector (solid aluminum) provides a pencil beam which is required for weather radar operation. With vertical polarization, a gridded spoiler (permanently attached to the parabolic spun-aluminum reflector) modifies the beam shape to provide a cosecant-squared pattern which is ideal for ground mapping. This spoiler grid is electrically transparent to horizontally polarize the waves, and thus provides no real degradation of the primary pencil beam pattern.

To accomplish this beam switching, then, no moving parts are required and only 0.6 watt is necessary to energize the polarization rotator. This



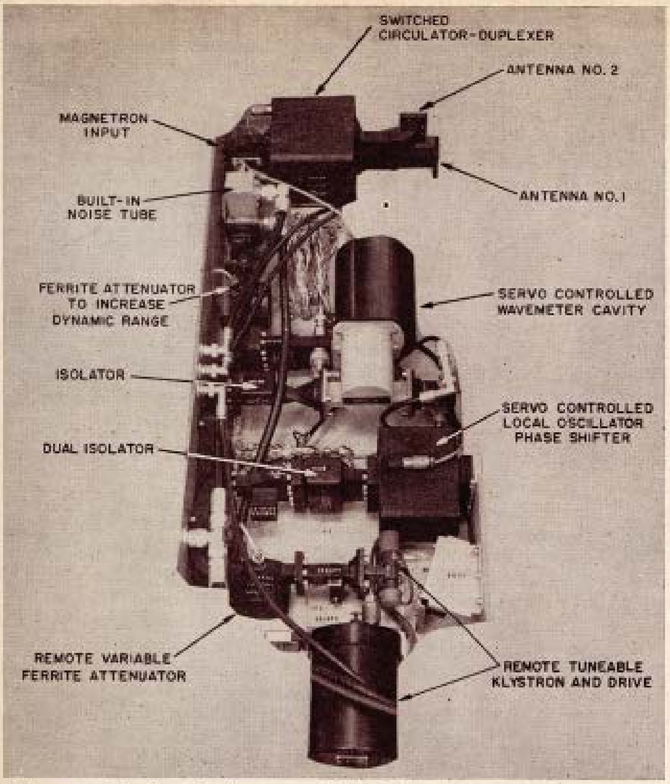


Figure 1 — Complex of microwave plumbing for systems application providing for remote antenna switching, receiver noise figure monitoring and phase correction

rotator has an insertion loss of less than .4 db and will handle up to 70 kw peak power at a pressure corresponding to 25,000 feet altitude. Similar antennas have been constructed at frequencies up to 36 kmc/s for helicopter navigation systems.

Microwave ferrite techniques also make possible polarization diversity, providing instantaneous changeover from linear (vertical or horizontal) to right- or left-hand circular polarization, for rain clutter reduction, etc.

High Speed Microwave Switches

Mechanical switches which heretofore have been used in a number of microwave system applications have been limited to switching speeds nominally in the order of 50 milliseconds. These mechanical devices are cumbersome, expensive and like all mechanical devices are subject to problems if exposed to a military environment, especially in missile borne equipments.

With the advent of microwave ferrite devices, Faraday rotation effect, differential phase shifts, etc., it is now possible to accomplish switching at extremely high speeds. With Faraday rotation, switching speeds in the microseconds are commonplace. Figure 2 shows a medium power ferrite switch based on the principle of Faraday rotation.

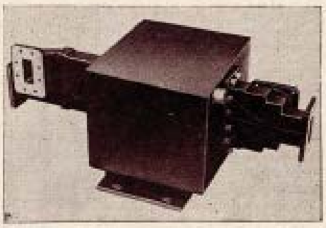


Figure 2 — Microwave switch capable of microsecond switching speeds

For narrow-band applications, solid dielectric supported Faraday rotators are used with appropriate orthogonal junctions. For extremely broad-band applications, cruciform or quadruple ridged waveguide structures are used to cover 12% bandwidths.

To achieve extremely high switching speeds, it is necessary to avoid the shortcircuiting effect of the waveguide itself on the magnetic field winding. Several techniques, including the use of extremely thin-wall stainless steel waveguides, provide a solution to this problem.

Figure 3 — High powered switched circulator for combined switching and duplexing

Ferrite switches of this type, however, are limited in power handling capacity to something like 50 kw at X-band. To provide high powered switching, devices such as the switched circulator shown in Figure 3 can be used. This basic switch is a phase shift differential circulator arranged with an electromagnet to provide for switching between the two output ports. This very interesting and useful switch is non-reciprocal, that is to say, all reflected signals are returned to a common receiver port, thus, making it possible for a radar to be connected alternately between two antennas and return all the receive signals directly to the receiver without further switching. This also provides inherent magnetron to antenna isolation. Switches of this type have been constructed to handle 250 kw over 12% bands in X-band with under .3 db insertion loss. Switching speeds of this type are nominally in the order of 3 milliseconds. With suitable driver circuitry, it is possible to increase this switching time down to speeds as fast as 50 microseconds, with the expense of higher power driver circuitry.

To realize the high speed switching potentialities of the microwave ferrite devices, electronics again comes into its own and it is here where electronics and microwaves are intimately connected. A number of driver circuits are possible for high speed ferrite switches using both hydrogen thyratrons with pulse forming networks or special line circuitry as well as hard tube modulators and the newer transistors. A combination of permanent magnetic fields with electromag-

netic pulsing circuits makes it possible to provide switches which are permanently connected in one position and may be pulsed into another position for a short interval. This avoids the penalty of constantly providing a steady electromagnetic biasing field with its inherent power consumption. We have only scratched the surface in applying high speed switches to microwave systems.

Electronically Controlled Ferrite Devices

Microwave ferrites, like any other magnetic components, introduce a number of problems. Hysteresis effects, variations of saturation magnetization with temperature, et cetera; all introduce variable performance in ferrite devices. To counteract these effects for precision applications, the use of a closed loop servo system (as shown in Figure 4) is exceedingly valuable for correcting all the variable parameters in the ferrite device itself. The output wave form is monitored by the directional coupler and bolometer mount. A servo amplifier compares it electronically with the input wave form.

If the output wave form deviates from the desired modulating wave form, a correction signal is immediately introduced into the modulator. This makes the output compare exactly with the input wave form so as to take out the effects that would cause errors in the modulated wave form. The accuracy with which this can be done is only limited by the speed of response of this modulating winding and the servo loop gain. From a practical point of view, very precise control of amplitude and phase can be accomplished by this electronic technique of "closing the loop" on the particular circuit element.

Microwave Filter Developments

In the past several years, it has become painfully apparent to microwave systems operators, especially the microwave relay people, that something has to be done about the control of spurious harmonic radiation from radar sets. Front end selectivity also is required on radar sets for friendly interference elimination.

Microwave radar designs have only recently been involved in the application of tuning techniques which are old hat in the low-frequency radio game. Television interference is something that has plagued the radio amateurs since World War II. This interference with microwave relay channels carrying television programs has only begun to be eliminated by filtering techniques in the microwave industry.

Fixed tuned filters in the microwave relay game are common for communication links, microwave relay, etc., but for radar applications, tunability is required. The problem of ganging several cavities and getting these to track over a wide tuning

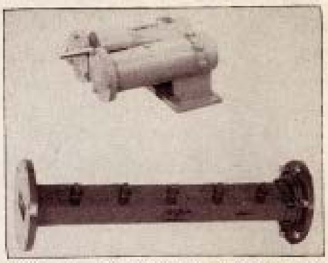


Figure 5 — Examples of microwave filters: Upper — single knob broadband tunable, Lower — Unit fixed tuned for microwave relay applications

range is not new to receiver designers, but is complicated by several orders of magnitude at microwaves because of the precision required in producing the resonant cavities and the tiny motions involved in tuning these cavities. Single knob multiple cavity filters have been built for several applications and examples of the fixed and tunable filters are shown in Figure 5.

The two-section, gang-tuned preselector filter shown here provides characteristics similar to those of a stand-

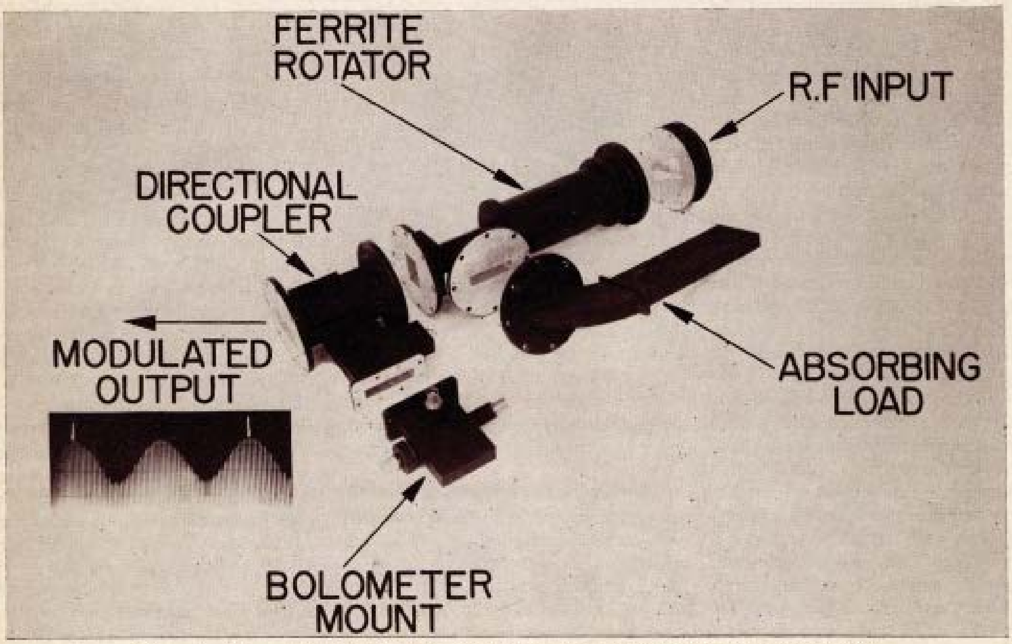


Figure 4 — Servo controlled microwave attenuator using electronic closed loop servo operation

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ard four-section model. Each section contains two orthogonal TE_{111} modes, which have the added advantage of a broad tuning range free from crossing or interfering modes. This filter is especially adapted to front-end rejection when high selectivity is required along with minimum size and weight.

The unit illustrated is designed to be continuously tuned over a frequency range of 7500 to 8500 mc/s. Insertion loss does not exceed 2.0 db for a 25 mc/s bandwidth. Rejection obtained with these characteristics is at least 50 db at $F_o \pm 60$ mc/s.

Also shown in Figure 5 is a fixed-tuned filter used in a variety of assemblies for microwave relay applications. A maximally flat (Butterworth) response is obtained with less than 1.0 db insertion loss for a bandwidth of 25 mc/s. At 50 mc/s from F_o the rejection is at least 55 db down. The VSWR of this unit does not exceed 1.20 over its normal pass band.

For broadband radar applications, multisection preselector filters (combined with microwave discriminators and a servo loop) can be used to automatically track the transmitter frequency as the frequency is shifted. For such applications, quarter wave coupled low loss circular TE_{011} modes have been used with as many as 4 cavities ganged to a single shaft which is controlled by the servo motor. The discriminator cavity utilizes an identical section to provide exact tracking between the discriminator frequency determining cavity and the receiver preselector filter. To provide freedom from temperature variations, these cavities are generally constructed of Invar which has a coefficient of expansion of nearly zero. This combination calls for the utmost ingenuity from the microwave component designer, electronic circuit designer and mechanical engineer in order to design a rugged and practical assembly.

Waveguide structures, being essentially high pass structures, will propagate frequencies far above the normal operating frequency range by the very nature of the waveguide medium. This propagation may be both in the fundamental mode and in higher order modes. But the very fact that these harmonics are propagated leads to interference problems which are difficult to eliminate. To provide for a low pass structure in the waveguide, it is necessary to use special techniques to provide for rejection of higher unwanted frequencies. The most common method for doing this is to go into single ridge waveguide by means of a suitable transition and provide a Tchebysheff array of resonant slots cut into the ridge. These slots act as chokes at the harmonic frequencies and prevent the transmission of unwanted harmonic output. Such harmonic filters are required in present-day radars to avoid the problem of interfering with microwave relay systems as was mentioned earlier. Filters of this type have been designed to cover as far as the fourth harmonic of the desired signal frequency without introducing more than 0.5 db insertion loss. With suitable pressurization, such filters can handle substantial amounts of peak power.

Microwave filters differ from conventional filter elements in that distributed constants must be used to make up the filters. Resonant sections of transmission line waveguide, coaxial or stripline, are coupled in any of a wide variety of ways to provide the kind of filter response that is required. For the frequency region from 1,000 to 5,000 mc/s, stripline filters have been widely used for fixed-tuned applications. In the frequency range above 5,000 mc/s, waveguide cavities are necessary to realize high enough "Q's" to be useful. The waveguide cavities are generally sections of waveguide with appropriate iris structures (either direct or quarter wave coupled, depending on band width) and can be tuned by means of capacitive tuning screws. For very high orders of skirt selectivity in microwave filters, it is necessary to go to higher order mode cavities which generally are constructed in round waveguide in a TE_{011} mode.

Flexible Waveguide Trends

Flexible waveguide, in use now for some 16 years, has gone through a whole host of developments. Today, flexible waveguides can be considered essentially equivalent to rigid waveguides in all aspects; high peak power handling capacity, attenuation and mismatch. The newer techniques provide for seamless constructions, extremely good repeated flex life, and for high temperature construction techniques. All-aluminum flex guides are under development with silicon rubber jacketing to meet continuous operating conditions at 500°F.

The use of a circular electric guide with a corrugated transmission line structure has recently proved successful for very long runs of waveguide in both military and commercial applications. We shall, in the future, see a lot of circular waveguides, especially where very long runs of waveguide are involved. Figure 6 shows a corrugated construction designed for use

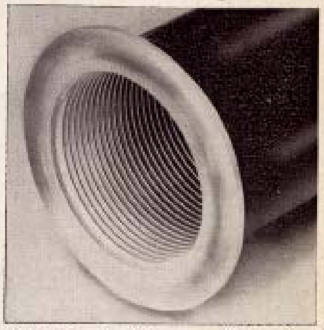

Figure 6 — Flexible waveguide designed for circular electric mode for extremely long waveguide runs at X-band

in a fundamental circular electric TE_{01} wave which has demonstrated attenuation as low as .006 db per foot at X-band making runs of 1000 feet of waveguide practical for specialized applications.

Precision Casting of Microwave Components

New microwave requirements continually challenge the producer of cast components. Tight mechanical tolerances have brought increased emphasis on dimensional control, while proper electrical performance demands improved surface finish and minimum porosity. Complex internal designs make ordinary machining difficult; thus precision casting of microwave components has come into its own in the last few years.

The investment process is particularly useful in casting ferrous metals. This ancient art, combined with the latest in pattern and investment technology, can provide castings of extreme complexity. With modern waxes and plastics, soft metal molds, water soluble wax corings and ingenious wax-welding techniques, parts are made which no other metal-forming process can duplicate.

Plaster casting techniques have been adaptable to the needs of microwave plumbing. Castings made in plaster molds are noted for their uniform hardness and machineability. Slow solidification prevents most internal stresses which cause warpage and distortion, while very smooth surfaces in-

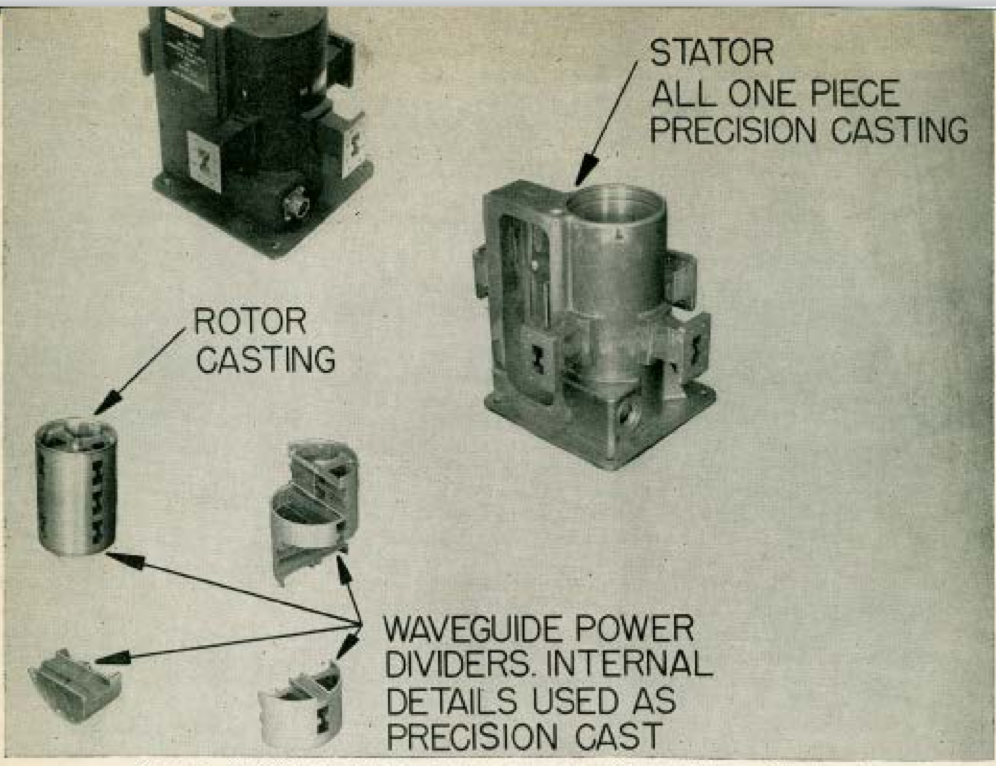

Figure 7 — Precision cast multiple position waveguide switch providing straight through connection, two-way and three-way power split

sure even further dimensional accuracy.

For large scale production, die casting in half-sections which can then be joined by soldering and dip-brazing techniques has also proven to be a practical production technique for microwave plumbing. In general, however, this technique is limited only to large runs where the rather complex and expensive tooling costs can be readily spread over a large quantity of units. Electroforming of precision parts still holds its own for the very complex shapes and very tight dimensional tolerances which even the best in precision casting techniques cannot hold. However, the cost of electroforming is generally prohibitive and with present-day isolators to protect transmitters, receivers, and a number of devices from the effects of undesirable mismatches, there has been some slackening possible in dimensional tolerances for practical waveguide plumbing. It is hoped that this trend will continue.

Some of the sophisticated casting techniques in use today are represented by this compact three-position waveguide switch shown in Figure 7, with cutaway sections of the piston and stator. A plaster mold used for the piston is assembled from nine separate sections; the stator mold requires thirteen. Linear tolerances for both units are $\pm$ .002″, while angular tolerances are held to $\pm$ .0° 15′. Cast in Alcoa No. 356 aluminum alloy, the total assembly weighs 5 lbs., 12 ounces.

Special Transmission Lines

With the advent of extended wide band microwave devices for these traveling wave tubes, transmission line components have been required to keep up with the potential needs for this service as well as the requirements for jamming applications.

Double and single ridge waveguides have recently come into very common usage. A whole series of double ridge and single ridge waveguides is now being considered for standardization by the Electronic Industries Association Committee (SQ-11. 1. 3). It is hoped that a series which will suit a wide variety of applications will soon be standardized.

Circular waveguides have recently been standardized for both TE_{11} and TE_{01} operating modes. This is the recently released EIA Standard RS-200.

Strip transmission lines have had a tremendous amount of development since the initial announcements of the basic idea by Federal Telecommunication Laboratories. However, strip transmission line applications have been limited to those applications where space considerations are paramount and some slight performance degradation can be allowed. For the bulk of high performance microwave systems, striplines have now only a small amount of application, but for those applications where space is paramount, stripline techniques offer a very potent tool to the microwave component future.

Surface wave transmission lines, hybrid EH modes in dielectric rods for the millimeter region, image lines, etc., all foretell of possible low loss transmission line structures for the high frequency frontiers.

Microwave tube techniques, microwave ferrite devices, solid state physics coupled with microwave engineering, open up for the future a whole new concept in the microwave plumbing line.


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A PASSION FOR PLUMBING: 50 YEARS OF WAVEGUIDE ASSEMBLIES AND COMPONENTS

When approached to write this cover story 50 years on from Tore Anderson's original article, which appeared in the very first issue of *Microwave Journal*, I agreed to write it for two particular reasons. First, as a Brit, it is a privilege to have the opportunity to acknowledge how well and professionally *Microwave Journal* has served the international microwave industry for the last half century.

Secondly, I am privileged to have had the honour of meeting Tore Anderson at European Microwave Week in London, England, in 2001. The event was particularly notable as it occurred only a few weeks after the tragic events of September 11. However, it is perhaps a sign of the man's commitment, interest and downright defiance that well into his 80s he was prepared to travel to London, when men half his age were not. I cannot claim to have known him well, but he seemed a charismatic, distinguished gentleman, with a passion for his field of work.

He not only impacted on me personally, but also on the Cobham Group of which Credowan is a part. He was instrumental in setting up Hyper Technologies, our sister company, in Les Clayes Sous Bois, France. Anderson set them on their path to becoming France's leading supplier of waveguide components for the space and defence industries, which they have been since the late 1960s.

This article will hopefully pay respect to and reflect upon his original article, offer opinions on some of the important developments since 1958, and gaze into the microwave crystal ball to see what the future holds. My 30 years of industry experience has been gained on this side of the Atlantic and although I shall acknowledge international developments the perspective will be from a European standpoint.

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FERRITE TECHNOLOGY

Anderson's 1958 article opened with a comment concerning microwave ferrite technology and it is perhaps unremarkable that 50 years later this technology is still used in waveguide and coaxial technologies for one of the most fundamental building blocks of microwave systems, the isolator or circulator. The power levels used in radar systems and satellite communications ease ever upwards, and with it the need to reassess structures and materials. However, due to its fundamental physics, ferrite technology has always been able to offer relatively straightforward tracking of these power levels to satisfy this market need, although I do not believe that there will be a major leap forward in the foreseeable future.

TEST EQUIPMENT

The biggest single factor aiding the development of the microwave industry over the last five decades, with waveguide assemblies and components being no exception, is for engineers to have the ability to test what it is they are designing and making. Slotted line six-port reflectometers and similar highly complex test set-ups, which existed in the 1960s, eventually gave way to proper S-parameter measurements, using network analysers, originally supplied mainly by the Hewlett Packard Co. I remember the UK launch of the HP8510 network analyser, which, perhaps for the first time, offered a dynamic range, speed and multiplicity of test points that could finally accurately measure passive microwave components reliably and consistently. Until this point our industry had, in many ways, become bogged down with metrology issues, where microwave measurements were made using complex and difficult equipment manufactured to truly outstanding dimensional accuracies.

The reality, however, was that due to variations of temperature, etc., this equipment was not offering the kinds of consistency needed. Systems designers often needed to build in measurement error, as part of their system's architecture. Temperature-controlled standards laboratories abounded in all major companies. There was a need to constantly verify and calibrate equipment, which was frankly often being used at the absolute limit of its accuracy level. The HP8510 broke this down. ***Figure 1*** shows a 10-year old instrument still in use in the Credowan clean room, doing microwave testing on high dynamic range cavity filters for the Inmarsat satellite programme.

The HP8510 required calibration kits for both coaxial and waveguide use, which had to be manufactured to previously unprecedented high standards of accuracy. Instrumental in their development was a sadly missed character in our industry, Mario Maury, who drove the Maury Microwave Co. to becoming a world player in this field. The Wiltron Co., now part of the Anritsu Group, quickly followed with its 360 equipment, offering many of the features of the HP8510.

Fuelled by this healthy commercial competition, network analyser development has progressed. Some time early in the 1990s, Marconi Instruments in the UK shook up the market with the launch of the 6200 microwave test set. This was in fact a scalar system, but was very easy to use, small and compact, offering lots of functions. For a while it looked like the industry may route in that direction, with microwave instrumenta-

▲ *Fig. 1 An HP8510 network analyser in use in the background in the Credowan clean room testing filters for the Inmarsat satellite programme.*

tion becoming lower in cost, more functional and easy to use.

It is fair to say that in 2008 test issues are much less of a problem. The days of disputes between design and test teams over the 10th of a dB are long gone. Disputes between suppliers and customers over whether a product may or may not be to specification are now mainly behind us. This in itself has generated huge improvements.

WHAT ABOUT THE PLUMBING?

Tore Anderson, like me, was, I think, a waveguide man at heart. He covered plaster casting techniques in some detail, but I do not believe that this technology has made it to the 21st century. However, lost-wax casting, which was pioneered by MDL in the US in the 1950s and was brought to Europe in the 1960s by Christopher Shaw of MicroMetalsmiths, still forms the basis of a significant percentage of waveguide technology. These simple castings, which sell for as little as $20 to $30 each, are suitable for both flame brazing and dip brazing, two techniques that are used all over the world for the assembly of aluminium waveguide assemblies.

The second technology that could not have been envisaged in 1958 was the degree to which CAD modelling and advances in CNC machining would open up opportunities for producing parts machined from solid metal and then assembled either by the use of screws or dip brazing. The ability to electromagnetically model and programme accurately facilitates machined designs that can be near perfect. This has pushed the barriers, particularly for products such as microwave filters, to performance levels that were previously unobtainable.

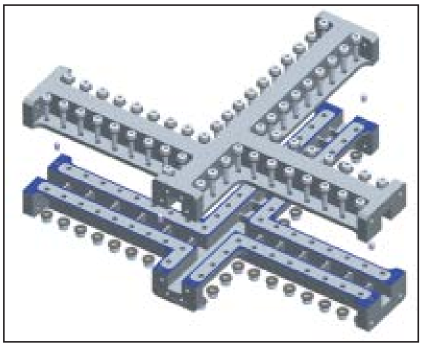
Also, various companies around the world have successfully developed zero tuning screw technologies, enabling lower cost production. At the other end of the scale, many world leading filter companies are now producing waveguide filters with microwave performances way above what was possible with the previous generation. This advance in machining technology is illustrated in ***Figure 2***, which shows a Triplexer machined to cavity tolerances of 0.0005 of an inch. This was something that was unachievable only 10 years ago.

This technology has also challenged an associated manufacturing technique, that of plating. Waveguide structures fundamentally improve their loss characteristic by some 30 percent if silver plated, when compared to unfinished aluminium or alochromed aluminium, a technique that has been known for many decades. The application of an effective silver plate, normally laid over a nickel undercoat, has become a great art. But the search for a consistent and electrically high quality silver plate is on and although current technologies offer excellent results I predict that both a cost and performance step can be achieved by the cracking of this particularly challenging nut.

FLEXIBLE WAVEGUIDE

Many in our industry might not appreciate that Airtron Inc., which originally started in New York State in the 1940s, pretty much invented the concept of flexible waveguide. For those non-waveguide specialists reading this article, flexible waveguide is basically one of two technologies. Flexible twistable waveguide pioneered by Airtron, and still being produced in significant quantities today by companies like Microtech in the US and Mitec in Canada, consists of a helically wound interlocking brass silver-plated strip.

This offers the customer not only the ability to twist the waveguide, but also to bend it in either the E or the H plane (narrow or broad wall). This product must be used with care, however, as over enthusiastic bending or twisting can lead to RF leakage prob-



▲ *Fig. 2 An exploded view of a waveguide triplexer used in the passive intermodulation testing of satellites.*

lems. It is not designed for broadly dynamic applications, but more to take up tolerance, vibration and low level movements.

Pioneered to some degree since Anderson wrote his article has been so-called seamless flexible waveguide. This product cannot be significantly twisted, but again can, within reason, be bent within the E and H planes. This is formed from a tube that is then crimped to offer a similar looking profile to twistable waveguide. These products have been developed up to high frequencies. ***Figure 3*** shows the wide variety of waveguide sizes now available in flexible waveguide, ranging all the way from 1.5 GHz, WR650 sizes, right through to 94 GHz, WR10.

Predicting the development of flexible waveguide is problematic, but I believe that the battle to consistently manufacture such waveguide above 18 GHz is not a 'done deal' yet. Products beyond 40 GHz are still far from economic and the phase stability of all flexible waveguide also needs improving. If progress is to be made, the next few years need to yield genuine progress in this area of waveguide technology. Integration of subsystems also offers a threat to the long-term use of this product, with integration removing the need for many interconnecting waveguide components.

Anderson also briefly discussed double-ridged waveguide, and it is perhaps worthwhile considering this topic in more detail. Double-ridged waveguide offers much broader frequency coverage than its rectangular waveguide equivalent. 7.5 to 18 GHz is covered by WRD750 and 18 to 40 GHz is covered by WRD180, which are two of the most frequently used sizes. While the microwave performance is not of the same quality as conventional rectangular waveguide, and the manufacturing challenges are considerably more difficult, these waveguide sizes are used for a number of key applications.

The most common application of double-ridged waveguide is probably the electronic warfare market where they are utilised for broadband jammer systems. Most airborne and naval systems have jammers as a fundamental part of their set-up. They are generally substantially full of waveguide components, waveguide assemblies, flexible waveguide, couplers, loads and transitions, all of which are double ridged.

The second application for these parts is frequency agile radars, although they are generally less common now than they were 10 or 15 years ago. The third and final use of double-ridged waveguide is for so-called 'tri-band' assemblies. This is where a single antenna can be pointed at three different satellites, working in three different frequency bands. Again, this is less popular now than it was perhaps 10 years ago, but remains a current application.

Circular Waveguide

Towards the end of Anderson's article he talks about circular waveguide being, in his view, a component of the future. I am personally unaware of it being a significant option for most systems. One of the main reasons being that in many situations it is quite impractical, which is a problem when trying to design components. It also has serious performance problems when having to turn corners.

However, elliptical waveguide certainly still has a major part to play, particularly in the communications sector of the waveguide industry, but in general the integration of microwave radios and ever smaller and more co-located design options is reducing the overall requirement. Although circular waveguide is particularly useful for long straight lengths, in many ways the next technology I will cover has perhaps supplanted it.

Fibre Optics

The purists amongst you will wonder why I am writing about fibre optics in a waveguide article, but the reality is that for transmission of analogue or digital data, fibre optics has

▲ *Fig. 3 The range of flexible waveguides routinely manufactured in the current generation.*

taken over a number of functions that previously would have been serviced by long waveguide runs. One element of this business is rotary joints, which is a technology I shall try to explain in more detail. Most radar systems have a 360° scan. In microwave terms, in order to join the parts on the rotating antenna to the parts on the ship or ground system which is not rotating, a rotary joint is required.

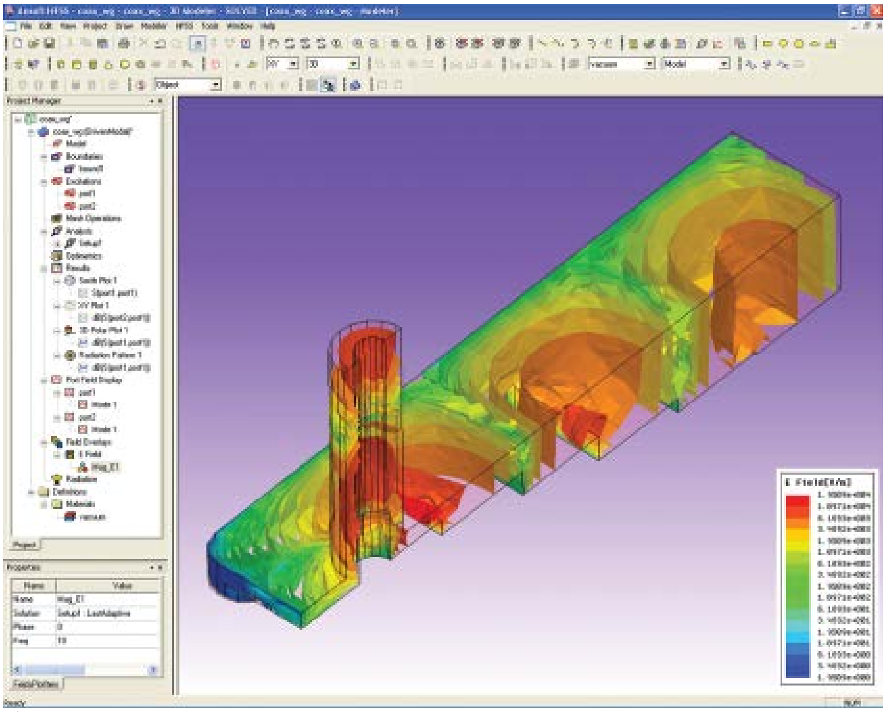
Waveguide rotary joints are generally constructed from a simple concept: a transition from rectangular to circular waveguide, a precision device that rotates one part against the other part, which, now being circular, can be done with almost no interruption of signal, and finally a transition back to rectangular. Most waveguide joints, however, are more complicated, in that they also need to transmit coaxial signals through. There are two options: to make the waveguide section more annular, thus surrendering the centre line to the rotating part/another technology (perhaps coaxial); or to position these elements down the centre of the waveguide and to compensate for the potential interruption.

SPACE: THE NEW FRONTIER

When reviewing developments in the waveguide world, one cannot escape the fact that the dominant application for conventional waveguide assemblies has become, at least within Europe, the satellite industry. The year 1958 was just before the first unmanned satellite was launched, which I imagine had no waveguide fitted to it. The major breakthrough for the industry occurred in July 1962 when Telstar was launched. This offered extremely limited satellite capability; however, it is the first event I am aware of where a waveguide travelled into space. I believe it was a piece of WR229, but you may know otherwise.

November 1972 saw the launch of the first Anik A1 satellite over northern Canada that supplied telephone communications for the first time to a remote area, which would have previously been uneconomical. This heralded an era during the 1970s and 1980s when satellite technology gained momentum and progressed.

In the 1970s satellites would have offered 12 channel capabilities and incorporated around 50 or 60 waveguides. Modern satellites can have upward of 500 waveguides and can offer 64 high power communication channels with a great degree of interconnection and redundancy built in. The demands of quality and performance in the space industry are an order of magnitude higher than that in the defence industry, which has



▲ *Fig. 4 An early coax-to-waveguide transition electromagnetic software model, courtesy of Ansoft UK.*

driven processes and design techniques ever forward.

The space industry, for instance, uses ultra-lightweight waveguide assemblies, with wall thicknesses as little as 0.4 mm, which is a quarter of the wall thickness of waveguide used by other industries. This offers a massive weight reduction, which is especially significant when you realise that each kilogram costs in the region of $50,000 to put into space. There is, however, no compromise on electrical performance, and with power levels in satellites now fast approaching 3 kW CW, waveguides will have an important role to play for a long time to come. Waveguide offers massive power handling and budget savings over the only sensible alternative, coaxial technology, at least at the frequencies of interest.

COMPUTER-AIDED MODELLING AND DESIGN

When considering microwave technology in the last 50 years the impact of software modelling cannot be ignored. Ansoft launched HFSS in 1990, and while there are many competitive software programmes in use, in Europe, it is dominant. When launched, for the first time, it provided design engineers with the ability to quickly and relatively accurately model the structures within a few hours of the performance specification parameter being defined.

This meant that in the components industry, even at quotation level, an exercise lessening risk could be undertaken, which increases the reliability of timescales and costs. This eliminates from the loop many of the traditional risks to both customer and supplier. ***Figure 4*** illustrates an early version of the HFSS.

More than ever software offers the design engineer the opportunity to get it right the first time. This saves machining time, prototyping and proving. In the current era perhaps the most exciting benefit of these programmes is the ability to export them into CNC programming, saving a huge amount of time. In my youth, scruffy bits of paper were generated by the design team, where hoards of draughtsmen (I was one of them) converted these into workable prototypes by pencil.

This task would often have to be performed many times before a unit was complete. These days design offices are under far more pressure to deliver to ever-tighter time scales and this is only possible because of improvements in the tools available to design. The future is attractive, as these software tools become more reliable and easy to use, bringing the concept of direct prototyping tantalisingly close.

HIGH FREQUENCY APPLICATIONS

In 1958 the waveguide world stopped at around 18 GHz; now it is 100 GHz+. Applications for radio telescopy are at 77 GHz or above and radar systems are routinely working at 95 GHz, offering highly accurate and reliable short-range target identification. Only those of us in the microwave industry appreciate the ‘wow factor’ of buying a German car that has a small 94 GHz radar fitted to its bumper to aid parking. I suspect exploitation of these frequencies will keep us waveguide boys busy for many a year to come.

FINAL THOUGHTS

When attempting to look forward in any technology the probability is that you will get some things right and some things wrong. However, much of what Tore Anderson prophesied 50 years ago did come to fruition and continues to do so. The fundamental laws of physics surrounding the microwave industry do not change, but probably what keeps us all working away is the people, who, by and large, are kind, considerate and honest.

It is still possible to be successful by supplying components of good quality, and to offer friendly flexible services to customers. We are not yet totally driven by the pound, Euro or dollar. Those who carry a little influence should still work hard to keep the flame of enthusiasm burning, the same flame that I saw in a man in his 80s in London in 2001. ■

Nigel Bowes *joined RF/microwave connecter manufacturer Sealectro, Portsmouth, UK, in a junior design role in 1977, progressing to a technical support role in 1979. Spells at TCE, Bradley Microwave and EEV led to him joining Credowan in 1990, initially as sales manager, then as sales director from 1995. Bowes was a founder member of the ARMMS RF and Microwave Society, the UK offshoot of ARFTG.*

Raytheon Wins Army Precision-guided Projectile Development Contract

Raytheon Co., teamed with General Dynamics Ordnance and Tactical Systems, has been selected by the US Army to develop the XM 1111 Mid-range Munition for the Future Combat System's Mounted Combat System. Valued at $232.3 M, the 63-month contract covers system design and development.

"This award establishes Raytheon as the leader in the development of affordable precision-guided projectiles," says Louise Francesconi, president of Raytheon Missile Systems. "We embrace our role as the primary provider of precision projectiles for the United States and we look forward to working in partnership with the Army, General Dynamics Ordnance and Tactical Systems and our suppliers as we develop this revolutionary capability for the Army's current and future forces."

Mid-range Munition incorporates proven technology using a dual-mode seeker suite comprising an imaging infrared sensor and a digital semi-active laser seeker. The dual-mode seeker was developed and successfully demonstrated during a two-year, army-managed science and technology program.

In its proposal, Raytheon chose a multipurpose chemical energy warhead for the Mid-range Munition. "For the beyond-line-of-sight mission, we believe that the chemical energy warhead, with proven lethality against the primary target of threat armor, is the best solution," said Rodger Elkins, director of advanced tactical weapons for Raytheon's Advanced Programs product line. "It provides better effects against the secondary targets of buildings, fortifications and light armor than a less versatile kinetic energy penetrator." Raytheon's aggressive cost control initiatives provide the Army with a proven, low-risk, affordable product as it enters into the system design and development phase. Such initiative cost solutions are easily transferable to Raytheon's other precision-guided projectiles, such as the company's highly successful, combat-proven Excalibur 155 mm artillery projectile. Work on the Mid-range Munition will be performed at Raytheon facilities in Tucson, AZ.

Honeywell Technology to Help US Military Rapidly Analyze Intelligence

Honeywell announced that it is developing a revolutionary system for the Defense Advanced Research Agency (DARPA) that could dramatically improve the military's intelligence analyzing capabilities by allowing analysts to evaluate images from satellites, ground cameras and surveillance aircraft more precisely and quickly than ever before. The Honeywell Image Triage System (HITS) will enable Department of Defense (DoD) personnel to analyze intelligence images up to six times faster than the current computer-based system through the use of high-tech sensors that monitor signals in the human brain. Honeywell is developing the system as part of DARPA's Neurotechnology for Intelligence Analysis (NIA) program. "Computer-based systems currently in use cannot process enormous volumes of intelligence imagery fast enough to meet the needs of the military," said Bob Smith, vice president, Advanced Technology, Honeywell Aerospace. "That is why we are developing technology that speeds-up the intelligence analysis process by tapping into brain signals associated with split-second visual judgments. As a result, we are going to give the analyst the ability to identify dangerous threats to our troops more quickly, precisely and effectively than ever before." The human brain is capable of responding to visually salient objects significantly faster than an individual's visual-motor, transformation-based response. Simply put, when examining an image, an analyst's brain can register a discovery long before the analyst becomes fully aware of it. Honeywell's technology uses sensors to monitor brain activity in real time, automatically identifying and recording brain signals to tag intelligence images worthy of additional review. The system presents data to analysts in high-speed bursts of 10 to 20 images per second. Head-mounted electroencephalogram (EEG) sensors detect neural signals associated with target recognition as the images are viewed. Neural signals, known as "event related potentials," are used to tag the images that contain likely target or threats. At the end of the high-speed scan, the analysts are able to focus on the small subset of key images tagged by the brain scan instead of searching slowly and systematically through every inch of high-resolution satellite images like current techniques require.

Honeywell's triage analysis methods will ultimately apply to a diverse range of imagery, including high resolution electro-optical, infrared and video imagery. It could eventually be used in a broad range of military and commercial operations, including medical diagnosis and geospacial analysis. "HITS is going to help the military to analyze more intelligence imagery everyday. By more quickly identifying threats to our troops, Honeywell is helping the US military keep them out of harm's way," Smith said.

Northrop Grumman's LITENING System Achieves Operational Availability Milestone

Northrop Grumman announced that the LITENING Advanced Targeting (AT) pod has achieved more than two years of operational availability consistently above 95 percent among all US customers. LITENING AT systems are currently deployed with the US Air Force Reserve Command, Air National Guard, Marine Corps, Air Combat Command and coalition forces.

"The reliability that matters most to the warfighter is when the system is turned on and it works time and time again," said Mike Lennon, vice president of Targeting and Surveillance programs at Northrop Grumman's Defensive Systems Division. "LITENING AT has demonstrated reliability when called upon to perform surveillance or targeting missions. With over 765,000 operational hours (of which over 370,000 are combat hours), more than all other targeting pods combined, this milestone is truly a remarkable feat that is unsurpassed by any other advanced targeting pod in the world."

The key to LITENING AT's operational availability is an aggressive In-Service Reliability Improvement Program (ISRIP). This program is a continual process in which operational pods are evaluated under mission conditions for design deficiencies. The ISRIP provides engineering information on failure modes and mechanisms, resulting in the continual incorporation of improvements and corrective actions that lead to improved LITENING AT availability. Northrop Grumman is preparing to deliver initial fourth generation LITENING systems next year to US customers. The fourth generation version of LITENING will feature the most advanced 1024 × 1024 pixels (1k × 1k) forward-looking infrared (FLIR) sensor for improved target detection and recognition ranges under day and night conditions, new sensors for improved target identification, and other advanced target recognition and identification features. Other product improvements already incorporated into LITENING as part of the fourth generation version include a new 1k charge-coupled device sensor, which provides improved target detection and recognition ranges under daylight conditions. Northrop Grumman's LITENING AT system is a self-contained, multi-sensor laser target-designating, navigation and sensor system that enables aircrews to detect, acquire, track, identify and engage ground targets for highly accurate delivery of both conventional and precision-guided weapons. In addition, LITENING pioneered the use of video downlinks that provide ground forces with battlefield situational awareness from the perspective of an airborne platform. Since the Introduction of LITENING in 1999, the system has undergone numerous upgrades to ensure continued combat relevance in an ever-changing battlespace, with the fourth generation version the next step in its evolution. To date, almost 500 LITENING AT pods have been ordered with over 400 systems fielded, the largest number of any advanced targeting and sensor systems. The LITENING AT system is currently deployed on AV-8B, A-10, B-52, F-15E, F-16 and F/A-18 aircraft, and is being integrated with the US Marine EA-6B. ■

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RFMD Acquires Filtronic Compound Semiconductors

RF Micro Devices Inc. (RFMD) has entered into a definitive agreement with Filtronic Plc to acquire its wholly owned subsidiary, Filtronic Compound Semiconductors Ltd. (FCSL), for approximately £12.5 M in cash. The acquisition price includes the purchase of FCSL's six-inch GaAs wafer fabrication facility at Newton Aycliffe, UK, which is currently a major supplier of GaAs pHEMT semiconductors to RFMD, along with the purchase of the company's millimetre-wave RF semiconductor business. The transaction is expected to be completed before the end of RFMD's fourth fiscal quarter, ending in March 2008, subject to customary closing conditions. "The acquisition of Filtronic Compound Semiconductors is expected to increase our manufacturing volume, lower our overall cost structure and provide RFMD with a high-volume supply of GaAs pHEMT," said Bob Bruggeworth, RFMD's president and CEO.

RFMD expects the addition of FCSL's high-volume GaAs fab to significantly reduce its GaAs pHEMT sourcing costs and provide additional capacity, thereby providing the company the opportunity to capture incremental revenue that otherwise might be subject to capacity constraints during calendar year 2008. Additionally, the company expects the addition of Filtronic Compound Semiconductors' millimetre-wave business to strengthen the product portfolio of its recently formed Multi-Market Products Group and be accretive to its target margin profile for its multi-market business.

The agreement provides for ongoing supply to Filtronic's point-to-point business for at least three years and for it remaining at its current site. Following completion Filtronic will cease its activities in compound semiconductor manufacture and supply. FCSL will enter into a supply contract and lease, including provision of support services to its point-to-point business.

QinetiQ Enters Australian Defence Arena

QinetiQ Group Plc has signed agreements to purchase two Australian defence consulting businesses: Ball Solutions Group Pty Ltd. and Novare Services Pty Ltd. The companies are being acquired for a total cash consideration of A$20 M and are subject to Australian and US Government regulatory approval. This is expected to be completed by the end of February 2008, after which the companies will trade as QinetiQ Consulting Pty Ltd.

The acquisitions are QinetiQ's first investment in Australia and are the latest execution of the company's continuing strategy to grow its Europe, Middle East and Australasia (EMEA) capabilities. Ball Solutions and Novare Services provide QinetiQ with a presence of 185 staff located in Canberra, Sydney, Melbourne, Brisbane and Adelaide. They will enhance the company's portfolio of defence- and security-based expertise, provide additional routes to market, and broaden its customer base through existing relationships and contractual arrangements.

Ball Solutions Group is a provider of professional and consulting services, primarily to the Australian Department of Defence. It has annual revenues of A$29 M and operates in three main areas: business systems and applications, data acquisition and management, and operations research and analysis.

Novare, which has annual revenues of A$6.1 M, provides engineering and logistics services to the Australian Department of Defence, its prime contractors and selected commercial partners. Its core expertise is in aerospace systems, advanced technical data management, and performance-based contracting and explosive ordnance and weapons.

New Bid to Develop Innovation Centres

The Engineering and Physical Sciences Research Council (EPSRC) and the Technology Strategy Board, together with the Biotechnology and Biological Sciences Research Council (BBSRC), are seeking bids from leading UK universities who wish to host two new Innovation and Knowledge Centres (IKCs). The IKCs will promote the early commercialisation of world class research, by combining within a single integrated centre the best research with the best business development, market analysis, and commercialisation skills and partnerships to accelerate its exploitation.

Aimed at providing a major boost to the early commercial exploitation of emerging technologies, the new centres will each receive financial support of around £9.5 M, spread over five years. The EPSRC (together with the BBSRC where appropriate) and the Technology Strategy Board will contribute £7 M and £2.5 M respectively, with further funding coming from universities, industry and other sponsors.

The new initiative follows the establishment of two pilot IKCs by EPSRC in November 2005—one at Cambridge University in Advanced Manufacturing Technologies for Photonics and Electronics, and one at the Optic Technium Centre in North Wales in Ultra Precision and Structured Surfaces, involving Cranfield, UCL and Cambridge universities.

Universities that express an interest in hosting one of the new centres will enter into a thorough assessment and selection process with a decision anticipated in September 2008. The IKCs will provide support for five years of intensive early stage development and commercialisation, which will bring technologies close to market.

SELEX GALILEO Takes Singles Title

SELEX S&AS and Galileo Avionica are now operating internationally as a single company within the Finmeccanica Group and will be known as SELEX GALILEO. Historically both companies have traded separately and each has developed a strong client base and a reputation for excellence. The new name celebrates this tradition and will facilitate continued brand recognition, which the company is keen to retain and develop further.

The initiative is a key part of the company's integration plan and will create a platform that will enable all of the benefits of combined working to be realised. It also confirms the importance and continued development of both existing companies within the Finmeccanica Group and offers clients a one-stop shop to a comprehensive range of products.

The executive team believes that the new name will offer a high recognition factor, offering clients the reassurance that the high standards they currently enjoy will continue to be available on an even greater scale than before.

European First for Astrium Ka-band Satellite

Astrium has been selected by Eutelsat Communications to deliver the first European multi-beam satellite to operate exclusively in the Ka-band and dedicated to providing broadband and broadcast services across the wider Europe. Currently designated as KA-SAT, the satellite marks a material step forward in multi-beam satellites. It will be launched in 2010 and positioned at 13° East in geostationary orbit.

Based on the Eurostar E3000 platform developed by Astrium, the satellite will operate more than 80 spot beams simultaneously, which makes it the largest multi-beam Ka-band satellite ever ordered worldwide. KA-SAT is the 17^{th} satellite commissioned by Eutelsat from Astrium, a wholly owned subsidiary of EADS, and the 23^{rd} Eurostar E3000 ordered.

The satellite will feature a high level of frequency reuse and a flexible assignment of resources to adjust to market demand. It is equipped with four multi-feed deployable antennas with enhanced pointing accuracy, and will be able to operate at a payload power of more than 11 kW throughout its 15-year design lifetime. ■

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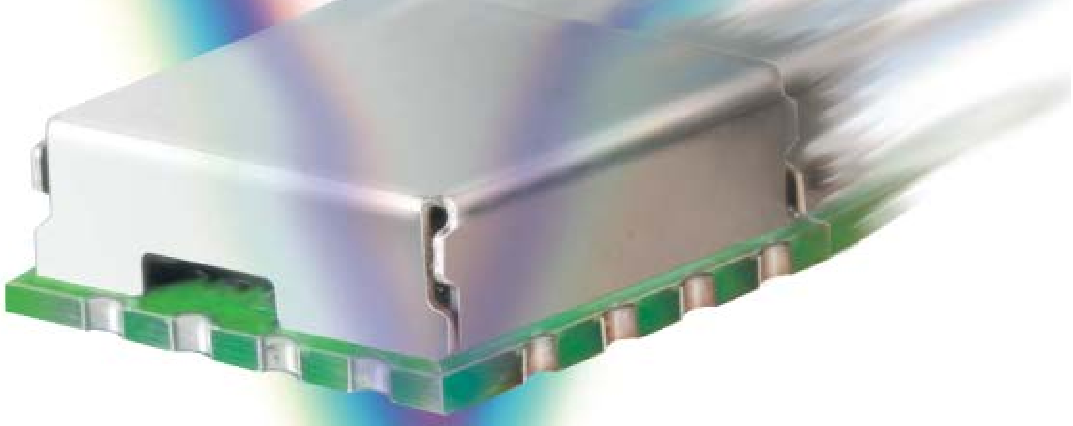

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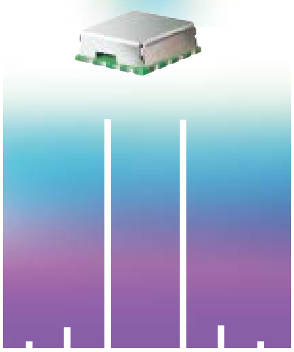

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LAVI-9VH+	820-870	990-1040	120-220	+19	+36	+23	7.2	46	46	15.95
LAVI-10VH+	300-1000	525-1175	60-875	+21	+33	+20	6.3	50	45	22.95
LAVI-17VH+	470-1730	600-1800	70-1000	+21	+32	+20	6.8	52	50	22.95
LAVI-22VH+	425-2200	525-2400	100-700	+21	+31	+20	7.7	50	45	24.95
LAVI-2VH+	2-1100	2-1100	2-1000	+23	+34	+23	7.5	48	47	24.95
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Substantial Markets for MMICs Built Using Compound Semiconductors

A recently released report from Engalco ("The Compound Semiconductor MMICs Report") indicates that the global markets for such CS MMICs will grow steadily from $2.6 B in 2006 to over 5.1 B in 2014. MMICs using GaAs, GaN, InP, InGaP and SiGe are considered and the report focuses on the following application segments: cell phones, defense, ISM, SATCOM and wireless infrastructure. CS MMICs are implemented as switches, amplifiers, oscillators, frequency synthesizers, frequency converters and complete transceivers.

Chips built using GaAs continue to dominate the market, although both InP and SiGe MMICs experienced increasing market shares over the years—both occupying markets worth hundreds of millions of dollars. Markets for GaN MMICs grow very strongly over the time scale considered here. InP chips are increasingly important in certain defense and space applications while InGaP MMICs find more and more applications as cell phone power amplifiers.

Defense consistently represents the largest segment for CS MMICs, typically taking more than 39 percent of the total. By 2014 defense markets will be worth over $2 B, while SATCOM, wireless infrastructure and cell phones (GaAs and InGaP) will be in the medium to high hundreds of millions of dollars markets for CS MMICs. Industrial, Scientific and Medical (ISM) and WiMAX markets are smaller, but also (especially WiMAX) increasingly significant markets.

Markets for MMICs into cell phones, WiMAX terminals and other related devices are particularly important and growing most notably in China, India, Japan and Korea. However, defense markets remain substantial in North America (especially the US) and this factor forces the overall markets to be led by North America until 2014 during which year the extensive region known as the "Rest of the World" (RoW) finally overtakes North America. China, most notably, is of course within this RoW region.

In this report average selling prices (ASP) and shipments are provided in selected instances—again with forecasts to 2014. A total of 53 RFIC manufacturing and "fabless" companies are identified and 23 of these are profiled in depth. The players that have fabless operations are identified and the entire industry structure is critiqued in detail including worldwide sales operations for each player. Engalco is a tech-sector consultancy, industry analysis, market forecasting and publishing concern. With strong experience in all relevant commercial and defense segments, the firm specializes mainly in the RF/microwave, wireless, fiber-optics, photonics and related electronics sectors. Since its inception in 1989, Engalco has been responsible for many published market reports and the completion of several private client projects in these sectors. The firm's mission is to continue providing a range of vital types of analysis, research and publishing services, in addition to customized consultancy based upon proven specialist capabilities. For further information, contact Engalco at +44 (0) 1262 424 249 (GMT) or e-mail: enquiries@engalco-research.com.

Ultra-wideband Beginning to Take Off

The market for ultra-wideband (UWB) silicon is finally beginning to take off, reports In-Stat. Though regulatory hurdles over UWB still persist worldwide, the first UWB-enabled notebook PCs have shipped this year from Dell, Lenovo and Toshiba, the market research firm says.

"The primary question for UWB now is: Will other product segments follow where PCs lead?," says Brian O'Rourke, In-Stat analyst. "UWB is a very flexible technology in that it supports multiple standards, including WUSB, Bluetooth 3.0, IP over UWB and Video over UWB. This should enable the technology to gain design wins in a wide range of product segments, including PC peripherals, Consumer Electronics (CE) and mobile phones."

Recent research by In-Stat found the following:

- UWB-enabled notebook PCs hit the market in mid-2007. PC peripherals will follow in 2008.
- CE and communications applications with UWB will not hit the market in volume until 2010.
- In 2011, over 400 million UWB-enabled devices will ship.

The research, "Ultra-wideband 2007: PCs Finally Hit the Global Market," covers the worldwide market for ultra-wideband. It contains analysis and annual shipment forecasts through 2011 for the penetration of UWB into 26 separate applications within the following product segments: PC, PC peripheral, CE, Communications and Industrial/Medical. The forecast for UWB into each application is broken down by WiMedia UWB and proprietary UWB penetration. Profiles of leading UWB chip vendors and IP suppliers are included. In addition to the report, O'Rourke and other In-Stat analysts provide consulting services on a variety of technical and market topics regarding the semiconductor and electronics industries.

This research is part of In-Stat's Multimedia & Interface Technologies service, which identifies and forecasts the markets for key interface technologies and multimedia semiconductors and tracks penetration of these technologies into PCs, PC peripherals, consumer electronics and communications applications. It also examines competitors, industry agendas, market shares, technology platforms, semiconductor technology and shipments. Supply and demand-side insights are combined to examine these dynamic, evolving technologies.

RF Power Semiconductor Market Will Near $1 B in 2012

By 2012, the total high power RF semiconductor market will be nearing $1 B, with the markets outside the wireless infrastructure starting to take up the slack, reports a new study from ABI Research. But, according to research director Lance Wilson, "The shape of the industry five year hence will depend on three critical questions. At the manufacturing level, will the introduction of gallium nitride and silicon carbide RF power devices mean the demise of Si LDMOS? With mobile/3G infrastructure markets in decline, will they continue to drive the RF power semiconductor industry as they have in the past? Will the market segments outside the wireless infrastructure shore-up this market space?"

To answer these and other questions, ABI Research undertook a market sizing study for all power semiconductors with power outputs above 5 W, operating at frequencies of 3.8 GHz and below. (A later study will target those operating at higher frequencies.) The study sizes the RF power semiconductor market into six usage-based segments and 24 sub-segments, providing a highly detailed, market-driven analysis

The six major segments are: wireless infrastructure, military, ISM (industrial/scientific/medical), broadcast, commercial avionics and non-cellular communications. Each of these is subdivided into between two and six specialty segments. The need for such a study arose, according to Wilson, because "This market has been overshadowed for many years by the wireless infrastructure sector. Now that new 3G/cellular wireless infrastructure deployments are declining, there is a paucity of information about how the rest of the industry is faring. This study puts wireless infrastructure—which is well understood—into the context of the rest of these markets."

The new study, "RF Power Semiconductor Devices," offers five-year detailed market forecasts for all major market segments and sub-segments, along with market share data for the major industry vendors, technologies and segments. It forms part of two ABI Research Services, the RF Power Devices Research Service and the Wireless Semiconductors Research Service. ■


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INDUSTRY NEWS

■ **John Dunbabin**, owner and president of Connecting Devices Inc. (CDI), passed away on September 8, 2007, from pancreatic cancer. A graduate of Cal Poly, San Luis Obispo, with degrees in mechanical engineering and business, John went to work for CDI. In 1975, he and his partners, Ralph Black and Chuck Wirtz, purchased the company. CDI, a well-recognized supplier of coaxial connectors and cable assemblies for over 30 years, was sold to Tensolite in 2001, after which John retired. Dunbabin held several patents, but is most well known in the industry for his prized possession, the 18 GHz radius right angle SMA connector. He went on to develop other interface versions, including type N, TNC and the 40 GHz K. He was an active participant in the various interconnection committees, including the EIA CE-4.0 Committee for RF Connectors and Cable assemblies, where he assisted in the development of the critical specifications governing connector performance. John was well known within the engineering circles of the major defense electronic companies for his engineering expertise, and "hands on" approach in developing interconnection packaging solutions.

■ Emanuel Merulla, antenna design engineer for **MegaWave Corp.**, Boylston, MA, has applied a new absorbing boundary technique in the **Flomerics** MicroStripes 3D electromagnetic (EM) simulation solution to accelerate the design of low-profile and zero-profile antennas installed at ground level, usually for military applications. The new technique enables the Earth to be truncated to a much smaller size with minimal impact on simulation accuracy and reportedly cuts simulation times from days to an hour or two. The challenge was to create a boundary condition that absorbs the field propagating into the Earth, without disturbing the ground waves that contribute to the overall antenna radiation pattern. Inserting an absorbing surface into the Earth and matching its impedance to the fields achieved this.

■ Satellite communications systems developer **Newtec** made IP software developer **Tellitec** a fully integrated subsidiary. Newtec is a Belgian group of companies of which Newtec Cy N.V. is the parent company. Tellitec is made up of Tellitec Communications bvba, based in Sint-Niklaas, Belgium, and Tellitec Engineering GmbH, based in Berlin, Germany. The move cements the existing relationship between the two companies, which has seen a number of Tellitec products integrated into Newtec's offerings. Tellitec's TCP/IP acceleration, traffic shaping and security software are all utilised in Newtec's Sat3Play. Tellitec's software is also used in conjunction with Newtec's professional equipment in many satellite systems for applications such as IP trunking and digital signage.

■ In December 2007, the **WiMAX Forum** announced plans to create the first ever WiMAX Forum Designated Certification Laboratory in India by the end of 2008. This laboratory will enable WiMAX equipment vendors in the country to accelerate the certification process targeting the Indian market. Ron Resnick, president and chairman of the WiMAX Forum, said that WiMAX is the key to addressing India's huge market demand for broadband Internet, and preparing to meet the future needs of the country's communication needs. Citing the recent inclusion of WiMAX technologies in the International Telecommunication Union's IMT-2000 set of standards, Mohammad Shakouri, the Forum's vice-president of marketing, added that the WiMAX spectrum will become more readily available to operators worldwide and help India develop a cost-effective wireless telecommunication infrastructure.

■ UK-based telecommunications infrastructure organization, the **Alan Campbell Group (ACG)**, has invested a six-figure sum in new test and training facilities at its headquarters in Warwick, RI. The move comes as the company continues to grow its broadcast, microwave and telecommunications solutions and services. The purpose-built training center, which covers an area of almost 2500 sq. ft., also includes an 8.5 m training tower and microwave link, so that employees, clients and other organizations can undertake installation and commissioning training. The initiative has seen extensive co-operation with equipment manufacturers in a bid to provide one of the UK's foremost training facilities for the broadcast and telecommunications industries.

■ **TÜVRheinland of North America**, a provider of independent testing and certification services, received accreditation under the National Voluntary Laboratory Accreditation Program (NVLAP) for its electromagnetic compatibility (EMC) and telecommunications testing laboratory in Rochester, NY. Administered by the US National Institute of Standards and Technology (NIST), NVLAP confirms that a testing lab and its personnel have the technical qualifications and competency to perform specific EMC and telecommunications tests and/or calibrations. The accreditation conforms to all requirements of the ISO/IEC 17025:2005 standard.

■ **Infineon Technologies** and the automotive system manufacturer, **Delphi Corp.**, are to collaborate closely on developing a new generation of body control units based on the standard AUTomotive Open System Architecture (AUTOSAR). Delphi is to contribute comprehensive systems and software know-how and long-standing experience in the area of body electronics, while Infineon will provide expertise in automotive microcontrollers to the co-development project.

■ According to a recent report by **Strategy Analytics**, a Boston-based market research firm, the success of free-to-air digital terrestrial television markets in the UK, France, Spain, Italy and Germany has resulted in a marked improvement in the prospects for Integrated Digital TVs over

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DCRO Series				
DCRO8589-5	820 to 900	0.5 to 5	-111	+5
DCRO85100-12	850 to 1000	0.5 to 24	-123 *	+12
DCRO92103-5	920 to 1030	0.5 to 10	-112	+5
DCRO123127-10	1230 to 1270	0.5 to 8	-116	+10
DCRO127175-5	1270 to 1750	0.5 to 18	-107	+5
DCRO128177-12	1280 to 1775	0.5 to 24	-112	+12
DCRO128177-9	1280 to 1775	0.5 to 24	-106	+9
DCRO150165-8	1450 to 1650	0.5 to 10	-109	+8
DCRO159161-12	1575 to 1610	0.5 to 12	-117	12
DCRO160260-5	1600 to 2600	0.5 to 15	-95	5
DCRO168172-8	1680 to 1720	0.5 to 10	-116	8
DCRO178205-10	1785 to 2050	0.5 to 12	-109	10
DCRO197277-10	1970 to 2770	0.5 to 28	-105 *	10
DCRO204235-8	2040 to 2350	0.5 to 24	-109	+8
DCRO205242-10	2050 to 2420	0.5 to 15	-108	+10
DCRO215265-10	2150 to 2650	0.5 to 15	-104	+10
DCRO219250-8	2190 to 2500	0.5 to 24	-106	+8
DCRO243298-5	2430 to 2980	0.5 to 15	-101	+5
DCRO250300-10	2500 to 3000	0.5 to 24	-107	+10
DCRO270400-8	2700 to 4000	0.5 to 18	-93	+8
DCRO273290-10	2730 to 2900	0.5 to 15	-108	+10
DCRO285345-5	2850 to 3450	0.5 to 24	-98	+5
DCRO307331-10	3075 to 3310	0.5 to 20	-102	+10
DCRO310430-5	3100 to 4300	0.5 to 10	-80	+5
DCRO354374-10	3540 to 3740	0.5 to 15	-102	+10
DCRO360382-8	3600 to 3820	0.5 to 24	-102	+8
DCRO490575-5	4900 to 5750	0.5 to 24	-88	+5
DCRO500630-5	5000 to 6300	0.5 to 18	-77	+5
MFC Series				
MFC1223-12	120 to 230	0.5 to 24	-115	+12
MFC1926-12	190 to 260	0.5 to 12	-114	+12
MFC1921-5	195 to 210	0.5 to 10	-120	+5
MFC2931-5	290 to 310	0.5 to 10	-121	+5
MFC2941-12	290 to 410	0.5 to 24	-110	+12
MFC4151-12	410 to 510	0.5 to 15	-112	+12
MFC6170-5	610 to 700	0.5 to 5	-113	+5
MFC7995-5	790 to 950	0.5 to 15	-114	+5
MFC8192-5	810 to 920	0.5 to 5	-106	+5
MFC96103-5	960 to 1030	0.5 to 8	-115	+5
MFC-S-1000	1000 to 2100	1 to 18	-99	+12
MFC102110-5	1020 to 1100	0.5 to 5	-106	+5
MFC114133-5	1140 to 1330	0.5 to 10	-105	+5
MFC138165-5	1380 to 1650	0.5 to 24	-102	+5
MFC170195-5	1700 to 1950	0.5 to 10	-104	+5

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the past year or so. The report projects that digital terrestrial tuners will become the norm across the bulk of the European TV market over the coming years. "Integrated Digital Television Global Market Forecast" says that global demand for integrated digital TVs in 2007 reached 61.7 million units, worth $61.8 B in retail revenues.

■ The Reynosa, Mexico, antenna manufacturing operations of **Andrew Corp.** has received the prestigious Industry of the Year Award for 2007, an annual regional award jointly given by the Mexican government's Secretaria de Economia and the local chapter of the Cámara Nacional de la Industria de Transformación (Canacintra), a 66-year-old organization dedicated to promoting Mexican industry worldwide. Andrew was selected for the strong employment opportunities that it offers the community and the company's ongoing employee training and development initiatives. Andrew opened its Reynosa operations in 2003 and supplies markets in North, Central and South America.

■ **Trompeter Electronics**, a wholly-owned subsidiary of Emerson Network Power Connectivity Solutions, announced that it has increased its overall customer performance rating by three positions in the 2007 Bishop & Associates Connector Industry Survey. Trompeter's ranking rose to seventh overall, and gained in four of five of the most important measures (technical expertise, quality of inside sales assistance, hitting acknowledged ship dates and product quality). Trompeter's highest overall performance ratings in the survey were for technical expertise and field sales support.

■ **Eyelit Inc.**, a manufacturing software provider for visibility, control and coordination of manufacturing operations, announced that **HelioVolt**, a producer of highly efficient thin-film solar products, has selected Eyelit's Enterprise Manufacturing Execution Suite (MES) to provide a cost-effective manufacturing software infrastructure for its global manufacturing network. The Eyelit solution includes complete tracking of serialized PV glass panels, completed solar panels, associated consumables, raw material, and inventory management and tool tracking.

CONTRACTS

■ **Panasonic Mobile Communications Co. Ltd.** and **Nokia Siemens Networks** will cooperate to build the Super 3G (LTE) Base Station project for **NTT DoCoMo Inc.**, Japan's largest mobile operator. Panasonic has been involved with the standardization and development of elements of LTE technology, which is the next generation system for mobile networks like GSM, W-CDMA/HSPA and CDMA. Similarly, Nokia Siemens has demonstrated LTE technology with data speeds in the 160 Mb/s range and a handover between LTE and HSPA in 2007.

■ WiMAX chipmaker **Sequans Communications** is leading a new WiMAX development project that was recently established and funded by the European Commission. The purpose of the project is to develop a new air interface for the next generation of WiMAX, and to make key contributions to the IEEE 802.16m task group, which has been established to develop technical specifications for next generation WiMAX systems. The project, dubbed WiMAGIC (Worldwide Interoperability for Microwave Broadband Access System for Next Generation Wireless Communications), has been accepted by the European Commission within the 7th Framework Programme for Research. WiMAX2 will be backwards compatible with current Mobile WiMAX™ systems based on the IEEE 802.16e-2005 standard, but is intended to deliver much higher performance. Working with Sequans are 12 partners, six technology companies and six universities, from France, the United Kingdom, Germany, Italy, Belgium, Greece and Turkey. The WiMAGIC project commenced in January and will continue for three years.

■ **European Antennas Ltd.** has supplied antennas to **BAE Systems** for the Continuous Wave Doppler Radar project that the company has developed for the UK Aberporth Test and Evaluation Range and operated by QinetiQ on behalf of the UK Ministry of Defence. To satisfy the $2 M contract, BAE Systems developed the CW Doppler system, which incorporates state-of-the-art technology and a system architecture that uses commercial components to provide improvements in operation, simplifying logistics support and minimizing life cycle costs.

■ **Tampa Microwave**, a designer and manufacturer of RF and microwave communications and test equipment for commercial and government applications, announced that the company has obtained a United States Government Services Administration (GSA) Schedule. The contract number GS-07F-0590T applies to Tampa Microwave's converter, carrier monitoring and satellite simulator products. This contract places Tampa Microwave on an approved GSA schedule, enabling various government agencies to purchase products directly from the company.

■ **NEC Corp.** has signed a framework contract to supply microwave communication systems to Polish 3G mobile operator **P4 Sp.z.o.o.** (P4), the mobile operating arm of Polish telecom carrier Netia SA. The company will supply the advanced PASOLINK NEO point-to-point wireless access systems to enable P4 to accelerate its network infrastructure and facilitate provision of stable and high quality 3G services. The microwave system will be employed to carry out transmission among mobile base stations, with P4 planning to install around 10,000 hops in the next five years, and NEC expecting to provide around 1000 hops to mainly northern and middle areas of Poland, as well as to Warsaw, to fulfill the initial demands of the framework contract.

■ **Brightcomms Inc.**, a network planning and optimization services provider, has selected **ZK Celltest**, a developer of wireless network drive test solutions, to work on a multi-vendor network planning and optimization services project in Central and South America focusing on the GSM/EDGE/UMTS/HSDPA, CDMA EV-DO REV.A, and WiMAX arenas.

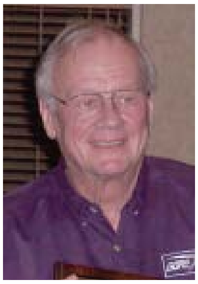
PERSONNEL

■ On January 1, 2008, Huber + Suhner appointed two new group management members, **Patrick Riederer** and **Urs Ryffel**, marking the completion of the Group's reorganization into three divisions. The move is part of the

company's strategy to intensify its focus on its core business of providing 'Electrical and Optical Connectivity' solutions and to concentrate its activities on three technologies: Radio Frequency, Fiber Optics and Low Frequency. This also provides the framework for the group's forward strategy and the future organization structure. The new appointments see Riederer taking charge of the new Low Frequency Division and Ryffel the Fiber Optics Division. The third division, Radio Frequency, will continue to be headed by **Hanspeter Bär**.

▲ *David Gilmour*

■ **David Gilmour** has been appointed to the position of microwave design engineer in the Engineering Division of Link Microtek. He brings particular knowledge and expertise that will extend the division's capabilities into the area of active design—for example, where subsystems require built-in amplifiers, oscillators or mixers. He spent his early years with GEC Marconi, initially as a graduate engineer in the Radar Systems Department and subsequently as a development engineer. He then joined Channel Master (formerly Cambridge Industries), where he was responsible for all aspects of the design and testing of a new dual low-noise block for use in home satellite TV systems.



▲ *Harmon Banning*

■ **Harmon Banning**, a retired Gore associate, received the Automated RF Techniques Group (ARFTG) Career Award in November 2007. Banning had a long and distinguished career in the RF/microwave industry that spanned over 45 years. Companies that Banning worked with included: General Electric Co., Andrew Alford Consulting Engineers, Weinschel Engineering Inc. and W.L. Gore & Associates. During his acceptance speech, Banning thanked Gore's Chuck Carroll for hiring him as the first microwave engineer at the company.

■ Inphi Corp. announced it has appointed **Ron Torten** to the new position of vice president of worldwide sales. Reporting directly to Young Sohn, Inphi's president and chief executive officer, Torten assumes responsibility for the company's entire sales organization, which includes an extensive network of direct and independent sales organizations, manufacturer's representatives and distributors in North America, Europe and Asia. Torten, with more than 10 years experience in executive and general management positions, joins Inphi from NemeriX, where he was chief executive officer. Before his work at NemeriX, Torten was vice president, worldwide materials at Agilent Technologies, where he was responsible for $1.3 B in spending for Agilent's Semiconductor Products Group. Prior to that, he worked as vice president and general manager for the Networking and Entertainment Division of Agere Systems, and with Quantum Corp., where he served in a variety of product marketing and supply chain positions.

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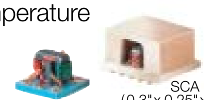

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SBTC-2-10-5075+	50-1000	50/75 Ω	3.49
SBTC-2-10-7550+	5-1000	50/75 Ω	3.49
SCA-4-10+	5-1000	50 Ω	6.95
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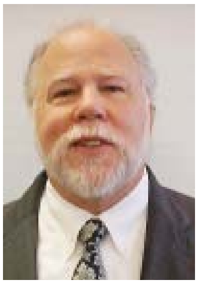
▲ Markus Hellenthal

■ On March 1, 2008, **Markus Hellenthal** will take up the positions of chief executive officer and senior vice president of Thales Germany. He has also been appointed director of the Thales Security Solutions & Services Division of Thales Germany. Hellenthal is a member of the European Security Research and Innovation Forum (ESRIF), is a co-founder and chairman of the European Organisation for Security (EOS), and vice president of the Security Commission of the European Association for Aeronautic, Space, and Defence Industry (ASD).

■ ANADIGICS Inc., a provider of semiconductor solutions in the broadband wireless and wireline communications markets, has announced the appointment of **Gilles Delfassy**, retired senior vice president of the Worldwide Wireless Terminals Business Unit of Texas Instruments, to its board of directors. An industry veteran with over 28 years of experience in global business development and wireless technology, Delfassy had been at the helm of Texas Instrument's successful wireless terminals business unit since its inception in 1995, growing it into a multibillion-dollar operation.


▲ Gregory E. Pollack

■ The Phoenix Company of Chicago, a manufacturer of interconnect products, has announced the promotion of **Gregory E. Pollack** to the position of corporate director of sales and marketing, RF products. He had previously been director of sales and marketing for Palco Connector, an affiliate company located in Naugatuck, CT. Pollack is now responsible for all RF product sales in North America, which will also include related D-subminiature connectors and filter products.

■ RF Micro Devices, a maker of RF systems, has named **John Ocampo** and **Casimir Skrzypczak**, to its board of directors. Both were former members of the board of directors of Sirenza Microdevices, which RF Micro recently acquired.

REP APPOINTMENTS

■ **Digi-Key Corp.** and **Roving Networks Inc.** announced today that the companies have entered into a global agreement wherein Digi-Key will distribute Roving Networks' wireless solutions utilizing Bluetooth and 802.11 Wi-Fi technologies. The company designs, manufactures and markets embedded modules, serial adapters, network access devices and sensors, allowing access from Bluetooth enabled PCs, PDAs, cell phones, networks and machine-to-machine communications.

■ **AtlanTec** has appointed key sales representatives in the US. In the New York/New Jersey Metropolitan mar-

Broadband Amplifiers by AML Communications

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Model	Frequency (GHz)	Gain (dB)	Flatness (dB) max	NF (dB) max	P1dB (dBm) min	VSWR (In/Out)	DC Current @ +12/+15VDC
Broadband Low Noise Amplifiers							
AML016L2802	0.1 – 6.0	28	±1.25	1.3*	+7	2.0:1	190
AML48L3001	4.0 – 8.0	30	±1.0	1.2	+10	1.8:1	150
AML412L3002	4.0 – 12.0	30	±1.5	1.5	+10	1.8:1	150
AML218L0901	2.0 – 18.0	9	±1.0	2.2	+5	2.5:1	60
AML0518L1601-LN	0.5 – 18.0	16	±1.0	2.7	+8	2.2:1	100
AML0126L2202	0.1 – 26.5	22	±2.25	3.5*	+8	2.2:1	170
AML1226L3301	12.0 – 26.5	33	±2.0	2.8	+8	2.5:1	200
Broadband Medium Power Amplifiers							
AML0016P2001	0.01 – 6.0	21	±1.25	3.2*	+23*	2.0:1	480
AML26P3001-2W	2.0 – 6.0	28	±2.5	6	+33	1.8:1	1500
AML28P3002-2W	2.0 – 8.0	30	±2.0	5.5	+33	2.0:1	2000
AML218P3203	2.0 – 18.0	32	±2.5	4	+25	2.0:1	450
AML618P3502-2W	6.0 – 18.0	35	±2.5	4	+33	2.0:1	1850
Narrow Band Low Noise Amplifiers							
AML23L2801	2.8 – 3.1	28	±0.75	0.7	+10	1.8:1	150
AML1414L2401	14.0 – 14.5	24	±0.75	1.5	+10	1.5:1	130
AML1718L2401	17.0 – 18.0	24	±0.75	1.6	+10	1.8:1	150

Low Phase Noise Amplifiers

Part Number	Frequency (GHz)	Gain (dB)	Output Power (dBm)	Phase noise (dBc/Hz) at offset 100Hz	1KHz	10KHz	100KHz
AML811PN0908	8.5 – 11.0	9	17	-154	-159	-167	-170
AML811PN1808	8.5 – 11.0	18	18	-152.5	-157.5	-165.5	-168
AML811PN1508	8.5 – 11.0	15	28	-145.5	-153.5	-158.5	-164.5
AML26PN0904	2.0 – 6.0	9	20	-150	-165	-165	-178
AML26PN1201	2.0 – 6.0	11	15	-155	-160	-160	-175

High Dynamic Range Amplifiers

Part Number	Frequency (MHz)	Gain (dB)	P1dB (dBm)	OIP3 (dBm)	DC
AR01003251X	2 – 32	21	32	52	+28V @ 470mA
AFL30040125	50 – 500	23	28	53	+28V @ 700mA
BP60070024X	20 – 2000	32	30	43	+15V @ 1100mA

*Above 500MHz.

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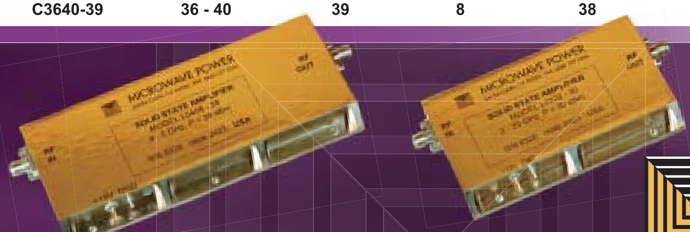
Model	Frequency (GHz)	Psat (dBm)	Psat (W)	P1dB (dBm)	Gain (dB)	DC Current(A) @ +12V or +15V
Broadband Microwave Power Amplifiers						
L0104-43	1 - 4	42.5	17.8	41.5	45	14
L0204-44	2 - 4	44	25	42.5	45	14
L0206-40	2 - 6	40	10	38.5	40	8.5
L0208-41	2 - 8	41	12	40	40	17
L0218-32	2 - 18	32	1.4	31	35	5
L0408-43	4 - 8	43	20	41.5	45	17
L0618-43	6 - 18	43	20	41.5	45	22
L0812-46	8 - 12	46	40	45	45	28
Millimeter-Wave Power Amplifiers						
L1826-34	18 - 26	34	2.5	33	35	4
L1840-27	18 - 40	27	0.5	26	30	2
L2240-28	22 - 40	28.5	0.7	27	30	3
L2630-39	26 - 30	39	8.0	38	40	15
L2632-37	26 - 32	37	5.0	36	38	10
L2640-31	26 - 40	31	1.2	30	30	5
L3040-33	30 - 40	33	2.0	32	33	9
L3337-36	33 - 37	36	4.0	35	40	12
L3640-36	36 - 40	36	4.0	35	40	10

High-Power Rack Mount Amplifiers

Model	Frequency (GHz)	Psat (dBm)	Psat (W)	P1dB (dBm)	Pac (kW)	Height (in)
C071077-52	7.1 - 7.7	52.5	170	51.5	1.8	10.25
C090105-50	9 - 10.5	50	100	49	1	8.75
C140145-50	14 - 14.5	50.5	110	49.5	2	10.25
C1416-46	14 - 16	46	40	45	0.35	5.25
C1820-43	18 - 20	43	20	41.5	0.25	5.25
C2326-40	23 - 26	40	10	39	0.25	5.25
C2630-45	26 - 30	45	30	44	0.45	5.25
C3236-40	32 - 36	40	10	39	0.25	5.25
C3640-39	36 - 40	39	8	38	0.24	5.25



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ket and Upstate New York region, the representative is **RF Electronic Sales Co. Inc.**, Tel: (516) 624-3800, Fax: (516) 624-2920, e-mail: info@rfsales.com, www.rfsales.com. In Northern California, the contact is **StarTech Sales Inc.**, Tel: (408) 309-9067, Fax: (650) 969-6668, e-mail: linda@startechsales.com. In Southern California, it is **Amawave**, Tel: (760) 414-9660, Fax: (760) 414-9675, e-mail: sales@amawave.com, www.amawave.com. Marketing in the Western Region is coordinated through the new sales office at **AtlanTec, Western Regional Sales**, 30520 Rancho California Rd., Suite #107-140, Temecula, CA 92591. The contact is Walt Carpenter, Tel: (310) 880-7885, Fax: (951) 699-2175, e-mail: walt.carpenter@AtlanTecRF.com.

■ **Reactel Inc.**, a designer and manufacturer of RF and microwave filters, diplexers and sub-assemblies, announced that **NW Technical Sales Inc.** will be its sales representative for Washington, Oregon and Idaho. Contact: Barbara Boersema, (360) 387-4204, bboersema@nwtechsales.com; or Herm Boersema (360) 387-4044, hboersema@nwtechsales.com.

■ **Vaunix Technology Corp.** announced the appointment of two new representatives to sell its line of Lab Brick™ test equipment. **High Tech Sales** (www.htssales.com) serves the six New England states and upstate New York. **Jay Stone Associates** (www.jsarep.com) covers Northern California and Northern Nevada.

■ **Davidson Optronics Inc.**, a manufacturer of high quality optics and optical instruments, announced a new exclusive government services partnership agreement with **Technical Communities Inc.** The agreement authorizes Technical Communities to present the catalog of Davidson Optronics products, including autocollimators, alignment telescopes, interferometers, mirrors, optical flats, prisms, instrument stands, surface quality samples and the TV Optoliner Camera Calibration System to US government agencies, military organizations and prime federal contractors. Technical Communities is the owner and operator of GSAMart, TestMart, NAVICPMart and EurekaSpot.

■ **Hirose Electric (USA) Inc.**, a subsidiary of one of the largest electronic connector manufacturers, and **Future Electronics** have signed an agreement covering North and South America. Hirose designs and manufactures thousands of connector types for myriad applications, including mobile computer, communication, automotive and medical.

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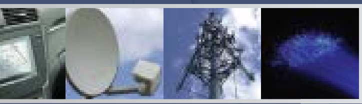

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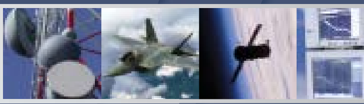

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This compact and lightweight signal generator also features a USB interface and innovative control software ensuring carefree integration within various test environments while improving overall productivity and equipment utilization.

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- Test & Measurement
- R&D Laboratories

Performance

- High Output Power: +17 dBm
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- Phase Continuity Capability; Integer Mode Architecture

Advantages

- Versatile: Higher Drive Simplifies Test Set-ups
- Efficient: Fast Frequency Switching: 200 μs
- Accurate: Incorporates Hittite MMICs
- Flexible: Manual or Software Control via USB

SYNTHESIZED SIGNAL GENERATION

Frequency (GHz)	Function	Frequency Resolution (MHz)	1 GHz Max Power Output (dBm)	100 kHz SSB Phase Noise (dBc/Hz) @ 1 GHz	100 kHz SSB Phase Noise (dBc/Hz) @ 4 GHz	Spurious @ 1 GHz (dBc)	Switching Speed @ 100 MHz Steps (μs)	Part Number
0.7 - 8.0	Signal Generator	1	+17	-78	-83	-48	<200	**HMC-T2000**

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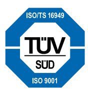

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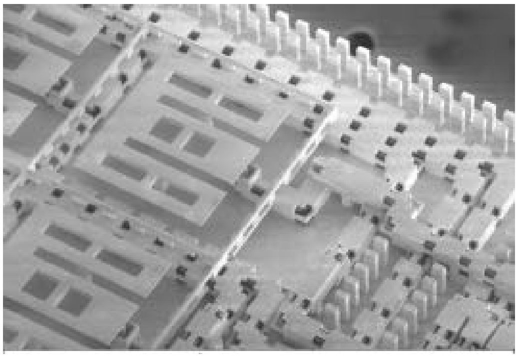
How would you like to design circuits with perfectly shielded, low-loss, purely TEM broadband transmission lines, which could be stacked next to and on top of each other with no coupling? The lines can be tens of centimeters long, cross at multiple levels and at any angle, and holes could be left to plug in actives or other surface-mount components. Impossible? A radically new way to design and fabricate microwave and millimeter-wave circuits recently grew from an idea to reality: PolyStrata™ microfabrication technology offers the possibility of producing miniature, dense and very complex three-dimensional (3D) metallic-dielectric components with an unprecedented ability to go directly from 3D CAD drawings to identical intricate 3D miniature circuit components.[1] As a result, one can now design dense multi-layer meshes of micro-coaxial cables that do not couple to each other and operate with low loss well into the millimeter-wave region. ***Figure 1*** shows a photograph of a portion of a phased array with reactively-loaded patch antennas and a feed network implemented in air-filled micro-coaxial lines made of copper. This is the first wafer-scale integrated coaxial millimeter-wave phased array that includes a Butler matrix coaxial beamformer, air-patch antennas, and MMIC switches and amplifiers. The entire phased array is 15 × 2 cm in area.

The PolyStrata microfabrication process is the first manufacturing technology that can

Fig. 1 A portion of a 4 × 4 element monolithic phased-array radar showing several micro-fabricated antennas and micro-coaxial feeds.



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Boulder, CO
DAVID SHERRER, CHRIS NICHOLS, JEAN-MARC ROLLIN AND KEN VANHILLE
Rohm and Haas Electronic Materials
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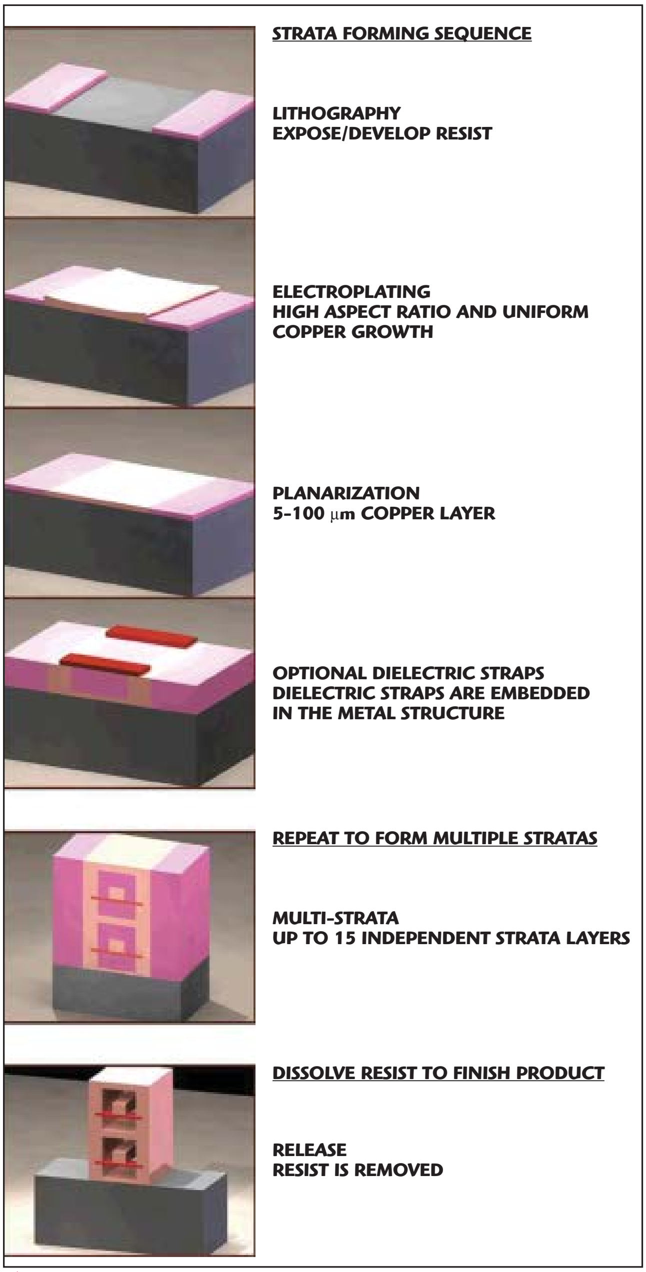
deposit a dozen or more precision patterned layers of both metals and polymers on a flat sheet, and then release them to allow gaps and mechanical flexibility, resulting in sophisticated miniature devices with features ranging from a few microns to several centimeters. Dozens to thousands of devices can be fabricated on a single substrate. With this technology, it is possible to dramatically reduce the size of coaxial lines, actuators, valves, engines, motors, pumps, sensors and other electromechanical products that would otherwise be impractical or impossible to produce with other manufacturing approaches. Great freedom in realizing structural designs is possible with finished parts matching their CAD designs with micron level accuracy. The added degrees of freedom allow the designer to work with completely new components, as well as to fabricate components that are difficult or impossible to machine or fabricate otherwise, such as high-frequency waveguides and antennas.

Commercialization of PolyStrata components at Rohm and Haas is currently focused on one market segment—microwave electronics. The technology and patented process for “air-core recta-coax” is the key to miniaturized 3D microwave devices for new high-quality circuits that can be either monolithically fabricated as a free-standing module or can be released from the substrate to create surface-mountable components for other substrates. Its greatest value lies in its delivery of superior performance, integration, size reduction and cost reduction for products in the 10 to 200 GHz range. These frequencies are of increasing use and interest for the evolving needs in military communications, radar and sensing systems, and are of rapidly growing interest for civilian applications such as automotive radar, satellite communications, cellular back-haul, point-to-point data links and terahertz imaging.

Currently much of the development funding for PolyStrata technology comes from the Department of Defense (DoD)



▲ *Fig. 2 Polystrata fabrication process.*

through the Defense Advanced Research Projects Agency (DARPA) under two major programs: 3D-MERFS (3D Micro-Electrical-RF-Systems), which is developing millimeter-wave phased arrays for satellite communications, and DMT (Disruptive Manufacturing Technologies), which is developing broadband GaN-PolyStrata hybrid microwave amplifiers. Both of these programs are being developed with defense contracting partner BAE Systems Inc. and in collaboration with electromagnetic and circuit design researchers at the University of Colorado at Boulder.

Fabrication techniques such as precision milling, EDM and silicon micromachining have achieved some success in making basic circuit structures. Meanwhile, the smaller size possible in transmission lines such as microstrip and coplanar waveguides used in MMICs and hybrid circuits have been relegated primarily to 2D or at best 2.5D planar structures with reduced performance at higher frequencies due to loss, dispersion and isolation. In contrast, the PolyStrata process is a fully 3D fabrication technique, which employs additive sequential-build micro-forming.

In the PolyStrata microfabrication process, metal and dielectric patterns are formed into a series of polymer molds and planarized multiple times, as illustrated in ***Figure 2*** for the simple cross-section of a square air-filled coaxial line. Each layer can be from 10 µm to over 100 µm thick, for example, with high aspect ratios with a dozen or more layers that are fused together. At the end of the process, the polymer mold material is removed through release holes in the metal, leaving air in its place with free-standing metal and dielectric structures behind. The release holes are designed to introduce minimal radiation and ohmic loss and are electrically small for all frequencies of interest. In order to support freestanding structures such as the center conductor of the coaxial line, thin (5 to 25 µm) patterned low-loss dielectric strap holders are added in the process. The dielectric straps can also be designed to support thin-film microelectronic materials such as SiCr for integrated resistors. Currently, the bulk-electroformed metal is copper, which can be post processed with tarnish-protective electroless silver or nickel-gold coatings.

All the processes typically occur at temperatures below 150°C, allowing the possibility of building the structures directly on completed wafers of active devices. The finished components can stay on the substrate on which they are built, but can also be chemically released and flip-chip mounted or soldered onto any other substrate or on top of other PolyStrata devices.

The fundamental properties of PolyStrata air-filled micro-coaxial lines and the resulting advantages for microwave and mm-wave systems include:

• ***Ultra-low dispersion***. As the size of a coaxial line is reduced, the frequency at which modes other than the TEM mode can propagate increases. The dielectric straps that hold the center conductor are a very

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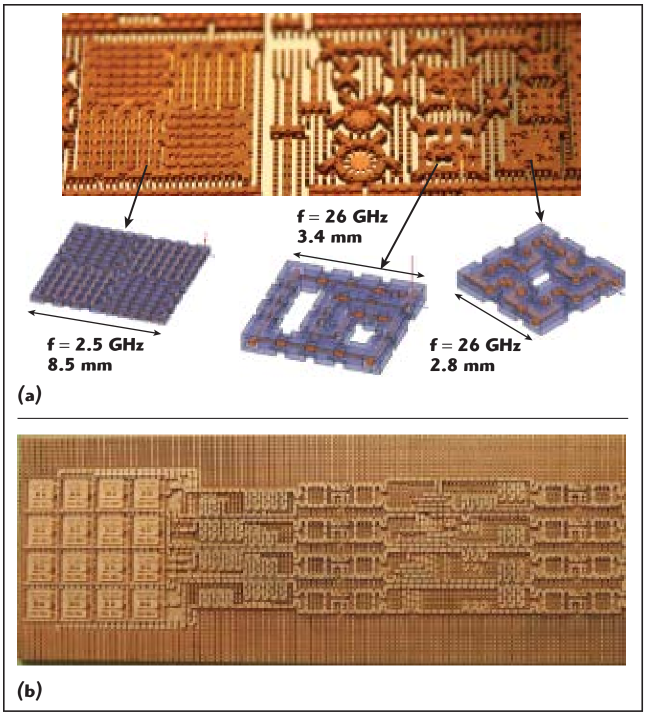


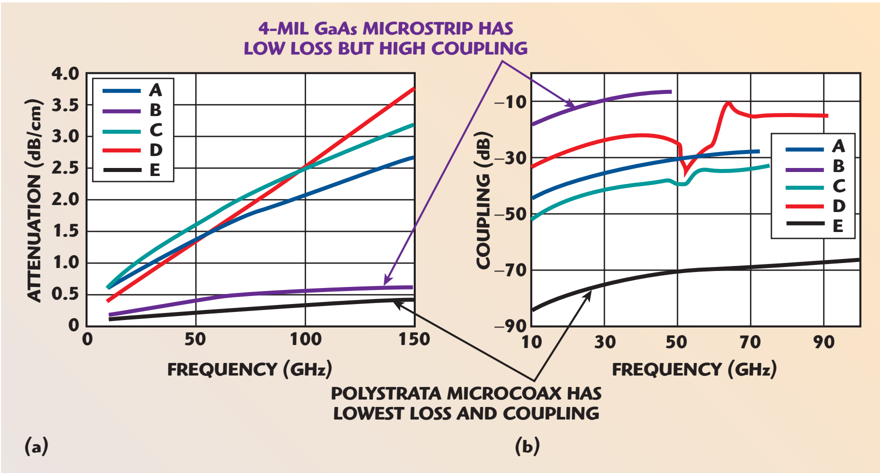
▲ *Fig. 3 Miniaturization of components using the isolation property of Polystrata micro-coaxial lines. A 6 GHz and a 26 GHz branch line coupler and a 26 GHz rat race coupler are shown for size comparison (a) and (b) shows a 16-element beam-forming antenna array, fabricated for low-loss Ka-band operation with a total footprint of 13 cm by 2 cm.*

small fraction of the volume of the coaxial line (< 1 percent), and have an extremely small effect on wave propagation along the coax. Although strictly speaking the mode is quasi-TEM because of the dielectric, for all practical purposes the mode can be considered as TEM up to very high frequencies. For example, for a 250 µm square-cross-section coaxial line, the TEM mode propagates alone up to > 450 GHz.[2] The TEM mode locally has the same properties as a uniform plane wave, that is, the phase velocity, group velocity and impedance are not functions of frequency. Thus, very broadband components can be designed using this type of line as a building block. For example, a 20 to 50 GHz bandwidth Lange coupler is easily designed using PolyStrata technology.[3] In addition, the process aspect ratios allow lines with characteristic impedances between 15 and 100 Ω to be fabricated in the same fabrication run.

- ***Very low loss per wavelength***. Loss in guided wave components is due to metallic loss, which increases with frequency due to the skin effect and roughness, and dielectric loss due to the finite conductivity of the insulating material. It is fairly easy to show that even if the dielectric in a coaxial line is perfect, the lowest loss corresponds to the lowest relative permittivity, that is, to an air dielectric. The very first measurements of 250 µm wide lines fabricated with 5 copper layers showed a loss of 0.18 dB/cm around 26 GHz,[2,4] while more recent results with added layers demonstrate as low as 0.07 dB/cm loss around 38 GHz.[5]
- ***Extremely high isolation***. A coaxial cable is a shielded line, and although the PolyStrata process typically employs release holes in the outer conductor to dissolve out the lossy dielectrics used in processing, careful electromagnetic design of the hole position, number and size has resulted in very low radiation. Measured coupling between two lines that are fabricated with touching outer conductors is below –60 dB through 50 GHz.[5] Independent testing by the Mayo Institute demonstrated measured cross talk at Ka-band (37 GHz) between lines on a 200 µm pitch to be less than –62 dB, which was the noise floor of the measurement system. The extremely high isolation between neighboring lines enables dense interconnects, components with drastically reduced size and 3D layouts that give an entire new degree of freedom in circuit design. ***Figure 3*** illustrates the possibilities in size reduction of standard components using this technology over a range of frequencies. This type of new design enables extremely high-density circuits. For example, in the Butler matrix feed for a phased array, there were 1534 transmission line elements in an area of 5.65 cm^2.

To illustrate some of the fundamental properties previously discussed, a simple comparison with standard technologies is shown in ***Figure 4***. As can be seen, compared to microstrip or CPW on GaAs or alumina, Polystrata micro-coaxial lines have the best loss-isolation combination.

Most multi-layer transmission line media require a solid dielectric, such as in the case of LTCC and multi-layer fluoropolymer materials. Although these technologies provide high-density interconnects and have relatively low loss up to W-band,[6] the PolyStrata approach has advantages in terms of lower loss, much lower dispersion and significantly reduced coupling for neighboring lines, thus allowing high density circuits. The micro-coax lines hold promise for applications at frequencies significantly above W-band. In addition, PolyStrata micro-coaxial



▲ *Fig. 4 Attenuation (a) and coupling (b) for Polystrata 250 µm micro-coaxial lines (E), microstrip on 50 µm (A) and 200 µm (B) GaAs, and CPW on 125 µm GaAs (C) and 200 µm Alumina (D). For coupling, 700 µm separation is assumed between all lines.[5]*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lines have a much larger fraction of the volume that is metallic, allowing for improved heat management with a thermal conductivity of nearly 400 W/mK.

Initial efforts to microfabricate air-filled coaxial components were reported.[7–9] These researchers examined air-filled coaxial transmission lines in addition to other high-quality air-filled millimeter-wave technologies. The micro-fabricated coaxial technology discussed in References 10 through 16 with a nickel-based N-layer process and periodic metal supports for the inner conductor has been used to demonstrate couplers, filters and resonators. Air-filled coaxial components produced by stacking laser micromachined layers in which the center conductor is suspended using short-circuiting stubs is investigated in Reference 17. PolyStrata technology has the unique advantage of producing multiple layers of coax, producing coax with a dielectrically isolated center conductor, incorporating embedded thin-film microelectronics on the embedded dielectrics, and producing all of this using scalable manufacturing processes. These accomplishments have been in part realized by engineering an application specific set of materials by Rohm and Haas especially for this process, including a new negative photoresist mold material that can dissolve without swelling.

A number of publications to date describe in detail the electrical properties of the air-filled copper micro-coaxial lines and passive components such as resonators, branch-line couplers and antennas, which were realized in the first implementations of PolyStrata technology over the past couple of years.[1–5,18–22] ***Table 1*** illustrates the design, fabrication and measured characteristics of several specific devices demonstrated in the first generation of PolyStrata components developed in the DARPA 3DMERFS program. The left-hand column shows the CAD models of a Ka-band branch-line hybrid,[19] a cavity-backed antenna[21] and a quasi-planar high-Q resonator.[22] Starting from a zero-order circuit model, a specialized layout routine enables automatic creation of files corresponding directly to the complete geometry of the component, including release holes, dielectric straps and any interconnects. The resulting file can be directly imported for simulation in the Ansoft HFSS FEM tool. After optimization using full-wave electromagnetic analysis, the CAD files are used for PolyStrata fabrication at the Rohm and Haas fab in Blacksburg, VA. Photographs of fabricated devices corresponding directly to the CAD drawings in the first column are presented in the second column. Calibrated measurements using off- or on-wafer calibration standards are then performed and compared to predicted performance, as shown in the third column. Component specifications are collected from measured data on a number of components across a wafer.

The performance of the first generation of PolyStrata components is excellent. For example:

- the hybrids have an amplitude and phase mis-balance of < 0.1 dB and

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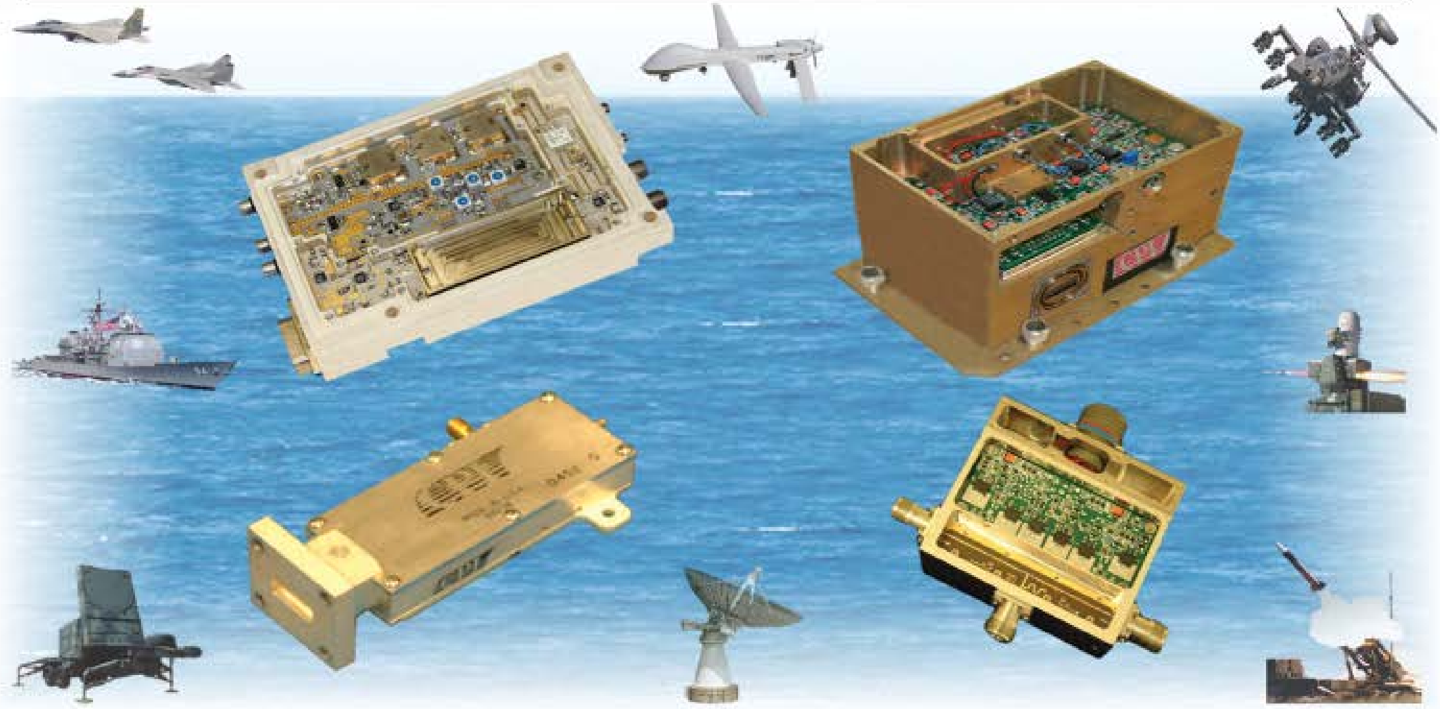

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two degrees over a five percent bandwidth centered at 35 GHz;
• the antennas have a five percent 2:1 VSWR bandwidth with 6.8 dBi predicted gain at 36 GHz;
• the miniaturized resonators have an unloaded Q factor over 830.[22] In addition, for a given cavity height, normalized by frequency, the record high unloaded Q for a microfabricated cavity resonator has been demonstrated.[20]

Other components that have been designed and are either already fabricated and characterized or in the process of fabrication include:
• 1:2, 1:3, 1:4 divider/combiner networks in the frequency range from 2 to 110 GHz;
• micro-coaxial baluns and transformers that are broadband, e.g. 2 to 14 GHz;
• a variety of couplers from C- to W-bands: branch-line hybrids, rat-race hybrids and broadband Lange couplers; narrowband antennas, such as cavity-backed patches and coaxial colinear arrays; filters and duplexers using both coupled cavity designs and transmission-line resonator designs up to Ku-band;
• monolithically integrated embedded resistors both in-line for low power applications and on-substrate for high-power applications;
• micro-coaxial lines with a range of impedances from 12 to 110 Ω;
• millimeter-wave (above W-band) rectangular dominant-mode waveguides and waveguide-coaxial adaptors;
• jumpers and cross-overs with extremely low coupling up to W-band that can be integrated or surface or flip-chip mounted;
• interconnects from microcoaxial lines to CPW probes, CPW on the substrate, CPW flip-chip pads on a different substrate, microstrip, as well as transitions to connectors and waveguides; and
• high-quality and current handling lumped inductors integrated in series or parallel with the microcoaxial line.

In addition, Rohm and Haas and AFRL have been jointly exploring millimeter-wave applications of PolyStrata under a cooperative research agreement (CRADA 07-291-SN-01). Under this agreement, the Air Force is investigating the benefits of PolyStrata for millimeter-wave components such as filters, voltage-controlled oscillators and wideband switch matrices. Successful testing of 40/50 GHz diplexers has recently been completed and the results will be submitted for publication soon.

Many of these and other building block components will be characterized, parametric models produced and a design library generated. This library can allow designers to import these elements into circuit simulators to realize their own microwave systems in the Polystrata technology.

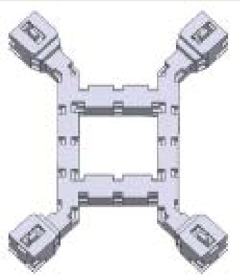
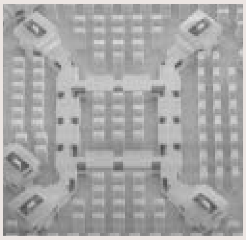
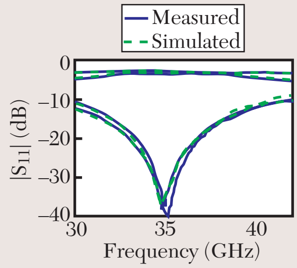
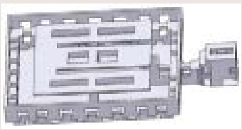
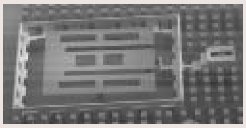
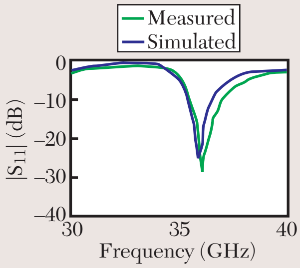
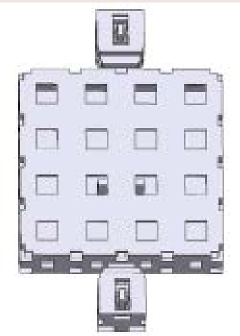
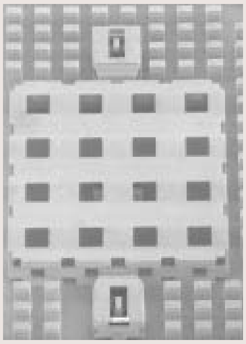
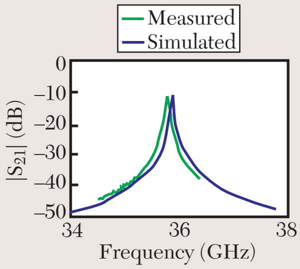
The micro-coaxial environment combined with the PolyStrata technology allows improved components, but also allows the creation of new types of components, which can be integrated in different ways into hybrid monolithic integrated circuits (HMIC). Due to the lithographic nature of the fabrication, tolerances are on the order of a few microns across

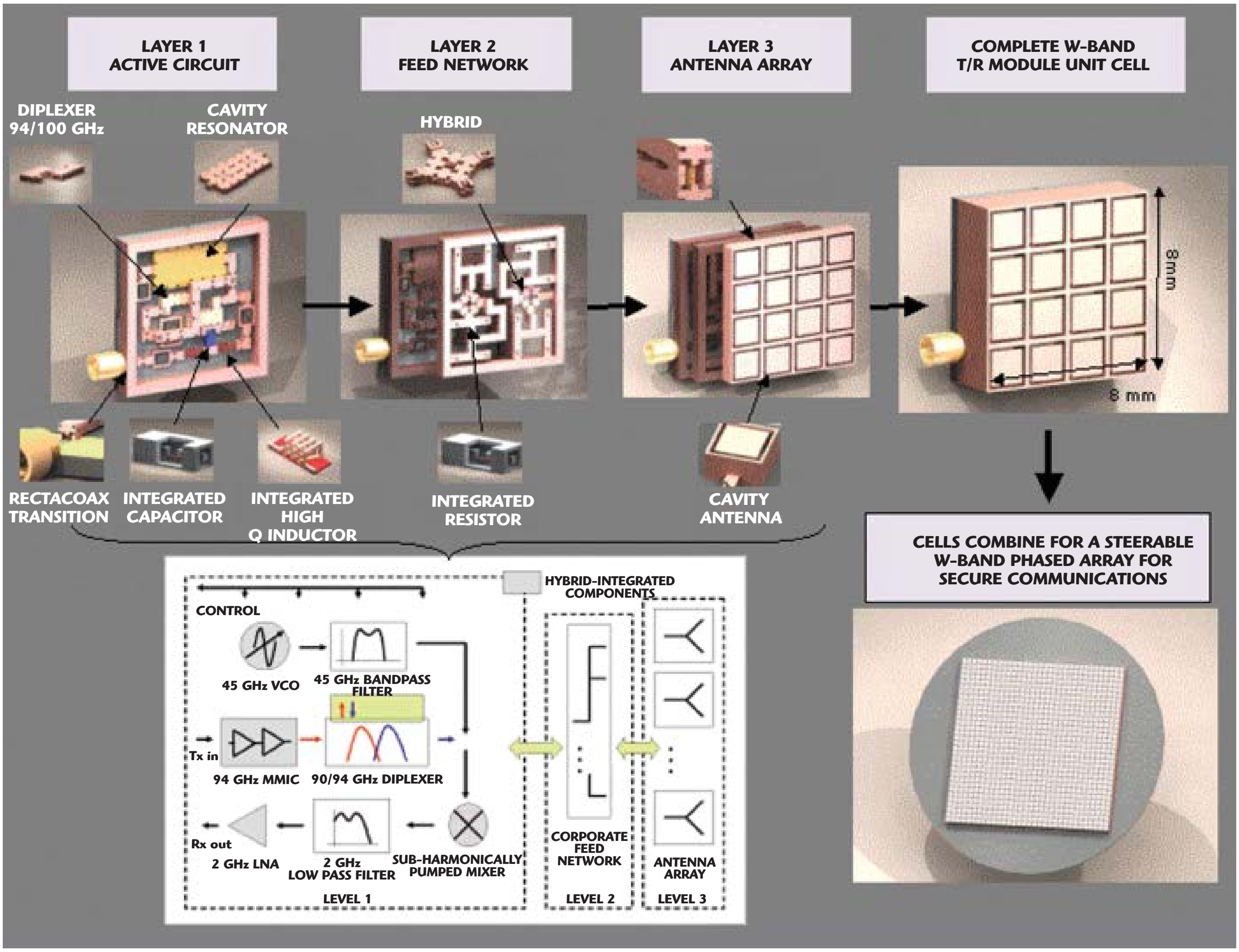
tens of centimeters of line length. This allows a complete toolbox of phase-controlled components to be transferred directly into the technology eliminating the parasitics, cost, and space associated with interconnects and device mounting tolerances when mounting discrete devices in traditional assemblies.

In order to obtain high-performance military and commercial EHF modules, there needs to be an attractive means to bring the best passive and active technologies together. Unfortunately, these have not converged to a single active semiconductor platform with the best technologies desired for amplifiers, digital circuits, mixed signal circuits, phase shifters, tuners and switches. Thus, heterogeneous hybrid active device integration is currently being developed through the monolithic creation of device "sockets" that allow both flip-chip and wire-bond integration. The sockets can be designed to handle devices from the transistor level (200 × 200 µm die) up to relatively large ICs and MMICs, and with a relatively high positional tolerance. Thus, traditional flip-chip mounting tools can be used while still minimizing parasitic reactances. Such sockets integrate both thin film solders, diffusion barriers and solder wick-stops to allow direct chip attach. Alternatively, active-side-up mounting and wedge bonds into such sockets is also possible when either metallurgy or on-chip parasitics make flip-chip difficult. Due to the PolyStrata backplane being composed primarily of metallic copper, thermal mounting pads and heat-routing solutions can be directly implemented allowing both rapid local spreading and transfer of heat to secondary heatsinks and thermal back-planes. Multi-die mounting challenges are being addressed by the use of transient liquid phase solder stacks, such as the Au-Sn system, that can be made to reflow only once for a limited time when heat is pulsed through the die to be mounted. CTE differences are addressed by building compliant structures directly into the socket. Solving the challenging work on active device integration for high thermal density components, specifically GaN, is ongoing through

TABLE I

MOVING DIRECTLY FROM CAD TO NEARLY IDENTICAL HARDWARE WITH PERFORMANCE MATCHING THE SIMULATIONS ARE ROUTINELY ACCOMPLISHED USING THE POLYSTRATA TECHNOLOGY, AS IS SHOWN HERE FOR THE Ka-BAND BRANCH-LINE COUPLER, THE PATCH-LIKE ANTENNA AND THE CAVITY RESONATOR

	Design	Fabrication	Results	Specs
90° Hybrid Coupler				• Measured 5% bandwidth with RL > 20 dB and 0.1 dB loss • Dimensions without test ports are 2.4 mm × 2.7 mm × 2.7 mm
Antenna				• Measured antenna bandwidth is 5.1% around 36 GHz • Antenna dimensions are 0.8 mm × 2.8 mm × 3.2 mm • Gain is 6.8 dBi
Cavity Resonator				• Measured unloaded Q = 830 • Cavity dimensions are 0.8 mm × 3.3 mm × 3.3 mm • Measured f_0 is within 0.3% of the predicted value



▲ *Fig. 5 A conceptual 3D W-band phased-array T/R module implemented from Polystrata transceiver "cells" illustrates the ability to provide miniaturization and integration.*

DARPA support of the Disruptive Manufacturing Technologies (DMT) program.

Where can PolyStrata micro-coaxial technology help? Commercial applications for the technology include miniature radar systems and components, satellite matrix switches, lossless baluns for phase matching of power amplifiers to their packages, high-Q inductor banks for filters, point-to-point EHF data link components, antenna diplexers, low-loss power combiners for solid-state microwave amplifiers and automotive radar systems. Rohm and Haas is actively seeking partners to develop the technology for these and other applications.

Military applications are numerous due to the extremely high performance characteristics of the demonstrated components and the dramatically improved size and isolation compared to existing technologies. The goal of the 3D-MERFS DARPA program is to produce assemblies of PolyStrata panels for phased arrays for on-the-move multi-point communications including SATCOM. This will enable high bandwidth real time data communications between command vehicles, air vehicles and global command stations using satellite links and point-to-point and multi-point communications. Key to the deployment of these systems is a substantial reduction in size, weight and power required for the phased-array panels that will provide low profile transmit and receive functions. The second area of development funded by the DARPA DMT program, also in partnership with BAE Systems, is aimed at developing cost-effective decade-bandwidth microwave amplifiers capable of displacing the existing traveling-wave tube amplifiers used for communications, radar and electronic warfare applications. This will be accomplished by hybrid integration of GaN transistor technology into a monolithic PolyStrata amplifier module.

Other military applications stem from the unique electrical properties previously described. For example, the high isolation implies that usual constraints of how close the transmit and receive parts of a communications or radar system can be are no longer limited by the transmission line medium. Another consequence of high isolation is that the coaxial lines can be built in multiple interconnected levels with low-loss sharp 90° turns. This allows a higher density of transmission lines and components as compared to traditional 2D structures such as microstrip and CPW, and provides the freedom of using crossovers wherever needed.

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ZHL-10W-2G	800-2000	43	+40	+41	7.0	+50	24	5.0	1295.00
• ZHL-20W-13	20-1000	50	+41	+43	3.5	+50	24	2.8	1395.00
• ZHL-50W-52	50-500	50	+46	+48	4.0	+55	24	9.3	1395.00
• ZHL-100W-52	50-500	50	+47	+48.5	6.5	+57	24	9.3	1995.00
▲ *Without Heat Sink/Fan*									
ZHL-5W-2GX	800-2000	49	+37	+38	8.0	+44	24	2.0	945.00
• ZHL-10W-2GX	800-2000	43	+40	+41	7.0	+50	24	5.0	1220.00
• ZHL-20W-13X	20-1000	50	+41	+43	3.5	+50	24	2.8	1320.00
• ZHL-50W-52X	50-500	50	+46	+48	4.0	+55	24	9.0	1320.00
• ZHL-100W-52X	50-500	50	+47	+48.5	6.5	+57	24	9.0	1920.00

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Such a simple thing as high isolation coaxial crossovers, highly challenging to do at millimeter wavelengths, enables new products like miniature MxN switch matrices to be realized. In active antenna arrays, for example, electronically-scaned arrays (ESA), the unit cell needs to be smaller than half of a free-space wavelength squared. As the frequency increases to W-band, the wavelength and thus allowed real estate per element scales down faster than the size of the active elements (MMICs). PolyStrata multilayer technology enables design in the third dimension allowing more functionality for a given footprint. An example of a T/R module for an active array is shown in ***Figure 5*** with the 16-element antenna and all core electrical functionalities included within the profile of 0.64 square centimeters. Such cells could be used alone for tiny high-bandwidth data links or combined into large arrays and digitally steered.

For THz applications, such as radar, imaging and radiometry, coaxial lines become too lossy even if they are TEM, and waveguides become a better choice. For example, at the 0.67 THz minimum of the water-vapor absorption window, a dominant-mode rectangular waveguide is 350 × 160 μm in cross-section. Such RF and LO PolyStrata waveguides and waveguide components are compatible in size with PolyStrata IF micro-coaxial lines, allowing for integrated heterodyne terahertz receivers in the near future.

In conclusion, the new PolyStrata microfabrication technology promises to provide revolutionary improvements in size and performance for existing millimeter-wave systems and produce new components and systems formerly impossible to create. It has already enabled unprecedented improvements in component and system size and electrical performance at high frequencies. The micro-coaxial line technology has demonstrated low loss, low dispersion, low coupling and low parasitic radiation of batch fabricated integrated millimeter-wave components.

Inquiries regarding the technology can be addressed to David Sherrer (dsherrer@rohmhaas.com) or Jean-Marc Rollin (jrollin@rohmhaas.com) at Rohm and Haas Electronic Materials, 3150 State Street, Blacksburg, VA 24060, (540) 552-4610. ■

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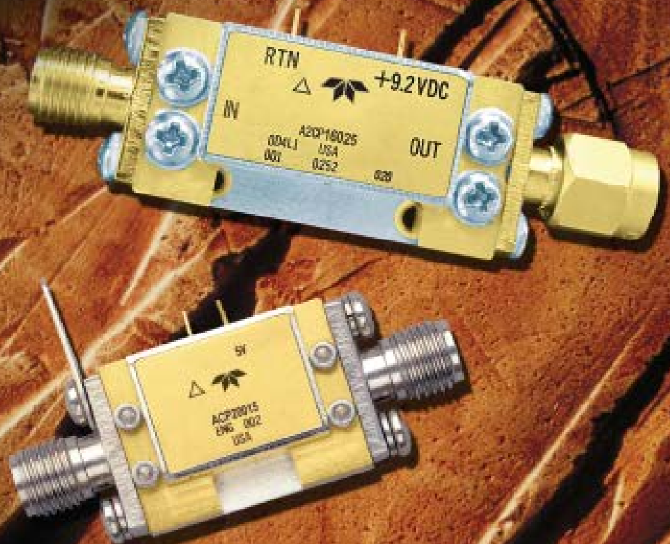

Model	Freq. Range (GHz)	Small Signal Gain (dB) Typ.	Noise Figure (dB) Typ.	Power Output at 1dB Comp. (dBm) Typ.	Intercept Point 3rd/2nd (dBm) Typ.	D.C. Volts Nom.	D.C. mA Typ.
A3CP7029	3.0-7.0	27.5	3.6	27.5	33.5/51	12	425
ACP8017	3.0-8.0	11.5	4.2	21.5	31/48	12	125
A2CP11039	5.0-11.0	12.0	4.0	33.0	42/57	15	1500
ACP12019	6.0-12.0	10.5	4.1	28.0	39/52	10	210
A2CP14639	6.0-14.0	11.0	4.0	33.0	42/57	15	1500
ACP16025	8.0-16.0	7.5	4.3	29.0	42/65	12	253
ACP18015	8.0-18.0	9.2	4.0	15.5	23/31	5	63
A2CP18225	10.0-18.0	15.0	4.5	25.5	35/44	12	325
ACP20015	2.0-20.0	10.0	4.5	16.0	26/29	5	76
ACP20215	2.0-20.0	20.0	4.8	18.0	28/45	5	156

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Zoya Popović *received her Dipl. Ing. degree from the University of Belgrade, Serbia, in 1985, and her PhD degree from Caltech in 1990. She is the Hudson Moore Jr. Chaired Professor of Electrical and Computer Engineering at the University of Colorado at Boulder. Her research interests include high-efficiency and low-noise microwave circuits, quasi-optical millimeter-wave techniques, smart and multi-beam antenna arrays, intelligent RF front ends, RF optics and wireless powering for batteryless sensors.*

Sébastien Rondineau *received his PhD degree from the University of Rennes 1, France, in 2002. He was a research fellow at the University of Colorado at Boulder from 2002 to 2006. Currently a research assistant professor at the Microwave and Active Antenna Laboratory, University of Colorado at Boulder, his research interests include the method of analytical regularization in computational electromagnetics, mode matching, conformal mapping, micro-scale interconnects, Butler matrices, propagation and scattering of waves, homogeneous and inhomogenous dielectric lenses, discrete lens arrays and antennas, dispersion-controlled 2D Rotman lenses, nonlinear polymers applied to rectification-modulation for laser, terahertz and microwave signals.*

Dejan S. Filipović *received his Dipl. Eng. degree in electrical engineering from the University of Nis, Serbia, in 1994, and his MSEE and PhD degrees from the University of Michigan, Ann Arbor, MI, in 1999 and 2002, respectively. From 1994 to 1997, he was a research assistant at the University of Nis. From 1997 to 2002, he was a graduate student at the University of Michigan. He is currently an assistant professor at the University of Colorado at Boulder. His research interests include the development of mm-wave components and systems, multiphysics modeling, antenna theory and design, as well as in computational and applied electromagnetics.*

David Sherrer *received his BS degrees in physics and philosophy in 1993 and his MS degree in electronic engineering 1996 from Virginia Tech. He founded ACT MicroDevices Inc. in 1996, which became Haleos Inc. in 2001. Haleos was acquired by Rohm and Haas in 2002 and he has served as the director of research and product development at what is now the Rohm and Haas Microfabrication Center in Blacksburg, VA for the past five years. His interests include product development and commercialization in the areas of advanced packaging, microdevices, microfabrication and advanced materials.*

Chris Nichols *received his BS degree in physics from Arkansas State University in 1990. In 1992, he received his MS degree in physics from The College of William and Mary. He received his PhD degree in applied science from The College of William and Mary in 1996, where his thesis work involved the engineering of a novel hyperthermal neutral stream etch process tool for charge-free wafer stripping.*

Jean-Marc Rollin *received his undergraduate degree in material science from Universite d'Orsay in 1998 and his PhD degree in physics from the University of Bath, UK, in 2005. He began his career in 1999 working on packaging and flip-chip assembly technology for high-speed optoelectronic devices at the Corning Research Center, France, from 1999 to 2002. In October 2002, he moved to the department of physics in Bath, UK, where he spent three years of research toward his doctorate, working on millimeter receivers for the British National Space Center. His research interests include the design and fabrication of III-V submillimeter-wave mixers and circuit development.*

Kenneth Vanhille *received his BS degree in electrical engineering from Utah State University in 2002, and his MS and PhD degrees in electrical engineering from the University of Colorado at Boulder in 2005 and 2007, respectively. He is currently a senior engineer with Rohm and Haas Electronic Materials, Blacksburg, VA. His technical interests include high-frequency packaging techniques, millimeter-wave components and systems, and antenna design.*

DESIGN OF A MICROWAVE GROUP DELAY TIME ADJUSTER AND ITS APPLICATION TO A FEEDFORWARD POWER AMPLIFIER

This article presents a design method for a microwave group delay time adjuster (GDTA) and its application to a feedforward (FFW) power amplifier (PA). The GDTA consists of a variable capacitor and a variable equivalent inductor. The variable equivalent inductor is realized using a high impedance transmission line terminated with a variable capacitor. These components are controlled by two separate bias voltages. The group delay time can be adjusted by varying the capacitance and inductance while keeping a fixed resonance frequency. The proposed GDTA is fabricated for the Korean RFID frequency band (908.5 to 914 MHz). A group delay time variation of approximately 3 ns is obtained with satisfying transmission flatness. When the proposed GDTA was applied to the base station FFW PA system, the loop group delay time matching was much easier and required less effort and time, while achieving an excellent linearization result compared to the conventional FFW PA system.

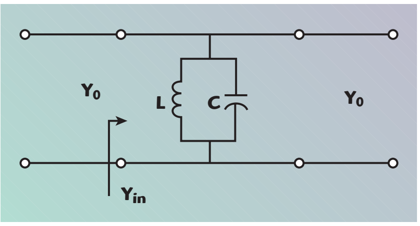
As linear modulation and demodulation is adopted in communication systems for spectrum efficiency, the system performance is limited due to nonlinearity, particularly in the power amplifier. The nonlinearity of a system can be explained as AM-AM, AM-PM, intermodulation distortion (IMD) and adjacent channel leakage ratio (ACLR). Several linearizing techniques have been introduced to overcome these nonlinearities.[1–3] When a digital/analog predistortion or a FFW technique is applied to the nonlinear system, a group delay time matching as well as amplitude and out-of-phase matching are critical. While a variable attenuator and a phase shifter are widely used for the magnitude and phase control, there are few circuits available for control of the group delay time.[4]

Moreover, a feedback receiving signal, originating from the transmitter (Tx) antenna of the same site, deteriorates the performance of

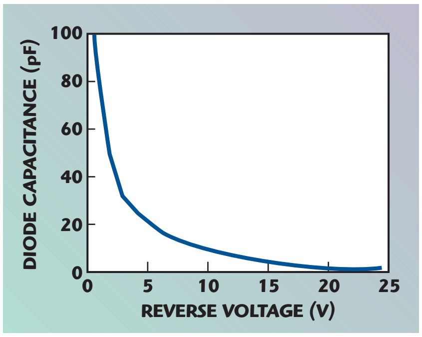
HEUNGJAE CHOI AND YONGCHAE JEONG
Chonbuk National University
Jeonju, Korea
J.S. KENNEY
Georgia Institute of Technology
Atlanta, GA
CHUL DONG KIM
Sewon Teletech Inc.
Kyungki, Korea

the received (Rx) signal and results in co-channel interference in the repeater system. The delay time of the co-channel interferer from Tx to Rx is different, case by case, and due to environmental conditions. The amplitude, phase and electrical delay time of the correction signal should be adjusted to effectively cancel the broadband interferer.[5,6]

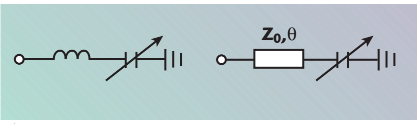
Until now, there have been few microwave circuit GDTAs. A GDTA, consisting of different paths having different physical length, was introduced.[7] However, it could not control the group delay continuously. In this article, a microwave GDTA is proposed that is capable of continuous group delay time control. The proposed GDTA is expected to play a key role in a number of applications where group delay time compensation is critical for broadband signal cancellation. To show its validity, a GDTA and base station FFW PA system were designed, fabricated and measured, using the proposed GDTA as an application example.



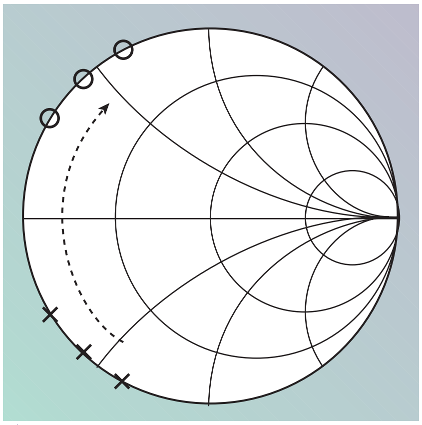
▲ *Fig. 1 Shunt resonant circuit.*



▲ *Fig. 2 Measured capacitance of the Sony 1T362 varactor diode.*



▲ *Fig. 3 A virtual variable inductor using a transmission line.*


▲ *Fig. 4 Transformation from a capacitive to an inductive characteristic.*

ADJUSTABLE GROUP DELAY THEORY

A group delay gives the measure of how long it takes a signal to propagate through a system. In general, the rate of change of the total phase shift with respect to angular frequency is called the group delay (GD), and is defined as[8]

$$GD = -\frac{d\phi}{d\omega} \qquad (1)$$

where

$d\phi$ = total phase shift
ω = angular frequency

Also, the group delay flatness in the operating frequency band is an important parameter for observing the phase linearity of a receiver system, transmitted signal and so on.

To find the method to control the group delay, it is necessary to analyze a shunt resonance circuit, as shown in ***Figure 1***. The input admittance of the resonance circuit is expressed as

$$Y_{in} = Y_0 + j\left(\omega C - \frac{1}{\omega L}\right) \qquad (2)$$

and the transmission characteristic can be expressed as

$$S_{21} = \frac{2Y_0}{\sqrt{4Y_0^2 + \left(\omega C - 1/\omega L\right)^2}} \exp\left(j\left(\tan^{-1}\frac{1-\omega^2 LC}{2\omega LY_0}\right)\right) \qquad (3)$$

If the particular resonance frequency, $\omega_0^2 LC = 1$ of the parallel resonator is maintained, the magnitude and the phase coefficient would be kept constant. Then GD, the differential phase component of the transmission coefficient with respect to the angular frequency, can be derived from Equation 4 at the particular resonance frequency, by using Equations 1 and 3.

$$GD = \left.\frac{2Y_0L\left(1+\omega^2 LC\right)}{4\omega^2L^2Y_0^2 + \left(1-\omega^2 LC\right)}\right|_{\omega_0^2 LC=1} = \frac{1}{\omega_0^2 Y_0 L} = CZ_0 \qquad (4)$$

From Equation 4, the group delay time increases proportionally to the capacitance. On the contrary, as the inductance increases, the group delay time decreases, proving the inverse proportionality to the inductance. Keeping the resonant frequency fixed, the group delay time can be adjusted by several combinations of a capacitance and an inductance.

IMPLEMENTATION AND MEASUREMENT OF THE GDTA

Varactor Diode Measurement

A varactor diode is a semiconductor device that is widely used in many applications where a variable capacitance is required. The operation of the varactor diode is based on the fact that a reverse biased PN junction acts as a variable capacitor. The diode capacitance versus reverse voltage of the Sony 1T362 device used has a variation of approximately 2.3 to 100 pF, as shown in ***Figure 2***.

Variable Equivalent Inductor and the GDTA Unit

There are few variable inductors in microwave devices. Even though there is an active inductor using a gyrator structure that can change the inductance, the quality factor (Q) is not high enough and changes according to the control voltage.[9,10] For that reason, the active inductor is not yet widely used. The series combination of a lumped inductor and varactor diode can be used as a variable equivalent inductor. Since it is difficult to fabricate high Q inductors with a small tolerance, however, the combination of varactor diode and lumped inductor is not suitable. A transmission line of characteristic impedance Z_0, terminated with a varactor, can also be used as a variable inductor, as shown in ***Figure 3***. A transmission line characteristic shifts from capacitive to inductive, as shown in ***Figure 4***. However, the

physical length of a transmission line is too long in case of a low operating frequency.

In this work, a high impedance transmission line, terminated with a varactor, is used to implement the variable inductor. ***Figure 5*** shows the lumped element equivalent circuit of the transmission line, where Z_t and θ are the characteristic impedance and electrical length of the tramission line, respectively. The values of the equivalent lumped elements are

$$L_t = \frac{Z_t \sin\theta}{\omega}, \quad C_t = \frac{1-\cos\theta}{Z_t \omega \sin\theta} \qquad (5)$$

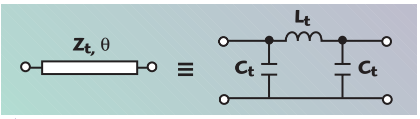


Fig. 5 A high impedance transmission line and its equivalent circuit.

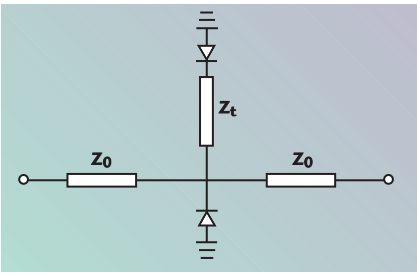


Fig. 6 The proposed GDTA unit.

Using the varactor diode and the proposed variable equivalent inductor, the GDTA unit shown in ***Figure 6*** was designed. The varactor diode is operated as the variable capacitor, and the high impedance transmission line terminated with the varactor diode is operated as the variable equivalent inductor.

The transformation procedure of the variable equivalent inductor is depicted in ***Figure 7***. The capacitor C_1 denotes the variable capacitance and C_2 is used for the variable equivalent inductor with the high impedance transmission line, respectively. The high impedance transmission line was replaced with the lumped element equivalent circuit. Since C_2 shares node A with C_t, and C_1 shares node B with C_t, these pairs of capacitors can be substituted with C' and C_2+ C_t. Finally, C_1+ C_t can be represented as C'' and the series connection of L_t and C' can be substituted with L'. Equation 6 shows the equivalent reactance of the transmission line terminated with the varactor diode. As long as the equivalent reactance (X_L) is positive, it has an inductive characteristic. Therefore, as C' is varied, a variable inductance can be obtained.

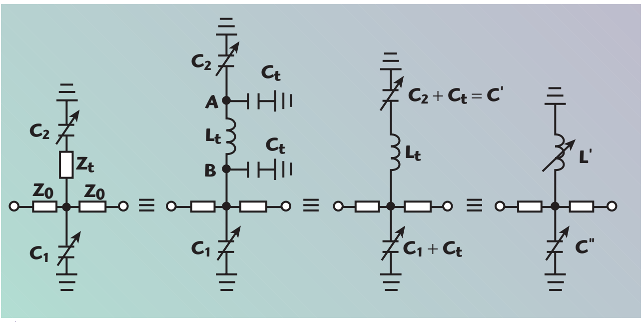


Fig. 7 Equivalent circuit of the unit GDTA using a high impedance transmission line.

$$X_L = \frac{\omega_0^2 L_t C' - 1}{\omega_0 C'} \qquad (6)$$

TABLE I

MEASURED RESULTS AT 911 MHz FOR THE UNIT GDTA

Group Delay (ns)	S_{21} (dB)	S_{11} (dB)
0.420	–0.23	–31.40
1.420	–0.77	–21.30
2.468	–1.45	–16.30
3.479	–2.20	–13.10

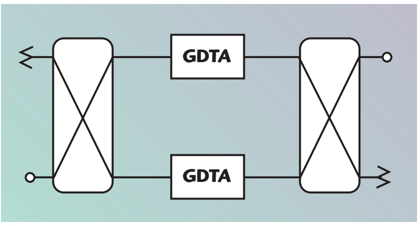


Fig. 8 Block diagram of the balanced GDTA using two unit GDTAs.

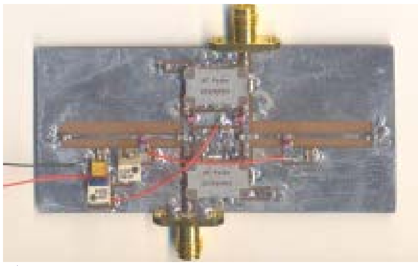
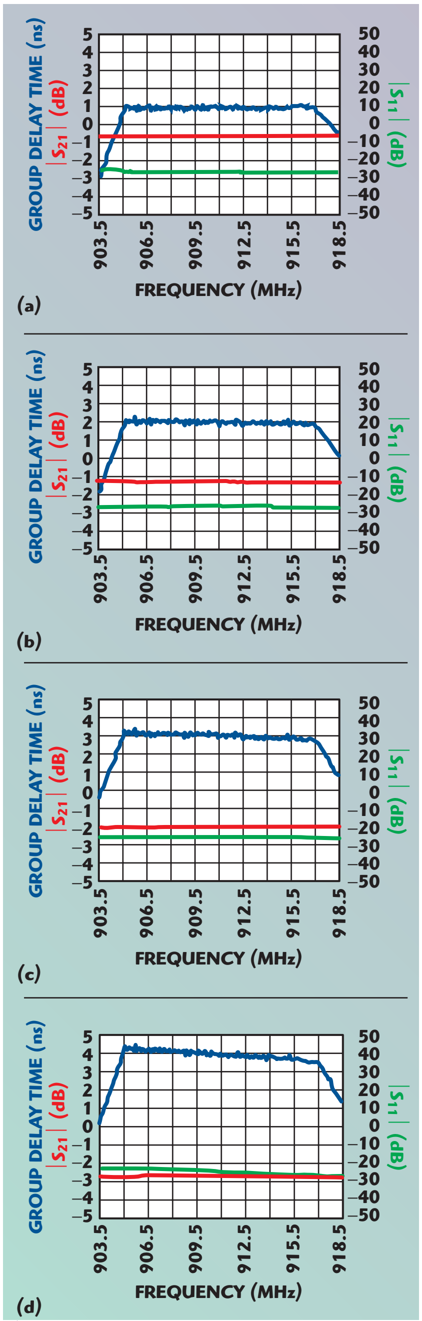


Fig. 9 The fabricated balanced GDTA.

TABLE II

MEASURED RESULTS FOR THE BALANCED GDTA

Group Delay (ns)			S_{21} (dB)			S_{11} Max (dB)	Control Voltage (V)	
908.5 MHz	911 MHz	914 MHz	908.5 MHz	911 MHz	914 MHz		V_C	V_L
1.005	1.041	1.025	–0.65	–0.64	–0.64	–25.65	25.0	0.0
2.000	2.010	1.970	–1.36	–1.37	–1.39	–26.74	10.0	14.4
3.051	3.077	2.986	–1.96	–1.95	–1.95	–24.84	8.3	17.5
4.021	3.938	3.792	–2.68	–2.68	–2.71	–24.41	7.0	19.8



▲ *Fig. 10 Electrical characteristics of the balanced GDTA at 1 ns (a), 2 ns (b), 3 ns (c) and 4 ns (d).*

The values of the variable capacitor and inductor are controlled by two separate bias voltages that must satisfy the fixed resonance condition. The measured results of the proposed GDTA unit, tested at 911 MHz, are shown in ***Table 1***. As GD is increased, the reflection characteristics are getting increasingly worse, due to the parasitic component of the varactor diode.

The Balanced GDTA

In order to obtain better reflection characteristics of the GDTA, a balanced GDTA structure is proposed and shown in ***Figure 8***. It is composed of two hybrid couplers (RF Power, S03A888N1) and two unit GDTAs. The overall circuit size is 79 × 39 mm, as shown in ***Figure 9***. The implemented GDTA was tested in the Korean RFID frequency band (908.5 to 914.0 MHz). The group delay measurements of the proposed balanced GDTA are shown in ***Table 2*** and ***Figure 10***.

Although a group delay time variance greater than 3 ns could be obtained, the transmission and the group delay time flatness in the high group delay time region are in a trade-off relationship, so that there was no choice but to limit the actual variation range to 3 ns. In that case, the magnitude flatness is less than 0.1 dB in the pass band and the maximum reflection coefficient is approximately –24.4 dB. These satisfactory results can be applied to systems where the group delay time matching with good flatness is critical.

BASE STATION FFW PA DESIGN USING THE PROPOSED GDTA

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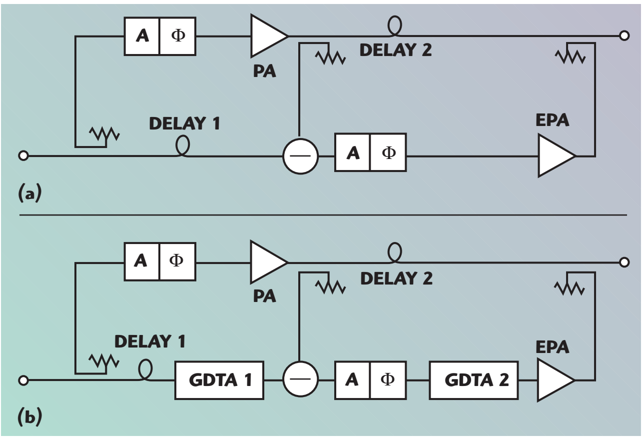
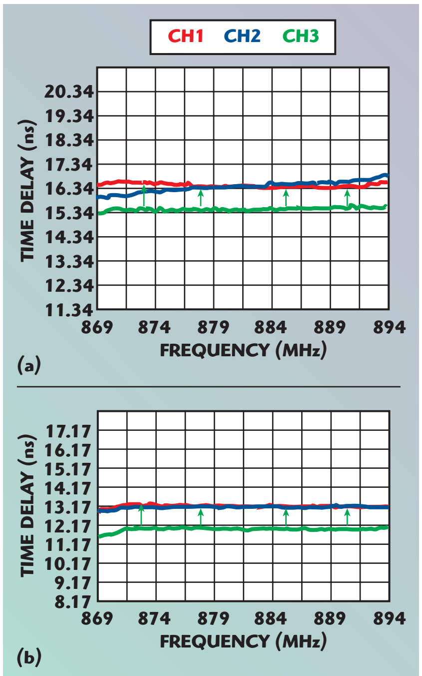


▲ *Fig. 11 Block diagrams of the conventional FFW PA (a) and the proposed FFW PA using GDTA (b).*



▲ *Fig. 12 Carrier cancellation loop group delay adjustment process (a) before GDTA tuning and (b) the IMD cancellation loop.*

essential, and must be matched simultaneously. Due to the fact that the conventional signal canceller cannot satisfy the out-of-phase and equal group delay matching at the same time inherently, an equal group delay signal canceller has been proposed.[11]

To prove the validity of the proposed GDTA, an FFW PA for the digital cellular band using a balanced GDTA and equal group delay signal canceller was implemented. The performance of the implemented linearization system with a commercial power amplifier of 120 W PEP for base station use was measured. ***Figure 11*** shows the block diagrams of the conventional FFW PA and of the proposed FFW PA using the GDTA and the equal group delay signal canceller. GDTA 1 is put between the delay 1 and signal canceller, and GDTA 2 is inserted in front of the error power amplifier (EPA). Usually, the group delay matching is a time-consuming process and requires much effort to obtain wideband signal cancellation. One of the several advantages of the GDTA is that the group delay time matching is much easier to achieve by just adjusting the control voltages.

Figure 12 shows the group delay time matching process of the carrier cancellation loop and IMD cancellation loop. After finishing the coarse tuning using a coaxial cable, the fine-tuning is done very easily with simple voltage controls. The blue lines are the amount of the time delay of the main and error amplifier path, and the green and red lines represent the time delay before and after the fine-tuning, respectively. The mismatch of the carrier cancellation loop is due to the poor group delay flatness of the main amplifier.

Figure 13 shows the signal cancellation loop suppression results, using the proposed GDTA, measured with a network analyzer. The proposed canceller cancels the input signal by more than 23 dB from 869 to 894 MHz. The IMD cancellation characteristic using the proposed GDTA is also shown. The input signal is cancelled by more than 30 dB within 880 ±50 MHz. The frequency bandwidth, in which the signal is cancelled more than 20 dB, is greater than 160 MHz.

For experimental verification, the output power spectral density of the FFW PA was measured with and without the FFW loop, using a forward-link CDMA IS-95A four-carrier signal for the digital cellular band. These measurement results are shown in ***Figure 14***. The ACLRs at 3.125 and 4.375 MHz offset are shown through the output dynamic range, and the measured power spectral density of the implemented FFW PA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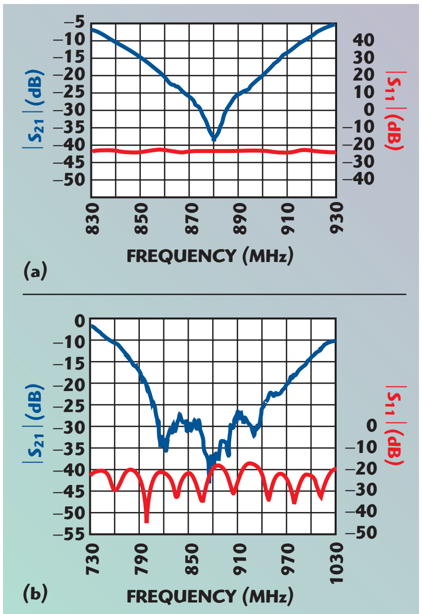
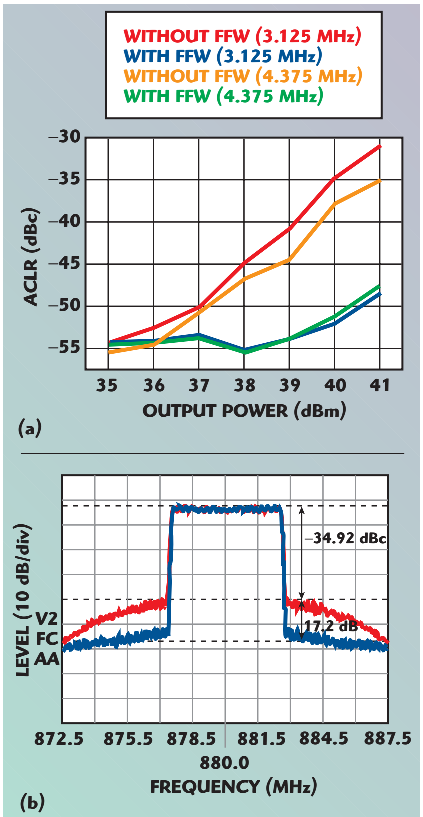
at an average output power of 40 dBm is shown before and after cancellation. The ACLR at a 3.125 MHz offset is –52.12 dBc, improved by approximately 17.2 dB by the cancellation. The amount of improvement is smaller than expected from the results shown on the network analyzer because of the limitation of the measurement setup. The proposed system shows excellent linearity throughout the output dynamic range.

CONCLUSION

A new GDTA unit was designed that can control the group delay time of a signal using a parallel resonance circuit. Keeping the resonance frequency fixed, the group delay time can be adjusted by the combination of values of capacitance and inductance through a simple voltage control. The fabricated balanced GDTA improves the poor reflection characteristics of the single GDTA unit and offers a group delay time variation of approximately 3 ns. Also, the validity of the proposed GDTA was established by applying the circuit to a feedforward linearization. The pro-



▲ *Fig. 13 Carrier cancellation loop suppression of the FFW PA using the GDTA (a) and IMD cancellation loop (b).*



▲ *Fig. 14 Measured ACLR characteristics over the dynamic range (a) and power spectral density of the FFW PA using GDTA (b), with and without the FFW loop.*

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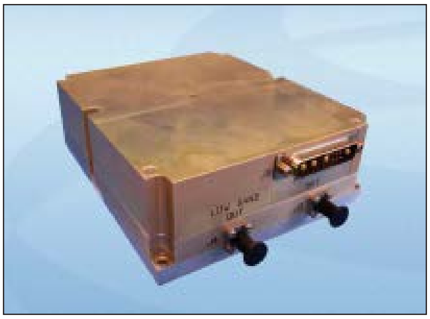

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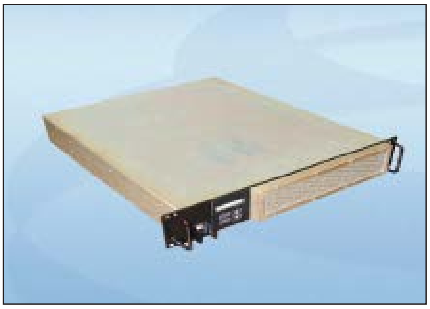

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posed GDTA will contribute not only to the improvement of the quality of a communication, but also to the simplification of the group delay time tuning procedure of a communication system. ■

ACKNOWLEDGMENT

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Heungjae Choi *received his BS and MS degrees in electronic engineering from Chonbuk National University, Jeonju, Korea, in 2004 and 2006, respectively. He is currently working toward his PhD degree. His research interests include broadband linearization and high-efficiency RF PAs.*

Yongchae Jeong *received his BS, MS and PhD degrees in electronic engineering from Sogang University, Seoul, Korea, in 1989, 1991 and 1996, respectively. From 1991 to 1998, he was a senior engineer in the information and communication division of Samsung Electronics. Since 1998, he has been in the division of electronics and information engineering at the Integrated Circuit Design Education Center of Chonbuk National University, Jeonju, Korea. He is currently an associate professor teaching and conducting research in the areas of microwave devices, base station amplifiers, linearization technology and RFIC design.*

J. Stevenson Kenney *received his BSEE, MSEE and PhD degrees in electrical engineering from the Georgia Institute of Technology in 1985, 1990 and 1994, respectively. He has over 14 years of industrial experience in wireless communications. He has held engineering and management positions at Electromagnetic Sciences, Scientific Atlanta, Pacific Monolithics and Spectrian. In January 2000, he returned to Georgia Tech as an associate professor in electrical and computer engineering. His research interests include acoustics, microsystems and microwave design.*

Chul Dong Kim *received his BS degree in electronic engineering from Seoul National University, Seoul, Korea, in 1971, and his PhD degree from the University of Wisconsin, Madison, in 1985. He is currently president and chief executive officer (CEO) of Sewon Teletec Inc., Kyungki, Korea, a company specializing in RF PAs.*

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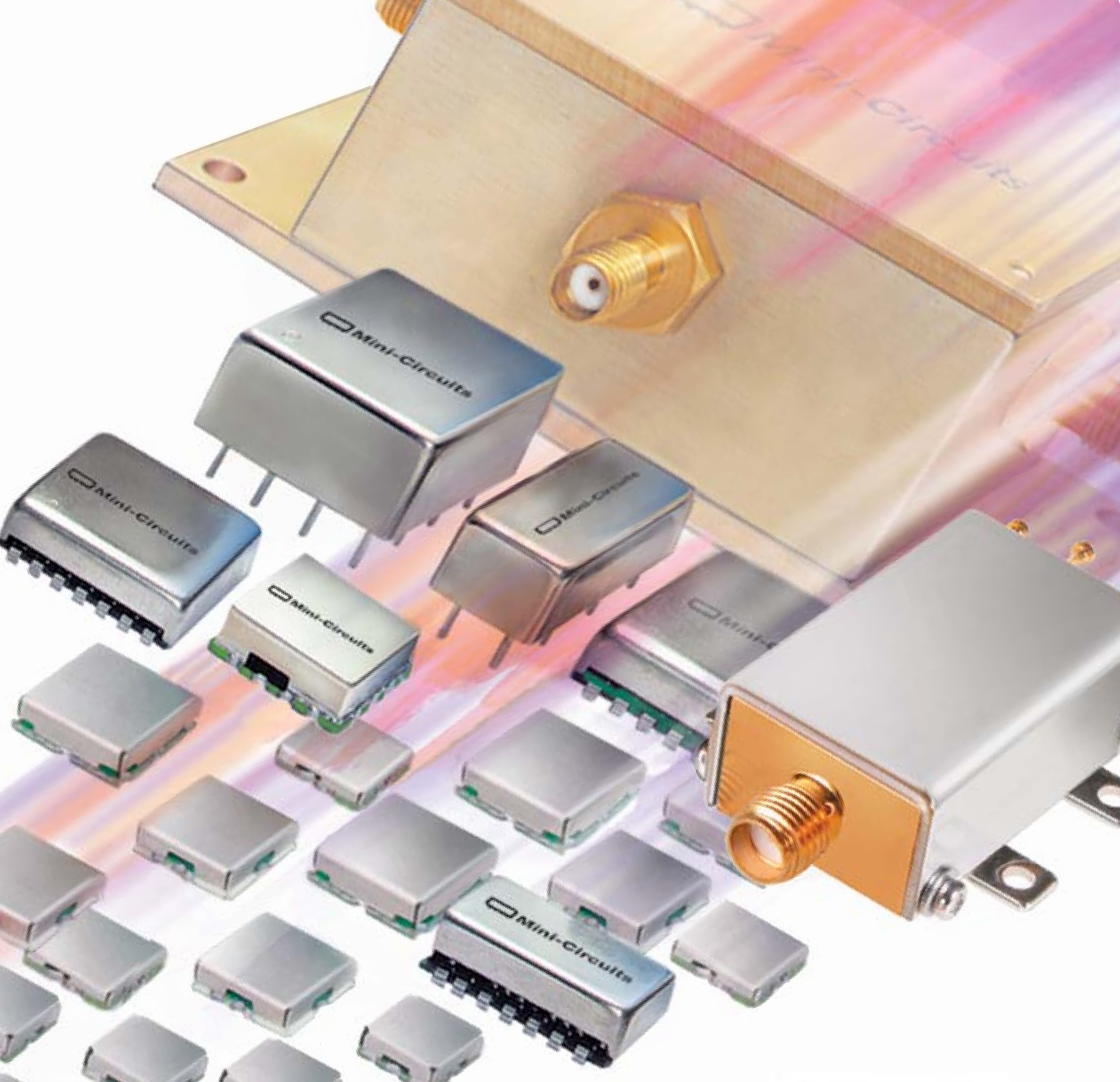
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HIGH EFFICIENCY BROADBAND POWER AMPLIFIERS

This article is devoted to the design of broadband high efficiency power amplifiers for microwave and RF applications through the synthesis of the load impedance (or load admittance) required by power transistors at fundamental and harmonic frequencies to operate into a specific amplification class. Broadband design of the most popular high efficiency amplification classes is covered, even though the design technique shown in this article can be applied to any amplification class. It is shown that the load requirements of some amplification classes cannot be easily satisfied over wide bandwidths because of the parasitic effects exhibited by transistors operating at high frequencies. This fact indicates that some amplification classes are more suitable for broadband operation than others at high frequencies. Design, simulation and measurements of a broadband class-E power amplifier prototype are shown to verify the usefulness and accuracy of the methods and techniques described.

The technical definition of an amplification class is not obvious. Patents are among the best documents to explain and define what an amplification class is.[1,2] Reviewing the claims sections of those documents is an interesting exercise in understanding the inherent complexity of an amplification class definition.

From a simplified point of view, an amplification class can be defined by a set of electric conditions that must be fulfilled simultaneously at the output of a transistor. Usually, these electric conditions are a set of current and voltage waveforms in the time domain or their counterpart set of load impedances/admittances at fundamental and harmonic frequencies, obtained as the quotient of the Fourier series voltage and current components. A proper load, with simultaneous proper driving, leads transistors towards any specific amplification class. This definition of amplification class, based on spectral load-pull analysis, is especially useful at high frequencies because many of the design techniques used at these frequencies, measurement procedures, etc., rely on the power of spectral analysis.

Table 1 shows the load impedance or admittance required by a single-ended ideal transistor at the fundamental and harmonic frequencies when operating in the most popular amplification classes. The load impedances and admittances shown were obtained as the quotient of the Fourier components of a tran-

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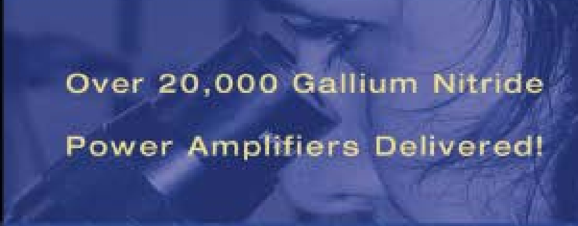

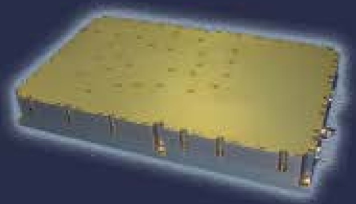

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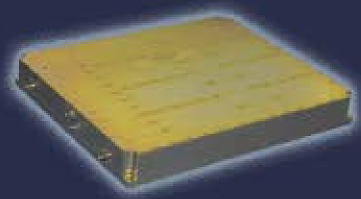

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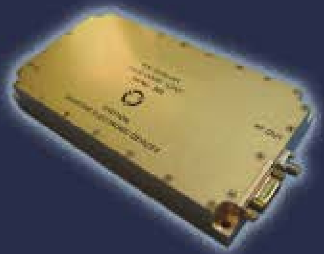

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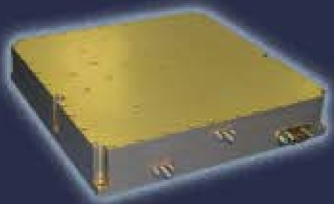

SSPA 0.8-2.5-200
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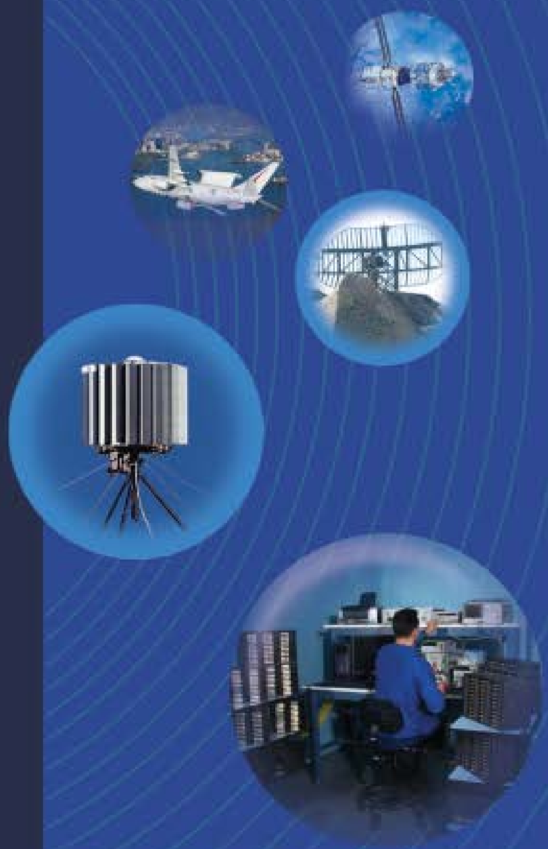

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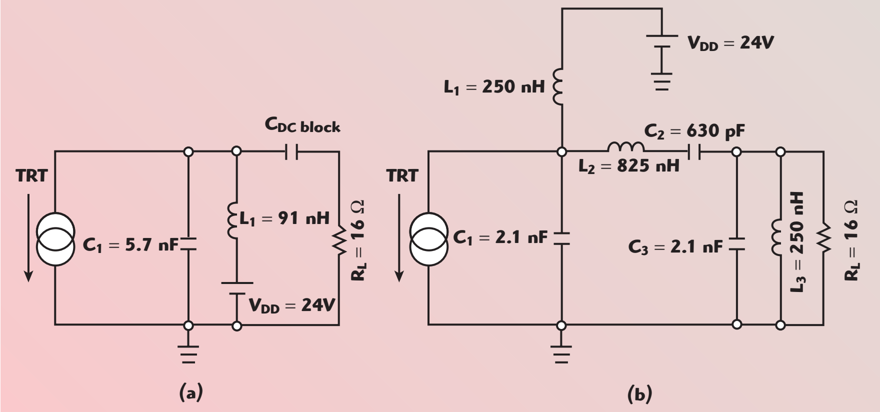
TABLE I
IMPEDANCE AND ADMITTANCE LOADS REQUIRED FOR USUAL AMPLIFICATION CLASSES

	Load Impedance (Z_L) at Harmonic n: 1, 2, 3...			Load Admittance (Y_L) at Harmonic n: 1, 2, 3...		
Class	f_o	$(2n)f_o$	$(2n+1)f_o$	f_o	$(2n)f_o$	$(2n+1)f_o$
B,C				resistive	short-circuit	short-circuit
D, voltage switching	resistive	short-circuit	open-circuit			
D, current switching				resistive	open-circuit	short-circuit
E				complex: resistive + capacitive	imaginary: capacitive	imaginary: capacitive



▲ *Fig. 1 Narrow (a) and broadband (b) class-B amplifier topologies.*

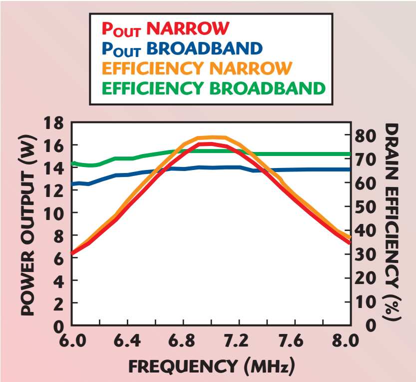
sistor's output voltage and current waveforms. The transistor is considered ideal and lossless (pure current source or switches).

BROADBAND RF HIGH EFFICIENCY POWER AMPLIFIER DESIGN

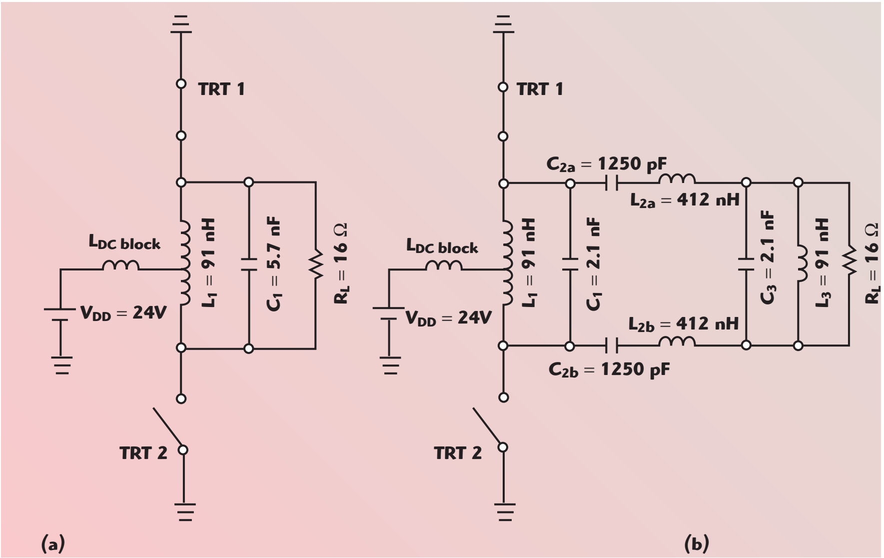
The following few steps describe a straightforward way to design broadband power amplifiers, high efficiency or not, based on load synthesis theory:

- From the desired output power P_{OUT} and power supply DC voltage V_{DC}, determine the load impedance or admittance required by the transistor operating into the selected amplification class. The values given in the table help to predict the load's frequency profile. The maximum transistor's values of voltage and current impose a limit for power supply DC voltage and output power P_{OUT}.
- Design a network to provide the load calculated in step 1 over the whole desired bandwidth. The required load must be provided both at the fundamental and harmonic frequencies, at least the second and third.[3]
- Provide the proper driving waveform (energy in time) required by the transistor to exercise the output voltage and current waveforms inherent of the desired amplification class. High efficiency amplification classes usually require transistor switching and therefore these classes, such as classes D or E, demand more sophisticated driving circuits than conventional classes (A to C) because more energy must be delivered to the transistor input (gate or base) in a shorter time.

The next few sections will explain how to design broadband power amplifiers operating in some of the most popular RF amplification classes: B, C, D and E, although the described design strategy can be applied to any amplification class.



▲ *Fig. 2 Maximum output power and drain efficiency for class-B amplifiers.*



▲ *Fig. 3 Current switching class-D amplifiers; (a) narrowband and (b) broadband.*

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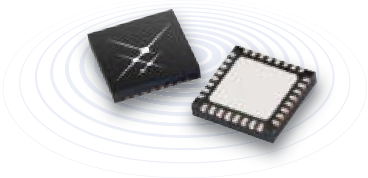

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BROADBAND CLASS-B POWER AMPLIFIER

The admittance required by classes B and C is resistive at the fundamental frequency and short circuits at the harmonics. These load conditions (compatible with class-A) can be easily accomplished when using RF transistors, because their output capacitance C_{OUT} can be embedded into the output load network contributing to the generation of the required short-circuit condition at harmonics.

Usually, communication electronics textbooks[4] have used parallel tuned R-L-C tank circuits across the transistor output to illustrate class-B and -C circuits. When those circuits are tuned at the fundamental frequency amplified by the circuit and their quality factors are high, they provide the required load conditions for class-B and -C operation, generating typical class-B and class-C voltage and current waveforms if the transistors are properly driven. Unfortunately, the high quality factor required for the parallel load networks (needed to achieve a sufficient strong short-circuit condition at the second and third harmonics) contribute to narrow the amplifiers' bandwidth.

Figure 1 shows class-B (or -C) amplifiers using classical R-L-C circuits shown in textbooks. ***Figure 2*** shows the simulated output powers P_{OUT} and drain efficiencies η_d of the class-B amplifiers. This load network has a loaded quality factor Q = 4 at 7 MHz. All the circuit elements are considered ideal, linear and lossless.

A broadband class-B amplifier design requires a load circuit providing the same admittance profile provided by the narrowband version, but obviously over a wider bandwidth. One of the circuits capable of providing such load admittance is a bandpass filter with a shunt first element. If a strong attenuation at the stop band is provided, a strong short-circuit condition at the harmonics is provided also. The bandpass of the filter must coincide with the desired amplification band while the suppressed band must coincide with its harmonics. This circuit is shown in the figure. Usually filter orders higher than three (six lumped elements) are not suitable for RF and MW amplifiers because the element losses and finite Q reduce the efficiency of the amplifier. This fact limits the design flexibility and broadband performance forcing the designer to accept some tradeoffs, including ripple in the bandwidth or amplification class purity, for example. The broadband load network shown is intended for a class-B (or -C) amplifier designed on the basis of a Chebishev bandpass filter, blending a wide bandwidth, low ripple over its bandpass and strong suppression of harmonics (which means low impedance at harmonics). All the circuit elements are ideal and lossless. A remarkable power and efficiency bandwidth improvement over the narrowband circuit is observed.

The uniform harmonic requirement of classes B and C (short circuit) is quite compatible with the loading effect of the transistor's intrinsic output capacitance C_{OUT}. Therefore, broadband operation of class-B amplifiers is not uncommon

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and there are examples of class-B push-pull designs in literature exhibiting multi-octave bandwidths.[5] Amplifiers intended for 50 Ω systems usually require impedance transforming networks to provide the required resistive load to the amplifier. In broadband design, broadband impedance transforming networks are required also; these transforming networks must be capable of transforming at least one or two harmonics besides the fundamental. There are two usual solutions for this problem:

- Using broadband transformers usually based on transmission lines.
- Using broadband impedance transforming networks based on lumped elements or transmission lines.

These impedance-transforming networks can also be used to include the loading functions described in the broadband RF high efficiency power amplifier design section. Unfortunately, the bandwidth of a network combining transforming and loading functions is smaller than the bandwidth of a load network without transforming duties for the same number of elements.

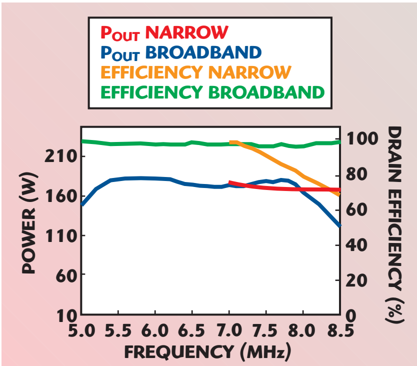
HIGH EFFICIENCY BROADBAND AMPLIFIERS

Among high efficiency amplification classes, those based on transistor switching, such as classes D and E, are known for their extremely high efficiency, theoretically 100 percent. Their popularity in the RF and MW world is increasing, but still some misunderstanding about these amplification classes exist; for instance, some engineers still think that narrowband is a requisite of high efficiency amplification. Nevertheless, high efficiency wideband switching amplification design is possible using the techniques shown previously.

Class-D

Two versions of the class-D amplifier[6] are widely known: current switching and voltage switching (voltage switching class-D is sometimes confused with class-F).

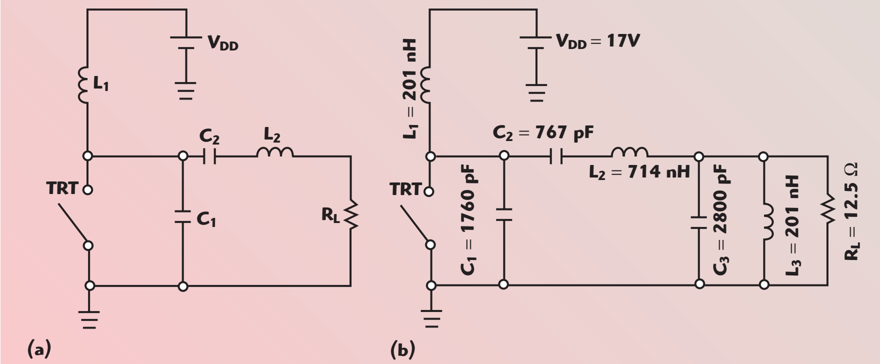
As shown in the table, a transistor requires alternate harmonic load behaviour to operate into class-D: open circuits at $(2n+1)f_0$, short circuits at $(2n)f_0$ for voltage switching class-D, short circuits at $(2n+1)f_0$ and open circuits at $(2n)f_0$ harmonics for switching current class-D. This nonuniform harmonic load cannot be provided easily to a transistor operating at high frequencies for different reasons. The low reactance exhibited by the transistor's intrinsic output capacitance C_{OUT} is one of them. The load requirements of class-D make it difficult to absorb C_{OUT} into the amplifier load network,



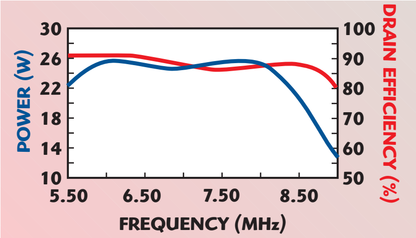
▲ *Fig. 4 Maximum output power and drain efficiency for current switching amplifiers.*

especially in the switching voltage mode. This is one of the causes that contribute to preclude class-D at high frequencies.

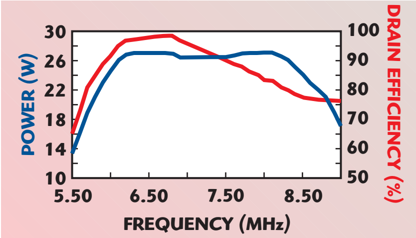
The alternate frequency dependance nature of the load impedance required for class-D cannot be easily provided by a single-ended wideband load network design, even though some solutions exist. Unlike single-ended transistors, push-pull transistor pairs require uniform load impedance distribution over frequency from drain to drain (drain-to-source load requirements are the same as for the single-ended version) to operate into class-D and this is the reason why class-D amplifiers are usually shown as push-pull designs in classical textbooks.[4] The most usual textbook load circuits capable of providing switching current class-D amplification are shown in ***Figure 3***.



▲ *Fig. 5 Classical (narrowband) (a) and broadband (b) class-E amplifiers.*



▲ *Fig. 6 Simulated output power and drain efficiency of a broadband class-E amplifier.*



▲ *Fig. 7 Measured output power and drain efficiency of a broadband class-E amplifier.*

The operation of a nominal switching current class-D requires a quality factor Q approximately greater than four for the parallel tank L_1-C_1-R_1 of the load network, in order to provide proper termination at the harmonics. Unfortunately, high values of Q also contribute to reduce the bandwidth of the amplifier. Decreasing Q is not a solution to improve amplification bandwidth because low Q leads to amplification class degeneration caused by improper loading at harmonics.

It is possible to design broadband switching class-D amplifiers using the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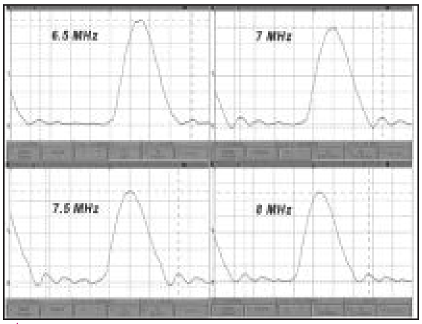
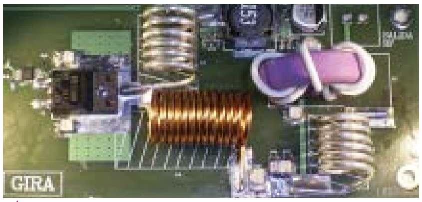
design techniques shown previously. The application of the described technique is quite easy for push-pull designs using ideal transistors ($C_{OUT} = 0$) because a uniform load at the harmonics is required from drain to drain. Unfortunately, the intrinsic transistor capacitance C_{OUT} located across the real transistor's drain and source tends to lower the impedance load at the harmonics, degrading the open-circuit condition required by voltage switching class-D at $(2n+1)f_0$ harmonics and current switching class-D at $(2n)f_0$. However, current switching class-D is a better candidate for high frequency broadband operation than the switching voltage version of class-D, because the C_{OUT} effect over mode degradation is less evident.



▲ *Fig. 8 Measured V_{ds} waveforms at different frequencies.*

A bandpass filter with a shunt capacitor as a first element can provide the load conditions required by an ideal push-pull transistor pair to operate into wideband current switching class-D, because the load impedance profile requirements of the pair are the same as the conditions required to operate into class-B (the driving requirements are completely different). The load circuit shown for broadband has been designed this way using a third-order Chebishev bandpass filter (ripple=0.01 dB). ***Figure 4*** shows the output power P_{out} and drain efficiency η_d obtained by simulation using the circuits shown and an ideal push-pull switching transistor pair.



▲ *Fig. 9 A wideband class-E amplifier prototype.*

Class-E

Class-E[7] exhibits important advantages that favor this high efficiency amplification class at high frequencies. Its advantages do not only arise because the transistor is driven into the ON condition when the drain-to-source voltage is zero (ZVS condition), but also because the derivative of the drain-to-source voltage is zero at the OFF to ON switching instant (optimum class-E operation). This feature allows absorbing undesired switching effects always found in high frequency transistors to some degree, besides providing some tolerance against load deviations from its optimum value. On the other hand, the maximum output power capability P_{MAX} of class-E is not as high as the P_{MAX} achieved by other high efficiency classes such as class-D (this statement is only valid for most known first order class-E amplifiers).

The load admittance conditions required by a switching transistor to op-

erate into class-E were shown in the table. The original and best-known load networks capable of providing class-E are shown in ***Figure 5***. When properly designed,[8] this load network provides an exact class-E operation over a bandwidth valid for power conversion applications but sometimes not sufficient for communications applications. Reduction of the quality factor (Q) of this network is not a solution to increase the bandwidth of a class-E amplifier, not only because lowering Q decreases spectral purity of the amplified signal but also because the power versus frequency profile is not flat.

The load admittance required by a class-E amplifier, as shown in the table, is complex at the fundamental and capacitive at the harmonics as explained previously,[9] not requiring alternating from capacitive to inductive behaviour at harmonics as in class-D. Therefore, the load frequency response of the load networks required for broadband class-E amplification is not so different than the responses described in previous sections for broadband class-B or -C. A suitable load network for broadband class-E operation could be derived from these load networks after some modifications in order to provide the complex load at the fundamental and the required capacitive load value at harmonics.

The figure shows a load network based on lumped elements that provides broadband operation for the class-E amplifier. It is derived from a bandpass filter with a first element shunt.[9] This load network provides a complex load admittance at the fundamental and pure capacitive load admittance at harmonics over a broad bandwidth. The network is made of lumped elements but could be synthesized by any other technique suitable for a specific application, such as transmission lines, if the required load profile is provided. The component values shown in this figure were calculated for a specific amplifier that will be described later and obviously must be calculated in any other case.

Figure 6 shows the simulated output power and efficiency versus frequency obtained with HEPA Plus[10] for the wideband class-E amplifier, using real components. The quality factor of the passive components is estimated to be Q = 125 for the inductances and Q = 1000 for the capacitors. The value of C_1 has been decreased to accommodate the C_{OSS} of the transistor (International Rectifier IRLI530G), and the values of C_3 and L_3 have been slightly modified to absorb the imaginary impedance component of the ferrite loaded Ruthroff transmission line transformer used in the amplifier. It is important to note that, in wideband designs, the effects of components must be taken into account not only at the fundamental but also at least at the two first harmonics ($2f_0$ and $3f_0$).

The actual measurements of output power P_{OUT} and drain efficiency of this amplifier are shown in ***Figure 7***. The differences in output power and efficiency between measurements and simulations can be related to the losses in the transformer and printed circuit board besides imperfect component models and driving circuit. A slight frequency shift is also

observed between the measured and simulated results, which is related to the proximity to the resonance frequency in some passive components that changes their low frequency value. The amplifier's transistor drain-to-source waveforms were measured with a digital oscilloscope and are shown in ***Figure 8***. These measurements show quasi-nominal class-E operation over the whole operating bandwidth of the amplifier.

Figure 9 shows a photograph of an amplifier embedded in an experimental HF EER communications transmitter. The high-Q air core silver-plated coils, high-Q porcelain capacitors and the 4:1 impedance Ruthroff transmission line transformer that converts the 50 Ω load into the 12.5 Ω required by the amplifier load network are clearly shown in the photograph besides the power transistor that requires only a copper polygon pad on the PCB to dissipate heat.

CONCLUSION

This work has shown that designing broadband high efficiency power amplifiers is possible using load-pull design techniques and synthesis of broadband load networks. This article is focused on the most popular high efficiency classes (D and E besides non high efficiency class-B), but the design principles explained here can be extended to the design of any broadband amplifier operating in any amplification class. Several simulations and measurements taken on a broadband class-E prototype have been shown to illustrate the effectiveness of this design technique.

The design methods shown in this article are devoted to the transistor output network, but the proper design of broadband high efficiency power amplifiers also requires efficient broadband drivers. This is not a trivial problem, especially at high frequencies and microwaves, and deserves further research. ■

ACKNOWLEDGMENT

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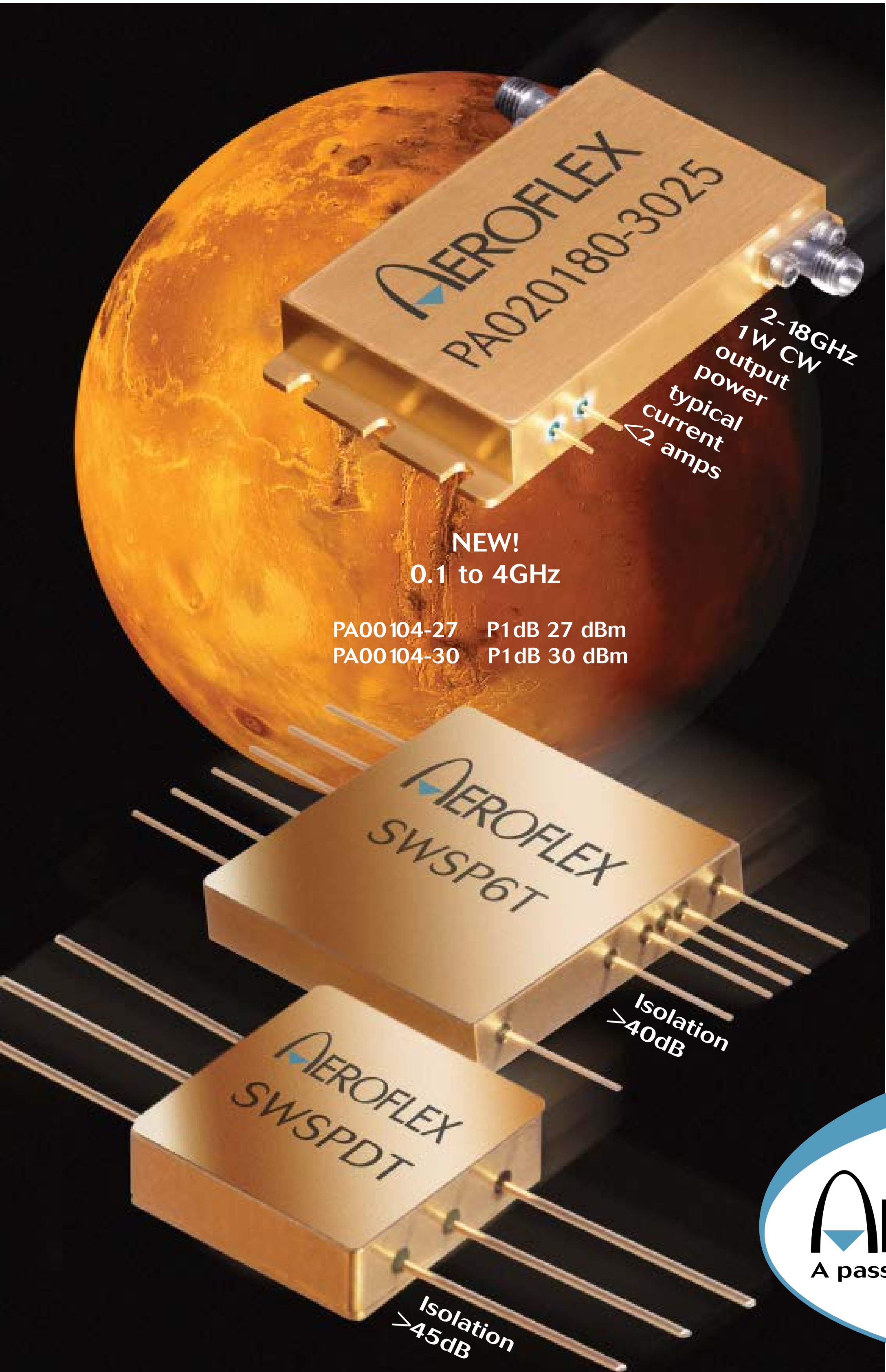

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DESIGN OF A CPW-FED PRINTED ANTENNA FOR ULTRA-WIDEBAND APPLICATIONS

This article describes a compact and simple coplanar waveguide monopole antenna for ultra-wideband (UWB) applications. The overall size of the printed antenna is 26 × 35 × 1.6 mm, which is very compact, low profile and can be integrated in an ultra-wideband transceiver for further integration. The wideband performance is achieved by properly choosing the dimensions of the rectangle-semicircle-rectangle shape of the antenna. The design of the proposed antenna is suitable for ultra-wideband applications, which covers the 3.1 to 10.6 GHz band. The printed coplanar waveguide antenna is fed by a 50 Ω microstrip line, with a small rectangle for broadband operation. For a –10 dB return loss, the operating bandwidth of the antenna is 3.1 to 11 GHz. The antenna gain varies from 1.47 to 5.02 dBi. Both impedance and radiation characteristics of this antenna are studied. The proposed antenna has a very simple geometrical structure and proves to be a good candidate for ultra-wideband applications.

In recent years, wireless communications have progressed very rapidly. Broadband antenna design has become very important for wireless applications. UWB is a high data-rate and short-range wireless technology, utilizing the unlicensed radio spectrum from 3.1 to 10.6 GHz. The UWB antenna is one of the major components of UWB communication systems. Some coplanar waveguide (CPW) antennas have been proposed for wideband application.[1–10] The UWB-based systems may be embedded into a variety of portable devices. One of the critical issues in UWB system design is the size of the antenna for portable devices because the size greatly affects the bandwidth and gain. Therefore, the miniaturization of antennas capable of providing a broad impedance matching bandwidth and offering an acceptable gain is a challenging task.[2] The UWB antenna plays a unique role because it behaves as a bandpass filter and should be designed to avoid undesired distortions. Some of the critical requirements of a UWB antenna design include: ultra-wide bandwidth, omnidirectional radiation patterns, constant gain and group delay over the entire band, high radiation efficiency and low profile. The broadband property and excellent impedance matching of the proposed design lead to desirable performance, such as good antenna gain and radiation patterns. (A planar elliptical monopole antenna for UWB applications was proposed earlier.[3]) In this article, a small-size

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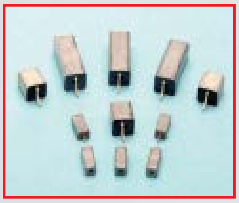

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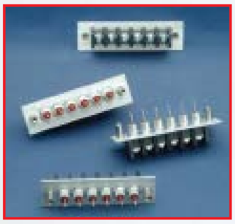

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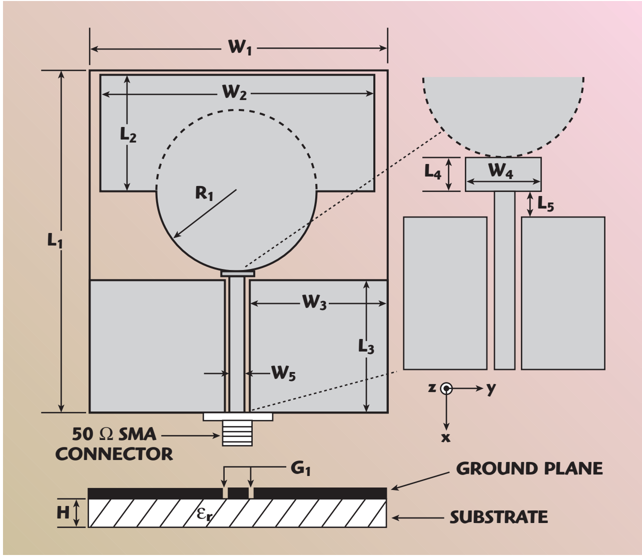
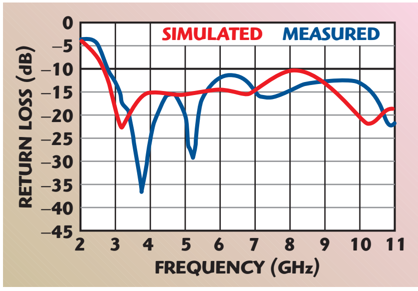


▲ *Fig. 1 Geometry of the printed CPW-fed UWB antenna.*

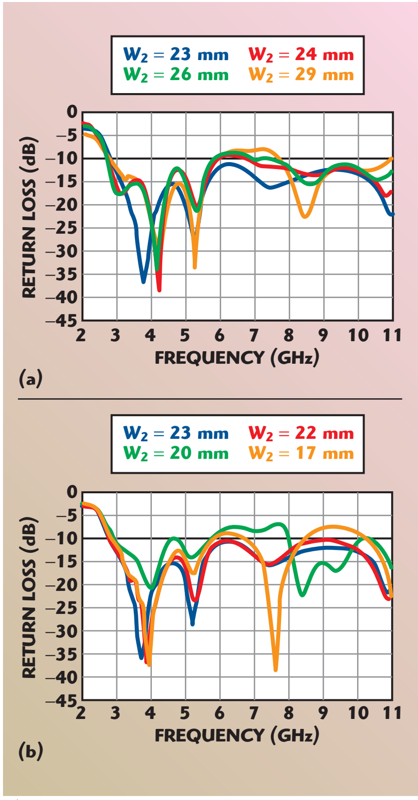
antenna with a CPW feed line for UWB systems is presented. Compared to the planar elliptical monopole antenna, this antenna can produce satisfactory results, such as better gain and good radiation. In this study, a small-size and a good impedance matching of the antenna are obtained and the good radiation characteristics of the constructed prototype are also shown. It is designed to cover the 3.1 to 10.6 GHz UWB band. The planar rectangle-semicircle-rectangle antenna is etched onto an FR-4 substrate. It is expected that a simple feed and a wide impedance bandwidth are good for practical applications. The simulations and measurement results show that the impedance characteristics of this antenna reduced the ground-plane effect on the performance of a small printed UWB antenna. The performance of the antennas was tested in the frequency domain.

TABLE I
CPW-FED UWB ANTENNA DIMENSIONS

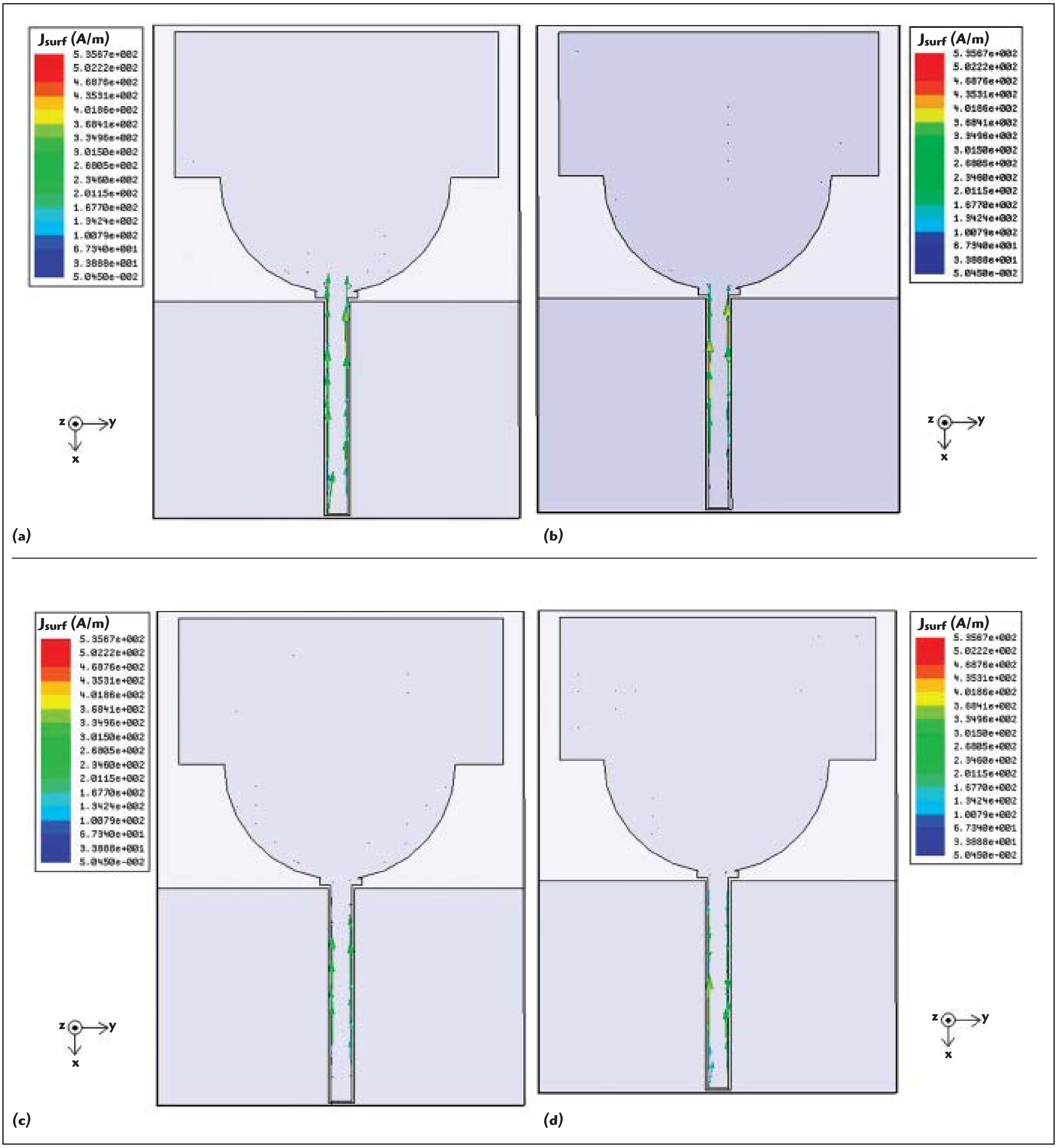
Antenna Parameter	Units (mm)
L_1	35
L_2	10.3
L_3	15.4
L_4	0.5
L_5	0.2
W_1	26
W_2	23
W_3	12.07
W_4	3
W_5	1.5
G_1	0.18
R_1	8.2
H	1.6
ε_r	4.4



▲ *Fig. 2 Measured and simulated return loss of the proposed antenna.*



▲ *Fig. 3 Measured return loss for different W_2 dimensions; (a) $W_2 > W_2$ nominal and (b) $W_2 < W_2$ nominal.*



▲ *Fig. 4 Normalized current distributions at (a) 3.1, (b) 5.5, (c) 7.5 and (d) 10.6 GHz.*

ANTENNA DESIGN AND EXPERIMENTAL RESULTS

Figure 1 shows the geometry of the proposed UWB antenna and ***Table 1*** lists the antenna dimensions. The rectangle-semicircle-rectangle shape shown is the radiator of the proposed design. The rectangle of dimension $W_2 \times L_2$ is located on top of the radiator; the small rectangle of dimension $W_4 \times L_4$ is located at the bottom of the radiator. A semicircle of radius R_1 is inserted between the rectangles to form the radiator. Two small rectangle metal patches ($W_3 \times L_3$) on the sides of the antenna serve as capacitive loads. Capacitive loading reduces the input impedance variation with frequency of the antenna. The capacitance can be adjusted by varying the distance between the rectangle patches and the main part of the antenna. The radiator and ground plane were etched on the FR-4 substrate (ε_r = 4.4 and 1.6 mm thick). The overall size of the antenna and ground plane is 26 × 35 mm ($W_1 \times L_1$) and 12.07 × 15.4 mm ($W_3 \times L_3$). The antenna is excited by a 50 Ω CPW feed line. The width of the cen-

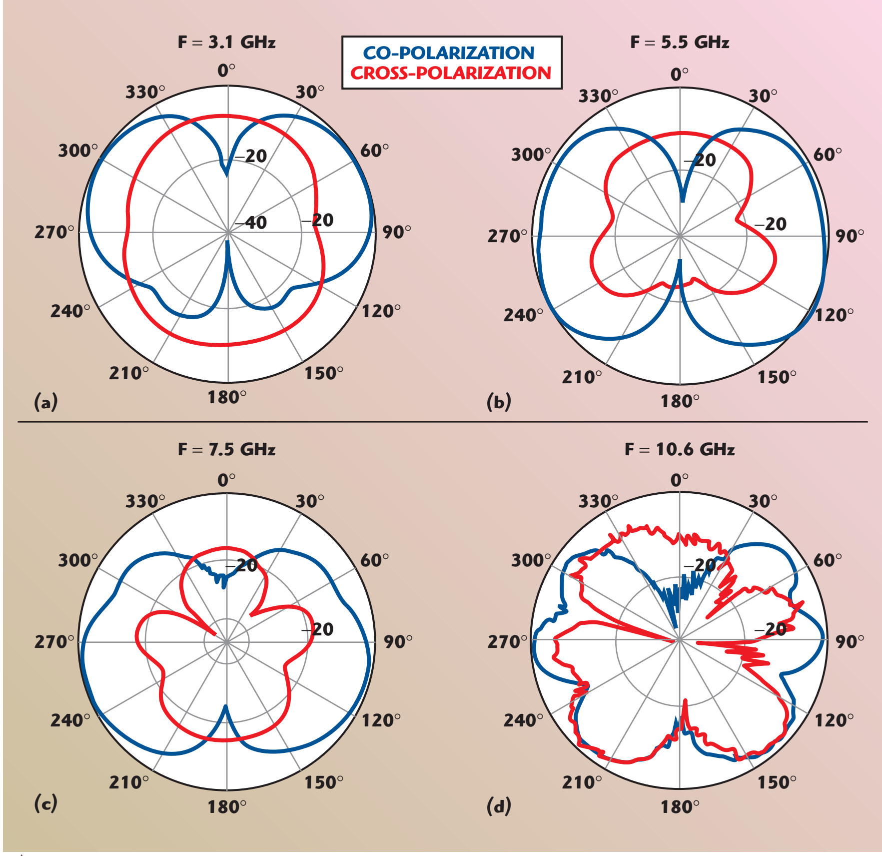


Fig. 5 *Measured radiation pattern in the E-plane (x-z).*

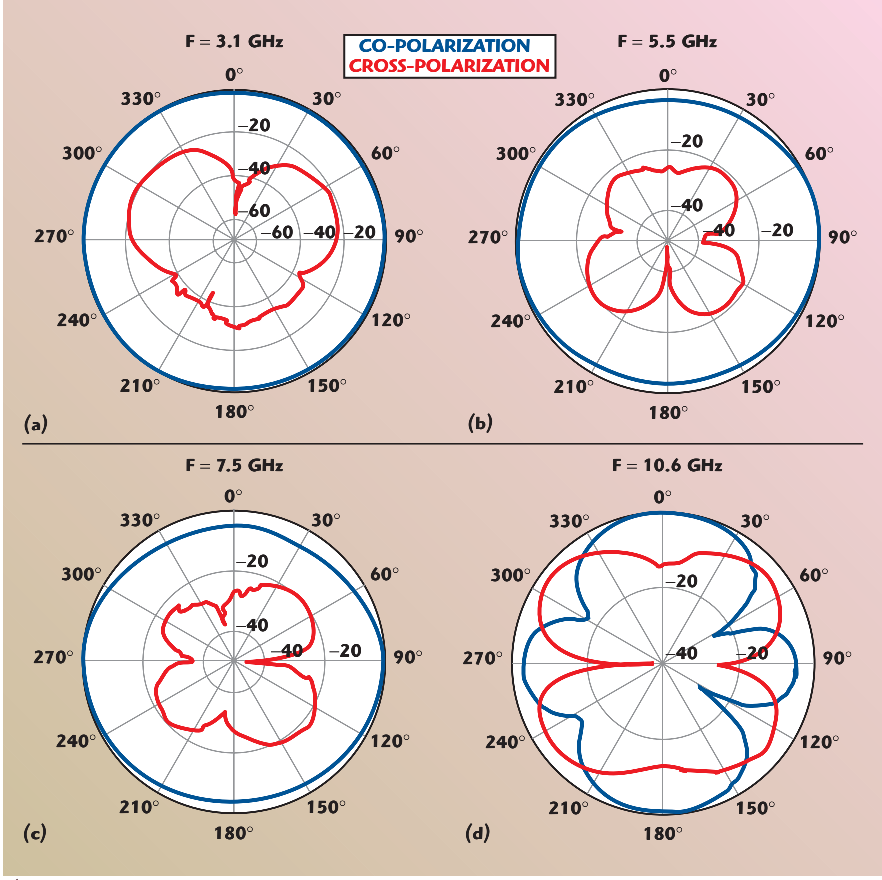


Fig. 6 *Measured radiation pattern in the H-plane (y-z).*

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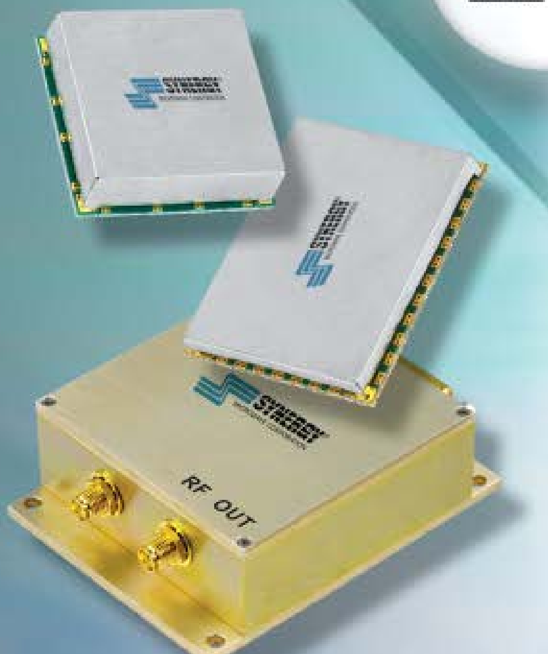

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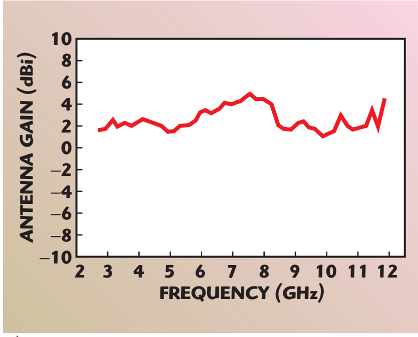

▲ *Fig. 7 Measured gain of the proposed UWB antenna.*

ter strip (W_5) and gap (G_1) of the CPW line are 1.5 and 0.18 mm, respectively, to achieve a 50 Ω characteristic impedance. The spacing between the bottom edge of the tuning stub and the ground plane (L_5) is 0.2 mm, which critically controls the impedance matching and the power coupling from the feed line to the tuning stub. To verify its performance, the proposed UWB antenna was fabricated and measured. ***Figure 2*** shows the measured and simulated return losses. The antenna achieved a –10 dB bandwidth from 3.1 to 11 GHz and covers the band assigned for the UWB applications.[1] The return loss of the proposed antenna was measured with an HP-8720ES network analyzer. The excitation source, with a 50 Ω internal resistance, was directly connected between the center strip end and ground planes of the CPW line through an SMA connector and an RF cable to the vector network analyzer. Usually, the RF cable significantly affects the performance of an antenna under test. It is found, however, that the RF cable hardly affects the lower edge frequency at 3.1 GHz. ***Figure 3*** illustrates the return loss characteristics for different rectangle lengths (W_2); all other dimensions remain the same. It is observed that the length of W_2 determines the impedance matching in the 6 to 8 GHz band. ***Figure 4*** shows the normalized current distributions at four different frequencies. The current density in the center strip of the CPW line and lower edge of the semicircle structure is higher at the lower frequencies. Therefore, the effect from the ground planes on the antenna is small. The radiation patterns were measured at 3.1, 5.5, 7.5 and 10.6 GHz in the x-z plane and y-z plane, and are shown in ***Figures 5*** and ***6***. The UWB antenna gain is shown in ***Figure 7***. The maximum gain is most important to evaluate the communication possibility. However, the average gain (2.768 dBi) in the y-z plane should be considered only. This is because the average gain is meaningless in the x-z plane, which has a null point. This plane is similar to the E-plane radiation from a dipole. Therefore, the average gain was calculated only for the y-z plane, with approximately an omni-directional radiation. In addition, it is expected that, in general, the smaller CPW structure can affect the radiation patterns of the UWB antenna less than the other existing approaches. The measurements show that the antenna has dipole-like radiation characteristics, and the variation in the radiation patterns is slight across the frequency range of interest. This feature provides another important parameter that can be used to change the performance of the antenna. The antenna was designed to have an impedance bandwidth from 3.1 to 11 GHz.

CONCLUSION

A compact and low-profile planar rectangle-semicircle-rectangle antenna is presented and investigated. It is a

good candidate for UWB applications and can be integrated within transceivers. Parametric studies have been done for further investigations of the rectangle-semicircle-rectangle pattern. As a result, the average gain of the antenna has been increased and the ground-plane effect on the impedance response has been reduced. The performance of the antenna has been evaluated in the frequency domain. The proposed antenna can easily be excited by a 50 Ω microstrip line printed on the FR-4 dielectric substrate and can achieve good impedance matching over the operating frequencies. The proposed antenna design, with good gain, is suitable for UWB applications. ■

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Wen-Shan Chen *received his BSc degree in electronic engineering technology from the National Taiwan Institute of Technology (now known as the National Taiwan University of Technology) and his PhD degree from National Sun Yat-Sen University, Kaohsiung, Taiwan, ROC, in 2001. From 2001 to 2002, he was an assistant professor at the Chien-Kuo Institute of Technology, Changhua, Taiwan, ROC. He is currently an assistant professor in the department of electronic engineering at Southern Taiwan University, Tainan, Taiwan, ROC. His research interests include antenna design, RF and microwave circuits.*

Kai-Cheng Yang *received his MSc degree from the Southern Taiwan University of Technology, Taiwan, ROC, in 2005. He is currently a PhD student in the department of electronic engineering at Southern Taiwan University, Tainan, Taiwan. From 2003 to present, he was engaged in the development of ultra-wideband antennas and ultra-wideband systems. He has conducted research on ultra-wideband antenna characteristics in the frequency and time domains. His current research interests include ultra-wideband antenna design, mobile small antennas and ultra-wideband systems.*

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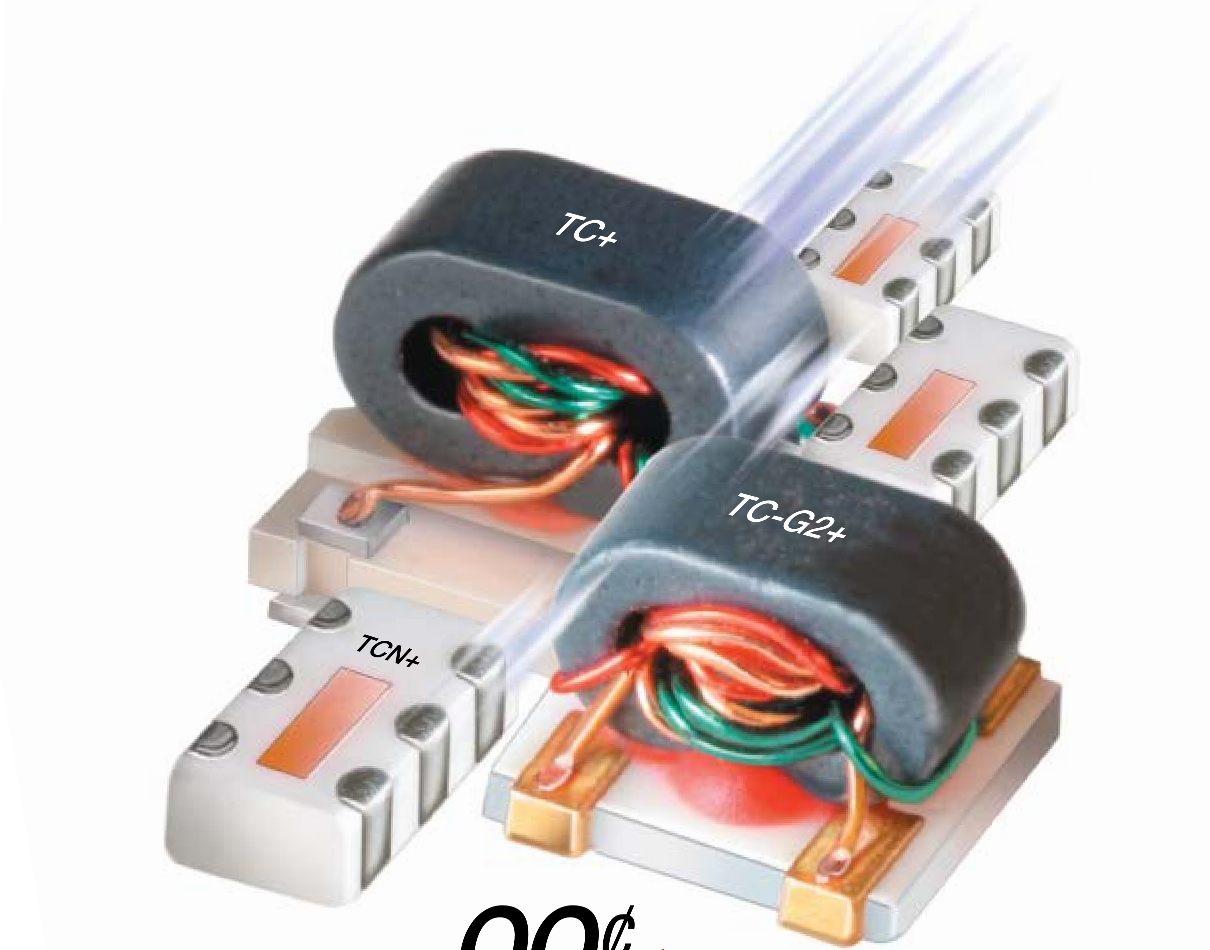

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RF/IF MICROWAVE COMPONENTS

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A 5 GHz RFIC Single Chip Solution in GaInP/GaAs HBT Technology

Several high performance GaInP/GaAs heterojunction bipolar transistor (HBT) radio frequency integrated circuits (RFIC) implemented by our research group are reviewed in this article. These demonstrated RFICs include source inductively degenerated cascode low noise amplifiers with inter-stage matching, shunt-series shunt-shunt dual-feedback wideband amplifiers, a broadband Gilbert down-conversion micromixer, Gilbert down-conversion mixers with polyphase filters for image rejection, a dual-conversion Weaver receiver, Gilbert up-conversion mixers with output LC current mirror and quadrature VCOs.

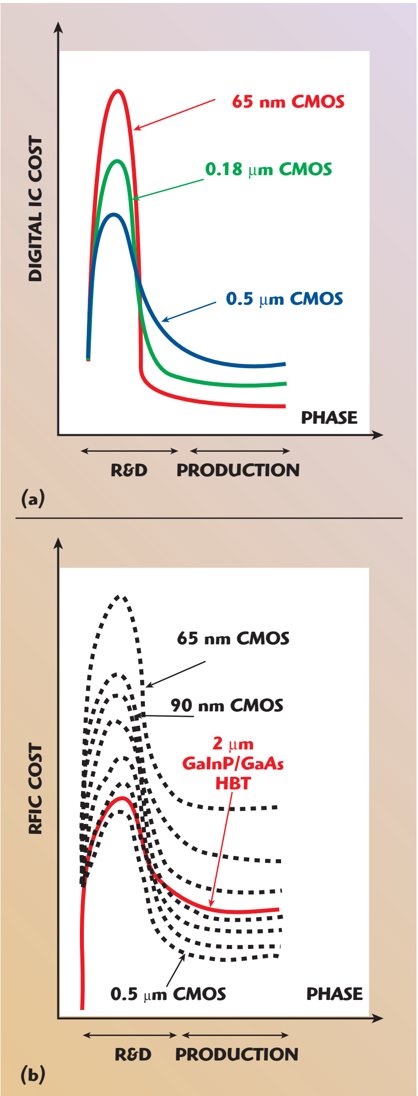
Commercially available 5 GHz WLAN transceivers—with the exception of power amplifiers (PA)—have recently been using advanced CMOS and SiGe BiCMOS technology.[1] It is commonly believed that RFICs made with Si technology, especially CMOS technology, have the lowest cost and can be easily integrated with digital CMOS ICs to form a wireless system on a chip (SOC). In practice, CMOS transceivers integrated with digital CMOS ICs have been successfully demonstrated. However, it is still difficult to integrate the high power PA with the RF transceiver. There exist stand-alone high power CMOS PAs for cellular applications and low end SiGe PAs integrated with RF transceivers for 2.4 GHz WLAN applications. However, the strong coupling in the Si substrate prevents integrating the power amplifier with the RF transceiver. Thus, the commercially available PAs at 5 GHz are stand-alone and dominated by the GaAs technology.

As the scaling down of the CMOS device by deep submicron technology continues, the cost of fabrication becomes very high and the device operating voltage decreases. The integration of high power amplifiers with the SOC thus becomes more difficult. Moreover, the size of the RFICs does not follow the same scaling rule as the digital ICs. It is worthwhile to mention that the cost of research and development for the deep submicron CMOS IC design has increased dramatically due to the high cost of photo masks. In the past, the CMOS technology was very cost effective when compared with the 2 μm GaInP/GaAs HBT technology. As the channel length is shrinking, the R&D cost barrier of the deep

CHIN-CHUN MENG AND
TZUNG-HAN WU
National Chiao Tung University
Taiwan, ROC

submicron CMOS is much higher than that of the 2 µm GaInP/GaAs. The R&D cost of the 0.13 µm CMOS technology is 44 times the cost of the GaAs HBT technology.[2]

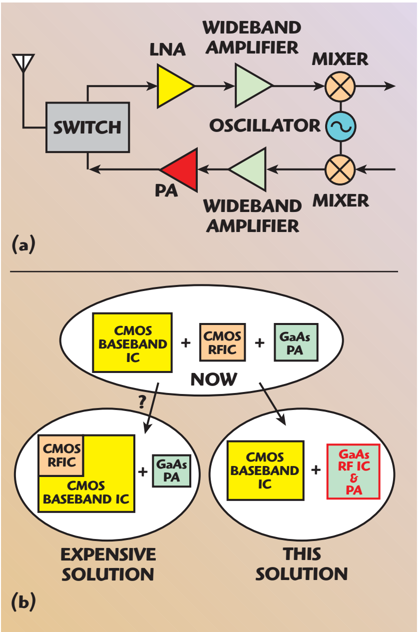
Although it is believed that the cost can be lowered down when the final product enters the mass production phase, the R&D cost barrier makes it very hard to finish a final product. The concept of the barrier for the CMOS R&D cost is illustrated in ***Figure 1***. The Y-axis is the cost and the X-axis is the phase. On the top, the cost reduction of the digital circuit as CMOS is scaled down and is similar to a conventional diagram of the activation energy in chemistry. On the bottom, the diagram for the RFIC is shown when the size of the CMOS is scaled down. Only when the RF solution provider spends an enormous investment can the final product can be realized.



▲ *Fig. 1 The cost for digital scaling (a) and RF scaling (b).*

The GaInP/GaAs HBT technology needs only roughly 10 mask steps while CMOS technology has more than 20 mask steps. There already exists a six-inch GaAs fabrication as compared with the 12-inch Si fabrication. Thus, there is a chance that the production cost for GaAs HBT RF transceivers can be lower than that for CMOS RF transceivers. If the external GaInP/GaAs HBT PA is still unavoidable, it is straightforward to think of the possibility of integrating the whole transceiver including PAs in GaInP/GaAs HBT technology. RF transceivers contain many key components such as LNAs, mixers, wideband amplifiers and VCOs, as shown in ***Figure 2***. In this article, many GaInP/GaAs HBT RFIC building blocks, except PAs for 5 GHz applications, are presented because 5 GHz GaInP/GaAs HBT PAs are commercially available. The goal is to build up a high performance GaAs RFIC single chip solution as shown in the figure.

The GaInP/GaAs HBT technology is suitable for the RFIC design. The semi-insulating substrate eliminates the notorious substrate coupling, and the RF performance can be improved. For instance, the LO substrate leakage of the Gilbert mixer can be eliminated. A state-of-the-art 2LO-to-RF isolation for the direct-conversion sub-harmonic Gilbert mixer has been achieved.[3] The other advantage of the GaInP/GaAs HBT technology is its low 1/f noise corner. The CMOS transistor suffers from the 1/f noise because the inversion layer is located adjacent to the Si-SiO_2 interface. Many dangling bonds (traps) existing in this interface make the device 1/f noise worse. On the other hand, the ledge of the HBT structure[4] and the low DX centers of the GaInP/GaAs material make the 1/f noise of the HBT device minimal. The 1/f noise is very important for the RF circuits, especially for the oscillator and the direct-conversion mixer. The 1/f noise of the mixer can directly influence the output of the mixer, and the CMOS direct-conversion Gilbert mixer suffers from the worst 1/f noise. The experimental results show that the GaInP/GaAs HBT has a 1/f noise corner as low as 400 Hz (depending on the bias condition and the emitter area), and several excellent direct-conversion sub-harmonic Gilbert mixers without 1/f noise are demonstrated. Moreover, a record high phase noise of the VCO was also demonstrated.[5]



▲ *Fig. 2 Block diagrams of a wireless transceiver including the power amplifier (a) and a GaAs RFIC single chip (b).*

LNA AND WIDEBAND AMPLIFIERS

A cascode LNA with source inductive degeneration has been designed.[6] The 2 µm GaInP/GaAs HBT LNA, without inter-stage matching, has a 14 dB power gain and a 2.37 dB noise figure at 5.2 GHz, while the 2 µm GaInP/GaAs HBT LNA, with inter-stage matching, has a 19.5 dB power gain and a 2.22 dB noise figure at 5.2 GHz. The circuit is biased at 3.6 V with a current consumption of 2.3 mA.

The shunt-series shunt-shunt dual-feedback wideband amplifier[7,8] is the most popular topology for the RF gain building block. The design methodology of the wideband amplifier has been developed by identifying poles and zeros of the wideband amplifier.[9-11] The shunt-series shunt-shunt wideband amplifier is a high speed Cherry-Hopper amplifier with a global shunt-series feedback. The experimental results show that a small-signal gain of 16 dB and a 3 dB bandwidth of 11.6 GHz with in-band input/output return losses less than

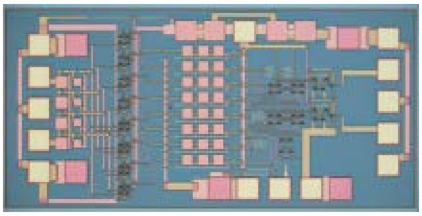
10 dB have been achieved. These values agreed well with those predicted from the analytic expressions that were derived for voltage gain, bandwidth, input and output impedances.

The design trade-off between gain bandwidth and matching bandwidth, using emitter capacitive gain peaking, has been demonstrated.[12] Experimental results show that the power gain is 28 dB and the input/output return losses are better than 12 dB from DC to 6 GHz for the wideband amplifier without emitter capacitive gain peaking. The power and noise performance are very similar for both types of wideband amplifiers. Both circuits have an 8 dBm OP1dB and a 20 dBm OIP3 at 2.4 GHz. The noise figures of both designs are below 2.8 dB from 1 to 6 GHz. A simple down-converter consisting of the wideband amplifier used for LNA has been also demonstrated.[13]

GILBERT DOWN-CONVERTERS

The micromixer proposed by Gilbert[14,15] is an ideal circuit topology for active RF mixer designs. The micromixer consists of a common-emitter single balanced mixer, a common-base single balanced mixer and a resistive degenerated current mirror. The micromixer can be viewed as an active balun that is able to generate differential signals from a single-ended RF input. Since the GaInP/GaAs HBT technology provides a semi-insulating substrate and a metal-plated ground, a microstrip line structure is suitable for signal propagation. The micromixer is good because the input resistors in this topology achieve the input impedance matching and thus the chip area is saved. A DC to 8 GHz wideband GaInP/GaAs HBT micromixer has been demonstrated.[16] Its conversion gain is 11 dB using a resistive load and current injection technique.

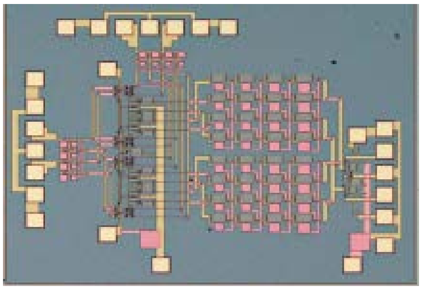
The GaInP/GaAs HBT device has intrinsically an excellent 1/f noise performance. Consequently this technology is very suitable for direct-conversion mixers. Several direct-conversion sub-harmonic Gilbert mixers have been demonstrated.[3,17,18] All of them have state-of-the-art 1/f noise performance caused by the device characteristic and record high port-to-port isolation resulting from the semi-insulating substrate. ***Figure 3*** shows a photograph of the die of a direct-conversion sub-harmonic Gilbert down-converter with I/Q outputs.



▲ *Fig. 3 The die of a 5.7 GHz GaInP/GaAs HBT sub-harmonic Gilbert down-converter.*

The image signal suppression is a very important topic in RF receiver designs. The double quadrature Hartley down-converter with polyphase filters is a popular image rejection method for low IF receivers.[19,20] The double quadrature down-converter consists of four Gilbert mixers and two passive four-section polyphase filters. Its die photograph is shown in ***Figure 4***; the die size is 2 × 2.5 mm. The desired signal and the image signal can be separated after being mixed down by four Gilbert mixers. The IF polyphase filters can then filter out the desired signal from the image signal. A 5.2 GHz, 11 dB gain, IP1dB = –17 dBm and IIP3 = –10 dBm double quadrature Gilbert down-converter with polyphase filters[21] has been demonstrated using GaInP/GaAs HBT technology. The image rejection ratio is better than 40 dB with the LO at 5.17 GHz and the IF is in the range of 15 to 40 MHz.

Another suitable solution to deal with the image signal is the Weaver architecture.[22] A Weaver down-converter has been demonstrated using GaInP/GaAs HBT technology[23] with some advantages, such as the semi-insulating substrate and accurate thin-film resistors. The Weaver system is a double-conversion image rejection heterodyne system, which requires



▲ *Fig. 4 Die photograph of a 5.2 GHz GaInP/GaAs HBT double quadrature down-converter with polyphase filters.*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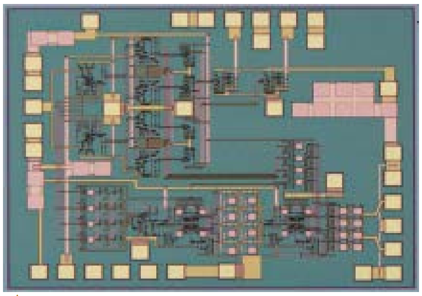
no bandpass filters in the signal path and no quadrature networks. The Weaver down-converter has image rejection ratios of 48 and 44 dB when the RF frequency is 5.2 and 5.7 GHz, respectively. The integration level of this GaInP/GaAs IC is quite high and the IC contains 166 GaInP/GaAs HBTs. The die photograph of the Weaver down-converter is shown in ***Figure 5***. The die size is 2 × 2.5 mm.

GILBERT UP-CONVERTERS

A miniature lumped-element rat-race hybrid[24] and an LC current combiner are used in the LO port and the RF port of the up-conversion micromixer, respectively.[25] The fully integrated micromixer has a conversion gain of 1 dB, an OP1dB of –10 dBm and an OIP3 of 2 dBm, when the input IF = 300 MHz, the LO = 4.9 GHz and the output RF = 5.2 GHz. The output RF return loss is 23 dB at 5.2 GHz and the IF input return loss is better than 25 dB for frequencies up to 8 GHz.

In addition, the operation principle and the analytic function of the LC current combiner, with the effect of the series resistor in an inductor, have been developed. The LC current combiner can be treated as a bandpass and passive current mirror load. Compared with low pass and active current mirror load, the LC current combiner has a better performance when the output frequency is increased. Therefore, the LC current combiner is an ideal topology for up-conversion mixer design.

An up-conversion micromixer with integrated VCO has also been demonstrated.[26] A cross-coupled LC oscillator with an oscillation frequency of 4.3 GHz and a cascode buffer amplifier are also integrated on the same chip. The fully integrated up-conversion micromixer has a conversion gain of –2.5 dB, an OP1dB of –12.5 dBm and a 40 dB RF-to-IF isolation, when the input IF = 0.9 GHz and thus the output RF = 5.2 GHz. The IF input return loss is better than 25 dB for frequencies up to 6 GHz, while the RF output return loss is better than 12 dB for frequencies from 5.15 to 5.35 GHz.



▲ *Fig. 5 Die photograph of a 5.2/5.7 GHz 48 dB image rejection Weaver down-converter.*

VCO AND DIVIDERS

A GaInP/GaAs HBT quadrature VCO[27] has also been implemented. A fully integrated GaInP/GaAs HBT quadrature VCO using a stacked-transformer LC tank has been demonstrated[28] at 5.43 to 5.31 GHz with a low phase noise performance. The GaInP/GaAs HBT device has a small low frequency noise because of the low base resistance, the suppression of trap-related 1/f noise by the device passivation ledge over the extrinsic base surface and the absence of DX trap center in the GaInP material. A stacked transformer has the highest mutual coupling factor (close to one) between two spiral inductors[29] and the GaAs semi-insulating substrate permits a high self-resonant frequency for the stacked transformer. The quadrature VCO at 5.38 GHz has a phase noise of –127.4 dBc/Hz at 1 MHz offset frequency, an output power of –4 dBm and a figure of merit (FOM) of –191 dBc/Hz.

A 4.9 GHz, transformer-based, super-harmonic VCO has been demonstrated[5]; its phase noise is –131 dBc/Hz at 1 MHz offset frequency. The state-of-the-art VCO has a figure of merit (FOM) of –198 dBc/Hz. A 5.7 GHz interpolative VCO,[30] with a wide tuning range, has been demonstrated.[31] The frequency tuning is achieved by interpolating two fixed oscillators instead of changing the tank capacitor. The demonstrated tuning range is 500 MHz. A 50 percent duty cycle divide-by-three GaInP/GaAs HBT prescaler has been demonstrated.[32] The input frequency can be up to 1.7 GHz and the output singles have a 50 percent duty cycle.

CONCLUSION

Several key RFIC building blocks, including an LNA, a wideband amplifier, an up/down-conversion micromixer, a Hartley image rejection down-converter, a Weaver image rejection down-converter, VCOs and a

divider have been designed and implemented using the 2 μm GaInP/GaAs HBT technology. The GaInP/GaAs HBT technology is suitable for RFIC design, and this work has demonstrated the possibility of a fully integrated RF transceiver. ■

ACKNOWLEDGMENTS

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Chin-Chun Meng *received his BS degree in electrical engineering from National Taiwan University, Taipei, Taiwan, ROC, in 1985, and his PhD degree in electrical engineering from the University of California at Los Angeles (UCLA) in 1992. He then joined the Hewlett Packard Component Group, Santa Clara, CA, in 1993 as a member of the technical staff. He is now an associate professor in the department of communication engineering at National Chiao Tung University, HsinChu, Taiwan, ROC. His current research interests include radio frequency integrated circuits (RFIC), high frequency circuit and high speed devices.*

Tzung-Han Wu *received his BS and MS degrees in electrical engineering from National Chung-Hsing University, Taichung, Taiwan, ROC, in 2001 and 2003, respectively. He is currently working toward his PhD degree in the department of communication engineering at National Chiao Tung University, Hsinchu, Taiwan, ROC. His current research interests include RFICs and MMICs.*

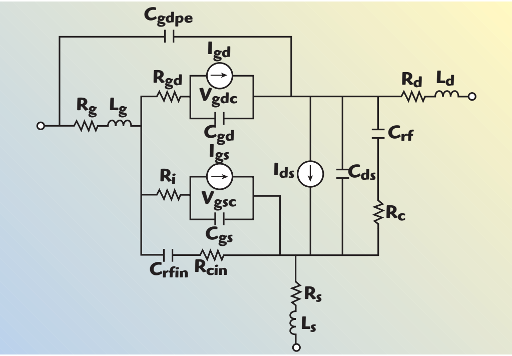
EXTRACTING A NONLINEAR ELECTRO-THERMAL MODEL FOR A GaN HFET

This article describes the procedure used to extract a nonlinear model for a gallium nitride (GaN) power HFET. The source device is a 2 mm gate-width GaN-on-silicon HFET produced by Nitronex Corp., although the procedure can be applied to many other types of transistors. The Angelov2 model was chosen as the vehicle for this work since it is numerically well behaved and is available in both Applied Wave Research's Microwave Office (MWO) and Agilent's Advanced Design System (ADS) EDA tools. The extracted model is scalable and temperature dependent and has been verified under both small- and large-signal conditions for devices up to 36 mm in gate width. Comparisons of measured and simulated results are presented.

The development of GaN technology has brought with it the need for accurate nonlinear active device models that can be easily used in standard design tools. A GaN HEMT model should ideally be scalable with gate width and should be able to predict the performance of the device over the anticipated range of frequency, power, bias conditions and temperature. This article describes the process used to extract such a model for the Nitronex GaN-on-silicon HFET fabricated using the NRF1 process.[1] The procedure is generally applicable to a wide range of transistors, but the results may not apply to devices fabricated by other processes, including those in GaN.

A variety of transistor models, both proprietary and public, are available. In the present case, a public model was sought, for which information existed in the literature, was available in major electronic design automation (EDA) platforms and could ideally be ported from one design platform to another with minimal changes. Also, due to the anticipated usage of these devices in nonlinear applications, it was important to use a model that had minimal numerical convergence issues and was well behaved when used in a harmonic-balance environment. The Angelov2 model was able to meet these criteria and was chosen for this effort. The model equivalent circuit is illustrated in ***Figure 1***. This model is available in both Agilent's Advanced Design System (ADS) and in Applied Wave Research's Microwave Office (MWO), where it is known as Angelov2C. The model is based on the work of Angelov and his colleagues at Chalmers University in Sweden.[2] It is useable in a wide range of applications, but here the focus is on power amplifiers, since this is how most designers would use this device.

Fig. 1 Angelov2C equivalent circuit model.



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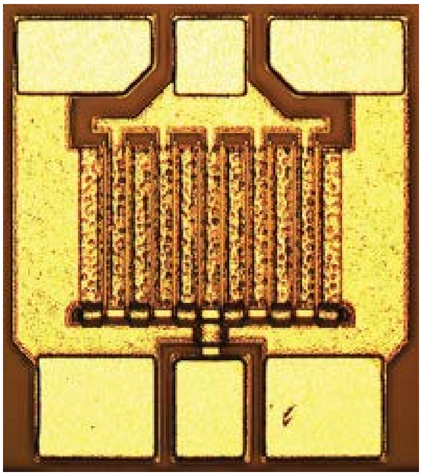
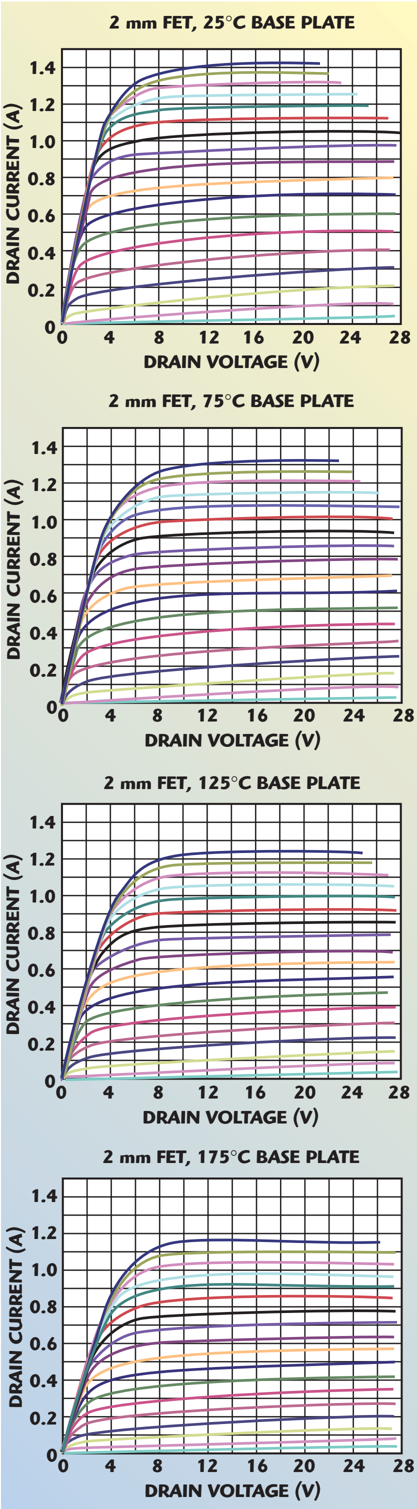
DATA COLLECTION

The extraction process started with the choice of a device that is representative of the HEMT process. Although various device sizes were available, the total gate width of the chosen device was 2 mm, composed of ten 200 µm fingers. A photograph of the coplanar waveguide (CPW) probe-able device is shown in ***Figure 2***. This style of device is included in the production masks of all device sizes in a probe-able configuration. In addition, the current levels obtainable with this gate width are compatible with the limitations of the pulsed I-V test equipment and the device is amenable to accurate S-parameter measurement over a wide frequency range. First, a production wafer was chosen, which by definition meets all electrical parametric specifications. Sixteen 2 mm devices were diced from a uniform distribution about the wafer and mounted four to a Cu/MoCu/Cu (CPC) package flange. The devices were attached to the flange by a standard AuSi eutectic bonding process. The criteria used to select the median device from these 16 parts were pulsed I-V at V_{GS} = 0 V curves (pulsed I_{DSS}) and small-signal parameters at 2.14 GHz. Prior to data collection, the selected 2 mm device was DC biased at 28 V with a drain current calculated to give a junction temperature of 200°C for one hour to provide the effects of burn-in. An Accent DIVA D265 pulsed I-V system was used to collect a family of curves, with the gate biased from –2 to +2 V in 0.2 V steps, and swept from 0 to 48 V on the drain in 0.5 V steps. The source was maintained at ground potential. The instantaneous power was limited to 30 W. The pulse width was 2 µs, with 2 ms between pulses for a duty cycle of 0.1 percent, which eliminates self-heating. In addition, to loosely emulate hysteresis effects at RF, the I-V curve data points were collected pulsed from a quiescent point close to a typical operating condition used under RF (V_{DS} = 28 V, Class AB bias). The pulsed drain characteristics were taken as a function of base plate temperature in increments of 25° from 25° to 175°C. The drain characteristics collected post burn-in and after the entire set of measurements were compared and found to be nearly identical. ***Figure 3*** shows the IV curve families at 25°, 75°, 125° and 175°C. Next, S-parameter measurements were collected over a frequency range of 100 MHz to 10 GHz. Since the S-parameter mea-



▲ *Fig. 2 Photomicrograph of the device used in the model.*

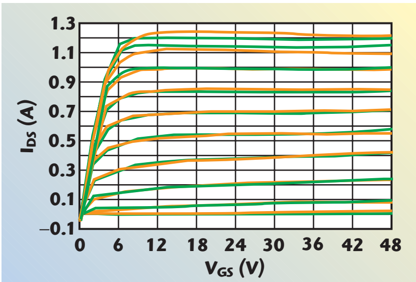


▲ *Fig. 3 Pulsed drain characteristics of a 2 mm device at different base plate temperatures.*

TABLE I

PRIMARY I-V RELATED PARAMETERS

I_{pk0}	current at peak G_m
V_{pks}	gate voltage at peak G_m in saturation
D_{vpks}	delta gate voltage at peak G_m near 0 V_{ds}
P1	polynomial coefficient for channel current
P2	polynomial coefficient for channel current
P3	polynomial coefficient for channel current
A1phar	saturation parameter
A1phas	saturation parameter
V_{kn}	knee voltage
Lambda	channel length modulation parameter
Lambda1	channel length modulation parameter
L_{vg}	coefficient for Lambda parameter
B1	unsaturated coefficient for P1
B2	unsaturated coefficient for P2
R_g	gate resistance
R_d	drain resistance
R_i	gate-source resistance
R_s	source resistance
R_{gd}	gate-drain resistance



▲ *Fig. 4 Drain characteristics simulated with base plate temperature set at 125°C and measured from a 2 mm device.*

surement system is not pulsed, there is self-heating, due to the power dissipation at the quiescent operating point. Data was again taken at base plate temperatures, in increments of 25° from 25° to 175°C. A full set of S-parameters was measured at each bias point with V_{DS} = 7, 28 and 48 V and the gate stepped in increments of 0.1 V, from below pinch-off (V_{GS} = –2 V) to a gate voltage for which the calculated T_J exceeded 200°C.

MODEL EXTRACTION

Once the I-V and RF data were collected, a subset was used to begin construction of the model. First, a fit was made to the pulsed I-V at a base plate temperature selected to match a typical operating temperature under RF drive (125°C). There were approximately 14 parameters and five DC circuit resistor values that needed to be determined at that time. The list of these parameters is given in ***Table 1***. Once a satisfactory fit was obtained, as demonstrated in ***Figure 4***, S-parameter data at several bias points along the anticipated load line were added to the model project. Three drain voltages were chosen (V_{DS} = 7, 28 and 48 V), with the gate biased sufficiently negative to give a drain cur-

TABLE II
PRIMARY C-V RELATED PARAMETERS

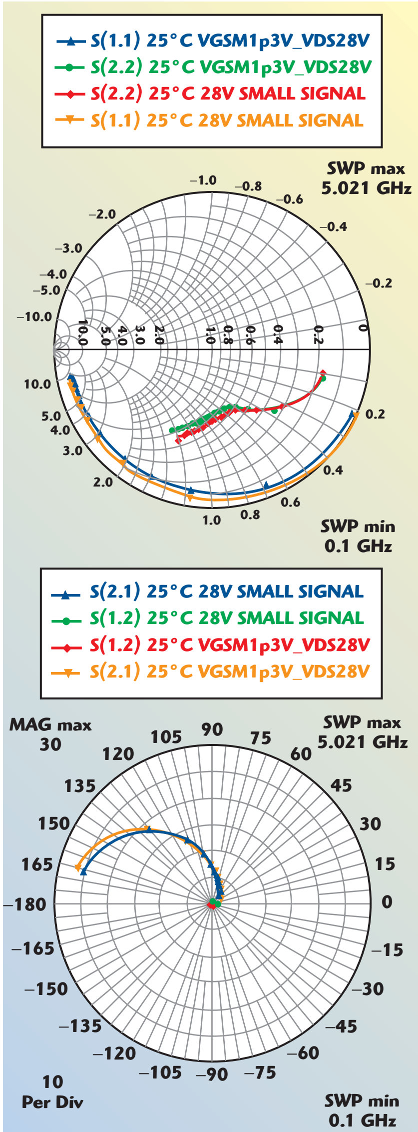
V_{gspi}	gate-source pinch-off capacitance
C_{gs0}	gate-source capacitance
P10	polynomial coefficient for capacitance
P11	polynomial coefficient for capacitance
P111	polynomial coefficient for capacitance
P20	polynomial coefficient for capacitance
P21	polynomial coefficient for capacitance
C_{gdpi}	gate-drain pinch-off capacitance
C_{gd0}	gate-drain capacitance
P30	polynomial coefficient for capacitance
P31	polynomial coefficient for capacitance
P40	polynomial coefficient for capacitance
P41	polynomial coefficient for capacitance
C_{ds}	drain-source capacitance
L_g	gate inductance
L_d	drain inductance
L_s	source inductance

TABLE III
RF EFFECTS, GATE IV AND SOFT BREAKDOWN

C_{gdpe}	external gate-drain capacitance
R_c	R for frequency dependent output conductance
R_{cmin}	minimum value of R_c resistance
tau	internal time delay
C_{rf}	C for frequency dependent output conductance
R_{cin}	R for frequency dependent output conductance
C_{rfin}	C for frequency dependent output conductance
I_j	gate forward saturation current
P_g	gate current parameter
N_e	ideality factor
V_{jg}	gate current parameter
V_{tr}	breakdown voltage
L_{sb0}	soft breakdown fitting parameter
V_{sb2}	soft breakdown fitting parameter

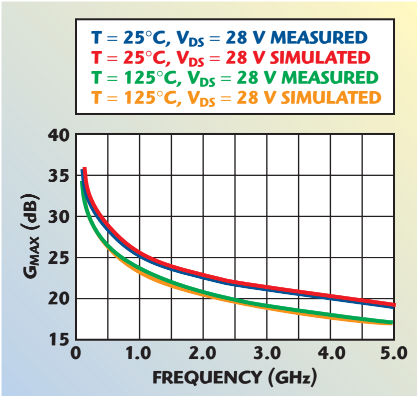
TABLE IV TEMPERATURE RELATED PARAMETERS			
R_{th}	thermal resistance	C_{th}	thermal capacitance
T_{cipk0}	temperature coefficient of I_{pk0} parameter	T_{cp1}	temperature coefficient of P1 parameter
T_{ccgs0}	temperature coefficient of C_{gs0} parameter	T_{ccgd0}	temperature coefficient of C_{gd0} parameter
T_{c1sb0}	temperature coefficient of L_{sb0} parameter	T_{crc}	temperature coefficient of R_c parameter
T_{ccrf}	temperature coefficient of C_{rf} parameter	T_{nom}	parameter measurement temperature

rent which resulted in approximately 25°C temperature rise due to self-heating. With the base plate temperature set to 100°C, the self-heating brought the junction temperature to approximately 125°C, which is a typical operating temperature and the temperature of the pulsed I-V used for the fit. Another 17 primary parameters affect the small-signal fit across the bias. The parameters and their descriptions are tabulated in ***Table 2***. These fitting parameters were determined using optimization with the I-V parameters fixed. Once a reasonable fit was obtained to the small-signal parameters over the frequency range of 100 MHz to 10 GHz, the model parameters that affect both I-V and the S-parameters were re-

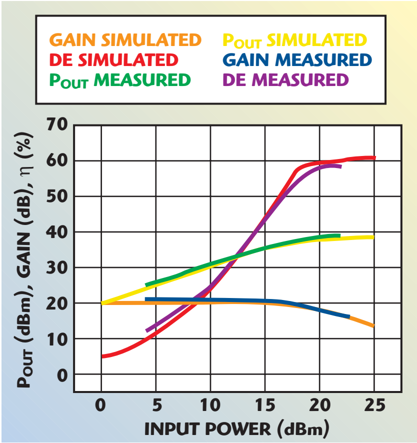


▲ *Fig. 5 Simulated and measured S-parameters at V_{DS} = 28 V and I_{DS} = 55 mA swept over a 100 MHz to 5 GHz frequency range.*

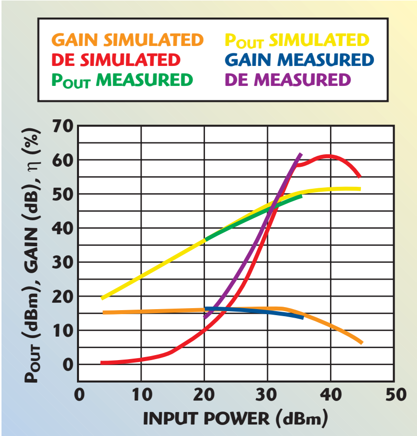
optimized. In addition to the primary fitting parameters already mentioned, there are seven parameters specifying secondary circuit elements on the input and output sides of the model equivalent circuit, three parameters are related to the soft breakdown and another four parameters are defining the gate forward characteristics. All of these parameters are described in ***Table 3***. The gate diode parameters were fit to the measured data at a 125°C base plate temperature, with special attention to the forward bias region up to a current density of 10 mA/mm. The gate diode current affects the shape of the drain characteristics as the gate forward bias is increased, resulting in some interplay with the drain I-V fitting parameters that had to be accounted for. Next, the temperature dependence was incorporated, using two parameters related to the drain voltage fit, three parameters relevant to the S-parameters and a soft breakdown temperature dependence parameter. The fit was made over three temperatures. A thermal resistance value was provided to allow the model to calculate self-heating based upon the dissipated power. A thermal capacitance was also specified to provide approximate thermal transient behavior. ***Table 4*** lists all of the temperature related parameters.



▲ *Fig. 6 Simulated and measured G_{MAX} as a function of frequency and temperature.*



▲ *Fig. 7 Simulated and measured load-pull results for the 2 mm device.*



▲ *Fig. 8 Simulated and measured load-pull characteristics of XPT25100.*

MODEL VALIDATION

For top-level verification, the model was used to simulate I-V and small-signal RF parameters. ***Figure 5*** shows the measured and modeled S-parameters with S_{11} and S_{22} plotted on a Smith chart, and S_{21} and S_{12} on a polar chart. ***Figure 6*** compares the measured and simulated data for the maximum available gain, G_{max}, as a function of frequency and temperature. Validation of the large-signal performance is demonstrated by comparison of a simulated load-pull to actual measurements of the 2 mm device. The power sweep data was collected from the device, including output power, gain and drain efficiency, on a standard load-pull system. The frequency was 2.14 GHz and the drain bias was 28 V with the gate biased to give a quiescent drain current of approximately 55 mA. The input impedance was fixed at a standard value for a 2 mm device testing, and the output impedance was tuned for maximum output power. The input and output impedance values used in the measurements were directly entered into the simulated load-pull. The measured and simulated values are compared in ***Figure 7***. As preparation for delivery as a product model to users, a model for the package and any internal matching circuit are combined with the device model. This simulation is compared to the measured RF performance of packaged devices of various gate peripheries. One example of such a product is the Nitronex XPT25100. ***Figure 8*** shows the modeled versus measured results for the XPT25100 device. This is a 36 mm gate-width device mounted in an air-cavity package with internal pre-matching on the input side.

CONCLUSION

The completed Angelov2C-based model has been determined to be robust in terms of convergence under a wide range of conditions. The current-voltage (I-V) output agrees quite well with measurements over the temperature range from 25° to 175°C, from +2 to –2 V on the gate, and 0 to 48 V on the drain. The small-signal output matches reasonably well from 0.1 to 10 GHz over the typical load line of the device under operation. The large-signal behavior is predictive and is close to the actual tested device behavior. Self-heating is accurately modeled using a periphery dependent thermal resistance. This device model has been used to provide accurate packaged product models for a number of products and other anticipated device designs. ■

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CMOS AGC Design Strategies

The automatic gain control (AGC) circuit is a critical building block in modern wireless transceivers. It is used in both the transmitter (TX) and receiver (RX). In the TX, the AGC is used to regulate the output power level. For example, a well-known issue in a CDMA system is the problem of simultaneously receiving two signals of different strength. If two users transmit to the base station (BS) at the same time, the received power from the close user will be much higher and will jam the signal from the far away user if the power level difference is large. It is desirable to use an AGC to control each TX's output power so that the power received from all users is equal. In the RX, the received signal can vary drastically in a mobile environment. At the same time, the analog-to-digital converter (ADC) requires a fixed input level. An AGC circuitry can be used to stabilize the received power level at the ADC's input.

This article presents seven widely used topologies for the AGC...

Original equipment manufacturers (OEM) demand highly integrated transceiver integrated circuits (IC) from RFIC vendors. CMOS technology has been the technology of choice because of its low cost and higher integration features. This article focuses on the AGC implementations in CMOS technology. AGC circuitry has been well studied and researched. This article presents seven widely used topologies for the AGC, including variable transconductance, variable degenerated feedback, variable biasing at the gate, variable biasing at the source, variable supply, variable feedback and variable T network. Each topology is discussed in detail.

The control voltage is an important topic. It is highly desirable to have a gain control voltage that behaves exponentially with the input voltage. The purpose is to achieve a wide dynamic range or a linear-in-dB performance. The gain control voltage has to be well regulated against temperature and process variations. The gain control circuitry is an art by itself. It deserves a detailed discussion in a separate article. Here, the control voltage is assumed.

LOUIS FAN FEI
Garmin International
Olathe, KS

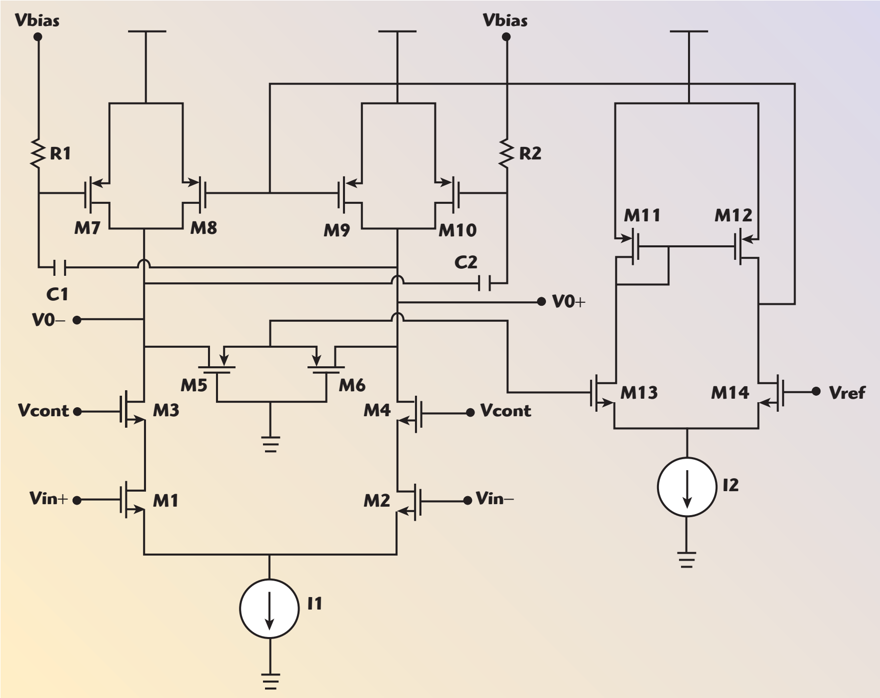

Fig. 1 *Variable transconductance AGC circuit.*

VARIABLE TRANSCONDUCTANCE AGC

The variable transconductance AGC circuit is shown in ***Figure 1***. Its fundamental theory is based on a FET's gain variation as the FET changes from a saturation mode to a triode mode. In the saturation region, the current-voltage (I-V) curve has the steepest slope, thus the highest gain. As the mode changes, the slope begins to flatten out. M1 and M2 are the gain blocks. Their operating mode is controlled by the gate voltage of M3 and M4. The drain voltage of M1 and M2 is equal to $V_{cont} - V_{gs}$ (M3 and M4). $V_{gs1} - V_t + V_{gs3}$ is the borderline value for V_{cont}. Above it, M1 and M2 are in the saturation region (high gain). Below it, M1 and M2 are in the triode region (low gain). As V_{cont} transitions from a high to a low voltage, the gain will follow accordingly. The load in this circuit is of the current source type. M7 and M10 are the primary load. M8 and M9 are the bleeding elements used in the common mode feedback (CMFB). The reason for using a CMFB circuit is because of the current source type load. The drain voltages at M3 and M4 are not well defined. The mismatch between the PMOS (M7, M10) and the NMOS current source (I1) will pull M7 and M10 into a triode region from the desired saturation region. M5 and M6 are the common mode sensing resistors implemented with the FETs. This voltage is compared to a reference voltage. The error voltage is fed back to control the bias current in the bleeding current source (M8 and M9). The comparator is implemented with M11 to M14. This variable conductance AGC works well, up to a low gigahertz range.[1]

VARIABLE DEGENERATED FEEDBACK AGC

An AGC with a variable degenerated feedback is shown in ***Figure 2***. Its fundamental principle is to vary the degenerated feedback resistor in a differential amplifier. The gain of the differential amplifier is proportional to the ratio of the load resistance to the feedback resistor. As the degenerated feedback resistor's value is varied, AGC is accomplished. M1 and M2 are the differential amplifier pair. M5 is the degenerated variable feedback resistor implemented with a FET in the triode region. M3 and M4 are the fixed degenerated resistance to improve the linearity of the gain block. Again, the CMFB with FETs from M8 to M11 are used in this circuit to keep the current source load M6 and M7 in the saturation region. There are two differences in this

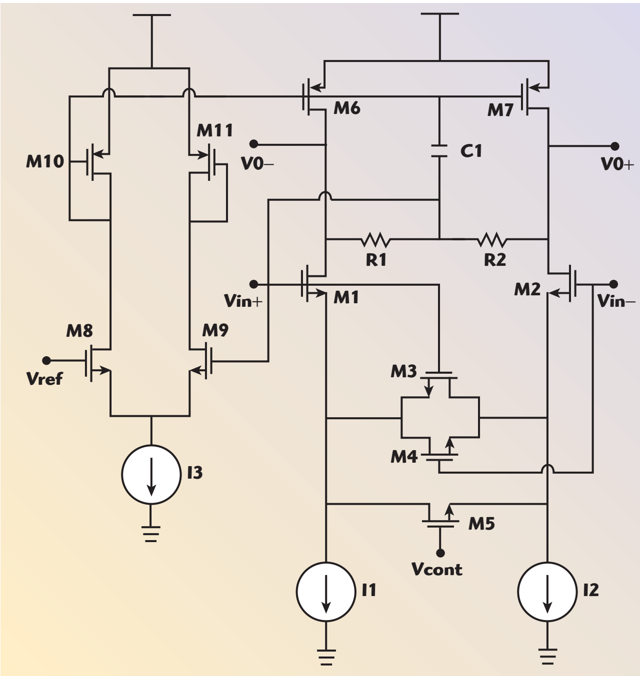

Fig. 2 *Variable degenerated feedback AGC circuit.*

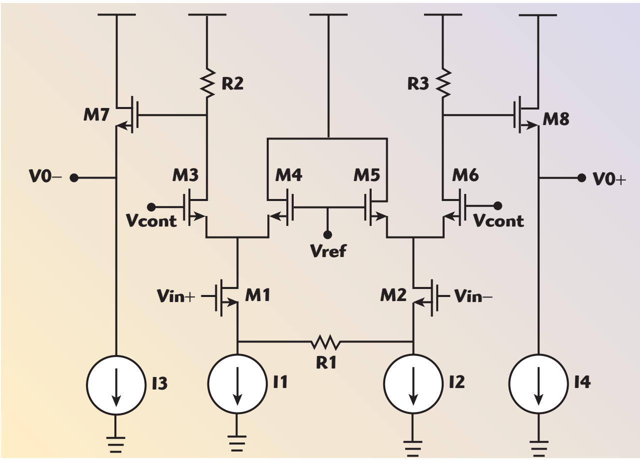

Fig. 3 *Variable gate biasing AGC circuit.*

CMFB implementation. First, the true sensing resistors R1 and R2 are used. Second, the feedback voltage directly controls M6 and M7 without the bleeding elements. This implementation works better at low frequencies[2] because the variable resistance M5 is not well controlled at a high frequency due to the parasitic capacitance.

VARIABLE GATE BIASING AGC

The AGC with a variable biasing at the gate is shown in ***Figure 3***. This topology works well at gigahertz frequencies and is widely used. Its fundamental principle is to vary the gain by controlling the bias current. The gain control voltage is compared to a reference voltage. If the gain control voltage is higher, it will supply more current to the gain element, thus the amplifier will have more gain. M1 and M2 are the basic differential amplifiers. M3 to M6 form the comparing stages. They provide gain as well, when their bias current is increased. In that case, the gain stage can be considered as a differential cascode circuit. M7 and M8 are the output buffers to lower the output impedance. The variable bias current at the gate is well suited for high frequency operation because of its simplicity.

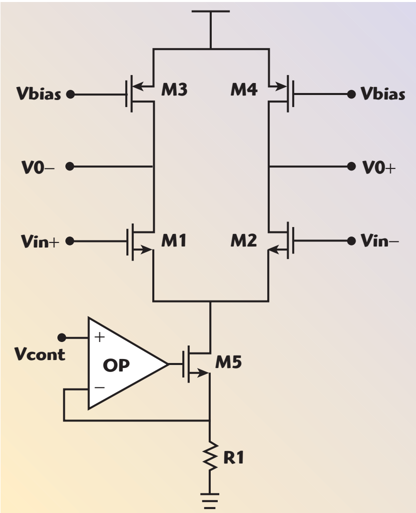

Fig. 4 Variable source biasing AGC circuit.

VARIABLE SOURCE BIASING AGC

A variable bias can be done either at the gate or the source. The variable bias at the source is shown in ***Figure 4***. Its principle is the same as for the variable gate biasing, only this time the gain control is done by varying bias current at the source. The circuit shown is a much-simplified version. The CMFB circuit is omitted, since it is similar to the ones shown previously. The AGC performance is similar to the one shown for the variable gate biasing circuit.

VARIABLE SUPPLY AGC

A variable supply AGC, shown in ***Figure 5***, is easy to understand and easy to implement. It has been reported in the literature.[4] The basic gain element is a CMOS inverter biased at one half of V_{dd}. When a CMOS inverter is biased at $V_{dd}/2$, its I-V curve is at the steepest point, thus it has a large gain. By varying the supply, the slope will change. Hence, a variable gain can be accomplished. M1 and M7 and M2 and M8 are two pairs of inverters, one for each of the differential input signals. M3 to M6 are the switches to reduce leakage between the input and output of the inverter amplifier. They are always on. The leakage will reduce the AGC range if it is not dealt with. M9 and M10 are essentially a resistor divider to obtain one half of V_{cc}.

VARIABLE FEEDBACK AGC

A variable feedback AGC is described next. Gain control using feedback is well known. Such a design is shown in ***Figure 6***. The amplifier's gain comes from a common source stage M1 and a common gate stage M2. C1, C2 and L1 are the input-matching elements. L1 doubles as the DC return for M3. L2 and L4 are the output-matching network. L3 is a radio frequency choke. The variable feedback path consists of M3, R5 and C6. C6 is selected to be a short circuit at the frequency of the interest. Excellent RF VGA performance has been reported.[5]

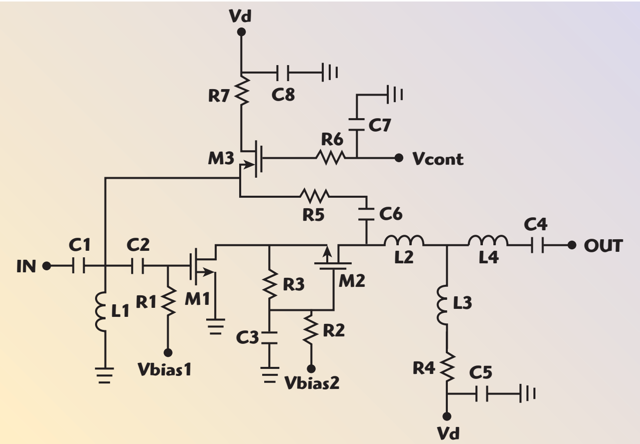

Fig. 6 Variable feedback AGC circuit.

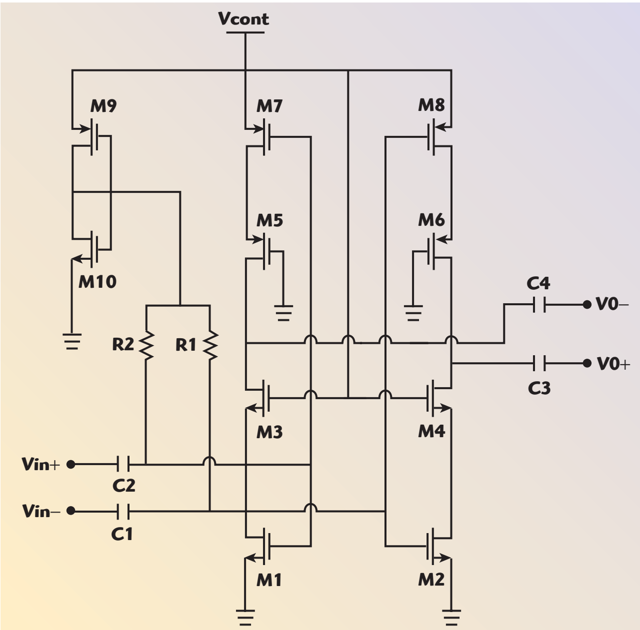

Fig. 5 Variable supply AGC circuit.

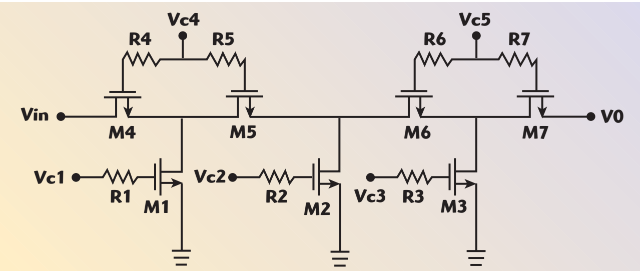

Fig. 7 Variable T network AGC circuit.

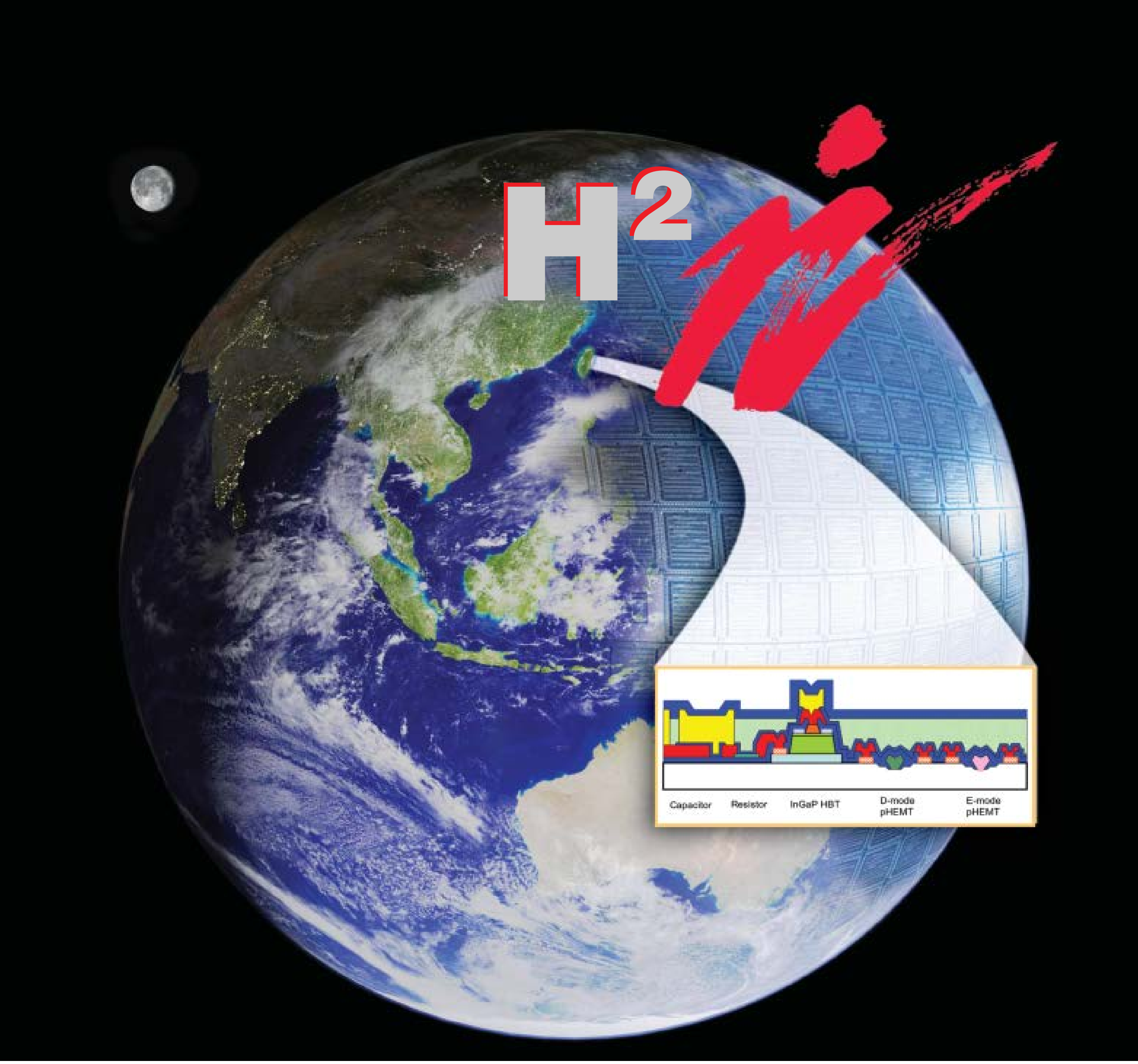
H2
Capacitor
Resistor
InGaP HBT
D-mode pHEMT
E-mode pHEMT

TABLE I

AGC PERFORMANCE RESULTS AND COMPARISON

Figure	Control Range (dB)	Upper Frequency	Complexity	Gain/Loss	Reference #
1	> 90	~900 MHz	high	gain	1
2	> 80	~2 GHz	high	gain	3,2
3	> 20 per stage	~1 GHz	medium	gain	many
4	> 20 per stage	~1 GHz	medium	gain	many
5	> 70	~2 GHz	low	loss	5
6	> 10	4 GHz	high	gain	6
7	> 30	10 GHz	medium	loss	7,8

VARIABLE T NETWORK

In an AGC circuit the gain control block and the gain block are sometimes separated to have a more modular design. In those instances, a gain control block can be a voltage variable attenuator (VVA). The VVA has been used for a long time in the microwave industry. With the continuous improvement in CMOS technology, a VVA implemented in CMOS technology has gained popularity.[6,7] The basic principle of a VVA is a variable resistive pad. A fixed attenuation pad is typically implemented with three resistors in a T or a Pi network. For example, a T network with two series 26 Ω resistors and a shunt 35 Ω resistor will give 10 dB attenuation. By varying the shunt and series resistances complementarily, the VVA operation can be done easily. A two-stage T variable pad is used in ***Figure 7***. M2 is used to further improve the attenuation range. With a good CMOS process, the RF portion can be implemented fairly easily. The difficult part is to generate a precise control voltage for the series and the shunt FETs. The variable T or PI network VVA is well suited for broadband and high frequency operation.

CONCLUSION

There are many topologies at the disposal of CMOS transceiver IC designers. Seven different designs based on different principles are presented and discussed. Each one has its pros and cons. For example, a variable T network is a very good topology for high frequency operation, but offers no gain. A variable transconductance AGC is a high performance circuit, but requires a CMFB circuit, increasing the complexity and limiting the upper operating frequency. It is beneficial for the IC designer to realize the strengths and weaknesses of each topology. A comparison between the different approaches is given in ***Table 1***. An AGC topology needs to be carefully examined and selected for the specific application at hand. ■

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Louis Fan Fei *received his BSEE and MSEE degrees from Georgia Tech in 1996 and 1998, respectively. He worked on microwave instrument circuits for HP/Agilent in Colorado Springs, CO, in the summer of 1997 and on WLAN and wireless local loop circuits at Lucent/Agere Systems from 1998 to 2003. He is now an RF engineer at Garmin International, where he designs GPS receivers.*

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A PUSH-ON CONNECTOR SERIES

The development of the multi-coax/DC connector has been prolonged and demanding, taking over 25 years. At first there was the development of the Quick Connectors or 'push-on' type connectors, which were originally designed and introduced for applications where limited space requirements made tightening, torquing and loosening a threaded coupling nut difficult, impossible or time consuming. As an example, ***Figure 1*** shows Spectrum's push-on connectors that mate with standard SMA, N, TNC, 7/16 and F series connectors.

The next issue to be addressed was the demand for high power blind mates, which are needed for high power components, to be designed on a modular basis. Hence, the SBX, SBY (shown in ***Figure 2***) and SBZ connector series were developed and introduced for a wide range of microwave interconnect problems and mating applications for modularized packages, racks and panels, and dense packaging. Their design means that in most cases they are not visible after the modules have been connected, as they can be integrated completely into the package.

Fig. 1 Push-on series SMA, N, TNC, 7/16 and F connectors.

Push-ons and blind mates serve applications where a number of coaxial lines are to be connected and disconnected in seconds. However, there are other fields, particularly for airborne and shipborne applications, or even in test centers, where a higher number of RF lines need to be packaged densely. As well as possessing the facility to be connected and disconnected easily, securely fastened in seconds and locked safely, they also need to be rugged and able to withstand the stringent requirements of military programs and be capable of operating in harsh environments.

Fig. 2 Blind-mate SBY connectors connecting a limiter circulator assembly.

SPECTRUM ELEKTROTECHNIK GMBH
Munich, Germany

EIGHT-LINE CONNECTION

The SQ series has been designed to meet these requirements. The first to consider is the SQ-8, which uses the standard size 21 MIL-C-38999 shell. This type of shell offers five keyed connector versions, eliminating connection errors, ensuring that only the correct harness can be connected with the proper mating connector at the equipment. They are available with different finishes—aluminum nickel-plated or cadmium-plated. As its name suggests, the SQ-8 is designed for connecting eight RF lines at once. It is illustrated in ***Figure 3***. It has eight floating and spring-loaded inserts in both the male and the female unit, ensuring good connection at the interfaces for the best electrical performance and enabling operation for frequencies up to 25 GHz.

Accurate mating and spring-loaded interfaces are required even at lower frequencies when the cable assemblies of a harness have to be phase matched. Replaceability is guaranteed for any damaged or defective coaxial line of the harness, which can be replaced in seconds by just turning the bayonet catch of the coaxial insert at the SQ-8. Two different flexible cables are available for the SQ-series, Type 11 and Type 43, offering a trade-off between insertion loss and flexibility, but both ensuring operation to 25 GHz.

HIGH FREQUENCY OPERATION

The internal dimensions of a coaxial insert or connector and cable, and the constants of their dielectrics are the only limiting factors of the operating frequency range, assuming that state-of-the-art design criteria is used. Therefore, there is no reason that any SMA should not operate properly at least to 18 GHz, or even 26 GHz, depending on certain limiting criteria of the cable. Spectrum's push-on SMAs operate to 26 GHz, the N and TNCs to 18 GHz, the 7/16 to 7.5 GHz, and the complete SQ and SM families to 25 GHz.

The operating frequency range of the SQ series is ensured by instrument grade design and spring-loaded interfaces, ensuring that the male and female mate exactly, with no uncontrolled gap at the interface. Also important is the fact that the electrical performance of connectors is not just dependent on the design, but also on the tolerances of the different components of the coaxial connector or the inserts—namely the center contact, the dielectric and the outer conductor. Precision parts are critical, so for the electrical performance of the connector or insert Spectrum allows a tolerance of 5/1000 of a millimeter (2/10000 of an inch).

The SQ-8F version of the connector has been developed for certain applications where the spring-loaded design of the male unit was not required (for example, when an angled configuration of the male connector, which cannot be handled with spring-loaded inserts, is to be used). The SQ-8F utilizes eight coaxial inserts and the male inserts terminate the coaxial cable by being securely mounted in the housing of the size 21 MIL-C-38999 shell.

The bulkhead or four-hole panel mount female inserts remain floating, ensuring excellent connection for good electrical performance up to 25 GHz. And any damaged and defective coaxial line of the female part of the harness can be replaced in seconds, using the bayonet catch. Replacing a coaxial line in the male SQ-8F is also possible by unthreading the back body of the coaxial insert.

12-LINE CONNECTION

For certain applications eight coaxial RF lines in a compact housing are not sufficient. Hence, the SQ-12F has been developed, accommodating 12 coaxial RF lines in a standard size 25 MIL-C-38999 shell. The SQ-12 is illustrated in ***Figure 4***. This connector uses the same technology as the SQ-8F—five keyed shells are available, aluminum nickel- or cadmium-plated, together with coaxial inserts for Type 11 and Type 43 cables. Effectively, it is an enlarged version of the SQ-8F with securely mounted inserts in the male unit and spring-loaded inserts in the female unit.

Often in airborne applications bulkhead feed through connectors are required to be mounted in walls between chambers of different pressure. To meet these requirements the SQ-8P and SQ-12P series are available, which offer this type of sealed Bulkhead Feedthrough Jack (BFJ). All coaxial lines in this female connector are mounted and sealed firmly in the MIL-C-38999 shell (sizes 21 and 25, respectively), while the male connector uses inserts, which are floating and spring-loaded, ensuring proper mating interfaces. The SQ-8P and SQ-12P series are color-coded and have special markings to make it clear that it is not possible to replace a coaxial line in a sealed BFJ connector without damaging the seals. Replacement can only be carried out by the manufacturer.

EXCHANGEABILITY

This pressurized condition apart, the exchangeability of the coaxial inserts within the SQ-series is guaranteed. The spring-loaded male inserts of the SQ-8 male, SQ-8P male and SQ-12P male are the same, as are the fixed male inserts of the SQ-8F male and SQ-12F male. Identical female inserts are used in the SQ-8 female, SQ-8F female and SQ-12F female.

▲ *Fig. 3 The SQ-8 connector using six of the possible eight lines.*

▲ *Fig. 4 The SQ-12 male and SQ-12 four-hole flange mount connector.*

▲ *Fig. 5 The SM23-DC26 multi-coax/DC connector.*

Also identical are the pressurized female inserts of the SQ-8P and SQ-12P. This means that, with the exception of the cable assemblies used in the pressurized connectors, cable assemblies can be exchanged from the SQ-8F to the SQ-12F, and vice versa.

23-LINE CONNECTION

For certain applications, even 12 RF coaxial connections are not enough. There is also the need for DC and driver signals. Hence, the development of the SM23-DC26 multicoax/DC connector, which connects and disconnects 23 coaxial RF lines (shown in ***Figure 5***) and 26 signal lines in seconds. For this design, a minor modification at the spring finger system of the outer conductor of the SMA push-on was necessary in order to meet the insertion and withdrawal force requirement of a maximum of 150 N (for all 23 coax lines, including the 26 DC and driver signal paths).

The female coax inserts terminating the cable use the standard SMA female interface, mating with any standard SMA male connector, while for the male part SMA push-ons incorporating a lower insertion force design are employed. This ensures that any standard SMA female connector can mate with any of these coax lines by just being pushed on, instead of threading and torquing.

With 23 RF lines in a connector there is the possibility that one, or even several may be damaged at some time and will need to be replaced. The cable assemblies are mounted in groups of four or eight that are securely fastened by mounting bolts in the supporting structure. This ensures that any coaxial line can be replaced quickly. The maximum operating frequency is guaranteed to 25 GHz and the connector uses Type 11 or 43 cables.

PHASE MATCHING

Modern systems often require phase matching of harness cable assemblies. Hence, Spectrum uses the latest cable manufacturing and interface cutting techniques, together with advanced adjustable connector designs that can meet almost any phase matching. Selecting the right materials and aging techniques as part of well defined processes is also an important parameter in order to produce cable assemblies and harnesses that are capable of operating in temperature ranges of –54° to +115°C as standard. Extended temperature ranges from –72° to +200°C can be accommodated and for some sophisticated receivers connectors are available that operate at –200°C.

All connectors are RoHS-compliant and meet the condition and corrosion requirement to MIL-STD-202, method 101, condition B. The SQ connector series is also compliant to thermal shock to MIL-STD-202, method 107, condition B, vibration to MIL-STD-202, method 204, condition D, and shock to MIL-STD-202, method 213. Additional information may be obtained via e-mail at specelek@compuserve.com.

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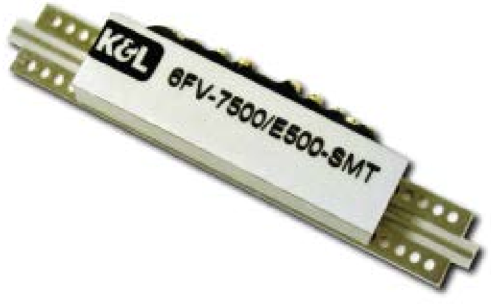
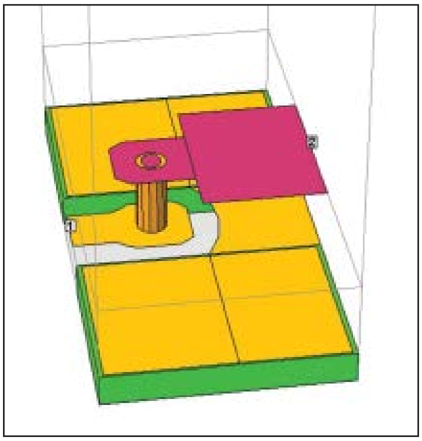
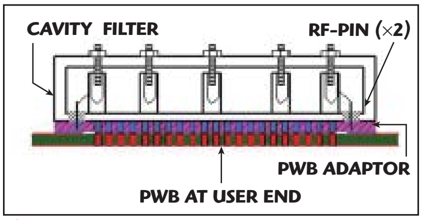


LEADLESS SMT CAVITY FILTERS

At present, market demand for miniaturization of SMT components is satisfied at the expense of poorer component insertion loss and limited levels of ultimate rejection. While high Q components offer increased range and/or reduced noise figure at the system level, miniaturized components fit mechanical constraints and tight budgets. The Leadless SMT Air Cavity Filter provides an option for better balancing of design requirements between the existing extremes.

Fig. 1 SMT transition from 13-mil RO4003 through 31-mil RO4003 to the cavity filter. ▼





▲ Fig. 2 The completed filter mounted at the user's end.

THE SOLUTION

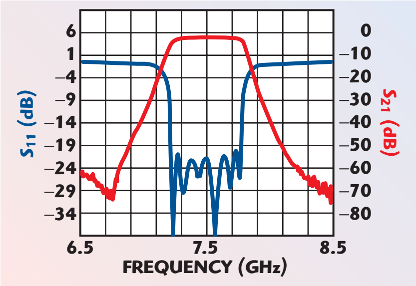
In most cases, the printed wiring board (PWB) of choice for the user's end module is a microstrip structure consisting of a low dielectric (2 to 10) organic material. In the proposed solution (patent pending), an additional PWB is soldered to the base of the filter, which carries the RF signal from the microstrip structure to the RF pin positioned in the floor of the filter, as depicted in ***Figure 1***. Using a planar simulator, such as Sonnet, the transition is analyzed over a wide frequency range, and its S-parameters are stored. Next, a cavity filter is designed to suit the RF specifications and then optimized between (in cascade with) the stored S-parameters at both of its ports, as shown in ***Figure 2***. The filter is matched between two complex loads by changing the internal impedance and couplings between resonators. Correct tap points to the first and last resonators are also determined in the final steps of the design.

Between the I/O ports, the adapting PWB is filled with plated-through-holes (PTH) to ensure maximum isolation by keeping RF leakages down. RF leakage is a typical problem and the primary cause of deteriorating the ultimate rejection in miniaturized SMT filters. Assembly of the filter and PWB adaptor is accomplished using SN-96 solder, with a melting range of 221° to 229°C, so that the completed unit can be reflowed into the user's end-product using SN-63 solder. The RF signal path transitions from a microstrip to a stripline structure to a vertical plated-through-hole, entering the cavity filter via a coaxial RF pin. The RF pin provides the filter with complete shielding from humidity, which is often encountered during PWB cleaning after the solder reflow phase.

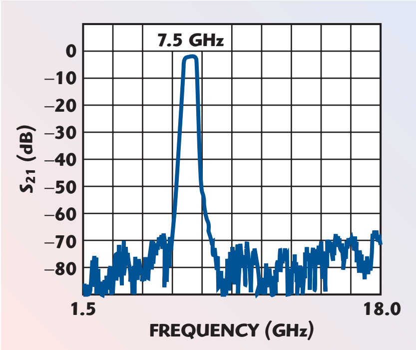
TEST RESULTS

A five-pole Chebyshev bandpass filter centered at 7500 MHz with a 500 MHz equal-ripple bandwidth was built and tested. The filter was assembled and soldered to an RO4003

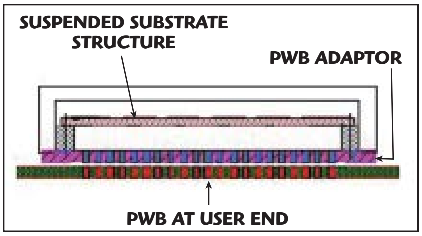
K&L MICROWAVE INC.
Salisbury, MD



▲ *Fig. 3 Narrowband response (loss is inclusive of two SMA connectors and the test fixture).*



◀ *Fig. 4 The filter's wideband response (ultimate rejection maintained through large PTH population).*



▲ *Fig. 5 SMT transition to microstrip/suspended substrate structures.*

PWB with a thickness of 31 mils. One end of the RF pin was soldered to a loading wire, while the second end was soldered to the inner PTH conductor. The filter assembly was reflow soldered to a test fixture made of RO4003 with a thickness of 13 mils. With a ground plane spacing of 0.13" and a 3 dB bandwidth of 600 MHz, the estimated unloaded Q predicted an insertion loss at mid-band of just above 1 dB. The narrowband and wideband responses, shown in ***Figures 3*** and ***4***, are in excellent agreement with predicted performance.

SMT FILTERS FROM MODERATE TO LARGE BANDWIDTHS

Cavity (TEM) filters have limited support for moderate (> 50 percent) to large (> 100 percent) bandwidths, due to the finite close proximity of the resonators. With careful analysis and tuning of transitions, the PWB adaptor concept is viable for these wider bandwidths, but a different filter structure must be used. The approach can be extended by substituting a suspended substrate structure for the cavity structure, particularly for high pass and low pass responses. This variation is depicted in ***Figure 5***.

CONCLUSION

A new transition from microstrip to cavity filters has been presented. This solution provides a platform for higher Q filters to be mounted via SMT, reducing connector count and required space. The increased ultimate rejection provides sharper roll-offs and enhanced dynamic range for systems. Broadband devices with extended Q are also possible.

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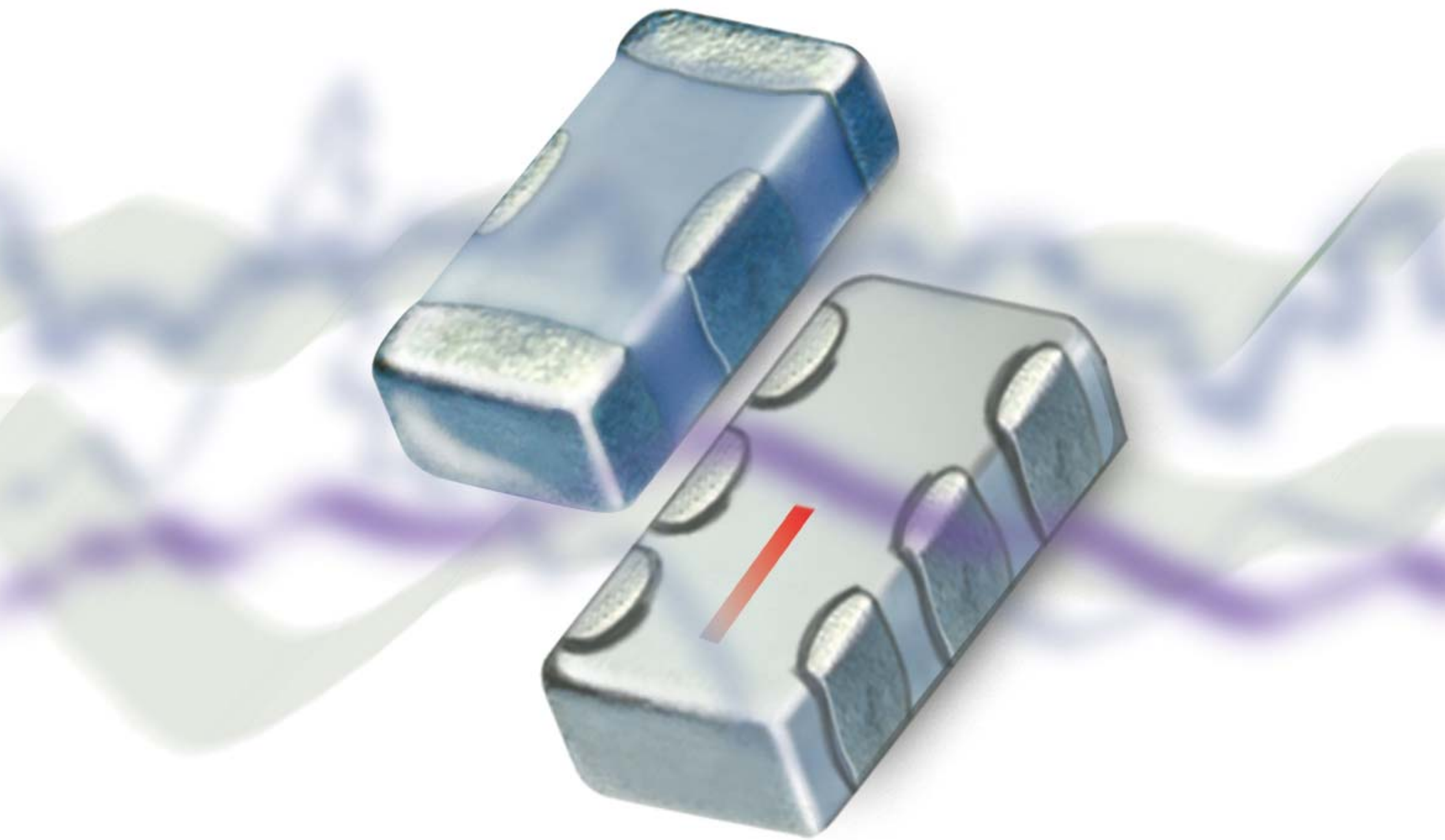

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A new and exciting technical conference, IEEE COMCAS (Conference on MW, Communications, Antennas and Electronic Systems) will be held at the Hilton Tel Aviv, Israel, May 13–14, 2008. This conference expands upon and follows the success of the local IEEE MTT/AP&AES Chapters supported meeting held every year in Tel Aviv. The last meeting was held in May 2007 with over 530 delegates participating. The new 2-day technical program is being greatly expanded to cover a variety of complementary subjects and a technology exhibition. The idea is to create a very diverse and multidisciplinary conference where engineers and scientists from various complementary electronics disciplines can meet and discuss subjects of common interest. Emphasis will be on applications oriented research and development, from antennas, device engineering to circuit applications to systems and software. Support will be provided by the local IEEE Section/Chapters for AP, MTT, AES, EMC, Com Soc and SSC. So all bases will be covered allowing for a very robust and interesting 2-day meeting. There will be lots of MW, AP, Radar, SSC, EMC and Communications folks participating so that your work and participation should be a rewarding experience.

This is an exciting opportunity to visit Israel and learn about exciting technology development from local speakers in addition to sharing ideas with the international S&T community. Prof. Linda Katehi, Provost, University of Illinois at Urbana-Champaign, and Raviv Melamed, General Manager, Mobile Wireless Group, Intel Corp., will be the keynote speakers. Dr. John Vig, President Elect for the IEEE (2008) and Mr. Elya Joffe, President of IEEE EMC Society will be involved in addition to many other distinguished representatives from the other IEEE Societies.

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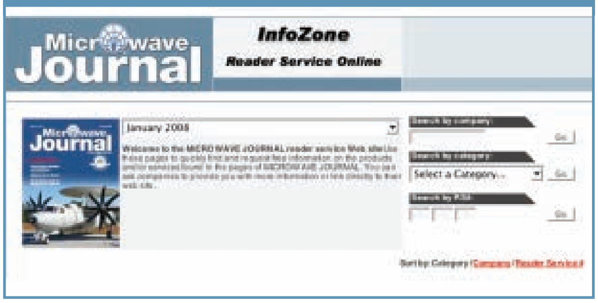
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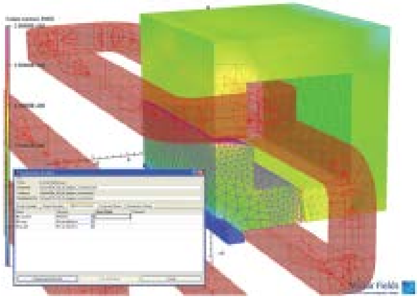


INTELLIGENT OPTIMIZATION TOOL

Optimizer is new intelligent tool for Vector Fields' electromagnetic modeling and simulation software that will automatically find the best solution to a design problem. Optimizer automatically selects and manages multiple goal-seeking algorithms to eliminate the need for manual intervention and to make optimization feasible in virtually all design cases. Optimizer works in conjunction with the Opera electromagnetic design package, which is available in general-purpose form, or with solvers dedicated to specific electromagnetic applications. The tool automatically applies and dynamically manages the algorithms to eliminate the usual requirement to perform lots of time-consuming simulations.

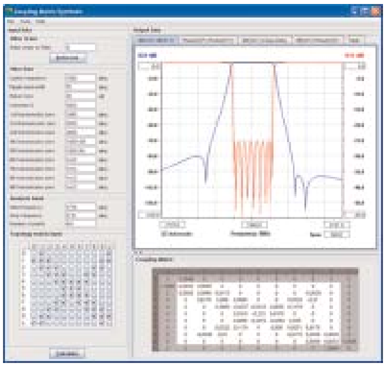
Vector Fields Inc.,
Aurora, IL (630) 851-1734, www.vectorfields.com.
RS No. 310

Vendor	Vendor Part Number	Modelithics Model Part Number	Body Style	Part Values
AVX	ACCUP	CAP-AVX-0402-001	0402	0.1 – 33 pF
Murata	GRM155R71E	CAP-MUR-0402-003	0402	4.7 – 470 nF
Taiyo Yuden	EMK042	CAP-TAI-01005-001	01005	0.5 – 15 pF
Taiyo Yuden	LJMK042	CAP-TAI-01005-002	01005	100 – 10K pF
Taiyo Yuden	TMK063	CAP-TAI-0201-001	0201	10 - 180 pF
Taiyo Yuden	JMK063	CAP-TAI-0201-002	0201	22K – 220K pF
Taiyo Yuden	EMK063	CAP-TAI-0201-003	0201	150 – 10K pF
Coilcraft	0604HQ	IND-CLC-0604-001	0604	4.5 – 10.4 nH
Murata	LQW15A	IND-MUR-0402-001	0402	1.5 – 82 nH
Murata	LQW18A	IND-MUR-0603-001	0603	2.2 – 470 nH
Taiyo Yuden	HK1005	IND-TAI-0402-001	0402	1 – 120 nH
TDK	MLG1005S	IND-TDK-0402-002	0402	1 – 390 nH
Toko	LL1005-FHL	IND-TKO-0402-101	0402	1 – 100 nH

GLOBAL MODELS LIBRARY FOR AGILENT-ADS

Modelithics Inc. has released an enhanced version of its CLR Library™ of highly scalable, passive surface-mount component global models for Agilent-ADS. This upgrade adds several new models, including 01005-, 0201-, 0402- and 0603/0604-size capacitors and inductors from vendors such as AVX, Murata, Taiyo-Yuden, Coilcraft, Toko and TDK. In addition, the 5.0 release includes a new feature that will automatically update the layout geometry for pad-scalable models to match user-specified values for the pad dimension parameters. This significant upgrade will be available free of charge to all CLR Library (for ADS) customers currently under a Modelithics Platinum Maintenance contract. This update will be available for other supported simulators in the near future.

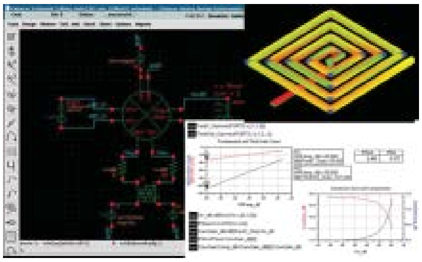
Modelithics Inc.,
Tampa, FL (813) 866-6336, www.modelithics.com.
RS No. 311



FILTER AND COUPLING MATRIX SYNTHESIS SOFTWARE

Guided Wave Technology's Filter and Coupling Matrix Synthesis software facilitates synthesis of N+2 coupling matrices for Chebyshev bandpass-filtering functions, with arbitrary finite-position transmission zeroes. The software also facilitates coupling matrix synthesis through topology matrix definition. It gives a fast and accurate overview of insertion loss, isolation, group delay and coupling coefficients versus filter order, return loss and transmission zero positions. The software allows placement of complex transmission zeroes, which opens up for group delay shaping and analysis.

Guided Wave Technology ApS,
Hilleroed, Denmark, www.guidedwavetech.com.
RS No. 312



RFIC SIMULATION SOFTWARE

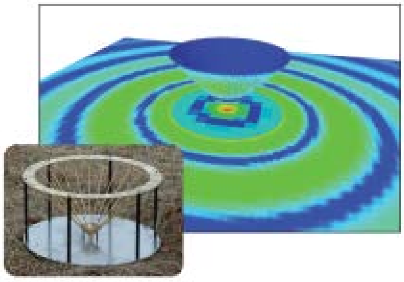
Agilent Technologies Inc. has released GoldenGate Plus for RFIC simulation, analysis and verification. Agilent's GoldenGate Plus product line speeds the design of large-scale RFICs for wireless communication products. It combines the high-capacity GoldenGate simulator, acquired from Xpedion in 2006, with a customizable data display, electromagnetic (EM) simulation, and system-level design and simulation. The GoldenGate simulator is fully integrated into the Cadence Analog Design Environment. Its unique algorithms are optimized for the challenging demands of large and complex RFIC design, and enable full characterization of complete transceivers prior to tape-out.

Agilent EEsof EDA,
Santa Clara, CA (408) 345-8886, http://eesof.tm.agilent.com.
RS No. 313

HARNESS DESIGN SOFTWARE

Tyco Electronics has introduced HarnWare V5.4, the latest version of its harness design software. HarnWare harness design software allows designers to produce drawings and specifications for a wide range of wire harnesses. The finished drawing packages produced by HarnWare contain general assembly drawings, wire lists, complete bills of material, wiring schematics, labor estimates, harness weight estimates and other items. Some of the main upgrades in HarnWare V5.4 include: IGES export options for HarnVis, support of Visio 2007 and support of Windows Vista and Vista security features. In addition to the functionality improvements, Harnware V5.4 includes a complete update to Tyco Electronics' part number and product catalog for improved component selection options.

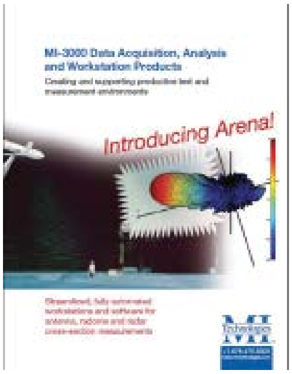
Tyco Electronics Corp.,
Berwyn, PA (610) 893-9800, www.tycoelectronics.com.
RS No. 314



LOW-PROFILE ANTENNA DESIGN FEATURE

MegaWave Corp. has applied a new absorbing boundary technique for the Flomerics MicroStripes 3D electromagnetic (EM) simulation solution that accelerates the design of low-profile and zero-profile ground antennas. In order to accurately model ground waves using electromagnetic simulation, the Earth normally needs to be modeled to at least three times the skin depth of the wave to allow space and time for the ground wave to be differentiated from the fields that propagate into the Earth that are ultimately dissipated in the dielectric losses. The new technique creates a boundary condition that absorbs the field propagating into the Earth model without disturbing the ground waves that contribute to the overall antenna radiation pattern.

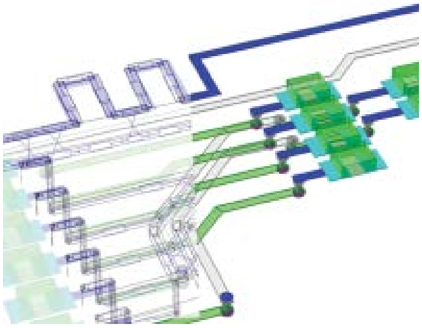
Flomerics Inc.,
Marlborough, MA (508) 357 2012, www.flomerics.com.
RS No. 315



MICROWAVE TEST AND MEASUREMENT

MI Technologies has introduced its MI-3000 Arena™ data acquisition and analysis software package. The MI-3000 Arena's user interface is specially designed to create productive work environments for antenna, radome, radar cross-section, and other microwave test and measurement applications. The MI-3000 Arena package offers four work environments: The Quick Pattern environment lets users easily collect and plot data in a focused, straightforward manner; the Standard environment provides easy access to all the features of the MI-3000; the Tool Kit environment allows users to easily set up test and measurement processes for repeatability; the Classic environment offers users the convenience of working with their familiar displays with access to all MI-3000 features.

MI Technologies,
Suwanee, GA (678) 475-8300, www.mi-technologies.com.
RS No. 316

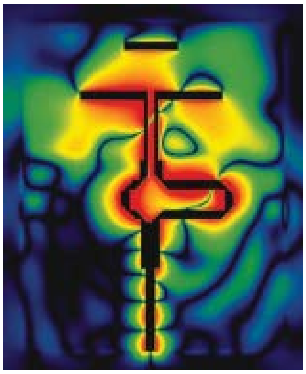


MLCC MODEL LIBRARY

Samsung Electro-Mechanics Co. Ltd. (SEMCO) has released a model library of its state-of-the-art, high-density, miniaturized, surface-mount multilayer ceramic chip capacitors (MLCC) for use with AWR's Microwave Office® design suite. The Samsung/AWR MLCC library consists of hundreds of capacitor models, including high-frequency, high-capacitance, high-voltage, low profile, super small array and low inductance ceramic capacitors (LICC). The component models themselves utilize S-parameter data taken directly from the actual device characterization process, which in turn yields excellent accuracy of the capacitor's electrical response within Microwave Office simulations (frequency- and time-domain). The Samsung MLCC library is free to AWR customers.

Applied Wave Research (AWR) Inc.,
El Segundo, CA (310) 726-3000, http://web.appwave.com.
RS No. 317

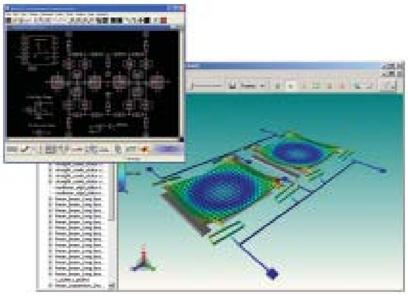

NEVER
COMPROMISE
YOUR
CONNECTION



3-D ELECTROMAGNETIC SOLVER

Remcom has released XFdtd® 6.5, the latest version of its full-wave 3-D electromagnetic solver based on the finite difference time domain (FDTD) method. XFdtd® 6.5 includes important features from previous versions, such as the patent-pending Fast Meshing Algorithm and both distributed-memory MPI cluster computing and GPU hardware acceleration. In addition, version 6.5 offers many new features and improvements, including multi-frequency sinusoidal results such as Efficiency, SAR and Antenna Patterns from one transient excitation; improved results for frequency-dependent materials using Cole-Cole parameters; periodic boundary conditions with phase shift; improved waveguide excitation; nonlinear diodes with variable parameters; Ludwig polarization; and independent specification of time delay for multiple sources.

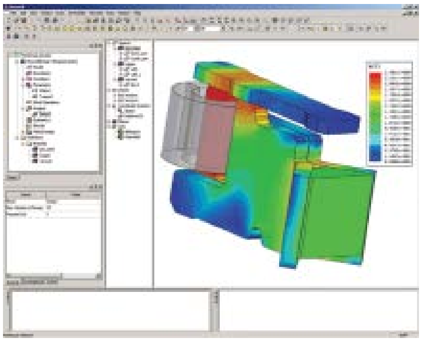
Remcom,
State College, PA (814) 861-1299, www.remcom.com.
RS No. 318



MEMS VISUALIZATION TOOL

Coventor Inc. has added a 3-D visualization tool called Scene3D to its schematic-based MEMS design environment ARCHITECT. With Scene3D, users can create 3-D views of an ARCHITECT schematic and visualize simulation results with fully contoured three-dimensional animations. ARCHITECT with Scene3D creates a rapid virtual prototyping environment for the most challenging MEMS and MEMS-enabled systems. ARCHITECT with Scene3D not only helps the user to ease the design process, but also to document and communicate from initial steps to full production across all design and management levels. ARCHITECT Scene3D provides output filters to generate 2-D masks or 3-D solid models in standard formats, making it seamlessly fit into most established design flows.

Coventor Inc.,
Cary, NC (919) 854-7500, www.coventor.com.
RS No. 319



MAXWELL MAGNET MATERIAL LIBRARY

Ansoft Corp. has announced the availability of a new library of permanent magnet materials from Shin-Etsu Magnetics Inc. for its Maxwell® electromagnetic field simulation software. The library contains data for more than 31 high-performance permanent magnets defined at different operating temperatures using rare-earth elements that can be downloaded by Ansoft customers and are ready for use within Maxwell. Permanent magnet materials are used in many applications, including motors, sensors and actuators. Maxwell users now have access to the latest materials from Shin-Etsu to use directly within their simulations of new or existing designs.

Ansoft Corp.,
Pittsburgh, PA (412) 261-3200, www.ansoft.com.
RS No. 320

EMC LAYOUT AND DESIGN SOFTWARE

As part of the curriculum in Donald Sweeney and Roger Swanberg's EMC by Your Design Seminar/Workshop (April 3, 4, 7 and 8, 2008; Hilton Hotel, Northbrook, IL), students will use, and then take home free-of-charge, a copy of the proprietary EMC Layout and Design software program created by the instructors. This proven software package addresses design considerations from component level, through circuit boards, to enclosure level, including cabling and interconnects, and enhances the theories presented both in the class and in the Mardiguian textbook. The four-day seminar/workshop is presented in a practical, hands-on style providing a step-by-step design process to avoid EMC problems.

D.L.S. Electronic Systems Inc.,
Wheeling IL (847) 537-6400, www.dlsemc.com.
RS No. 321

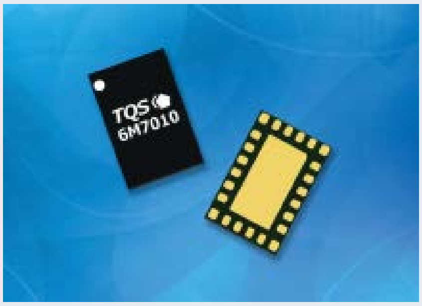
SMT Mixer

Hittite Microwave has introduced a new HMC258LC3B GaAs MMIC sub-harmonic SMT mixer intended for microwave radios, VSAT, test and measurement, instrumentation and military applications from 14.5 to 19.5 GHz. The unit has an integrated LO amplifier housed in a 3 × 3 mm leadless RoHS-compliant ceramic SMT package. The HMC258LC3B features a wide IF bandwidth of DC to 3.5 GHz, and high 2LO-to-RF isolation of 45 dB that eliminates the need for additional filtering. The HMC258LC3B features a LO amplifier with a nominal 0 dBm drive requirement and requires no external matching components, making it ideal for integrated subsystem applications. The RF and LO ports of the HMC258LC3B are DC blocked and matched to 50 Ω for design convenience, and the device consumes only 42 mA from a +5 V supply.

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

RS No. 217

WiFi Front-end Module



TriQuint Semiconductor is shipping a new Model SCM6M7010 dual-band WiFi front-end module (FEM) for wireless RF chip manufacturing, covering the 2.4 to 5.0 GHz frequency bands in the WiFi portion of RF solutions. TriQuint's new front-end module enables a size reduction and enhanced performance because all critical device functions are built into a single chip. By utilizing three modules in parallel within the RF front end, three receive and transmit "3 × 3" signal paths are available instead of one, enabling significantly higher data rates.

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

RS No. 219

P2P Driver Amplifiers

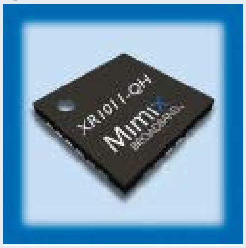
Tyco Electronics has introduced a new family of M/A-COM driver amplifiers for point-to-point (P2P) radios. The new driver amplifier family covers allocated P2P bands from 4.9 to 15.4 GHz: the M/A-COM MAAM-007523 amplifier covering 4.9 to 8.5 GHz and the MAAM-007524 amplifier covering 10.0 to 15.4 GHz. The amplifier family features +32 dBm IP3 (third-order intercept point) linearity and P1dB levels ranging from 19 to 21 dBm. They are self-biased and may be operated with drain supplies ranging from 4.5 to 8.0 V to optimize system performance including linearity, gain and power efficiency. Each amplifier part is available in bare die and plastic packaged options. M/A-COM's family of power amplifiers is RoHS-compliant and compatible with a 260°C reflow temperature.

Tyco Electronics Corp.,
Berwyn, PA (610) 893-9800,
www.tycoelectronics.com.

RS No. 220

MMIC Receiver

Mimix Broadband has introduced its XR1011-QH GaAs monolithic microwave integrated



circuit (MMIC) receiver that covers the 4.5 to 10.5 GHz frequency bands. The highly integrated receiver has a noise figure of 1.8 dB and 13 dB conversion gain across the band. The receiver integrates an image reject mixer, an LO buffer amplifier and a low noise amplifier within a fully molded 4 × 4 mm QFN package that is RoHS-compliant. The image reject mixer eliminates the need for an image bandpass filter after the amplifier to remove thermal noise at the image frequency. The XR1011-QH is well suited for wireless communications applications such as millimeter-wave point-to-point radio, local multipoint distribution services (LMDS), SATCOM and VSAT.

Mimix Broadband Inc.,
Houston, TX (281) 988.4600,
www.mimixbroadband.com.

RS No. 221

Custom Switch Matrix

The Renaissance DC–6 GHz multifunctional WiMAX custom matrix is compact and designed with instrumentation to the DUT ports that are synthesized to a custom RF configuration. With a total of two DUT ports, six instrument ports, and six auxiliary ports, this RF head-end switch matrix contains combiners, switches, programmable attenuators and required components for RF modulation. The industry standard 19-in. rack-mounted switch matrix occupies a space of 2U. The six auxiliary ports aid in the calibration of six corresponding instrument ports and are controlled using a GPIB/IEEE-488.2 interface.

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

RS No. 222

RF Power Divider

Narda Microwave-East's 4436 RF power divider covers 500 MHz to 8 GHz and is available in two-way, three-way, four-way and eight-way versions. Insertion loss ranges from 1.0 to 1.5 dB in the two-way version (depending on frequency) 2.0 to 3.0 dB in the three-way version, 1.5 to 4.5 dB in the four-way version and 2.0 to 8.0 dB in the eight-way version. Isolation is 12 to 20 dB in the two-way version, 12 to 18 dB in the three-way version and 12 to 17 dB in the four-way and eight-way versions. Phase balance of all versions ranges from 6° to 15°. The 4436 accepts a CW RF input power of 500 mW CW and 1.5 kW peak and operates over a temperature range of 0° to +70°C with humidity up to 95 percent (non-condensing).

Narda Microwave-East,
Hauppauge, NY (631) 231-1700,
www.nardamicrowave.com.

RS No. 223

WiMAX Power Divider

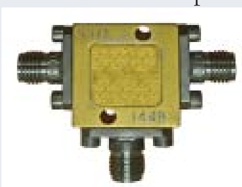
Response Microwave has introduced a new application-specific series of power dividers/combiners for signal routing within WiMAX distribution applications. The family includes two- and four-way units that operate between 800 to 6000 MHz. Electrical performance offers typical insertion loss of 0.45 dB, isolation of 22 dB minimum, VSWR of 1.25:1 typical, phase unbalance of 5° maximum and amplitude unbalance of 0.5 dB maximum. Power handling of up to 50 W CW is available. The new devices are available with SMA female connectors standard and alternate interfaces, including reverse polarity, upon request.

Response Microwave Inc.,
Devens, MA (978) 772-3767,
www.responsemicrowave.com.

RS No. 224

Impedance-matched Pickoff Tee

Picosecond Pulse Labs has announced its new Model 5372 14 dB impedance-matched pickoff tee. The Model 5372 provides exceptional impedance matching on the through-line of the pickoff tee, minimizing unwanted signal re-



flections. The Model 5372 provides an impedance match (–25 dB) that rivals a power divider and an insertion loss (–2 dB) that is only moderately higher than a pickoff tee. The Model 5372's performance is useful for applications such as serial data testing where the clock is embedded in the data signal. Additional applications include picking off a portion of the signal for triggering and other measurement purposes.

Picosecond Pulse Labs Inc.,
Boulder, CO (303) 443-1249,
www.picosecond.com.

RS No. 226

Cavity Topology Filter

The EWT-11-0515 is a cavity topology filter for WiMAX applications. It is factory tunable from 3400 to 3600 MHz. The pass band insertion loss is 2.5 dB at center frequency ±3.5 MHz and > 20 dB at center frequency ±7 MHz. VSWR is 1.5:1 over the pass band frequency range. The EWT-11-0515 has Type N connectors standard, but other options are available. The package size is 3.0 × 3.0 × 1.5 in.

EWT Inc.,
Salisbury, MD (410) 749-3800,
www.ewtfilters.com.

RS No. 227

Coax Circulator

Raditek's new RADC-225-400-N23-400WR coaxial circulator model covers the 225 to 400 MHz band. Performance is 1.0 dB insertion loss, 17 dB isolation and 1.4:1 VSWR at –15° to +35°C, and 1.5 dB insertion loss, 15 dB isolation and 1.5:1 VSWR over the full operating temperature range of –10° to +50°C. The RADC-225-400-N23-400WR features 400 watts of reflected power handling.

Raditek,
San Jose, CA (408) 266-7404,
www.raditek.com.

RS No. 228

Variable Attenuator/Modulator

American Microwave Corp. is offering its Model AGT-2018-60D-100 Option RW, a

broadband variable attenuator/modulator with 60 dB dynamic range designed to operate over frequencies of 0.5 to 18 GHz. The unit has a rise and fall time of 3 µsec maximum, a VSWR of 2.2:1 maximum, an insertion loss of 5.2 dB maximum and a transfer function of 10 dB/V. The size of the unit is 2.0 × 1.81 × 0.50 in.

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

RS No. 229

2.0 to 18.0 GHz Power Divider

Planar Monolithics Industries is offering offer its Model ADP-2-218-M-BB Miniature

Power Divider. This power divider is designed to operate from 2.0 to 18.0 GHz, with an insertion loss of 2.2 dB maximum, isolation of 16.0 dB minimum and a VSWR of 2.0:1 maximum. Power handling is 1.5 W at 2.0:1 VSWR and 2.0 W at 1.2:1 VSWR. The size is 0.779 × 1.026 × 0.300 in. with the connector shrouds removed.

Planar Monolithics Industries (PMI) Inc.
Frederick, MD (301) 631-2029,
www.planarmonolithics.com.

RS No. 230

Quad-phase Modulator

The MITEQ Model SMT2640LC15MDQ is a 2-bit TTL-controlled millimeter-wave quadphase modulator with an operational frequency range of 26 to 40 GHz and modulation rates from DC to 40 MHz. The Model SMT2640LC15MDQ has a typical phase balance of < ±15 degrees and an amplitude balance of < ±2.5 dB.

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

RS No. 231

SMA Switch

RLC Electronics' Micro Miniature SMA Switch is a single pole two-position type. The

switch incorporates SMA connectors to allow high-density packaging and excellent electrical performance through 26.5 GHz. The switch is available in failsafe and latching configurations with a choice of three different frequency ranges and three different coil voltages.

RLC Electronics Inc.,
Mount Kisco, NY (914) 241-1334,
www.rlcelectronics.com.

RS No. 232

Ceramic Quadraplexer

Lorch Commercial and Wireless (LCW) offers its DR-1737/2140, a ceramic quadraplexer for the GSM and UMTS frequencies. The DR-1737/2140 quadraplexer exhibits less than 3.0 dB of insertion loss across the passbands of 1710 to 1765 MHz and 1805 to 1860 MHz, and less than 2.0 dB of insertion loss across the passbands of 1920 to 1980 MHz and 2110 to 2170 MHz while providing greater than 45 dB of rejection. The unit measures 3.4 × 1.0 × 0.4 in.

Lorch Commercial and Wireless,
Salisbury, MD (866) 729-8509,
ww.lorchwireless.com.

RS No. 233

Ceramic GPS Diplexer

The Reactel 2DX-1227/1575-M is a ceramic diplexer that passes both the L1 and the L2 GPS frequencies. It is the perfect unit for applications requiring small size and high performance. This ultra low profile unit features loss of less than 1 dB and isolation in excess of 40 dB.

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

RS No. 234

4 GHz Attenuators

Coaxial Dynamics has announced its new broadband 6902-BNCF series of 2 W BNC at-

tenuators rated from DC to 4 GHz, which includes WiMAX, WiFi and WiBro testing applications. VSWR is 1.25:1 maximum through 4 GHz and the accuracy is ±0.3 dB to 6 dB, ±0.5 dB to 20 dB and ±0.75 dB to 30 dB. Standard dB values include 3, 6, 10, 20 and 30 dB with others available on special order. All BNC models have bi-directional operation and other connector types are available. The length is 1.4 in. maximum.

Coaxial Dynamics,
Middleburg Heights, OH (440) 243-1100,
http://coaxial.com.

RS No. 236

COMPONENTS

High-power Connectors and Contacts

Anderson Power Products' (APP) High Power (45 amp) Connector and Contact Series is for applications that require high-power connectors to a PCB. The High Power Connector and Contact Series may be pre-assembled in one- or two-row configurations, reducing assembly costs and eliminating accidental connector separation. Connectors and contacts are also available separately, allowing for customization of connector configurations. The connectors are RoHS-compliant, have a UL rating of 45 amps per circuit and utilize contacts that are composed of copper alloy with tin plating. The connectors are available in many colors and with multiple accessories that include mounting wings, spacers and board mounting staples.

Anderson Power Products,
Sterling, MA (978) 422-3600,
www.andersonpower.com.

RS No. 225

SMP Blind-mate Connectors

Johnson® a wholly-owned subsidiary of Emerson Network Power, has introduced a new line of SMP Blind-mate Connectors that can handle frequencies up to 40 GHz. This new precision connection interface is a micro-miniature, slide-on/snap-on interconnect system that's ideal for high-density packaging. The system can correct axial and radial misalignment and is compatible with all SMP and GPO® connectors. To achieve optimum performance, Johnson's new line of SMP Blind-mate Connectors includes 26 different connectors, adapters and mounts and nine new assembly tools. The company is also providing detailed assembly instructions and makes use of industry standard tooling whenever possible for customer convenience and compatibility.

Emerson Network Power,
Columbus, OH (614) 888-0246,
www.emersonnetworkpower.com.

RS No. 235

AMPLIFIERS

RF Power Amplifier

The Advanced RF Amplifier Model BCPA-800-4000-2C is suitable for delivering reliable output power over the instantaneous frequency range of 800 to 4000 MHz. The PA is ideal for military communications and jamming platforms as well as commercial applications, such as WiMAX. Suitable for both linear and compressed amplifier applications, the PA utilizes the latest in GaN HEMT device technology.

BC Systems Inc.,
Setauket, NY (631) 751-9370,
www.bcpowersys.com

RS No. 238

RF Amplifier

The Aethercomm Model SSPA 0.5-2.5-50 is a high power, broadband, GaN RF amplifier that operates from 500 to 2500 MHz. This amplifier was designed for broadband jamming and communication systems platforms. It is packaged in a modular housing that is approximately 6.4 × 3.4 × 1.06 in. It has a typical P3dB of 40 to 50 W and noise of 10.0 dB at room temperature. Typical gain is 53 dB with a gain flatness of ±2.5 dB. Input VSWR is 2.0:1 maximum. Class AB quiescent current employing a +28 VDC supply is ~2.0 amps, typical. The Model SSPA 0.5-2.5-50 operates from a +28 VDC input voltage.

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

RS No. 237

Solid-state Amplifier

Stealth Microwave's SMTR2425-11B40 is a solid-state amplifier for use in 802.11b WLAN systems. This SSPA utilizes state-of-the-art LDMOS FET transistors that allow for more efficient operation while still meeting EVM and spectral mask requirements. Designed primarily for military use, the design can be applied for various ISM band applications as well. Features include automatic gain control circuitry that provides consistent 10 W output over a wide input range, an LED Tx/Rx mode status indicator, a +12 V power supply (a +28 V version is available), a rugged weatherproof housing and various available DC/RF connector options.

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

RS No. 239

Switch Filter Amplifier

Lark has engineered a new Switch Filter Amplifier (SFA) series that is available in both ce-

Voltronics Corp
Chip Trimmer Capacitors are the Smart Choice!
Our Chip Trimmer Capacitors
■ Stability Better Than ±1%
■ RoHS Compliant
■ Immediate Delivery
JZ
JR
JV
Actual Size
JQ
JN
Delivery:
Up to 50,000 pieces stock to 4 weeks on most parts!
Voltronics CORPORATION
The Trimmer Capacitor Company
A DOVER COMPANY
RoHS COMPLIANT
CERTIFIED ISO 9001
100 Ford Road, Denville, NJ 07834
973.586.8585 • Fax: 973.586.3404 • e-mail: info@voltronicscorp.com
www.VoltronicsCorp.com
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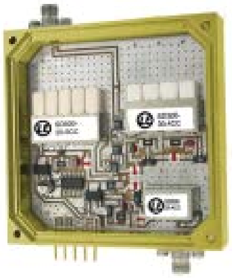


ramic and lumped element configurations. The SFA series offers a frequency range of 100 to 3000 MHz with a bandwidth range of 1 to 40 percent with a typical return loss of 18 dB/14 dB. The noise figure of 1.5 to 5.0 dB combined with 300 ns switching speed, 10 to 40 dB gain and bias of 10 and 5 VDC make Lark SFAs useful for receiver applications and improvement of overall system performance.

Lark Engineering Co.,
San Juan Capistrano, CA (949) 240-1233,
www.larkengineering.com.

RS No. 240

SOURCES

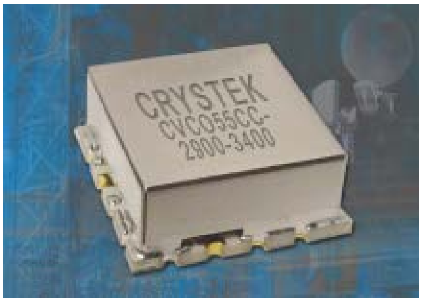
Coaxial Resonator Oscillator

Z-Communications Inc. has introduced its new CRO2780D-LF lead-free, RoHS-compliant, coaxial resonator oscillator for the S-band (2745 to 2815 MHz), featuring ultra-low phase-noise performance of -110 dBc/Hz at 10 kHz offset. This design offers typical tuning sensitivity of 31 MHz/V. It is designed to provide 8 dBm output power (typical) at 5 VDC supply while drawing 20 mA (typical) over the extended operating temperature range of –40° to 85°C. The oscillator comes in Z-Communications' industry-standard MINI package, measuring 0.50 × 0.50 × 0.22 in. This VCO is ideal for automated surface-mount assembly and reflow.

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

RS No. 241

2900 to 3400 MHz VCO



Crystek's CVCO55CC-2900-3400 VCO operates from 2900 to 3400 MHz with a control voltage range of 0.5 V~18 V. This VCO features a typical phase noise of –107 dBc/Hz at 10 kHz offset and has excellent linearity. The model CVCO55CC-2900-3400 is packaged in the industry standard 0.5 × 0.5 in. SMD package. Input voltage is 8.0 V, with a max current consumption of 35 mA. Pulling and pushing are minimized to 0.5 MHz and 1.0 MHz/V, respectively. Second harmonic suppression is –16 dBc typical. The CVCO55CC-2900-3400 is ideal for use in applications such as digital radio equipment, fixed wireless access, satellite communications systems and base stations.

Crystek Corp.,
Ft. Myers, FL (239) 561-3311,
www.crystek.com.

RS No. 242

Frequency Synthesizers

ITT Microwave Systems has introduced two new models in its WaveCor™ line of high performance frequency synthesizers. The WaveCor™ 5.0 and the WaveCor™ 10.0 synthesizers operate over a frequency range of 300 MHz to 5.0 GHz and 300 MHz to 10.0 GHz, respectively. Both frequency synthesizers provide low phase noise and exceptional spurious levels combined with extremely fast switching speeds. Both models are available in a 3U rack-mount chassis.

ITT Microwave Systems,
Lowell, MA (978) 441-0200,
www.ittmicrowave.com.

RS No. 243

SUBSYSTEM

Cooling Filters

The new GORE® Cooling Filters use ambient air to cool electronic components in outdoor enclosures and Gore's membrane technology to protect sensitive electronics from extreme environments where they may encounter corrosive particles, sand, or salty environments. The technology behind the GORE® Cooling Filters is based on a proprietary expanded polytetrafluoroethylene (ePTFE) membrane. This microporous membrane allows cool, clean air to flow into the cabinet while screening out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harmful contaminants and has a 99.0 percent particle filtration efficiency at the 0.3 µm level (1 cm/sec). GORE® Cooling Filters incorporate high performance Gore Series 3000 filtration media into a rigid anodized aluminium frame, providing the most reliable protection possible. Cabinets fitted with GORE® Cooling Filters easily pass the most stringent requirements, including IP55 and NEMA 3R. GORE® Cooling Filters can be customized to fit small to large base station units for mobile communication that cover a wide range of wireless infrastructure such GSM, UMTS, WiMAX and LTE. They are also appropriate for wire-lined cabinets such as ADSL and power enclosure applications.
W. L. Gore & Associates Inc.,
Newark, DE (410) 506-7787, www.gore.com.

RS No. 245

TEST EQUIPMENT

Log Periodic Antenna

AR RF/Microwave Instrumentation has redesigned its popular AT5080 log periodic antenna to extend its frequency coverage. The new model AT6080 extends from 80 MHz to 6 GHz for radiated EMC testing. The exceptionally broad frequency range addresses existing RF susceptibility requirements as well as anticipated future developments. The frequency range is also matched to work directly with AR "W" and "S" Series RF power amplifiers. The robust design can accommodate the high power levels necessary to generate significant E-fields. The AT6080 can also be calibrated for RF emissions testing.

AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.arww-rfmicro.com.

RS No. 244

Handheld Spectrum Analyzer

Boonton has introduced a new 9103 handheld spectrum analyzer operating at frequencies up to 7.5 GHz. The instrument supports many microwave applications, featuring the typical measurements of standard desktop spectrum analyzers such as channel power, occupied bandwidth and adjacent channel power ratio. Boonton's 9103 supports a wide range of applications with accessories for cable faultfinding, EMC and radiation measurements. Applications covered with the 9103 handheld spectrum analyzer include aviation signals, directional radio, VSAT and signals in the 5 GHz unlicensed band, such as Wireless LAN and WiMAX. RFID signals are best analyzed in the zero-span mode provided by the spectrum analyzer.

Wireless Telecom Group Inc.,
Parsippany, NJ (973) 386-9696, www.boonton.com.

RS No. 216

12.5 Gbps 1:8 Demultiplexer

Inphi Corp.'s 1385DX 12.5 Gbps 1:8 demultiplexer with latched comparator input enables test and measurement, defense and aerospace designers to develop high speed data acquisition front ends and to deserialize high speed signals. Part of the High Speed Logic family of devices, the 1385DX operates at bit rates from DC to 12.5 Gbps. The 1385DX features a high-speed sampling clock and high-bandwidth latched comparator input that can be used to sample high-bandwidth analog signals and demultiplex them to a lower data rate for post-processing via a low

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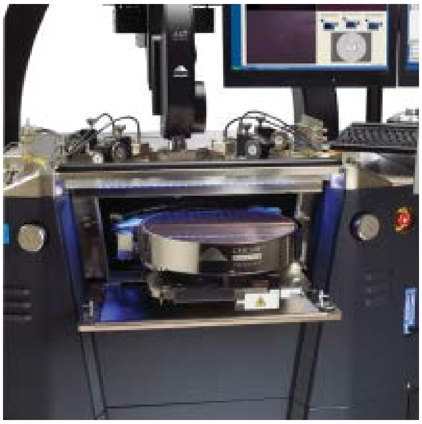
speed FPGA or ASIC. The 1:8 deserialization, coupled with an on-chip synchronization circuit and adjustable output levels, allows the use of multiple demultiplexers in parallel, with automatic alignment of the parallel output buses of the demultiplexers.

Inphi Corp.,
Westlake Village, CA (805) 446-5100,
www.inphi-corp.com.

RS No. 247

300 mm Wafer Probing Station



Cascade Microtech introduced its new Elite 300, 300 mm wafer probe stations for advanced on-wafer measurements for semiconductor devices. Based on the company's Cascade family of wafer probing products, the Elite 300 handles process nodes at 45 nm and below. Elite 300 applications include RF/DC device characterization and modeling, wafer-level reliability, IC failure analysis and design debug. To meet a variety of market needs, the Elite 300 is available in three station models: The Elite 300/AP features PureLine II, AttoGuard and MicroChamber technologies, with a premium package of automation tools. The Elite 300/M includes the MicroChamber, while the Elite 300/S features an open platen with safety enclosure.

Cascade Microtech Inc.,
Beaverton, OR (503) 601-1000,
www.cascademicrotech.com.

RS No. 246

The International Microwave Symposium is the headline conference of the IEEE Microwave Theory and Techniques Society (MTT-S). This will be the largest technical Conference to be held in Atlanta in the next two years and will feature a large trade show as well as a wide variety of technical papers and workshops. The IEEE MTT-S International Microwave Symposium 2008 (IMS2008) will be held in Atlanta, GA, Sunday, June 15 through Friday, June 20, 2008, as the premiere event of Microwave Week 2008.

MICROWAVES ON MY MIND ATLANTA IMS2008 INTERNATIONAL MICROWAVE SYMPOSIUM June 15–20, 2008

Microwave Week 2008: The IMS 2008 technical sessions will run from Tuesday through Thursday of Microwave Week. Workshops will be held on Sunday, Monday and Friday. In addition to IMS2008, a microwave exhibition, a historical exhibit and the RFIC Symposium (www.rfic2008.org) will also be held in Atlanta during Microwave Week 2008.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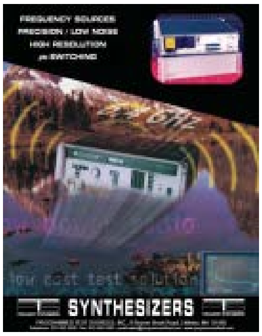
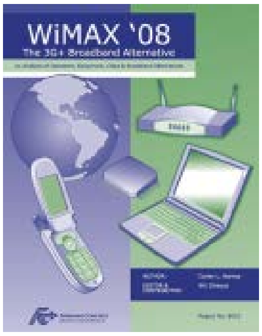


This catalog describes the complete line of frequency synthesizers from Programmed Test Sources Inc. (PTS). These synthesizers produce fast-switching, low phase-noise precision frequencies. With easy remote programming, they are vital in advanced measurement or production systems and also serve as stand-alone test equipment.

Programmed Test Sources Inc., Littleton, MA (978) 486-3400, www.programmedtest.com.

RS No. 200

WIMAX MARKET STUDY



Forward Concepts has published its newest in-depth study of the global WiMAX market. The new 300-page study, "WiMAX '08: The 3G+ Broadband Alternative," is an in-depth analysis of operators, equipment, chips and broadband alternatives, both wired and wireless. The study provides equipment and chip forecasts by type through 2012.

Forward Concepts, Tempe, AZ (480) 968-3759, www.fwdconcepts.com.

RS No. 201

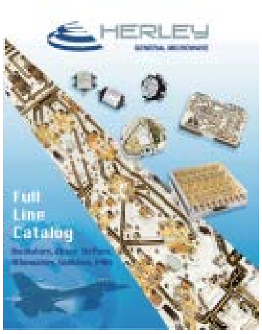
ELECTRO-MECHANICAL CATALOG

Allied Electronics, a subsidiary of Electrocomponents plc, has released its 2008 catalog featuring 10 new manufacturers and more technical information and product photos than ever before. The 2008 Allied catalog showcases more than 100,000 products from over 300 suppliers, including new suppliers such as Ametek Pittman, Crystek, Hirschmann, Marathon, OPTEK, Pass & Seymour, Pico and RECOM. Allied has significantly expanded its product offering of pneumatics and has enhanced its connector section to make it easier to find products.

Allied Electronics Inc., Fort Worth, TX (800) 433-5700, www.alliedelec.com.

RS No. 202

COMPONENTS CATALOG

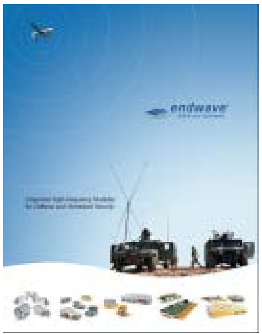


Herley Industries has released its new Full Line Components Catalog. The publication includes full color photographs, block diagrams and salient performance characteristics of control components, including oscillators, phase shifters, attenuators and switches. The company has introduced a number of new products, including a line of fast indirect synthesizers (FIS), which include compact and low phase noise models.

Herley Industries Inc., Lancaster, PA (631) 630-2020, www.herley.com.

RS No. 203

HF MODULES FOR DEFENSE



This catalog details Endwave Defense Systems' product capabilities in single function and multifunction components and subsystems. The company's products operate from 1 to 100 GHz and include integrated transceivers, JCA amplifiers, oscillators, synthesizers, up/down-converters, frequency multipliers, and microwave switch arrays.

Endwave Defense Systems Inc. (EDSI), San Jose, CA (408) 522-3180, www.endwave.com.

RS No. 204

OFDM WHITE PAPER

Orthogonal frequency division multiplexing (OFDM) is a form of digital modulation used in a wide array of communications systems. OFDM is spectrally efficient, carrying more data per unit of bandwidth than such services as GSM and W-CDMA. OFDM tolerates environments with high RF interference. Finally, OFDM works well in harsh multi-path environments. This white paper explains what OFDM is, why it's important, where it's used, and what test instrumentation is required to maintain it.

Keithley Instruments Inc., Cleveland, OH (440) 248-0400, www.keithley.com.

RS No. 205

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SPST								
0.2 – 2	SW1-002020RN1NF	1.7	70	1.6:1	10/10	20	35	35/70
2 – 8	SW1-020080RN1NF	2	80	1.7:1	10/10	20	35	35/70
4 – 12	SW1-040120RN1NF	2.2	80	1.7:1	10/10	20	35	35/70
2 – 18	SW1-020180RN1NF	3	80	2:1	10/10	20	35	35/70
1 – 18	SW1-010180RN1NF	3	70	2:1	10/10	20	35	35/70
SP2T								
0.2 – 2	SW2-002020RN1NF	1.5	70	1.6:1	10/10	20	35	60/60
2 – 8	SW2-020080RN1NF	1.8	80	1.7:1	10/10	20	35	60/60
4 – 12	SW2-040120RN1NF	2.2	80	1.7:1	10/10	20	35	60/60
2 – 18	SW2-020180RN1NF	2.8	80	2:1	10/10	20	35	60/60
1 – 18	SW2-010180RN1NF	3	70	2:1	10/10	20	35	60/60
SP3T								
0.2 – 2	SW3-002020RN1NF	1.6	70	1.6:1	20/20	150	180	85/85
2 – 8	SW3-020080RN1NF	1.9	80	1.7:1	20/20	150	180	85/85
4 – 12	SW3-040120RN1NF	2.4	90	1.7:1	20/20	150	180	85/85
2 – 18	SW3-020180RN1NF	3	80	2:1	20/20	150	180	85/85
1 – 18	SW3-010180RN1NF	3.1	70	2:1	20/20	150	180	85/85

Note: The above models are all reflective switches. Absorptive models are also available, please contact MITEQ.

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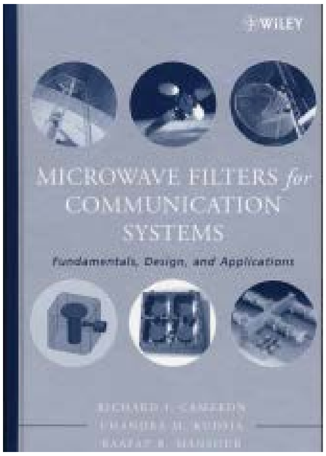
Microwave Filters for Communication Systems: Fundamentals, Design and Applications



R.J. Cameron, C.M. Kudsia and R.R. Mansour
Wiley Interscience • 802 pages; $135
ISBN: 978-0-471-45022-1

This book captures the fundamentals and practical aspects of modern microwave filter design. Chapter 1 is devoted to an overview of communication systems. The principles that unify communication theory and circuit theory approximations are explained in Chapter 2. Chapter 3 describes the synthesis of the characteristic polynomials to realize the classical maximally flat, Chebychev and elliptic function low pass prototype filters. Chapter 4 presents the synthesis of characteristic polynomials of low pass prototype filters with arbitrary amplitude response using a computer-aided optimization technique. Chapter 5 provides a review of the basic concepts used in the analysis of multiport microwave networks. Chapter 6 reviews some important scattering parameter relations. In Chapter 7, filter synthesis based on the [ABCD] matrix is described. In Chapter 8, the concept of a N × N coupling matrix is presented. Chapter 9 develops methods of similarity transformation to realize a wide range of topologies. Two unusual circuit sections are introduced in Chapter 10. Theoretical and experimental techniques for evaluating the resonant frequency and unloaded-Q of microwave resonators are described in Chapter 11. Chapter 12 addresses the synthesis techniques for the realization of low pass filters. Chapter 13 deals with the practical design of dual-mode bandpass filters. Chapter 14 presents the use of EM simulators for designing microwave filters. Chapter 15 offers several techniques for EM-based design of microwave filters. Chapter 16 develops the design of dielectric resonator filters. Chapter 17 deals with the analysis and synthesis of allpass networks. Chapter 19 is devoted to the computer-aided techniques for tuning microwave filters. Chapter 20 deals with the high power considerations in the design of microwave filters and multiplexing networks.

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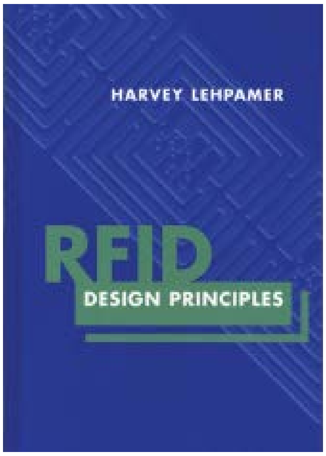
RFID Design Principles



Harvey Lehpamer
Artech House • 283 pages; $99, £55
ISBN: 978-1-59693-194-7

Radio frequency identification (RFID) is an emerging technology and one of the most rapidly growing segments of today's automatic identification data collection (AIDC) industry. However, this emerging technology is not new; in fact, it is currently being used in numerous applications throughout the world. It was originally implemented during World War II to identify and authenticate allied planes in an identification system known as Identification, Friend or Foe.

RFID usage is steadily increasing and companies across many industries are now looking at RFID to streamline operations, meet regulatory requirements and prevent the introduction of counterfeit products into the supply chain to protect both customer safety and company profitability. Industry experts view RFID not as competition with, but as a complement to barcode technology. RFID technology, in fact, overcomes certain limitations found in some barcode applications. This book introduces prospective users and system designers to the basics of RFID technology, including applications, benefits, technical characteristics, security and privacy, and standardization, design and implementation of RFID's technical and economic challenges. Numerous issues beyond the detailed technical and sheer operational capabilities of RFID must be considered. Due to the large number of considerations that must be undertaken, only a few intangible and theoretical considerations, such as security, privacy, social, ethical and future considerations are presented. In addition, a wide number of new and exciting topics and concepts are briefly introduced, some of them, at least at this point, only marginally of interest to RFID, with the hope of piquing readers' interest in pursuing these new technologies.

To order this book, contact:
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MCA1-12GL	4	3800-12000	6.5	38	11.95
MCA1-24	7	300-2400	6.1	40	5.95
MCA1-42	7	1000-4200	6.1	35	6.95
MCA1-60	7	1600-6000	6.2	30	7.95
MCA1-85	7	2800-8500	5.6	38	8.95
MCA1-12G	7	3800-12000	6.2	38	10.95
MCA1-24LH	10	300-2400	6.5	40	6.45
MCA1-42LH	10	1000-4200	6.0	38	7.45
MCA1-60LH	10	1700-6000	6.3	30	8.45
MCA1-80LH	10	2800-8000	5.9	35	9.95
MCA1-24MH	13	300-2400	6.1	40	6.95
MCA1-42MH	13	1000-4200	6.2	35	7.95
MCA1-60MH	13	1600-6000	6.4	27	8.95
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U.S. Patent # 7,027,795

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Germany
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jwissling@horizonhouse.com

Israel
Oreet Ben Yaacov
Oreet International Media
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5-10 GHz Mimix SmartSet	Buffer Amplifier	XB1007-QT	4.0-11.0	23.0	+/-1.5	4.5	+20.0	+30.0	100 @ 4.0	3x3
	Power Amplifier	XP1035-QH	5.9-9.5	26.0	+/-1.0	-	+29.0	+39.0	500 @ 6.0	4x4
	Power Amplifier	XP1039-QJ	5.9-8.5	15.0	+/-1.0	-	+34.5	+49.0	1150 @ 8.0	6x6
	Receiver	XR1011-QH	4.5-10.5	13.0	+/-1.0	1.8	+6.0	+16.0	130 @ 4.0	4x4
	Doubler	XX1002-QH	5.0-12.0 fout	16.0	+/-1.5	-	+16.0 Psat	-	125 @ 5.0	4x4
	Transmitter	XU1012-QH	5.0-10.0	-8.0	+/-1.0	-	+7.0	+17.0	120 @ 4.0	4x4
10-16 GHz Mimix SmartSet	Buffer Amplifier	XB1008-QT	10.0-21.0	17.0	+/-2.0	4.5	+19.0	+32.0	100 @ 4.0	3x3
	Power Amplifier	XP1033-QT	12.5-16.5	15.0	+/-1.0	-	+25.0	+35.0	460 @ 5.0	3x3
	Power Amplifier	XP1034-QH	12.5-16.5	19.0	+/-1.0	-	+30.0	+40.0	700 @ 7.0	4x4
	Receiver	XR1007-QD	10.0-18.0	13.5	+/-1.0	2.7	+5.0	+15.0	150 @ 5.0	7x7
	Doubler	XX1000-QT	15.0-45.0 fout	10.0	+/-2.0	-	+18.0 Psat	-	200 @ 5.0	3x3
	Doubler	XX1002-QH	5.0-12.0 fout	16.0	+/-1.5	-	+16.0 Psat	-	125 @ 5.0	4x4
	Transmitter	XU1014-QH	8.0-18.0	-10.0	+/-1.0	-	+2.0	+12.0	80 @ 4.0	4x4

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