Vol. 49 • No. 1

January 2006

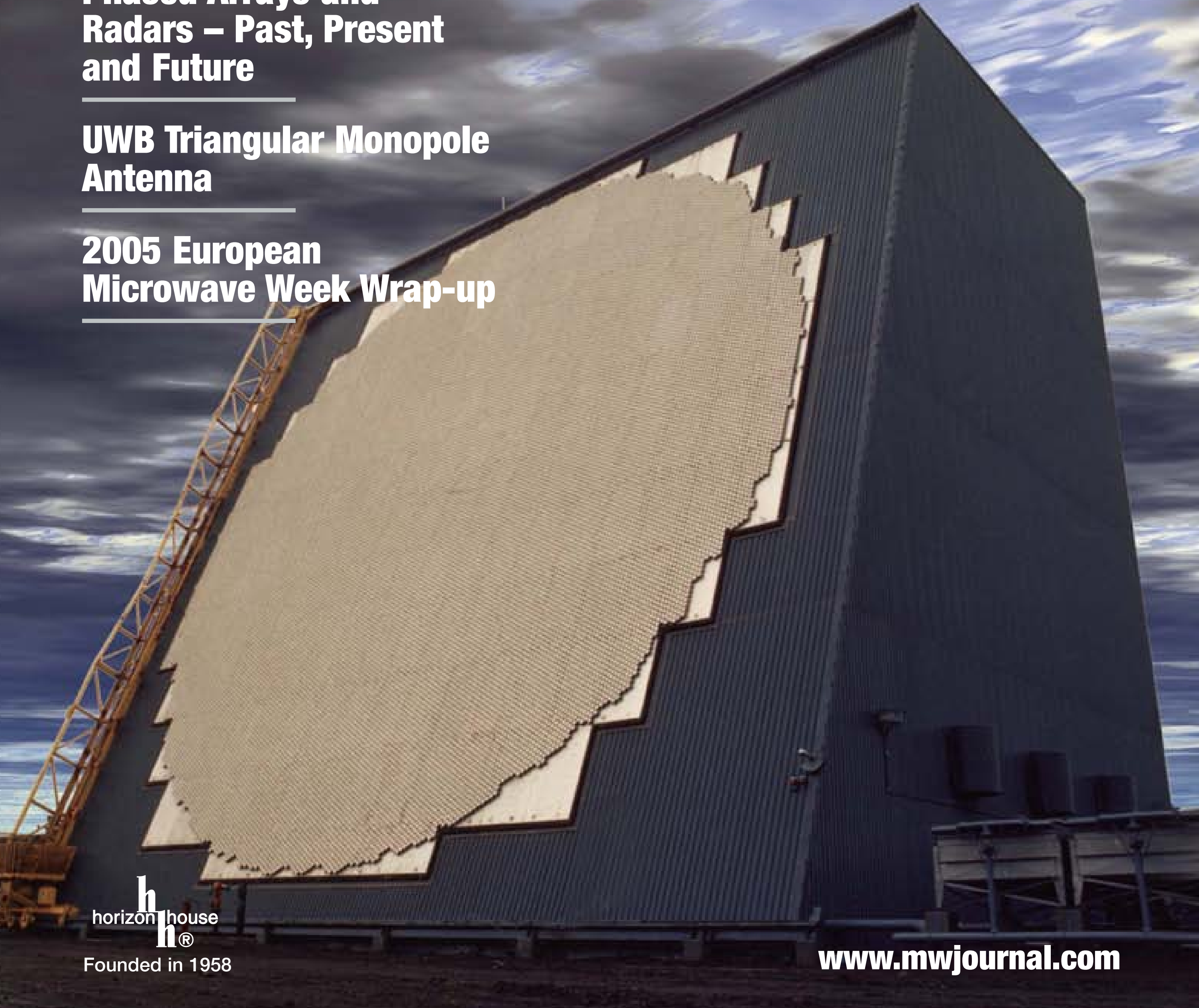
Microwave Journal

Radar/Antennas

Phased Arrays and Radars – Past, Present and Future

UWB Triangular Monopole Antenna

2005 European Microwave Week Wrap-up



horizon house
Founded in 1958

www.mwjournal.com

JANUARY 2006 VOL. 49 • NO. 1

FEATURES

49 Years of Publishing Excellence

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

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

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

Posted under Canadian international publications mail agreement #0738654

Microwave Journal

FEATURES

TECHNICAL FEATURES

PRODUCT FEATURES

DEPARTMENTS

STAFF

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

EUROPE

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

CORPORATE STAFF

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

Executive Editorial Office:

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

European Editorial Office:

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

www.mwjournal.com

Printed in the USA

2006... THE YEAR OF THE DOG

It seems only fitting to recognize the Chinese New Year, with all of the attention being paid these days to the Asian market. Greater China has evolved into the most dynamic market in the world, with vast implications for the microwave industry. With that in mind, *Microwave Journal* will publish a "Special Report" in the March issue, written by market expert Jack Daniels of EastBridge Partners, LLC. Jack will discuss the current state of the microwave industry in China and present options for entry into Greater China. Watch for this and other timely articles focused on emerging markets and technologies this year. This month, industry icon Eli Brookner of Raytheon presents an overview of phased arrays and radars in the "Cover Story," as we continue our monthly features addressing the current state and future trends of specific product sectors. If you were unable to attend last October's European Microwave Week event, check out European Editor Richard Mumford's recap in this month's "Special Report."

I'm pleased to announce the launch of the completely redesigned www.mwjournal.com, to debut next month. We've taken the hundreds of articles contained in our archives and added lots of new and unique resources to create a dynamic portal to the RF/microwave industry. You'll find daily news updates, complete event listings and links, and a directory of manufacturers that provides easy access to company and product information from over 1000 manufacturers. New features include the "Custom Cable Assembler" and "RF to Light 100" index, resources unique to our web site. The "Ask Harlan" column will be expanded and will soon be featured on-line and in print. Readers will be invited to submit answers to the featured "Question of the Month," with the chosen answer appearing in *Microwave Journal* and all of the answers appearing on our web site, along with editor Harlan Howe's answers and insight.

The *Microwave Flash* e-mail newsletter has a new look and new features this year as well. You'll find the latest news, product announcements and industry events delivered to you weekly. If you're not already a subscriber, you can sign-up on our web site. You can also sign-up for our new eNewsletter, the *RF to Light 100*. Produced by industry veteran Gunter Vorlop, this feature delivers financial data and analysis of 100 of the publicly traded companies in the RF to lightwave industry, broken down into seven major sectors and updated weekly. I think you'll find it to be a valuable resource.

Last year, we introduced the digital edition of *Microwave Journal*. Recently, we upgraded to a format that allows users to access the magazine instantly on-line, with no download required. You can move the issue to your computer for off-line reading as well.

The digital edition allows you to link to authors and advertisers, e-mail articles to colleagues, print articles and receive each issue much faster. You can check it out at www.mwjournal-digital.com.

You'll also find some subtle changes within these pages, as we are always looking for ways to improve your reading experience. As always, I welcome your comments at csheffres@mwjournal.com.

Wishing all of our readers a happy, healthy and prosperous New Year.

Carl Sheffres
Publisher

INVITED PAPER

PHASED ARRAYS AND RADARS — PAST, PRESENT AND FUTURE

This is a survey article summarizing the recent developments and future trends in passive, active, bipolar and monolithic microwave integrated circuitry (MMIC) phased arrays for ground, ship, air and space applications. Covered is the DD(X) ship radar suite; THAAD (formerly GBR); European COBRA; Israel BMD radar antennas; Dutch shipboard APAR; airborne US F-22, JSF and F-18 radars, European AMSAR, Swedish AESA, Japan FSX and Israel Phalcon; Iridium (66 satellites in orbit for a total of 198 antennas) and Globalstar MMIC space-borne active array systems (these last two are for communications, but the technology is the same as used by radar systems. In fact, the IRIDIUM T/R module technology derives from technology developed for a space-based radar); Thales (formerly Thomson-CSF) 4" MMIC wafer, 94 GHz seeker antenna; digital beamforming; ferroelectric row-column scanning; optical electronic scanning for communications and radar; the MMIC C- to Ku-band advanced shared aperture program (ASAP) and AMRFS antenna systems for shared use for communications, radar, electronics countermeasures (ECM) and electronic support measures (ESM); and the continuous transverse stub (CTS) voltage-variable dielectric (VVD) antenna.

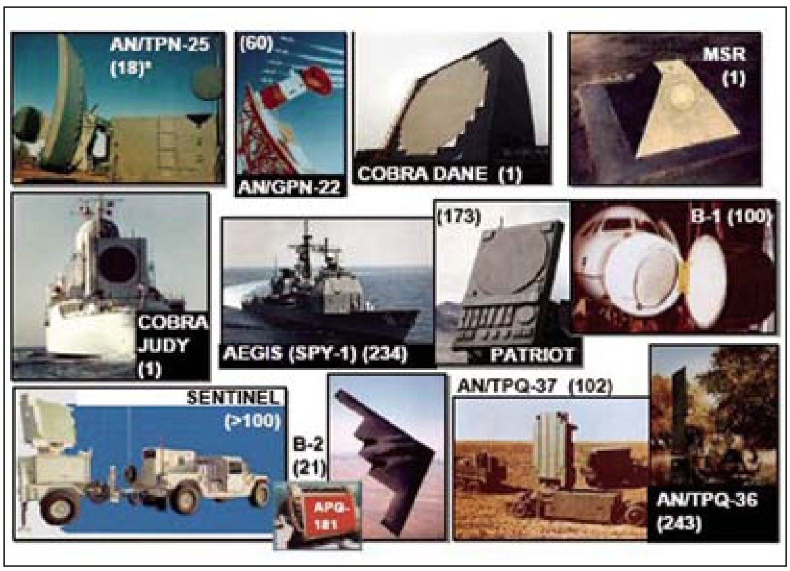
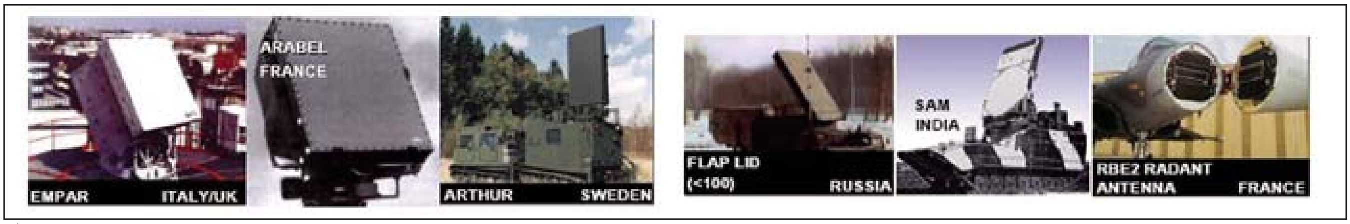


Fig. 1 Examples of US passive phased arrays having large productions.

ACCOMPLISHMENTS OVER THE LAST TWO AND A HALF DECADES

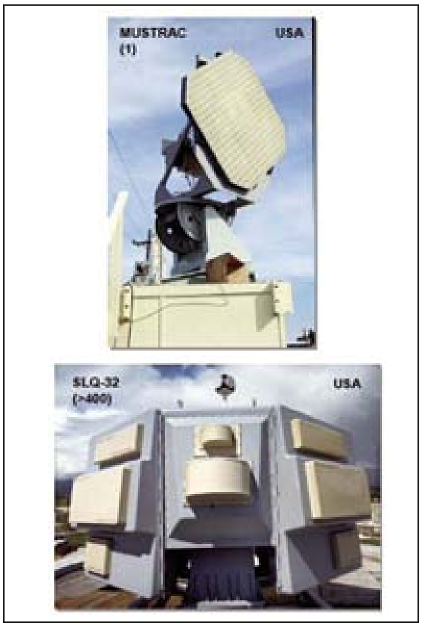
Phased arrays have come a long way in the last three decades. This is illustrated by the many tube passive arrays and solid-state active arrays, which use discrete and MMIC technologies that have been deployed or are under development.[1–24,82–84,86] ***Figures 1*** and

ELI BROOKNER
Raytheon Co.
Sudbury, MA



▲ *Fig. 2 Examples of passive phased arrays from around the world.*

2 show passive phased arrays, the first generation of phased arrays. ***Figure 3*** shows Rotman lens arrays. ***Figure 4*** shows active solid-state arrays using discrete components, the second generation. ***Figures 5*** and ***6*** are for phased arrays using microwave analog integrated circuits (MMIC), the third generation. The numbers manufactured are shown in parentheses in the figures. Note that in some cases, very large numbers have been produced, even for MMIC active phased arrays (see ***Table 1***). Also, one sees that phased arrays are being developed around the world. Included are the new L-band GEC-Marconi S185OM (SMARTELLO), which will provide very long range search for the SAMPSON radar on the Royal Navy Type 45 anti-air warfare (AAW) destroyer and the new AMS L-band RAT 31DL.[86] The SMARTELLO uses the SMART-L antenna and elements of the Martello. The Iridium satellite system has been deployed; it consists of a constellation of 66 satellites. It was a great technological success but unfortunately not a financial one.[14] It is still in operation, however. In fact, three replacement satellites were launched in 2002. ***Figure 7*** shows additional phased arrays that have recently come under development, for



▲ *Fig. 3 Examples of ROTMAN lens arrays.*

▲ *Fig. 4 Examples of active arrays using discrete components.*

which the technology is not specified. Included are the US Army's joint land attack cruise missile defense elevated netted sensors system (JLENS), consisting of a long range 3-D surveillance radar and a high frequency precision tracking and illumination radar deployed in an aerostat; the medium extended air defense system (MEADS) UHF surveillance radar; the US Army's multi-mission radar (MMR); UK/US airborne stand-off radar (ASTOR), the UK equivalent of the US joint STARS (JSTARS), and the US Marine Corps affordable ground-based radar (AGBR) and multiple role radar system (MRRS). ***Figures 8*** and **9** give the state-of-the-art of GaAs MMIC power amplifiers and of GaAs and InP low noise amplifiers (LNA).[85] The People's Republic of China has come a long way in a very short time in the development of phased arrays — passive, active, over-the-horizon, dual-band, wide-band, ultra-low sidelobe, synthetic-aperture, adaptive, digital-beamforming, super-resolution and phase only null steering.[76] The question addressed now is what does the future hold?

DEVELOPMENT OF MMIC ACTIVE PHASED ARRAYS

With the recent awards of production and development contracts for MMIC active phased array contracts, such as for three THAAD EDM (engineering development model) radars, COBRA radars, SAMPSON radars, sea-based test XBR radars, forward-based BMDs radars, MEADS radars, air traffic navigation, integration and coordination system (ATNAVICS) radars, four-faced active phased-array radar (APAR) system, the new B-2 radar, multi-platform radar technology insertion program (MP-RTIP) on E-10A (upgrade of the Joint STARS), MP-RTP on Global Hawk, F-15C (AN/APG-63(V), 25 already in service), F-16, F/A-18, F/A-22 and F-35 joint strike fighter (JSF) airborne radars, the planned development

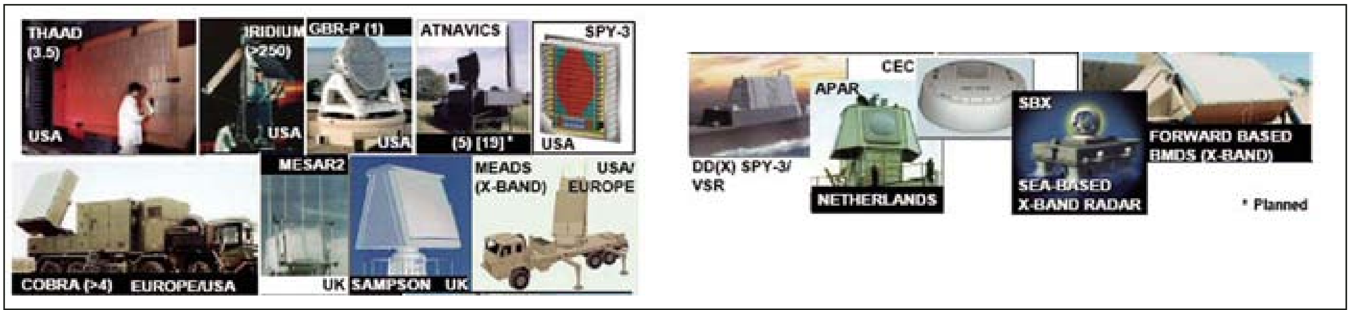


Fig. 5 Examples of ground and shipboard MMIC active arrays deployed and under development.

contracts for the new US DD(X) ship and SPY-3/VSR radar suite, the future looks very good for MMIC radars.[79,80,83] The new X-band SPY-3 under development for the DD(X) ship, the US Navy's first active radar, is planned to be used for the detection, tracking and illumination of low flying, anti-ship, cruise missiles and is expected to consist of a three-faced radar.[83] When not supporting engagement operations, it will perform horizon search, surface search and periscope detection.[83] The cooperative engagement capability (CEC) is a Navy ship and communications array antenna. ***Figures 10*** and ***11*** show space-based radar and digital beamforming phased-array systems that have been deployed or are under development.

RESEARCH AND DEVELOPMENT WORK FOR FUTURE PHASED-ARRAY SYSTEMS

Clutter Rejection for an Airborne System (STAP and DPCA)

To cope with ground clutter and sidelobe jamming for airborne radar, extensive work is ongoing toward the development of an airborne phased array using space-time adaptive processing (STAP).[25,26] STAP is a general form of displaced phase center antenna (DPCA) processing. STAP had been demonstrated several years ago on a modified E2-C system by NRL.[27,28] More recently, a flight demonstration STAP provided 52 to 69 dB of sidelobe clutter cancellation relative to the main beam clutter.[29] This system used an array mounted on the side of an aircraft. The antenna had 11 degrees of freedom in azimuth and two in elevation, for a total of 22. Before STAP, the antenna RMS sidelobe level was -30 dBi; with STAP, it was –45 dBi.

C- to Ku-band Multi-user Advanced Shared Aperture Program (ASAP) MMIC Array and Dual-band AMRFS and RECAP Arrays

The COBRA DANE radar system has a 16 percent bandwidth and the Rotman lens multi-beam array systems have a 2.5 to 1 frequency bandwidth. Technology had been carried out to develop an active MMIC phase-phase steered array that has a greater than 2 to 1 frequency bandwidth and at the same time is shared by multiple users. Specifically, the Naval Air Weapons Center (NAWC) and Texas Instruments (TI, now part of Raytheon) were developing a broadband array having continuous coverage from C- through Ku-band that would share the functions of radar, passive electronic support measures (ESM), active electronic counter measures (ECM) and communications.[30] To achieve this wide bandwidth, a flared notch-radiating element was used. Cross notches were used so that horizontal, vertical or circular polarization could be obtained. They built a solid-state T/R module that provides coverage over this wide band from C- to Ku-band continuously. The module had a power output of 2 to 4 W per element, a noise figure between 6.5 and 9 dB, and power efficiency between 5.5 and 10 percent, over the band. A 10 by 10-element array, having eight active T/R modules, was built for test purposes. A typical full-up array would be approximately 29" wide by 13" high. With this type of array, it would be ultimately possible to use simultaneously part of the array as radar, part of the array for ESM, part for ECM and part for communica-

▲ *Fig. 6 Examples of airborne MMIC active arrays deployed and under development.*

TABLE I

EXAMPLES OF RADAR PHASED ARRAYS HAVING LARGE PRODUCTIONS

System	Frequency Band	Number Manufactured	Number of Phase Shifters/Array	Total Number of Elements Manufactured	Manufacturer
AN/TPN-25	X	18	824	14,850	Raytheon
AN/GPN-22	X	60	443	26,580	Raytheon
COBRA DANE	L	1	15,360 (34,769 Els.)	15,360 (34,769 Els.)	Raytheon
PAVE PAWS	UHF	4	1,792/face (2,677 Els.)	14,336 (21,416 Els.)	Raytheon
BMEWS UPGRADE	UHF	2	2,560/face (3,584 Els./face)	12,800 (17,920 Els.)	Raytheon
COBRA JUDY	–	1	12,288	12,288	Raytheon
PATRIOT	C	173	5,000	1,730,000	Raytheon
AEGIS (SPY-1)	S	234	4,000	936,000	Lockheed-Martin
B-1	X	100	1,526	152,600	Northrop Grumman
AN/TPQ-37	S	102	359	36,618	Raytheon
AN/TPQ-36	X	243			Raytheon
FLAP LID	X	> 100 (?)	10,000	> 2 million (?)	Russia

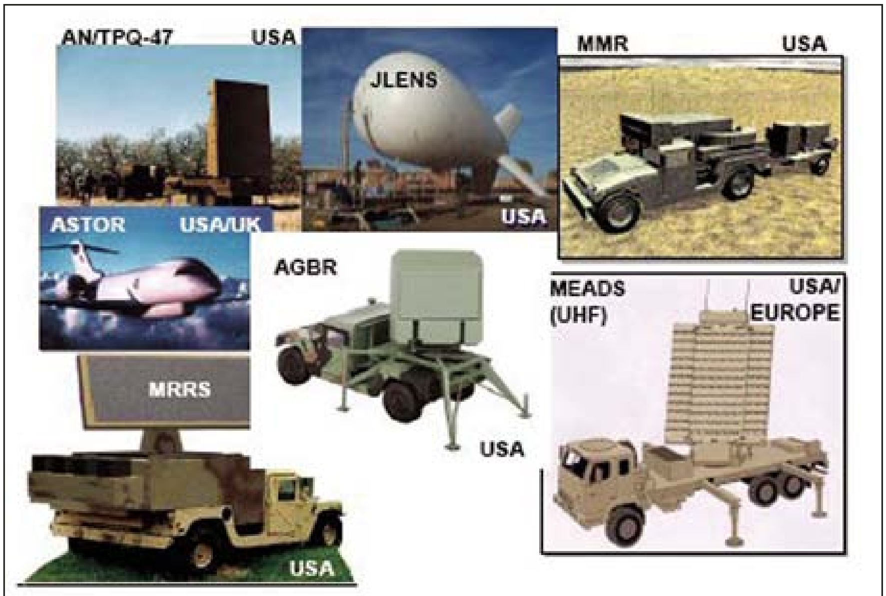


Fig. 7 Other phased-array systems under development.

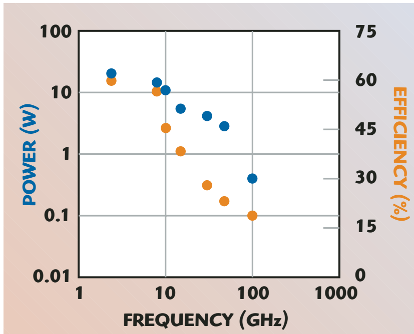


Fig. 8 State-of-the-art of GaAs MMIC PAs.

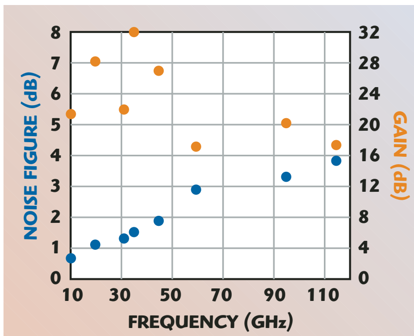
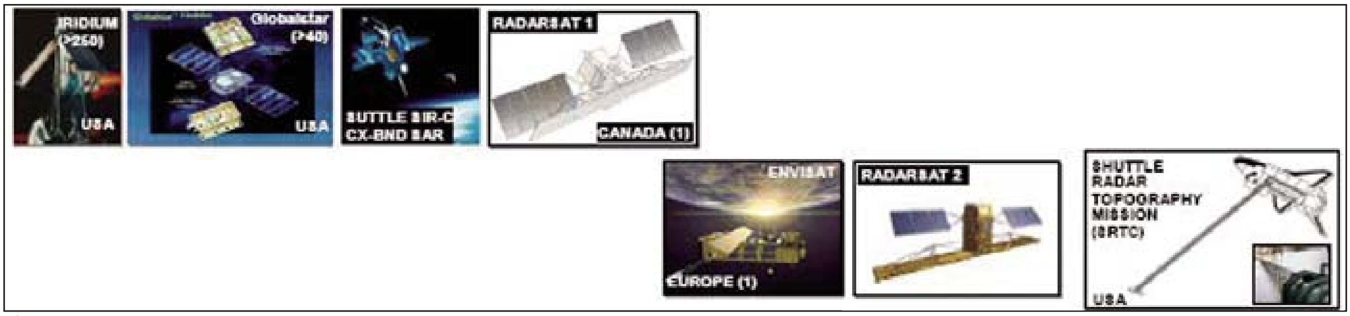


Fig. 9 State-of-the-art of GaAs and InP MMIC LNAs.

tions. The parts used for each function would change dynamically, depending on the need. Also, these parts could be non-overlapping or overlapping, depending on the needs. Although the ASAP funding has ended, the shared aperture technology is now being pushed forward by the US Office of Naval Research (ONR) advanced multifunction radar frequency system (AMRFS) program[71,78] and the DARPA reconfigurable aperture program [RECAP] program. DERA of the UK had been developing a dual frequency array which would enable a single radar to use L-band for search and X-band for track, so as to avoid the use of a single compromise frequency for search and track.[52] Consideration is being given to the use of waveguide L-band radiating elements and dipole X-band elements.

Digital Beamforming and Its Potential

Table 2 lists where digital beamforming (DBF) has been operationally used, some developmental systems that have been built, and its significant advantages. The first operational radars to use digital beamforming are the over-the-horizon (OTH) radars, specifically the GE OTH-B and Raytheon relocatable OTH radar (ROTHR). The ROTHR receive antenna is approximately 8500 feet long. More recently, Signaal used digital beamforming for their deployed 3-D stacked beam SMART-L and



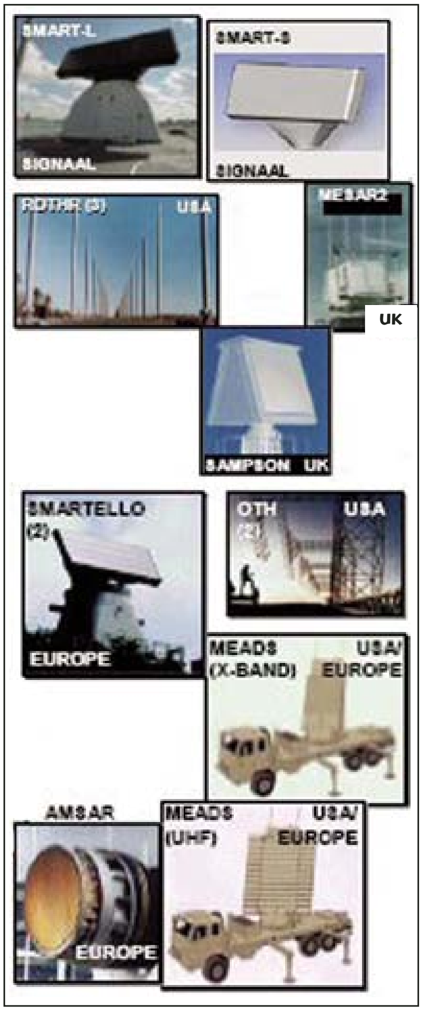
▲ *Fig. 10 Space-based phased-array systems.*

SMART-S shipboard systems. Each row is down converted and pulse compressed with SAW lines and then analog-to-digital (A/D) converted with 12-bit, 20 MHz Analog Devices A/Ds. The signal is then modulated onto an optical signal and passed down through a fiber optic rotary joint to a digital beamformer where 14 beams are formed.[31]

A number of experimental DBF systems have been developed. One is the Rome Laboratory (Hanscom AFB, MA), 32 column linear array at C-band that can form 32 independent beams and uses a novel self-calibration system.[32] Rome Laboratories has also developed a fast digital beamformer that utilizes a systolic processor architecture[77] based on the quadratic residue number system (QRNS).[32] MICOM (US Army) built a 64-element feed that used DBF for a space-fed lens.[33] The experimental British MESAR S-band system does digital beamforming at the sub-array level.[34] This experimental system has 16 sub-arrays and a total of 918 waveguide-radiating elements and 156 T/R solid-state modules. Roke Manor Research Ltd. of Britain has built an experimental 13-element array using digital beamforming on transmit as well as on receive.[35] This experimental system uses the Plessey SP2002 chip running at a 400 MHz rate as a digital waveform generator at every element. Doing digital beamforming on transmit allows one to put nulls in the direction of an ARM threat or where there is high clutter.

The National Defense Research Establishment of Sweden has built an experimental S-band antenna operating between 2.8 and 3.3 GHz, which does digital beamforming using a sampling rate of 25.8 MHz on a 19.35 MHz IF signal.[23] The advantage of using IF frequency sampling rather than base band sampling is that one does not have to worry about the imbalance between the two I and Q channels, or the DC offset. They demonstrated that, by using digital beamforming, they could compensate for amplitude and phase variations that occur from element to element, across angle and across the frequency band. Via a calibration, they were able to reduce an element-to-element gain variation over angle, due to mutual coupling, from ±1 dB to approximately ±0.1 dB. Using equalization, they were also able to reduce a ±0.5 dB variation in the gain over the 5 MHz bandwidth to less than ±0.05 dB. With this calibration and equalization, they were able to demonstrate peak sidelobes 47 dB down, over a 5 MHz bandwidth. A 50 dB Chebyshev weighting was used. The RMS of the error sidelobes was down 65 dB from the peak near boresight.[63] They demonstrated that the calibration was maintained fairly well over a period of two weeks. This work demonstrates the potential advantage offered by digital beamforming with respect to obtaining ultra-low antenna sidelobes. These results were not achieved in real time in the field, although that is ultimately the goal.

MIT Lincoln Laboratory developed the technology for an all-digital radar receiver for airborne surveillance array radar like that of the UHF E-2C.[43] They are A/D sampling directly at UHF (~430 MHz) using a Rockwell 8-bit, 3 Gbps A/D running at room temperature. Three stages of down conversion are done digitally and because the A/D quantization noise is filtered, the effective number of bits of the A/D is increased. For example, if the signal bandwidth is only 5 MHz, the increase in signal-to-noise ratio is 3 GHz/2 (5 MHz) = 25 dB, so the increase in the number of



▲ *Fig. 11 Phased arrays that use digital beamforming.*

effective bits is 25 dB divided by 6 dB/bit or 4.2 bits to yield 12 bits total. The whole digital receiver is on an 8" by 8" card that uses three 0.6 μm chips. In the future these three chips could be replaced by a single 0.35 μm CMOS chip.

The Naval Research Laboratory (NRL), MIT Lincoln Laboratory and NSWC are jointly developing an L-band active array which has an A/D converter at every element.[64,65,81] Using digital beamforming, NRL demonstrated the ability to obtain a constrained beamwidth with frequency, while at the same time achieving low sidelobes over specified angles and frequency bands.[66]

MIT Lincoln Laboratory had been developing a high performance, low power signal processor to do digital beamforming and signal processing for a notional X-band Discoverer II space-based radar.[67,68] This notional version of the system did ground moving target indication (GMTI) and synthetic aperture radar (SAR) mapping. Its antenna consisted of 12 subarrays and 4 SLCs. The signal bandwidth was assumed to be 180 MHz. For this system, it is necessary to do the signal processing on-board and in real time, because telemetering the signal down would require too high a data rate –35 Gbps, if a 12-bit A/D is assumed — well beyond the present state-of-the-art. The on-board signal processor must do digital beamforming, pulse compression, Doppler processing, STAP and SLC. To do this on-board and in real time requires a signal processor capable of 1100 GOPS (1.1 TERAOP). Lincoln Laboratory has shown that it is feasible to do the processing on board using a systolic array type architecture having a volume less than one seventh of a cubic foot, and weighing less than 13 kg with a power consumption less than 55 W. With the digital processing field being moved forward rapidly by the commercial world, by the year 2016 it is expected that one 9U 16" by 14.5" board would provide a throughput of 600 GFLOPS (floating OPS). It would consist of 64 chips, each providing 10 GFLOPS use a 0.07 μm technology and have a 1.25 GHz clock. Texas Instruments (TI) road map, for its TMS320 digital signal processor (DSP), indicates that by the year 2010 they expect to be able to do 3 trillion, 8-bit OPS (3 trillion instructions per second or 3 TIPS), on a single TMS320 chip.[69] With 32-bit fixed-point operations, this chip would do 0.75 TIPS. Assuming 10 percent efficiency, 15 chips would do the notional Discover II processing. Such processing capability could help make the experimental Swedish ultra-low sidelobe antenna and airborne STAP array feasible.

Row-column Steered Arrays

The Naval Research Laboratory (NRL) had been developing two row-column array steering techniques, which have the potential for low cost two-dimensional steered arrays.[36,37] The first technique, the one closest to possible deployment, involves using two arrays back-to-back. The first array steers the beam in azimuth, the second in elevation. The first array consists of columns of slotted waveguides, with each column having at its input one ferrite phase shifter to provide azimuth scanning. The second array is a RADANT lens array, consisting of parallel horizontal conducting plates between which are connected many diodes. The velocity of propagation of the electromagnetic signal passing through a pair of parallel plates of the array depends on the number of diodes that are on or off in the direction of propagation. By appropriately varying this number, as one goes from one pair of plates to the next in the vertical direction, one creates a gradient on the signal leaving the lens in the vertical direction so as to steer the beam in elevation. The estimated production cost of the hybrid row-column steered array is $3 million. It is possible to use two RADANT lenses to provide two-dimensional electronic scanning, one RADANT lens providing elevation scan while the second provides azimuth scan.[38] Thales has developed such a RADANT antenna for the Dassault Aviation RAFALE multi-role combat aircraft.[38]

The second NRL row-column steered array involves using two ferroelectric lenses.[37] The first lens consists of columns of ferroelectric material placed between conducting plates. A DC voltage is applied across each pair of plates. The dielectric constant of the ferroelectric material depends on the DC voltage applied between the plates. As a result the phase of the electromagnetic signal passing through a ferroelectric column will depend on this DC voltage. Consequently, by applying an appropriate DC voltage across the ferroelectric columns, one can create a phase gradient in the horizontal direction for the signal leaving the first lens and thus scan the beam in azimuth. A second such lens, rotated 90°, would steer the beam in elevation. Considerable work is still necessary before a practical ferroelectric phased array is produced. This work has been shifted from NRL to industry.

The Raytheon Co. is developing a row-column steered array that employs phase shifters for steering in the H plane (see ***Figure 12***) and a voltage variable dielectric (VVD) ceramic material used for a continuous transverse stub (CTS) antenna architecture for steering in the E plane.[41] Changing the voltage across the VVD changes its dielectric constant and, in turn, the velocity of propagation along the VVD. It provides for a lightweight, low cost, small thickness antenna. They are looking to apply this technology to aircraft radar antennas and commercial antennas. Engineers and scientists have been talking about achieving electronic scanning of lasers since the 1960s. Some thought this was a pipe dream, but these doubters have since been proven wrong. Raytheon[40,57] has demonstrated an electronically steered phased array for laser and optical beams. This array, which is carried around in a briefcase, represents a major breakthrough in the scanning of laser and optical beams. The scanning is achieved using a row-column scanning architecture similar to that of the ferroelectric scanner previous-

TABLE II

DIGITAL BEAMFORMING

Where Used:	Advantages:
• OTH-B (GE): I-D	• Flexibility
• ROTHR (Raytheon): I-D • SMART-L and SMART-S (SIGNAAL): I-D Stacked Beam Systems	– Antenna Weighting – Growth with Technology • Adaptive Processing
	• Improved Performance
Developmental Systems:	– Ultra-Low Sidelobes
• Rome Lab: 32 Columns	– Dynamic Range
32 Independent Beams	– Jammer and Clutter Suppression
• MICOM: Array Feed OF 64 Elements	– Reduced EMI
• British MESAR: Subarray DBF	• Multibeams
• British: DBF on Trans. and Rec. 13 EL	
• Lincoln Lab. All-Digital UHF Receiver: 8 Bit 3 GSPS A/D	
• AMSAR: Subarray DBF	

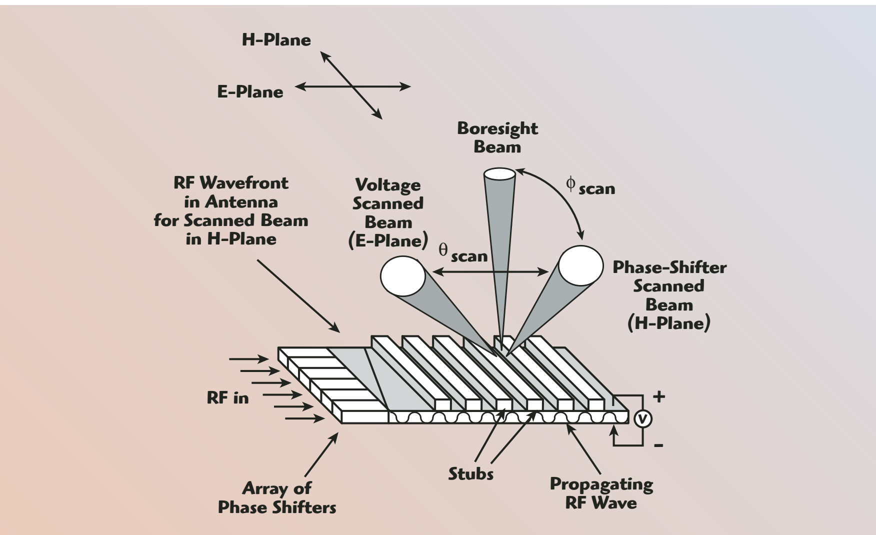
ly described, with liquid crystal used instead of the ferroelectric material. In production, the cost per phase shifter for an optical phased array is estimated to be pennies.[40,57]

Novel Electronically Steerable Plasma Mirror

NRL had been pursuing the development of a novel electronically steerable plasma mirror in order to provide electronic beam steering.[39] Here, a plasma sheet is rotated to steer the beam in azimuth and is electronically tilted to steer the beam in elevation. Switching to different initiation points in the cathode rotates the plasma mirror. Tilting the magnetic field around the plasma tilts the plasma mirror. This is done using coils placed around the plasma. These coils are placed so as not to block the microwave signal. A 50 by 60 cm plasma mirror has been generated, for which the measured antenna patterns had sidelobes approximately 20 dB down.[39]

95 GHz Reflect-array Using 4" MMIC Wafers

Colin[38] described a very aggressive effort wherein an MMIC was taken to the point of wafer integration — 4" wafers. Specifically, Thales has built an experimental missile seeker antenna, which uses two 4" wafers.[38] One wafer has the dipole elements and one bit PIN diode phase shifters printed on it. The second 4" wafer contains the driving circuits that are linked to the first through bumps. The antenna has 3000 elements. The beam width is 2° and can be steered ±45°. They have reported having obtained low sidelobes.[38]



▲ *Fig. 12 Low cost 2D electronically scanned antenna approach based on two technologies: CTS antenna architecture and VVD materials.*

Micro-electro-mechanical System (MEMS) Components

The MEMS integrated circuit mechanical switch holds the promise for a 4-bit X-band phase shifter having low loss (1.5 dB), low power consumption (1 mW) and low cost ($10 per phase shifter).[70] If such a phase shifter bears fruit, it would be possible to revert back for some applications to the passive phase-phase scanned array architecture having one power amplifier feeding many low cost phase shifters. Instead of a tube, the power amplifier could be a solid-state amplifier. This could reduce the number of T/R modules needed and hence the cost of a phase-phase scanned array by a considerable amount. The MEMS technology is being funded by DARPA.[70] They are looking at using MEMS in their RECAP program to obtain reconfigurable ultra-wideband antennas for multi-user applications as done with the ASAP program described above.[74,75]

Low Cost Phase Array for the Automobile

One tends to think of phased arrays as expensive. A low cost 77 GHz phased array has been developed for automotive intelligent cruise control radar, whose total consumer cost needs to be less than $300.[72,73] Two antennas, one for transmit and one for receive, and their beamformer networks are photo-etched on a single sheet of copper clad dielectric. The antennas consist of series fed columns of patch radiators, while the beamformers are Rotman lens, one for each array. The beams are scanned in azimuth by switching between input ports of the Rotman lens.

CONCLUSION

Based on the above accomplishments, ongoing developments, research and large numbers of programs that are looking to effectively use phased arrays, it is apparent that the future for phased arrays is very promising and should lead to exciting developments. Phased arrays have come a long way and can be expected to make major strides in the future. For further reading on recent developments in phased arrays around the world, the reader is referred to References 1 to 14, 40, 46, 62, 82 and 83. ■

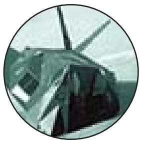
ACKNOWLEDGMENT

The author would like to thank Doug Venture of the Raytheon Co. for his help.

REFERENCES

Due to space limitations, the large number of references used in this article can be found on the *Microwave Journal* web site at www.mwjournal.com.

Eli Brookner *has been at the Raytheon Co. since 1962, where he is a Principal Fellow. There he has worked on the ASDE-X radar, ASTOR Air Surveillance Radar, RADARSAT II, Affordable Ground Based Radar (AGBR), major Space Based Radar programs, NAVSPASUR S-band upgrade, CJR, COBRA DANE, PAVE PAWS, MSR, COBRA JUDY, THAAD, Brazilian SIVAM, SPY-3, AEGIS, BMEWS, UEWR and COBRA DANE Upgrade. Prior to Raytheon he worked on radar at the Columbia University Electronics Research Lab [now RRI], Nicolet and the Rome AF Lab. He was awarded the IEEE 2003 Warren White Award for Excellence in Radar Engineering "For Significant Advances in Development and Education of Phased Array Radars." He is a Fellow of the IEEE, AIAA and MSS. He has published four books, the most recent being* Tracking and Kalman Filtering Made Easy, *John Wiley & Sons Inc., 1998. His previous three books were* Practical Phased Array Antenna Systems *(1991),* Aspects of Modern Radar *(1988) and* Radar Technology *(1977), all published by Artech House Inc. He gives courses on radar, phased arrays and tracking around the world. He was banquet speaker and keynote speaker six times. He has over 110 papers, talks and correspondences to his credit. In addition, he has over 80 invited talks and papers. For one paper he has received the Journal of the Franklin Institute Premium Award. For another he (along with his co-authors) received the Wheeler Prize for Best Applications Paper for 1998. He received his BEE degree from The City College of the City of New York in 1953, and his MEE and DrSc degrees from Columbia University in 1955 and 1962, respectively.*



Raytheon Receives $1.3 B Contract Modification for JLENS Development

Raytheon Co. received a $1.3 B contract modification from the US Army for system development and demonstration of the Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS). Raytheon's Integrated Defense System (IDS) JLENS provides a long-duration, wide-area cruise missile defense capability, while also providing elevated communications capabilities and supporting situational awareness for the battlefield commanders. The system provides over the horizon detection and tracking of incoming cruise missiles with sufficient warning to enable air defense systems to engage and defeat the threat. Each JLENS consists of a long-range surveillance radar and a high performance fire control radar, each integrated in a large aerostat connected via tether to a ground-based processing station. System testing is scheduled to begin in 2009, with program completion in 2011. "The JLENS program provides unprecedented capability to our warfighters through the combination of long-range surveillance with precise tracking to support engagement of a variety of targets over extremely large geographic areas," said Tim Carey, vice president of IDS Integrated Air Defense. "The program is an important piece of the Army's strategy to provide a reliable and robust cruise missile defense by using a network of sensors to support a wide variety of weapons within the Army system of systems command and control paradigm." Work on the program will be performed at Raytheon sites located in Massachusetts, California, Texas and Maryland. Raytheon's Integrated Defense Systems will develop the fire control radar and processing station. TCOM, LP, based in Maryland, will develop the aerostat and associated ground equipment. Based in Tewksbury, MA, Integrated Defense Systems is Raytheon's leader in joint battlefield integration. With a strong international and domestic customer base, including the US Missile Defense Agency, the US Armed Forces, Integrated Defense Systems provides a wide spectrum of integrated air and missile defense and naval and maritime warfighting solutions.

Northrop Grumman Awarded Contract to Produce RQ-4B Global Hawks

The US Air Force has awarded Northrop Grumman Corp. a contract to begin production of the next five RQ-4B Global Hawk aerial reconnaissance systems. The new $60 M contract will allow the company to start purchasing long-lead parts for the unmanned air vehicle, the enhanced integrated sensor suites for four of the air vehicles, one mission-control element and one launch-and-recovery element. Production of the hardware for these five new RQ-4B air vehicles is expected to begin late this year, with assembly starting next year. "This contract demonstrates the commitment and continued confidence that the Air Force has in Global Hawk's capabilities and operational performance, and the need for this unique intelligence, surveillance and reconnaissance system," said George Guerra, Northrop Grumman's Air Force Global Hawk program manager. "These vehicles will be the first operational Global Hawks with full multi-intelligence capabilities, including signals intelligence." Northrop Grumman is currently producing five RQ-4B Global Hawks at its manufacturing facility in Palmdale, CA, as part of several previous limited-production contracts. The new RQ-4B Global Hawk is designed to carry 3000 pounds of payload, 50 percent more than the original RQ-4A configuration. This increased capability will allow the Air Force to install additional sensors on the air vehicle, increasing the amount and types of information available to warfighters. Global Hawk flies autonomously at an altitude of more than 60,000 feet, above inclement weather and prevailing winds, for more than 35 hours at a time. During a single mission, it can provide detailed intelligence, surveillance and reconnaissance information in near-real time over 40,000 square miles — approximately the size of Illinois.

Boeing Awards Harris Corp. $2.8 M Development Contract for NOAA's GOES-R

Harris Corp. announced that it has been awarded a six-month, $2.8 M program definition and risk reduction (PDRR) contract by the Boeing Co. for the ground processing segment of the National Oceanic and Atmospheric Administration (NOAA) geostationary operational environmental satellite – series R (GOES-R) program. When ready to launch in 2012, GOES-R will feature highly advanced sensor technology and will provide much higher resolution and data frequency than the current GOES spacecraft family. Value of the GOES-R PDRR work for Harris could reach $8 M by 2007 if NOAA exercises all its options for this phase of the contract. Under the GOES-R contract with Boeing, Harris is responsible for the design and development of the GOES-R ground segment. This includes developing a data processing and command-and-control ground prototype for the overall satellite system architecture. The PDRR phase will end with a "fly-off" competition in 2007, with NOAA selecting a single team for development and production of the end-to-end system. "We are extremely pleased to have this opportunity to work with Boeing to develop a processing system that will support the next generation of geostationary weather satellites for NOAA," said Al Dukes, president of the Civil Programs business unit of Harris Corp.'s Government Communications Systems Division (GCSD). "GOES-R represents a quantum leap in the quantity, timeliness and accuracy of remotely sensed meteorological data. We look forward to fielding a winning prototype solution for the Boeing team." GOES-R will carry several operational instruments, including the 16-channel Advanced Baseline Imager, which will provide visual and infrared imagery of the Western Hemisphere every five minutes; a Hyper-spectral Environmental Suite, which will provide full disk atmospheric soundings to assist in severe weather forecasting; an extended Solar X-Ray Imager; and a Space Environment Monitoring Suite, which will monitor the effects of solar activity on the Earth's atmosphere. This suite of instruments will produce over 100 times the information provided by the current system and will offer a wide variety of unique observations of the environment, with particular emphasis on severe weather and hurricane activity in the Western Hemisphere. Harris ground data processing systems consist of complex suites of hardware and software that receive sensor data from satellites and process it into useable environmental parameters under stringent timelines, turning the data into useable information. The company's command and control systems feature commercial-off-the-shelf (COTS) design and high levels of flexibility. Designed for government and commercial applications, they support single-satellite missions as well as the largest and most complex satellite fleets deployed today.

L-3 Communications Awarded $11 M Contract to Provide Cryptographic Unit

L-3 Communications announced that its Communication Systems-East (L-3 CS-East) division has been awarded a contract by Lockheed Martin to design and develop the TRANSEC COMSEC Unit (TCU) for the Mobile User Objective System (MUOS), a next-generation narrowband tactical satellite communication system that will provide significantly improved and assured voice and data communications for the mobile warfighter. Lockheed Martin Space Systems, Sunnyvale, CA, is the prime contractor and system integrator for MUOS, which will replace the current narrowband tactical satellite communications system known as the Ultra High Frequency Follow-On (UFO) system. The US Navy's Communications Satellite Program Office, based in San Diego, CA, is the government agency responsible for acquiring MUOS and narrowband satellite communications for the Department of Defense (DoD). The value of the initial contract award to L-3 Communications is approximately $11 M for delivery of the first two flight units and a spare flight unit in 2007. L-3 CS-East will provide the crypto units to Lockheed Martin facilities in Newton, PA, where MUOS satellites will be developed. ■

West African Regulators Agree to ICT Regulatory Framework

In a landmark agreement aimed at creating a harmonized information and communication technology (ICT) market, regulators from 15 West African nations have agreed to a common regulatory framework for their national ICT markets. The agreement marks a significant step forward for the region, which is seeking to create a single market based on the European Union model.

Regulators hammered out the new framework during a validation workshop when more than 100 participants took part, including representatives from the regulatory authorities of Burkina Faso, Cape Verde, Côte d'Ivoire, Ghana, the Gambia, Guinea, Liberia, Mali, Niger, Nigeria, Senegal and Togo as well as regional organizations including CATIA, the Economic Community of West African States (ECOWAS), the European Commission, the FCC, the West African Monetary Union (UEMOA), USAID and members of the private sector.

By favouring a market-based approach to the provision of ICT services, the new guidelines are designed to spur investment and development in the West African ICT sector. Once widely adopted, it is hoped that they will prove instrumental in helping propel some of the world's poorest nations into the Information Society.

SpaceForScience Programme Targets South Eastern Europe

Alcatel Alenia Space has entered into partnership with the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the European Space Agency (ESA) in the frame of the SpaceForScience programme. This is aimed at providing telecommunication and multimedia satellite services for education and research institutes in South Eastern Europe.

The programme facilitates the scientific and technical cooperation within various scientific communities in Europe and especially in Southern and Eastern Europe. Using satellite technology, scientific institution members of the programme are able to benefit from new services. The programme provides added value broadband services via a satellite applications platform provided and hosted by Alcatel Alenia Space in Cannes, France. The company is responsible for the deployment of the global network, from the applications platform to the user sites.

The company's president and CEO, Pascale Sourisse, said, "Alcatel Alenia Space was eager to provide broadband satellite connectivity to the scientific community within the UNESCO initiative. This technology enables the provision of broadband access and added value applications to isolated institutions and enhances the cooperation in Europe. In a second step, this programme can be replicated and enlarged to benefit other countries in the world."

45 nm System Collaboration for Toshiba and NEC

Toshiba Corp. and NEC Electronics Corp. have agreed to collaborate on the development of CMOS logic process technology for the 45 nm generation. As advances in semiconductor process technologies become more complex, time consuming and expensive, the joint development will allow the companies to share burdens and accelerate development, while raising system LSI performance and quality.

Under the terms of the agreement, engineers from both companies will collaborate at Toshiba's Advanced Microelectronics Centre in Yokohama, Japan, on development of fundamental CMOS process technology, which they will be able to implement at their manufacturing facilities. The companies will also separately discuss how to handle the development of value-added and differentiated process technologies. The companies have also begun to discuss comprehensive collaboration in development, such as design environments and product development, as well as collaboration in manufacturing to achieve more efficient use of capital investment and increase capacity utilization rates.

Technology Transfer in UK Gets Academic Boost

Against the backdrop of the UK government's continued emphasis on using innovation to drive economic growth, QinetiQ announced the creation of the UK's first professorship in technology transfer in the physical sciences. The £1 M professorship, which is jointly funded by QinetiQ and the Engineering and Physical Sciences Research Council (EPSRC), has been awarded to Imperial College London.

The professor's role will be to lead academic research to establish reliable mechanisms, which develop wealth-creating products and services from physics-based sciences. An appointment will be announced in spring 2006 to commence in September 2006. The professorship is one element of an extensive programme of university collaboration announced by QinetiQ. Building on existing links with universities in the UK and overseas, the defence and security technology company has launched a university partnership programme to provide new market opportunities for university science and technology through joint bidding, joint programmes of work and the sharing of resources.

Professor John O'Reilly, chief executive of EPSRC, added, "The UK produces research of international quality in a range of disciplines, from maths to materials science, and from IT to structural engineering, and there is an increasing need to accelerate the translation of the knowledge generated into innovation. This new professorship will ensure that the UK's ability to transfer research into technological change becomes an even more effective driver of the knowledge economy in the future."

Europe's Semiconductor Industry Reports on Competitiveness

Following the publication of the first EECA-ESIA *European Semiconductor Industry: 2005 Competitiveness Report* a high level meeting was held to highlight and discuss its findings. Europe's Enterprise and Industry Commissioner, Günter Verheugen and the European Semiconductor Industry Association (ESIA) discussed the report and how the semiconductor industry in Europe can maintain and enhance its competitiveness. A delegation of ESIA members from STMicroelectronics, Infineon, Philips, Freescale Semiconductor, Micron and Robert Bosch, focused on key findings and how they link to the Commission's initiatives to boost Europe's competitiveness.

The report portrays a comprehensive picture of a sector, which is able to produce record growth rates, making substantial contributions to the development of the European economy, and to lead state-of-the-art technology innovation. It has created worldwide leading centres of excellence in various locations across Europe. With up to 20 percent of annual revenues re-invested in R&D, and furthermore up to 25 percent in capital expenditures, semiconductor companies are at the top of Europe's innovation list. Despite a continuous rise of the Asia-Pacific region and declining total shares of other regions, Europe has been able to maintain a relative stable market share of around 20 percent.

ESIA proposes ten concrete measures to boost competitiveness. These include promoting a generalized tax credit system on R&D spending, adopting the Commission's original R&D 7th framework proposals, reversing the European brain drain, promoting more and stronger multiple partnerships, establishing a sectoral framework, ensuring consistent and efficient customs operations, and pooling expertise in the EU and national institutions.

Carlo Bozotti, president of ESIA and CEO of STMicroelectronics, commented, "Semiconductors are the enabling technology for the Information Society, and their contribution to the success of the European economy is essential. The semiconductor industry in Europe has mobilized all its energy to face the challenges highlighted in the report. By communicating its call for action, ESIA hopes that the report will serve as a catalyst for implementing measures that reflect the real needs of our industry." ■

Breaking Stalemates: What Does the EWC Announcement Mean for 802.11n?

One of the Wi-Fi industry's most closely watched stalemates received a new twist. Faced with a deadlock between two competing groups and proposals for the shape of an 802.11n protocol standard, TGn Sync and WWiSE agreed to build a combined proposal that would forge a compromise between the two industry associations. However, the working group had not yet devised a specification for the combined proposal, when news reached the market that four major companies — Broadcom, Intel, Atheros and Marvell, holding the lion's share of the Wi-Fi market — had formed a third camp with the aim of writing a whole new proposal. It is now known that the breakaway group consists not of four companies, but 27, calling themselves the Enhanced Wireless Consortium (EWC). The EWC has now released its specifications for 802.11n, saying, "by introducing a specification with widespread industry support, the EWC hopes to speed ratification of an 802.11n standard, while enabling an ecosystem of high performance WLAN products built to a common set of guidelines. This widely accepted specification will benefit consumers by, among other things, ensuring the interoperability of next-generation wireless products across a variety of brands and platforms." While appearing to preempt the IEEE working group's efforts, the EWC said that some of its members, many of whom belong to TGn Sync or WWiSE, "will continue to work within the IEEE Task Group 'N' to facilitate a ratified 802.11n standard." What does it mean for the industry and for consumers? ABI Research senior analyst Philip Solis says, "This announcement means that companies can start building EWC-compliant Wi-Fi chipsets and products immediately, with EWC-compliant probably reaching the market by the fourth quarter of 2006. The result will be MIMO Wi-Fi products that are more than just interoperable with existing Wi-Fi products; EWC-compliant products will have the full benefits of increased range and throughput with other EWC-compliant products. Whether or not the EWC specification will form the basis of an eventual IEEE 802.11n protocol remains to be seen, but if so, that would mean availability of 'pre-802.11n' systems sooner than might have been expected."

Explosive Market Growth for SATCOM Antennas

A new 465-page report is now available from Engalco on the subject of "SATCOM Antennas — the Worldwide Industry and Market Opportunities to 2012." This report indicates that the overall global market will grow from \$887 M in 2005 to reach \$6.68 B in 2010, that is an anticipated eight-fold increase in the next five years. Demand is rapidly being driven upwards on many fronts and this report segments market data as follows (mostly covering both commercial and military): aircraft, ground control hubs, VSAT terminals, land mobile, shipping and spacecraft. All types of SATCOM antenna technologies are considered in this report and the market is segmented into dish-reflector-based and flat-panel-based (including phased arrays). A total of 56 company profiles and detailed financial data on the market are provided (123 charts), together with unit prices and shipments in many cases, all with forecasts to 2012. Strongly increasing requirements for two-way broadband Internet connectivity include: rural area needs, sea-going ships, RVs, trucks and to some extent railways. Up-coming military implementations such as WGF, AEHF, the transformational satellite program in the US and Skynet 5 in the UK are also very important. Another significant driving factor is that recently, the FCC has strongly promoted an increase in the use of SATCOM — driven by experiences with recent hurricane disasters like Katrina and Rita. In terms of investments to meet these increasing demands, some broadband satellite constellations have already been launched into orbit (Thuraya and Wildblue, for example). Further commercial and military launches are planned over the years' ahead and these, plus earlier investments, will provide the systems availability for a strong and rapid growth of airborne and terrestrial hardware and services, including SATCOM antennas. For further information, contact enquiries@engalco-research.com.

Calling from the Troposphere: The Coming Market for In-flight Wireless

Between January 1 and December 31, 2005, a staggering 1.2 billion passengers will have flown on some 28 million flights worldwide. Historically, passengers have been forbidden to use their mobile communications — cellular phones or Wi-Fi-equipped portable devices — in flight. But that is starting to change. Wi-Fi has been installed on a number of airlines, including Lufthansa, Singapore Airlines and Austrian Airlines. Others intend to follow suit. A whole new market is being created. A new study from ABI Research, "In-flight Mobile and Wi-Fi Services: Market Potential and Challenges," provides a comprehensive review and assessment of this complex but potentially lucrative market. It assesses regulatory bottlenecks and technical solutions, as well as forecasting market growth and capital expenditure. Mobile phones were originally banned in flight because they log on to terrestrial networks and cause network management chaos; but they also radiate at their maximum power, and there was concern about possible interference with the aircraft's avionics. Now, companies such as Qualcomm, Siemens and Ericsson have developed pico-cell technologies that will allow the use of both GSM and CDMA mobile phones during flights, without causing any interference. "The in-flight Wi-Fi and mobile communications market holds considerable promise," says ABI Research's director of research for Europe, Jake Saunders, "but regulatory hurdles, satellite communication bandwidth and pricing will constrain the market potential in the short to medium term." ABI Research believes that the market will develop once the regulatory barriers have been removed. For the next five years, much of the activity will be Wi-Fi related, but as regulatory obstacles to mobile communications are removed, their usage on aircraft will build. "We expect that in-flight mobile communications services will start in Europe in 2007," adds Saunders. "Asia will follow, then North America."

Bluetooth Product Shipments More Than Double Again

Bluetooth is firmly established as a short-range wireless solution for voice and data transmission, as 2005 will be the fourth consecutive year in which Bluetooth-enabled product shipments more than double, reports In-Stat. This year's shipments are forecast to be 316 million units, a total that will rise to 866 million in 2009, the high tech market research firm says. "Mobile phones are at the core of Bluetooth's popularity," says Brian O'Rourke, In-Stat analyst. "They are in turn helping Bluetooth penetrate into other products, including notebook PCs, mono and stereo headsets, automobiles and portable digital music players."

A recent report by In-Stat found the following:

- Bluetooth will need to constantly adapt in the face of competition that includes wireless USB, Wireless 1394 and Wi-Fi.
- Results from In-Stat's Residential Technology Survey (RTS) of typical US consumers indicate increasing recognition of Bluetooth and significant interest in cordless stereo headsets.
- Chips complying with Bluetooth 2.0 + Enhanced data Rate (EDR) are beginning to hit the market in 2005, providing both greater bandwidth and lower power consumption.

The report, "Bluetooth 2005: The Future is Here," provides analysis and five-year unit shipment and revenue forecasts for all Bluetooth-enabled products, including those in the PC, communications and consumer electronics segments. The report also contains responses on Bluetooth and wireless headsets from In-Stat's annual RTS. Brief profiles of major Bluetooth silicon suppliers are also provided. ■

INDUSTRY NEWS

■ **Microsemi Corp.** and **Advanced Power Technology Inc.** (APT) announced the signing of a definitive agreement for Microsemi to acquire APT. With this acquisition, Microsemi, a designer and manufacturer of high performance analog solutions and high reliability semiconductor solutions, expands its portfolio of analog mixed signal offering in the RF marketplace and also its high reliability offering in the defense/aerospace and medical marketplace. Under the terms of the agreement, each APT shareholder will receive $2.00 per share in cash and 0.435 shares of Microsemi common stock for each share of APT common stock.

■ **EMS Technologies Inc.** announced the closing of the sale of its Space & Technology/Montreal division to **MacDonald, Dettwiler and Associates Ltd.**, Vancouver, BC, Canada. EMS originally announced the signing of a definitive agreement for the sale on October 31st. The two companies have worked to obtain the necessary approvals from the Competition Bureau, Industry Canada pursuant to the Competition Act, customers and other third parties. Final terms of the sale were not disclosed.

■ **Agilent Technologies Inc.** announced an agreement with **Auriga Measurement Systems** to jointly develop and market integrated device-modeling systems for the semiconductor industry. The companies plan to pair Agilent's IC-CAP parameter extraction and device modeling software and instrumentation with Auriga's test instrumentation. The first system planned is a pulsed-bias/pulsed-RF solution for isothermal characterization and modeling. As part of this agreement, Auriga plans to develop software modules for Agilent's IC-CAP software, providing measurement and hardware drivers to allow data acquisition, and new device model extraction routines for Auriga device models.

■ **Cascade Microtech** is expanding its capabilities in the semiconductor failure analysis market. In August 2005, the company introduced eVue digital imaging system, a new tool for sub-micron probing to ease the problems of failure analysis on rapidly shrinking geometries. Cascade Microtech announced it has entered into a business and technology partnership with **Credence Systems Corp.** to further expand its failure analysis market penetration. The terms of the relationship were not disclosed.

■ **Taconic** and **Modelithics**™ announced that they have begun a collaboration whereby Modelithics will significantly increase its use of Taconic's high performance printed circuit board substrate materials in developing its substrate-scalable discrete and surface-mount component models for active and passive components.

■ **TestMart** announced an agreement with **Ophir RF**, a designer and manufacturer of high power, solid-state, broadband and band-specific amplifiers. The deal provides the US government and federal contractor marketplace with special pricing on a select catalog of RF power amplifiers. In related news, **Summitek Instruments**, a manufacturer of software products designed to automate spectrum management as well as S-parameter measurements, announced a new partnership agreement with TestMart Inc. TestMart will provide government marketplace services to better serve Summitek's diverse United States federal and defense-related customers. The agreement authorizes TestMart to present a special catalog of Summitek products to be made available specifically to the government and military markets.

■ **Xpedion Design Systems Inc.**, a provider of next generation RFIC simulation, and **Jazz Semiconductor**, an independent wafer foundry focused primarily on specialty CMOS process technologies, announced a partnership to deliver a qualified model and simulation environment for next generation RFIC design.

■ **Andrew Corp.** has signed a WCDMA infrastructure patent license agreement with **QUALCOMM Inc.** Under the terms of the worldwide royalty-bearing agreement, QUALCOMM has granted Andrew a license to develop, manufacture and sell WCDMA picocell and microcell base station systems.

■ **WiQuest Communications Inc.**, a fabless semiconductor company focused on the design and production of complete high performance, ultrawideband (UWB) wireless solutions, announced the opening of its first international customer development and sales support center. The new WiQuest office is located at 23F, No. 105, Sec. 2, Tun Hua South Road, Da An District, Taipei City, Taiwan, ROC. The phone number is +886-2-2709-7816 and e-mail is info@wiquest.com.

■ **Shimadzu Scientific Instruments Inc.**, a developer of analytical instrumentation, announced the availability of a complete range of analytical instruments to assist manufacturers in attaining Restriction of Hazardous Substances (RoHS) directive and Waste Electrical and Electronic Equipment (WEEE) directive regulatory compliance. In addition, Shimadzu provides all the equipment that companies need to assess ongoing compliance with established end-of-life vehicle regulations.

■ **Centro de Tecnología de las Comunicaciones S.A.** (CETECOM), in Spain, has enhanced its accredited testing service range for the mobile communications industry. CETECOM Spain has been granted ISO 17025 accreditation for testing of 3G technologies, enabling it to offer conformance testing services for 2G/2.5G and 3G technologies, covering RF, protocol, SIM/USIM and audio capabilities.

■ The Swiss **HUBER+SUHNER** Group, a global supplier of components and systems for electrical and optical connectivity, has been producing radio frequency products at its subsidiary company in Tzcew/Gdansk, Poland, since 2003. In November 2005, this plant received the ISO/TS 16949 certificate and now represents the company's third site to be awarded a certificate for this exacting automotive standard.

■ **Jacket Micro Devices Inc.**, an integrator of RF components used in wireless communication products, announced that it has joined the WiMAX Forum, an industry consortia dedicated to promoting and certifying compatibility and interoperability of broadband wireless products.

■ **RF Micro Devices Inc.** (RFMD) announced it has commenced shipments of highly integrated transmit modules to multiple handset manufacturers. Transmit modules are comprised of RFMD's power amplifiers with integrated PHEMT switch technology.

■ **ANADIGICS Inc.** announced that the company is shipping production volumes of InGaP HBT power amplifiers to **LG Electronics** for the VX9800 CDMA phone.

CONTRACTS

■ **Sensors Unlimited Inc.** announced it has been awarded a contract by the **Defense Advanced Research Projects Agency** (DARPA) Microsystems Technology Office to develop a 1280 × 1024 pixel, dual-wavelength, visible and shortwave infrared focal plane array. The contract will be awarded in three, 12-month phases and if fully executed, will total $4,576,176.

■ **AR Worldwide Modular RF** announced that it has received an order from **Amron International** for 71 tactical communications amplifiers. The order, for model KMW1030 (20 W, CW 30 to 512 MHz), is the latest in a series of orders from Amron, and is unique in that the amplifiers ordered are specifically for use in "HumVee" fighting vehicles rather than as Man-Pack units. AR Worldwide was awarded the order mainly because of its ability to customize the units and deliver them in a short time period.

■ **Boeing Co.**, Kent, WA, has placed a follow-on order for a space qualified hermetically sealed multi-throw switch in support of its Sea Launch Program. **Renaissance Electronics** has developed mechanical processes to achieve the severe requirements for space flight applications. Renaissance participation in this space flight program further expands the company's ability to support high level defense and space programs.

■ **RF Industries'** RF Neulink Telemetry Division announced it has been awarded an initial contract, valued at approximately $300,000, for its flagship NL6000 wireless modem for the program manager for training systems, training products and services provider to the **US Marine Corps.** (USMC). The contract includes $71,000 of non-recurring engineering expenses procured by SRI International, the USMC's lead systems integrator for range modernization and transformation.

FINANCIAL NEWS

■ **Ansoft Corp.** reports sales of $18 M for the second quarter of fiscal 2006 ended October 31, 2005, compared to $15.9 M for the same period in fiscal 2005. Net income for the quarter was $4.1 M ($0.32/per diluted share), compared to a net income of $1.9 M ($0.14/per diluted share) for the second quarter of last year.

NEW MARKET ENTRY

■ **Silicon Laboratories Inc.**, a designer of high performance, analog-intensive, mixed-signal ICs, announced its entry into the frequency control market with the Si530 and Si550 families of oscillators (XO) and voltage-controlled oscillators (VCXO) for applications up to 1.4 GHz. These product families include the quad frequency XO and VCXO devices. Leveraging the company's DSPLL® technology, both the Si530 and Si550 families provide short lead times, high reliability and good performance that make them ideal for applications such as networking equipment, base stations, test and measurement equipment, and storage area networks.

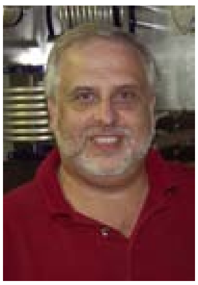
PERSONNEL

■ **Peter W. Staecker** has been elected to serve as vice president-elect of IEEE Technical Activities. He will assume the office as vice president on January 1, 2007.


▲ Erik Tobiason

■ **Erik Tobiason** has accepted the position of president of Vitronics Soltec. Tobiason takes the helm of Vitronics Soltec after five years of serving as president of Graphics Microsystems Inc. (GMI), a Dover Diversified company. Tobiason began his career with Dover as vice president engineering and R&D of GMI.

■ WJ Communications announced that it has appointed **Haresh P. Patel** as senior vice president, sales and marketing. Patel brings over 22 years of semiconductor industry experience managing sales, marketing and divisional P&L organizations. Patel replaces Javed S. Patel, who has resigned from his position at the company. Most recently, Patel was vice president, worldwide sales and marketing at Agilent Technologies, where he managed a 350 person sales and marketing organization.


▲ Jerry Brown

■ **Jerry Brown** has been named vice president of sales for LBA Technology Inc. Brown will manage sales and distribution of LBA antenna system and related radio frequency products.


▲ Steve Lu

■ picoChip announced it has appointed **Steve Lu** to be the company's vice president sales Asia Pacific. Most recently, Lu was vice president of marketing and strategy for Sipod Communications in Shanghai, China.

■ Aperto Networks, a WiMAX systems provider, announced that it has appointed **Glenn Tamaru** as vice president of operations. Tamaru, who has

25 years of operations experience, was most recently vice president of operations at GoDigital Networks in Fremont, CA.


▲ Bruce Valentine

■ IDI/Synergetix announced that **Bruce Valentine** has joined the team by accepting the position of business development manager for connector products in Europe. Valentine will help to guide business growth of the OEM product sales in the European sales region.

■ 4RF Communications has appointed **Jarlath Lally** to the role of global director of marketing. He will operate from 4RF Europe, based in the UK, where he will be responsible for helping the company to expand its global customer reach, and develop new markets for its wireless networking solutions. Lally has worked for 4RF Communications since January 2005 as a strategic account manager. From 2002 to 2004, he worked as an independent consultant with a client list that included network operators, regulators and ICT equipment vendors. Prior to that he held management roles at Cisco, Stratex Networks and NEC.


▲ Jarlath Lally

■ Comarco Wireless Test Solutions announced that **Carlos Oliu** and **Charles Blount** have joined the company as managers of South American sales and North American sales, respectively. They will also oversee the rapidly expanding distribution networks in their territories. Oliu served as a major accounts executive with Willtech International, marketing wireless testing equipment to carriers. Blount supervised and directed technical sales support and all engineering services sales for wireless test systems at Ericsson.

REP APPOINTMENTS

■ **Aeroflex** has signed a distribution agreement with **Maxtronix Inc.** to distribute its product portfolio in the Philippines. Under the terms of the agreement, Maxtronix will operate as exclusive distributor for Aeroflex ATE products and services including flying probe test systems, power manufacturing defects analyzers, and in-circuit and combinational testers. The distributor has offices in Paranaque City and Cebu City, dedicated to selling sophisticated equipment for semiconductor, SMT and thru hole assembly technology.

■ **Nordic Semiconductor** and **Nu Horizons Asia Ptd. Ltd.** announced the signing of a Pan-Asian partnership agreement. This agreement involves the distribution for all of Nordic's products throughout the territories of China, Hong Kong, Taiwan, India, Korea, Malaysia, Singapore, Thailand, Australia and New Zealand.

■ **MI Technologies** announced it has selected **Adler Instrumentos S.L.**, Madrid and Barcelona, to represent the company's line of RF and microwave test and measurement products to customers in Spain. MI Technologies' automated test and measurement systems are used to evaluate wireless, satellite and telematics antennas, radomes, radar cross section and microwave component characteristics.

■ **Microtech** announced the appointment of **Hytech Associates Inc.** as its exclusive sales representative for southern California. Hytech can be reached at 717 Lakefield Road, Suite B, Westlake Village, CA 91361 (818) 991-7491, fax: (805) 379-2128 or e-mail: hytech@hyth.com.

■ **International Manufacturing Services Inc.** (IMS), a manufacturer of high quality thick film resistors and substrates to the electronics industry, announced the appointment of **W. Howard Associates Inc.** to represent its products in the states of Colorado, Utah, Montana, Wyoming and Idaho. The company can be contacted at 6770 S. Dawson Circle, Suite 100, Centennial, CO 80112-4224 (303) 766-5755, fax: (303) 766-2488 or e-mail: service@whoward.com. In related news, IMS announced the appointment of **NextWave Technologies** to represent its products in Israel. NextWave can be reached at PO Box 25180, Tel-Aviv 61253 Israel 972-3-9619000, fax: 972-3-9619005 or visit www.nextwave.co.il.

■ **Wenzel Associates Inc.**, a manufacturer of precision low noise crystal oscillators and related RF devices, subassemblies and synthesizers for the communications, navigation, military and test equipment markets, announced the appointment of **C-Wave Inc.** as the company's representative for southern California. C-Wave can be reached at (310) 937-3521 or visit www.cwaveinc.com.

■ **RelComm Technologies Inc.**, a designer and manufacturer of RF coaxial relay products, has appointed **Associate Technical Sales LLC** to represent the company in southern California. For more information, visit www.ats1rep.com.

■ **Praxsym Inc.** announced the addition of **Winncom Technologies** as a registered distributor for resale of the PM-2458 broadband wireless power meter. Winncom Technologies is a provider of wireless networking solutions, offering a complete selection of unlicensed and licensed wireless data and voice products. For more information on the PM-2458, visit www.vswrmeter.com.

WEB SITE

■ **American Technical Ceramics** (ATC) introduced expanded product offerings for ATC QUIKBuy™, where customers may place on-line orders for small product quantities. ATC QUIKBuy offers the EIA-size ultra-low ESR capacitors, the 600F (0805) and 600S (0603). ATC has now expanded its on-line product offerings to include the 600L (0402), as well as RF capacitors: the 100A (0505) and 100B (1111). The ATC QUIKBuy Product Selector enables customers to easily select specific capacitance values and case sizes. ATC QUIKBuy also creates an on-line customer profile to expedite repeat orders. Visit www.atceramics.com and select: ATC QUIKBuy.

EUMW 2005: A SOPHISTICATED SUCCESS

Haute cuisine, chic cafés, restaurants and, of course, fine wines are the staple diet for Parisians. Last October, however, the city also served up a mouth-watering array of technology and innovation as the 8th European Microwave Week was staged at the CNIT La Défense, International Conference and Exhibition Centre. The event made every effort to satisfy the appetite of its global attendees and visitors, hungry to hear about and discuss new developments, view the latest products, and take the opportunity for professional and personal networking. There was also the opportunity to taste the delights of a sophisticated, cosmopolitan and hospitable city. Even a less than hospitable national one-day industrial strike did little to dampen spirits with the microwave community proving its resilience.

That resilience has been evident in recent years as the industry has had to cope with depressed markets in certain sectors and uncertainty in others. Confidence has been rebuilt slowly but surely. EuMW 2005 played a vital role in boosting this confidence by focusing on the commitment and drive being channelled into technological and product development, and by highlighting the positive efforts being made. That the Week had such an impact is a tribute to the prolonged dedication and endeavour of EuMW general chairman, Raymond Quéré; secretary, Michèle Lalande, treasurer, Bernard Jarry and their associates at GAAS® – chairman, Robert Plana; ECWT – chairman, Serge Toutain; EuMC – chairman, Jean-Louis Cazaux and EuRAD – chairman, Joseph Saillard. During the year they have been supported by countless people, including local organisers, the TPC-members, the members of the review boards, the organizers of the workshops, short courses and special sessions, and the members of the EuMA Board of Directors. Horizon House Publications played its part, organizing the European Microwave Exhibition, running the registration system, liaising with the venue and contributing to the organisation of the conferences. Invaluable as always were the many industrial companies and organisations that lent their financial and practical support.

RICHARD MUMFORD
Microwave Journal ***European Editor***

THE CONFERENCES

The four separate but complementary conferences — GAAS®2005, the European Gallium Arsenide and other Compound Semiconductors Application Symposium; the European Conference on Wireless Technology (ECWT 2005); the 35th European Microwave Conference (EuMC 2005) and the second European Radar Conference (EuRAD 2005) were supported and enhanced by a variety of dedicated workshops, short courses and tutorials, focusing on specific, up-to-the-minute topics in the field of microwave technologies.

GAAS®2005

Papers were submitted from 25 countries, covering a broad spectrum of topics in the area of RF and microwave electronic devices and circuits. The result was a conference that featured more than 90 oral presentations in 18 sessions and four workshops and short courses. Focused sessions were organised that addressed activities in two EU Networks of Excellence as well as on new emerging technologies such as GaN and NanoCMOS. There were also sessions on 3D MCM modules for space applications, microwave and mm-wave ICs in silicon technology. Significantly, too, there was a session dedicated to industrial aspects, featuring invited speakers from industry and an industrial round table panel session.

PRIZES AND AWARDS

As always there was fierce competition for the prizes given to the best papers and the Fellowship awards. The €1,500 Alcatel Alenia Space Prize was won by Koli Yamanaka from the Mistsubishi Electric Corp. R&D Centre, Kamakura, Japan. Awarded with the WIN Semiconductors prize of €1,500 was Rachid Driad from the Fraunhofer Institute of Applied Solid State Physics, Freiburg, Germany. Elisra awarded €1,500 to Sanghyun Seo from Technische Universität Darmstadt, Germany, while the UMS Prize of €1,500 went to Jean Godin from the Alcatel-Thales III-V Lab, Marcoussis, France. To encourage the youth and invest in the future, four €3,000 Young Research Fellowships were awarded to: Antonio Raffo from the University of Ferrara, Italy; Masoud Movahhedi of AmirKabir University of Technology, Tehran, Iran; Krishnamurthy Lokesh from the University of Manchester, UK; and Vikas Manan of the University of California, Santa Barbara, US. A fifth Fellowship of €3,000 was shared by Rocco Giofrè and Antonio Nanni of the University of Rome Tor Vergata, Rome, Italy.

ECWT

The conference is an international forum for the presentation and discussion of the latest developments in the field of wireless communication technologies. To underline that fact, 136 papers, submitted by authors from 25 countries, were presented during the 16 oral sessions and two poster sessions. In the opening and closing sessions, keynote speakers provoked keen discussion when addressing the present trends in the wireless communications field. Seven sessions were co-organised with the European Microwave Conference, together with a focused session on Wireless Personal Area Networks.

PRIZES

The ECWT Best Paper Prize was won by David Marchaland from ESIEE-ESYCOM/STMicroelectronics, France, while the ECWT Young Engineers Prize went to Georg Strasser of LMC, Austria.

EuMC

There was a significant rise in the number of submissions compared to previous years. There were 53 regular oral sessions, including three focused sessions on specific topics and 16 joint sessions with the other three conferences. Special emphasis was given to the activities of the different Networks of Excellence and there were lunchtime poster sessions each day in the European Microwave Exhibition hall.

Demonstrating that it has become a truly international conference, there was a dramatic rise in interest from Asia, with South Korea leading all other countries, including France, the host country. From the Middle East to Far East Asia, North and South America, Africa, Oceania, Eastern and Central Europe, there were contributions from 49 countries.

PRIZES

The €5,000 EuMC Prize awarded by the EuMA for the best paper presented at the conference went to Hiroshi Murata, Kazumasa Kaneda, Akira Enokihara and Yasuyuki Okamura from Osaka University and Matsushita Electric Industrial Co., Japan. Two €2,000 Young Engineers Prizes were awarded. They went to Stefan Mueller of Technische Universität Darmstadt, Germany, and Alessandro Ocera from the University of Perugia, Italy.

EuRAD

Building on the success of the first European Radar Conference in Amsterdam last year, EuRAD 2005 received an increased number of high level papers with contributions from many countries. It encompassed a wide range of topics, including radar devices, systems and processing techniques. Within the conference framework radar and radar related researchers were given the platform to present their progress and offer new insights during oral and poster sessions as well as two focused sessions, one workshop and one short course.

PRIZES

Two prizes sponsored by Raytheon were awarded by the EuRAD TPC and the General Assembly of the EuMA. The European Microwave Association Radar Prize of €3,000 was awarded to D. Cerutti-Maori, et al., FGAN-FHR/ARB, Wachtberg, Germany. To encourage the student fraternity, the €2,000 European Radar Conference Young Engineer Prize went to J.C. Diot, et al., Université de Limoges, France.

THE EXHIBITION

Paris is renowned as being the centre of the world's fashion industry but it was the microwaves and RF, wireless technologies, semiconductor and radar communities that took centre stage at the CNIT. And just as the top designers use the Paris catwalks to show off their latest creations, the European Microwave Exhibition provided a stage for companies from across the globe to showcase their wares. Indeed, some used it to launch brand new products or show their latest creations for the very first time. Read on to discover the stars of the RF and microwave winter collection and get an insight into future trends as the key products paraded at the show are highlighted; apologies to those companies that have not been mentioned due to space constraints.

Test and measurement crosses the boundaries of the different industry sectors that EuMW embraces, so it is no surprise that manufacturers in the field are particularly active, targeting the event for new product introductions.

That is definitely the case for Agilent Technologies, which made a number of key announcements. Particular emphasis was given to the new low cost compact spectrum analyzer (CSA), which is the first in a series of intuitive, low cost spectrum analyzers that enable technicians, R&D and manufacturing engineers to make complicated RF measurements with speed, ease and confidence. The company also chose to demonstrate

its Synthetic Instruments product portfolio for the first time in Europe, using the capabilities of its existing bench top instruments to create a portfolio of synthetic instruments that support the LXI standard.

Also introduced were two additional models to the N6030A series arbitrary waveform generator (AWG) family. The N6032A, a dual-channel AWG designed for radar and military communications, delivers 625 MS/s and 15 bits of vertical resolution per channel to create wideband waveforms up to 250 MHz wide. The N6033A generator, designed for satellite communications and general-purpose wideband applications, delivers 625 MS/s and 10 bits of vertical resolution per channel.

Sharing the Agilent stand and similar ambitions to develop significant products, Cascade Microtech launched its WinCal 2006 software to address the testing challenges brought on by the increase in the volume of complex, high speed semiconductors that are designed and tested for use in mobile communications products.

The software is designed to provide an easy and successful path for RF wafer testing for the experienced engineer or those new to RF device characterization. It solves a wide variety of common problems including data correlation, training of new users, obtaining correct calibration coefficient definitions, calibration verification, erroneous use of untrimmed or non-50 Ω loads, and determining the source of unexpected or suspect measurement data.

Proving that they too can be prolific in the test and measurement arena, Rohde & Schwarz introduced a plethora of new products. The focus was on the new family of network analyzers, all of which have the same operating concept and a common remote-control command set. The R&S ZVA24 analyzer is the high end model. It is available as a two-port and four-port version and covers a frequency range from 10 MHz to 24 GHz. It has a dynamic range of more than 145 dB and a measurement speed of 3.5 µs per measurement point. The R&S ZVB20 network analyzer targets the medium price segment with high measurement speed, a wide dynamic range of more than 130 dB and maximum output power of up to +13 dBm.

The R&S ZVT8, the world's only eight-port network analyzer, features true multi-port architecture and offers very short measurement times while maintaining high measurement accuracy and a wide dynamic range. Also showcased was a complete measurement solution for WiMAX signals, a versatile spectrum analyzer and a compact measurement system for determining electromagnetic susceptibility.

For Ansoft, three products made their European debut. First, the Q3D Extractor v7 is a 3D quasi-static electromagnetic parasitic extraction tool. New features have been introduced that make it easier and more reliable for engineers to import 3D CAD models and integrated circuit, printed circuit board and package layouts from third-party tools. A new fault-tolerant meshing algorithm has been added to make the meshing process tolerant to anomalies that occur in geometric data from CAD/EDA software programs.

Second, HFSS v10 is the new release of the company's flagship high frequency/high speed electromagnetic design product, introducing new capabilities for design-flow efficiency that allow users to easily share CAD models and results across existing CAD/CAE products. Finally, the Turbo Package Analyzer v4.2 is the latest version that combines new bidirectional integration with Synopsys' Encore package-design software with the company's 3D electromagnetic simulation. It enables full parasitic extraction of complex IC packages, such as ball-grid arrays.

Keeping up the interest, Anritsu made two major announcements. The first being pulse modulation enhancements to the company's MG3690B signal generators for more precise and convenient simulation of pulsed signals used in civilian and military radar applications. These enhancements provide more narrow-leveled pulses, increased resolution when using the internal pulse generator and include higher frequency internal waveform generators to simulate modulated signals. The signal generator's pulse modulation performance responds to emerging needs of radar systems, especially those operating in the 1 to 2 GHz L-band.

The second is the launch of two wideband peak power meters, the single sensor input ML2495A and the dual sensor input ML2496A, which are designed for the demands of the rapid rise time radar measurement and the latest 4G wireless applications. The ML2490A series has been designed with a 65 MHz mainframe bandwidth and displays a typical rise time of 8 ns with 1 ns resolution when used with the company's new MA2411B pulse sensor. The ML2490A measures the peak, average and crest factor of both the continuous OFDM and framed OFDM, and is suitable for WLAN and WiMAX applications.

EuMW 2005 saw APLAC Solutions exhibit in its own right for the last time, following its recent acquisition by Applied Wave Research. However, it was made evident that its input will be very much in evidence in the future. More immediately, AWR announced a robust, feature-packed 2006 version of its flagship product, Microwave Office design suite. This latest version offers a new integrated filter synthesis solution using Nuhertz Technologies' filter synthesis technology. This feature offers complete synthesis capability for passive, transmission line, active, switched capacitor and digital filters, as well as two graphical user interfaces, one for the power user who requires advanced options and capabilities, and one for the mainstream user who needs ease-of-use. This latest development together with other key updates ensures that the design suite continues to deliver key productivity improvements to microwave designers, shortening design cycle time and speeding time-to-market for RF/microwave products.

Centre stage on the Aeroflex stand was taken by a new test capability, the PN95-DSM digital spectrum monitoring (DSM) option that has been added to the expanding PN9500 phase noise test system. The DSM option allows the user to view the spectrum of a signal in the same way as a spectrum analyzer and also integrates specific processes that are ideal for radar testing. The PN95-DSM measures power level, power variation, adjacent channel power and harmonic distortion, and more measurements are possible by setting markers. The company also showed the PN9276 microwave down converter, which has had its frequency boosted to 50 GHz to enable phase noise testing for higher frequency applications.

Now very much a key contributor to the Week is the Microwave Innovation Group, which showcased its WASP-NET and previewed Version 6.1, the enhanced features of which will include dielectric resonator filters, dielectric loaded horns, horns with shaped subreflectors, ridged waveguide slot arrays, LTCC filters and diplexers, extended combline elements, advanced broadband OMT elements, 3D black box elements, and 64 bit and multi-processor options.

Staying with German companies, Computer Simulation Technology previewed the CST Microwave Studio 2006. This time domain 3D EM simulator features a major redesign of the architecture, together with substantial new functionality. Most significant is the use of the CST Design Environment as a common access point to the company's solver technology. Structures are presented in 3D and schematic views and the comparison of models and co-simulation is facilitated by a new multi-document interface. No more details could be given as the product was still being developed but that can now be remedied by turning to the Product Feature on page 150 for the full story.

Not test and measurement but still focusing on the German companies, Antennessa launched two products. First, the INSITE box is an RF EMF monitoring station. Remotely operated, it makes on-going isotropic and selective measurements in twelve frequency bands: FM, TV3, TETRA, TV4&5, GSM Tx and Rx, DCS Tx and Rx, DECT, UMTS Tx and Rx, and WiFi. Second, the company completes its range of EMF measurement systems with EME GUARD, a new alarm dosimeter developed to protect workers from the risks associated with RF electromagnetic fields.

Moving over the border and to the EuMW host country, France, OMMIC targeted the show to introduce a new range of products to include six-bit phase shifters, six-bit attenuators and complete integrated core chips at X- and C-band. These products take advantage of OMMIC's 0.18 µm enhancement-depletion technology that allows for the complete integration of functions. The first products include CGY2170UH and CGY2175UH, which are fully integrated 'core chip' functions for phase array radar at X- and C-band, respectively.

As for the Italian representation, ABF Elettronica presented a 7/8 GHz duplexer, which is particularly suited to high capacity digital radio applications in outdoor units and is an alternative to the dielectric resonator approach. Important features are low cost, high reliability, quick frequency tuning, good performance and compactness. Characteristics include tunability frequency ranges of 7.1 to 7.4 GHz, 7.4 to 7.7 GHz, 7.7 to 8.1 GHz and 8.1 to 8.5 GHz. It has six resonators and an operating temperature range of –33° to +70°C.

Demonstrating the significant global impact of the exhibition, several non-European companies took the opportunity to launch new products. For instance, Peregrine Semiconductor unveiled the next generation of its UltraCMOS™ process technology. The first devices to be released on the company's HaRP™-enhanced UltraCMOS™ process are the PE42672 SP7T and the PE42660 SP6T RF switches for quad-band GSM and GSM/WCDMA handset applications. The former is said to be the world's first monolithic SP7T switch with an on-board CMOS decoder. This highly integrated solution simplifies and lowers the cost of RF designs by reducing overall part count by as many as six devices and 13 wire bonds. The PE42660 switch is drop-in compatible with the PE4263 GSM handset switch that was released at the end of 2004.

Similarly, TriQuint Semiconductor debuted four new high performance wideband millimetre-wave amplifiers with industry leading power bandwidth performance. The TGA4521 is a wideband millimetre-wave driver amplifier covering the 32 to 45 GHz frequency range, that features +25 dBm saturated output power and +24 dBm, 1 dB compressed output power. The TGA4522 is a balanced version of the TGA4521, offering a higher output power capability with +27.5 dBm saturated and +27 dBm, 1 dB compressed performance at 38 GHz.

The TGA4046 is a balanced high power amplifier MMIC for Q-band applications, particularly military and commercial satellite uplink communications with a saturated output power of +33 dBm and 1 dB compressed power of +32 dBm. Finally, the TGA4040 is a medium power amplifier/frequency multiplier MMIC for a variety of applications including military and commercial satellite communications, electronic warfare, digital radio and instrumentation.

Illustrating the diversity of the products on display, Analog Devices has extended its portfolio of leading RFICs with the ADF7020-1 transceiver. Designed to address short range device (SRD) wireless connectivity applications in home and building automation, wireless video and audio, automatic wireless metering and security applications, the transceiver is a single-chip solution for the 135 to 650 MHz frequency range with good co-channel and adjacent channel rejection. The transceiver supports data rates of 0.15 to 200 kbits/s frequency shift keying and 0.15 to 64 kbits/s amplitude shift keying. The device operates on a +2.3 to +3.6 V power supply with programmable output power from –16 to +13 dBm in 0.3 dBm steps.

This product round up began with Agilent and will finish with it too in the guise of Agilent Semiconductor Products, which announced the expansion of its family of millimetre-wave integrated circuits to include low cost, surface-mount amplifiers operating in the 20 to 40 GHz frequency range. The new product family consists of seven devices. The AMMP-6231 is a high performance, low noise amplifier ideally suited for 18 to 31 GHz receive chains. The AMMP-6345 and AMMP-5040 are driver amplifiers for 20 to 45 GHz broadband applications. The AMMP-5024 is a travelling-wave amplifier operating from 100 kHz to 40 GHz. Two others, AMMP-6425 and AMMP-6430, are high performance, 1 W power amplifiers for use in frequencies from 17 to 33 GHz. Finally, the AMMP-6130 is a frequency multiplier with an integral driver amplifier operating in the 30 GHz satellite band.

SOCIAL EVENTS

The extracurricular activities that are organised are just as important as the academic and have become an integral part of the Week. On Monday evening, guests of the GAAS Association enjoyed the traditional GAAS Dinner, but at a typically chic location, in a restaurant located on the fifth floor of the famous La Samaritaine store in the historical heart of Paris, with a splendid view of the city.

It was more the exchange of views that the EuMW 2005 Welcome Reception, sponsored by Agilent, EuMA and Horizon House, provided as it accomplished the difficult feat of bringing together the registered conference delegates from all four conferences and the exhibitors participating in the show, thus providing academics with the rare opportunity to exchange

ideas with those who actually turn the theory into practice. On Wednesday evening, attendees realized that life does not get much better as they were treated to a Gala Cocktail Evening combined with a trip on the Seine to savour the historical heart of Paris.

SPONSORS

An interesting and challenging conference, allied to an exhibition that attracts the leading global players are the key ingredients of a successful event, but it is the added extras that gives the Week its own memorable and unique flavour. That can only be achieved with the support and encouragement of commercial sponsors, many of which have made specific features their own in recent years. That is the case with Platinum Sponsors Agilent, whose contribution to the Welcome Reception has made it a social highlight. Thanks also to Ansoft for the delegate bags, WIN Semiconductors for the badge cords and Mician for the visitor bags. Welcome sustenance was provided during the coffee breaks, which were sponsored by Ansoft, Mimix, AEP, Micrometrics and Ultrasource, while the two Cyber Cafés sponsored by CST provided an intellectual caffeine boost and the opportunity to visit (among others) the EuMW web site with its Rohde & Schwarz sponsored banner. Rohde & Schwarz also played a vital part in the conference preparations with their all-important support of the TPC dinner. And finally, those who attended the event would not have missed the Tektronix footsteps, which combined practicality with humour.

MANCHESTER 2006

It's a new venue, a new city and an extended format as the G-Mex/MICC Complex in Manchester, England, plays host to the 9th European Microwave Week, over six days, on 10 to 15 September 2006. The microwave community should feel at home in the world's first industrial city, which boasts a wealth of historical and modern attractions, together with a plethora of restaurants, pubs and bars as well as the Manchester United Football Club, of course. As for the event itself the organisational team is in place, with the goal of providing four strong, responsive and challenging conferences, complemented by a healthy exhibition featuring international players and an attractive and vibrant social agenda. ■

PERFORMANCE COMPARISONS BETWEEN DIELECTRIC RESONATOR ANTENNAS AND PRINTED MICROSTRIP PATCH ANTENNAS AT X-BAND

The performance of a cylindrical dielectric resonator antenna (DRA) and a circular printed microstrip patch antenna (MPA) are compared at X-band. Comparisons between the antenna sizes, transmission coefficients, radiation patterns, gains and radiation efficiencies are discussed. Similar broadside radiation modes are excited for both antennas. The antennas are fabricated or etched on the same dielectric materials and designed with the same matched frequency range. It is concluded that the DRA has a wider bandwidth and a higher gain than the MPA. The radiation efficiency of the DRA is nearly 95 percent, while it is only approximately 80 percent for the MPA, due to the conduction losses.

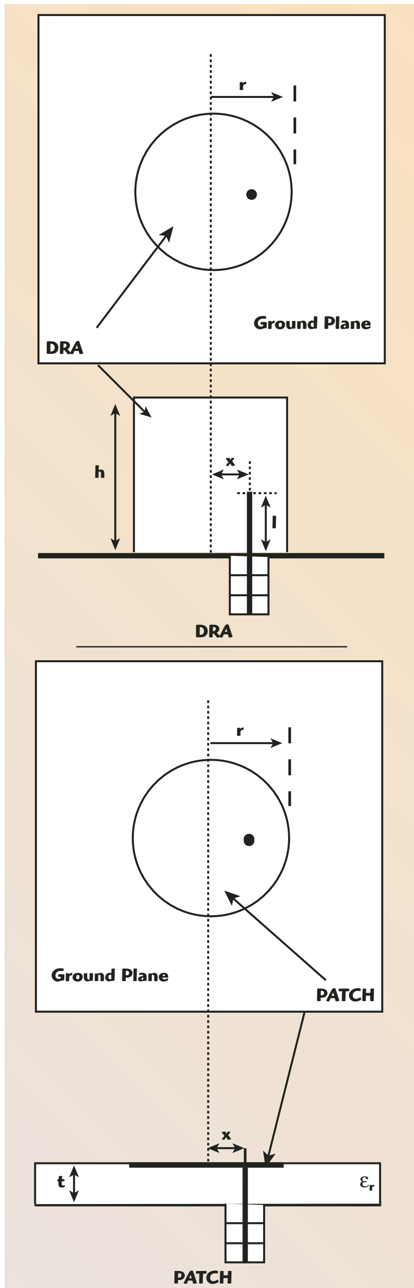
Microstrip patch antennas (MPA)[1–5] and dielectric resonator antennas (DRA)[6–7] have been studied extensively. They share the advantages of low profile, lightweight, ease of fabrication and are easy to excite by different methods. Both antennas are viable candidates for numerous applications, either as individual elements or in an array environment. However, metallic and dielectric losses are usually associated with most MPAs when they are printed on dielectric substrates.[3] On the other hand, there is no metallic loss for the DRAs. Hence, they have the inherited advantage of higher radiation efficiency at high frequencies.[7] A comparison between DRAs and microstrip patches was performed numerically.[8] The advantages of the DRA over the MPA were clear. Measurement of the radiation efficiency could be a means to compare the losses in the antennas. The conduction losses, dielectric losses and surface wave losses all contribute to lowering the radiation efficiency, which can be accurately measured by the Wheeler cap method.[9–11]

R. CHAIR, A.A. KISHK, K.F. LEE AND D. KAJFEZ
University of Mississippi
Oxford, MS

In this article, the performance of a cylindrical DRA[5,12–14] and a circular MPA[15–18] at X-band are studied experimentally. Both the DRA and MPA are excited by a coaxial probe and resonate at 9.9 GHz. The locations of the feeds are carefully chosen in order to excite the broadside radiation modes. The MPA is excited in the TM_{11} mode and the DRA in the $HEM_{11\delta}$ mode. In order to have a fair comparison, the MPA is printed on the same dielectric material that is used to fabricate the DRA. The bandwidths for the DRA and MPA are 10.3 and 1.3 percent, respectively, with a dielectric constant of 10.2 used for both antennas. The antenna gain of the DRA is 1 dB higher than for the MPA. The Wheeler cap method is employed to measure the radiation efficiency. It is shown that the radiation efficiency for the MPA is 80 percent and 95 percent for the DRA. As expected, the conduction losses of the MPA reduced the radiation efficiency and the gain of the antenna in X-band.

ANTENNA GEOMETRIES AND MEASUREMENT SETUP

Figure 1 shows the geometries of the cylindrical DRA and the circular MPA. Both antennas are designed to have a good match at approximately 9.9 GHz. The circular-shaped MPA has a radius r = 2.45 mm (0.082 λ_0) and is printed on a dielectric substrate with a dielectric constant ε_r = 10.2 and a thickness t = 0.64 mm



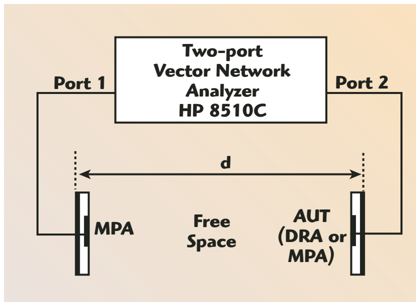
▲ *Fig. 1 Geometries of the DRA and MPA.*

(0.021 λ_0), where λ_0 is the free space wavelength at 9.9 GHz. The TM_{11} mode is excited by an off center coaxial probe. The probe has a radius r_f = 0.3 mm and is off-centered in the MPA by x = 0.4 µm. The cylindrical DRA has the following dimensions: r = 3.3 mm (0.11 λ_0), h = 5.08 mm (0.17 λ_0), ε_r = 10.2, r_f = 0.4 mm, x = 2 mm and l = 2.54 mm. Both antennas are mounted on a square ground plane 30 by 30 mm (1 λ_0 × 1 λ_0). A two-port HP8510C vector network analyzer (VNA) is used to measure the transmission coefficients. The measurement setup is shown in ***Figure 2***. Port 1 of the VNA is connected to a reference MPA, which is identical to the MPA mentioned earlier, and Port 2 is connected to the DRA or MPA for comparison. The antennas, connected to Ports 1 and 2, are separated by a certain distance d between the two ground planes. The measurement is taken when both antennas are facing each other. Since broadside modes are excited for both antennas, the maximum radiation is normal to the ground plane.

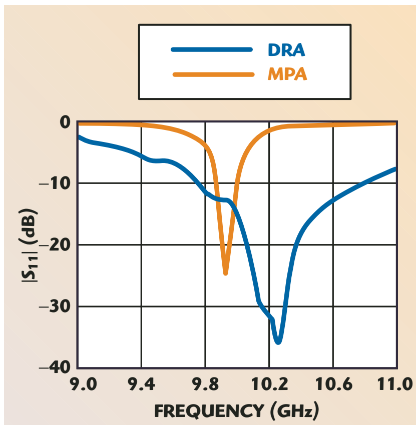
MEASUREMENT COMPARISONS

Transmission Coefficients and Antenna Gains

The measurement is made using the setup described in the previous section. The MPA is connected to Port 1, as a common transmitting antenna. The receiving port (Port 2 of the VNA) is connected to the antenna under test (AUT). First, the return losses of all the antennas are measured to ensure a good match at the desired frequency of 9.9 GHz. ***Figure 3*** shows the return losses of the MPA and DRA. The resonant frequency for the DRA is 10.2 GHz. It has a matched frequency range from 9.75 to 10.81 GHz, with a 10.3 percent impedance bandwidth (S_{11} < –10 dB). The MPA has a minimum return loss of –25 dB at 9.9 GHz. Its impedance bandwidth is 1.3 percent with a matched frequency range from 9.87 to 9.99 GHz. The comparison is performed at 9.9 GHz, which shows a good match (S_{11} < –13 dB) for both antennas.



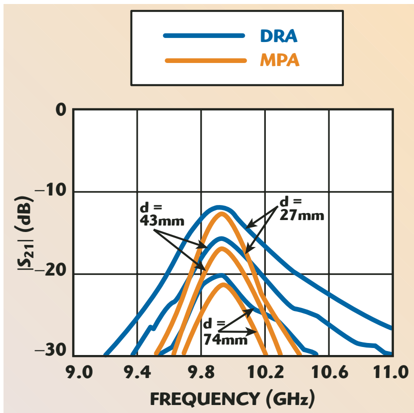
▲ *Fig. 2 Setup for measuring S_{21}.*



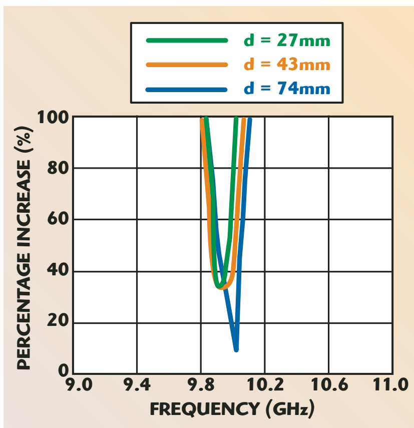
▲ *Fig. 3 Return losses of the DRA and MPA.*

The transmission coefficients were measured with both antennas separated by a distance d = 27 mm (0.9 λ_0), 43 mm (1.43 λ_0) and 74 mm (2.47 λ_0). These distances were chosen to have the antennas placed within both the Fresnel region (18.6 mm < d < 60 mm) and in the far field region (d > 60 mm). The measured transmission coefficients S_{21} are shown in ***Figure 4***. The transmission coefficients for the DRA are found to be –11.8 dB, –15.7 dB and –20.4 dB when d = 27 mm, 43 mm and 74 mm, respectively. When the MPA is connected, the transmission coefficients are found to be –12.8 dB, –16.6 dB and –21.5 dB at d = 27 mm, 43 mm and 74 mm, respectively. The power received by the DRA is always 1 dB higher than by the MPA, at 9.9 GHz. In addition, the Q-factor of the DRA is found to be lower than the MPA, which leads to the transmission coefficient levels of the DRA dropping at a slower rate than for the MPA. The percentage increase of the power received by the DRA compared to the MPA is shown in ***Figure 5***. The 1 dB differences between the DRA and MPA is equivalent to about 25 percent more power received/transmitted by the DRA than by the MPA, with the same input power. The matching of the MPA deteriorates quickly due to its narrow bandwidth, when the MPA will no longer receive or radiate the signal efficiently. It is noted that the percentage differences of the power received by the DRA and MPA grows quickly when the frequency is below or above 9.9 GHz. The same characteristics are found for different distances d. The percentage increase in the receiving power by the DRA is mainly due to the mismatch of the MPA.

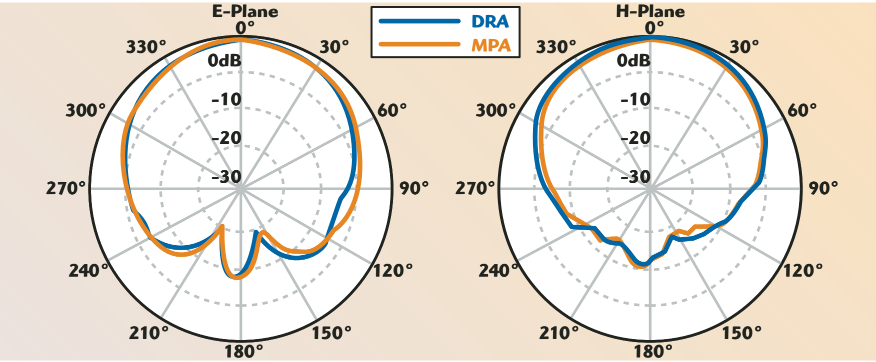
A similar test was also performed in the far field range, inside an anechoic chamber. A standard gain horn from Narda Microwave was used as the transmitting antenna. The AUT was located two meters away from the transmitting horn. The average



▲ *Fig. 4 Measured S_{21} for the DRA and MPA.*



▲ *Fig. 5 Percentage increase in the power received by the DRA compared to the MPA.*



▲ *Fig. 6 Radiation patterns of the DRA and MPA.*

gains of the DRA and MPA, measured in the broadside direction, were 7.7 and 6.7 dBi, respectively.

Radiation Pattern

The radiation patterns of both the DRA and MPA were measured at 9.9 GHz. With the off-center probe excitation, the $HEM_{11\delta}$ and TM_{11} broadside modes are excited in the DRA and MPA, respectively. The co-polar radiation patterns of both antennas are depicted in ***Figure 6***. The DRA has a 3 dB beamwidth of 86° and 90° in the E- and H-plane, respectively. The MPA 3 dB beamwidth is 88° in the E-plane and 90° in the H-plane. It is noted that both antennas are radiating with similar beamwidth and front-to-back ratio.

Radiation Efficiency

The radiation efficiencies of both the DRA and MPA are measured by the Wheeler cap method. For accurate results, it is required that the antenna be enclosed by a conducting cavity, the Wheeler cap.[9] A conducting cylindrical cap is used to shield the antenna. Since the antenna is prevented from radiation by the cap, the measured input resistance is equivalent to the loss resistance.[11] The radiation efficiency is defined by the ratio between the radiated power and the total input power. By computing the input resistance with and without the cap, the radiation efficiency can be found as

$$\eta_{rad} = \frac{P_{rad}}{P_{tot}} = \frac{R_{rad}}{R_{tot}} = \frac{R_{in} - R_{cap}}{R_{in}} \qquad (1)$$

where

P_{rad}, R_{rad} = radiated power and resistance

P_{tot}, R_{tot} = total input power and resistance

R_{in} = input resistance without the cap

R_{cap} = input resistance with the cap

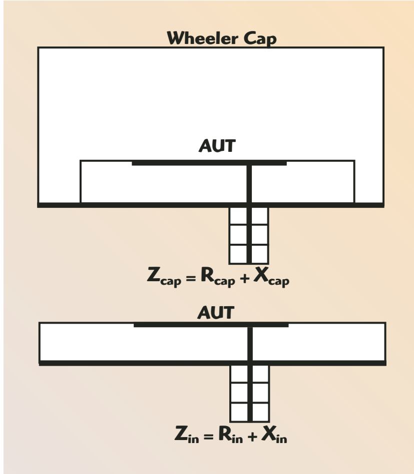
The measurement setup is shown in ***Figure 7***. Using Equation 1, the radiation efficiency of the DRA and MPA at 9.9 GHz are measured to be approximately 95 and 80 percent, respectively. Both antennas have similar amounts of dielectric loss. The lower radiation efficiency of the MPA is mainly caused by the conduction losses. A second way[18] to measure the antenna efficiency by the Wheeler cap method is to determine the unloaded Q factor of both the radiating antenna, Q_{0rad}, and the covered antenna, Q_{0cov}. The radiation efficiency at the resonant frequency is then computed as

$$\eta = 1 - \frac{Q_{0rad}}{Q_{0cov}} \qquad (2)$$

For the two antennas discussed here, the results obtained by the second method are also provided in ***Table 1***. It can be seen that the results of both methods lead to the following conclusion: the DRA radiation efficiency is 93 percent or higher, while the MPA radiation efficiency is 81 percent or lower.

DISCUSSION

In this section, the performances of both the DRA and MPA are summarized. The MPA occupies a smaller vol-



▲ *Fig. 7 Measurement setup for the Wheeler cap method.*

TABLE I

PERFORMANCE OF THE CYLINDRICAL DRA AND CIRCULAR MPA

	Cylindrical DRA	Circular MPA
Radius (r) (mm)	3.3 ($0.11\lambda_0$)	2.45 ($0.082\lambda_0$)
Height (total thickness) (h) (mm)	5.08 ($0.17\lambda_0$)	0.64 ($0.021\lambda_0$)
Dielectric constant (ε_r)	10.2	10.2 (substrate)
Resonant frequency (f_0) (GHz)	9.9	9.9
Bandwidth (BW) (%)	10.3	1.3
Radiation mode	$HEM_{11\delta}$	TM_{11}
Transmission coefficient (S_{21}) (dB)		
d = 27 mm	–11.8	–12.8
d = 43 mm	–15.7	–16.6
d = 74 mm	–20.4	–21.5
3 dB beamwidth		
E-plane (°)	86	88
H-plane (°)	90	90
Antenna gain (dBi)	7.7	6.7
Radiation efficiency (η_{rad})		
Method 1 – from Equation 1 (%)	95	80
Method 2 – from Equation 2 (%)	93.4 ± 1.6	80.7 ± 0.3

ume than the DRA. The MPA has a 50 percent smaller volume than the DRA, as well as a lower profile. The height of the DRA is eight times greater than the MPA. The matched bandwidth of the MPA is only 1.3 percent, but the DRA bandwidth is nearly eight times greater (10.3 percent). Both the DRA and MPA are excited with broadside radiating modes and the radiation patterns are nearly the same. By comparing the gain and the radiation efficiencies, it is concluded that the conduction losses of the MPA causes the gain to be 1 dB lower than the DRA and the MPA has a radiation efficiency of only 80 percent.

CONCLUSION

The performance of a cylindrical dielectric resonator antenna (DRA) and a circular microstrip patch antenna (MPA) were compared at X-band. The DRA, without conduction losses, was showing higher radiation efficiency than the MPA. The DRA had a 1 dB gain higher than the MPA. In addition, the matched bandwidth of the broadside-radiating mode of the DRA is 10 percent and only 1.3 percent for the MPA. Both antennas showed similar radiation patterns with similar beamwidth. However, the advantage of using MPA was its smaller volume. ■

ACKNOWLEDGMENT

This work was partially supported by The Army Research Office under Grant No. DAAD19-02-1-0074. The authors would like to thank Rogers Corp. for providing the microwave substrate materials through the University Program.

References

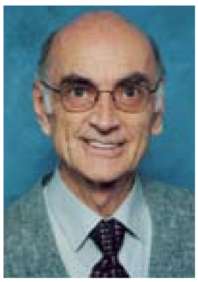
1. G.A. Deschamps, "Microstrip Microwave Antennas," *3rd USAF Symposium on Antennas*, 1953.
2. J.Q. Howell, "Microstrip Antennas," *1972 IEEE International Antennas and Propagation Symposium Digest*, pp. 177–180.
3. J.R. James and P.S. Hall, *Handbook of Microstrip Antennas*, Peter Peregrinus Ltd., London, UK, 1989.
4. R. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House Inc., Norwood, MA, 2001.
5. I. Bahl and P. Bhartia, *Microstrip Antennas*, Artech House Inc., Norwood, MA, 1980.
6. S.A. Long, M.W. McAllister and L.C. Shen, "The Resonant Cylindrical Dielectric Cavity Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 31, No. 5, May 1983, pp. 406–412.
7. K.M. Luk and K.W. Leung, *Dielectric Resonator Antennas*, Research Studies Press Ltd., Hertfordshire, UK, 2003.
8. A.A. Kishk, M. Zunoubi and D. Kajfez, "A Numerical Study of a Dielectric Disk Antenna Above Grounded Dielectric Substrate," *IEEE Transactions on Antennas and Propagation*, Vol. 41, No. 6, June 1993, pp. 813–821.
9. H.A. Wheeler, "The Radian Sphere Around a Small Antenna," *Proceedings of the IRE*, Vol. 47, No. 8, 1959, pp. 1325–1331.
10. E.H. Newman, P. Bohley and C.H. Walter, "Two Methods for the Measurement of Antenna Efficiency," *IEEE Transactions on Antennas and Propagation*, Vol. 23, No. 4, April 1975, pp. 457–461.
11. R. Chair, K.M. Luk and K.F. Lee, "Radiation Efficiency Analysis on Small Antenna by Wheeler Cap Method," *Microwave and Optical Technology Letters*, No. 2, April 2002, pp. 112–113.
12. G.P. Junker, A.A. Kishk and A.W. Glisson, "Input Impedance of Dielectric Resonator Antennas Excited by a Coaxial Probe," *IEEE Transactions on Antennas and Propagation*, Vol. 42, No. 7, July 1994, pp. 960–966.

13. A.A. Kishk, H.A. Auda and B.C. Ahn, "Radiation Characteristics of Cylindrical Dielectric Resonator Antennas with New Applications," *IEEE Antennas and Propagation Society Newsletter*, Vol. 31, 1989, pp. 7–16.
14. S.A. Long, L.C. Shen and P.B. Morel, "Theory of the Circular Disk Printed-circuit Antenna," *Proceedings of the IEEE*, Vol. 125, 1978, pp. 925–928.
15. A.G. Derneryd, "Analysis of the Microstrip Disk Antenna Element," *IEEE Transactions on Antennas and Propagation*, Vol. 27, 1979, pp. 660–664.
16. S. Yano and A. Ishimaru, "A Theoretical Study of the Input Impedance of a Circular Microstrip Disk Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 29, 1981, pp. 77–83.
17. W.C. Chew, J.A. Kong and L.C. Shen, "Radiation Characteristics of a Circular Microstrip Antenna," *Journal of Applied Physics*, Vol. 41, 1980, pp. 3907–3915.
18. R.K. Mongia, A. Ittipiboon and M. Cuhaci, "Measurement of Radiation Efficiency of Dielectric Resonator Antennas," *IEEE Microwave and Guided Waves Letters*, Vol. 4, No. 3, March 1994, pp. 80–82.

Ricky Chair *received his B. Eng. and PhD degrees in electrical engineering from the City University of Hong Kong in 1998 and 2002, respectively. He is currently a research fellow of electrical engineering at the University of Mississippi. He has co-authored one book chapter in* Microstrip Antennas, *and published over 50 technical papers in international journals and conferences. His research interests include the design and analysis of printed microstrip antennas, dielectric resonant antennas, applied electromagnetics, and microwave theory and measurement techniques.*

Ahmed A. Kishk *received his BS degree in electronic and communication engineering from Cairo University, Cairo, Egypt, in 1977, and in applied mathematics from Ain-Shams University, Cairo, Egypt, in 1980. In 1981, he joined the department of electrical engineering, University of Manitoba, Winnipeg, Canada, where he obtained his M.Eng and PhD degrees in 1983 and 1986, respectively. He is currently a professor at the University of Mississippi, where his research interests include the areas of design of millimeter frequency antennas, soft and hard surfaces, phased array antennas and computer aided design for antennas.*

Kai Fong Lee *received his BSc and MSc degrees from Queen's University, Canada, in 1961 and 1963, respectively, and his PhD degree from Cornell University in 1966, all in electrical engineering. He held research, teaching and administrative positions at various institutions in the United States and was the founding head of the department of electronic engineering at City University of Hong Kong. He has been dean of the school of engineering and professor of electronic engineering at the University of Mississippi since 2001. His publications include a textbook on antennas, ten invited book chapters, 163 journal articles and 130 conference papers.*



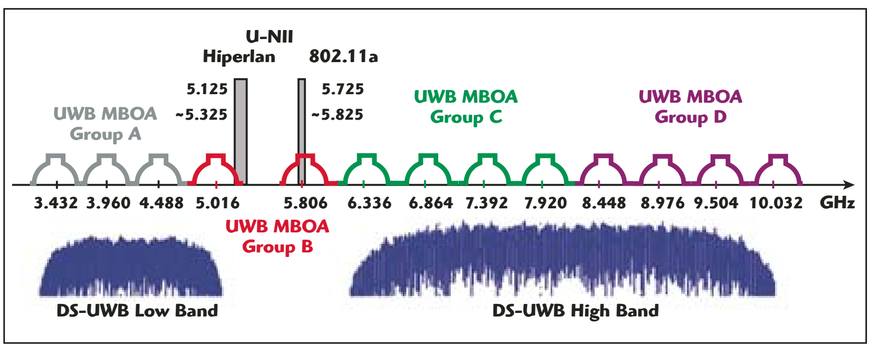
Darko Kajfez *obtained his electrical engineer's degree (Dipl. Ing.) from the University of Ljubljana, Slovenia, in 1953, and his PhD degree from the University of California at Berkeley in 1957. He is currently emeritus professor of electrical engineering at the University of Mississippi. His research interests include RF and microwave measurements and analysis.*

A PRINTED UWB TRIANGULAR MONOPOLE ANTENNA

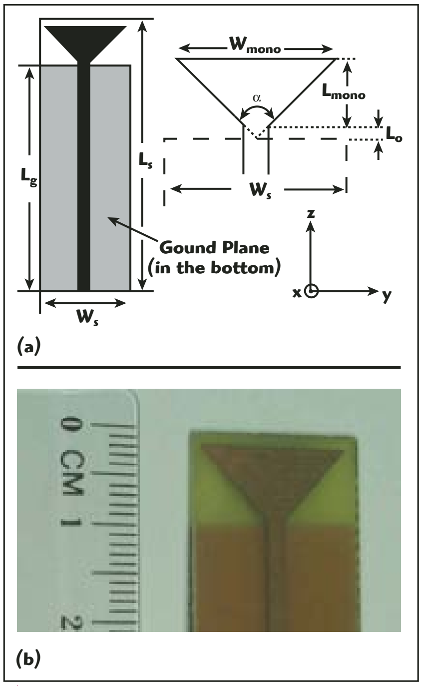
A planar printed triangular monopole antenna (PTMA) is presented for ultra-wideband (UWB) communications. The HFSS 3-D EM solver is employed for design simulation. A printed PTMA has been fabricated on a FR-4 substrate. The measured VSWR is less than 3 from 4 to 10 GHz. In the UWB communications frequency range, the measured phase distribution of the input impedance is quite linear and the H-plane patterns are almost omni-directional. The Kirchhoff's surface integral representation (KSIR) was adopted in the developed FDTD code to compute the far-field distributions from the near-field ones in the time domain. This is to investigate the radiated power spectral density (PSD) shaping to comply with the Federal Communications Commission (FCC) emission limit mask. The effect of various source pulses (first-order Rayleigh pulses with σ = 20, 30 and 50 ps) on the radiated PSD shaping is also studied.

The emerging ultra-wideband (UWB) radio is the technology for transmitting and receiving short, information-encoded, electromagnetic impulses.[1,2] UWB technology is loosely defined as any wireless transmission scheme that occupies a bandwidth of more than 25 percent of a center frequency, or more than 1.5 GHz. According to the Federal Communications Commission (FCC),[3] the frequency band of UWB (the category of communications and measurement systems) should be contained between 3.1 and 10.6 GHz. ***Figure 1*** shows the spectrum allocation of the current UWB system for multi-band OFDM (MBOA) and direct sequence (DS) CDMA UWB. The MBOA has four groups (group A, B, C and D) and thirteen bands, each with a bandwidth of 500 MHz. The DS-UWB system has a low band from 3.1 to 5.15 GHz and a high band from 6 to 10.1 GHz. Due to its extremely wide operating bandwidth, it could possibly interfere with other existing electronic systems operating at the same time. In

Fig. 1 Spectrum allocation for UWB communications.



H.R. CHUANG, C.C. LIN AND Y.C. KAN
National Cheng Kung University Tainan, Taiwan, ROC



▲ *Fig. 2 Geometry and a realized printed PTMA.*

order to make it compatible with existing narrow-band radio services, the maximum permissible effective isotropic radiated power (EIRP) density is set as –41.3 dBm/MHz.[3] Hence, the emission limits of the radiated power are a critical consideration in UWB radio systems, especially for the antenna design.

In general, there are two ways to limit the radiated PSD shaping to conform to the standard mask set by the FCC:[4] the first is to design the antenna as a special filter to suppress the unwanted radiation outside the UWB band or, second, to select a source pulse in the specific band to let the radiated PSD meet the FCC required emission limits. In this article, the second approach is used. Here, a printed monopole-type antenna is adopted for the design of a broadband antenna for UWB application.[5,6] The design simulation, fabrication and measurements of a printed planar triangular monopole antenna (PTMA), fabricated on a FR-4 PCB, are reported. The HFSS 3-D EM simulator is employed for design simulation. The antenna input VSWR, the phase of the input impedance and the radiation patterns are presented. Also, an FDTD code, developed with the Kirchhoff's surface integral representation (KSIR), is used to compute the time-domain far-field distribution. This is to investigate the radiated PSD shaping to comply with the FCC emission limit mask. First-order Rayleigh pulses with σ = 20, 30 and 50 ps are used and the resulting PSD are compared.

ANTENNA DESIGN

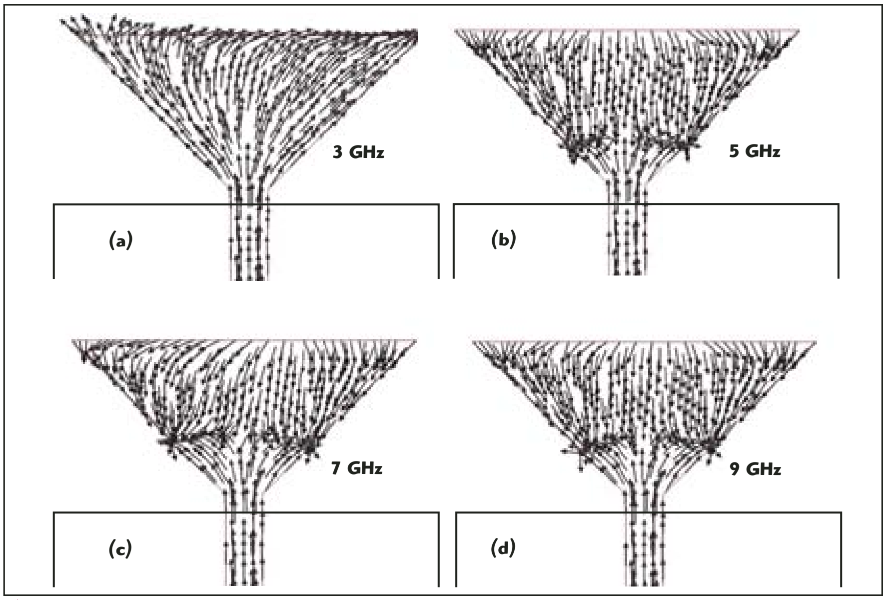
In this article, a printed PTMA is developed, based on a triangular monopole antenna.[5,6] The structure of this antenna consists of a tapered radiating element excited by a suitable feed-structure, such as a coplanar waveguide (CPW) or microstrip line. As shown in ***Figure 2***, the antenna geometry, the width, length and flare angle of the antenna are denoted by W_{mono}, L_{mono} and α, respectively. A 50 Ω microstrip line is used to feed the PTMA at the apex angle of the triangular patch. The distance between the end of the monopole and the terminal of the microstrip line is denoted by L_0. The antenna is printed on one side of a FR-4 substrate with a width W_s, a length L_s and a thickness T. On the other side of the substrate, a ground plane of width W_s and length L_g is printed. The detailed parameters of the antenna are summarized in ***Table 1***. The figure also shows the photograph of a printed PTMA fabricated on a FR-4 substrate.

MEASUREMENT RESULTS

The HFSS-simulated current distributions of the printed PTMA at 3, 5, 7 and 9 GHz are shown in ***Figure 3***. The simulation shows that the currents of the PTMA are almost distributed along the same directions (z-axis), which is similar to the behavior of a monopole

TABLE I
ANTENNA DIMENSIONS

W_{mono} (mm)	17
L_{mono} (mm)	7.6
L_0 (mm)	1
α	90°
L_s (mm)	60
W_s (mm	20
L_g (mm)	50
T (mm)	1
PCB substrate (ε_r, tanδ)	(4.7, 0.018)

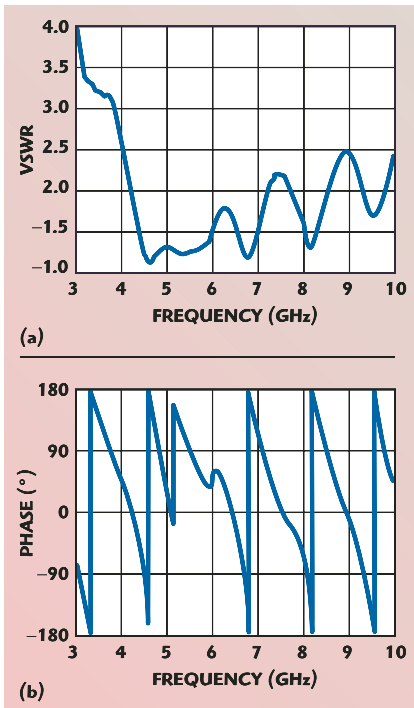


▲ *Fig. 3 HFSS-simulated current distribution of the printed PTMA at (a) 3, (b) 5, (c) 7 and (d) 9 GHz.*

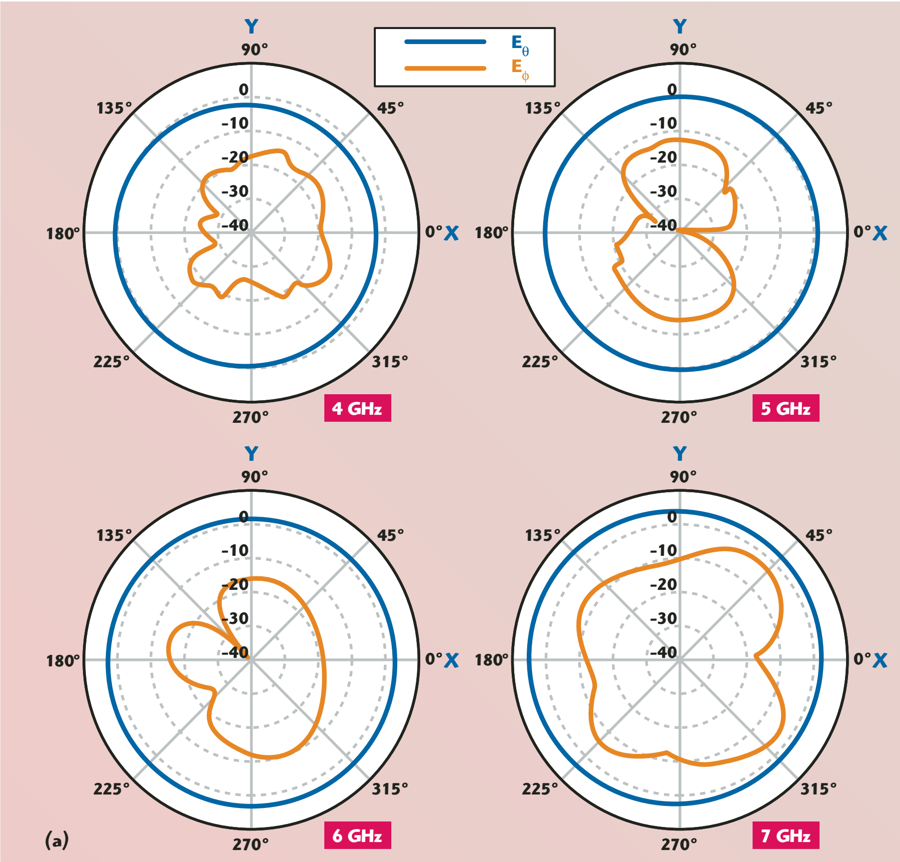
antenna. ***Figure 4*** shows the measured antenna input VSWR and the phase of the input impedance from 3 to 10 GHz. The measured input VSWR is less than 2.5 from 4 to 10 GHz and the measured phase distribution of the input impedance is also quite linear except in the frequency range from 5 to 6 GHz. The measured representative H-plane (xy-plane, $\theta = 90°$) and E-plane (xz-plane, $\Phi = 0°$) antenna patterns at 4, 5, 6 and 7 GHz are shown in ***Figure 5***. It can be seen that the H-plane patterns are all quite omni-directional.

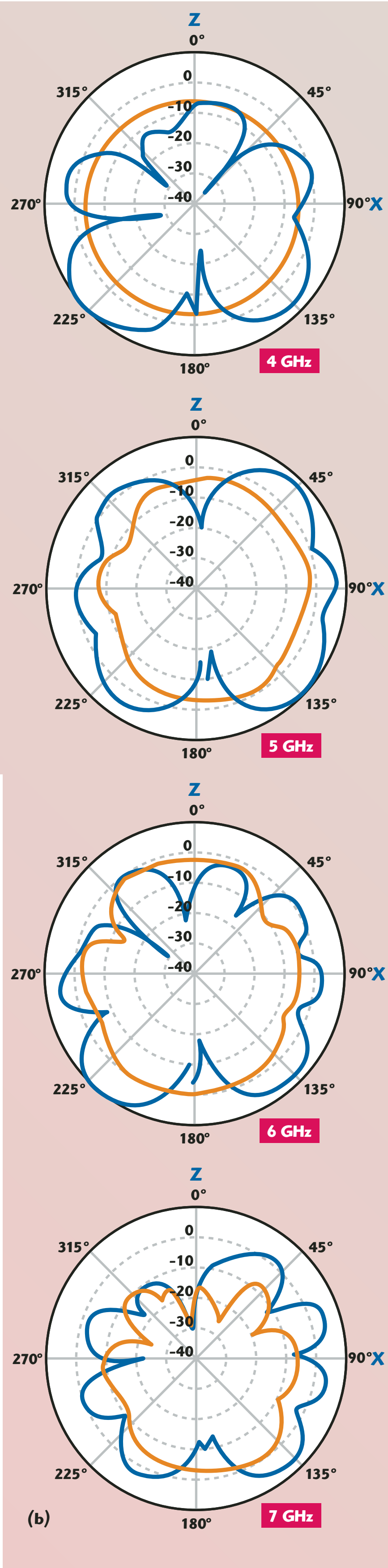
RADIATED POWER SPECTRUM DENSITY (PSD)

For the conventional narrow-band antenna design, the frequency-domain information is more useful and significant than the one in the time domain. For a UWB radio system excited with a short pulse, the study of temporal properties will be helpful in designing and analyzing the UWB antenna. The desired time-domain information can be readily obtained by using time-domain numerical methods, such as the finite-difference time-domain (FDTD) method. However, since the FDTD method is inherently a near-field technique, a time-domain near- to far-field transformation is employed to efficiently compute the far-field antenna parameters.[7,8] Ultimately, the frequency-domain response can be obtained with the fast Fourier transform (FFT). The effect of various source pulses on the radiated PSD shaping are then studied by using the first-order Rayleigh pulses, which are differentiated Gaussian pulses. The parameter σ is used to describe the time duration when the normalized single level, $v_0(\sigma)$, of the source pulse equals to e^{-1}. The first-order Rayleigh



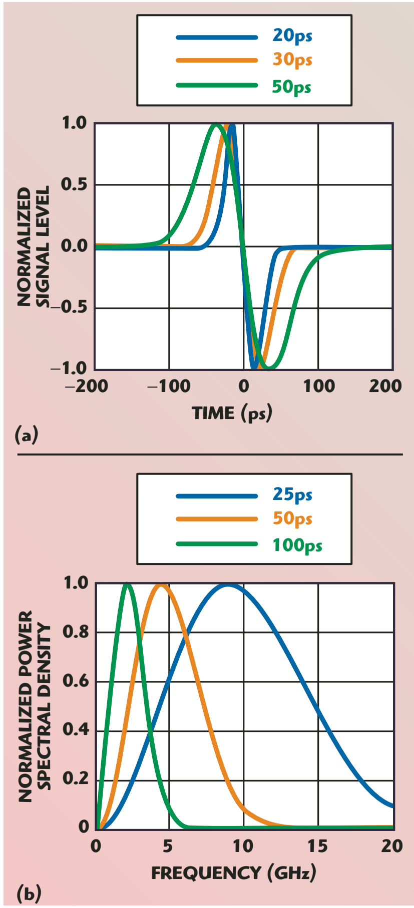
▲ *Fig. 4 Measured antenna input VSWR (a) and phase of the input impedance (b).*



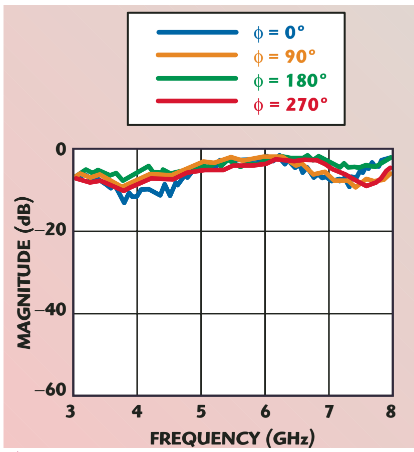


▲ *Fig. 5 Measured antenna patterns; (a) H-plane and (b) E-plane.*

pulses with σ = 20, 30 and 50 ps are used in the FDTD computation. It is noted that the first-order Rayleigh pulses with σ > 60 ps are not considered here because their corresponding spectra of 10 dB bandwidths do not fully occupy the desired 7.5 GHz bandwidth for UWB communication. ***Figure 6*** shows the time-domain and frequency-domain waveforms of these first-order Rayleigh pulses. Unlike the Gaussian pulse, these Rayleigh pulses are monocycle pulses in the time domain and do not generate any direct current (DC) component in the frequency domain. For UWB antenna design, the transfer function of the antenna is important both to comply with the FCC power emission limits and to preserve the transmitted waveform information. The transfer function of an antenna is defined as the ratio of radiated electric fields in the frequency domain and the spectrum of a source signal (voltage) at the transmitting antenna.[4] For the FDTD calculation, the transfer functions of the antenna can be obtained by applying the definition. For measurement, the transfer functions can be derived from the transmission scattering parameters, S_{21}, the input impedance and the an-



▲ *Fig. 6 Waveforms of first-order Rayleigh pulses; (a) time domain and (b) frequency domain.*

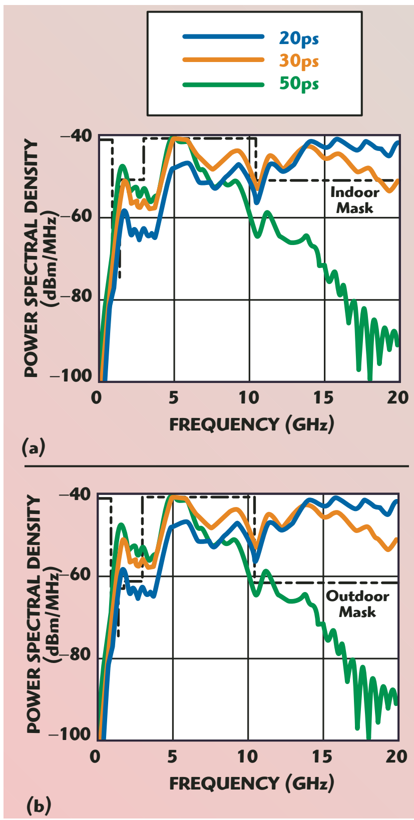


▲ *Fig. 7 Measured antenna transfer function at ϕ = 0°, 90°, 180° and 270° in the H-plane.*

tenna gain.[9] The measured transfer functions of the printed PTMA at Φ = 0°, 90°, 180° and 270° in the H-plane are plotted in ***Figure 7***. Due to the instrument's limitations in the anechoic chamber, only the frequency band from 3 to 8 GHz is presented. A good agreement among transfer functions at Φ = 0°, 90°, 180° and 270° is observed because of the omni-directional radiation pattern of the printed PTMA in the H-plane. The magnitudes of the transfer functions are close to a flat response over the interested frequency band. From the signal point of view, this PTMA antenna is a bandpass filter with nearly constant magnitude. Hence, the desired radiated PSD of the printed PTMA can be achieved readily once the source pulses have been properly evaluated. ***Figure 8*** shows the computed radiated PSD of the printed PTMA excited by the first-order Rayleigh pulses with σ = 20, 30 and 50 ps. The co-polarized component of the printed PTMA, E_θ, in the direction of θ = 90° is computed at the distance of r = 2 m. All the computed results of PSD are normalized to –41.3 dBm/MHz. In comparison with the FCC's indoor and outdoor masks, it is found that the radiated PSD of the first-order Rayleigh pulses with σ = 20, 30 and 50 ps all comply with the FCC's indoor and outdoor mask from 2 to 10.6 GHz. Beyond 10.6 GHz, however, only the pulse with σ = 50 ps can comply with the FCC's indoor and outdoor masks.

CONCLUSION

This article presents a PTMA for UWB communication. The HFSS 3-D EM simulator is employed for design simulation. The printed PTMA is fabricated on a FR-4 PCB substrate. The measured VSWR is less than 3 from 4 to 10 GHz. The measured phase distribution of the input impedance is quite linear (except in the frequency range from 5 to 6 GHz). The H-plane patterns are almost omni-directional in the UWB fre-



▲ *Fig. 8 FDTD simulated PSD shaping of the E-field of the printed PTMA with first-order Rayleigh source pulses (σ=20, 30 and 50 ps); (a) indoor and (b) outdoor.*

quency band. The antenna transfer functions at Φ = 0°, 90°, 180° and 270° in the H-plane are measured and a nearly flat response can be observed. The KSIR is used in the developed FDTD code to compute the time-domain far-field distribution. This is to investigate the PSD shaping to comply with the FCC emission limit mask. The effect of different source pulses (first-order Rayleigh pulses with σ = 25, 50 and 100 ps) on the radiated PSD shaping is studied. Due to the flat response of the antenna transfer function, the desired radiated PSD of the printed PTMA can be readily achieved with a proper source pulse. It is found that only the radiated PSD of the first-order Rayleigh pulse with σ = 50 ps can comply with the FCC's indoor mask above 2 GHz. As for the outdoor mask, the same pulse can comply with the FCC emission limit. ■

References

1. K. Siwiak and D. McKeown, *Ultra-wideband Radio Technology*, John Wiley & Sons Inc., UK, 2004.
2. S. Roy, J.R. Foerster, V.S. Somayazulu and D.G. Leeper, "Ultra-wideband Radio Design: The Promise of High Speed, Short-range Wireless Connectivity," *Proceedings of the IEEE*, Vol. 92, February 2004, pp. 295–311.
3. US 47 CFR Part 15 Ultra-wideband Operation FCC Report and Order, 22 April 2002.
4. Z.N. Chen, X.H. Wu, H.F. Li, N. Yang and M. Chia, "Considerations for Source Pulses and Antennas in UWB Radio System," *IEEE Transactions on Antennas and Propagation*, Vol. 52, July 2004, pp. 1739–1748.
5. J.M. Johnson and Y. Rahmat-Samii, "The Tab Monopole," *IEEE Transactions on Antennas and Propagation*, Vol. 45, January 1997, pp. 187–188.
6. H.M. Chan, "Microstrip-fed Dual Frequency Printed Triangular Monopole," *Electronics Letters*, Vol. 38, June 2002, pp. 619–620.
7. A. Taflove, *Advances in Computational Electromagnetics*, Artech House Inc., Norwood, MA, 1998.
8. O.M. Ramahi, "Near- and Far-field Calculations in FDTD Simulations Using Kirchhoff's Surface Integral Representation," *IEEE Transactions on Antennas and Propagation*, Vol. 45, May 1997, pp. 753–759.
9. T.G. Ma and S.K. Jeng, "Planar Miniature Tapered-slot-fed Annular Slot Antennas for Ultra-wideband Radios," *IEEE Transactions on Antennas and Propagation*, Vol. 53, March 2005, pp. 1194–1202.

Huey-Ru Chuang *received his BSEE and MSEE degrees from National Taiwan University, Taipei, Taiwan, in 1977 and 1980, respectively, and his PhD degree in electrical engineering from Michigan State University, East Lansing, MI, in 1987. He is currently a professor at the Institute of Computer and Communication, National Cheng Kung University, Tainan, Taiwan. His research interests include mobile antenna design, RF/microwave integrated circuits and RFIC/MMIC for wireless communications, computational electromagnetics and its applications. He is a winner of the Agilent 2003 Worldwide University Equipment Grants.*

Chi-Chang Lin *received his BSEE and MSEE degrees from Tatung University, Taipei, Taiwan, in 1999 and 2001, respectively. He is currently working toward his PhD degree in electrical engineering from National Cheng Kung University, Tainan, Taiwan. His research interests include EM computation and wireless communication antenna design.*

Yao-Chiang Kan *received his BS degree from National Cheng Kung University, Tainan, Taiwan, in 1988, and his MS and PhD degrees in electrical engineering from Michigan State University, East Lansing, MI, in 1994 and 2000, respectively. He is currently an assistant professor in the department of information and telecommunications at Ming Chung University, Taipei, Taiwan. His research interests include computational electromagnetics and wireless sensor networks.*

A NOVEL BROADBAND DESIGN OF A PRINTED RECTANGULAR SLOT ANTENNA FOR WIRELESS APPLICATIONS

A novel compact rectangular slot antenna printed on a dielectric substrate and fed by a 50 Ω microstrip is presented. Both impedance and radiation characteristics of this antenna are studied. Experimental results indicate that a 2:1 VSWR bandwidth of 3.95 GHz is achieved at operating frequencies from approximately 1.83 to 5.78 GHz, which is approximately five times that of a convectional printed wide-slot antenna. The good radiation characteristics of the constructed prototype antenna are also shown in this article. The broadband bandwidth and good radiation properties of the proposed design are suitable for most wireless applications.

The conventional printed wide-slot antenna has an operating bandwidth on the order of 10 to 20 percent.[1,2] Because modern wireless applications often require broadband operation, some printed wide-slot antennas for broadband operation have been reported.[3-6] A square slot antenna,[3] with a fork-shaped microstrip feed structure, was investigated for broadband operation. The fork-shaped microstrip feed structure was applied to a printed round corner rectangular wide-slot antenna[4] and a broadband design was achieved. A semicircular slot antenna[5] with a protruded small rectangular slot was excited by a 50 Ω microstrip. Recently, an isosceles triangular slot antenna[6] with a small rectangular slot for broadband operation was proposed, and has shown an impedance bandwidth of 77 percent for a 2:1 VSWR. However, the impedance bandwidth of this antenna design is still not enough to cover most wireless applications. It is important to enhance the impedance bandwidth of microstrip-fed wide-slot antennas.

In this article, a novel design of a microstrip-fed, printed rectangular slot antenna, with a small trapezoidal slot tuning for wireless applications, is proposed. The radiation characteristics of such a design are also

WEN-SHAN CHEN
Southern Taiwan University of Technology
Tainan Hsien, Taiwan, ROC

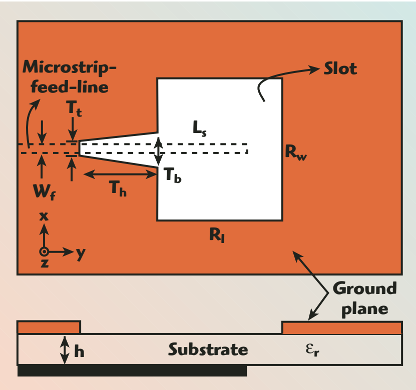


Fig. 1 The geometry of the proposed antenna.

investigated. The proposed antenna can be easily excited by a 50 Ω microstrip printed on an FR-4 dielectric substrate, and good impedance matching can be obtained for operation at frequencies within the wireless communications system bands. A comparison of the proposed design with a corresponding isosceles triangular slot antenna[6] is also given.

ANTENNA DESIGN

Figure 1 shows the geometry of the novel broadband rectangular slot antenna printed on a dielectric substrate. In this study, the dielectric substrate material is FR-4 with a thickness h = 1.6 mm and relative permittivity ε_r= 4.4. For design convenience, the proposed antenna is fed by a 50 Ω microstrip, printed on the dielectric substrate. The microstrip, with a width W_f = 3.0 mm, is placed on the centerline of the rectangular slot (y axis). In order to achieve broadband operation, a small trapezoidal slot is placed on the feed side of the rectangular slot. The primary slot is the rectangular slot, which has a horizontal width of R_w and a vertical length of R_l. The small trapezoidal slot has a top width T_t, a bottom width T_b and a vertical height T_h. The two slots are etched in the ground plane that is on the opposite side of the dielectric substrate. The design parameters of the proposed antenna can easily be determined. The perimeter of the polygonal slot at the lowest operating frequency required is given by

$$L_{perimeter} = T_t + 2\sqrt{T_h^2 + \left(\frac{T_b - T_t}{2}\right)^2} + 2R_l + 2R_w - T_b \qquad (1)$$

The perimeter of the polygonal slot can be determined to be approximately two guided wavelengths in the slotline at the lowest operating frequency. Then, by fine tuning the small trapezoidal slot and adjusting the length of the 50 Ω microstrip feed-line, a new resonant mode can be excited in the proximity of the fundamental resonant mode and good impedance matching over a broad frequency range can be obtained.

EXPERIMENTAL RESULTS AND DISCUSSION

The proposed antennas were simulated with the High Frequency Structure Simulator (HFSS) from Ansoft and the prototypes were fabricated and measured with a HP-8720ES network analyzer. The first parameter under design was the size of the rectangular slot. For the designs shown in ***Table 1***, the ratio of R_l to R_w is approximately 1:1.5. To achieve the requirements of wireless applications, the perimeter of the polygonal slot, $L_{perimeter}$, was chosen to be approximately 180 mm, which corresponds to approximately $2\lambda_g$ at 1.83 GHz (λ_g is the guided wavelength at the lowest frequency of operation). ***Table 2*** shows $L_{perimeter}$ and bandwidth of all the antennas studied. ***Figure 2*** shows the measured and simulated return loss results of the proposed antenna 1 with an impedance bandwidth of 104 percent for VSWR = 2. The impedance bandwidth obtained with the present design is approximately five times that of a conventional printed wide-slot antenna. From Tables 1 and 2, for antenna 1 with the widest bandwidth, the ratio of T_b to R_w is about 1:4 and the ratio of T_t to T_b is about 1:8. The optimal microstrip feed-line length L_s was chosen to achieve a good impedance match for the constructed prototype. By observing the influence of various parameters on the antenna performance, it was found that the dominant factor in the proposed antenna designs for wireless communications applications is the perimeter of the polygonal slot in terms of λ_g. From that numerical experiment, λ_g can be calculated as

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{r,eff}}} \qquad (2)$$

where the $\varepsilon_{r,eff}$ is determined by

$$\varepsilon_{r,eff} = \frac{\varepsilon_r + 1}{2} \qquad (3)$$

Then, the lowest frequency (f_L) relative to a half of the $L_{perimeter}$ is formulated by

$$f_L \approx \frac{C_0}{\frac{L_{perimeter}}{2}}\left(\frac{1}{\varepsilon_{r,eff}}\right)^{\frac{1}{2}} \qquad (4)$$

where C_0 is the speed of light in free space.

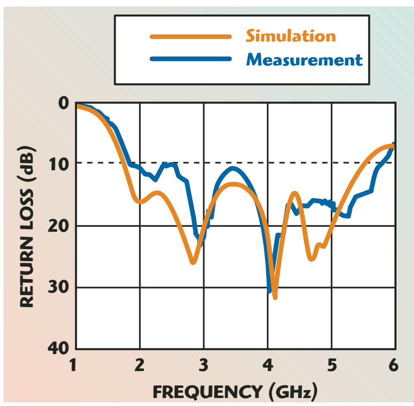


Fig. 2 Measured and simulated loss of antenna 1.

TABLE I
DIMENSIONS OF THE PROPOSED ANTENNAS

	T_t	T_b	T_h	R_l	R_w	L_s
Antenna 1	1.40	11.0	19.5	30	45	46
Antenna 2	4.60	7.0	19.5	30	45	46
Antenna 3	4.60	11.0	23.7	30	45	46
(dimensions in mm)						

TABLE II
CHARACTERISTICS OF THE PROPOSED ANTENNAS

	$L_{perimeter}$ (mm)	f_L (calculated) (GHz)	f_L (GHz)	f_H (GHz)	BW (%)
Antenna 1	180.4	2.02	1.83	5.78	104
Antenna 2	186.6	1.96	1.95	4.08	71
Antenna 3	191.2	1.91	2.13	6.00	95

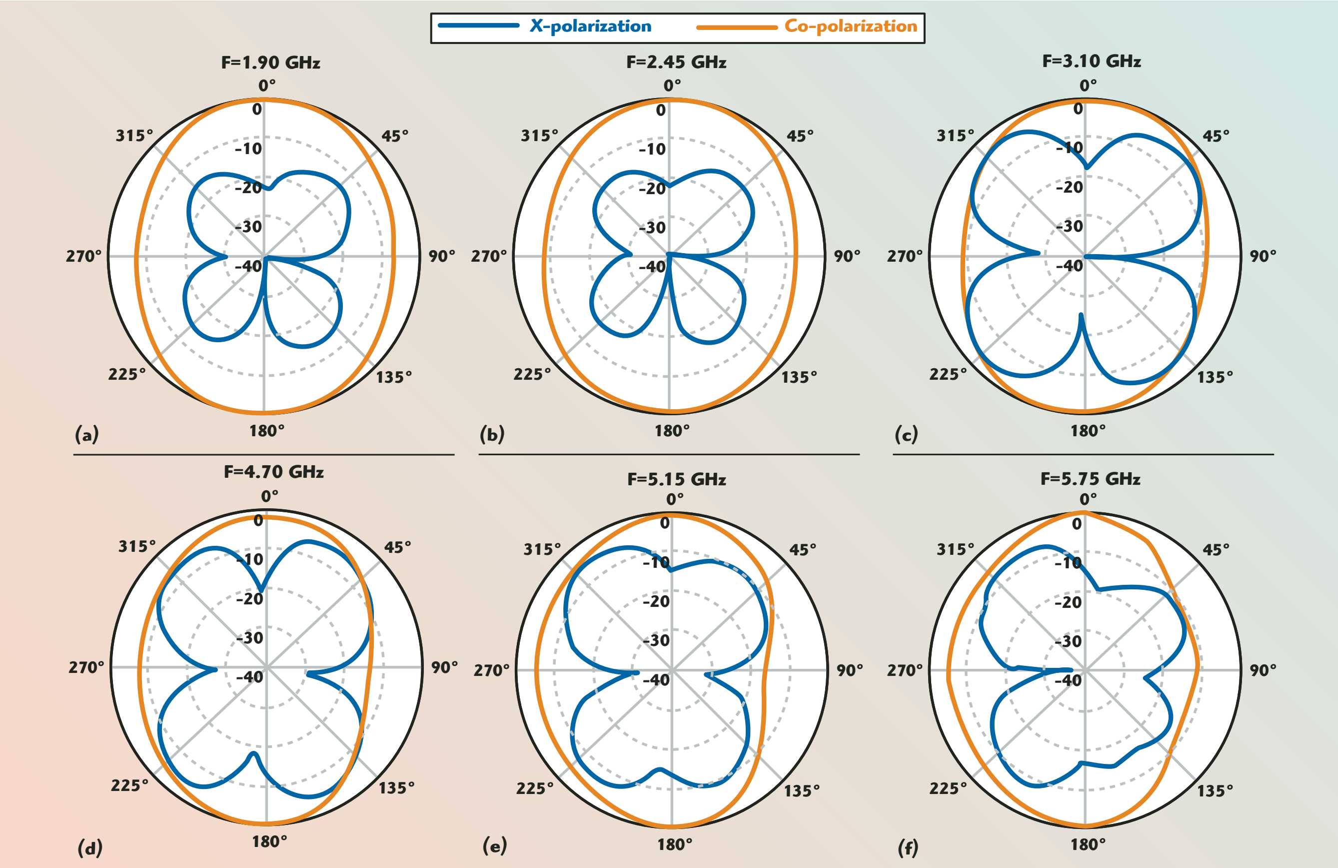


Fig. 3 Measured far-field radiation patterns for antenna 1 in the x-z plane.

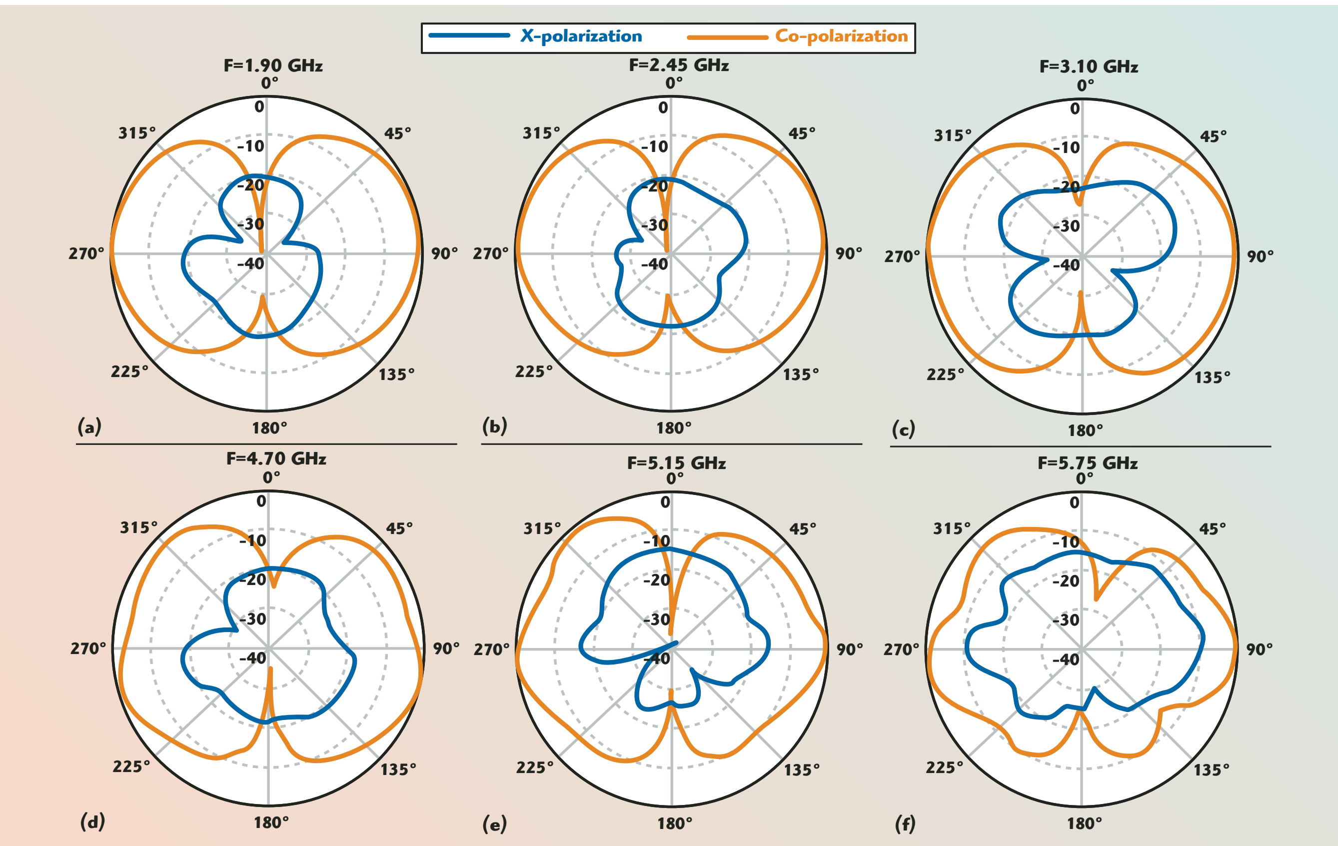
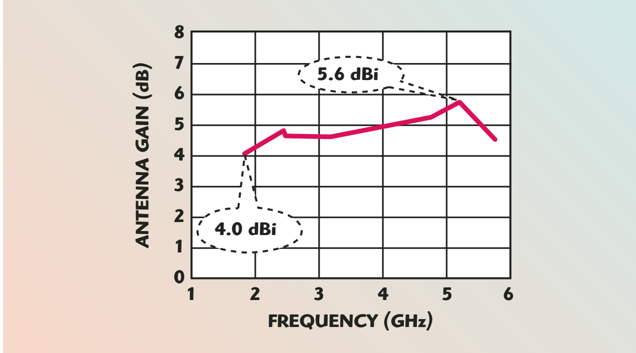


Fig. 4 Measured far-field radiation patterns for antenna 1 in the y-z plane.



▲ *Fig. 5 Measured peak gain of antenna 1.*

TABLE III

CHARACTERISTICS OF THE PROPOSED ANTENNA AND THE ISOSCELES TRIANGLE ANTENNA

	Maximum Antenna Gain (dB)	Gain Variation (dB)	f_L (GHz)	f_H (GHz)	BW (%)
The isosceles triangular slot antenna[6]	5.9	1.8	2.33	5.23	77
The proposed antenna (Antenna 1)	5.6	1.6	1.83	5.78	104

For the reasons mentioned above, antenna 1 is the optimum design. Its radiation characteristics have been measured in the STUT Anechoic Chamber. ***Figures 3*** and ***4*** show the measured radiation patterns in the x-z plane and y-z planes, respectively, at F = 1.90, 2.45, 3.10, 4.70, 5.15 and 5.75 GHz . Antenna 1 is suitable for GSM (1900 to 1990 MHz), PCS (1900 to 1990 MHz), IMT-2000 (1920 to 2170 MHz), Bluetooth (2400 to 2484 MHz), IEEE 802.16a/e, IEEE 802.11b/g (2400 to 2484 MHz), IEEE 802.15.3a (UWB), PHS (1905 to 1915 MHz), PACS (1930 to 1990 MHz), UMTS (Regular 1, 2, 3), IEEE 802.11a (5150 MHz) and HIPERLAN /1 /2 (5150 MHz). It is also noted that, for antenna 1, the radiation patterns in the x-z plane and y-z plane are good, which makes the proposed antenna suitable for practical applications. The measured peak antenna gain for antenna 1 is also presented in ***Figure 5***. It shows a peak gain of approximately 5.6 dBi; the gain variation is observed to be less than 1.6 dB.

A comparison of the proposed design with a corresponding isosceles triangular slot antenna[6] is given in ***Table 3***. It shows a small gain variation for the proposed antenna design compared to that of the isosceles triangular slot antenna. In addition, the 104 percent impedance bandwidth of the proposed antenna is larger than that of the isosceles triangular slot antenna.

CONCLUSION

A microstrip-fed, printed rectangular slot antenna with a small trapezoidal slot for broadband operation has been implemented. Experimental results show that the impedance bandwidth of a printed rectangular slot antenna can be significantly improved by selecting the proper dimensions of the small trapezoidal slot and the perimeter of the polygonal slot. The results, obtained in this study, show that the impedance bandwidth for the proposed antenna is approximately 104 percent (1.83 to 5.78 GHz) for a 2:1 VSWR. In addition, the proposed antenna also shows a compact structure and a simple feeding structure, compared to a corresponding printed wide-slot antenna. The design of this proposed antenna, with broadband operation, is suitable for most wireless applications. ■

ACKNOWLEDGMENT

The partial financial funding of this study by the National Science Council, Taiwan, Republic of China, under contract number NSC92-2213-E-218-038, is gratefully acknowledged.

References

1. M. Kahrizi, T.K. Sarkar and Z.A. Maricevic, "Analysis of a Wide Radiating Slot in the Ground Plane of a Microstrip-line," *IEEE Transactions on Microwave Theory and Techniques*. Vol. 41, No. 1, January 1993, pp. 29–37.
2. S.M. Shum, K.F. Tong, X. Zhang and K.M. Luk, "FDTD Modeling of a Microstrip-line-fed Wide-slot Antenna," *Microwave and Optical Technology Letters*, Vol. 10, 1995, pp. 118–120.
3. H.L. Lee, H.J. Lee, J.G. Yook and H.K. Park, "Broadband Planar Antenna Having Round Corner Rectangular Wide Slot," *2002 IEEE Antennas and Propagation International Symposium Digest*, Vol. 2, pp. 460–463.
4. J.Y. Sze and K.L. Wong, "Bandwidth Enhancement of a Microstrip-line-fed Printed Wide-slot Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 49, 2001, pp. 1020–1024.
5. W.S. Chen, C.C. Hung and K.L. Wong, "A Novel Microstrip-line-fed Printed Semicircular Slot Antenna for Broadband Operation," *Microwave and Optical Technology Letters*, Vol. 26, No. 4, August 2000, pp. 237–239.
6. W.S. Chen and F.M. Hsieh, "A Broadband Design for a Printed Isosceles Triangular Slot Antenna for Wireless Communications," *Microwave Journal*, Vol. 48, No. 7, July 2005, pp. 98–112.

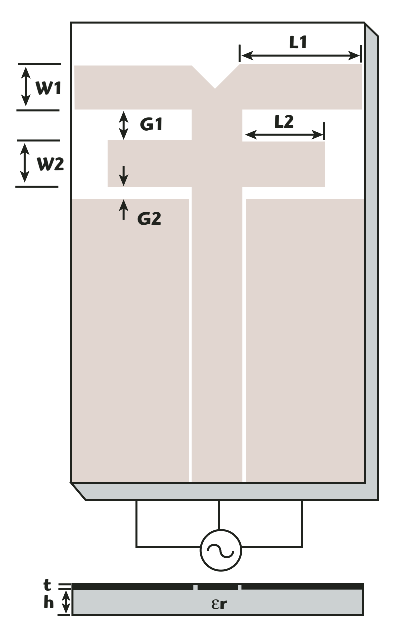
Wen-Shan Chen *received his BS degree in electronic engineering technology from the National Taiwan Institute of Technology (now the National Taiwan University of Technology) and his PhD degree from National Sun Yat-Sen University, Kaohsiung, Taiwan, ROC, in 2001. From 2001 to 2002, he was an assistant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

A DESIGN OF DOUBLE T-TYPE MICROSTRIP ANTENNAS FOR BROADBAND AND CONTROL OF RESONANCE

In this article, the design and fabrication of a planar, wide band, microstrip antenna is proposed where the resonance frequency is controlled. This new configuration for a wide band microstrip antenna shows an omni-directional radiation pattern. By properly choosing the gap between the stubs and the length of the upper stub, the resonance frequency can be controlled over approximately 700 MHz. An antenna impedance bandwidth of 450 MHz (VSWR = 2.0) can be obtained within the IMT2000 frequency band. The characteristics of the proposed antenna were analyzed using the FDTD method.

Patch antennas, printed on a circuit board, are suitable for integration within a communication device since they occupy a very small volume within the system, while at the same time decreasing the final product fabrication cost. The use of this kind of printed patch antenna permits concealing the antenna within the system, so that possible damage caused by a protruding antenna can be avoided. A number of researchers have studied the improvements relating to the narrow bandwidth of patch antennas. In this article, a solution to the problems of narrow bandwidth and frequency control is offered. A bandwidth of 22.5 percent was required for this antenna. It was difficult to find the required resonance frequency relative to the electrical size of the antenna. Antennas have been designed with a very small size relative to the wavelength at the operating frequency. A modified planar T-type microstrip antenna is proposed as a viable solution, where the resonance frequency is controlled by adjusting the length of the stub. The proposed dual-T antenna uses two stubs, which are fed by a CPW transmission line. Experimental results show that the frequency tuning depends on the lengths and gap of the dual stubs. The frequency shift is determined mainly by calculating the gap between stubs and the length of the upper stub. Several designs were investigated experimentally and, within these, the characteristics of the input impedance and radiation patterns were analyzed. This article

HYEONJIN LEE
Dongkang College
Gwangju, Korea
YEONGSEOG LIM
Chonnam National University
Gwangju, Korea



▲ *Fig. 1 Geometry of the proposed dual-T antenna.*

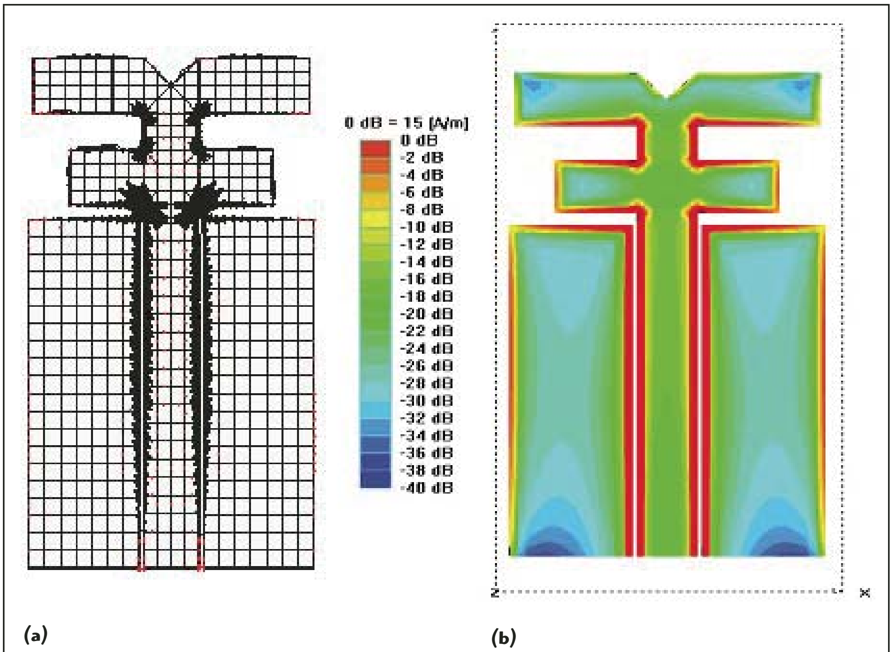
TABLE I
DESIGN PARAMETERS FOR THE PROPOSED ANTENNA

L1 (mm)	14	G1 (mm)	4
L2 (mm)	10	G2 (mm)	1.5
W1 (mm)	6	W2 (mm)	6

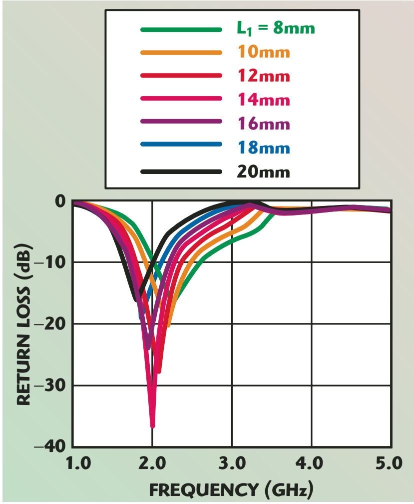
details the design of the IMT2000 band antenna and the construction and analysis of its prototypes. The impedance bandwidth obtained was approximately 470 MHz, as determined from a return loss of –10 dB.

ANTENNA DESIGN AND DESCRIPTION

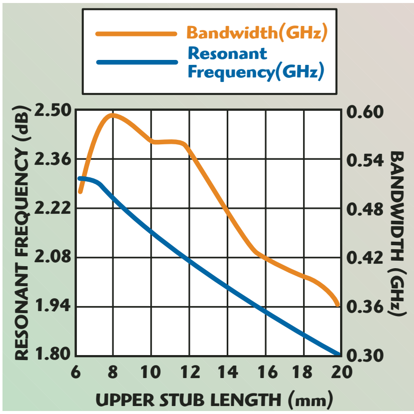
The design of CPW-fed patch antennas has received a lot of attention recently. This is because a CPW-fed patch antenna has the advantage of offering a significant bandwidth, while being easy to integrate within monolithic microwave integrated circuits (MMIC) and low temperature co-fired ceramic circuits (LTCC). A few attempts have been made to increase the bandwidth of CPW-fed patch antennas. The geometry of the proposed CPW-fed dual-T microstrip patch antenna is shown in ***Figure 1***. ***Table 1*** shows the parameters used in the design of the antenna. The antenna was printed on an FR4 substrate with a thickness h = 1.6 mm and a relative permittivity ε_r = 4.2, with a length of λ/4 to λ/3 and a width of 6 mm. The antenna was excited by a CPW feed line, whose impedance is controlled by the width of the strip and the gap between the strip and ground. The gap between the two stubs was set at G1 = 4 mm. The spacing between the lower stub and the edge of the ground plane was G2 = 1.5 mm. The length of the upper and lower stubs were chosen as L1 = 14 mm and L2 = 10 mm, respectively. The dual-T microstrip patch antenna was fabricated and analyzed with various design parameters. As a first step, the input im-



▲ *Fig. 2 Simulated vector surface current (a) and electrical field distribution (b) at 1.8 GHz.*

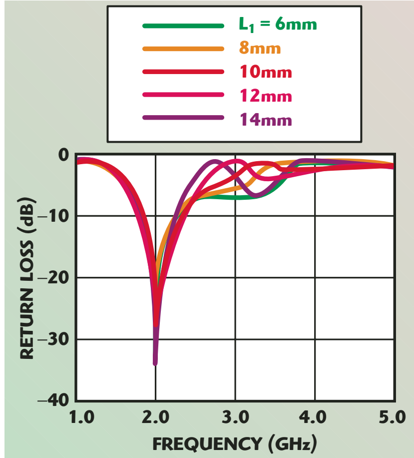


▲ *Fig. 3 Simulated return loss versus frequency for different L1 stub lengths.*

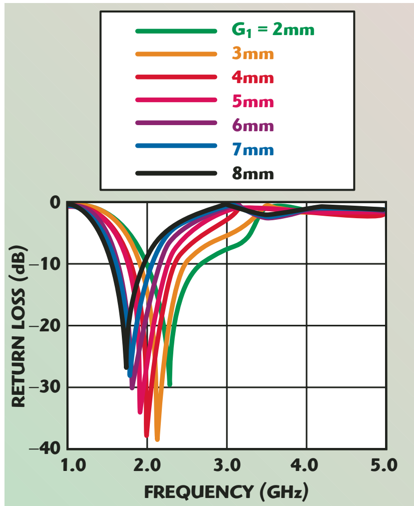


▲ *Fig. 4 Resonant frequency and bandwidth versus upper stub length.*

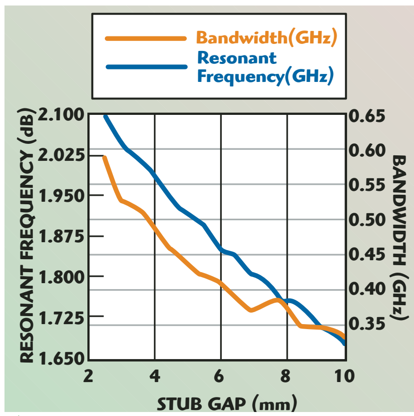
pedance was obtained as a function of the width and gap of the CPW-feed line. The L1, L2, G1 and G2 parameters were then varied and their effect on the characteristics of the antennas was investigated. ***Figure 2*** shows the simulated surface current distribution at 1.8 GHz. The current distribution at the edge of the dual stub is zero. ***Figure 3*** shows the simulated return loss versus frequency for different lengths of the upper stub L1. The value of L1 was varied from 8 to 20 mm. When L1 was increased from 8 to 20 mm, the fundamental resonance was shifted to a lower frequency. However, when L1 increased beyond 20 mm, there was a poor response in the fundamental resonance. A large frequency shift occurred in the fundamental resonance when changing the parameter L1. The values for L2, G1 and G2 were fixed at 10, 6 and 1.5 mm, respectively. ***Figure 4*** shows the resonating frequency and bandwidth versus the length of the up-



▲ *Fig. 5 Simulated return loss versus frequency for different lengths of the lower stub, Lz.*

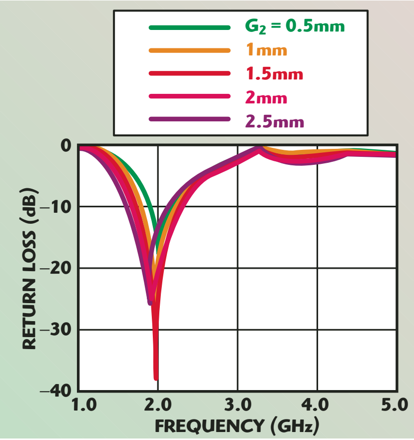


▲ *Fig. 6 Simulated return loss versus frequency for different gaps, G1.*

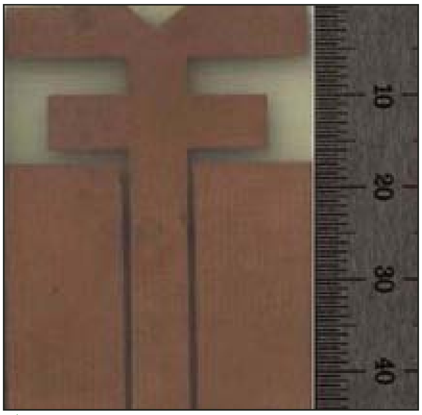


▲ *Fig. 7 Resonance frequency and bandwidth versus gap between stubs, G1.*

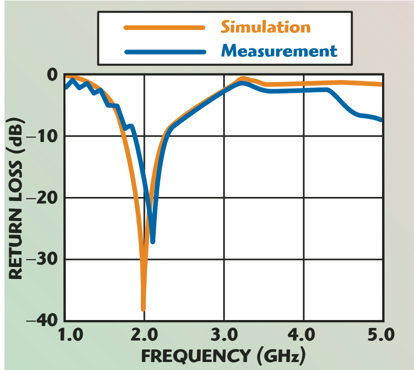
per stub. It shows that the fundamental resonant frequency varies inversely with the length L1. ***Figure 5*** shows the simulated return loss versus frequency as a function of the length of the lower stub of the dual-T antenna L2, varying



▲ *Fig. 8 Simulated return loss versus frequency for various gaps, G2.*

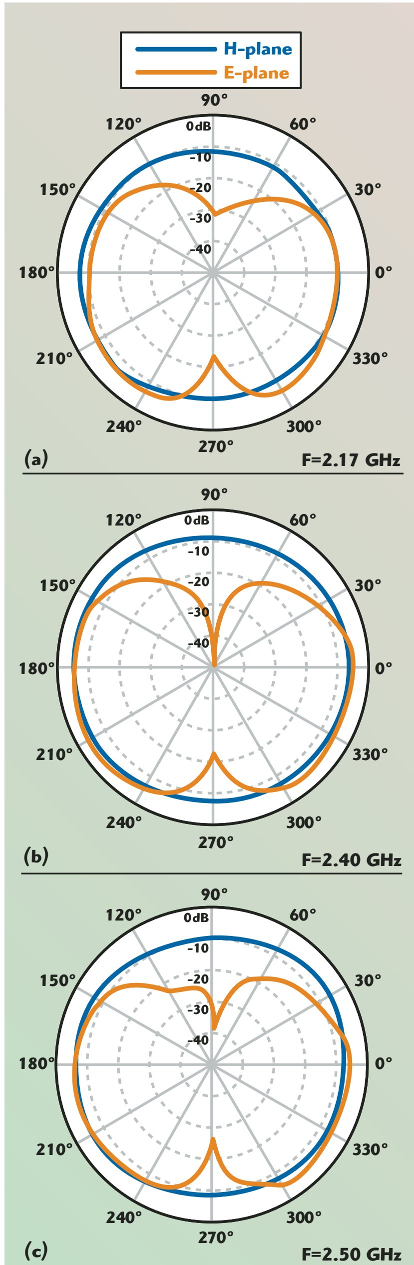


▲ *Fig. 9 The fabricated antenna.*



▲ *Fig. 10 Measured and simulated return loss versus frequency.*

from 6 to 14 mm. When L2 is increased from 6 to 14 mm, the fundamental resonant frequency does not shift, but the return loss changes. ***Figure 6*** shows the return loss when G1 is varied from 2 to 8 mm. The center frequency of the antenna changed appreciably. When G1 was increased from 2 to 8 mm, the fundamental resonance shifted to a low frequency. Here, the values of L1, L2 and G2 were fixed at 14, 10 and 1.5 mm, respectively. ***Figure 7*** shows the resonance frequency and bandwidth versus the gap between the dual stubs. The resonance frequency varies inversely with the length of the gap G1. ***Figure 8*** shows the return loss simulated for a change in the gap G2 between 0.5 and 2.5 mm while keeping L1 = 14 mm, L2 = 10 mm and G1 = 4 mm. The resonance frequency does not show much change. ***Figure 9*** shows a photograph of the fabricated antenna. ***Figure 10*** shows a compari-



▲ *Fig. 11 Measured E- and H-plane radiation patterns at (a) 2.17, (b) 2.40 and (c) 2.50 GHz.*

son between the measured and simulated return losses of the antenna. The simulated and measured data of the proposed antenna are approximately the same. Some errors occurred due to phase differences between the two stubs as a result of poor manufacturing in the laboratory. ***Figure 11*** shows typical measured omni-directional radiation patterns of the antenna at three frequencies, plotted along the E-plane (y-z plane) and H-plane (x-z plane).

CONCLUSION

CPW-fed dual-T antennas, with a widened tuning stub for broadband operation and controlled frequency, were designed and successfully fabricated. The efficient proposed antenna was achieved simply by tuning the gap between the stubs and the length of the upper stub. The return loss and radiation patterns were simulated by using the FDTD method and were measured using a vector network analyzer, model 37325A, and an anechoic chamber Stargate-32A. By properly choosing the gap between stubs and the length of the upper stub, the center frequency can be shifted by approximately 700 MHz. An antenna impedance bandwidth of 450 MHz can be obtained within the IMT2000 band. ■

References

1. W. Menzel and W. Grabherr, "A Microstrip Patch Antenna with Coplanar Feed Line," *IEEE Microwave Wave Letters*, Vol. 1, November 1991, pp. 340–342.
2. P.L. Sullivan, "Analysis of an Aperture Coupled Microstrip Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 34, No. 8, August 1986.
3. H.M. Chen, Y.F. Lin, C.C. Kuo and K.C. Huang, "A Compact Dual-band Microstrip-fed Folded Loop Antenna," *IEEE International Symposium on Antennas and Propagation Digest*, Vol. 2, July 2001, pp. 124–127.
4. K.F. Lee and W. Chen, *Advances in Microstrip and Printed Antennas*, Wiley Interscience, Hoboken, NJ, 1997, pp. 71–109.
5. K.D. Katsibas, C.A. Balanis and P.A. Tirkas, "Folded Loop Antenna for Mobile Communications Systems," *IEEE International Symposium on Antennas and Propagation Digest*, Vol. 3, July 1996, pp. 1582–1585.
6. H. Lee and Y. Lim, "Printed Monopole Antenna of Dual-band for Omni-directional Radiations Patterns," *The Institute of Electronics Engineers of Korea*, Vol. 40, November 2003, pp. 655–659.
7. H.M. Chen and Y.F. Lin, "Printed Monopole Antenna for 2.4/5.2 GHz Dual-band Operation," *IEEE International Symposium on Antennas and Propagation Digest*, Vol. 3, June 2003, pp. 60–62.

Hyeonjin Lee *received his BS degree in electrical engineering from Chosun University, Gwangju, Korea, in 1982, his MS degree in electronics engineering from Wonkang University, Iksan, Korea, in 1988, and his PhD degree in electrical engineering from Chonnam National University, Gwangju, Korea, in 1996. From 1997 to 1998, he was a visiting professor at the Microwave Laboratory, Division of Electrical Engineering, Pennsylvania State University. In 1991, he joined the faculty of Dongkang College. His research interests include antennas, microwave integrated circuits and RFID.*

Yeongseog Lim *received his BS and MS degrees in electronic engineering from Seoul National University, Korea, in 1980 and 1982, respectively, and his PhD degree from Chongbuk National University, Korea, in 1989. Since 1984, he has been a professor in the school of electronics and computer engineering, Chonnam National University, Gwangju, Korea. His research interests include the numerical analysis of electromagnetic waves and microwaves, antennas and RF circuit design.*

EXPERIMENTAL ANALYSIS OF A MULTI-BAND AND HIGH GAIN OPEN SLOT ANTENNA WITH DUAL REFLECTOR

In this article, a wide-band, open slot antenna with dual reflectors is proposed. It has been constructed and its performance measured. It has a modified circular feed structure for easy impedance matching to the wide slot. The dual reflectors lead to a reduced beam-tilt angle and an improved half-power beam width in the E-plane for each frequency band. Bandwidths of 24.7 percent (755 to 968 MHz) and 73.1 percent (1574 to 3389 MHz) were obtained for a VSWR less than 2.0. This antenna also offers high gain characteristics. The proposed antenna can be used in cellular, GSM, DCS, PCS, IMT-2000 and WLL applications.

Slot antennas have been investigated since at least the 1940s[1] and are treated in many textbooks on electromagnetism. In these antennas, the feeding method generally uses a microstrip line crossing the center of the slot. However, this method increases the radiation resistance, which makes the impedance matching difficult.[2] To solve this problem, Yoshimura[3] and Pozar[4] have proposed a second way, which offsets a short-circuited tuning stub and an open circuit-tuning stub at both ends of the slot.

Bi-directional slot antennas for broadband operation (30 to 90 percent) have been described.[5,6] Unfortunately, these antennas have a low gain. A directional slot, backed by a ground plane, has shown higher gain than a bi-directional slot antenna, but the radiation pattern of a directional antenna has many nulls at higher frequencies, which restrict a wider application for wireless communications. Therefore, a technique to enhance the radiation of microstrip antennas has been proposed,[7] although the narrow bandwidth of the antenna is still a major obstacle. An open slot structure has already been published;[8] however, its major fault is a beam tilt and a narrow half-beam width at cellular, DCS, PCS, IMT-2000 and WLL frequencies.

In this article, a new structure for a printed, open slot antenna with dual reflectors is proposed. An open slot antenna is made by etching a rectangular slot in the ground plane of a microstrip. The proposed antenna uses a modified circular feed structure, which can provide a good impedance match for a wide

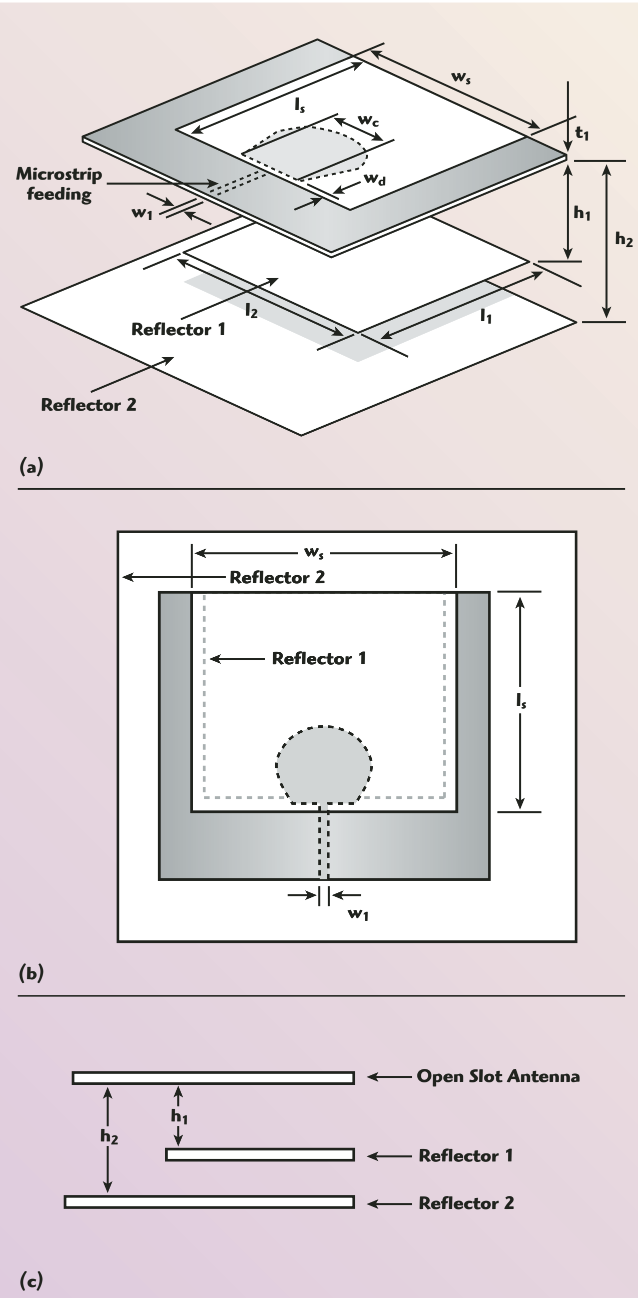
HYUN-CHUL GO
Hankook Antenna Co. Ltd.
Bucheon, Korea
YONG-WOONG JANG
Keukdong College
Chungbuk, Korea

slot. Moreover, the dual reflectors (reflectors 1 and 2) lead to an enhanced beam tilt angle and half-power beam width of the E-plane pattern in each frequency band. This antenna also shows wide-band and high gain characteristics.

ANTENNA STRUCTURE AND EXPERIMENTAL RESULTS

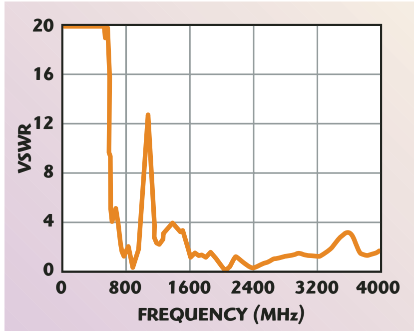
The geometry of the proposed circular-fed, open slot antenna with dual reflectors for dual- and wide-band operation is shown in ***Figure 1***. The open slot antenna is etched in the ground plane on the substrate FR-4 ($\varepsilon_r = 4.3$) with a thickness $t_1 = 1.6$ mm. The open slot antenna has a slot width w_s and a length l_s, chosen to improve bandwidth, and the top of the slot is opened to reduce the radiation tilt angle in the E-plane for practical applications. The microstrip line width w_1 is designed for a 50 Ω input impedance. The modified circular microstrip feed line is used as a feeding method to match easily to the wide slot. The reflectors 1 and 2 are positioned with height h_1 and h_2 from the back of the open slot antenna. Reflector 1 is used for the upper band impedance matching and directional pattern; Reflector 2 is used for enhancing the beam tilt angle and providing an increment in the half-power beam width in the E-plane pattern. ***Figure 2*** shows a photo of the fabricated antenna. The reflectors are made of aluminum plates and the antenna is fed through a coaxial cable and a 50 Ω SMA connector. The fabricated antenna dimensions are l_s = 120 mm, w_s = 132 mm, w_c = 32 mm, w_d = 2.5 mm, h_1 = 28 mm and h_2 = 45 mm. The low frequency band is affected by l_s, w_s and h_2. The upper band is affected by w_c, w_d and h_1. The overall size of the proposed antenna is 180 mm × 160 mm × 47.6 mm. The VSWR of the proposed antenna was measured with an HP8753 ES network analyzer. The far-field radiation patterns were measured in an anechoic chamber.

The measured VSWR data of the proposed antenna is shown in ***Figure 3***. The measured bandwidth is 755 to 968 MHz in the

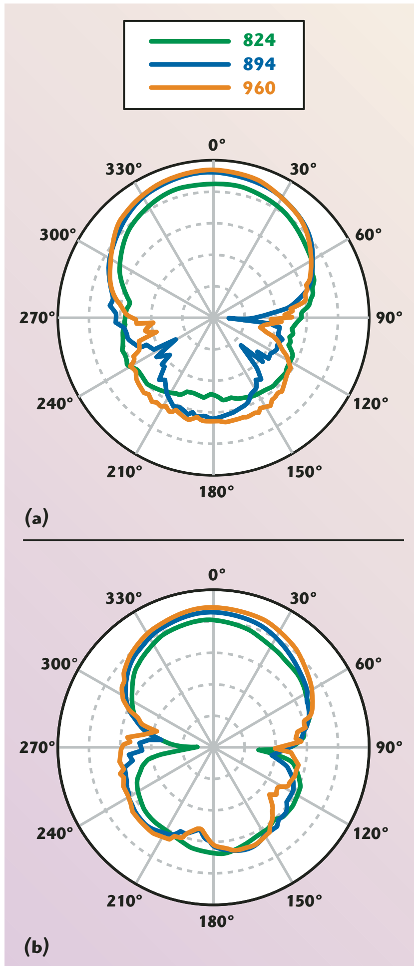


▲ *Fig. 1 Structure and design parameters of the proposed antenna; (a) three-dimensional view, (b) top view and (c) side view.*

▲ *Fig. 2 The fabricated antenna.*



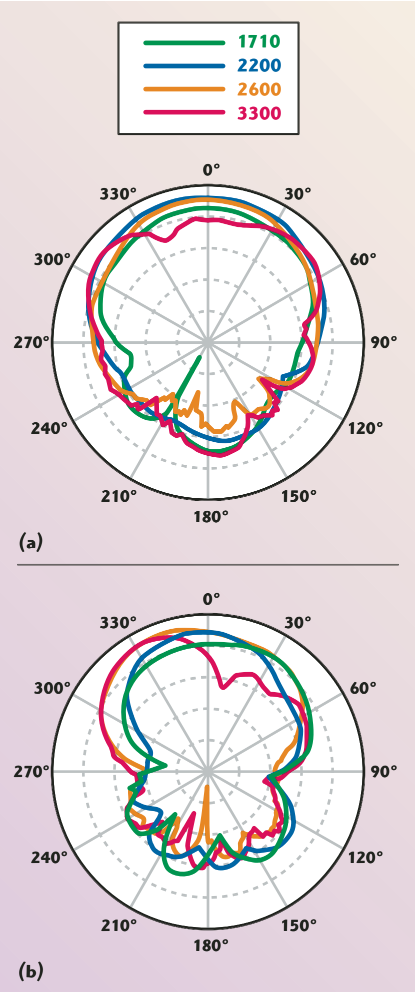
▲ *Fig. 3 Measured VSWR versus frequency.*



▲ *Fig. 4 Lower band (a) H-plane and (b) E-plane radiation patterns.*

lower band and 1574 to 3389 MHz in the upper band. The VSWR ≤ 2 bandwidth is approximately 24.7 percent at the lower band and 73.1 percent at the upper band. The proposed antenna shows its dual-band and wide-band characteristics. After calibration, the far-field radiation patterns were measured using a horn antenna. ***Figure 4*** shows the H-plane and E-plane radiation patterns at the lower band. ***Figure 5*** shows the H-plane and E-plane radiation patterns at the upper band. ***Table 1*** shows the measured characteristics (gain, beam tilt angle and half-power beam width (HPBW) of the E-plane) of the proposed antenna. This antenna reduces the beam tilt angle of the E-plane for practical applications such as DCS, PCS, IMT-2000 and DMB. The measured maximum gain is 9.51 dBi at 0.96 GHz and 8.46 dBi at 2.2 GHz, respectively.

The measured gain versus frequency for the cellular and GSM bands is shown in ***Figure 6***. The gain is relatively high over most of the band, which is most probably due to the effect of the finite size of the antenna substrate, that is the power in the surface wave is not confined to the substrate but diffracted by the substrate edge, an effect which was

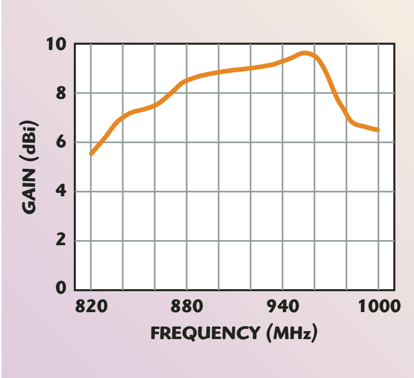


▲ *Fig. 5 Upper band (a) H-plane and (b) E-plane radiation patterns.*

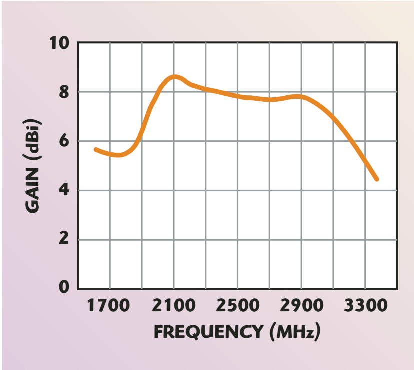
TABLE I

MEASURED CHARACTERISTICS

Frequency (MHz)	Gain (max) (dB)	E-plane Beam Peak Angle (°)	E-plane HPBW (°)
Lower Band			
824	5.5	–2	69.94
894	8.78	0	66.18
960	9.51	0	62.26
Upper Band			
1710	5.6	–2	62.65
1880	5.55	0	84.52
2000	7.87	10	84.4
2100	8.42	–2	67.6
2200	8.76	–6	75.73
2300	8.1	–4	58.38
2600	7.55	–2	55.34
3000	7.8	–2	32.74
3300	4.3	–48	28.93



▲ *Fig. 6 Measured antenna gain in the lower frequency band (cellular and GSM).*



▲ *Fig. 7 Measured antenna gain in the upper frequency band (PCS, IMT-2000 and WLL-band).*

not taken into account in the analysis. The measured gain is 5 dBi over the entire usable frequency band, but drops off rapidly past the band edges. The measured gain versus frequency for the PCS, IMT-2000 and WLL bands is shown in ***Figure 7***. The measured gain is also 5 dBi over the entire band in the usable frequency band, but drops off rapidly past the band edges. This is due to impedance mismatch and pattern degradation, as the back radiation level increases rapidly at these frequencies.

CONCLUSION

In this article, a modified, circular-fed, open slot antenna with dual reflectors is proposed. The measured bandwidth of the proposed antenna is approximately 24.7 percent at the lower band and 73.1 percent at the upper band for a VSWR ≤ 2.0. The experimental results of this antenna showed a multi-band and a high gain characteristic. The proposed antenna offers a reduced beam tilt angle of the E-plane pattern for practical applications such as cellular, GSM, PCS, IMT-2000 and WLL. ■

References

1. H.G. Booker, "Slot Aerials and Their Relation to Complementary Wire Aerials," *Journal of the IEE (London)*, Part IIIA, Vol. 93, 1946, pp. 620–626.
2. R. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House Inc., Norwood, MA, p. 442.
3. Y. Yoshimura, "A Microstripline Slot Antenna," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 20, No. 11, November 1972, pp. 760–762.
4. D.M. Pozar, "Reciprocity Method of Analysis for Printed Slot and Slot Coupled Microstrip Antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 34, No. 12, December 1986, pp. 1439–1446.
5. Y.W. Jang, J.C. Chai and H.S. Shin "A Large Bandwidth T-shaped Microstrip-fed Ground Plane Slot Antenna," *Microwave Journal*, Vol. 45, No. 1, January 2002, pp. 503–507.
6. Y.W. Jang, "Experimental Study of Large Bandwidth Three-offset Microstripline-fed Slot Antenna," *IEEE Microwave and Wireless Components Letters*, Vol. 11, No. 10, 2002, pp. 425–427.
7. A.K. Bhattacharyya, "Effects of Finite Ground Plane on the Radiation Pattern Characteristics of a Circular Patch Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 38, 1990, pp. 152–159.
8. H.C. Go and C.Y. Lee. "A New Open Slot Antenna for Wide and Dual-band Operations," *2003 Asia-Pacific Microwave Conference Digest*, Vol. 3, pp. 1864–1867.

Hyun-Chul Go *received his BS and MS degrees in electronics engineering from the Korea University of Technology and Education, Cheonan, Korea, in 1999 and 2001, respectively. Since 2001, he has been working as a research engineer in the R&D Center of Hankook Antenna Co. Ltd., Bucheon, Korea. His current research interests include internal antennas, wide-band and high gain antennas for repeaters and UWB antennas.*

Yong-Woong Jang *received his BS and MS degrees from Myongji University, Seoul, Korea, in 1989 and 1991, respectively, and his PhD degree from Ajou University, Suwon, Korea, in 1999, all in electronics engineering. He is currently an associate professor in the department of information communications engineering at Keukdong College, Chungbuk, Korea. His main areas of interest include antennas, RF systems and numerical methods in solving electromagnetic problems.*

A SOFTWARE SUITE WITH TOTAL SYNERGY

Design engineers currently using CST MICROWAVE STUDIO® (CST MWS) appreciate its ease-of-use and the insight into devices which together facilitate a significant augmentation of throughput. Now though, these customers may be taken by surprise, because the box containing the eagerly awaited and much publicized new release is titled CST STUDIO SUITE™ 2006. Closer inspection reveals that this suite comprises the high frequency simulator CST MWS, the block schematic tool CST DESIGN STUDIO™ (CST DS), the low frequency simulator CST EM STUDIO™ (CST EMS), and last but not least, CST PARTICLE STUDIO™ (CST PS) dedicated to the fully consistent 3D simulation of free moving charged particles in electromagnetic fields. ***Figure 1*** shows the CST STUDIO SUITE™ 2006 interface.

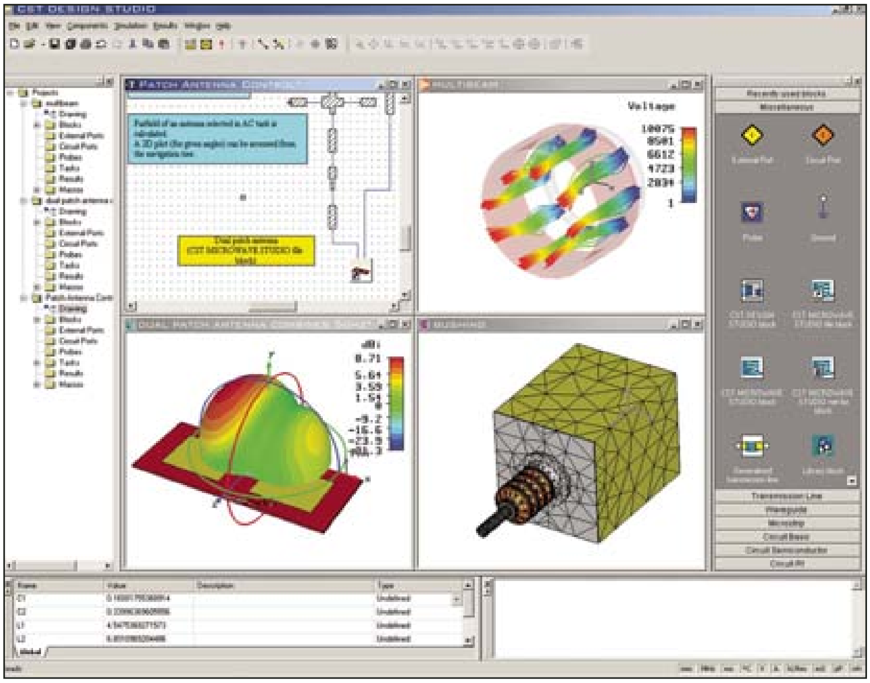
A NEW ENVIRONMENT

The synergetic advantages offered by this new suite should be all too apparent to users. For example, CST EMS' temperature solver can be used to evaluate the heat load due to high frequency electric field losses calculated by CST MWS, or the magnetization of ferrites, and all within one interface. An illustration is given in ***Figure 2***.

This is made possible by the newly implemented CST DESIGN ENVIRONMENT™ (CST DE), which is the access point to CST MWS and all other CST STUDIO simulators. Through the implementation of CST DE, CST MWS has gained a Multiple Document Interface, whereby several projects can be

CST OF AMERICA
Wellesley Hills, MA

opened simultaneously. Therefore, the user can easily switch between projects, compare and copy/paste results. CST DE also allows switching to the VBA editor.



▲ *Fig. 1 CST STUDIO SUITE™ 2006 interface.*

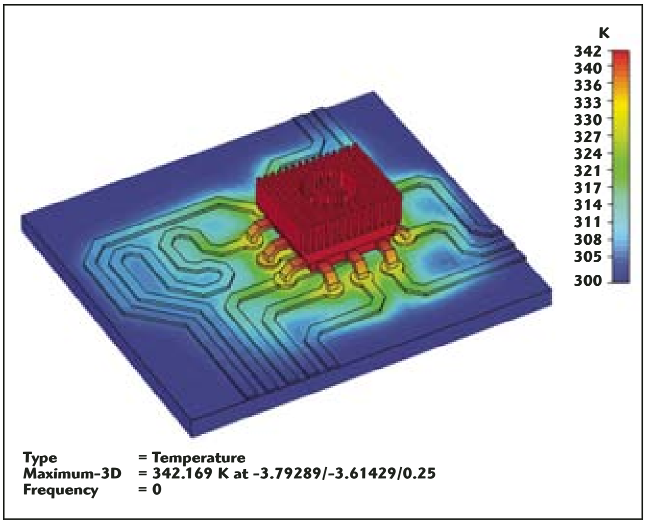
MODELING AND INTEROPERABILITY

The success of CST MWS has always been closely related to having introduced an easy-to-use interface to the 3D EM field simulation community. It allows fast modeling of complex structures, promoting design intent capture and implicit (together with explicit and even subsequent) parameterization of geometrical models. A wide range of interfaces to mechanical CAD tool formats is available too, and the imported CAD data can be parameterized and made accessible to optimization.

Entirely new are the interfaces to VDA-FS and Mecadtron formats. The interface to Cadence® Allegro® has undergone a complete rework, resulting in improved front-end performance. ***Figure 3*** shows a structure imported from Cadence. The interface also now features a stack-up editor. This represents a first step towards interfacing with other EDA-vendors like Mentor Graphics® or Zuken. Planar imports can be easily extended by an automated JEDEC compliant bond-wire creation and users can simply switch between an idealized and a solid model representation. In addition to CAD interfaces, current distributions, from SimLab PCBMod, for example, can now be loaded as sources for EMC/EMI studies.

SCHEMATIC VIEW

Upon opening a CST MWS project, the user will notice that an additional CST DS view is available. Even with the basic license, RLC elements as well as a few other components can be attached to the ports, and S-parameter simulations can be performed. A full CST DS license would enable access to a far wider range of circuit elements. The composition of larger systems out of small 3D CST MWS models (but also models originating from other simulation methods) is the key strength of

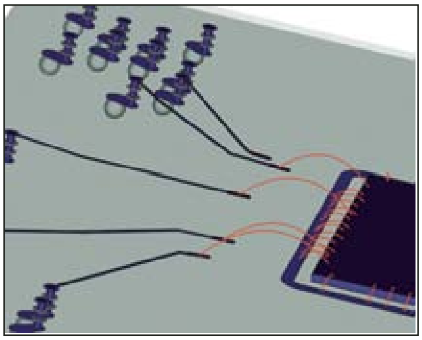


▲ *Fig. 2 Temperature distribution of an IC cooling element.*

CST DS. It employs sophisticated caching and interpolation schemes to speed up parameter studies and optimizations. It is strongly focused on improving 3D EM simulation performance, and takes some users one step along the path towards circuit simulation.

EM/CIRCUIT CO-SIMULATION

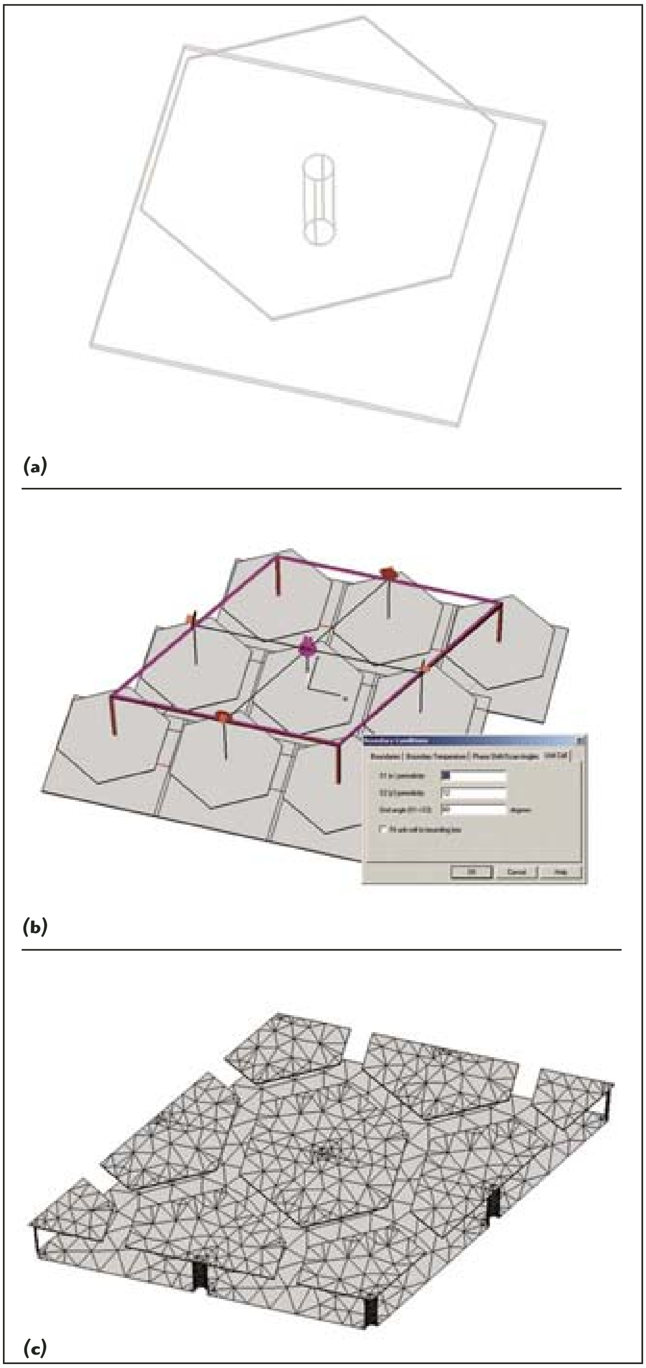
A major concern in today's high frequency design of PCBs and packages is signal integrity and radiated emission. With Agilent's ADS 2005A and CST MWS 2006, the companies now present an improved EM/circuit co-simulation scheme that enables the complete integration of 3D models in the ADS workflow. Any CST MWS model can be made available for co-simulation as a library element. The user can specify the parameters to be made accessible in the ADS circuit model. If used in tuning or optimization, intermediate results can be obtained by interpolating existing results. Whenever necessary (or wanted) a full 3D simulation can be launched directly from the ADS schematic. Each simulation result is added to the library element cache, thus continuously increasing its value.



▲ *Fig. 3 Structure imported from Cadence.*

SOLVER TECHNOLOGY

CST MWS is said to be the only commercial 3D simulator to offer time domain and frequency domain on Cartesian and tetrahedral grids, accessible through one easy-to-use interface. The flagship module, the transient solver, is the first choice for electrically large, complex or broadband structures. These capabilities have been extended by the implementation of 64-bit technology. Be-



▲ *Fig. 4 Creation of a unit cell; (a) single element, (b) automatic set-up of the unit cell and (c) the Floquet mode port boundary, calculation domain.*

sides the user interface, the company's proprietary Perfect Boundary Approximation (PBA®) technique can be seen as the other foundation stone on which its success has been built. Its implementation has been shown to significantly improve the efficiency of time domain methods through accurate geometrical structure representation.

The transient solver now takes advantage of a new meshing algorithm. The robust mesher shows excellent performance particularly for complex, imported structures.

Further improvements include the definition of frequency dependent material through tables. This also applies to voxel imports, thus enabling highly accurate broadband EM simulation of biological tissues.

The main focus of development for version 2006 has been the tetrahedral frequency domain (FD) solver. This complements the time domain solver, and shows its particular strengths if structures are electrically small or periodic. Particularly interesting is the ability to mesh the true surface of the structure without having to pre-segment rounded objects. Users can choose between an iterative solver, where memory requirements scale better with problem size, and a direct solver, which performs efficiently on multi-port structures, since the simulation time is not strongly dependent on the number of ports.

For periodic structures like phased arrays, PBGs, FSS and meta-materials the FD solver features a powerful algorithm that automatically sets up the unit cell for easy scan angle study. This is illustrated in ***Figure 4***. Also, an adaptive frequency sweep speeds up broadband investigations by reducing the number of simulations necessary to achieve the desired accuracy.

There are now two dedicated solvers for resonant high Q structures like filters. The first is based on a model order reduction (MOR) scheme, and calculates S-parameters directly and extremely quickly but without calculating fields. If the fields are required, the modal analysis approach can be applied. The Eigenmode solver that solves closed or periodic structures, taking losses into consideration, completes the palette of solvers.

PERFORMANCE AND AUTOMATION

Users of CST MWS can take advantage of multiple processors in several ways — by using the parallel processing functionality, by which one simulation can use several CPUs on one mainboard, or through the distributed computing scheme, which can also utilize other computers in a network. For parameter studies and optimizations, runs with different parameter sets are allocated from, and results are collected and evaluated in one central front-end. New parameter sets for the next run of simulations are set up and distributed again. This scheme has been significantly improved in terms of network traffic, error tolerance and stability.

VBA macro language is also implemented. This, together with the COM/DCOM interface, makes the software accessible through other software packages, for example, if a user wants to implement his own evaluation or optimization schemes. Multi-run simulations, like monostatic RCS calculation, can be automated easily using either pre or user defined macros.

POST PROCESSING

New post-processing features in version 2006 include the calculation of far fields over lossy ground, thus enabling the simulation of outdoor test ranges, a new broadband SPICE extraction scheme and average plots used for MRI applications.

The access to result data is facilitated through a sophisticated automatic post-processing scheme. Arbitrary goal functions can be derived for the two implemented automatic optimizers from a large, user extendable number of evaluations. For the visualization of parameter dependant result data, users can now employ tuning sliders.

CONCLUSION

CST MWS version 2006 is a versatile simulator that offers users significantly increased value through its integration in CST STUDIO SUITE,™ the new multiple document interface and numerous improvements in all areas. The company uniquely enables access to time domain and frequency domain, on Cartesian or tetrahedral meshes through one interface, and its application range now spans from static to optical frequencies.

CST of America,
Wellesley Hills, MA (781) 416-2782;

CST GmbH,
Darmstadt, Germany,
+ 49 (0) 6151 73030, www.cst.com.

RS No. 302

BROADBAND TACTICAL COMMUNICATIONS ANTENNAS

Military tactical communications require transportable radio systems that can be set up quickly in the field, under difficult conditions, to establish communication links. These radio systems are mounted in tactical operation centers (TOC), vehicles and shelters. Legacy antennas used in these systems operate primarily in the VHF or UHF frequency bands and have omni-directional radiation patterns. They are set up on the ground, mounted on vehicles, or attached to telescopic masts when the terrain requires additional height to establish a line-of-sight link.

To complement the latest generation of software-defined, multi-band/multi-mission radio designs utilized by the military, new tactical communication antennas are needed, featuring wider frequency bandwidth than was previously available. The need for dual- and tri-band antennas is also becoming more commonplace, as the number of antennas mounted on military vehicles continues to grow. The ability to accomplish multiple missions with a single aperture has become highly desirable. Chelton Microwave Sensor & Antenna Systems – Atlantic Division is designing wideband and multi-band antennas to address these requirements.

TABLE I

COM201B AND COM231 SPECIFICATIONS

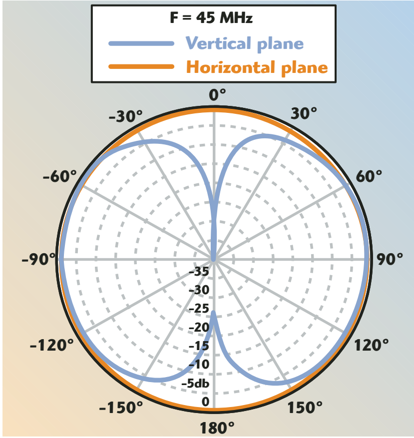
Frequency band (MHz)	30 to 88
Gain (dBi)	2 nominal
VSWR	3.5:1 maximum
Impedance (Ω)	50
Power handling (W)	200
Polarization	vertical

LEGACY ANTENNA DESIGNS

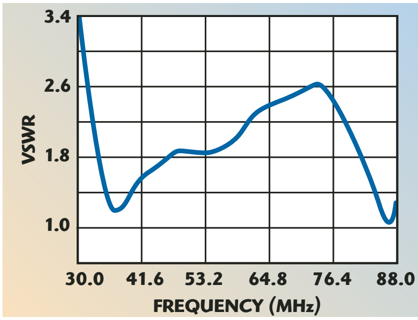
In the 30 to 88 MHz Single Channel Ground and Airborne Radio System (SINCGARS) band, there are a number of legacy antenna designs that have been used over the years. These are mainly biconic antennas for mast-mounted applications and whip-style antennas for vehicle applications. Improved alternatives to these conventional approaches are the COM201B and COM231 antennas designed for military tactical SINCGARS applications (see ***Table 1***). The COM201B is a ground-based antenna that can be deployed in a stand-alone, mast-mounted, or suspended configuration (see ***Figure 1***). The COM231 model is a vehicle-mounted antenna that includes a flexible spring

CHELTON MICROWAVE CORP.,
SENSORS & ANTENNA SYSTEMS –
ATLANTIC DIVISION, BOLTON, MA

▲ *Fig. 1 Tripod-mounted CM201B antenna.*



▲ *Fig. 2 Radiation patterns of the COM201B and COM231 antennas.*



▲ *Fig. 3 VSWR of the COM201B antenna with matching network.*

mount that enables the antenna to survive the rigors of driving on rough terrain. These antennas provide an omnidirectional radiation pattern in the horizontal or azimuth plane and a cardioid radiation pattern in the vertical or elevation plane, as shown in ***Figure 2***.

The COM201B antenna is designed with quick deployment and ease of operation in mind. The unique tripod metal-tube leg structures that serve as both mount and electrical ground plane allow the antenna to be installed directly on the ground or on rooftops, bunkers and shelters. These tripod/ground-plane radials telescope and can either be removed or folded up parallel to the active element for transport.

Physical properties designed into the COM201B have the effect of decreasing the electrical reactance of the antenna's elements, which, in turn, increases the frequency range (bandwidth) over which the antenna can be efficiently operated. The COM201B antenna's physical construction is such that the diameter-to-length is optimized to produce radiation across the 30 to 88 MHz frequency band, using a structure that has a reasonable size as well as effective radiation-efficiency characteristics. To make the antenna even more effective, the COM201B also includes a broadband, lumped element, impedance matching network. The network is located in the base of the lower radiating element near the feed point of the antenna. The network maximizes efficient transfer of power from the radio to the antenna field across the desired frequency range with a VSWR of less than 3.5:1, as shown in ***Figure 3***.

The COM231 vehicle-mounted antenna uses the same design techniques as the COM201B, but whereas the COM201B is equipped with the tripod metal-leg structures to provide a ground plane, the COM231 model uses the vehicle it is mounted to as its ground plane. The impedance matching circuitry of the COM231 antenna is similar to that which is used in the COM201B antenna, but because the COM231 is used in a mobile environment, additional lightning protection

TABLE II

COM237 SPECIFICATIONS

Frequency band (MHz)	30 to 512
Gain (dBi)	–2 typical
VSWR	3:1
Impedance (Ω)	50
Power handling (W)	150
Polarization	vertical

and high voltage protection circuitry is added. The COM231 is supplied with a standard military vehicle mount, as well as with a side-mount kit for attachment to shelters and some military vehicles.

Since the COM201B and COM231 antenna structures were specifically designed to deliver maximum low angle signals, their power on the horizon is greater than for other antennas of its type. In addition, the low loss impedance matching network and the higher length-to-diameter ratio of the antenna both work to increase the power gain on the horizon even further. Therefore, radio systems using these antennas can be expected to perform at distances greater than what is normally accepted to be radio line-of-sight using other antennas, and this has been confirmed in field trials by the US Army.

NEXT GENERATION MULTI-BAND DESIGNS

The COM201B and COM231 antennas were used as a starting point for the development of a new series of antennas to cover the ultra broadband frequency range of 25 to 2500 MHz, as required for the next generation communication and electronic warfare applications. Using technology developed from these legacy antenna designs, new antennas have been designed for both dual- and tri-band applications.

One such new antenna is the COM237 model, which operates over the 30 to 512 MHz frequency band and complements the latest software-defined radios that are currently being procured by the military (see ***Table 2***). This is a vehicle-mounted antenna that has the same mechanical footprint as the COM231 vehicular antenna (see ***Figure 4***). It has a base section 32" long, which is 3" in diameter and the remainder has a 1.75" diameter. The overall length of the antenna is 75". This broadband operation is accomplished by integrating a UHF radiator into the

▲ *Fig. 4 COM237 antenna mounted on a military vehicle.*

same space as a VHF radiator and employing techniques to reduce the overall antenna length. The VHF section is an end-fed monopole element operating in the 30 to 100 MHz range. The UHF section is a sleeve dipole operating from 100 to 512 MHz. The COM237 can be supplied in either a one-RF or two-RF port configuration. When supplied as a one-RF port antenna, the COM237 can interface to a software-defined radio and take full advantage of its wideband operation. When configured with two RF ports, this antenna can support both VHF (SINCGARS) and UHF (EPLRS, for example) bands of operation simultaneously, thus minimizing the number of apertures installed on the vehicle.

Another next generation antenna is the COM235, a multi-band antenna that covers the VHF (30 to 100 MHz), UHF (100 to 512 MHz) and L-band (900 to 2500 MHz) frequency bands. The design of this model builds upon the COM237 dual-band design by adding an additional bi-cone radiator on top to address the L-band requirement. This can be accomplished in a physical package size that is 3.5" in diameter, with an overall height of 70". This antenna can be configured with three separate RF ports, or two of the elements can be combined through a diplexer to reduce the number of RF ports. When configured with three RF ports, the single antenna can be used for three distinct missions such as SINCGARS, EPLRS and JTIDS. The isolation between the bands of operation is sufficient to operate this way. When the elements are combined to a single RF port, the antenna can be used for wideband detection and jamming applications.

A COM236 model has also been developed for JTRS. The COM236 again features a VHF (30 to 100 MHz) radiating element, a UHF (100 to 512 MHz) radiating element and an L-band radiating element covering 900 to 1850 MHz. The COM236 outline is similar to the COM201B, featuring an upper radiating diameter of 1.5", with an additional seven inches in height to accommodate the L-band radiating element.

CONCLUSION

New multi-band antenna designs are available to address wideband software-defined radio applications as well as multi-mission requirements. These multi-band antennas feature improved bandwidth, radiation efficiency and power handling performance in the same basic outline as legacy single-band antennas. The antennas are used in military tactical communications applications, as well as in some broadband detection and jamming applications.

Chelton Microwave Corp.,
Sensor & Antenna Systems – Atlantic Division
Bolton, MA (978) 779-7000,
www.cheltonmicrowave.com.

RS No. 301

NEW HIGH POWER SMT POWER DIVIDERS/ COMBINERS

The Wilkinson divider has long been popular with RF designers. In recent years, off-the-shelf, surface-mount technology (SMT) components of this type have become available and provide tremendous cost savings in high volume pick and place manufacturing. Some of its applications are found in power amplifier design and modern communication systems. Many applications employing the Wilkinson structure cannot be enhanced by the use of any available surface-mount or tab-contact component solution. However, through the use of new materials and manufacturing processes with new design techniques, these SMT power dividers provide better performance and wider applicability. These innovative, ceramic-based planar components now permit the realization of smaller and more integrated power amplifiers that can tolerate worse internal and external source and load mismatches.

The Wilkinson power divider has been well documented and used for many years as a building block in many RF and microwave splitting and combining networks. In power amplifier applications, the power divider allows single, large and expensive, high power amplifiers to be replaced with several, smaller and lower cost, power amplifiers. In addition, this power dividing/combining technique takes advantage of the linear operating region of the high power amplifiers, thus reducing intermodulation distortion.

The Wilkinson in-phase divider utilizes $\lambda/4$ transmission lines for impedance matching and an isolation resistor connected between each end of the $\lambda/4$ section(s). In an N-way power divider, the power division depends on the number N of output ports. The magnitude of the power division is calculated using the equation $10\log(1/N)$. The use of the resistors allows the ports to be matched. In addition, it isolates the output ports from one another at the center frequency.

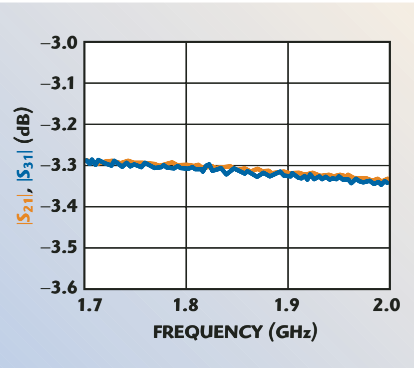
When used as a power divider, the input signal is split into signals of equal amplitude

FLORIDA RF LABS/EMC TECHNOLOGY
Stuart, FL

TABLE I

TYPICAL PERFORMANCE OF THE HYBRIX® GENERATION OF SMT POWER DIVIDERS

Two-way VSWR	Power (W)	Three-way VSWR	Power (W)
1.2	50	1.2	35
1.4	50	1.4	35
1.5	34	1.5	24
1.7	19	1.7	14
2.0	13	2.0	9



▲ *Fig. 1 Amplitude balance and insertion loss of a two-way power divider, including its test board.*

and phase at the output ports. As a result, each terminal of the isolation resistor will be at the same potential and, consequently, no potential difference and no voltage drop. A mismatch at one of the output ports will not affect the other outputs. This is due to the 180° phase difference when the reflected signal appears at the opposite end of the isolation resistor. On the other hand, combining signals of unequal magnitudes will cause a voltage drop across the resistor, thus dissipating power.

The general performance characteristics of a power divider are isolation, amplitude balance, phase balance, VSWR, power handling capability and insertion loss. As an indication of high performance, a power divider has a typical isolation of 20 dB and the higher the isolation, the less chance of leakage between the output ports. Generally, the isolation will degrade at higher frequencies.

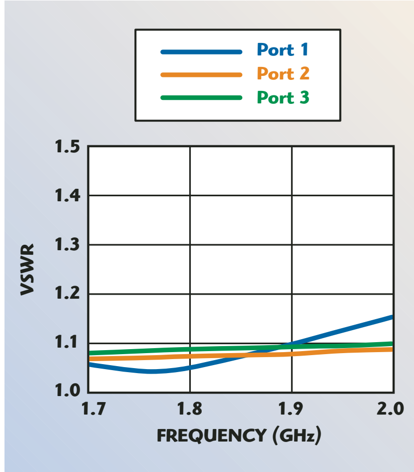
Amplitude and phase balances, sometimes referred to as amplitude and phase tracking, are also important indications. These are simply the amplitude and phase differences between the powers at the output ports. Amplitude balance typically increases with the number of output ports. The VSWR indicates how well the input and output ports are matched to each other and to external connections. In addition, the power handling capability is of high importance to the designer. The rating is usually given for matched conditions or matched power rating. For an unmatched system, the power handling is dependent upon the internal resistors used. Wilkinson power dividers are typically fabricated as a printed structure on Teflon-based material using chip resistors. In recent years, SMT versions have become readily available. The latest generation of SMT Wilkinson power dividers, fabricated on ceramic substrates, has recently become available and provides tremendous increases in performance, compared to SMT power dividers of previous generations. By utilizing a ceramic substrate, these products allow for higher thermal dissipation as opposed to those created with Teflon-based materials. ***Table 1*** illustrates the power performance of the new power dividers under different matching conditions.

TWO-WAY POWER DIVIDERS

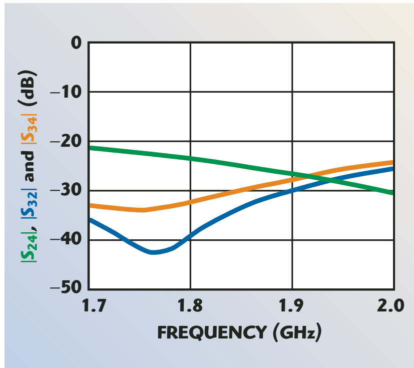
The HybriX® family of the SMT high power dividers is built on alumina, using thick film resistors and advanced screen-printing techniques, allowing better performance and wider applicability. In addition, smaller and more integrated circuits can be realized. These new generations of SMT high power dividers provide very low insertion loss, excellent return loss, very low VSWR, higher thermal dissipation and high power handling capacity up to 50 W. Typical measured S-parameter data for a two-way divider are shown in ***Figures 1*** and ***2***.

THREE-WAY POWER DIVIDERS

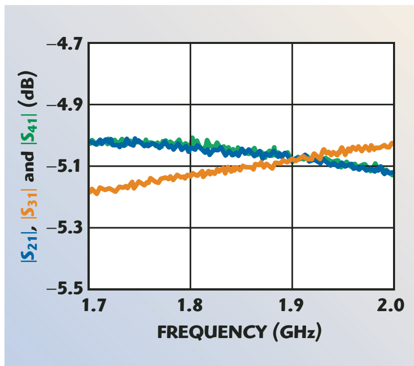
A single-stage three-way device can facilitate the development of power amplifiers with lower loss and more compact layouts. The three-way Wilkinson dividers in this new family



▲ *Fig. 2 VSWR of a two-way power divider.*



▲ *Fig. 3 Isolation of a three-way power divider.*



▲ *Fig. 4 Insertion loss of a three-way power divider, including its test board.*

of products are fabricated as completely planar microstrip structures. Typical measured RF performances for the HybriX three-way power divider, within the frequency range from 1.7 to 2 GHz, are shown in ***Figures 3*** to ***5***. For these measurements, all the devices were operated as power dividers, that is, port 1 was the input and ports 2, 3 and 4 were the outputs. The test fixture dissipation and mismatch losses have not been de-

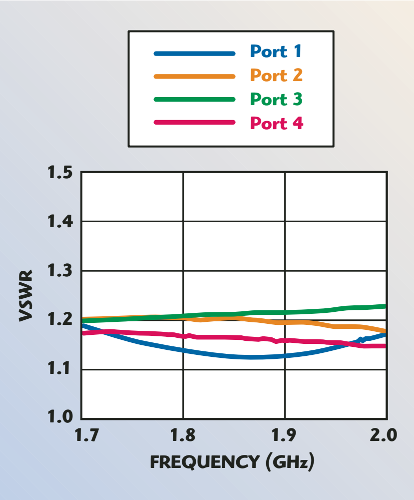


Fig. 5 VSWR of a three-way power divider.

embedded from these measured results. When referenced to 50 Ω, the total loss of the test board is approximately in the range of 0.08 to 0.15 dB.

FOUR-WAY POWER DIVIDERS

The four-way power dividers expand the product line offering and are designed using the same design and process methodology as the three-way dividers described earlier. The RF performances for the four-way, in-phase power dividers are similar to those of the other dividers. To that end, they have a very low insertion loss, excellent isolation, low VSWR, high power rating, excellent thermal dissipation, and very good amplitude and phase balance.

HIGH POWER TESTING

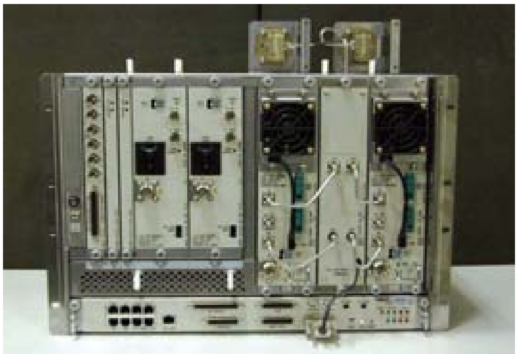
These high power SMT power dividers were tested by Modelithics Inc. to determine their power handling capabilities. The test conditions were as follows: The power divider was tested at increasing discrete power levels, each of 15 minutes duration. The base plate was held at a constant temperature of 85°C during the measurement. The S-parameter measurements were made between every increase in power level. The base temperature was monitored using a temperature probe, and the resistor temperature using an IR camera system. The parts met or exceeded the rated power.

CONCLUSION

Power dividers are commonplace in the RF world. Through the use of new materials and manufacturing processes together with new design techniques, power dividers have been reinvented. The latest generation of SMT high power dividers provides excellent isolation, low VSWR, low insertion loss, excellent return loss, high power rating, and very good amplitude and phase balance. In addition, their smaller size reduces the circuit area, thus allowing design flexibility.

Florida RF Labs/EMC Technology, Stuart, FL (800) 544-5594, www.rflabs.com.

RS No. 303



A COMPACT, COST-EFFECTIVE DIGITAL MICROWAVE RADIO SYSTEM

NEC America's brochure on its ever-growing family of digital microwave radio systems says "good things come in small packages." The NLite™ Lx is the latest addition to its NLite family of digital microwave radio systems and builds on the success of its predecessor, the NLite L. The new Lx version offers a compact, cost-effective digital microwave solution that delivers enhanced transmission capacity, allowing network operators the ability to transmit 3xDS3s plus 8xDS1s in a 30 MHz channel. The 7RU + 2RU WG interface allows up to four HS/HS systems in a single 19-inch rack.

The NLite Lx features a simple and flexible design that is consistent with other NLite series radios. By offering comparable installation guidelines and a similar, compact format, operators familiar with NEC's existing product line can smoothly transition to the new solution when upgrading, as well as save time and money on training costs. NLite Lx takes advantage of NEC's XPIC (cross pole interference cancellation) technology that allows users to expand to twice the current bandwidth capacity on a single microwave frequency pair.

The new radio system has been designed to meet the growing transmission requirements of wireless service providers by featuring a higher 3xDS3s plus 8xDS1s capacity (or SONET OC-3), a high power option of +33.5 dBm and increased reliability, all within a small, flexible format. The new system is initially available in three frequency bands — lower 6 GHz, upper 6 GHz and 11 GHz.

Standard power output for the radio's transmitter is 30.5, 28.5 and 25.5 dBm for the L6, U6 and 11 GHz frequency bands, respectively. A high power option of 33.5 dBm is available for the L6 GHz band. There is 20 dB of power output control per ATPC/MTPC (1 dB steps).

The unit utilizes 128QAM modulation with a channel bandwidth of 30 MHz. The transmit frequency is determined from a synthesized internal oscillator and features a stability of less than ±10 ppm. The receive signal level (RSL) at 10^{-6} is –69 dBm with a system gain

NEC AMERICA INC.
Irving, TX

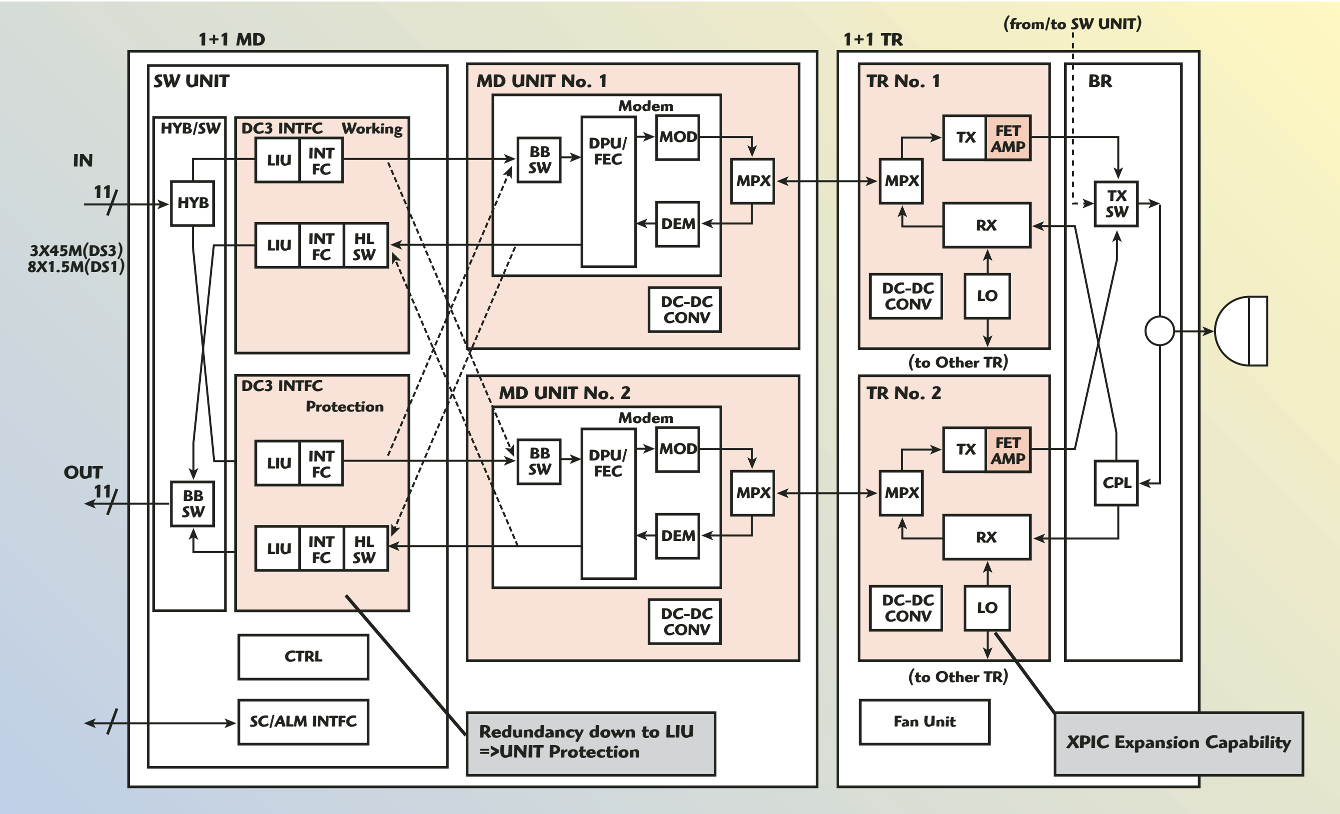


Fig. 1 NLite Lx functional block diagram.

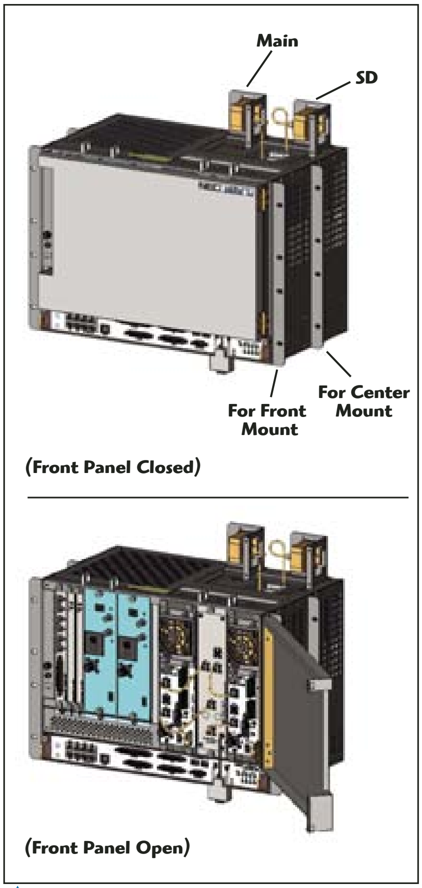


Fig. 2 The L6G/3xDS3 NLite Lx radio system.

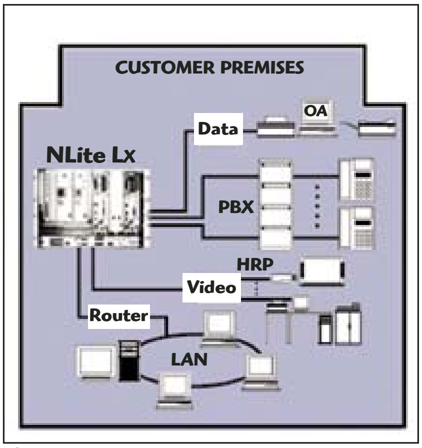


Fig. 3 A typical NLite Lx application.

of 99.5 dB at L6 GHz with standard power. Residual BER is less than 10^{-12}. ***Figure 1*** shows the NLite Lx system's functional block diagram.

The flexible architecture of the NLite Lx allows for split or all indoor configurations. The new microwave system, shown in ***Figure 2***, supports high performance broadband transmission services for interconnections within cellular networks. In addition, the new system features independent private LAN connections between backbone networks and users' premises (see ***Figure 3***).

Similar to other members of the NLite family, the NLite Lx radio system is compliant with SNMP protocol network management and centralized network management, and operates on standard platforms such as Windows NT or UNIX operating systems. Additional products in the NLite family include the NLite L series for small and medium capacity plus an economically friendly footprint, the NLite series for small and medium capacity with T1 plus Ethernet capability, and the NLite 155 series to satisfy medium and large capacity demands. For additional information and the system's full specifications, contact NEC America Inc.

NEC America Inc.,
Irving, TX
(888) NECWAVE (632-9283),
www.necwave.com.

RS No. 304

Spectrum Analyzer

The model N1996A is a compact, high performance spectrum analyzer (CSA) available in 3 and 6 GHz models and designed for use in a wide array of industries. This CSA enables R&D and manufacturing engineers and technicians to make precision RF measurements with speed, ease and confidence. The CSA incorporates a full-featured, general-purpose spectrum analyzer with an internal VSWR bridge and tracking generator. This allows customers to easily and accurately characterize single- and dual-port devices. Price: under $10,000.

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

RS No. 250

RF Connector

The Type N is a medium-sized RF connector used to satisfy larger coaxial cable types. This

durable and weatherproof connector operates in a frequency range from DC to 18 GHz and can withstand shock vibration. Applications include: antennas, aerospace, microwave radio, WLAN, PCS, cellular, radar and surge protection.

Christensen Smith Tran (CST),
Sparks, NV (775) 331-4866,
www.cstcable.com.

RS No. 216

Rotary Joints

The company's range of rotary waveguide joints has been expanded with the addition of a series of L-style models that are particularly suitable for outdoor applications such as SATCOM or military-radar systems. As well as offering IP65 environmental protection, the AM-RJL series rotary joints feature a rugged, lightweight aluminum construction, finished in Alochrom satin black epoxy paint. Covering the frequency range 5.8 to 15 GHz, the L-style joints are available in five different waveguide sizes from WR-137 to WR-62 and can be specified with or without mounting flanges.

Link Microtek Ltd.,
Basingstoke, UK +44 (0) 1256 355771,
www.linkmicrotek.com.

RS No. 217

High Efficiency Antenna

The model RP2-54-N is a broadband high efficiency 2' diameter antenna that was designed

for use in the point-to-point unlicensed 5 GHz WLAN communications band. This model operates in a frequency range from 5.25 to 5.85 GHz and in the licensed Public Safety band from 4.94 to 4.99 GHz. The reflector is precision spun aluminum. The mount includes azimuth/elevation fine adjustment capability and is designed to attach to a range of mast pipe sizes from 1.9" to 4.5" in diameter.

mWAVE Industries LLC,
Gorham, ME (207) 857-3083,
www.mwavellc.com.

Circle No. 218

Parabolic Antennas

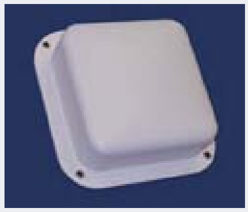
The SPX-3.5NS series of antennas covers a frequency range of 3.3 to 3.6 GHz or 3.5 to 3.8 GHz. Providing coverage down to 3.3 GHz makes these reliable parabolic dishes usable in numerous international bands including China. The standard SPX-3.5NS antennas now cover 3.3 to 3.6 GHz and can be ordered "tuned" to the 3.5 to 3.8 GHz bands when required. These antennas are available in diameters from 2 to 8 feet and accompany a three-year warranty.

Radio Waves Inc.,
N. Billerica, MA (978) 459-8800,
www.radiowavesinc.com.

RS No. 219

Hemi Antenna

This low profile redesigned Hemi antenna offers reliable wide area coverage, both indoors



and outdoors by providing good radiation patterns for areas using either circular or linear polarization. These linearly polarized Hemi antennas operate at 800 and 900 MHz. This antenna features the same coverage pattern associated with the standard hemi, but with linear polarization. These "Hemi" antennas are well suited for indoor use, but because of the radome to back plate weather seal, are very well suited for outdoor applications.

Astron Wireless Technologies Inc.,
Sterling, VA (703) 450-5517,
www.astronwireless.com.

RS No. 254

Advanced Positioner Controller

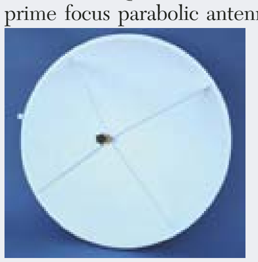
The AL-4806-3C series is a versatile, simple-to-operate positioner controller, offering full control of positioning subsystems in automated antenna measurement systems. It provides fully programmable control of antenna, test and target positioners, and is designed to provide the user with advanced control, while maintaining an intuitive interface for manual operations. Advanced microprocessor architecture assures optimal data throughput for automated data collections. Manual operation is a simple combination of axis selection and a user-adjustable control knob.

Orbit/FR Inc.,
Horsham, PA (215) 674-5100,
www.orbitfr.com.

RS No. 255

Parabolic Antenna

The model QRP-T0024Z01 is a broadband prime focus parabolic antenna. This single an-



tenna covers a frequency range from 18 to 40 GHz with 40 dB nominal gain at center frequency. The maximum VSWR is 1.35. The power handling is 10 W for CW mode with a K-connector and 800 W for CW and 5 kW for peak power with a WRD180c24 connection. This antenna is available with gain options ranging from 30 to 55 dB.

QuinStar Technology Inc.,
Torrance, CA (310) 320-1111,
www.quinstar.com.

RS No. 256

COMPONENTS

Absorptive PIN Diode Switch

The model SW2AD-23 is an absorptive SP2T PIN diode switch. This model provides 55 dB of isolation over the frequency range of 0.3 to 18 GHz with 3.5 dB insertion loss and 1.7 VSWR. The TTL driver is internal and is powered by ±5 V. The housing is 1.35" × 1.75" × 0.5" with SMA female connectors at all ports.

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

RS No. 229

Quick Connect Adapters

These Quick Connect adapters provide efficiency and save time in test and measurement applications by allowing for a complete connection in about one turn of the male coupling nut. The new family of adapters that feature Quick Connect include 7/16 DIN male to type N male, 7/16 DIN male to type N female, SMA male to type N female and SMA male to SMA female. The SMA units operate in the DC to 18 GHz range while the 7/16 DIN units operate from DC to 7.5 GHz. All units feature low VSWR.

Aeroflex/Inmet,
Ann Arbor, MI (734) 426-5553,
www.aeroflex-inmet.com.

RS No. 220

SP2T Reflective Switch

The model SWN-RAYR-2DR is a single-pole, two-throw, reflective switch module with options HPE2W, HS30NS and LVT25MV. It offers a low insertion loss of 1 dB typical, and an integral TTL driver that is designed for ultra low video transient, high power and operates between 600 to 1300 MHz.

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

RS No. 221

Directional Couplers

These directional coupler octave models operate in a 0.5 to 26.5 GHz frequency range. The couplers provide a convenient and accurate means for sampling microwave energy, and are ideally suited for monitoring incident and reflected power. This directional coupler family consists of three-port directional couplers, four-port bi-directional couplers, four-port dual directional couplers, four-port high power directional couplers and four-port directional detectors. All models offer high performance and quick delivery.

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

RS No. 226

E-band Diplexer

The E-band diplexer consists of two waveguide bandpass filters specially designed to pass a relatively wide portion of the spectrum, from 71 to 76 GHz and 81 to 86 GHz. Utilizing the propagation of a specific combination of modes, the diplexer is designed to provide a minimum of 15 dB return loss without any tuning. Waveguide interface flanges are WR-12.

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

RS No. 223

Flexible Cables

The CBL series of rugged, triple-shielded flexible cables is ideal for laboratory and in-field measurement applications requiring low insertion loss from DC to 18 GHz. These cables deliver high performance levels while withstanding 20,000 flexures without any failures. This series is available from stock in a variety of lengths and male connector types, including SMA to SMA, SMA to type N and type N to type N connectors. Price: $69.95 each (1–9). Delivery: available from stock.

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

RS No. 227

Four-channel Switch Bank

The model 4IFA-7000/10000-SR is a four-channel switch bank with channels at 7, 8, 9 and 10 GHz. The bank features 70 dB stopbands and a VSWR of 1.5. Amplitude matching of ±1 dB was specified for each channel. Size: 2.75 × 1.75 × 0.50 package with SMA female connectors.

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

RS No. 225

Threshold Detector/Coupler/Switch

The model TDCS-4T-10F-HP is an integrated threshold detector, 17 dB coupler and SPDT PIN diode switch. This device operates from 9 to 10.5 GHz (other frequency ranges are also available), with an insertion loss of 2 dB maximum, VSWR of 1.5 maximum, 2 W average RF input power handling capability and TTL threshold output. The TDCS-4T-10F-HP is designed to operate in harsh environments with stability over temperature and frequency. Size: 1.5" × 1.2" × 0.40".

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

RS No. 228

Protective Dust Caps

The continuing development of the QN snap-on connectors product range sees the addition of QN protective dust caps in both male and female versions. Both feature an attachment cord to prevent the cap from being lost when not in use. The QN range is available with 50 Ω impedance for frequency ranges up to 11 GHz. Its snap-on coupling mechanism provides a fast, reliable, user friendly, consistent mate.

***Radiall**, **Rosny Sous Bois**,*
Paris, France +33 1 49 35 35 35, www.radiall.com.

RS No. 230

Compact Diplexer

The model 2DP-900/1750-00 is a compact diplexer with minimum passbands of DC to 900 MHz and 1750 to 2300 MHz. Insertion loss measures 0.5 dB in the low band and 0.7 dB in the high band with passband VSWR less than 1.5 across the entire unit. Channel-to-channel isolation is greater than 50 dB, and the return loss is greater than 15 dB in each band.

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

RS No. 231

High Power Circulators/Isolators

The SMC series of surface-mount coplanar circulators and isolators operates from 800 to 2500 MHz. These circulators are designed for high power applications and are distinguished by good high power performance in congested multi-carrier environments. Models are available in typical bandwidths of 10 to 15 percent with isolation > 22 dB and insertion loss < 0.35 dB. Size: 1" square.

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

RS No. 232

No-solder Connector

The model EZ-200-NMH-D (3190-1918) is an improved no-solder EZ crimp connector for LMR-200 and LMR-200-LLPL. This model features a combination hex/knurl coupling nut that allows tightening by hand or with a wrench, and tri-metal plating instead of silver that eliminates tarnishing while providing good electrical performance. This model offers a ridged landing area on the aft end for better grip and sealing of the heat shrink boot to provide improved strain relief and weather sealing, and good VSWR performance to 8 GHz on both LMR-200 and LMR-200-LLPL. Price: $11.80.

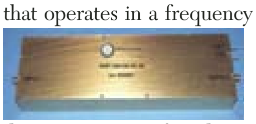
Times Microwave Systems,
Wallingford, CT (203) 949-8400, www.timesmicrowave.com.

RS No. 234

AMPLIFIERS

High Power Amplifier

The model 50AMP10M100-40-36 is a broadband, high power amplifier that operates in a frequency range from 10 to 100 MHz and is designed for defense, wireless and commercial radio applications. This model offers a gain of 40 dB minimum and flatness better than ±2 dB that allows a minimum output power at one dB compression of 36 dBm. This amplifier is supplied with SMA(f) input and output connectors and draws less than 1.2A in DC current from a +15 V supply. Size: < 2.5" × 8" × 1.2". Delivery: available from stock.



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

RS No. 235

Ku-band Power Amplifiers

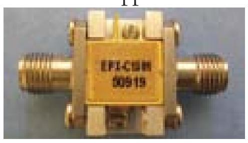
The model MPC4-1220 is a Ku-band power amplifier that offers a multitude of configurations to meet specific needs. The models are defined by the communication bands, have RF power levels of 45, 55 or 65 W, with optional features 04 (L-band block upconverter) and 09 (28 or 48 V DC power supply). This series is ideal for SATCOM systems serving military and commercial airborne and mobile platforms. Key features include: discrete mute control, 115/230 V AC power supply, monitor and control processor, forward and reverse power monitor, and outdoor enclosure with forced air. Size: 10.3" × 8.98" × 10.27". Weight: 23.2 lbs.

Sophia Wireless Inc.,
Chantilly, VA (703) 961-9573, www.sophiawireless.com.

RS No. 240

Modular Amplifiers

The model C1501 and model C1502 are modular amplifiers designed for communications applications such as SATCOM terminals and terrestrial radios. Both models span the 11 to 15 GHz band. The model C1501 offers a minimum gain of 10 dB while the C1502 offers 20 dB gain. Both models offer a typical power output (P1dB) at +11 dBm and typical noise figure of 4 dB. These amplifiers operate from 5 V DC. The C1501 draws a typical 80 mA and the C1502 will draw 150 mA. Price: C1501 – $275.00 and C1502 – $350.00 (100). Delivery: stock to eight weeks.



EPX Microwave Inc.,
San Carlos, CA (408) 313-4913, www.epxmicrowave.com.

RS No. 236

Solid-state Power Amplifier

The S51000 C-band series of solid-state power amplifier modules range from 12 to 200 W of output power. This series features good performance, reliability and cost effectiveness in a slim and compact package.

Locus Microwave Inc.,
State College, PA (814) 861-3200, www.locusmicrowave.com.

RS No. 238

Low Noise Amplifier

The model HMC374 is a surface-mount PHEMT MMIC low noise amplifier (LNA) for fixed wireless, CATV, microwave radio and cellular/3G base station and repeater applications from 0.3 to 3 GHz. This high dynamic range PHEMT MMIC LNA delivers 1.5 dB noise figure, +37 dBm output IP3 and 15 dB small-signal gain at 900 MHz. The +23 dBm saturated output power and the high output intercept point makes the HMC374 also suited for driving the RF port of a high IP3 mixer, and for transmitter pre-driver applications.

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

RS No. 237

E-band Modules

The model SCM-74056020-01 and model SCM-84056020-01 are engineering prototype modules developed for E-band communication link system demonstration. These two modules form a complete link to cover the entire 71 to 76 GHz and 81 to 86 GHz frequency spectrum. The modules implement a high stability free running DRO, active frequency multiplier, bandpass filter, power divider, sub-harmonically pumped mixer and upconverter, low noise amplifier and power amplifier and T/R diplexer. Size: 7" × 11" × 2.5".

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

RS No. 241

DEVICE

PIN Diode

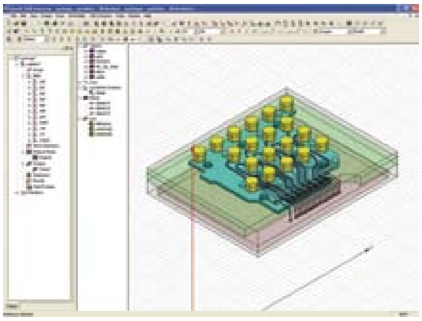
The model MA4PBL027 is an HMIC silicon beam lead PIN diode designed for a variety of wideband and broadband switching applications. The MA4PBL027 diode is fabricated on epitaxial wafers, which are designed to provide highly repeatable electrical characteristics and low parasitics. This diode is fully passivated with silicon dioxide, silicon nitride and a BCB protective polymer. The MA4PBL027 offers low C_t (30 fF), respectable R_s (2.8 V) and small L_s (0.3 nH). Price: $3.75 (10,000).

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

RS No. 242

SOFTWARE

Extraction Tool



The Q3D Extractor™ v7 is the most recent release of the 3D quasi-static electromagnetic parasitic extraction tool. The Q3D Extractor computes 3D RLC/2D RLCG parameters from interconnect structures and automatically generates an equivalent SPICE circuit. This release introduces new features that make it easier and more reliable for engineers to import 3D CAD models and integrated circuit, printed circuit board and package layouts from third-party tools. A new fault-tolerant meshing algorithm has been added to make the meshing process tolerant to anomalies that occur in geometric data from CAD/EDA software programs. The new release also provides automatic and interactive model healing techniques that allow users to detect and repair errors in imported geometry.

Ansoft Corp., Pittsburgh, PA (412) 261-3200, www.ansoft.com.

RS No. 244

SOURCES

Amplified Noise Source

The model NW6G-M is an amplified noise source that features broadband frequency coverage from 10 MHz to 6 GHz. This model is ideal for wireless test applications and covers all major wireless applications. The NW6G-M also features a power out of 0 dBm, flatness of ±2 dB, internal regulation, operates with +15 VDC and draws 200 mA. Size: 4" × 1" × 0.5".

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

RS No. 245

Militarized Rubidium Oscillator

The model 8130A is an off-the-shelf militarized rubidium oscillator that provides good overall performance for numerous tactical applications, and excels particularly for systems requiring good phase noise under vibration. The circuit boards of the 8130A are conformal-coated for moisture resistance, and special precautions are taken for improved shock vibration hardening. Key features include: a modern militarized design, 5 and 10 MHz sinewave outputs, a ruggedized high performance R_b physics package and an internal temperature compensation option. Price: $11,500 USD.

Symmetricom Inc., San Jose, CA (978) 927-8220, www.symmttm.com.

RS No. 246

Voltage-controlled Oscillator

The model V139ME01 is a voltage-controlled oscillator designed for the specialized mobile radio market in the VHF band. This oscillator covers 118 to 160 MHz within 1 to 16 VDC, which greatly reduces the tuning sensitivity. This model exhibits good single-sideband spectral purity of –115 dBc/Hz, typically, at 10 kHz from the carrier and is ready for any outdoor application as it is specified to operate over the temperature range of –35° to 85°C. Size: 0.50" × 0.50" × 0.13". Delivery: stock to four weeks.

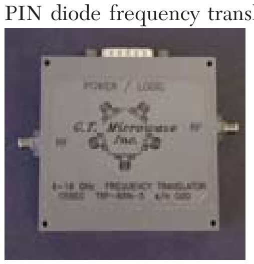
Z-Communications Inc., San Diego, CA (858) 621-2700, www.zcomm.com.

RS No. 247

SUBSYSTEM

Frequency Translator

The model T8P-68N-5 is a digitally controlled PIN diode frequency translator that operates from 6 to 18 GHz. This frequency translator offers 25 dB carrier suppression and 20 dB sideband suppression at a 500 kHz translation rate with 3 dB amplitude variation across the entire band. With less than 12 dB insertion loss and 1.9 VSWR, this frequency translator can handle +15 dBm CW, 1 W maximum RF input power. Size: 3" × 3" × 1".



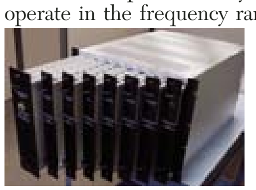
G.T. Microwave Inc., Randolph, NJ (973) 361-5700, www.gtmicrowave.com.

RS No. 248

SYSTEM

Multicoupler Switch System

This multicoupler switch system is designed to operate in the frequency range of 0.1 to 3000 MHz in three bands, having as many at 12 inputs and eight or more outputs. Any input can be switched to any or all of the outputs as selected by the host controller through an RS-232 or an RS-422 in-



terface. The unit has an overall gain of 0 ±3 dB and provides good output-to-output and output-to-input isolation. The unit's high dynamic range provides optimum performance over a wide range of input signal levels.

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

RS No. 249

TEST EQUIPMENT

WLAN Test Set

The MT8860B Wireless LAN test set is designed for radio layer measurements on all 802.11b/g devices. This integrated test set simulates a WLAN Access Point for testing devices under normal operating conditions, eliminating the need for special test mode software. When integrated into a production test system, the MT8860B measures all the key radio parameters including transmitter power, spectral mask and EVM as well as receiver sensitivity. A single test connection is all that is required to perform all measurements, which significantly reduces test times.

Anritsu Ltd., Luton, Bedfordshire, UK +44 (0)1582 433 433, www.anritsu.com.

RS No. 251

Transient Generator System

This TGAR transient generator system is capable of generating custom pulses and can handle a large percentage of existing specs. The complete TGAR system (consisting of the TG6083BU, TG6083PS, TG6083AS and TG6000LD) meets the requirements of ISO 7637-2 (2004) and SAE J1113-11. Features include: base current rating of 83 amps that covers 95 percent of DUT requirements, built-in oscilloscope that allows for easy pulse verification and self-calibration, pulse verification data is included in the DUT test report and LabView-based software, and built-in arbitrary waveform generators allow users to create custom waveforms.

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

RS No. 252

Microwave Journal CALL FOR PAPERS

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

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

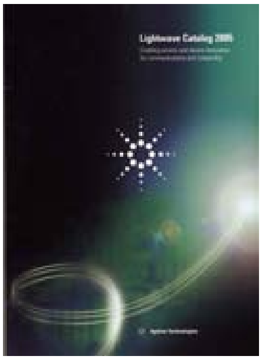
Papers should be submitted to the attention of the Technical Editor and will be reviewed promptly by our Editorial Review Board prior to acceptance. Articles outside of the monthly themes also will be encouraged.

SEND ALL MATERIAL TO:

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

NEW LITERATURE

LIGHTWAVE CATALOG



This test and measurement catalog provides detailed information on the company's solutions for optical, electrical, protocol and service-level testing for the installation and commissioning of broadband and triple-play services and infrastructures; photonic testing of next generation optical devices, digital microwave solutions for high speed communication buses; and backplane and multiservices test solutions for next generation triple-play devices.

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

RS No. 200

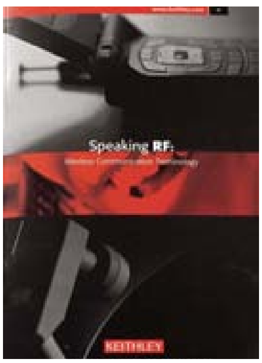
ELECTRO-MECHANICAL SWITCH CATALOG

This catalog presents the company's complete line of electro-mechanical switches with many options to suit any application from DC to 26.5 GHz. Models include single-pole, double-throw; double-pole, three-throw; single-pole, multi-throw; and transfer switches. Options include a wide variety of connectors and actuator voltages.

EPX Microwave Inc., Burlingame, CA (408) 313-4913, www.epxmicrowave.com.

RS No. 201

TERMINOLOGY GUIDE



"Speaking RF: Wireless Communication Terminology" is a 32-page guide that defines a variety of technical terms and decodes the many acronyms in the RF and wireless industry. Several useful tables are featured in the guide, including a quick Watts vs. dBm Conversion table and a Return Loss vs. VSWR table.

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

RS No. 202

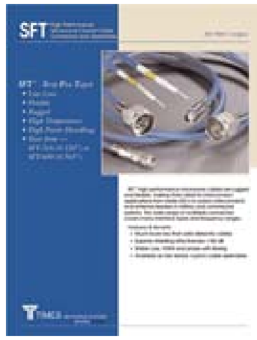
POWER AMPLIFIERS DATA SHEET

This data sheet provides complete detail on the company's 80 to 125 W Ku-band power amplifiers, the MPC8-1220 series. A product photograph, description, performance features, electrical and mechanical specifications, and outline drawings are also provided.

Sophia Wireless Inc., Chantilly, VA (703) 961-9573, www.sophiawireless.com.

RS No. 203

CABLE, CONNECTORS AND ASSEMBLY BROCHURE



This brochure features the company's ruggedized and flexible low loss SFT® coaxial cable assemblies that are ideal for interconnect applications ranging from inside LRUs to demanding military or commercial systems. The broad range of available connectors covers a multitude of interface types and frequency ranges.

Times Microwave Systems, Wallingford, CT (203) 949-8424, www.timesmicrowave.com.

RS No. 204

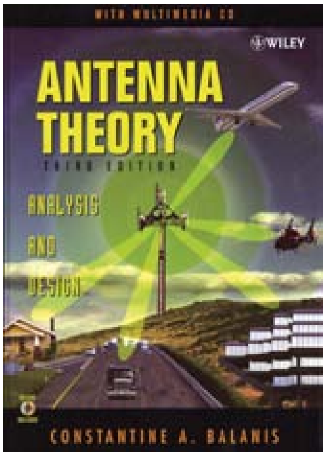
TECHNICAL GUIDE

This brochure, titled "Seven Technical Reasons to Specify Bulk Metal Foil," highlights the features and benefits of ultra-high precision bulk metal foil resistors. The updated brochure includes a new specification for power coefficients of resistance. It also describes a new alloy that improves the existing low temperature coefficient of resistance to almost zero.

Vishay Intertechnology Inc., Malvern, PA (402) 563-6866, www.vishay.com.

RS No. 205

Antenna Theory, Analysis and Design, Third Edition



Constantine A. Balanis
Wiley-Interscience • 1134 pages; $118.95
ISBN: 0-471-66782-X

This book's main objective is to introduce, in a unified manner, the fundamental principles of antenna theory and to apply them to the analysis, design and measurements of antennas. It is designed to meet the needs of electrical engineering and physics students at the senior undergraduate and beginning graduate levels, and those of practicing engineers. The third edition has maintained all of the features of the first two editions, including the three-dimensional graphs to display the radiation characteristics of antennas, especially the amplitude patterns. Many new features have been added to this edition:

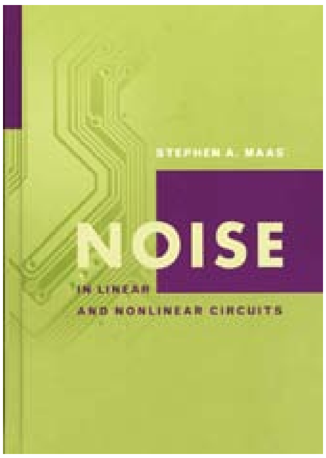
- A new chapter on smart antennas, which is presently a hot topic of current interest to antenna engineers in a number of application areas, especially wireless communications.
- A fractal antenna section, which introduces a new class of antennas that has received a lot of interest and attention after the second edition was published.
- New end-of-chapter tables that provide a summary of important equations in each of the respective chapters.
- Additional new figures, photos and tables to illustrate the concepts.
- Additional end-of-chapter problems.

An important new feature is the multimedia material on the accompanying CD, which presents:

- PowerPoint view graphs of lecture notes.
- End-of-chapter interactive questions for review.
- Animations and applets for most of the chapters based on Java.
- Second-edition Fortran computer programs translated to MATLAB.
- Additional new computer programs based on MATLAB with applications to topics in the various chapters.

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

Noise in Linear and Nonlinear Circuits



Stephen A. Maas
Artech House • 289 pages; $89, £55
ISBN: 1-58053-849-5

The theory of linear circuits has existed for some time but has never been collected into a comprehensive book. Nonlinear noise theory, similarly, has not been well covered in technical books. Collecting this information in one place, and explaining it in a straightforward manner, will be valuable to many people who must deal with these matters daily. This book addresses both broad theoretical and specific technical aspects of noise theory and circuit optimization. It will help professionals to optimize real world circuit performance and show how noise in both linear and nonlinear circuits can be analyzed and minimized. Chapter 1 introduces the concept of noise in communication systems, phase and amplitude noise, linear and nonlinear noise, noise analysis and circuit optimization. Chapter 2 is dedicated to noise and random processes, narrow band random processes, physical sources of noise and cyclostationary noise. Chapter 3 covers noise figure, noise temperature and the system noise model, mixer noise and noise measurement. Noise models of solid-state devices, such as lossy elements, Schottky barrier diodes, JFET and MOSFET, MESFET and HEMT, BIPOLAR and HBT, are described in Chapter 4. The noise theory of linear circuits is the subject of Chapter 5, while the noise theory of nonlinear circuits is treated in Chapter 6. Low noise amplifiers are an obviously important subject and are covered in some detail in Chapter 7. Chapter 8 explains the classical approaches to oscillator theory, nonlinear analysis of oscillators, noise in oscillators and optimization of low noise oscillators. Chapter 9 considers mixers and frequency multipliers, including essential mixer theory, noise in diode mixers, noise in FET resistive mixers, noise in active mixers, system considerations, and diode and active frequency multipliers.

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

Advertising Index

RS No.	Advertiser	Page No.	Phone	Fax	Web Address
1	A.J. Tuck Company	130	203-775-1234	203-775-4705	http://mwj.ims.ca/7955-1
2	AA MCS	171	+33(0)8 11 09 76 76	+33(0)1 76 91 50 31	http://mwj.ims.ca/7955-2
3	Advanced Switch Technology	187	613-384-3939	613-384-5026	http://mwj.ims.ca/7955-3
4	Advanced Technical Ceramics Company	114	423-755-5400	423-755-5438	http://mwj.ims.ca/7955-4
5	Aeroflex	9	516-694-6700	516-694-2562	http://mwj.ims.ca/7955-5
6	Aeroflex Plainview	157	800-645-8862		http://mwj.ims.ca/7955-6
7	Aeroflex/KDI-Integrated Products	133	973-887-8100 ext. 500	973-884-0445	http://mwj.ims.ca/7955-7
8	Aeroflex/Weinschel, Inc.	113	800-638-2048	301-846-9116	http://mwj.ims.ca/7955-8
	Agilent Technologies, Inc.	43	800-829-4444	415-857-5518	www.agilent.com/find/eesof-innovations
9,10	American Technical Ceramics	14,88	631-622-4700	631-622-4748	http://mwj.ims.ca/7955-9
11	AML Communications Inc.	37	805-388-1345	805-484-2191	http://mwj.ims.ca/7955-11
12	Anatech Electronics, Inc.	86	973-772-4242	973-772-4646	http://mwj.ims.ca/7955-12
13	Anritsu Company	125	800-ANRITSU	972-671-1877	http://mwj.ims.ca/7955-13
14	Ansoft Corporation	129	412-261-3200	412-471-9427	http://mwj.ims.ca/7955-14
15	Applied Computational Sciences	84			http://mwj.ims.ca/7955-15
16	Applied Wave Research, Inc.	11	310-726-3000		http://mwj.ims.ca/7955-16
17	AR Worldwide	91	215-723-8181	215-723-5688	http://mwj.ims.ca/7955-17
18	Astrolab, Inc.	53	732-560-3800	732-560-9570	http://mwj.ims.ca/7955-18
19	ATK Mission Research	56	937-490-4106		http://mwj.ims.ca/7955-19
20	BeckElec, Inc.	130	623-435-6555	623-435-0013	http://mwj.ims.ca/7955-20
21	Boonton Electronics (a Wireless Telecom Group Company)	COV 2	973-386-9696	973-386-9191	http://mwj.ims.ca/7955-21
22	Cernex, Inc.	78	408-541-9226	408-541-9229	http://mwj.ims.ca/7955-22
23	Channel Microwave Corporation	20	805-482-7280	805-987-8794	http://mwj.ims.ca/7955-23
24	Chelton Microwave Sensor & Antenna Systems	21	603-775-5200	603-775-5201	http://mwj.ims.ca/7955-24
25	Ciao Wireless, Inc.	50	805-389-3224	805-389-3629	http://mwj.ims.ca/7955-25
26	Coilcraft	16	800-322-2645	847-639-1469	http://mwj.ims.ca/7955-26
27	Colby Instruments	134	425-452-8889	425-452-8802	http://mwj.ims.ca/7955-27
28	COM DEV Saw Products	36	647-887-SAWS	519-622-1691	http://mwj.ims.ca/7955-28
29	Commercial Microwave Technology, Inc.	82	916-631-4363	530-642-9798	http://mwj.ims.ca/7955-29
30	Comtech PST Corp.	159	631-777-8900	631-777-8877	http://mwj.ims.ca/7955-30
31	CPI Beverly Microwave Division	19	978-922-6000	978-922-2736	http://mwj.ims.ca/7955-31
32	CSIRO – ICT Centre	184	+61 1300 301 509		http://mwj.ims.ca/7955-32
33	CST of America, Inc.	31	781-416-2782	781-576-5702	http://mwj.ims.ca/7955-33
34	CTT Inc.	71	408-541-0596	408-541-0794	http://mwj.ims.ca/7955-34
35	Daico Industries, Inc.	47	310-507-3242	310-507-5701	http://mwj.ims.ca/7955-35
36	dBm, LLC	46	973-709-0020	973-709-1346	http://mwj.ims.ca/7955-36
37	Deutsch Bus & Microwave	100	+33 (0)2 32 23 58 83	+33 (0)2 32 23 58 61	http://mwj.ims.ca/7955-37
38	EADS AG	111			http://mwj.ims.ca/7955-38
39	Eastern Wireless TeleComm, Inc.	40	410-749-3800	410-749-4852	http://mwj.ims.ca/7955-39
40	Elisra Electronic Systems Ltd. (Microwave Division)	35	972(3)617-5655	972(3)617-5299	http://mwj.ims.ca/7955-40
41	EM Research, Inc.	83	775-345-2411	775-345-1030	http://mwj.ims.ca/7955-41
42	Emhiser Micro-Tech	38	775-345-0461	775-345-1152	http://mwj.ims.ca/7955-42
43	Empower RF Systems, Inc.	143	310-412-8100	310-412-9232	http://mwj.ims.ca/7955-43
44	Endwave Defense Systems	27	408-522-3180	408-522-3181	http://mwj.ims.ca/7955-44
45	ET Industries	152	973-394-1719	973-394-1710	http://mwj.ims.ca/7955-45
47	EuMW 2006	167	+ 44 20 7596 8742	+ 44 20 7596 8749	http://mwj.ims.ca/7955-47
48	Evans Capacitor Company	26	401-435-3555	401-435-3558	http://mwj.ims.ca/7955-48
49	Feko	104	+27 21 880 1880		http://mwj.ims.ca/7955-49
50	Florida RF Labs Inc.	17	800-544-5594		http://mwj.ims.ca/7955-50
51	Freescale Semiconductor, Inc.	41			http://mwj.ims.ca/7955-51
52	G.T. Microwave Inc.	42	973-361-5700	973-361-5722	http://mwj.ims.ca/7955-52
53	Herley Industries, Inc.	92	631-630-2000	631-630-2066	http://mwj.ims.ca/7955-53
54	Herotek, Inc.	147	408-941-8399	408-941-8388	http://mwj.ims.ca/7955-54
55,56,57, 58,59,60	Hittite Microwave Corporation	72–73,75,77, 79,81,185	978-250-3343	978-250-3373	http://mwj.ims.ca/7955-55
	IEEE ICUWB 2006	177			
	IEEE MTT-S International Microwave Symposium	191,197	781-769-9750	781-769-5037	www.ims2006.org
61	Integra Technologies, Inc.	32	310-606-0855	310-606-0865	http://mwj.ims.ca/7955-61
62	Integrated Engineering Software	128	204-632-5636		http://mwj.ims.ca/7955-62

RS No.	Advertiser	Page No.	Phone	Fax	Web Address
63	Interad Ltd.	162	757-787-7610	757-787-7740	http://mwj.ims.ca/7955-63
64	Isola Corp.	115	800-845-2904		http://mwj.ims.ca/7955-64
65,66,67	J microTechnology	187	503-614-9509	503-531-9325	http://mwj.ims.ca/7955-65
68	KOR Electronics	137	714-898-8200	714-895-7526	http://mwj.ims.ca/7955-68
69	L-3 Randtron	39	650-326-4500		http://mwj.ims.ca/7955-69
70	Logus Microwave Corporation	139	561-842-3550	561-842-2196	http://mwj.ims.ca/7955-70
71	Lorch Microwave	69	800-780-2169	410-860-1949	http://mwj.ims.ca/7955-71
72	M/A-COM, Inc.	119	800-366-2266	978-442-5350	http://mwj.ims.ca/7955-72
73	M2 Global Technology, Ltd.	76	210-561-4800	210-561-4852	http://mwj.ims.ca/7955-73
74	Maury Microwave Corporation	6	909-987-4715	909-987-1112	http://mwj.ims.ca/7955-74
75	MECA Electronics Inc.	96	973-625-0661	973-625-9277	http://mwj.ims.ca/7955-75
76	MicroMetrics Inc.	141	603-641-3800	603-641-3500	http://mwj.ims.ca/7955-76
77	Micronetics	60	603-579-0900	603-882-8987	http://mwj.ims.ca/7955-77
78	Microsemi Corporation	117	949-221-7112	949-756-0308	http://mwj.ims.ca/7955-78
79	Microwave Development Laboratories	135	781-292-6680/6684	781-453-8629	http://mwj.ims.ca/7955-79
	Microwave Journal	140,188–189,190	800-225-9977	781-769-5037	www.mwjournal.com
81	Mimix Broadband, Inc.	109	281-988-4600	281-988-4615	http://mwj.ims.ca/7955-81
82,83,84, 85,86,87, 88,89,90, 91,92,93	Mini-Circuits	4–5,15,18, 45,57,58, 85,106–107,127, 175,183,195	718-934-4500	718-332-4661	http://mwj.ims.ca/7955-82
94,95	MITEQ Inc.	3,62–63	631-436-7400	631-436-7430	http://mwj.ims.ca/7955-94
96	Modelithics, Inc.	154	888-359-6359	813-558-1102	http://mwj.ims.ca/7955-96
97	Modular Components National, Inc.	118	410-879-6553	410-638-7356	http://mwj.ims.ca/7955-97
98	Molex	145	317-834-5600	317-834-5611	http://mwj.ims.ca/7955-98
99	MTI Wireless Edge	68	+972-3-9025050	+972-3-9025051	http://mwj.ims.ca/7955-99
100	Narda Microwave-East, an L3 Communications Co.	121	631-231-1700	631-231-1711	http://mwj.ims.ca/7955-100
101	Nexyn Corporation	80	408-982-9339	408-982-9275	http://mwj.ims.ca/7955-101
102	Noble Publishing Corporation	187	800-247-6553	770-448-2839	http://mwj.ims.ca/7955-102
103	NoiseWave Corp.	8	973-386-1119	973-386-1131	http://mwj.ims.ca/7955-103
104	OML Inc.	151	408-779-2698	408-778-0491	http://mwj.ims.ca/7955-104
105	Peak Devices, Inc.	87	978-422-7641	978-422-0011	http://mwj.ims.ca/7955-105
106	Picosecond Pulse Labs Inc.	105	303-209-8100	303-447-2236	http://mwj.ims.ca/7955-106
107	Prewell Corporation	112	82-31-420-8362	82-31-420-8301	http://mwj.ims.ca/7955-107
108	Pulsar Microwave Corporation	172	800-752-3043	973-779-2727	http://mwj.ims.ca/7955-108
109	Radio Research Instrument Co., Inc.	148	203-753-5840	203-754-2567	http://mwj.ims.ca/7955-109
110,111	Reactel, Incorporated	131,184	301-519-3660	301-519-2447	http://mwj.ims.ca/7955-110
112	Remcom	103	814-861-1299	814-353-1420	http://mwj.ims.ca/7955-112
113	REMEC Defense & Space	28	858-560-1301		http://mwj.ims.ca/7955-113
114	RF & Hyper Europe 2006	193	33 (0)1 49 68 51 00	33 (0)1 44 78 99 49	http://mwj.ims.ca/7955-114
115	RF Micro Devices	22–23	336-678-5570	336-931-7454	http://mwj.ims.ca/7955-115
116	RFHIC	136	82-31-250-5011	82-31-250-5089	http://mwj.ims.ca/7955-116
117	RLC Electronics, Inc.	25	914-241-1334	914-241-1753	http://mwj.ims.ca/7955-117
118	Rodelco Electronics Corp.	33	631-981-0900	631-981-1792	http://mwj.ims.ca/7955-118
119	Rogers Corporation	101	480-961-1382	480-961-4533	http://mwj.ims.ca/7955-119
120	Rohde & Schwarz GmbH	67	+49-1805-124242	+49-89-412913777	http://mwj.ims.ca/7955-120
121	Rosenberger	70	+49-8684-18-0	+49-8684-18-499	http://mwj.ims.ca/7955-121
122	Sarnoff Corporation	116	609-734-2553		http://mwj.ims.ca/7955-122
123	Sawtek, a TriQuint Company	48–49	407-886-8860	407-886-7061	http://mwj.ims.ca/7955-123
124	Sector Microwave Industries, Inc.	187	631-242-2300	631-242-8158	http://mwj.ims.ca/7955-124
125	Skyworks Solutions, Inc.	61	781-376-3000		http://mwj.ims.ca/7955-125
46	Schmid & Partner Engineering AG	155			http://mwj.ims.ca/7955-46
126	Sonnet Software, Inc.	COV 3	315-453-3096	315-451-1694	http://mwj.ims.ca/7955-126
127	Sophia Wireless Inc.	102	703-961-9573	703-961-9576	http://mwj.ims.ca/7955-127
128	Spacek Labs	120	805-564-4404	805-966-3249	http://mwj.ims.ca/7955-128
129	Spectrum Elektrotechnik GmbH	97	+49-89-3548-040	+49-89-3548-0490	http://mwj.ims.ca/7955-129
130	Spinner GmbH	153	+49 89 12601-257	+49 89 12601-287	http://mwj.ims.ca/7955-130
131	Stealth Microwave, Inc.	94	888-772-7791	609-538-8587	http://mwj.ims.ca/7955-131
132	Storm Products Company	99	630-754-3300	630-754-3500	http://mwj.ims.ca/7955-132
133	Swift & Associates	161	818-989-1133	818-989-4784	http://mwj.ims.ca/7955-133
134	Symmetricom	98	978-232-1497		http://mwj.ims.ca/7955-134
135,136,137	Synergy Microwave Corporation	65,149,173	973-881-8800	973-881-8361	http://mwj.ims.ca/7955-135

ADVERTISING INDEX

RS No.	Advertiser	Page No.	Phone	Fax	Web Address
138	Tektronix, Inc.	89	800-426-2200		http://mwj.ims.ca/7955-138
139	Teledyne Cougar	54	408-522-3838	408-522-3839	http://mwj.ims.ca/7955-139
140	Tensolite	13	866-282-4708	562-494-0955	http://mwj.ims.ca/7955-140
141	Tiger Microwave Corporation	156	+86-28-66070208	+86-28-66070496	http://mwj.ims.ca/7955-141
142	Trilithic Inc.	52	800-344-2412	317-895-3612	http://mwj.ims.ca/7955-142
123	TriQuint Semiconductor, Inc.	48–49	503-615-9000	503-615-8900	http://mwj.ims.ca/7955-123
143	TTE Inc.	162	310-478-8224	310-445-2791	http://mwj.ims.ca/7955-143
144	Universal Microwave Components Corporation	148	703-642-6332	703-642-2568	http://mwj.ims.ca/7955-144
145	Universal Microwave Technology, Inc.	138	+886-2-2698-9969	+886-2-2698-9968	http://mwj.ims.ca/7955-145
146	UTE Microwave Inc.	123	732-922-1009	732-922-1848	http://mwj.ims.ca/7955-146
147	Vectron International	7	1-88-VECTRON1	888-FAX-VECTRON	http://mwj.ims.ca/7955-147
148	Waveline Inc.	146	973-226-9100	973-226-1565	http://mwj.ims.ca/7955-148
149	Weinschel Associates	110	877-948-8342	301-963-8640	http://mwj.ims.ca/7955-149
150	Werlatone, Inc.	COV 4	845-279-6187	845-279-7404	http://mwj.ims.ca/7955-150
151	Win Semiconductors Corp.	95	310-530-8485	310-530-8499	http://mwj.ims.ca/7955-151
152	Winchester Electronics	30	203-741-5400	203-741-5500	http://mwj.ims.ca/7955-152
153	WJ Communications Inc.	29	800-WJ1-4401	408-577-6621	http://mwj.ims.ca/7955-153
154	Z-Communications, Inc.	93	858-621-2700	858-621-2722	http://mwj.ims.ca/7955-154
155	Zeland Software, Inc.	169	510-623-7162	510-623-7135	http://mwj.ims.ca/7955-155

Visit Microwave Journal *on the Web at* **www.mwjournal.com**

Visit mwjournal.com/info and enter RS# to request information from our advertisers

Microwave Journal

FEBRUARY 2006 ISSUE

What's Hot with RF Components and Systems

UWB Low Loss Bandpass Filter

Salvan: Cradle of Wireless

SALES REPRESENTATIVES

microwave journal

CARL SHEFFRES, PUBLISHER **ED JOHNSON, ASSOCIATE PUBLISHER** **KEN HERNANDEZ, TRAFFIC ADMINISTRATOR**

Eastern and Central Time Zones
Chuck Curley
Eastern Reg. Sales Mgr.
685 Canton Street
Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
ccurley@mwjournal.com

Michael Hallman
Eastern Reg. Sales Mgr.
4 Valley View Court
Middletown, MD 21769
Tel: (301) 371-8830
FAX: (301) 371-8832
mhallman@mwjournal.com

Eastern and Central Time Zones
Ed Johnson
Associate Publisher
PO Box 5962
Ocala, FL 34478-5962
Tel: (352) 620-2442
FAX: (352) 620-2443
ejohnson@mwjournal.com

Pacific and Mountain Time Zones
Wynn Cook
Western Reg. Sales Mgr.
PO Box 23200
San Jose, CA 95153
Tel: (408) 224-9060
FAX: (408) 224-6106
wcook@mwjournal.com

International Sales
Richard Vaughan
International Sales Manager
Tel: +44 207 596 8742
rvaughan@horizonhouse.co.uk

Michel Zoghob
Deputy Publisher
Tel: +44 207 596 8741
mzoghob@horizonhouse.co.uk

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

Germany, Austria, and Switzerland (German-speaking)
Juergen Wissling
Wissling Marketing Services
Riedstrasse 5
72813 St. Johann-Wuertingen
Germany
Tel: +49 7122 828140
FAX: +49 7122 828145
jwissling@horizonhouse.com

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

Korea
Young-Seoh Chinn
JES Media International
2nd Floor, ANA Bldg.
257-1, Myungil-Dong
Kangdong-Gu
Seoul, 134-070 Korea
Tel: +82 2 481-3411
FAX: +82 2 481-3414
yschinn@horizonhouse.com

Singapore
Hoong-Mun Koo
Publicitas
02-01 Wellington Bldg.
20 Bideford Road
Singapore 229921
Tel: +65 6836 2272
FAX: +65 6735 9653