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August 2007

Microwave Journal

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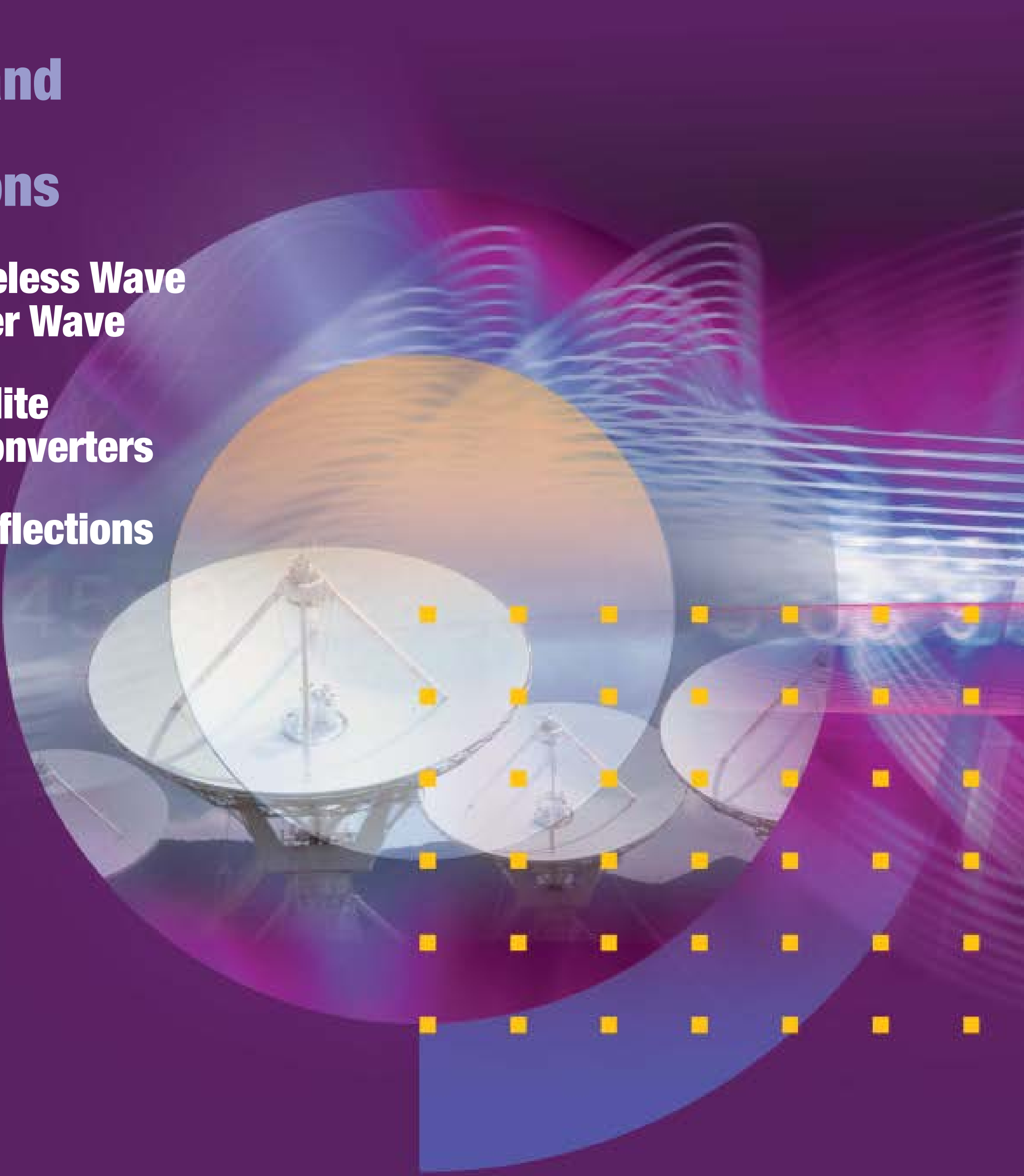
Satellite and mm-wave Applications

The Next Wireless Wave is a Millimeter Wave

Testing Satellite Frequency Converters

IMS 2007: Reflections from Hawaii



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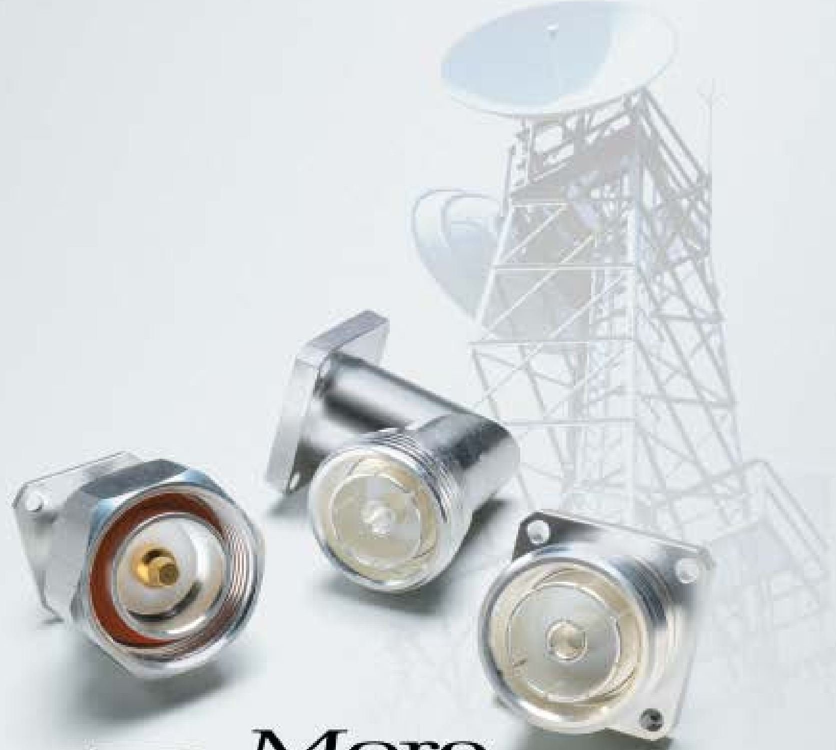

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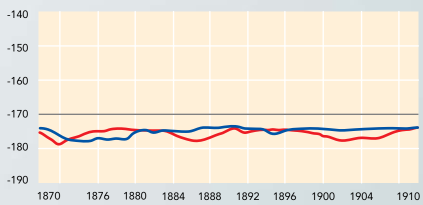

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Flomerics Inc.

Design of an antenna for military applications in the 5 to 6 GHz region requiring an omnidirectional azimuth pattern and a relatively narrow beam in elevation.

Composite Low Pass Filter Design with T and π Network on Microstrip Line

Z.D. Tan, J.S. Mandeep, S.I.S. Hassan and M.F. Ain
School of Electrical and Electronic Engineering, Universiti Sains Malaysia

Description of a planar composite low pass filter implemented in microstrip line designed by the image parameter method.

Microwave Journal Buyer's Guide

Product Focus: Satellite and mm-wave Applications

In conjunction with this month's editorial theme, we've compiled a complete listing of satellite and mm-wave application products currently featured in our on-line Buyer's Guide. The *Microwave Journal* on-line Buyer's Guide is the RF/microwave engineers' complete source for products and services featuring over 1000 companies.

How it works: Harlan has selected one question from his "Ask Harlan" column to be featured in the magazine. Please visit www.mwjournal.com/askharlan to provide an answer to this month's featured question (see below). Harlan will be monitoring the responses and will ultimately choose the best answer to the question. Although all of the responses to the featured question will be posted on our web site, we plan to publish the winning answer in the October issue. All responses must be submitted by **September 6, 2007**, to be eligible for the participation of the August question.

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

June Question and Winning Response

The June question was submitted by Eric Hakanson from Anritsu Co.:

Dear Harlan,

In your opinion, what's missing from today's microwave spectrum analyzers? What could be done that people would value significantly more than what is currently available?

There are two winning responses to the June question.
The first is from Peter Militch of Honeywell:

Modern analyzers are marvels of efficiency, accuracy and fidelity. I hesitate to complain, but since you asked… It is often necessary to measure signals that are sweeping. While it is possible to add tracking generator functions to typical analyzers, this is complicated and expensive. So if I could have asked for one feature, it would be a simple AFC tracking loop. You would configure the analyzer by specifying the approximate sweep rate and sweep range of the signal under observation (these values would generally not be the same as the current sweep range setting of the analyzer since the user may wish to observe just a portion of the spectrum in use) and then it would have to be smart enough to capture, track and display the signal. Even if only capable of tracking an unmodulated carrier, this would be a nice feature to have.

The second is from Charles Dorcey of the Department of Defense:

I would like to see "way more memory." While I am not familiar with Anritsu's specific products, I doubt that they have considered what could be done by adding vastly more memory to a spectrum analyzer. For example, suppose I want to track down a source of radio interference. As I rotate my antenna, I would like to see a raster display (power->color, with time on the vertical axis and frequency on the horizontal) so I can easily view the evolution of the spectrum as a function of angle. I am thinking a hundred or a thousand individual spectrum scans available at a time. And, because I do not want to type a label on each spectrum, allow voice annotation to measurements. I might try making a number of adjustments to equipment, and I do not want to take time to jot each one down in a notebook (especially if I am up on a tower), but after I have explored the options, I would like to roll back through the experiment and hear what I was doing at each step. A headset mic would provide good SNR, hands-free.

This Month's Question of the Month

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

Majid Ostadrahimi from the University of Manitoba has submitted this month's question:

Dear Harlan,

I am interested in measuring the reflected wave from an antenna, which is excited by the time domain impulse. Would it be possible to give me your suggestion? Should I use a wideband circulator? Generally, if we want to excite and measure antennas in the time domain, what can we do?

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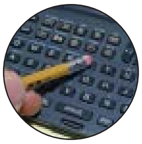

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AUGUST

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August 20–24, 2007 • Niigata, Japan
www.isap07.org

SEPTEMBER

IEEE INTERNATIONAL CONFERENCE ON ULTRA-WIDEBAND (ICUWB 2007)
September 24–26, 2007 • Singapore
www.icuwb2007.org

ANTENNA SYSTEMS AND SHORT-RANGE WIRELESS 2007
September 26–27, 2007 • Denver, CO
www.antennasonline.com

OCTOBER

COMSOL CONFERENCE 2007
October 4–6, 2007 • Newton, MA
http://comsol.com/conference2007

EUROPEAN MICROWAVE WEEK (EuMW 2007)
October 8–12, 2007 • Munich, Germany
www.eumweek.com

AOC INTERNATIONAL SYMPOSIUM AND CONVENTION
October 28–31, 2007 • Orlando, FL
www.crows.org

MILITARY COMMUNICATIONS CONFERENCE (MILCOM 2007)
October 29–31, 2007 • Orlando, FL
www.milcom.org

NOVEMBER

ANTENNA MEASUREMENT TECHNIQUES ASSOCIATION (AMTA 2007)
November 4–9, 2007 • St. Louis, MO
www.amta2007.com

2ND EUROPEAN CONFERENCE ON ANTENNAS AND PROPAGATION (EuCAP 2007)
November 11–16, 2007 • Edinburgh, UK
www.eucap2007.org

ARFTG 70TH MICROWAVE MEASUREMENT SYMPOSIUM
November 27–30, 2007 • Tempe, AZ
www.arftg.org

DECEMBER

ASIA-PACIFIC MICROWAVE CONFERENCE (APMC 2007)
December 11–14, 2007 • Bangkok, Thailand
www.apmc2007.org

JANUARY

IEEE RADIO AND WIRELESS SYMPOSIUM (INCORPORATING WAMICON)
January 22–24, 2008 • Orlando, FL
www.radiowireless.org

FEBRUARY

SATELLITE 2008 CONFERENCE AND EXHIBITION
February 25–28, 2008
Washington, DC
www.satellite2008.com

JUNE

IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM AND EXHIBITION (IMS 2008)
June 15–20, 2008
Atlanta, GA
www.ims2008.org

Workshops & Courses

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■ **Site:** Lake Tegernsee, Germany
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■ **Contact:** CST-Computer Simulation Technology +49 6151 7303-0 or e-mail: info@cst.com.

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■ **Site:** Aurora, IL
■ **Dates:** September 26–28, 2007
■ **Contact:** For more information, visit www.vectorfields.com.

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

■ **Topics:** This course presents the state-of-the-art in antenna measurements, including far-field, anechoic chamber, compact and near-field measurements. The course also includes range evaluation, compensation techniques and microwave holography. For more information, visit www.pe.gatech.edu.
■ **Site:** Atlanta, GA
■ **Dates:** October 22–26, 2007
■ **Contact:** Georgia Institute of Technology, Professional Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3500.

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■ **Dates:** For date information, please visit url.
■ **Contact:** Fairchild Semiconductor Corp., 82 Running Hill Road, South Portland, ME 04106 (207) 775-8100, www.fairchildsemi.com.

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■ **Dates:** Archived on-line for anytime viewing.
■ **Contact:** University of Illinois at Urbana-Champaign, 117 Transportation Bldg., 104 S. Mathews Avenue, Urbana, IL 61801 (217) 333-0897 or e-mail: deg@uiuc.edu.

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■ **Site:** For location information, please visit url.
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■ **Contact:** University of Wisconsin, Department of Engineering Professional Development, 432 North Lake Street, Madison, WI 53706 (800) 462-0876.

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Description	Frequency Range (GHz)	P1dB (Psat) / OIP3 (dBm)	Gain (dB)	NF / PAE (dB) (%)	Voltage / Current (V / mA)	Package Style	Part Number
HPA	7 - 8.5	(38) / –	21	– / 42	7 / 2000	Die	TGA2701
Driver Amp, SB	11 - 17	17 / –	23	6 / –	6 / 75	SM-06-12	TGA2507-SM
HPA	12 - 19	29 / –	25	–	5 - 7 / 435	SM-06-12	TGA2508-SM
2W HPA	12.5 - 16	(32) / 37	32	–	6 - 7 / 680	SM-01-24	TGA2503-SM
2W HPA	12.5 - 17	(33.5) / –	25	– / 25	7.5 / 650	SG-A1-6	TGA2510-EPU-SG
4W HPA	13 - 15	(36) / 41	25	–	7 / 1300	FL-A1-10	TGA8659-FL
6.5W HPA	13 - 16	(38) / –	24	–	8 / 2600	FL-A2-10	TGA2514-FL
2W HPA, PD	13 - 17	(34) / 38.5	26	– / 30	7.5 / 650	SG-A1-6	TGA2902-1-SCC-SG
2W HPA	13 - 17	(34) / 40	33	–	5 - 8 / 680	SG-A1-6	TGA8658-EPU-SG
K Brand HPA	17 - 20	30 (32) / (42)	20	–	7 / 825	Die	TGA4530
Driver Amp	17 - 24	22 / –	19	4 / –	5 / 270	SM-09-16	*TGA2521-SM**
HPA, AGC, PD	17 - 24	(29) / 38	22	–	5 / 712	SM-010-20	*TGA2522-SM**
HPA	17 - 27	29 (31) / 37	22	–	7 / 760	Die	TGA4502-SCC
Gain Block & 2x/3x Multi	17 - 40	18 (22) / 24	22	7 / –	5 / 140	SM-A3-16	*TGA4031-SM**
HPA	25 - 31	35.5 (36) / –	22	–	6 / 2100	CP-A1-8	TGA4905-CP
MPA	25 - 35	25 / –	18	–	6 / 220	SM-A4-20	TGA4902-SM
7W HPA	26 - 31	(38.5) / –	22	–	6 / 4200	CP-A3-8	TGA4915-EPU-CP
2W HPA	27 - 31	32.5 (33) / –	22	–	6 / 840	CP-A2-8	TGA4513-CP
1W HPA	28 - 31	30 / –	19	– / 25	6 / 420	SM-A4-20	TGA4509-SM
4W HPA	28 - 31	36 (36.5) / –	22	– / 22	6 / 1600	Die	*TGA4906**
7W HPA	29- 31	(38.5) / –	22	– / 20	6 / 3200	Die	*TGA4916**
Driver Amp	29 - 31	16 (17) / 22	15	–	6 / 1960	SM-A4-20	TGA4510-SM
MPA	33 - 47	27 (27.5) / 36	18	–	6 / 400	Die	TGA4522
HPA	36 - 40	30 / –	14	–	6 - 7 / 500	Die	TGA1171-SCC

NOTES: * = New, SB = Self Biased, PD = Power Detector

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COVER FEATURE
INVITED PAPER

THE NEXT WIRELESS WAVE IS A MILLIMETER WAVE

The past few years has witnessed the emergence of CMOS-based circuits operating at millimeter-wave frequencies. Integrated on a low cost organic packaging, this is the promise for high volume fabrication, lowering the cost and opening huge commercial impact opportunities. As standardization efforts catalyze the interest and investment of the industry, one can count on the spreading of millimeter-wave technology in the consumer electronic market place in the near future.

In the past few years, the interest in the millimeter-wave spectrum at 30 to 300 GHz has drastically increased. The emergence of low cost high performance CMOS technology and low loss, low cost organic packaging material has opened a new perspective for system designers and service providers because it enables the development of millimeter-wave radio at the same cost structure of radios operating in the gigahertz range or less.

In combination with available ultra-wide bandwidths, this makes the millimeter-wave spectrum more attractive than ever before for supporting a new class of systems and applications ranging from ultra-high speed data transmission, video distribution, portable radar, sensing, detection and imaging of all kinds.

While at a lower frequency the signal can propagate easily for dozens of kilometers, penetrate through construction materials or benefit from advantageous reflection and refraction properties, one must consider carefully the characteristics (in particular strong attenuation and weak diffraction) of the millimeter-wave propagation, and exploit them advantageously. The free-space loss (FSL) (after converting to units of frequency and putting them in decibel form) between two isotropic antennas can be expressed as[1]

$$\mathrm{FSL} = 92.4 + 20 \log F + 20 \log D$$

where

F = frequency in gigahertz and
D = line-of-sight distance in kilometers

As an example, at 60 GHz the free-space loss is much more severe than at the frequencies usually used for cell phone and wireless applications. The link budget at 60 GHz is 21 dB

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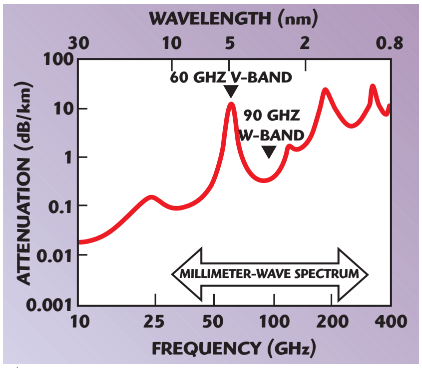

Fig. 1 *Average atmospheric gaseous attenuation of millimeter-wave propagation at sea level.*

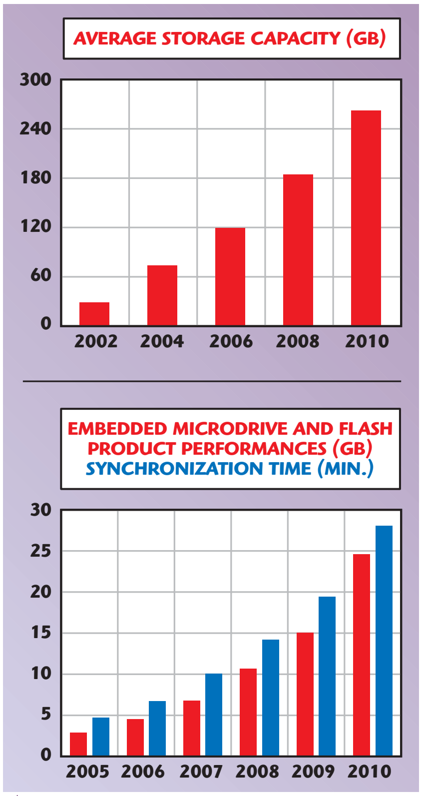

Fig. 2 *Average storage capacity trends.*

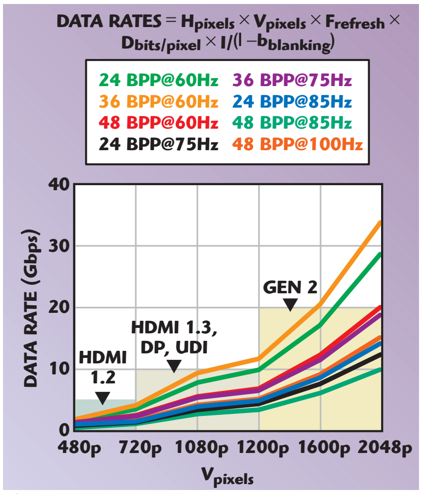

Fig. 3 *Uncompressed video data rates.*

less than the one at 5 GHz under equal conditions.[2] In addition, other loss and fading factors increasingly affect the millimeter-wave transmission, such as gaseous (see ***Figure 1***), rain, foliage, scattering and diffraction losses.

Beside the huge and unexploited bandwidth availability and the perspective of multi-gigabit to terabit networks, the potential of the millimeter-wave spectrum has many others attributes: enabling densely packed communication link networks, from very short range to medium range; leveraging frequency reuse to its paroxysm while increasing the security level of each link; integrating high efficiency radiating elements at the millimeter scale, leading to compact, adaptive and portable integrated systems; exploiting quasi-unlimited and unique electromagnetic signatures for detection, diagnostic or imaging.

Recently, the availability of standard CMOS technology enabling the design of MMIC circuits operating efficiently up to 100 GHz has revived the interest and investment in the 7 GHz of bandwidth unlicensed band in the 60 GHz spectrum. The specificity of the 60 GHz spectrum is the attenuation characteristics due to atmospheric oxygen absorption in the order of 10 to 15 dB/km over a bandwidth of about 8 GHz. This attenuation precludes long-range communications, but provides an extra spatial isolation that is beneficial for frequency re-use in an indoor dense local network, reduces co-channel interference and provides extra safety for secure short-range point-to-point links. In addition to supporting multi-gigabit networks, this makes the 60 GHz spectrum a great opportunity for indoor ultra-high speed short-range wireless communications, targeting multimedia applications and others.

Similarly, extremely fast growing opportunities for low cost commercial millimeter-wave systems are exploited at even higher frequencies, such as 77 GHz for automotive radar, 71 to 76 and 81 to 86 GHz for outdoor 10 Gbps networks, and 94 GHz for medical and security imaging. This just preludes terabits systems operating beyond 120 GHz and above.

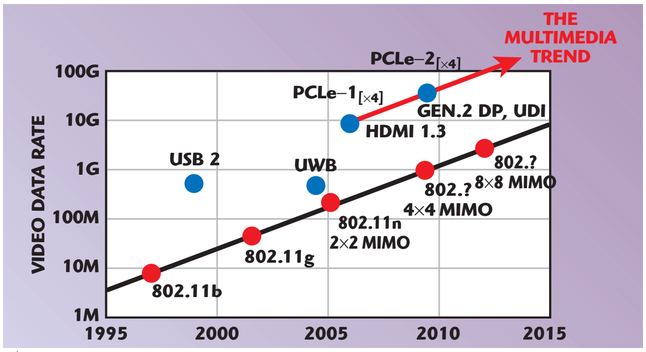

Fig. 4 *Uncompressed video data rates.*

THE MULTIMEDIA TREND

The emergence of a multitude of "bandwidth hungry" multimedia applications has definitely had a leading role in the renewal of interest in the millimeter-wave spectrum. The conventional WLAN systems (802.11a, b and g) are limited to a data rate of, at best, 54 Mb/s. Alternative solutions such as UWB and MIMO systems will start becoming available to extend the speed up to 600 Mb/s, targeting 1 Gb/s and above in the near future. It is noteworthy that wireless networks

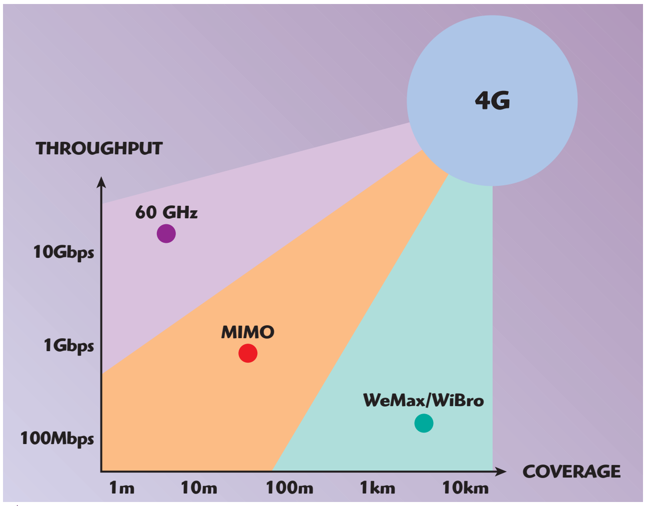

Fig. 5 *4G seamless connectivity including millimeter-wave systems.*

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tend to lag at least one generation behind wired LAN interconnect technology.[3-4]

Two primary types of applications are driving the requirement for even higher data rates: ultra-fast file sharing and uncompressed high definition video streaming. ***Figure 2*** illustrates the projected average storage capacity of PCs (desktop and laptop), reaching nearly 300 Gbytes in 2010, as well as the average storage capacity of embedded hard-drives and flash products. In the case of portable devices, especially in the case of smart cell phones, one can note a clear migration from micro-hard-drive toward high speed flash memory technology, exhibiting capacity up to 100 Gbytes and access speed exceeding the Gb/s in the horizon of 2010. It is obvious that today high speed wireless systems will lead to prohibitive synchronization time.

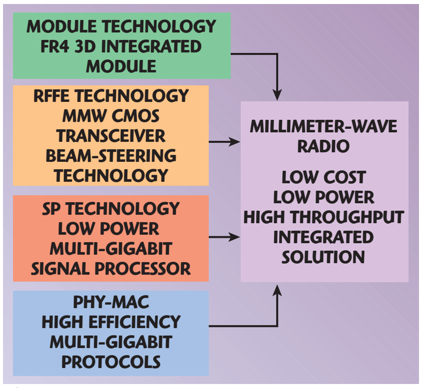
Figure 3 illustrates the data throughput requirement for uncompressed video streaming. It appears again that the data throughput requirement is well in excess of 1 or 2 Gbps, following a progression from 5 to 10 Gb/s and above.

This demand has since pushed the development of technologies and systems operating at millimeter-wave frequencies, while maintaining a cost structure similar to the one of conventional WLAN systems. These throughput requirements of multimedia systems are dictated by interconnect and interface technologies such as PCI-express, High Definition Multimedia Interface (HDMI), Display Port (DP) or Unified Display Interface (UDI), as shown in ***Figure 4***.

Two major standardization bodies, IEEE 802.15.3c and Ecma International TC32-TG20,[5–6] are specifically considering these requirements, in the particular case of the 60 GHz spectrum, for applications ranging from very low cost peer-to-peer interface up to high performance Wireless Personal Area Networks (WPAN), including high definition uncompressed video streaming. Back-compatibility should also be considered to provide seamless connectivity across the technologies that will support the coming 4G communications infrastructure (see ***Figure 5***).

CMOS-FR4: A LOW COST MILLIMETER-WAVE RADIO PLATFORM

Since the mid-90s, many examples of MMIC chipsets have been reported for millimeter-wave radio applications using GaAs FET and InP PHEMT technologies.[7] More recently, SiGe



▲ *Fig. 6 Module, CMOS MMIC, signal processing and high efficiency PHY-MAC technologies convergence toward low cost high performance millimeter-wave systems.*

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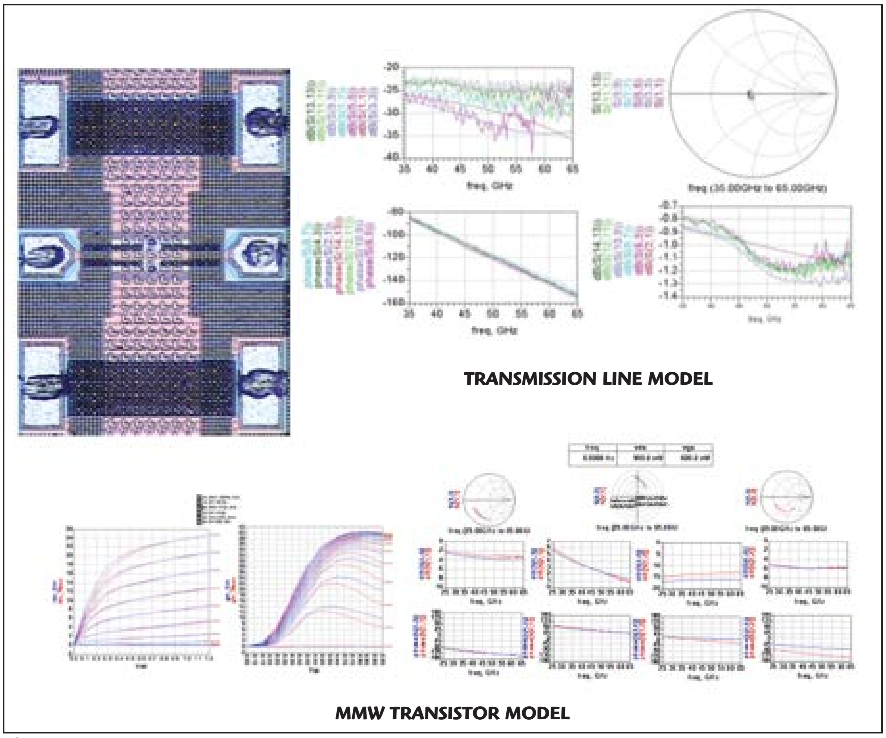
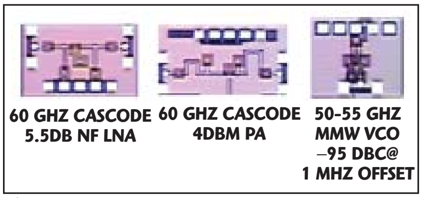


▲ *Fig. 7 Millimeter-wave optimized transistor test structure, passive and active (S-parameters) modeling.*

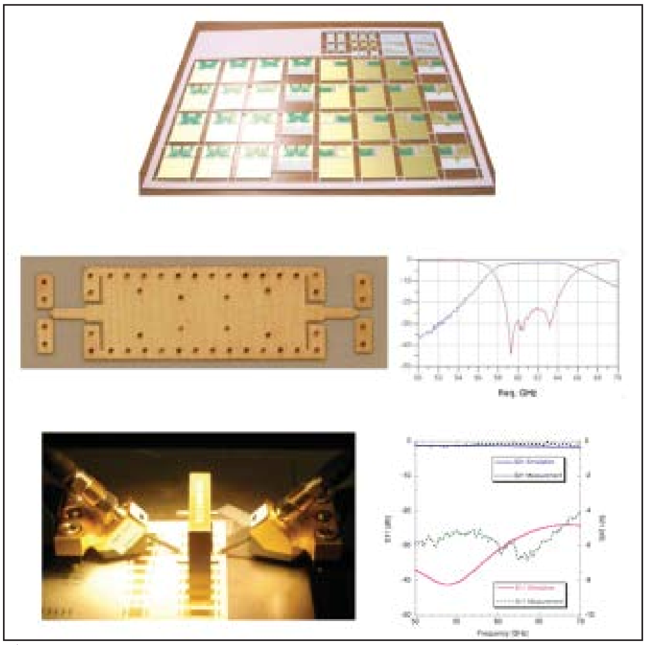


▲ *Fig. 8 V-band CMOS 90 nm chipset for multi-gigabit short-range multimedia applications.*

BiCMOS technology has also been demonstrated to be a viable alternative.[8] Despite their commercial availability and their performance, however, these technologies struggle to enter the market because of their prohibitive cost and their limited capability to integrate advanced baseband processing.

The steadily increasing frequency range of CMOS process technologies has now made the design of low cost, highly integrated 24 and 60 GHz millimeter-wave radio possible in silicon.[9–10] Proof of concept has been validated using CMOS 130 nm technology; however, CMOS 90 nm is the first technology node that enables high performance and power efficient implementation of 60 GHz transceivers suitable for high volume products.

In addition, the optimum combination and co-design of CMOS technology with low cost FR4-based packaging technology is a requisite to ensure the minimal cost structure possible, the key for the successful deployment of ultra-high speed, high capacity, 60 GHz WPAN and video streaming applications.



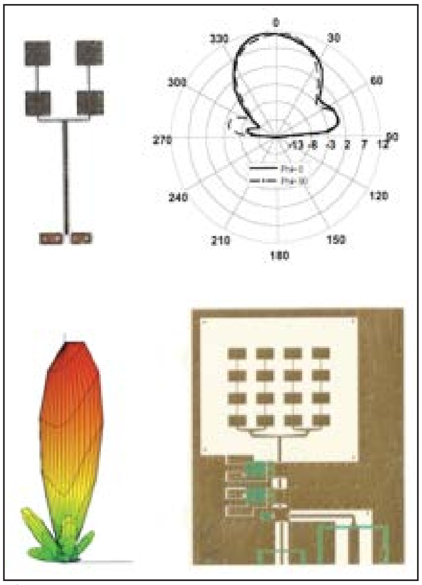
▲ *Fig. 9 A large panel area FR4-LCP multi-layer substrate, compact IWG filters and a wideband millimeter-wave feed-through transition.*

Finally, innovative PHY, MAC, ADC and signal processing approaches are required to provide simultaneously ultra-high bandwidth, very high PHY-MAC efficiency at an affordable price and an acceptable power budget. As depicted in ***Figure 6***, the convergence of module, CMOS MMIC, signal processing and high efficiency PHY-MAC technologies are the necessary key enablers of the coming generation of low cost, high performance millimeter-wave systems.

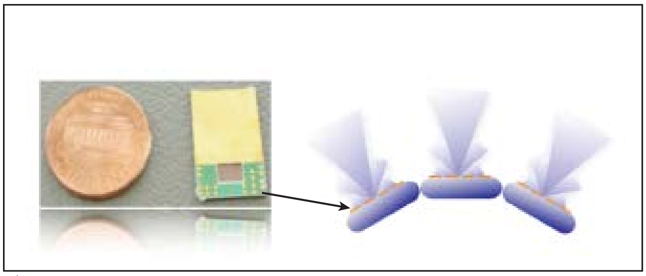
MILLIMETER-WAVE CMOS TECHNOLOGY

The CMOS technology has advanced to a point that a complete chipset for millimeter-wave applications can be implemented using silicon. In a standard 90 nm CMOS technology it is now possible to achieve an F_t and F_{max} beyond 150 GHz. Proper transistor geometry and layout, as well as complete and accurate modeling and optimized parasitic extraction methods up to the millimeter-wave frequency of interest are the entry point for such designs (see ***Figure 7***).

The use of millimeter-wave low loss micro-strip line and micro-inductors for matching purposes are very characteristic of this new generation



▲ *Fig. 10 LCP planar antenna array example for broad beam short-range and narrow beam medium range applications.*

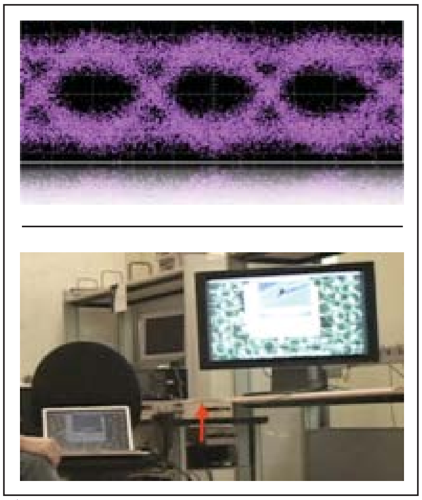


▲ *Fig. 11 Compact 3D integrated millimeter-wave modules, including embedded filter and antenna phased arrays, to be integrated into a multi-sector phased-array architecture.*

of millimeter-wave designs leading to more compact area and higher performance than its co-planar waveguide (CPW) counterpart. Power gain is in excess of 8 dB at 60 GHz and at a current density of 0.2 mA/μm enables reliable and low power circuit design. In addition, noise figures of 5.5 dB are achievable for similar biasing conditions, which make the optimization of low noise amplifiers easier. P1dB compression points of 4 to 7 dBm are reachable with fairly straightforward power amplifier designs. Fundamental frequency cross-coupled VCOs exhibiting phase noise better than –95 dBc/Hz at 1 MHz offset guaranties proper transmission and demodulation of multi-gigabit/s modulated signals. ***Figure 8*** shows an example of a V-band CMOS 90 nm chipset developed for multi-gigabit short-range multimedia applications.

Comparable figures of merit are also achievable at higher frequencies with the introduction of high volume production 65 and 45 nm CMOS technology, enabling now the design of low power E-band transceiver and targeting a high level of integration for systems such as 77 GHz automotive radar, 71 to 76 and 81 to 86 GHz 10 Gbps outdoor links, and 94 GHz imaging.

The research efforts at the Georgia Electronic Design Center have been focused on the development of a millimeter-wave CMOS fully integrated single chip radio suitable for multi-Gb/s applications. A super-heterodyne architecture using high IF frequency has been chosen and optimized to support wideband modulated signals. In addition, low power mixed-signal circuit techniques and innovative high speed analog-to-digital conversion are used to enable the



▲ *Fig. 12 The demodulated transmission of a multi-gigabit signal and experimental set-up of the video transmission through a one-inch thick wood table.*

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FR4-LCP-BASED MODULE AND ANTENNA TECHNOLOGY

Liquid Crystal Polymer has emerged as a promising low cost alternative for millimeter-wave module implementation. It combines uniquely outstanding microwave performances at low cost and large area FR4 PWB processing capability. It appears as a platform of choice for the packaging of the future 60 GHz gigabit radio. 24 × 18 inch FR4-LCP multi-layer substrates are fabricated using high volume standard PWB production lines. An example of a large panel area FR4-LCP multi-layer substrate is shown in ***Figure 9***. Compact filter designs using planar and integrated waveguide (IWG) techniques have been validated and measured, exhibiting less than 2 dB minimum insertion for a relative bandwidth of 8 percent at 61.5 GHz, and a rejection greater than 20 dB at 6 GHz offset.[6–11] A wideband millimeter-wave feed-through transition exhibiting less than 0.2 dB insertion loss has also been implemented.

One of the obvious attractiveness of the millimeter-wave is the small wavelength, allowing the integration of multiple radiating elements in an array configuration while occupying a minimum space (see ***Figure 10***). Numerous antenna array solutions have been developed to address various application scenarios ranging from VSR (very short reach) omni-directional to point-to-point link.[12-13]

Such generic packaging platforms provide a path of choice toward the low cost integration of scalable SISO-MIMO radio systems (SM radio) using compact multi-sector phased-array architecture that overcomes simultaneously the fundamental limitations of millimeter-wave signal propagation and CMOS technology. The multi-sector architecture can either be integrated on a single large panel or in a compact 3D integrated millimeter-wave module, including an embedded filter and antenna phased array, as shown in ***Figure 11***. Extended azimuth and elevation coverage, provided by conformal multi-sector configuration, and extended range (including non-LOS scenario) provided by high gain adaptive phased-array technology, are the breakthrough attributes of future commercial millimeter-wave systems.

15 GBPS AND HD-VIDEO MILLIMETER-WAVE TEST-BED

The GEDC has established an experimental millimeter-wave wireless test-bed, using 60 GHz as a demonstrator vehicle to study the channel characteristic of a real indoor environment. Researchers recently established a new world record for the highest data rate transmitted wirelessly at 60 GHz, achieving a peak data transfer rate of 15 gigabit/s at a distance of 1 meter, 10 Gigabit/s at a distance of 2 meters and 5 gigabit/s at a distance of 5 meters. In addition, high definition video streaming running at 1.485 Gb/s has been demonstrated through a one-inch thick wood table. Special efforts have been dedicated to the complete transceiver module implementation operating at a power budget well below the one hundred pico-joules range. ***Figure 12*** shows the demodulated transmission of the multi-gigabit signal and the experimental set-up of the video transmission through a one-inch thick wood table.

CONCLUSION

The development of millimeter-wave radios at the same cost structure of radios operating in the microwave region opens a new field of innovation for system designers. The convergence of a FR4-based module, CMOS MMIC, signal processing and high efficiency PHY-MAC technologies becomes today's reality, enabling the coming generation of low cost high performance millimeter-wave systems. The feasibility of ultra high speed wireless transmission beyond 10 Gbps has been demonstrated on a low power, low cost platform. A power budget well below the one hundred pico-joules/bit range has been achieved, already looking at the next level of innovation targeting 100 Gbps transmission and the femto-joule/bit power budget. The spreading of millimeter-wave technology in the consumer electronic market place is on its way, leveraging bandwidth availability at various frequencies, ranges and levels of system complexity. Peer-to-peer ultra fast synchronization and adaptive WPAN, for data and video distribution, will drive the cost down and further eases the adoption of low cost CMOS-based millimeter-wave platforms for automotive radar, outdoor point-to-point/point-to-multi-point links, portable radar, security, sensing and imaging systems, including numerous medical applications. ■

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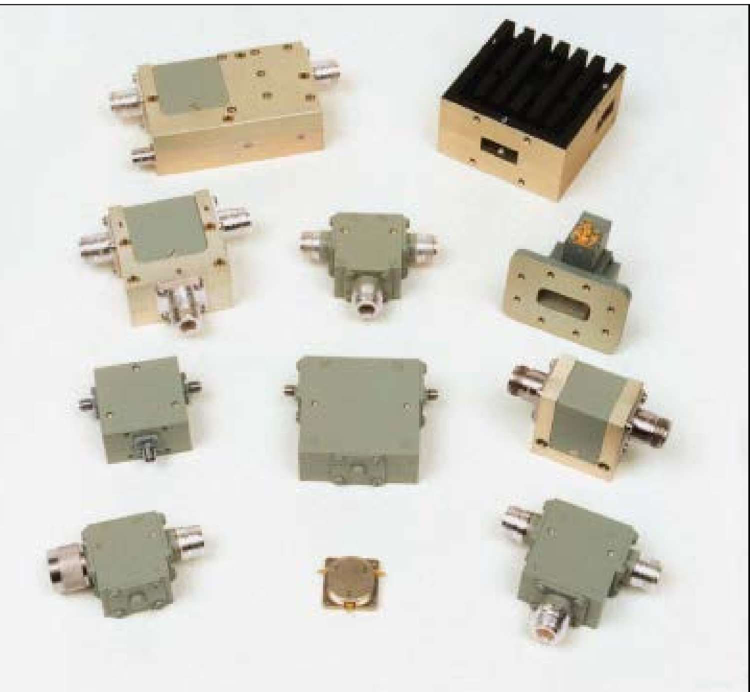

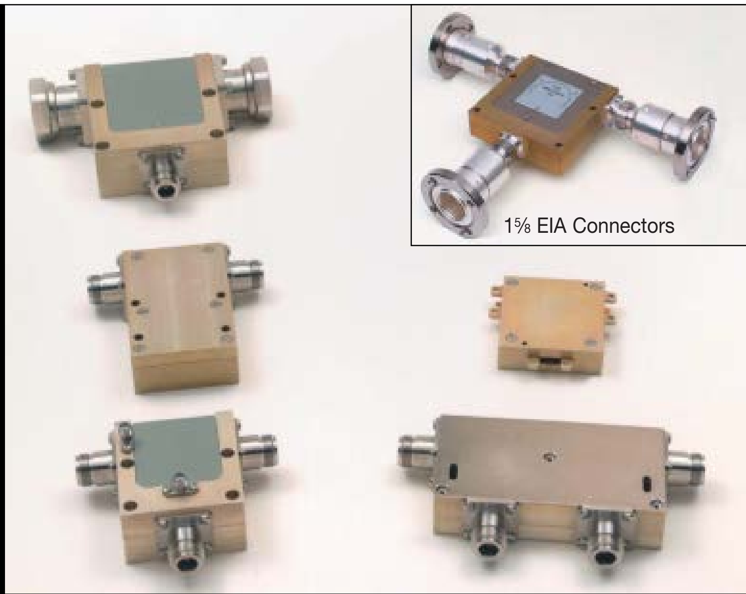

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Joy Laskar *received his BS degree in computer engineering from Clemson University in 1985. He received his MS and PhD degrees in electrical engineering from the University of Illinois at Urbana-Champaign in 1989 and 1991, respectively. Prior to joining Georgia Tech in 1995, he held faculty positions at the University of Illinois and the University of Hawaii. At Georgia Tech, he holds the Schlumberger Chair in Microelectronics, is the director of Georgia's Electronic Design Center, and heads a research group of 25 members with a focus on integration of high frequency mixed-signal electronics for next generation wireless and wired systems. He has authored or co-authored more than 400 papers, several book chapters (including three textbooks in development), numerous invited talks and has more than 25 patents pending. Most recently his work has resulted in the formation of two companies. In 1998 he co-founded an advanced WLAN IC company, RF Solutions, which is now part of Anadigics. In 2001 he co-founded a next generation analog CMOS IC company, Quellan, which is developing collaborative signal processing solutions for the enterprise, video, storage and wireless markets. He is a 1995 recipient of the Army Research Office's Young Investigator Award, a 1996 recipient of the National Science Foundation's CAREER Award, the 1997 NSF Packaging Research Center Faculty of the Year, the 1999 co-recipient of the IEEE Rappaport Award, the faculty advisor for the 2000 IEEE MTT International Microwave Symposium (IMS) Best Student Paper award, the 2001 Georgia Tech Faculty Graduate Student Mentor of the year, the recipient of a 2002 IBM Faculty Award, the 2003 Clemson University College of Engineering Outstanding Young Alumni Award, the 2003 recipient of the Outstanding Young Engineer of the Microwave Theory and Techniques Society, and he has been named IEEE Fellow from 2005. For the 2004-2007 term, he has been appointed an IEEE Distinguished Microwave Lecturer for his seminar entitled "Recent Advances in High Performance Communication Modules and Circuits." He was also named an IEEE Electron Devices Society Distinguished Lecturer in 2006.*

Stéphane Pinel *received his BS degree from Paul Sabatier University, Toulouse, France, in 1997, and his PhD degree in microelectronics and microsystems from the Laboratoire d'Analyse et d'Architecture des Systemes, Centre National de la Recherche Scientifique (CNRS), Toulouse, France, in 2000. He has worked on an UltraThin Chip Stacking (UTCS) European Project for three years involving Alcatel Space and IMEC (Belgium). He has been on the research faculty at the Georgia Electronic Design Center (GEDC) of the Georgia Institute of Technology, Atlanta, GA, since 2000. He has authored or co-authored over 125 journals and proceeding papers, two book chapters, numerous invited talks, participated and organized numerous workshops at international conferences such IMS, and holds four patents. He was the recipient of the first price of the SEE 1998 award, the second prize of the IMAPS 1999 award, and the 2002 International Conference on Microwave and Millimeter-wave Technology Best Paper Award (Beijing, China). His research interests include CMOS, SiGe and SOI RF and millimeter-wave circuit design, advanced 3D integration and packaging technologies, RF and millimeter-wave embedded passives (filters, antenna arrays) design using organic (Liquid Crystal Polymer) and ceramic materials (LTCC), RF-MEMS and micromachining techniques, system-on-package for RF and millimeter-waves front-end module. He is currently leading research efforts for the development of a 10 Gbps wireless test-bed at GEDC.*

Debasis Dawn *received his B.Eng. degree from Jadavpur University, India, in 1986, his M.Tech. degree from IIT Kanpur, India, in 1989, and his PhD degree from Tohoku University, Japan, in 1993, all in electrical engineering. He was a research associate at Tohoku University for five years and was engaged in various government funded research projects in the development of millimeter-wave circuits and millimeter-wave photonic circuits. He was a research engineer at Fujitsu Laboratories Ltd. in Japan for five years and was engaged in MMIC development and device modeling using GaAs pHEMT process technology. He also held a senior MMIC design engineer position at SONY Corp, Japan. He has been on the research faculty at the Georgia Electronic Design Center (GEDC) of the Georgia Institute of Technology, Atlanta, GA, since 2006, and is currently engaged in the development of RF front-end circuits for wireless personal area network (WPAN) applications using CMOS process technology. He has published more than 20 papers in international journals and conferences and holds two US patents. He is a member of the IEEE.*

Saikat Sarkar *received his B.Tech. degree in electronics and electrical communication engineering from the Indian Institute of Technology, Kharagpur, India, in 2003, and his MS degree from the Georgia Institute of Technology, Atlanta, GA, in 2005. He worked at Intel Corp., Hillsboro, OR, as a summer intern in 2004. He is currently pursuing his PhD degree at the Georgia Institute of Technology, where he is a member of the Microwave Applications Group at the Georgia Electronic Design Center (GEDC). He has authored or co-authored over 15 journal and conference papers. His research interests include silicon-based millimeter-wave front-end circuit design, system integration and the analysis of millimeter-wave high data rate low power wireless systems.*

Bevin George Perumana *received his B.Tech. degree in electrical engineering from the Indian Institute of Technology, Kharagpur, India, in 2002, and his MS degree in electrical engineering from the Georgia Institute of Technology, Atlanta, GA, in 2005, where he is currently pursuing his PhD degree in electrical engineering. In 2002 he became a research consultant with the Advanced VLSI Design Laboratory at the Indian Institute of Technology. He has held internship positions with the Communications Technology Laboratory of Intel Corp., Hillsboro, OR, and with PCS, Mumbai, India. He has been a graduate research assistant with the Microwave Application Group at the Georgia Institute of Technology, where his main research focus is CMOS wireless transceiver circuits.*

Padmanava Sen *received his B.Tech. degree in electronics and electrical communication engineering from the Indian Institute of Technology, Kharagpur, India, in 2003, and his MS degree from the Georgia Institute of Technology, Atlanta, GA, in 2005. He worked for IBM, Burlington, VT, as a co-op for seven months in 2004 and three months in 2006. He is currently pursuing his PhD degree from the Georgia Institute of Technology, where he is a member of the Microwave Applications Group at the Georgia Electronic Design Center (GEDC). He has authored or co-authored over 15 IEEE journal and conference papers. His research interests include the analysis and development of millimeter-wave silicon-based transmitters.*

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

Low Phase Noise Amplifiers — Phase noise (dBc/Hz) at offset

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

High Dynamic Range Amplifiers

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

*Above 500MHz.

Power Amplifiers by Microwave Power

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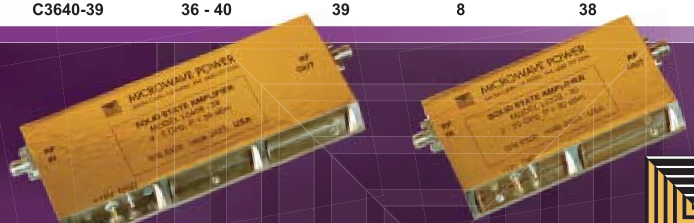
Model	Frequency (GHz)	Psat (dBm)	Psat (W)	P1dB (dBm)	Gain (dB)	DC Current(A) @ +12V or +15V
Broadband Microwave Power Amplifiers						
L0104-43	1 - 4	42.5	17.8	41.5	45	14
L0204-44	2 - 4	44	25	42.5	45	14
L0206-40	2 - 6	40	10	38.5	40	8.5
L0208-41	2 - 8	41	12	40	40	17
L0218-32	2 - 18	32	1.4	31	35	5
L0408-43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

High-Power Rack Mount Amplifiers

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



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OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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Milstar Satellite Constellation Repositioned to Enhance Global Coverage

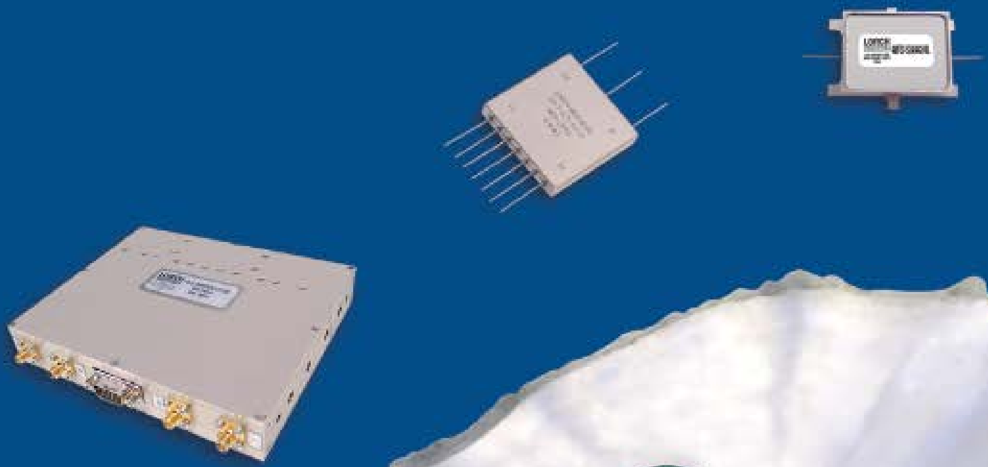
A combined US Air Force/Lockheed Martin team has successfully completed an on-orbit reconfiguration of the five-satellite Milstar constellation to maximize the system's capabilities to provide secure, reliable and robust communications to US and Allied Forces around the globe. Orbiting the earth at over 22,000 miles in space, the Milstar constellation—which has now surpassed 40 years of combined successful operations—provides a protected, global communications network for the joint forces of the US military and can transmit voice, data and imagery, in addition to offering video conferencing capabilities. The Milstar system is the only survivable, endurable means that the President, the Secretary of Defense and the Commander, US Strategic Command have to maintain positive command and control of this nation's strategic forces. This reconfiguration, which entailed repositioning the satellites relative to one another to maximize and improve the constellation's earth coverage visibility, was successfully executed during a seven-month period by a team of engineers from Lockheed Martin Space Systems, Sunnyvale, CA, the prime contractor, working with the 4th Space Operations Squadron at Schriever AFB, CO, the Air Force team which flies and maintains the Milstar constellation. This proven ability to realign the operational location of the entire spacecraft constellation with no unplanned service disruptions to the military forces deployed around the globe will be vital to bringing the follow-on Advanced Extremely High Frequency (AEHF) satellites into the nation's survivable, secure MILSATCOM architecture. "We are proud of the capability we have demonstrated to increase the effectiveness of this critical system to our customer," said Leonard F. Kwiatkowski of Military Space Programs. "Designed, built and operated by a talented and dedicated group of people, Milstar continues to deliver critical secure, real-time connectivity to the warfighter and we look forward to achieving mission success as we prepare to launch the first AEHF satellite next year." The AEHF team is led by the MILSATCOM System Wing, located at the Space and Missile Systems Center, Los Angeles Air Force Base, CA.

Raytheon Awarded $304 M for Ballistic Missile Defense System Upgrades

The Missile Defense Agency has awarded Raytheon Co. a $304 M contract to develop advanced tracking and discrimination capabilities for the Ballistic Missile Defense System (BMDS) forward-based AN/TPY-2-radar. Under the contract, Raytheon is responsible for the development and test of radar software, various engineering tasks, maintenance and support, infrastructure upgrades and deployment mission planning. Work will be performed at the company's Missile Defense Center, Woburn, MA, and the Warfighter Protection Center, Huntsville, AL. "This award underscores the importance of providing our warfighters with state-of-the-art missile defense technologies to address emerging threats," said Pete Franklin, vice president, National & Theater Security Programs for Raytheon Integrated Defense Systems (IDS). "The critical capabilities that Raytheon is developing will track missiles over a wide range and help guide interceptors to their targets." The BMDS program has been designed to counter evolving threats through the development and release of spiral capabilities. The first forward-based capability spiral was released on schedule in October 2006 and is now operational. Raytheon IDS is currently developing the second forward-based capability spiral with release planned in early 2008. Raytheon IDS designed and built the AN/TPY-2 radar drawing on extensive sensor knowledge from its X-band "Family of Radar." A high power, transportable X-band radar, the AN/TPY-2 is designed to detect, track and discriminate ballistic missile threats. It maximizes the capability of the BMDS to identify, assess and engage threats to the US, deployed forces and allies. As the prime contractor for this program, Raytheon IDS has delivered the first two of five planned AN/TPY-2 radars to the Missile Defense Agency. The first radar, delivered in November 2004, is currently deployed in Japan. It is the first new Missile Defense Agency system to be deployed as an operational asset outside the US. The second AN/TPY-2 radar recently completed acceptance testing at Vandenberg Air Force Base, CA. Raytheon is also responsible for whole-life engineering support for AN/TPY-2 radars under a contract awarded in June 2005. Integrated Defense Systems is Raytheon's leader in Joint Battlespace Integration providing affordable, integrated solutions to a broad international and domestic customer base, including the US Missile Defense Agency, the US Armed Forces and the Department of Homeland Security.

US Marine Corps Awards Harris $158 M in Orders for JTRS-approved Falcon III

Harris Corp., an international communications and information technology company, has been awarded a $218 M Indefinite Delivery, Indefinite Quantity (IDIQ) contract by the US Marine Corps for its next generation, JTRS-approved Falcon® III Tactical radios. Under the contract, the company received two orders totaling $158 M. Harris was chosen as the sole supplier of the handheld and vehicular radios, following a competitive bidding process. Harris will provide the US Marine Corps with its multiband, multi-mission, SINCGARS interoperable Falcon III AN/VRC-110, 20 W vehicular radio systems, which include Falcon III AN/PRC-152(C) multiband handheld radios. The IDIQ contracts calls for a maximum of 14,100 Falcon III AN/VRC-110 systems over three years. Radio Systems delivered under this contract are slated to be installed into two new Mine Resistant Ambush Protected vehicles (MRAP) and used in other applications for the US Marine Corps. MRAP vehicles are designed to provide military personnel with greater protection against improvised explosive devices. These vehicles recently have been identified as the highest priority acquisition by the Secretary of Defense. Harris is already providing Falcon radio systems for the US Navy MRAP vehicles. The US Marine Corps also will deploy Falcon III AN/VRC-110 radios to begin the transition and replacement of legacy SINCGARS radios. The AN/VRC-110 system expands the role of a traditional combat net radio from a single-mode SINCGARS VHF line-of-sight radio to a multi-mission radio with the capability to provide UHF line-of-sight communications, close-air support and tactical satellite communications, programmable encryption and software upgrades utilizing JTRS Software Communication Architecture (SCA). The Falcon III AN/VRC-110 handheld-based transceiver provides a quick "grab-and-go" feature allowing the Falcon III AN/PRC-152(C) handheld radio to offer continuous communications when removed from the vehicle, an important capability in urban environments. "We are pleased to work with the US Marine Corps to help advance tactical communications into the future with new JTRS-approved, multiband handheld-based vehicular systems," said George Helm, vice president and general manager of US Government Products for Harris RF Communications. "Harris Falcon III capabilities will help to ensure that commanders are connected to critical command and control applications in support of the US Marine Corps' goal of empowering decision makers at every tactical level. The Harris Falcon III system will enhance the operational effectiveness of forward-deployed forces, while providing the US Marine Corps business planners a low risk investment for the future." The agreement is the second IDIQ contract recently awarded to Harris for its Falcon III radios. In June, Harris was awarded a contract by the Joint Program Executive Office of the Joint Tactical Radio System (JPEO JTRS) to supply tactical radios to the Department of Defense for use by all branches of the military. ■

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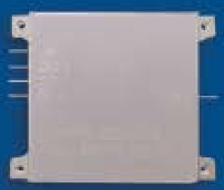

Narda Microwave-West, Over Forty Years of Innovative Quality Microwave Products...

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Up/Down Converters
Receivers
Filters/Ferrites
Diplexers and Multiplexers

Military

Amplifiers
Up/Down Converters
Filters/Ferrites
Notch Filters
Power Dividers/Combiners

Commercial

Amplifiers
Filters/Ferrites
Diplexers
Multiplexers
Integrated Assemblies

Narda Microwave-West offers a ***wide variety of Active and Passive catalog products*** for Space, Military and Commercial applications , however, if our catalog products do not meet your needs, our experienced design staff stands ready to meet your most rigorous requirements with timely and ***innovative customized component or integrated multifunction solutions.***

For over 40 years Narda Microwave-West has designed, manufactured and supplied high performance microwave products for a wide variety of Military, Space and Commercial applications. Narda Microwave-West's Active and Passive offerings include Linearized and Non-Linearized Channel Amplifiers, RF, Microwave and Millimeter Wave Low Noise and Power Amplifiers, Converters, Multipliers, Filters, Multiplexers, Power Dividers, Ferrites as well as integrated multifunction assemblies. Narda Microwave-West products are found in a variety of applications ranging from Armed Forces tactical and strategic platforms to space products installed in a variety of Commercial and Military Satellites currently in orbit or soon to be in orbit. Narda Microwave-West commercial products are used in a broad spectrum of commercial test equipment and telecommunications systems worldwide.

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Test Centre to Drive RFID Deployment

NXP Semiconductors, the independent semiconductor company founded by Philips, has established a Reference Design Centre (RDC) with the aim of facilitating deployment and adoption of RFID technology. Based near Graz, Austria, the RDC improves the performance and reliability of existing RFID systems by thoroughly testing applications under real life conditions for various industries.

Working in collaboration with key industry bodies such as EPCglobal and the International Organization for Standardization (ISO), the facility will help the company and its partners to deliver RFID solutions with optimum read ranges and system configuration. The RDC will develop new RFID solutions with a 'frequency agnostic' approach, as wireless frequency ranges are assessed and recommended based on the exact needs of the individual application.

NXP's RDC application specific analysis and optimization endeavours to transcend the simple design-in of products. All elements of the solution can be developed and evaluated from the first engineering sample to the middleware and the final product. Through collaboration with all stakeholders, this approach aims to ensure that systems integrators and end-users can rely on performance and benefit from improved return on investment.

"RFID technology fundamentally changes how organizations operate, so it is essential that, before implementing RFID solutions, all the elements are ready to use in your business environment," said Jan-Willem Reynaerts, general manager, RFID, NXP Semiconductors. "An environment such as NXP's RDC ensures these solutions are business ready, removing the need for beta testing, improving the calculation for the return on investment and providing an extra level of confidence for the customer."

Alcatel-Lucent University for Egypt

The newly inaugurated Alcatel-Lucent University Egypt is the company's first certified university in the Middle East and Africa and the 20th certified training centre within Alcatel-Lucent's global education network. Based in Cairo, the university's mission is to deploy learning and qualification solutions that will enable customers and employees in the Middle East and North and West Africa region to achieve their strategic business objectives.

By adopting a consultative approach to learning, the university seeks to maximize customer proficiency with Alcatel-Lucent products and solutions, while enabling employees to excel in their current roles and adapt to future job requirements. The teaching staff is made up of 14 instructors, each with engineering backgrounds and certified in pedagogical and technical aspects. The university is considered an institute of higher learning, offering an array of learning opportunities that support customers' current business needs, as well as employees' professional development.

Courses include product, technology, management and non-technical training. Learning solutions are offered in a wide variety of convenient and cost-efficient formats, including e-Learning, virtual/remote learning and classroom-based training. In 2006, the site taught more than 1800 people in its previous location at the Smart Village Egypt and at customer sites.

ST and Freescale Accelerate Automotive Activity

Freescale Semiconductor and STMicroelectronics, semiconductor suppliers to the automotive industry, have made significant progress in the areas of automotive IP development, flash technology alignment and new product definition. Since announcing their joint design initiative last year, the automotive units from both companies have focused product development efforts on a wide range of automotive applications.

They have established design centres in Naples, Agrate, Sao Paulo and New Delhi, each dedicated to extending the joint product roadmap. Staffed by a total of 130 design engineers, these design centres are focusing on developing MCU products optimized for specific automotive market segments.

One of the most significant developments to date has been the recent delivery of a common microcontroller architectural platform design. This design enables multiple products to be derived simultaneously using optimized peripheral sets, each for a specific target application. This approach can significantly reduce time to market and can help to accelerate both companies' goal of making Power Architecture™ technology the leading automotive microcontroller core. The partners plan to manufacture jointly designed Power Architecture MCU products on mutually aligned 90 nm process technology. Lead customers are expected to receive samples of the jointly developed products throughout Q1 2008.

picoChip Joins Femto Forum

picoChip has joined the Femto Forum, which supports and promotes femtocell deployment worldwide by bringing together the foremost femtocell equipment vendors with the major global mobile operators assessing the technology. The Forum is a not-for-profit membership organisation aimed at promoting the uptake of femtocell technologies through open standards, market education and ecosystem development.

The initial focus will be on pre-competitive standards-focused issues including radio planning and control, device provisioning and management and device to network standardization. In addition, a marketing task force will promote the benefits of femtocell technology for both operators and subscribers.

"The cost-effective provision of ubiquitous mobile broadband services as well as managing the threat posed by non-traditional telecoms operators represent two of the greatest challenges facing mobile operators today," said Simon Saunders, chair of the Femto Forum. "The Femto Forum will illuminate precisely how femtocells meet these challenges as well as marshalling the respective equipment vendors and operators into creating the best possible solutions for the market."

Asian Lab Offers Fixed and Mobile WiMAX Certification

The WiMAX Forum® has selected Bureau Veritas's Advance Data Technology Corp. (ADT) in Taiwan as the first Asian certification test lab of both fixed and mobile WiMAX certification services. WiMAX is a technology that provides an alternative to cable/DSL for the 'last mile' as well as mobile or personal broadband and is expected to have significant growth rates over the coming years. The WiMAX Forum is an industry-led, not-for-profit organization that was set-up to ensure compatibility and interoperability of equipment in this blossoming market and the selection of the ADT test lab expands its operations into Asia.

Oliver Butler, vice president of Bureau Veritas Electrical and Electronic Product Services, stated, "We are very pleased to have the opportunity to contribute to the success of this exciting technology, enabled by the investments we have made in the latest equipment, expertise and facilities at our WiFi/WiMAX certification test centre in Taiwan. With our network of offices around the world, and dedicated E&E labs and expertise in America, Asia, and Europe, Bureau Veritas is ready to support the WiMAX equipment market."

Mark Wang, president of Bureau Veritas ADT, continued, "We expect to launch our WiMAX Forum certification service in early Q4 2007, offering the same level of service as AT4 Wireless, Spain, which is currently the only facility in the world capable of providing both fixed and mobile WiMAX certification. And with WiMAX being a new technology with changing standards, our total solution portfolio and expertise in test, certification and debugging will enable equipment providers to achieve their market entry deadlines." ■

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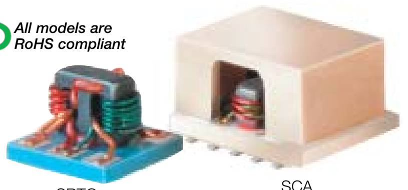

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SBTC-2-10-75+	10-1000	75 Ω	3.49
SBTC-2-15-75+	500-1500	75 Ω	3.49
SBTC-2-10-5075+	50-1000	50/75 Ω	3.49
SBTC-2-10-7550+	5-1000	50/75 Ω	3.49
SCA-4-10+	5-1000	50 Ω	6.95
SCA-4-10-75+	10-1000	75 Ω	6.95
SCA-4-15-75+	10-1500	75 Ω	7.95
• SCA-4-20+	1000-2000	50 Ω	7.95

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US Mobile WiMAX Market Moves from Uncertain to Vibrant

Just a little over a year ago, most people thought the United States would only see deployments of fixed WiMAX in rural areas with no DSL or cable modem service. During the summer of 2006, however, those who did not see the bigger picture got a reality check. In July, Clearwire made a firm commitment to shift its proprietary network to mobile WiMAX, receiving investments from Intel and Motorola. Shortly afterwards, Sprint Nextel announced its plans to deploy mobile WiMAX to make use of its extensive 2.5 GHz spectrum, becoming the first major mobile operator to commit to WiMAX. "Today we are watching major strategic alliances, partnerships and mergers taking place," said ABI Research principal analyst Philip Solis. "DirectTV and EchoStar announced a partnership with Clearwire, allowing Clearwire to bundle broadcast video and—when its network is deployed—provide the DBS companies with a fast, low latency pipe into the home." Sprint and Clearwire will also form a roaming arrangement, if not actually merge in some form. NextWave also has a lot of WiMAX-friendly spectrum, and its NextWave Broadband subsidiary will be selling mobile WiMAX chipsets, helping to enable more WiMAX devices faster, thus increasing the value of the spectrum it holds. In addition, there are many wireless ISPs looking to deploy mobile WiMAX. Horizon Wi-Com, for example, holds 2.3 GHz spectrum that it acquired from Verizon across much of the Northeast. These market trends and more are discussed in a new ABI Research Brief, "Mobile WiMAX in the United States," which provides detailed analysis of these service providers' past and present efforts and future directions.

E-wallet and GPS Phones on the Rise in Japan

E-wallet phones, GPS phones and related services are gaining traction today in the Japanese mobile phone market, reports In-Stat. Mobile TV phones are expected to gain favor as well, once there is a good revenue-generating business case, the high tech market research firm says. A trend-setting market, Japan provides a model for how other markets may adopt new mobile phone features. "In the advanced Japanese mobile phone market, the shipment of 3G phones exceeded 92 percent of 47.8 million phones sold in 2006," says Allyn Hall, a director with In-Stat. "The market is full of excitement as phones with brilliant displays, rich multimedia capabilities and various novel functions were introduced last year to gain customer acceptance and market share."

Recent research by In-Stat found the following:

- In 2006, 43.5 million 3G phones were sold in Japan.
- Camera, music player function and above 2.4-inch screens with at least 240 × 320 resolution have become standard.
- Ninety-eight new 3G models were launched in the last 12 months in Japan.

The research, "3G Mobile Handset Trends in Japan," covers the market for mobile phones in Japan. Getting to know the latest features of Japanese phones and how the business works is instructive in reaching for the same success in other markets. This research explores the key enablers of every novel function/service, why customers like them and how likely other markets are to adopt them.

Cellular M2M Module Markets to Show 31 Percent Growth Rate to 2012

Global markets for cellular machine-to-machine (M2M) modules will experience smooth and solid growth trajectory in coming years, according to a new ABI Research study. The compound annual growth rate during the forecast period between 2006 and 2012 is expected to reach 31 percent. Although cellular M2M module shipment numbers in the world's three main industrialized regions—North America (including Mexico), Europe and Asia-Pacific—are approximately equal at present, these markets differ significantly from each other in character. ABI Research senior analyst Sam Lucero says, "North America is a significant cellular market that differs from the other regional markets in three key aspects: the prevalence of CDMA air-interface technology; the significant share of the market comprised of OEM telematics; and the rigorous, expensive and time-consuming certification process required by the four main North American mobile network operators." Europe is considered to be the most important market, Lucero says, in term of its sophistication and openness to M2M, with technologies crossing a range of applications. Western Europe benefits from the ubiquity of GSM/GPRS technology, which helps promote adoption. Eastern Europe is at an earlier stage of market development and module vendors describe it as being more price-sensitive than the West, where a greater premium is placed on features, functionality and reliability. On a unit shipment basis, Asia-Pacific is the largest market, but it is characterized by a fragmented assortment of air standards, and a majority of those shipments are actually for wireless local loop (WLL) applications. "Wireless local loop is something of a gray area within M2M," notes Lucero, "because, unlike telemetry or telematics applications, WLL is centered more on enabling 'standard' fixed voice and data communications over cellular infrastructure. That does form the largest share of the market in the Asia-Pacific region." The diversity of the market characteristics is mirrored in the strategies, strength and weakness of module vendors. Many are global players, but have taken very different paths to address regional markets. "The Cellular M2M Module Market" study discusses these market forces, analyzes cellular M2M module vendor strategic responses, provides 2006 vendor market share data and forecasts cellular M2M module shipment and revenue growth for the period from 2006 to 2012, segmented by region, application and air interface standard.

More Than 180,000 Buildings to Receive In-building Wireless Systems by 2011

For many of us, the most productive times of our days, when communications are critical, are spent indoors. This reality, as well as increasing usage of 3G wireless data services, is creating a growing demand for better in-building coverage according to a recent report from ABI Research. According to principal analyst Dan Shey, "The combination of supply-side enablers—3G networks, handsets with advanced capabilities, mobile applications—with a strong customer need means operators will be focused on establishing a coverage footprint inside buildings to retain customers who are using mobile data services. We expect this market to show a compound annual growth rate of nearly 20 percent by 2011." Until now, carriers have focused on extending coverage from the macro network into buildings, but with 3G networks, that approach will have limited results for customers using data services that demand higher kilobit rates on a per-customer basis. "Traditional DAS and repeater systems will still play a major role in establishing indoor coverage," says Shey, "but look for femtocells and picocells to play an increasingly important role, not only supplementing current in-building systems, but also replacing them."

Immediate activity in the market for in-building wireless systems will occur in North America, Europe and other regions worldwide with an established and growing 3G footprint. However, operators with 2G networks should be considering in-building wireless systems as well. According to Shey, "Operators with 2G networks have an opportunity to learn from 3G operators and their in-building wireless deployments. In fact, any 2G operator with a 3G roadmap should ensure that it also include resources dedicated to in-building wireless deployments. Such a roadmap will maximize uptake of 3G services providing a faster return on their future 3G network investments." ■


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INDUSTRY NEWS

▲ S.M. Shajedul Hasan

S.M. Shajedul Hasan of Virginia Tech has won the first William Bazzy Fellowship. Hasan received his BS degree from Bangladesh University in 2002 and his MS degree from the University of Tennessee in 2005. He is currently a PhD candidate under the supervision of Dr. Steven Ellingson. His dissertation will be on the topic of RF front-end design for multiband/multimode radio for the public safety community. The project is funded by the US Department of Justice. Applications for next year's Fellowship are available on our web site: www.mwjournal.com.

■ **American Technical Ceramics Corp.** (ATC), a manufacturer of high performance electronic components, including capacitors and thin film circuits for a broad range of commercial and military applications, announced that it has signed a definitive merger agreement with **AVX Corp.** (AVX) pursuant to which all of the outstanding equity interests of ATC will be acquired by AVX.

■ **Auriga Measurement Systems LLC** announced it has acquired the DiVA Pulsed IV Instrument series from **Nanometrics Industries**, Milpitas, CA, for an undisclosed amount. Previously owned by Accent Optical Technologies, DiVA is a well-known supplier to the RF microwave industry and offers moderate power, low cost pulsed IV instruments.

■ **FCI** acquired **Smartag**, a specialized player in Radio Frequency Identification (RFID) tags manufacturing. This acquisition will allow the group to strengthen its RFID offer in a very dynamic market.

■ **Interconnect Devices Inc.** (IDI), a Kansas City, KS company, was acquired by Milestone Partners and IDI Management. Milestone Partners, based in St. David, PA, is a private equity firm that partners with management teams to invest in leveraged buyouts of middle market businesses. The company will remain in Kansas City at its present location at 5101 Richland Avenue. All of IDI's assets, employees and officers will continue to operate in their present capacity.

■ **AMI Semiconductor**, a designer and manufacturer of state-of-the-art mixed-signal and digital products for the automotive, medical and industrial markets, and **MagnaChip Semiconductor**, a designer, developer and manufacturer of mixed-signal and digital multimedia semiconductors, announced that MagnaChip will manufacture AMI Semiconductor's 0.35-micron SmartPower technology and continue existing joint development of ULP technology. This agreement follows a November 4, 2005 announcement of a 0.18-micron development and foundry relationship between the two companies.

■ **Walleye™ Technologies** and the Harmonix Division of **Terabeam Corp.** have formed an alliance to develop a next-generation, hand-held, portable imaging technology capable of "seeing" into and through solid objects. The Walleye Imaging System is a patent-pending technology platform that generates high quality digital images that can be readily displayed, stored, analyzed and transmitted. The Walleye Imaging System works like a digital "camera," but uses invisible wavelengths called millimeter-waves to see into and through objects.

■ **SkyCross**, a global wireless company providing antenna-centric RF solutions, announced a partnership with **Beceem Communications** to provide complete, integrated WiMAX solutions for last-mile broadband connectivity. The bundling of Beceem chipsets and SkyCross antennas provides superior performance while shortening and simplifying the design process to reduce time to market and associated costs. The convenient, one-stop RF solution is versatile, providing device manufacturers with the freedom to enable WiMAX on a wide range of mobile platforms.

■ **Ethertronics**, a provider of standard and customized embedded antenna solutions for wideband and multi-band wireless devices, announced that its design center in Taipei, Taiwan is fully operational. The company's Taiwanese presence will enable mobile device manufacturers to capitalize on Ethertronics' antenna expertise coupled with premier in-country design teams and logistics support.

■ **RFMW Ltd.** announced the opening of a direct sales and distribution office in Israel. RFMW is a specialized distributor that uniquely provides customers and suppliers with focused distribution of RF/microwave components as well as customer specific component engineering support. This direct sales office allows RFMW to quickly and effectively introduce products from RFMW's suppliers into the multitude of RF/microwave design centers and OEMs currently located in Israel, and support the supply chain to contract manufacturing locations in country or worldwide.

■ **2Wire**, a provider of broadband service delivery platforms, is expanding with a new office located in Nevada City, CA at the Nevada City Tech Center. 2Wire is rapidly growing to accommodate the needs of major telecom broadband providers, and plans to hire 10 to 20 additional employees to staff the new facility.

■ **Alereon Inc.**, a certified wireless USB technology leader for mobile ultrawideband (UWB) WiMedia, announced the opening of Alereon Semiconductors Pvt. Ltd., the company's new product oriented research and development (R&D) facility in Pune, India. Alereon's new state-of-the-art operation expands Alereon's team to accommodate the growth in interest for the company's certified USB solutions. The focus of the R&D center will be to continue to develop the company's patented UWB chipsets, such as the AL4000, for the next generation of products.

■ **Agilent Technologies Inc.** announced the expansion of technologies in its Advanced Design System (ADS) and


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GENESYS design platforms to provide a full spectrum of software tools for microwave and RF designers. The company is increasing investments in RF/microwave design and simulation technologies to help designers of monolithic microwave integrated circuit (MMIC), systems-in-package (SIP) and RF boards stay competitive when incorporating the latest communications standards and techniques.

■ **Mimix Broadband Inc.**, a supplier of gallium arsenide (GaAs) semiconductors from DC to 50 GHz, announced that the company has joined MoCA, an open industry driven initiative promoting distribution of digital video and entertainment through existing coaxial cable in the home. MoCA technology provides the backbone for whole home entertainment networks of multiple wired and wireless products.

■ **Andrew Corp.**, a global leader in communications systems and products, has been given the "Best Supplier Award" by the Brazilian division of **Huawei Technologies Co. Ltd.**, the Shenzhen, China-based provider of next-generation telecommunications networks. The award recognizes Andrew's key role in a Huawei project to supply parts and equipment for a cellular overlay network for Vivo Participacoe, a Brazilian mobile phone joint venture of Portugal Telecom and Telefonica. The Vivo project lasted about 18 months and involved more than 2700 sites spread over five Brazilian regions.

■ **Tyco Electronics Corp.** recently obtained approval from the Defense Supply Center Columbus (DSCC) for MIL-DTL-24308 connectors with zinc plating and chromate coating. This most recent approval from DSCC is for roughly 90 part numbers and includes printed circuit board-mount plug and receptacle connectors in vertical and right angle configurations. All of the part numbers in this approval are part of Tyco Electronics' series 109, standard density D-sub miniature connector line. The connectors incorporate size 20 contacts and are suitable for use in a range of military, aerospace, commercial and industrial applications.

■ **Radio Waves Inc.** announced that all of its telecom antenna products will have a five-year warranty. Due to its high reliability and rigorous quality control program known as "Target Zero," Radio Waves is able to offer this superior warranty on its microwave antennas. Terms and conditions for the Radio Waves warranty can be found in the new Radio Waves 2007/2008 microwave antenna catalog.

CONTRACTS

■ **Anaren Inc.** has received an $8 M contract from **Lockheed Martin Systems Integration – Owego** in New York for a major subsystem element on a Radar Warning (RWR)/Electronic Support Measure (ESM) system. The subsystem element is intended for Lockheed Martin's Maritime Helicopter Project (MHP) RWR/ESM system for use on Canada's new CH-148 Cyclone Maritime Helicopter. The contract calls for the first full-rate production and deliveries starting in March 2008, expanding over a two-year period.

■ **Cascade Microtech** announced that it recently closed the single largest probe station order in its 23-year history —an order in excess of US $4 M to a prominent Asian memory manufacturer for S300 wafer probe stations. The sale continues Cascade Microtech's strong presence in the memory characterization and test market. The company attributes its success to its close relationship with customers. Cascade Microtech's investment in its Asia infrastructure, ongoing technology development and strong focus on customer responsiveness were the critical factors in winning the order.

■ **Millitech Inc.** has received a $3.7 M award for the design and development of a next generation Satellite Communications on the Move (SOTM) antenna system. The award is from the Army Communications-Electronics Research, Development and Engineering Center (CERDEC), and includes the delivery of five prototype systems. The antenna systems are mounted on moving vehicles such as HMMWVs. The novel Active Quasioptic Array (AQA) antenna system will significantly increase currently available communication capabilities.

■ **RF Industries**' RF Neulink Telemetry Division announced it has been awarded a second phase follow-on contract, valued at approximately $380,000, for its flagship NL6000 wireless modem from **Manufacturing Technology Inc.** (MTI), the successor system integrator for training systems (PM TRASYS), training products and services to the United States Marine Corps.

■ **Tadiran Batteries**, a manufacturer of lithium batteries, has been selected by **BAE Systems** to supply its TLM-1530HP lithium batteries for a project with the Defense Advanced Research Projects Agency (DARPA) Advanced Technology Office. The high power, CR2-sized batteries from Tadiran will support a program to convert 60-millimeter (mm) mortars into a precision-guided munitions system.

■ **Credence Systems Corp.** announced that **ELMOS**, a developer and producer of customer-specific system solutions for the automotive sector, has selected its FALCON systems for the testing of semiconductors used in automotive devices through 2010. With the design of automotive semiconductors becoming more cost-sensitive and integral to future success, the Germany-based semiconductor manufacturer will use the FALCON GLX from Credence to achieve industry-leading scalability, cost-performance and flexibility.

FINANCIAL NEWS

■ TA Associates, a private equity and buyout firm, announced that it has led a $113 M investment in **FreeWave Technologies**, an independent provider of high performance spread spectrum and licensed radio products and services in the industry.

■ **SiGe Semiconductor**, a supplier of RF front-end solutions for wireless systems, announced it has raised US $20 M in an expansion round of financing. Samsung Ventures, the US-based venture capital investment arm for Samsung Venture Investment Corp. (SVIC), joins as a strategic investor participating in this round. The capital will fund expansion of SiGe Semiconductor's product lines supporting the Wi-Fi, WiMAX and GPS markets.

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■ **Provigent**, a provider of System-on-a-Chip (SoC) solutions for the broadband wireless transmission market, announced that Ray Stata, a highly regarded co-founder and chairman of Analog Devices, will join its Advisory Board. In addition, Stata Venture Partners will contribute funding to Provigent's fourth-round of financing, which will increase to $17 M. Stata Venture Partners joins Provigent's existing technology investors: Sequoia Capital, Pitango Venture Capital, Globespan Capital Partners, Ascend Technology Ventures, Magma Venture Partners, Delta Ventures and Dr. Andrew Viterbi, co-founder of QUALCOMM.

■ **Reactive NanoTechnologies Inc.** (RNT), developer and manufacturer of its patented NanoFoil® announced it has secured $14.3 M in a Series C round of financing led by Siemens Venture Capital and existing investor, Sevin Rosen Funds. NanoFoil, a reactive nano-layered material that precisely controls the instantaneous release of heat energy for joining and reaction initiation applications, enables rapid joining of similar and dissimilar materials without incurring thermal damage. The company will use the funds to expand global sales, marketing and distribution, and for ongoing applications engineering and development.

■ **Merrimac Industries Inc.** reports sales of $5.4 M for the first quarter of 2007 ended March 31, 2007, compared to $6.2 M for the same period in 2006. Net loss for the first quarter was $1.3 M ($0.41/per share), compared to $441,000 ($0.14/per share) for the first quarter of last year.

PERSONNEL

▲ *Bami Bastani*

■ Nitronex, a developer and manufacturer of high performance RF power transistors for the commercial and broadband wireless infrastructure markets, has added **Bami Bastani**, president and CEO of ANADIGICS, to its board of directors. Recently honored as an inductee to the New Jersey High-Tech Business Leader 2007 Hall of Fame, Bastani brings a wealth of knowledge and experience to Nitronex. He is currently a member of the board of directors for Glowpoint Inc., and is also on the Advisory Boards for Electrical Engineering at Ohio State University and the College of Engineering at the University of Arkansas.

■ SEMX Corp., the parent company of Semiconductor Packaging Materials (SPM), announced the appointment of **Paul Nikac** and **Vito Tanzi** to the positions of executive vice president of the corporation. Their new responsibilities include management of all SEMX operational units following the retirement of Kenneth J. Huth. Nikac has been vice president-operations of SEMX/SPM since 2003 and Tanzi has served as vice president-sales of SEMX/SPM since 2005.

■ The IEEE has named **Carl Edward Baum** as the recipient of its 2007 Electromagnetics Award, recognizing his contributions to fundamental principles and techniques in electromagnetics. These contributions have led

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HFCN-1200+	1220-4600	910	1.99	•	
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HFCN-1320+	1400-5000	1060	1.99		•
HFCN-1500+	1600-5500	1250	1.99	•	
HFCN-1600+	1650-5000	1290	1.99		•
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HFCN-1810+	1950-4750	1480	1.99		•
HFCN-1910+	2000-5200	1400	1.99		•
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HFCN-2275+	2450-7000	1770	1.99	•	
HFCN-2700+	2650-6500	1800	1.99	•	
▲HFCN-2700A+	2900-8700	2150	2.99		
▲HFCN-3100+	3400-9900	2450	2.99		
▲HFCN-3500+	3900-9800	2800	2.99		
▲HFCN-3800+	4250-10000	3200	2.49		•
▲HFCN-4400+	5000-10100	3500	2.99		
▲HFCN-4600+	5000-11000	3800	2.99		
▲HFCN-5050+	5500-10000	4200	2.99		•
▲HFCN-5500+	6000-11500	4500	2.99		
▲HFCN-7150+	7900-11000	6150	2.99		
▲HFCN-8400+	9000-13000	6000	2.99		•
			Total number of units in kit:	40	50

HFCN Models: -3800+, -5500+, -8400+ Patent Pending

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Model	Passband MHz	Stopband MHz (Loss >20 dB) Min.	Price $ ea. Qty. 10	DESIGNER'S KITS (5 of each model) K1 99.95	K2 119.95	K3 109.95	K4 175.95	K5 129.95
LFCN-80+	DC-80	200	3.99			•		
LFCN-95+	DC-95	230	3.99			•		
LFCN-105+	DC-105	250	3.99			•		
LFCN-120+	DC-120	280	3.99			•		
LFCN-160+	DC-160	330	2.99					
LFCN-180+	DC-180	370	2.99					
LFCN-190+	DC-190	400	2.99					
LFCN-225+	DC-225	460	2.99	•		•		
LFCN-320+	DC-320	560	2.99	•		•		
LFCN-400+	DC-400	660	2.99	•		•		
LFCN-490+	DC-490	800	2.99	•		•		
LFCN-530+	DC-530	820	2.99	•		•		
LFCN-575+	DC-575	900	2.99	•		•		
LFCN-630+	DC-630	1000	2.99	•		•		
LFCN-800+	DC-800	1400	1.99		•		•	
LFCN-900+	DC-850	1275	1.99		•		•	
LFCN-1000+	DC-1000	1550	1.99		•		•	
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LFCN-1700+	DC-1700	2375	1.99		•		•	
LFCN-1800+	DC-1800	2425	2.99				•	
LFCN-2000+	DC-2000	3000	1.99		•		•	•
LFCN-2250+	DC-2200	2900	1.99		•		•	•
LFCN-2400+	DC-2400	3600	1.99		•		•	•
LFCN-2500+	DC-2500	3675	1.99					•
LFCN-2600+	DC-2600	3750	1.99					•
LFCN-2750+	DC-2750	4000	1.99					•
LFCN-2850+	DC-2800	4000	1.99					•
LFCN-3000+	DC-3000	4550	1.99					•
LFCN-3800+	DC-3900	6000	2.99					•
LFCN-4400+	DC-4400	6700	2.99					•
LFCN-5000+	DC-5000	6850	1.99		•		•	•
LFCN-5500+	DC-5500	7200	1.99					
LFCN-5850+	DC-5850	7600	1.99					
LFCN-6000+	DC-6000	8500	1.99		•		•	•
LFCN-6400+	DC-5400	8300	1.99					
LFCN-6700+	DC-6700	9300	1.99		•		•	•
LFCN-7200+	DC-7200	9500	1.99					
			Total number of units in kit:	35	60	55	90	65

LFCN Models: U.S. Patent 6,943,646 except LFCN-800+, -1325+, -2000+ & -2400+.

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to new target-identification algorithms, various high power electromagnetic pulse radiators, and techniques for analyzing the response of complex electronic systems to electromagnetic fields. The IEEE is the world's leading professional association for the advancement of technology. Sponsored by the IEEE Antennas and Propagation, Electromagnetic Compatibility, Microwave Theory & Techniques and Geoscience & Remote Sensing Societies, the award recognizes outstanding contributions to electromagnetics in theory, application or education.

REP APPOINTMENTS

■ **Richardson Electronics Ltd.** announced it has expanded its product distribution agreement with **RF Monolithics Inc.** (RFM) to include products from RFM's subsidiary, Cirronet Inc. The agreement, which covers North America and South America, now includes distribution of Cirronet's line of ZigBee™ WPAN modules, 802.15.4 modules, and proprietary wireless sensor networking modules and complementary products.

■ **Channel Microwave Corp.** announced the appointment of **Scientific Devices** as the company's sales representative in Pennsylvania, southern New Jersey and Delaware. Scientific Devices can be reached at: 1635 Clemens Road, Harleysville, PA 19438 (215) 256-8641 or www.scidev-phila.com.

■ Electronic component distributor **Digi-Key Corp.** announced the broad expansion of its **Infineon Technologies** product offering to include Infineon's power semiconductors, discretes, sensors, wireless control products, communication ICs and microcontrollers.

■ **ANADIGICS Inc.**, a provider of semiconductor solutions in the rapidly growing broadband wireless and wireline communications markets, announced **Electronic Sales Professionals Inc.** (ESP) as the manufacturer's representative for the Eastern Canadian Region. ESP will represent ANADIGICS' complete line of wireless and broadband products.

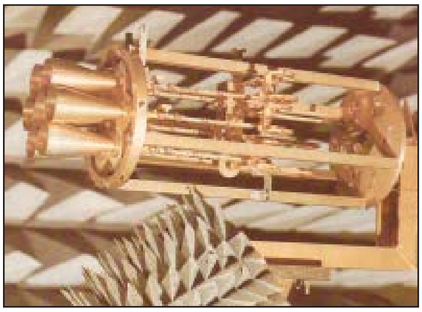
■ **TRAK Microwave Corp.** announced it has appointed **Telepro Inc.** to represent the company's products and services in Canada. Contact information: Telepro Inc., 230 Chemin du Golf , #409, Verdun, QC H3E 2A8, phone: (514) 667-7061, e-mail: hamo@telepro-inc.com or visit: www.telepro-inc.com.

■ **I.F. Engineering Corp.**, a manufacturer of high performance RF and microwave components and distribution systems, announced the appointment of **Sematron UK Ltd.** as its exclusive representative in the United Kingdom. Contact information for Sematron is: Sematron UK Ltd., Sandpiper House, Aviary Court, Wade Road, Basingstoke, Hampshire RG24 8GX, phone: +44 (0) 1256 812222, fax: +44 (0) 1256 812666, e-mail: sales@sematron.com or visit: www.sematron.com. In related news, **CrossPoint Technologies Inc.**, a manufacturer of high performance RF and microwave components and distribution systems, announced the appointment of Sematron UK Ltd. as its exclusive representative in the United Kingdom.

BEAM-FORMING NETWORK DEVELOPMENTS FOR EUROPEAN SATELLITE ANTENNAS

The development of multiple beams and reconfigurable antennas has always been tightly connected to that of beam-forming networks. The beam-forming network (BFN) is often the dominant component, the true "heart" of most multiple beams antennas. Beam-forming networks are complex networks used to precisely control the phase and amplitude of radio frequency (RF) energy passing through them, which is conveyed to the radiating elements of an antenna array. An example of a 20 GHz BFN developed by Selenia[1] (now Thales Alenia Space) for the European Space Agency (ESA) ASTP Program, circa 1982, is shown in ***Figure 1***. BFN configurations vary widely from just a few basic building blocks, up to tens of thousands of them depending on system performance requirements. A "fixed" BFN generates a time invariant set of spot beams of different shapes; in one such network, amplitude and phase coefficients are fixed at the time of design. A "reconfigurable" BFN allows on-orbit control of amplitude and/or phase excitation coefficients; this type of network, generating M beams and interfacing N radiating feeds, will need $M \times N$ control elements (variable phase shifters and variable attenuators). As far as passive BFNs are concerned, the choice of the transmission line technology depends on several parameters, such as operating frequency, bandwidth, power handling requirement, possibility of passive intermodulations and/or of multipactoring. At frequencies below C-band, TEM transmission lines are usually adopted (that is stripline, suspended microstrip and square coaxial line). The state-of-the-art of the TEM BFN technology is that of multi-layer, case-less microwave circuit design with inter-layer connections. The three-dimensional nature of the multi-layer approach allows flexibility in packaging topography as well as in the

Fig. 1 20 GHz beam-forming network developed by Selenia.



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European Space Agency
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M. LISI
Telespazio
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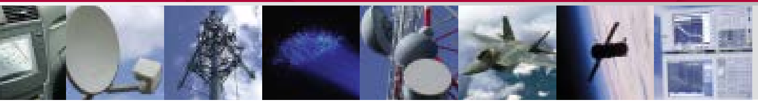
DIGITAL PHASE SHIFTERS



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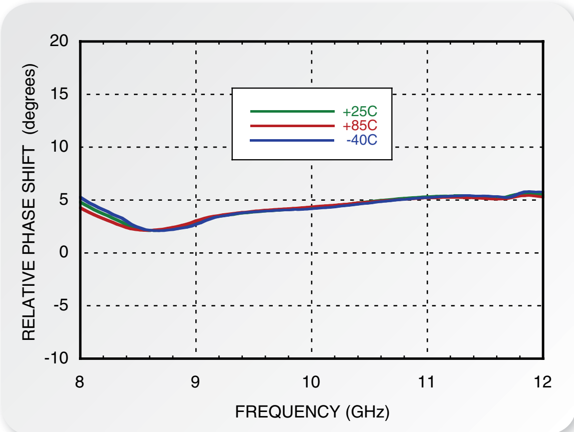
RMS Phase Error vs. Temperature



14 IN STOCK DIGITAL PHASE SHIFTERS COVERING 2.5 TO 18.5 GHz

Frequency (GHz)	Function	Insertion Loss (dB)	Phase Range (deg)	IIP3 (dBm)	Control Input (Vdc)	Package	Part Number
8 - 12	4-Bit digital	5	22.5 to 360	40	0 / -3V	Chip	**HMC543**
8 - 12	4-Bit Digital	6.5	22.5 to 360	37	0 / -3V	LC4B	**HMC543LC4B**
15 - 18.5	5-Bit Digital	6.5	11.25 to 360	42	0 / -3	Chip	**HMC644**
15 - 18.5	5-Bit Digital	7	11.25 to 360	42	0 / -3	LC5	**HMC644LC5**
2.5 - 3.1	6-Bit Digital	4	5.625 to 360	52	0 / +5	Chip	**HMC647**
2.5 - 3.1	6-Bit Digital	4	5.625 to 360	52	0 / +5	LP6	**HMC647LP6E**
2.9 - 3.9	6-Bit Digital	4	5.625 to 360	46	0 / +5	Chip	**HMC648**
2.9 - 3.9	6-Bit Digital	4	5.625 to 360	46	0 / +5	LP6	**HMC648LP6E**
3 - 6	6-Bit Digital	6.5	5.625 to 360	45	0 / +5	Chip	**HMC649**
3 - 6	6-Bit Digital	7	5.625 to 360	45	0 / +5	LP6	**HMC649LP6E**
9 - 12	6-Bit Digital	6	5.625 to 360	39	0 / -3	Chip	**HMC643**
9 - 12	6-Bit Digital	7	5.625 to 360	39	0 / -3	LC5	**HMC643LC5**
9 - 12.5	6-Bit Digital	6	5.625 to 360	42	0 / +5	Chip	**HMC642**
9 - 12.5	6-Bit Digital	6.5	5.625 to 360	42	0 / +5	LC5	**HMC642LC5**

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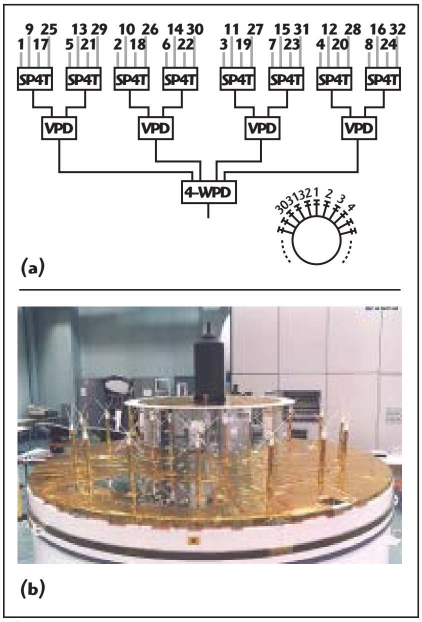
location of input and output ports. Utilizing a lamination process in autoclaves under high pressure and high temperature conditions, the multi-layer stack of “soft” material substrates is fused into a solid, high integrity assembly. At Ku-band and higher frequencies, waveguide BFNs are more often selected. In active phased-array antennas, beam-forming networks operating at IF frequencies have also been realized. The trade-off (in terms of mass, power consumption and overall complexity) between realizing the beam formation at RF or IF frequencies depends on the actual number N of array elements and the actual number M of beams to be generated. The adoption of digital signal processing architectures led to multiple beam antennas based on digital beam-forming (DBF) techniques. Such techniques allow the implementation of phased-array antennas (both in a Direct Radiating Array or in an Array-fed Reflector configuration) with full control of their potential capabilities, such as beam steering and shaping, interference rejection and nulling. A dedicated section needs to be devoted to the developments of Butler matrices and other beam-forming components for semi-active antennas, based on the multi-port amplifier concept. The aim of this article is to present a concise but systematic summary of the most important BFN principles and technologies. In doing that, the article will also describe the major developments performed in Europe on the subject.



▲ *Fig. 2 A reconfigurable BFN in a passive antenna; its (a) schematic and (b) L-band electronically despuned antenna.*

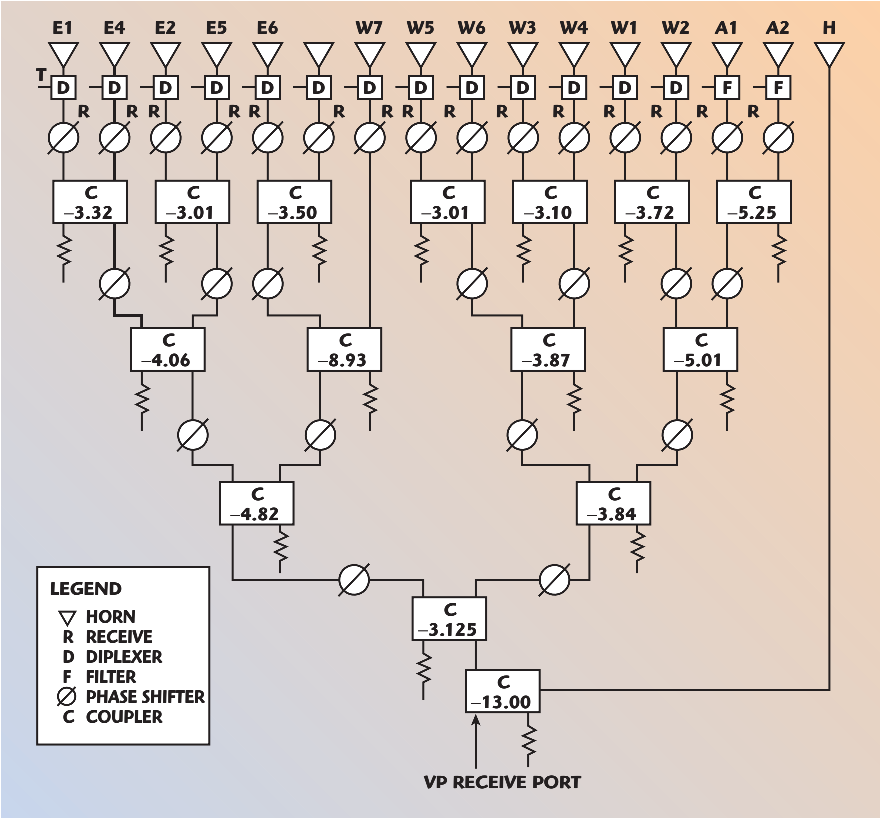
A PROPOSAL FOR A BEAM-FORMING NETWORK CLASSIFICATION

At present, a widely agreed and systematic classification for beam-forming networks does not exist. On the contrary, contradictory terminologies are quite often used, depending on the antenna systems in which the BFNs are included. A frequent confusion is generated by the indiscriminate application of the terms “passive” and “active” to both antennas and BFNs. An antenna is named “active” when each independently controlled radiating element (individual feed or subarray) is directly connected to the receive low noise amplifiers (LNA) or transmit power amplifiers (PA) amplifying modules. An active array antenna is usually a multiple beam antenna, but not necessarily reconfigurable or adaptive. On the other hand, many passive antennas exist that are reconfigurable and adaptive. ***Figure 2*** shows a schematic of a reconfigurable BFN in a passive antenna and an L-band electronically despuned antenna of Meteosat Second Generation from Thales Alenia Space.[2,3] It is therefore proposed to classify the beam-forming networks depending on their ability to generate steerable, reconfigurable or adaptive beams. Two main categories can be then identified: “fixed” (static) BFNs and “reconfigurable” (agile) BFNs. The main difference between a “reconfigurable” BFN with respect to a “fixed” one is the need for variable components: switches, variable attenuators, variable phase shifters and variable power dividers (VPD). The type of reconfigurability required, whether fast or slow, will drive the selection of the technology (electromechanical components, for instance, rather than fast-switching MMIC devices). All components in a BFN, both fixed (such as hybrid couplers, power splitters or transmission lines) and variable, will be equally affected by the passive or active nature of the antenna system they belong to. In beam-forming networks for passive antennas, power handling and losses are a major concern; this confines the available design options to a restricted number. In active antennas, where losses in the BFN are not a primary problem, a much wider range of technologies and techniques is available, leading to very lightweight and compact designs. From a technical viewpoint, beam-forming networks have been classified into four main families:

- Analog BFNs (either operating at RF or at IF frequencies)
- Spatial BFNs (such as lens antennas, reflective arrays, etc.)
- Digital BFNs, operating in the digital domain after an analog-to-digital conversion
- Optical BFNs, where optical techniques are applied to microwave modulated optical carriers.

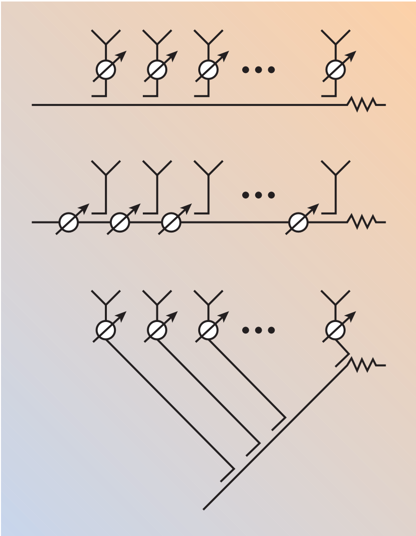
BEAM-FORMING NETWORK TOPOLOGIES

The fundamental problem in the design of any beam-forming network is that of achieving, at the N outputs of an RF network, a desired distribution of amplitudes and phases (excitation coefficients), in order to properly feed a corresponding number of radiating elements and obtain the required far-field composite pattern. It is evident from this definition that the basic components of a BFN are power dividers and phase shifters, either fixed or variable. Beam-forming network topologies can be divided in two main categories: lossless and lossy. A lossless topology is one that does not inherently foresee any power being dissipated in the network; should all components and the connecting transmission lines be ideal, that is lossless, then the overall network would be lossless itself. A lossy topology is one that foresees electrical losses as a way to achieve the required excitation coefficients. It can be shown that a lossless network can only produce a set of orthogonal excitation coefficients. In mathematical terms, this corresponds to saying that the scalar product of any two-excitation coefficients vectors is equal to zero. Lossless power divider networks can be of three main types: corporate dividers, serial dividers and Butler matrices. Corporate networks have a tree-like structure and usually divide into 2^N output ports, but odd-numbered power divisions are also feasible. They can be easily realized to deliver output signals in-phase with each other, by equalizing the path lengths



▲ *Fig. 3 Example of a corporate power divider network.*

from the input port to every output port. Their basic components, power dividers, can be power splitters (such as Wilkinson power dividers) or directional couplers (such as 90°, or quadrature, hybrids) (see ***Figure 3***). In serial networks, the output ports are connected to a common transmission line through each power divider. The amplitude distribution is adjusted by properly selecting the power-split ratio of the power dividers and the phase distribution by the path lengths. When the number of output ports becomes large, however, it is difficult to make each path length equal; therefore, the operating bandwidth narrows because of frequency scanning effects. Moreover, serial networks are more sensitive to errors deriving from their physical realization (see ***Figure 4***). Both corporate and serial networks can be realized with "matched" or "reactive" power dividers. Matched power dividers (as the already mentioned Wilkinson splitters or the 3 dB hybrids) contain isolation resistors and are able to cope with the variation of the impedance of the array elements as the beam is scanned. Reactive power dividers instead (such as T-junction power splitters) cannot prevent the propagation of the reflected signals and work best in fixed-beam operation, since it is not possible to match the elements of an array at all scan angles. A Butler matrix is a beam-forming network consisting of interconnected fixed phase-shift sections and 3 dB hybrid couplers.[4] The matrix produces N orthogonal sets of amplitude and phase output coefficients, each corresponding to one of the N input ports. A Butler matrix performs a dis-



▲ *Fig. 4 Serial power divider networks.*

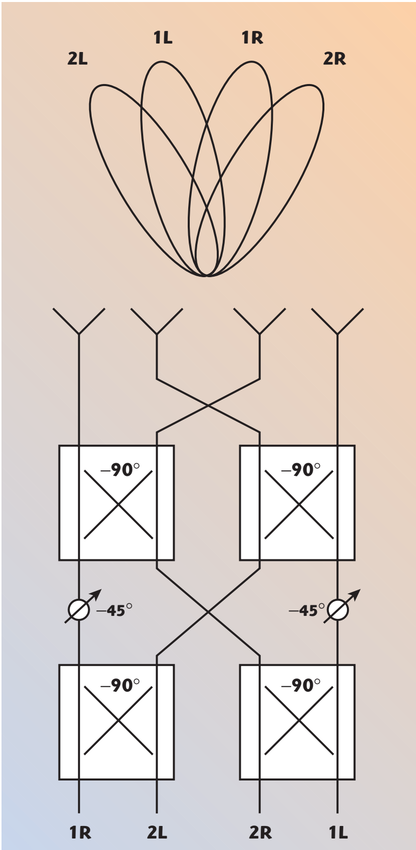
crete Fourier transform; it is, in fact, a hardware analog of the FFT radix-2 algorithm (see ***Figure 5***).

Butler matrices are used in multiport amplifiers[5–7] and in semi-active antenna configurations (see ***Figure 6***).[8,9] They can also be applied to the realization of beam-forming networks for two-dimensional arrays. A two-tier configuration is adopted: an upper tier beam-forming matrix (BFM), based on a two-dimensional Butler matrix, and a lower tier beam combining network (BCN), such as a multiple layer stripline circuit, combining a number (typically seven) of orthogonal beams (beamlets) to form a shaped "composite" beam ("beam synthesis" technique). It is worth mentioning two BFN topologies more often used for the realization of radar antennas: the Rotman lens and the Blass matrix. The Blass matrix consists of a number of travelling-wave feed lines connected to a linear array through another set of lines. The two sets of lines are interconnected by directional couplers at their cross over points. Despite its flexibility, the Blass matrix is normally used only in active antennas, because its physical realization usually results in high losses.

Before the advent of digital beam-forming techniques, analog beam-forming networks operating at IF frequencies were also considered. ***Figure 7*** shows the block diagram of the IF BFN designed and manufactured by Marconi SDS (now EADS Astrium Ltd.) for the ESA Multi-beam Array Model (MAM) project.[10] The BFN was based on the resistive matrix method, whereby the required phasing was obtained by combining samples of quadrature-phased beam signals through resistive summing networks at each node.

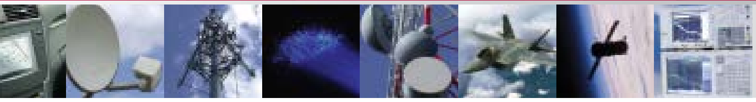
BEAM-FORMING NETWORK TRANSMISSION LINES

In the design of a BFN, the choice of the transmission line has to be taken after considering several parameters, such as operating frequency, bandwidth, power handling requirements, producibility, risk of passive



▲ *Fig. 5 Four-by-four Butler matrix.*

MMIC SWITCHES



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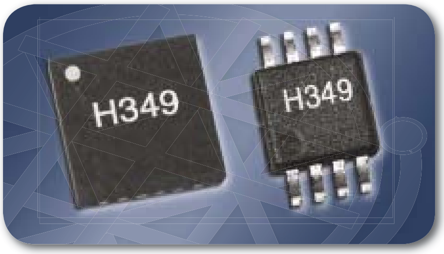

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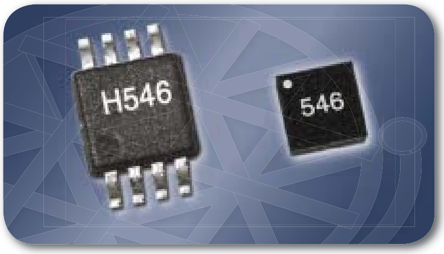

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	DC - 4	SPDT, Hi Isolation	0.9	65	31	52	**HMC349LP4CE**
	DC - 4	SPDT, Hi Isolation	0.9	57	31	53	**HMC349MS8GE**
	DC - 12	SPDT, Hi Isolation	1.5	55	27	50	**HMC232LP4E**
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	0.824 - 0.894	SPDT, 10W, T/R	0.6	22	> 40	65	**HMC446E**
NEW!	0.1 - 2.1	SPDT, 40W, Failsafe	0.4	20	46	74	**HMC646LP2E**
	DC - 3	SPDT, 3W, T/R	0.3	30	37	65	**HMC595E**
	DC - 3	SPDT, 5W, T/R	0.3	30	39	65	**HMC574MS8E**
	DC - 3	SPDT, 10W, T/R	0.5	30	> 40	72	**HMC484MS8GE**
	DC - 4	SPDT T/R	0.25	23	39	55	**HMC544E**
NEW!	DC - 6	SPDT T/R	0.6	27	37	54	**HMC536LP2E**
	DC - 6	SPDT T/R	0.5	27	37	56	**HMC536MS8GE**
	5 - 6	SPDT T/R	1.2	31	33	37	**HMC224MS8E**

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intermodulations and of multipaction discharge. When high power levels are considered and at high frequencies (Ku-band and above), waveguide technology is usually preferred, because of its unsurpassed performance in terms of low insertion losses and high power handling. Waveguide BFNs are usually realized in a multi-layer, clam-shell configuration. Each layer is machined as two mirror-image halves, with the waveguide cut along the middle of its wide dimension, where no current flow exists. The waveguide runs are obtained from billets of high stability aluminium alloy with numerically controlled milling machining. The realization of critical areas (such as where coupling occurs) is often obtained by electro-erosion. Once completed, the two halves of a layer are dowelled and bolted together. ***Figure 8*** shows a waveguide BFN from Thales Alenia Space[1] and a wideband Butler matrix from telecom Italia Lab.[11] At lower frequencies (C-band and below) waveguides are rather bulky. TEM transmission lines are a suitable alternative, in particular suspended-substrate line and square coaxial line ("squareax"), both of which are very

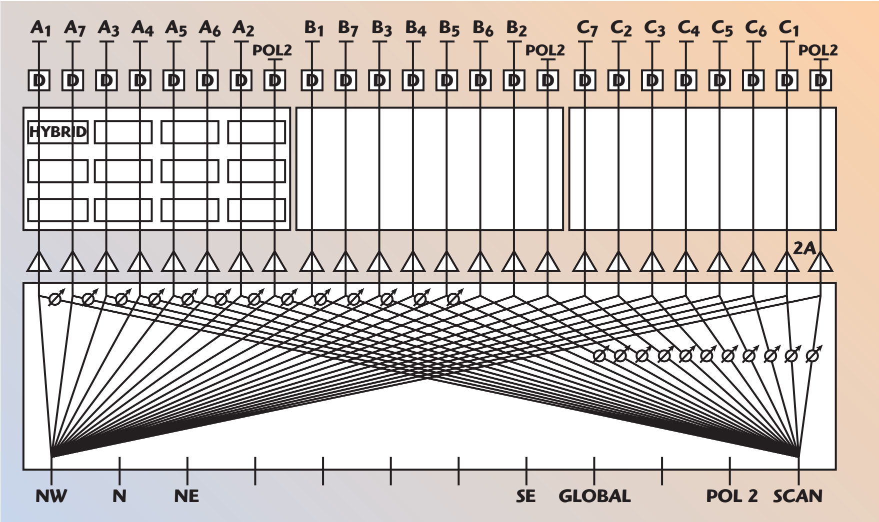


Fig. 6 Typical multi-matrix configuration for semi-active antennas.

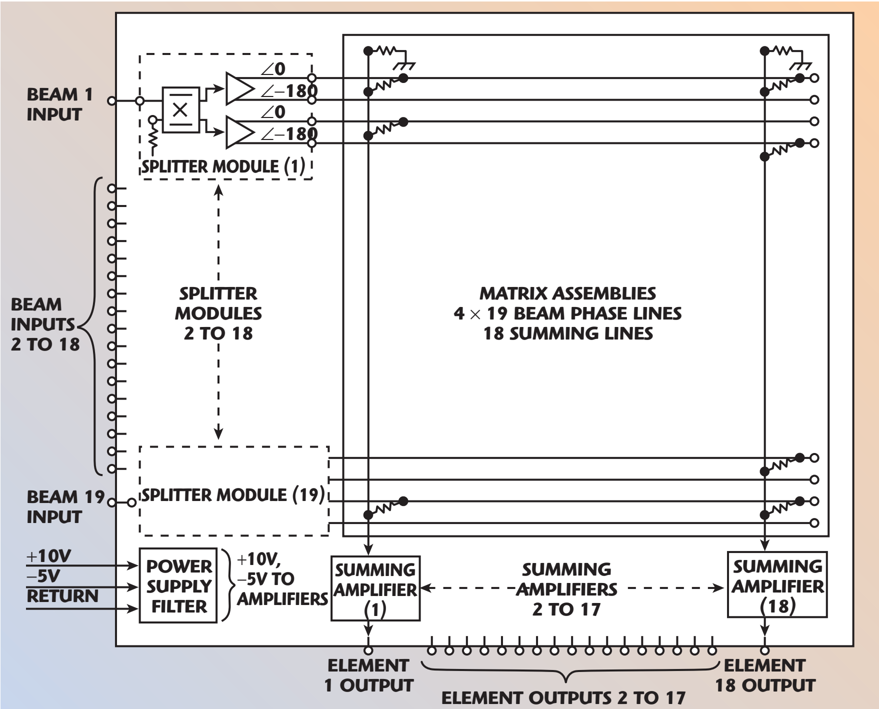


Fig. 7 MAM resistive matrix BFN.

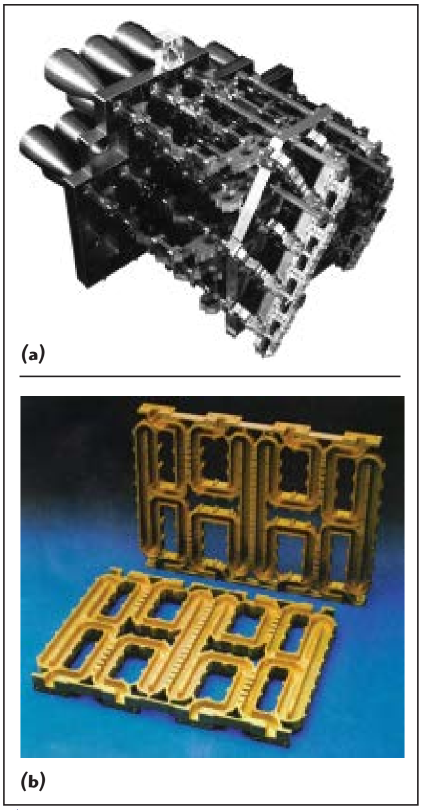


Fig. 8 Examples of (a) a waveguide BFN and (b) a wideband Butler matrix.

Fig. 9 C-band TEM line BFN.

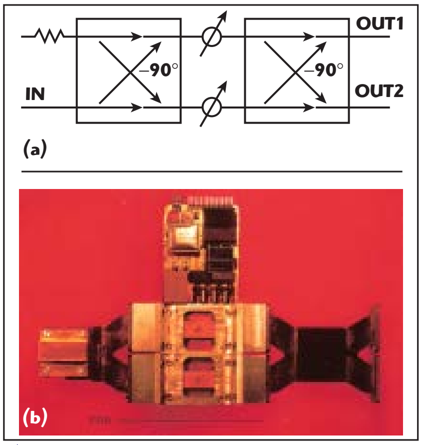
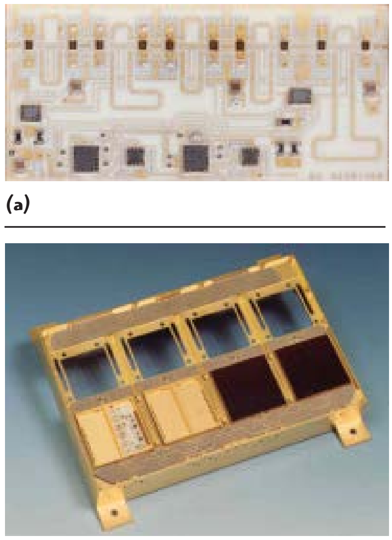


Fig. 10 Ku-band ferrite variable power divider's (a) schematic and (b) realization.

low loss and compact. ***Figure 9*** shows an Intelsat IX C-band TEM line BFN from EADS-Astrium GmbH.[12] Whenever losses are not of major concern (such as in active antennas), printed circuit TEM technologies, such as microstrip and stripline (either on "soft" or ceramic substrates), are widely adopted in the realization of control components and in that of dividing/combining networks. The state-of-the-art of printed circuit BFNs technology is that of multi-layer microwave circuit design with inter-layer connections. The three-dimensional nature of the multi-layer approach allows flexibility in packaging topography as well as input/output port location. Utilizing a lamination process in autoclaves under high pressure and high temperature conditions, the multi-layer stack of "soft" material substrates is fused into a solid, high integrity assembly.

BEAM-FORMING NETWORK COMPONENTS

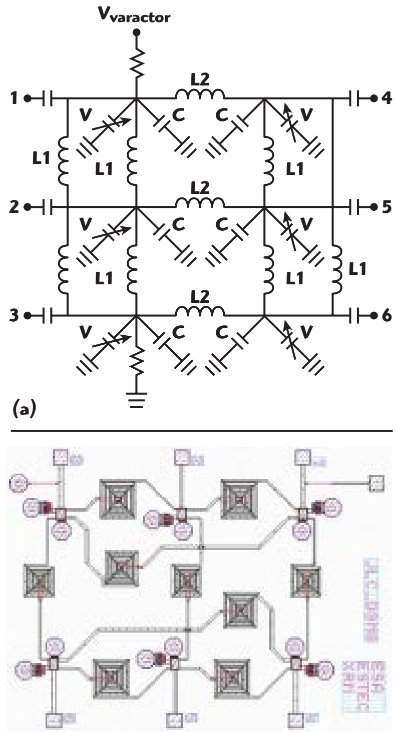
The realization of the beam-forming network for a multiple beam or reconfigurable antenna requires a wide range of microwave components, spanning from passive hybrid couplers and power splitters to variable power dividers (VPD) and vari-



(a)

(b)

▲ *Fig. 11 S-band MIC switched-line phase shifter (a) and 16-way assembly (b).*



(a)

(b)

▲ *Fig. 12 Three-by-three coupler cell with MESFETs for capacitance error tuning; a Polyphase network (a) and MMIC layout (b).*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VLF-80	DC-80	145	200	VLF-1525	DC-1525	1750	2040
VLF-95	DC-95	165	220	VLF-1575	DC-1575	1875	2175
VLF-105	DC-105	180	250	VLF-1700	DC-1700	2050	2375
VLF-120	DC-120	195	280	VLF-1800	DC-1800	2125	2425
VLF-160+	DC-160	230	330	VLF-2250	DC-2250	2575	2900
VLF-180+	DC-180	270	370	VLF-2500	DC-2500	3075	3675
VLF-190+	DC-190	280	400	VLF-2600	DC-2600	3125	3750
VLF-225	DC-225	350	460	VLF-2750	DC-2750	3150	4000
VLF-320	DC-320	460	560	VLF-2850	DC-2800	3300	4000
VLF-400	DC-400	560	660	VLF-3000	DC-3000	3600	4550
VLF-490	DC-490	650	800	VLF-3800+	DC-3900	4850	6000
VLF-530	DC-530	700	820	VLF-4400+	DC-4400	5290	6700
VLF-575	DC-575	770	900	VLF-5000	DC-5000	5580	6850
VLF-630	DC-630	830	1000	VLF-5500+	DC-5500	6200	7200
VLF-800	DC-800	1075	1275	VLF-5850+	DC-5850	6540	7600
VLF-1000	DC-1000	1300	1550	VLF-6000	DC-6000	6800	8500
VLF-1200	DC-1200	1530	1865	VLF-6400+	DC-6400	7200	8300
VLF-1400	DC-1400	1700	2015	VLF-6700	DC-6700	7600	9300
VLF-1450	DC-1450	1825	2025	VLF-7200+	DC-7200	8150	9500
VLF-1500	DC-1500	1825	2100				

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High Pass *VHF Models $24.95 ea. (1-9)*

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VHF-650	710-2490	650	480	VHF-2275	2450-7000	2275	1770
VHF-740	780-2800	740	550	VHF-2700	2650-6500	2500	1800
VHF-880	950-3200	880	640	VHF-2700A+	2900-8700	2700	2150
VHF-1200	1220-4600	1180	940	VHF-3100+	3400-9900	3100	2450
VHF-1300	1400-5000	1300	930	VHF-3500+	3900-9800	3500	2800
VHF-1320	1400-5000	1320	1060	VHF-3800	4250-10000	3800	3200
VHF-1500	1600-5500	1550	1250	VHF-4400+	5000-10100	4400	3500
VHF-1600	1650-5000	1600	1290	VHF-4600+	5000-11000	4600	3800
VHF-1760	1900-5500	1760	1230	VHF-5050+	5500-10000	5050	4200
VHF-1810	1900-4750	1810	1480	VHF-5500	6000-11500	5500	4500
VHF-1910	2000-5200	1910	1400	VHF-7150+	7900-11000	7150	6150
VHF-2000	2260-6250	2000	1530	VHF-8400	9000-13000	8400	6000
VHF-2100	2200-6000	2100	1530				

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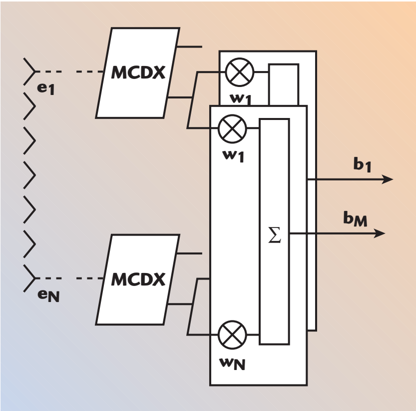
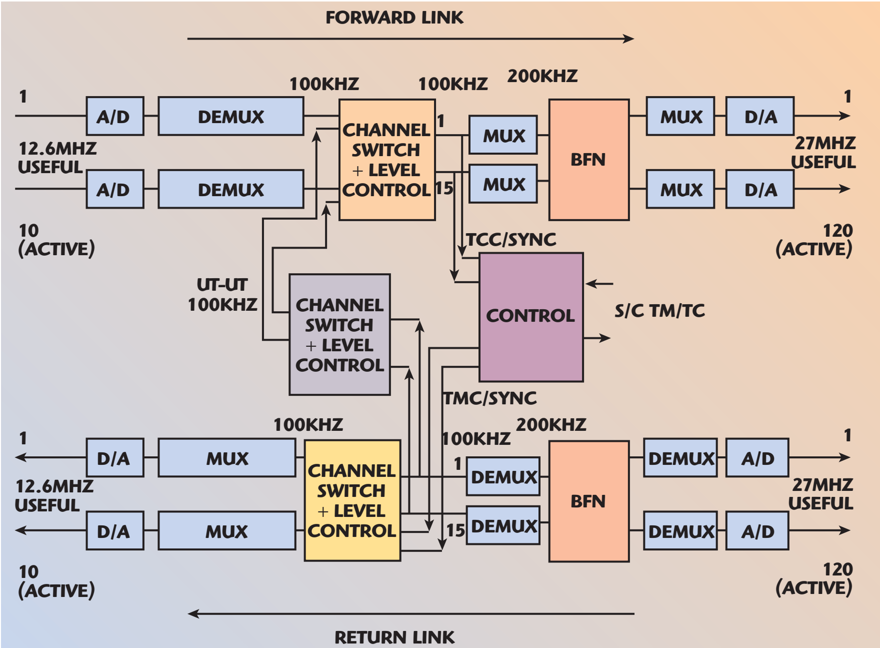


▲ *Fig. 13 Rx digital beam-forming network (DBFN).*

able phase shifters (VPS) (see ***Figures 10*** and ***11***). Therefore, the design and realization of a BFN needs an uncommon synergy of both conventional and advanced technologies (such as MMIC, MEM, ASIC), aiming not only at a very high degree of integration between RF and digital control functions, but also at the reduction of mass, dimensions, power consumption and cost. The use of MMIC technology has also been



▲ *Fig. 14 INMARSAT 4 processor architecture.*

proven to be highly effective in extending the dimensionality of Butler matrices for L/S-band direct radiating arrays applications. Polyphase networks, based on lumped constant capacitors and inductors, can replace the phase-shifting transfer characteristic of transmission-line Butler matrices. Basic MMIC cells, such as the three-by-three coupler cell from Dassault Electronics (now Thales) shown in ***Figure 12***, are suitable building blocks that, when appropriately interconnected in multi-layer structures, can constitute large order matrices while preserving low mass and volume characteristics.[13]

DIGITAL BEAM-FORMING NETWORK TECHNOLOGIES

Digital beam-forming (DBF) techniques have been successfully pioneered in the eighties for mobile narrowband applications.[14–16] The advantages of a digital implementation include precision, predictability and freedom from factors such as ageing, drift and component value variations. DBF methods are also particularly appropriate to match the upcoming trend of digital on-board processing payloads. DBF can be implemented both in transmit and receive; in both cases, amplitude and phase control elements of analog BFN realizations correspond to complex multiplications of the digitized signals, followed by summation (as well as digital interpolation as substitutes to analog true-time-delay). When the beams' bandwidth is lower than the total feed bandwidth (as in the case of frequency reuse schemes) the most effective architecture consists of performing demultiplexing of each wideband feed signal into narrower-band signals, and then performing beam synthesis at a lower sampling rate (see ***Figure 13***).

Nowadays DBF is commercially available on several mobile satellites operating at L-band, and the INMARSAT 4 processor (EADS Astrium first satellite successfully launched on 11 March 2005), shown in ***Figure 14***, represents the major outcome of ESA funded R&D programs on DBF.[17]

CONCLUSION

This article reviewed the basic concepts and techniques of beam-forming networks for satellite multiple beams and reconfigurable antennas. In so doing, some major developments performed in Europe on the subject have been described. Many of these developments were oriented to satellite missions (Meteosat, Eutelsat, Inmarsat, just to name a few) and sponsored by the European Space Agency. Today, Europe faces important and time-critical challenges relating to its independence and competitiveness in analog and digital beam-forming technologies. Maintaining and expanding

development and production capabilities, as well as acquiring real strategic independence in these key areas will be the challenge of the European space industry for years to come. ■

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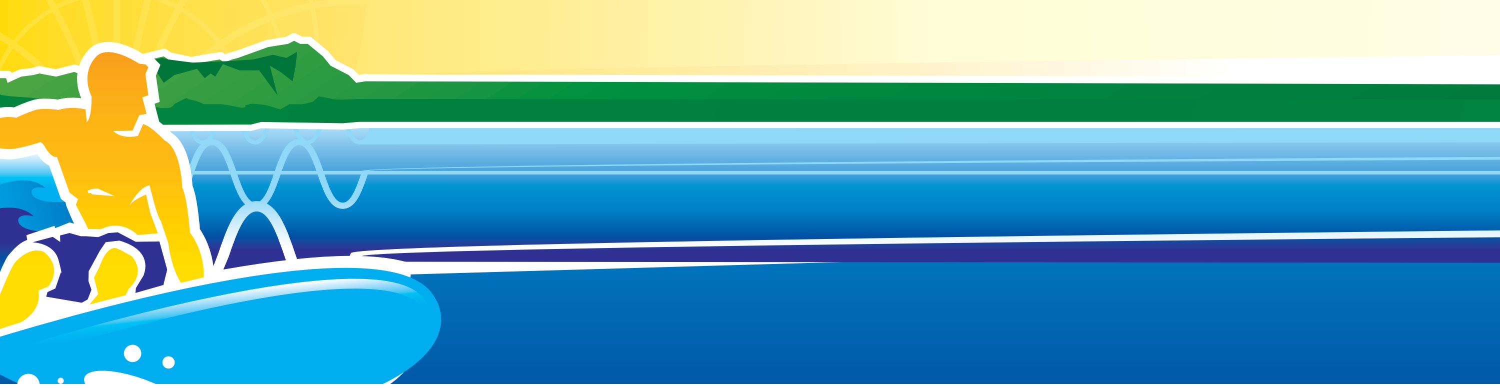
Marco Lisi *is presently chief scientist at Telespazio SpA, Rome, Italy, a company of the Finmeccanica group. He has worked for 27 years in the aerospace and telecommunications sectors, covering managerial positions in research and development, engineering and programs. He spent two periods of his professional life as a staff member of the European Space Agency (ESA) and three years in Palo Alto, CA, with Space Systems/Loral.*



IMS 2007: Reflections from Hawaii

IMS 2007 certainly set at least one record—it was the most enjoyable location this yearly event has had thus far. We're sure virtually all of the attendees and guests would agree that the beach was incredible, the weather fabulous, the accommodations superb and the convention center comfortable and accommodating. Microwave Week attracted 6952 attendees—not a record attendance by any means, but certainly a respectable turnout considering its remote location.

This year's success was a direct result of a lot of hard work by the 2007 general chair, Wayne Shiroma, and his very capable staff of volunteers that labored throughout the year to make this event a memorable experience. The symposium attracted 2392 delegates for the comprehensive technical program, a result that was more than a satisfying reward for their efforts. Congratulations should go to Wayne and his staff for a job well done.

Congratulations should also go to the general chair of the 2007 RFIC Symposium, Luciano Boglione, and his staff, and Dominique Schreurs, the general chair of the ARFTG Measurement Conference, and his team.

The theme this year was "Microwaves Across the Pacific" and it was particularly noteworthy that here was the first real military application of radar during that infamous Sunday in 1941 at Pearl Harbor. The world of microwaves came into its own after that fateful day.

The Technical Program

The technical symposium kicked off with two inspiring talks during the Plenary Session. Anil Kripalani, Sr. Vice President for Global Technology Affairs for Qualcomm, spoke of "The Future of Mobile Broadband," while Ryuji Kohno, Director of the Center of Medical Information and Communication Technology for Yokohama National University, talked of "The Next Direction of Advanced Wireless Communication Technology – Medical ICT."

The Honolulu venue certainly did not take away from the traditional depth and quality of the technical program. Tatsuo Itoh, this year's Technical Program Chair, and his team assembled a superb technical program of 523 oral presentations in seven parallel program sessions, seven panel sessions and four interactive forums comprised of 142 individual papers, and 47 workshops and short courses.

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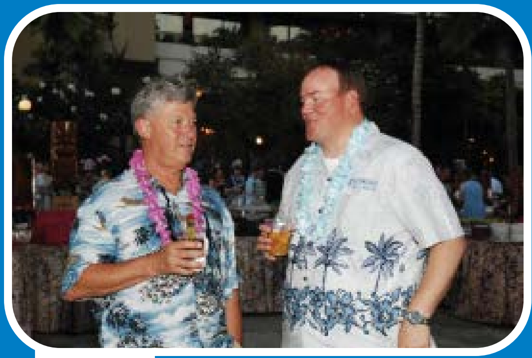
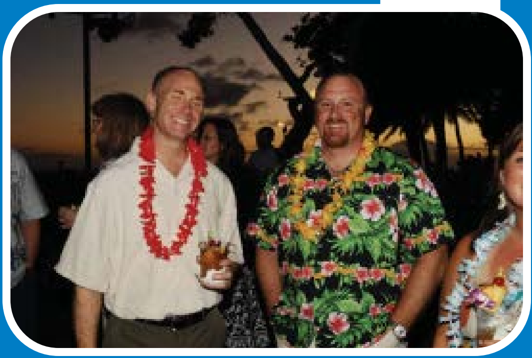




The Social Program

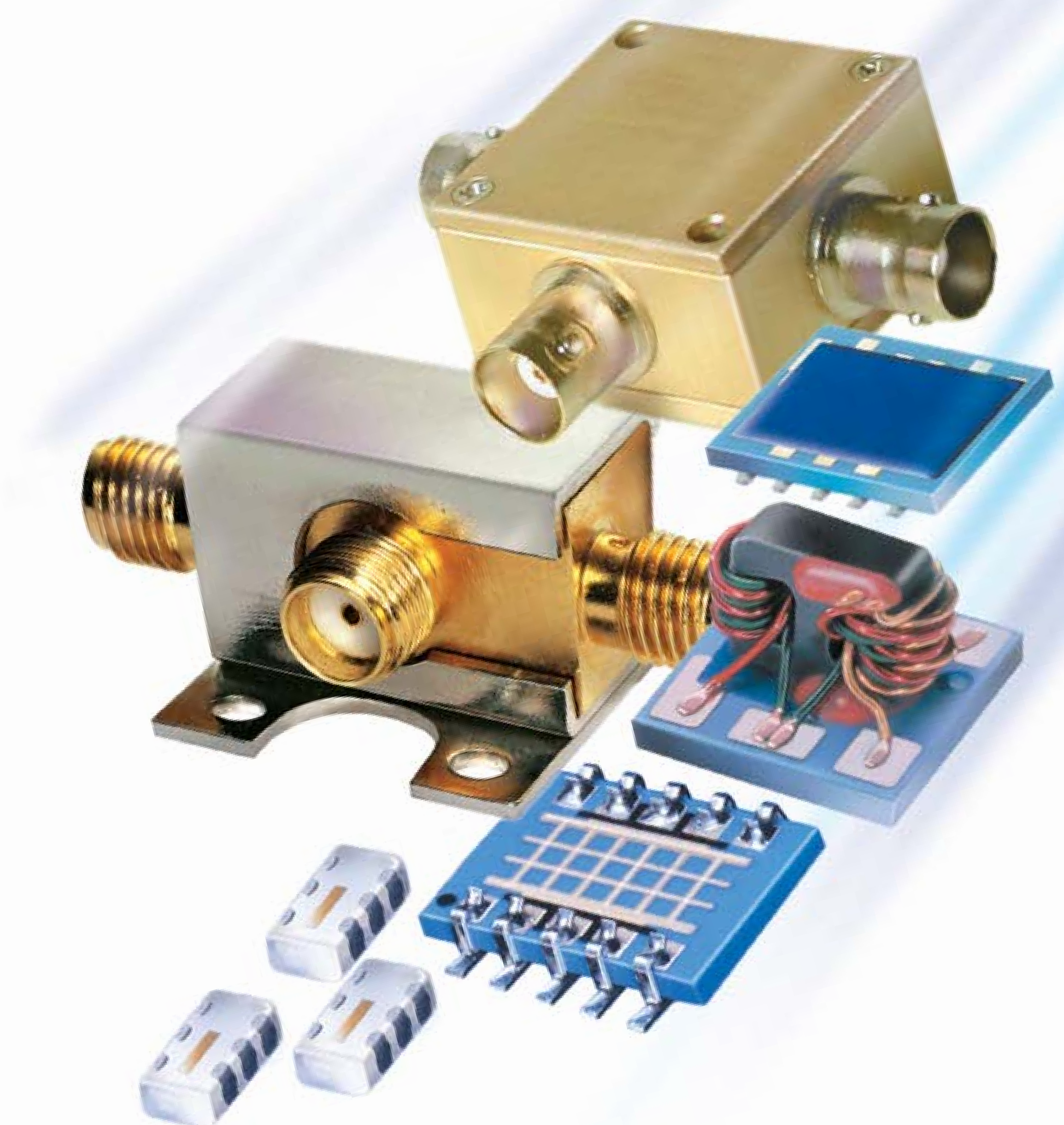
The social program kicked off with the traditional MTT-S/*Microwave Journal* Reception on Monday evening in the ballroom of the Honolulu Convention Center, where old friends and colleagues reacquainted. The Women in Microwaves Reception was held Tuesday evening, as was the Student Reception. Wednesday was the Industry-hosted Cocktail Reception followed by the MTT-S Awards Banquet. In addition, there was an extensive Guest Program that included a day trip to Maui and many other trips and tours. This had to be one of the best symposiums for playing tourist.

The Industry Exhibition

Over 300 companies made the long trip to Hawaii to showcase their new products and make new business contacts. It wasn't a record turnout, but for the companies that were there it had to be considered a good return on an enjoyable investment. There was an impressive line up of new products from some of the leading companies in the microwave industry. The IMS 2007 Industry Exhibition highlighted several key introductions from exhibitors around the globe. In addition, *Microwave Journal* published an online show daily sponsored by **Agilent**, **M/A-COM** and **RFMD** that highlighted many of the latest product entries being introduced. A comprehensive listing of those new product releases can be viewed on the *Microwave Journal* Web site at www.mwjournal.com/IMSProducts. A montage of photos from the Industry Exhibition appears on pages 78 and 79.

New Year, New Venue: Atlanta

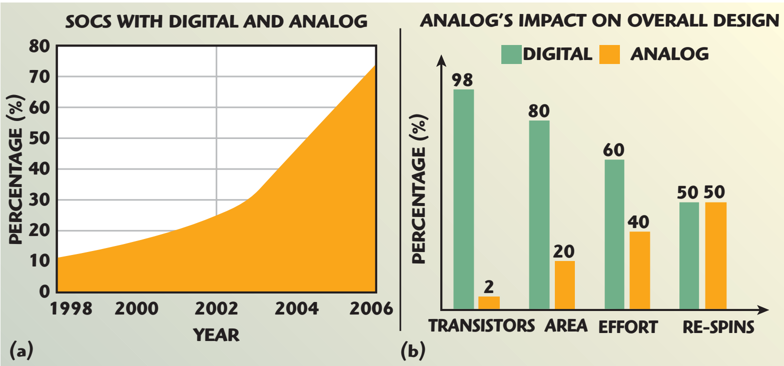
Next year Microwave Week returns to the East Coast. IMS 2008 will be held in Atlanta, GA, June 15 to 20. Atlanta is a great convention city and will no doubt be a gracious host to our annual event. We hope to see you all there next year. ■



RF-A/MS IC FUNCTIONAL VERIFICATION: REQUIREMENTS AND METHODOLOGY

To address the space, cost and power-consumption constraints of mobile portable devices from cell phones to PDAs and laptops, the trend in RFIC design is to combine the analog baseband (BB) and processor interface into a single chip solution (see ***Figure 1***). With new products experiencing narrow market-windows and shorter product life cycles, wireless applications are increasingly faced with the need to achieve "First Pass Functional Silicon." Silicon re-spins that are most often due to functional errors on average cost $1 M for 90 nm and below.

Fig. 1 SoC composition comparing analog-to-digital blocks (a) and the effect on first-pass design failure (b) (Aurangzeb Khan, Cadence, presented at the IEEE SSCS, Sept. 2003).



Meanwhile, system demands on RFIC functionality, as multi-band and multi-mode operations, for example, further complicate this objective. In order to increase RFIC "functionality and features" while ensuring greater first-pass success, design organizations are adding new design skills, software tools and design data structures to their existing flows. In this article, the author discusses his first hand experience working with design organizations as they face the challenges of developing the models, simulation capability and automation that will accurately verify the behavior of a device operating across the RF to digital domains.

DIGITAL-ORIENTED A/MS TO TRUE MIXED-SIGNAL FUNCTIONAL VERIFICATION

Advanced simulation capacity, model/design (silicon) accuracy and cross domain (time and frequency) capability are critical in addressing the engineering challenges associated with integrating analog, RFIC, custom digital

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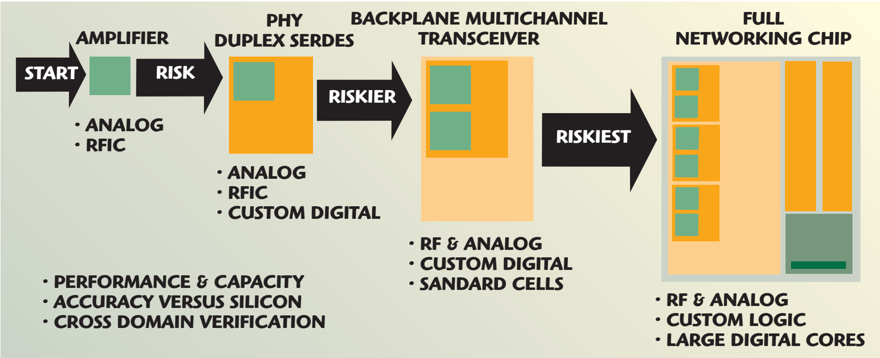
Cadence Design Systems Inc.
San Jose, CA

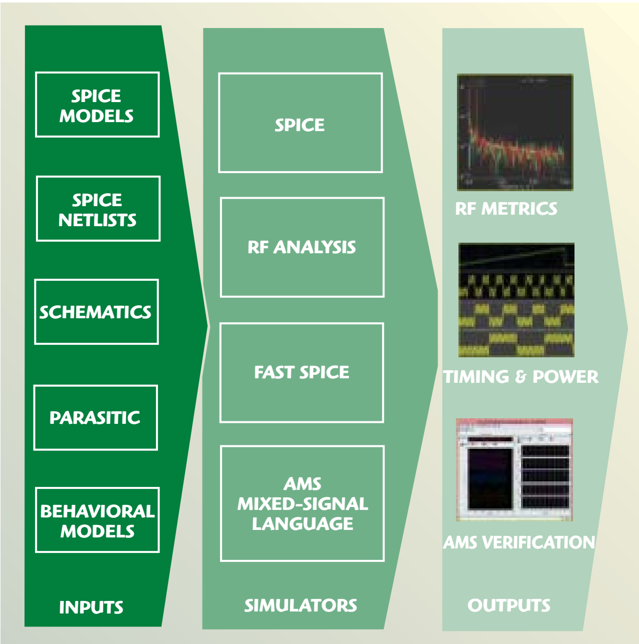


▲ *Fig. 2 Emerging SoC custom design flow with higher levels of integration being performed over time.*

and large digital cores (in system-on-chip) (SoC) designs (see ***Figure 2***). A top-down design methodology, which includes block-level specification and compliance sign-off, strategically combined with full-chip functional verification for RF-A/MS (radio frequency and analog mixed-signal) applications can help to enable First Pass Performance silicon and is thus emerging as a necessary step before final tape-out. The concept of full-chip functional verification for RF-A/MS ICs is relatively new.

Today, many organizations developing SoCs are reviewing their existing digital IC functional verification methods as a guide for developing full-chip RF-A/MS functional verification within their wireless RFIC design environment. In prior years, (digital) functional verification teams would code transactional behavior for RF/analog/mixed-signal sections of an IC using digital behavioral languages such as Verilog or VHDL. This code (sometimes referred to as “dummy analog”) would provide a degree of block-to-block connectivity checking, modeled with some block-delay characteristics of the digital and analog interfaces (A/D and D/A converters). However, since true mixed-signal simulation and top-down design are not an integral part of this mixed-signal verification procedure, design errors at the mixed-signal interfaces quite often went undetected before the IC was fabricated and tested.

Digital functional verification teams also experienced a significant slow-down in their simulation times (or test suite execution) when analyzing analog/mixed-signal blocks that were represented with Verilog-A behavioral models as opposed to simple, less accurate transaction code such as Verilog or VHDL. This reduction in simulation speed is due to the greater number of data points required for a continuous-time analog simulation of Verilog-A models compared to a discrete time digital solver using Verilog or VHDL.



▲ *Fig. 3 Modeling inputs, simulator types and typical outputs for multi-mode simulation-based full-chip verification.*

By containing the A/D and D/A interfaces within a model, mixed-signal behavioral languages such as Verilog-AMS and VHDL-AMS are able to provide excellent simulation efficiency with very accurate analog/mixed-signal block behavior. The advent of mixed-signal simulators such as AMS Designer from Cadence and standardization of mixed-signal behavioral languages (Verilog-AMS and VHDL-AMS) opened the door for both RF to baseband, top-down design and full-chip functional verification (see ***Figure 3***).

The demand for a full-chip functional verification methodology among RFIC (mostly RF/analog with a small amount of digital) and a/ms (complex, multi-million device radio and baseband) design groups is growing. Due to practical considerations, two distinct design verification methodologies have emerged depending on the focus of the design team. For RF-A/MS ICs with an emphasis on digital complexity, functional verification is being merged with digital verification CAD tools and methodologies (for example, assertion-based verification, coverage verification, et al.). In contrast, RF-A/MS ICs with little justification for dedicated digital verification will rely more on existing RFIC EDA tools and design methodologies for functional verification.

MODEL DEVELOPMENT AND CHARACTERISTICS

RFIC design groups utilizing true mixed-signal simulation technology as part of a top-down design methodology (system-level behavioral modeling) are generally better prepared to adopt a full-chip functional verification methodology. In addition to familiarity with top-down and bottom-up design process and practices, organizations with behavioral model language development and applicable model coding skills and established setup and characteristic simulation behavior of mixed-signal simulators will find it easier to implement RF-A/MS functional verification. Groups such as the IBM Silicon Solutions Engineering and IP Development team that are dealing with a broad range of designs every day, from high end foundry devices to memories, SERDES, standard cells, I/Os, cores and microprocessors have verification technology in place that is based on multi-mode simulation in-

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The primary technology enabler for RF-A/MS functional verification is a FVM (functional verification model) using languages: Verilog-A, Verilog-AMS or VHDL-AMS. As soon as chip-level definition, block-to-block integration, and block-boundary and pin definition is established, functional verification can begin.

The FVM development and testing process steps include:

- Developing block-level specifications for FVMs
- Developing FVMs and validating vs. circuit schematics
- Integrating and testing FVMs into various levels of hierarchy
- Performing full-chip functional verification

FVM MODEL REQUIREMENTS

Before developing the model specification for functional verification, it is important to determine the component's functionality as it relates to IC design complexity and which behaviors need to be simulated. If the design effort of the RF-A/MS IC is weighted toward the analog/mixed-signal, then it is highly probable that the FVM should contain "dual-functionality" in order to accommodate the following functional verification testing requirements:

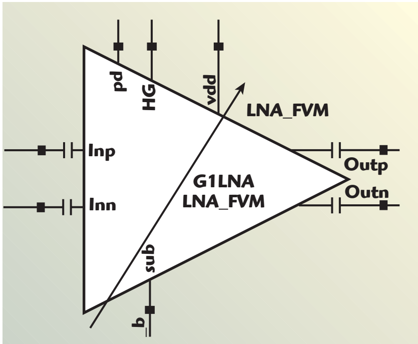
1. FVM functionality should support the digital solver in order to perform fast simulations that are used to check for overall: power-up, supply, bias and clock distributions, chip state conditions from processor interface control (or on-board CPU control), etc. The FVM functionality for this type of verification test suite is termed "DC static functionality."
2. As the IC database and block-designs become more complete, the FVM must support more time consuming tests to verify functionality of block-to-block signal quality transformation. Therefore, at the command-line the "signal quality functionality" of FVM can be selected for execution.

FVM specification for a block defines all the attributes for a given component with regard to its appearance in the design capture environment, electrical connectivity and behavior, and simulation control. It should be noted that the FVM specification is a dynamic document, but is typically frozen when the block boundary is frozen, which means block architecture in and around the block of interest is firm. The FVM Specification document is definitely frozen when FVM is validated against the circuit schematic.

A typical block model includes a functional description, block diagram, specification table, P_{in} description table, assertion list and behavioral model objectives and features. An example of the behavior objectives and features for a FVM specification is shown in ***Figure 4***. This FVM defines an LNA component that was used in an 802.11b/g IC design. The FVM is based on the Verilog-AMS language. The symbol for using the LNA in a top down design is shown in ***Figure 5***. Since functional verification may involve a "suite" of tests to be performed, it is important to obtain accurate functionality and assertion behavior, while ensuring the fastest verification simulation throughput possible.

FVM Behavior Objectives & Features
LNA: This is a simple model for Low Noise Amplifier built for Functional Verification
Figure A. Block Diagram with Pin-out
FEATURES:
The features of this model are:
— Simple LNA Operation
— Input and Output signals 'wreal' discrete discipline in order to take advantage of speed and still achieving accurate functionality
— Supply signals are analog
— Power down signal, 'pd', is logic
— Gain calculation is based on interpolated table model. The function used to accomplish this is $table_model and the gain magnitude closely matches the device-level output
— Assertions are built in. Checks for the status of power supply signals Vdd and sub when it goes
• below normal acceptable level
• returns back from abnormal condition
The input signal levels are limited by the tanh curve with measured saturation factor for each input
LIMITATIONS
This model does not include
— second-order effects
— IP3, P1dB, or NF
— Input/Output impedance since it is based on 'wreal' discrete disipline
...end LNA FVM specification example

▲ *Fig. 4 Behavior objectives and features for an LNA functional verification model.*

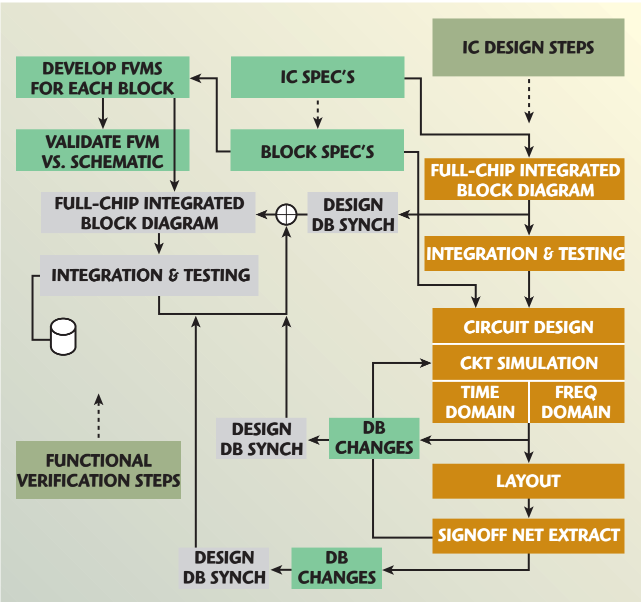


▲ *Fig. 5 Block diagram of an LNA-FVM used in the design capture environment includes pins for connecting the component to all signal paths and biases and control terminals.*

In this LNA block, the amplifier's gain over the simulation range is a valid user parameter describing RF performance. In this particular model nonlinear effects (intermodulation distortion, IIP3 and power compression, P1dB) and noise parameters (NF) are not model parameters. However, this LNA FVM does include bias range as well as analog and digital control level specifications such as V_{dd} functional verification limits, I_{dd} (sleep, standby, power-down and operational), input/output impedance: range-limits or "nominal" and analog and digital control levels/ranges. These are required specifications specifically for verifying block functionality.

To achieve both simulation speed and accuracy, it is imperative to use modeling techniques that take advantage of the particular behavioral modeling language being utilized and achieve optimum performance from the simulator. A good example can be seen with the above LNA example FVM. The use of the "wreal" function from the Verilog-AMS language allows the digital simulation solver to evaluate "wreal" (numeric value) change as a discrete event. This saves simulation time over the analog solver, which must use time-steps based on the period of the RF. For example: in an 802.11 b/g design, the RF period (1/2.45 GHz) divided by 20 or 40 samples required to achieve a smooth continuous time wave form leads to high sample rates (0.02 to 0.01 ps) and subsequent long simulation run times.

To ensure model accuracy the simulation results of the FVM must be consistent with those of the circuit schematic (fully modeled transistor-level IC design). The objective is to obtain a reasonable "signal quality" overlay of FVM and circuit schematic performance for a transient, periodic steady-state or harmonic-balance analysis simulation. Developing accurate performance from the FVM is a very important collaborative activity between the FVM modeler (sometimes from the Functional Verification Team) and the block design engineer.



▲ *Fig. 6 Functional verification and IC design flow.*

Surprisingly, test benches created by FVM developers will often have more flexibility using behavioral models for stimuli blocks and measurement blocks than what a block design engineer may create at the circuit level. This type of FVM test bench is not only versatile and comprehensive, but also re-usable. Most block design engineers are encouraged to enhance their existing schematic-level test benches to accommodate the comprehensive test bench features defined in the FVM. However, since the block design engineer owns the final design, he/she usually does the FVM validation sign-off.

Sometimes even though the FVM validation has been "signed-off," it is possible that insufficient functionality has been embedded within the FVM to fully demonstrate functionality at the top-level. For example: a radio (transmitter and receiver) based on a loop-back test bench configuration would require the ability to input the minimum number of symbols and frames into the transmitter and the ability to measure the EVM, BER and eye-diagrams on the output of the receiver for final functional quality test. An individual block designer may be unaware of all the required functionality testing at the system-level and thus leave this functionality out of the FVM. Therefore, entire design teams must work closely to develop FVM specification to ensure robust FVM blocks.

FVM INTEGRATION AND TESTING

Functional verification testing is a constant on-going process, occurring interactively and in-parallel with the IC design process. The major objective of the on-going verification process is to constantly obtain a functionally correct IC database at the block-to-block, bond-pad-to-bond-pad levels. Verification test suites are typically run over night as a result of some design Engineering Change Order (ECO) that has occurred during the IC design process. ***Figure 6*** presents a block diagram of the functional verification and design flow for an RF-A/MS IC.

The final quality of FVM functional performance is measured when all the FVM blocks (representing the various levels of IC hierarchy) are integrated to the full-chip level. Functional verification testing for the full-chip will typically be performed based on IC specifications. Therefore, the necessary stimuli will be supplied for all IC chip conditions and outputs observed and measured for expected results. Since full-chip functional verification is iterated throughout the IC design process,

TABLE I

FVM AND SPICE VERSUS ULTRASIM SIMULATION COMPARISONS

Test Bench	Simulation Solver	Total cpu Time (sec)	Ratio vs. Spectre_tran
Top_receiver_PB_MCW	Spectre_tran Usim_local Usim_localFE	53040 20160 1200	1x 2.6x 44x
Top_XCVR_AD_PLL_tb1	AMSD_fvm	103	515x

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MSQ5002000	5 to 20

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Model #	Description	Frequency (GHz)
SCS100800-8	8 dB	1 to 8
SCS100800-10	10 dB	1 to 8
SCS100800-20	20 dB	1 to 8
SCS5002000-8	8 dB	5 to 20
SCS5002000-10	10 dB	5 to 20
SCS5002000-20	20 dB	5 to 20

Double Balanced Mixers

Model #	LO Power (dBm) [Nom]	Frequency (GHz)	
		LO/RF	IF
SGM-2-7	+7	0.25 to 3.25	DC to 0.7
SGM-2-17	+17	0.25 to 3.25	DC to 0.7
SGM-3-7	+7	1.35 to 7	DC to 2
SGM-3-13	+13	1.35 to 7	DC to 2
SGS-5-10	+10	3 to 18	DC to 3.2

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once an acceptable set of tests vs. output results are captured, then the testing can be converted to an automated compare process.

FULL-CHIP FUNCTIONALITY AT THE DEVICE/COMPONENT LEVEL

With accurate FVM blocks in place, design groups are ready for full device-level functional verification/simulation. Recently, new technology derived from RF simulation has been applied to device-level simulators such as Cadence's Ultrasim and/or AMSUltra. These tools represent an evolution in the family of so-called "Fast Spice" simulators, which are necessary in order to maximize simulation throughput specifically for SoC with RF circuits. Instead of following the lead of SPICE simulators and solving a single large matrix, Fast SPICE partitions the circuit into many smaller stages. Each stage is solved as a single matrix, which results in speed-ups.

For RFICs, any blocks in the transmitter and receiver that are operating at high frequency represent potential bottlenecks for simulation throughput due to the "analog solver" and the small time-steps based upon a time-division of the smallest frequency period. Because of this, the best performance within a receiver and/or transmitter with standard "FastSpice" simulation historically has been in the range of 2× to 2.5× improvement over and above a standard SPICE analysis.

To meet the challenge of analyzing large device count circuit blocks, the next generation of Fast SPICE tools has been enhanced with "local Fast Envelope" analysis-mode capability. This feature can be applied "locally" to blocks of interest (RF blocks containing AM, PM, or FM modulation). This results in a 12 to 40 times simulation acceleration vs. SPICE simulation and removes the simulation throughput bottleneck. This large range of acceleration depends on verification objectives, that is, performance vs. functionality. Additionally, in device-level functional verification a higher speed can be obtained through lower accuracy settings, which may be an acceptable trade-off depending on performance-oriented verification requirements.

The ***Table 1*** FVM and UltraSim Simulation Comparisons for an 8 μs simulation run is an example taken from Cadence's RF Kit v5.2.1 for reference. Note that simulation throughput for using FVMs and using AMS Designer is listed.

CONCLUSION

IC design organization with experienced "digital-methods" functional verification team in place often set up automated functional verification tests at the beginning of the final design stages. However, very few RF-A/MS design organizations have a Functional Verification team (of the digital characteristic) actually performing true mixed-signal full-chip functional verification. Increased effort to develop automated verification testing among RF-A/MS IC design groups is expected as full-chip functional verification testing becomes a "simulation sign-off" requirement for tape-out. ■

TESTING SATELLITE FREQUENCY CONVERTERS

Frequency converters, a key component in modern satellite communications systems, create special characterization challenges for developers and manufacturers. The signals, processed by these converters and their modulation formats, can change dramatically from day-to-day and even hour-to-hour. The channels may be re-allocated to different services, and with its high cost, the life of the satellite may be expected to last longer than the services for which it was initially launched. Because of these factors, frequency converters must be tested with essentially generic signals and, from these simple tests, the distortion effects on more complex signals can be adequately predicted. One of the key tests is the frequency response across the conversion channels, including amplitude, phase and group delay ripple. While the amplitude response is relatively easy to measure, the phase and especially the group delay response of satellite converters present particularly difficult challenges. These difficulties often lie in the fact that, unlike most other applications of converters, the local oscillators (LO) are embedded in the converter and are completely inaccessible to outside instruments, even to the point of not providing a common 10 MHz reference signal. A technique was previously developed that provides for an absolute group delay measurement,[1,2] but this method requires a second reference mixer to provide an IF phase reference, and until now, it also required an additional LO signal identical to the LO provided to the device under test (DUT). Now a new method has been developed, applying that technique to the case of a frequency converter with an embedded LO. The difficulties in this technique (that is if there is no common reference) are described by Ballo.[2] The key aspect of this technique is frequency tracking the IF of the DUT, such that the frequency of the external LO used for the reference channel mixer can be adjusted to accommodate offset and drift in the DUT embedded LO. Further, the phase of the IF of the DUT is also tracked to accommodate phase shift or slight frequency offsets (less than 1 Hz offset is required to avoid difficulties in the delay measurement). This tracking is done through software techniques, which do not require additional phase-locking hardware or added pilot tones.

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UNDERSTANDING EFFECTS OF AN EMBEDDED LO

To evaluate the effects of an embedded LO on a mixer or frequency converter, it is important to review some details of the method.[2] The group delay of the frequency converter is computed from the phase response measurement of the converter. Normally, the group delay is defined as

$$D_G = -\frac{d\phi(\omega)}{d\omega} \tag{1}$$

where

$\phi(\omega)$ = phase of the frequency response
ω = radian frequency

For a mixer, an equivalent S-parameter representation has been described by Williams, et al,[3] which takes into account the effects of the phase of the LO, and defines the scattered waves as those scattered at the input, at the input frequency, and those scattered at the output, at the output frequency. The phase response of a mixer is given by[3]

$$\Phi_M(\omega) = \text{phase}\left(\left. \frac{b_2(\omega - \omega_{LO})}{a_{LO} a_1(\omega)} \right|_{a_2=0, |a_{LO}|=1} \right) \tag{2}$$

where Φ_M is the phase response of the mixer (here ω is taken as the input frequency, but the assignment is arbitrary; a_{LO} represents the LO drive signal, where the magnitude is assigned a unity value, so this essentially represents the phase of the LO; $a_1(\omega)$ is the input signal at the RF (input frequency), and $b_2(\omega - \omega_{LO})$ is the IF (output) signal at the output frequency. By rearranging Equation 2, the output phase related to the input is found to be

$$\phi(b_2(\omega - \omega_{LO})) = \phi(a_{LO} a_1(\omega)) \Phi_M(\omega) \tag{3}$$

where ϕ denotes taking the phase of the wave. In the case of a mixer with a constant LO, the effect of LO phase on the group delay is inconsequential. In cases where the LO is not constant, but accessible, a sample of the LO can be used to drive the reference mixer, effectively eliminating errors due to drift. However, in the case of an embedded LO, where the LO is not available to the reference channel, phase and frequency drift versus time affect the measured phase result at the output. When this drift is significant with respect to the measurement time aperture of the measurement system, it will have an effect on the group delay response. The effect of LO phase noise and drift can be illustrated by an example.

Consider a measurement with an IF bandwidth (BW) of 3 kHz and a measurement time of approximately 1/3 kHz or 330 µs. Two measurements are made at 100 kHz RF spacing, with 50 µs settling between points, thus the average measurement time is 380 µs (here one-half of each measurement time represents the average of the LO frequency change over that time). For the sake of this example, assume an LO frequency of 20 GHz that drifts at 0.1 ppm/day, which results in a drift of 2 kHz/day or 0.023 cycles/second or 8.33° per second. Over the measurement time-window, the LO would drift approximately 0.003°, which would affect the group delay by 0.003/(360 × 100 kHz) = 83 ps. This delay, due to drift of the LO, is in addition to any error from the LO being off frequency from the LO used in the reference channel mixer. The delay error due to the frequency error can be computed as

$$\text{delay error} = \frac{\text{frequency error} \bullet \text{measurement aperture}}{\text{frequency aperture}} \tag{4}$$

Consider a frequency offset error of 1 Hz. This represents 360°/sec, for a delay error of 3.8 ns, again assuming that the measurement time is 380 µs and the group delay frequency aperture is 100 kHz. Further, if the LO has a phase noise, it will directly translate to the IF phase, though the conversion of phase noise to phase deviation is not easily determined. One estimate is to assume the phase noise at the offset equivalent to the IF filter can be converted to phase deviation by treating it as an added noise floor. For example, at a 30 kHz offset, the phase noise might be –60 dBc, which may appear as approxi-

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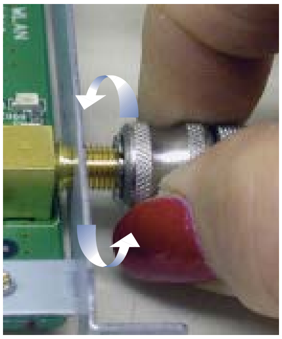

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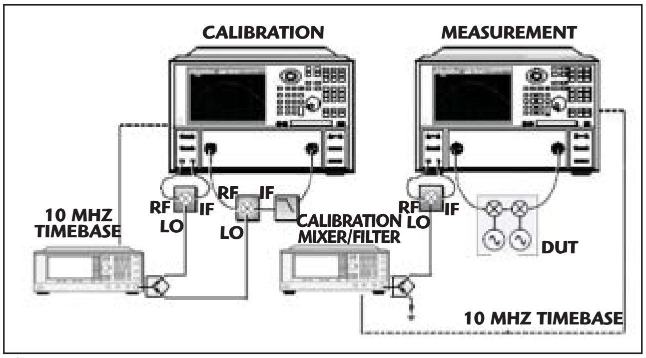
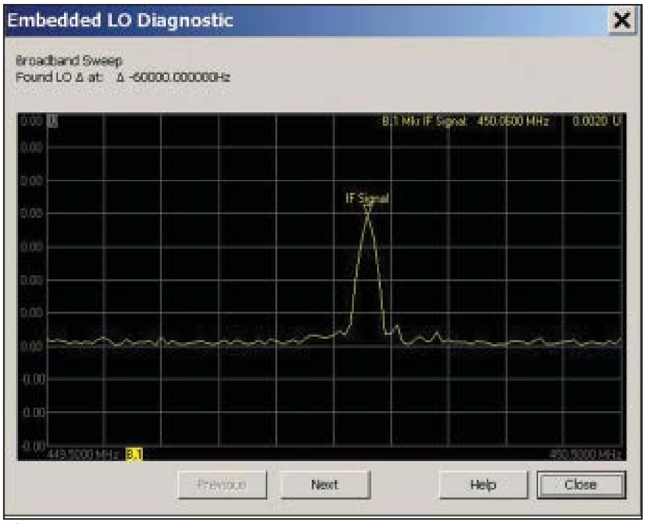


▲ *Fig. 1 Measurement system showing calibration and measurement setups.*

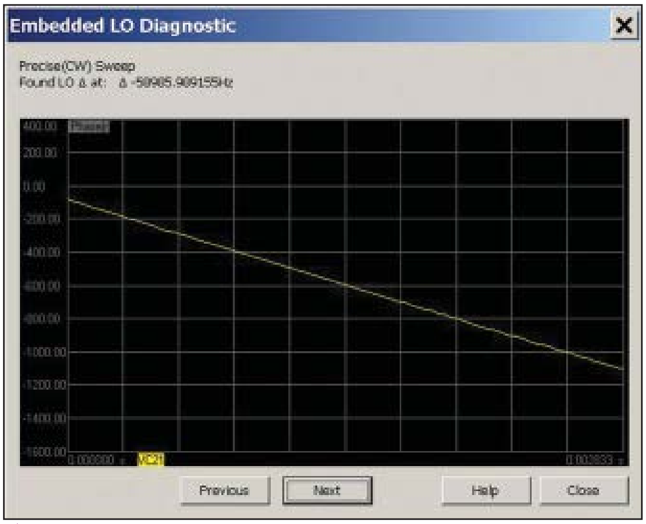
mately 58 milli-degrees of trace noise on the phase trace, and 1.5 ns of group delay noise. In many cases, a much lower level of delay noise is desired. In other circumstances, averaging is used to reduce the noise in a measurement, but without further processing, averaging will not work on these devices.

DETAILS OF THE MEASUREMENT SYSTEM

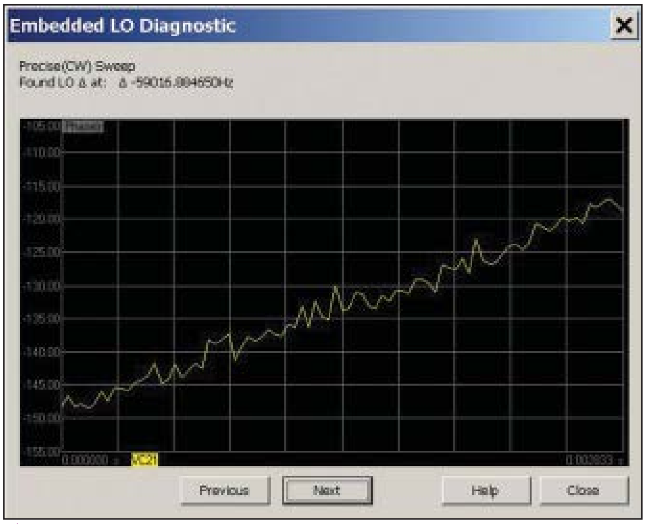
The measurement system is shown in ***Figure 1***. Note that the DUT is a conversion chain of any number of LOs. The calibration of the measurement system proceeds as described by Ballo.[2] For the measurement of the DUT, however, the LO of the DUT is used instead of the external LO. To avoid errors associated with offset in the DUT LO frequency, it must be measured very precisely. The LO frequency is determined in two steps: first a broadband frequency sweep may be made to determine the approximate frequency; a phase versus time sweep may then be made to determine the precise frequency. For many converters the approximate frequency is known, so the frequency only must sweep a narrow bandwidth, which may be set by the user. In practice, the VNA first IF (approximately 8 MHz) sets the maximum span of the broadband sweep, since going wider than about twice the IF may cause an image of the signal to appear in the receiver. The resolution of the broadband sweep is determined by both the number of measurement points and the bandwidth selected so more points are required for wider sweeps.



▲ *Fig. 2 Broadband sweep to detect the approximate IF frequency.*



▲ *Fig. 3 First phase versus time result, comparing the reference channel to the DUT channel.*

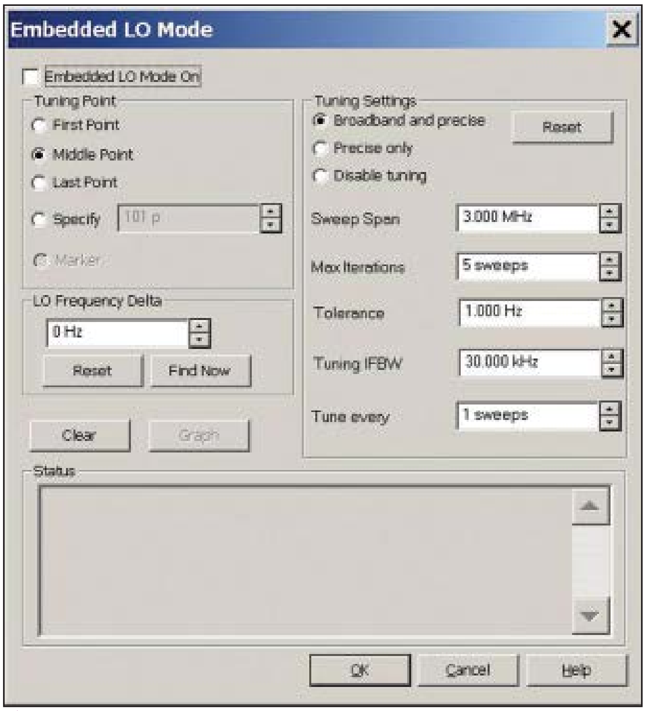


▲ *Fig. 4 Next phase versus time after updating the internal LO.*

Figure 2 shows the result of a broadband sweep, in which the magnitude of the IF output from the DUT is slightly off the center frequency (about 60 kHz high), where the frequency resolution is 10 kHz. Next, the reference LO and the receiver frequencies are offset by 60 kHz, and the measurement is switched to a ratio measurement to compare the phase of the DUT output with the phase of the reference mixer output, as a function of time. Since a digital IF is used in modern VNAs, phase versus time is only valid as long as the frequency offset from the VNA center frequency is less than one-half the IF BW (the IF BW sets the sampling rate). Because of this issue, the broadband sweep automatically sets the number of points so that the resolution is less than one-third the tuning IF bandwidth (BW). If the frequency is known more precisely than the tuning IF BW, then there is no need to use broadband tuning, which will improve the measurement time. ***Figure 3*** shows the first phase versus time plot. From this, the frequency error can be computed as

$$\Delta freq = \frac{\Delta phase}{360 \bullet \Delta time} \qquad (5)$$

For the sweep time of 2.83 ms, the offset is approximately 1 Hz per degree. This is a remarkably precise measurement of the frequency offset, and it can be done in a very short time. After this pass, the offset is just over 1 kHz (the approximation from the first step shows the external LO is about –59.985 kHz low). The frequency is reset to this value, but the IF filter has some phase response so an additional iteration is needed. ***Figure 4*** shows the result of the next phase versus time plot. With an offset of +31°, the LO frequency is –59.016 kHz. A final measurement phase versus time has almost no phase slope and the overall CW phase versus time trace has approximately a 1° of peak-to-peak noise, but using a least squares



▲ *Fig. 5 User interface for embedded LO to determine the DUT LO frequency.*

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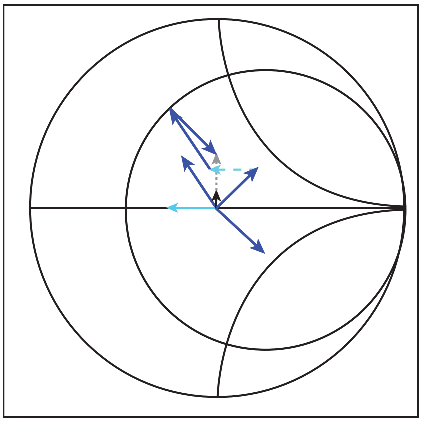
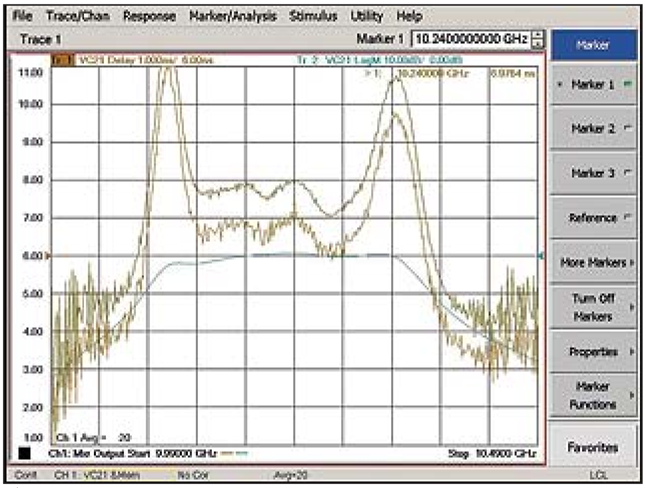


▲ *Fig. 6 Averaging several sweeps will result in the average value tending to zero.*

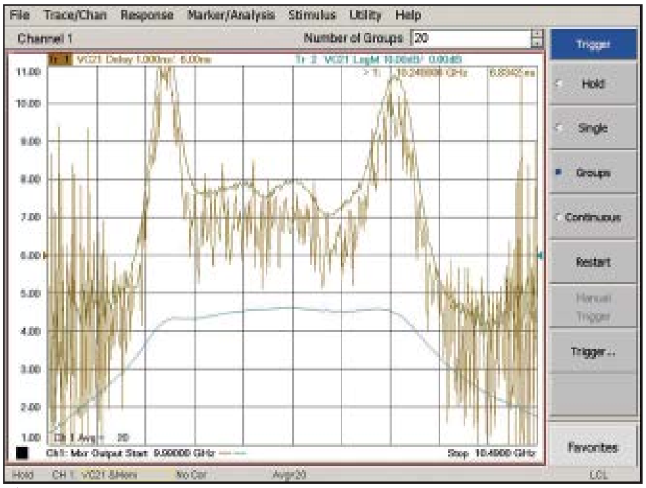
fit of the entire trace allows a precise computation of the average offset value over the measurement time, for a final value of –59,015.9 Hz low. Notice that with these four sweeps, a precise alignment of the reference LO with the external DUT LO is achieved with a total measurement time of less than 20 ms. The tuning sweep can be performed as often as just before every sweep to determine the frequency drift. For cases where the embedded LO is quite stable, the tuning may not need to be done on every sweep; the update rate can be set by the user, as shown in the user-interface dialog of ***Figure 5***. Now that the reference LO is frequency aligned with the embedded LO, the VNA can make a normal group delay measurement, but effects of the phase noise of the LO will still present an obstacle.

PHASE LOCKING THE RESULT

Now the system is set to measure the phase versus frequency of the DUT converter over the measurement frequency span. However, the frequency is still not completely precise, and the error frequency will cause the phase of the response to precess over time. ***Figure 6*** represents a polar view of a single frequency vector response measured over several sweeps (solid blue vectors). The average of these signals (dotted vectors) will tend toward zero as the phase varies sweep-to-sweep. ***Figure 7*** shows the delay response without averaging in two cases: the upper (memory) delay trace shows the delay when a common LO is used for both the reference and test mixers; the middle delay trace shows the response using two sepa-



▲ *Fig. 7 Delay responses without averaging.*



▲ *Fig. 8 Delay responses with averaging.*

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LCA-0408	4 – 8	25	1.0	1.5	2:1	2:1	10	200
LCA-0812	8 – 12	25	1.0	1.8	2:1	2:1	10	200
LCA-1218	12 – 18	25	1.5	2.8	2:1	2:1	10	200
LCA-0618	6 – 18	25	1.5	3.0	2:1	2:1	10	200
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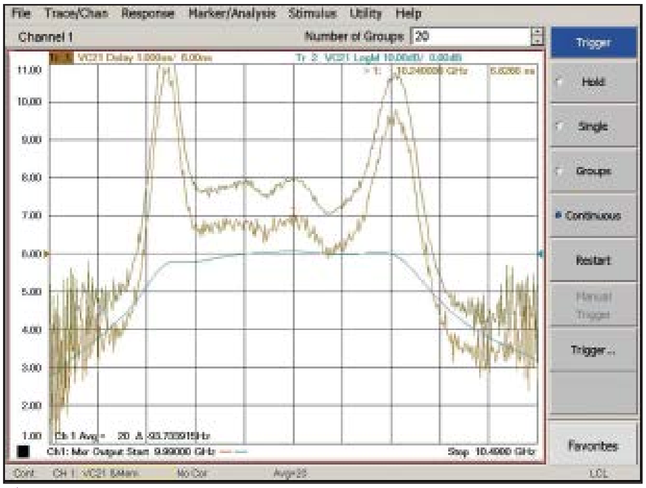

▲ *Fig. 9 Delay responses comparing the software tracking method with the measurement using a shared LO.*

rate LOs, but locking the 10 MHz reference together. The noise on the delay trace for the locked LOs is approximately 2.5 times greater than that of a shared LO (where phase noise effects are canceled). In both cases, 20 averages were used to reduce noise. The blue trace shows the amplitude response of the mixer. ***Figure 8*** shows the result with averaging, when the LOs are not locked to the same reference. The delay trace is about 25 times noisier, and the magnitude response is reduced due to the averaging effect. In this case, the phase of the signal to be averaged varies by a random amount each sweep. Thus, when this response is averaged, the signal level of the averaged trace is reduced, and with a constant noise floor, the noise begins to dominate. This is the result typically seen using the methods described in Reference 1. An added process step in the new method resolves this problem by phase tracking the response of each sweep within the software, and using the measured phase tracking to compensate the overall response to maintain a constant phase, at a frequency selected by the user. ***Figure 9*** compares the new method of software phase tracking with a measurement using a shared LO. The results are indistinguishable from those using a locked 10 MHz reference. Here the nearly identical group delay trace noise demonstrates that the software phase tracking technique provides equivalent frequency and phase stability to locking the time-bases of two independent oscillators. Note that the noise in the measurement is less than 125 ps rms, which is the limit of the measurement quality.

With this new method, the full error correction capabilities of a vector network analyzer can now be applied, including correcting for input and output mismatch, to a new class of devices: frequency converters with embedded local oscillators. The method has been applied to high gain converters, and provides good phase tracking when the signal-to-noise (measured with a 2 MHz resolution BW) is as little as 10 dBc. With frequency tracking and software phase locking, a remarkably accurate measurement of the group delay of these devices of less than 100 ps can be achieved. ■

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1. J. Dunsmore, "Novel Method for Vector Mixer Characterization and Mixer Test System Vector Error Correction," *2002 IEEE MTT-S International Microwave Symposium Digest*, Vol. 3, pp. 1833–1836.
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METALLIC PLATING OF WR-10 STAINLESS-STEEL WAVEGUIDE

A simple procedure is described for copper plating stainless-steel WR-10 waveguide sections, up to 40 cm in length. An anode with a uniform separation from all interior walls of the waveguide allows for efficient plating.

For mm-wave experiments executed at low temperatures, it is desirable to use a stainless-steel waveguide in the refrigerator for thermal isolation and to plate the waveguide with a higher conductive metallic layer to reduce microwave attenuation. While the electroplating of metal on stainless-steel is a well-established procedure, there are a number of individuals and commercial establishments who have been unsuccessful in plating the interior of WR-10 waveguide sections of 10 cm or longer. This note points out that copper plating of WR-10 stainless waveguides is relatively easy with conformal electrodes. Petencin[1] electroplated short, approximately 8 cm long sections of stainless WR-10 waveguide with copper. He suspended a platinum anode wire under tension down the center of the waveguide and pumped plating solution through the guide. This procedure was previously used to strike 20 cm sections of waveguide with a nickel coating, followed by gold plating of the nickel. The results were intermittent, because the uneven potential distribution in the corners of the guide made the nickel strike problematic. A successful procedure is reported here for copper plating of the guide. A copper ribbon, 0.5 mm by 1.76 mm in cross-section was used as an anode. The anode was inserted into the waveguide and insulated from it with beads of GE-7031 varnish, separated by 11 mm. The centered anode was separated from the cathodic guide by 0.4 mm on each side. This resulted in a more uniform potential distribution in the plating solution. The guide was mounted vertically. A flange at the top of the guide was bolted to a Teflon block through which the plating solution was pumped with a peristaltic pump. A positive voltage was applied to a wire attached to the anode that extended through the top of the block. A cleaning solution of 30 percent by volume H2SO4 was passed down the guide with a 1000 A/m^2 current applied to the anode for four minutes. Next, a plating solution of 240 g/l H_2SO_4 and 112 g/l $CuSO_4$ was pumped through the guide at the rate of 1 cc/sec with 100 A/m^2 for five minutes. Then the anode was shifted vertically by 5 mm and the process was repeated to plate the areas under the insulated beads. Finally the guide was rinsed with distilled H_2O. Plated waveguide sections of up to 40 cm were produced. Longer sections should present no problem. Resistivity measurements indicated

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an average copper thickness of 4 µm. The copper plated guide had a mm-wave attenuation of 6.6 dB/m compared to 23 dB/m for the unplated guide.

It is believed that the use of conformal electrodes would also allow for efficient nickel striking of the interior of the guide followed by gold plating of the nickel. This was not attempted since copper was sufficient for the purpose. ■

ACKNOWLEDGMENT

The authors wish to thank J.A. Heilman and G. Petencin for helpful conversations. B.D. Shank was supported by an NSF REU grant. This work was supported in part by NSF grant EIA-0085922.

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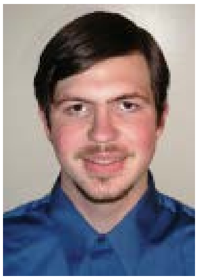
1. G. Petencin, private communication.



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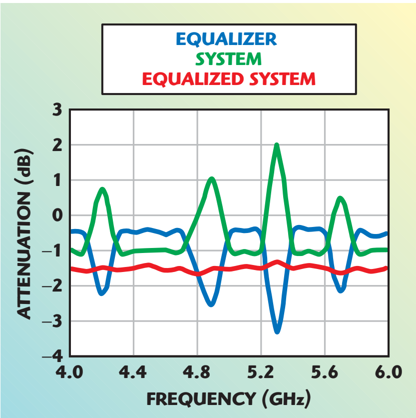
Jeremiah A. Heilman *was awarded his BS degree in physics from the University of Notre Dame, South Bend, IN, in 1997, where he studied high energy states of nuclei with the particle accelerator group. He completed his MS degree developing a quantum computer using electrons on liquid helium with Arnold Dahm in 2005. He is currently pursuing his PhD thesis work with Mark Griswold on the topic of parallel transmission hardware in MRI at Case Western Reserve University, Cleveland, OH.*

Arnold Dahm *received his PhD from the University of Minnesota and held a postdoctoral position at the University of Pennsylvania. He taught physics at Case Western Reserve University (CWRU) from 1968 until 2001, with Fulbright awards for sabbaticals at the University of Sussex and the University of Mainz. He is currently institute professor of physics, emeritus at CWRU.*

ADJUSTABLE MM-WAVE GAIN EQUALIZERS

Growing demand for higher communication bandwidths has led to considerable development of systems operating at millimeter-wave frequencies. These systems have, in turn, stimulated research and development efforts of 26 to 40 GHz components such as TWT and solid-state amplifiers and phase shifters. These novel components often suffer from bandwidth limitations due to variations in the gain-frequency response. Gain equalizers are used to correct the gain-frequency response of complex communication systems in order to increase serviceable bandwidth. While the need for this gain-frequency correction in mm-wave systems is great, field-adjustable mm-wave gain equalizers for 26 to 40 GHz frequencies have not been available. In response to these new markets and technological trends, Aeroflex/Inmet has recently developed field-adjustable gain-equalizer technology optimized specifically for mm-wave applications.

Fig. 1 Gain-frequency correction in a complex communication system.



To introduce gain-equalization at millimeter-wave frequencies, critical qualities such as versatility and high dependability must be met. The technology must utilize precise and stable mechanisms used in the tuning elements or tuners. Aeroflex/Inmet has 30 years of experience developing all types of fixed, adjustable and field-adjustable gain equalizers with broadband coverage for various military and commercial applications.

DESIGN OF mm-WAVE EQUALIZER PACKAGE

Gain equalizers are classified by the type of correction they provide, namely slope, parabolic and ripple equalizers (as shown in ***Figure 1***). Equalizers can also be divided into fixed (tubular) and adjustable (rectangular) models based on the end user's ability to modify the shape of the gain correction and the

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Ann Arbor, MI

gain-equalizer form factor (some examples of which are shown in ***Figure 2***).

The use of existing gain-equalizer technology was limited at higher frequencies by the higher mode cut-off in the SMA transmission lines, tuning filters and other coaxial elements, which had been proportionally scaled for optimal operation below 26.5 GHz. The first step in realizing a mm-wave equalizer was the development of a rectangular package with a long coaxial transmission line. The coaxial line accommodates the placement of multiple tuning elements while maintaining low reflection characteristics up to 40 GHz. This helps support various types of correction curves with minimum additional parasitic loss. In addition, the transmission line is robust with respect to environmental stress conditions as described by MIL-STD-202 standards.

To achieve low reflection characteristics, the design of a 2.5"-long coaxial transmission line and its transitions to 40 GHz 2.9 mm connectors was optimized with the help of a 3-D electromagnetic simulator. The length of the compensation step between the center conductor and outer conductor of the 2.92 mm bead was optimized in order to reduce coupling capacitance, as illustrated in ***Figure 3***. The developed package allowed installation of up to 10 tuning elements and the use of 2.9 mm and 2.4 mm connectors, as shown in ***Figure 4***.

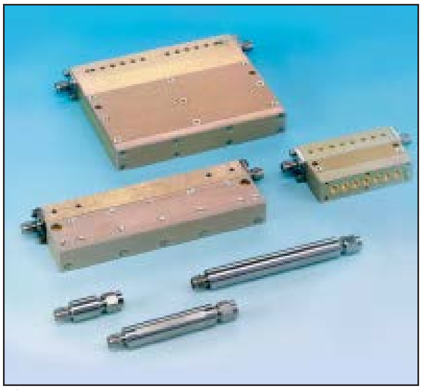

Fig. 2 Examples of gain equalizers.

40 GHz TUNING ELEMENTS

Equalization of the gain-frequency response is addressed by frequency- and amplitude-adjustable tuning elements that resonate at uncoupled frequencies. By carefully selecting the full-width half-maximum (FWHM) bandwidth, the resonance frequency and the magnitude of the loss (or quality factor) from every individual tuner element, it is possible to build various types of complicated correction curves. The slope and parabolic type equalizers for 26 to 40 GHz applications require the use of wide and medium-band tuners with FWHM bandwidths of ~3 and ~1 GHz, respectively. Narrow-band tuners with a FWHM bandwidth of less than 300 MHz can be utilized to generate a ripple-type equalizer.

An example of a Ka-band parabolic equalizer constructed using six medium- and wideband tuning elements (tuners) is shown in ***Figure 5***. The resonant frequency and the magnitude of the individual tuners are set

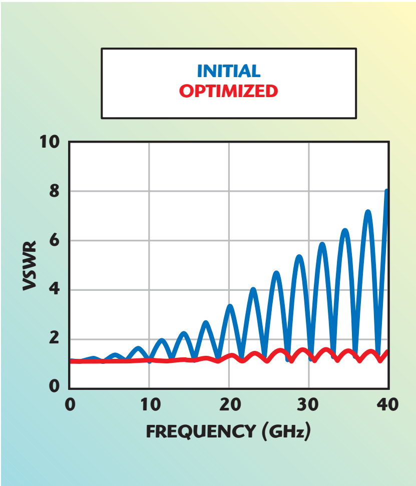

Fig. 3 Initial and optimized VSWR using a compensating step.

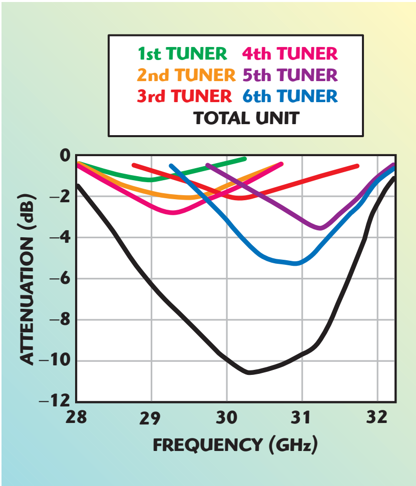

Fig. 5 Example of a Ka-band parabolic equalizer's performance.

Fig. 4 The equalizer's rectangular package.

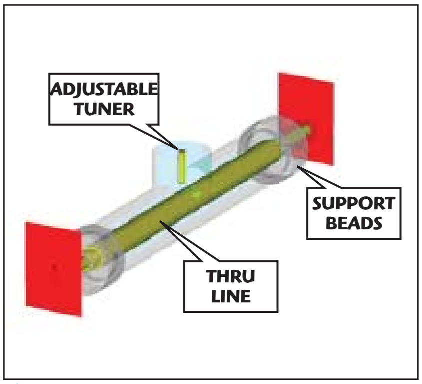

Fig. 6 3-D electrical model used in the 40 GHz tuner development.

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FPD750DFN	20	24	38	0.3	11.5*	24	38	N/A	5	230
FPD750SOT343	18	20	38	0.3	8*	20	38	N/A	3.3	230
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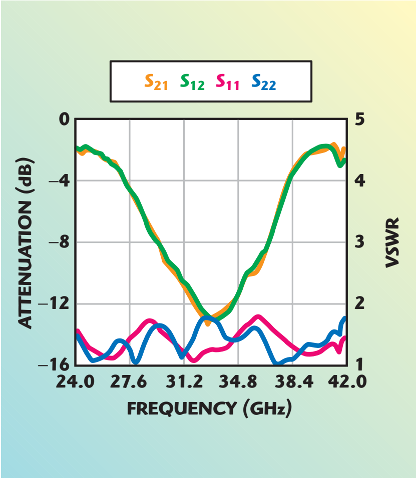
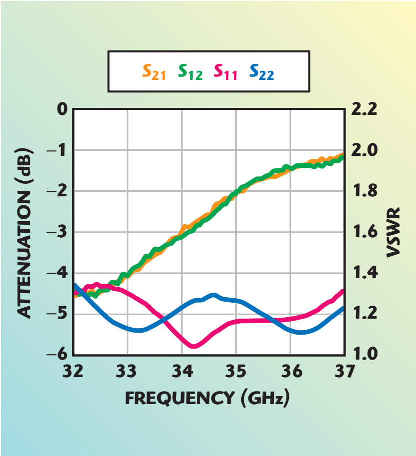


▲ *Fig. 7 Fully adjustable 10 dB parabolic-slope equalizer's performance.*



▲ *Fig. 8 A 4 dB negative-slope equalizer's performance.*

to oppose the gain bumps in the equalized system. The modification of tuning elements to operate up and above 40 GHz was complicated by the need to scale most of the piece parts by half, while still meeting the demanding requirements of precise and robust operation of the tuning screws.

A complete 3-D electrical model used for development of a 40 GHz tuner is shown in ***Figure 6***. The dimensions of the coupling cavity, length and diameter of the resistive element and the locations of the tuners were all optimized for maximum versatility and highest TEM-mode frequency of operation.

EXPERIMENTAL DATA

The new technology was demonstrated across the entire 26 to 40 GHz band using a fully adjustable 10 dB parabolic-slope equalizer (see ***Figure 7***), as well as a 4 dB negative-slope equalizer (see ***Figure 8***).

Most parabolic curves and linear slopes up to 15 dB are achievable across the broader 26 to 42 GHz band or within a selected sub-band. In addition to the linear and parabolic equalizers with slopes less than 15 dB as described above, this technology has also been applied successfully to extremely narrow-band ripple equalizers (120 MHz). Several prototype units exceeding the end-user's system requirements have already been delivered.

CONCLUSION

Adjustable-slope gain-equalizer technology suitable for flattening frequency response in 26 to 42 GHz TWT transmitter systems has been designed, demonstrated and delivered to engineers working at millimeter-wave frequencies. The new technology provides fully adjustable mm-wave equalizers of linear, parabolic and ripple-removal types.

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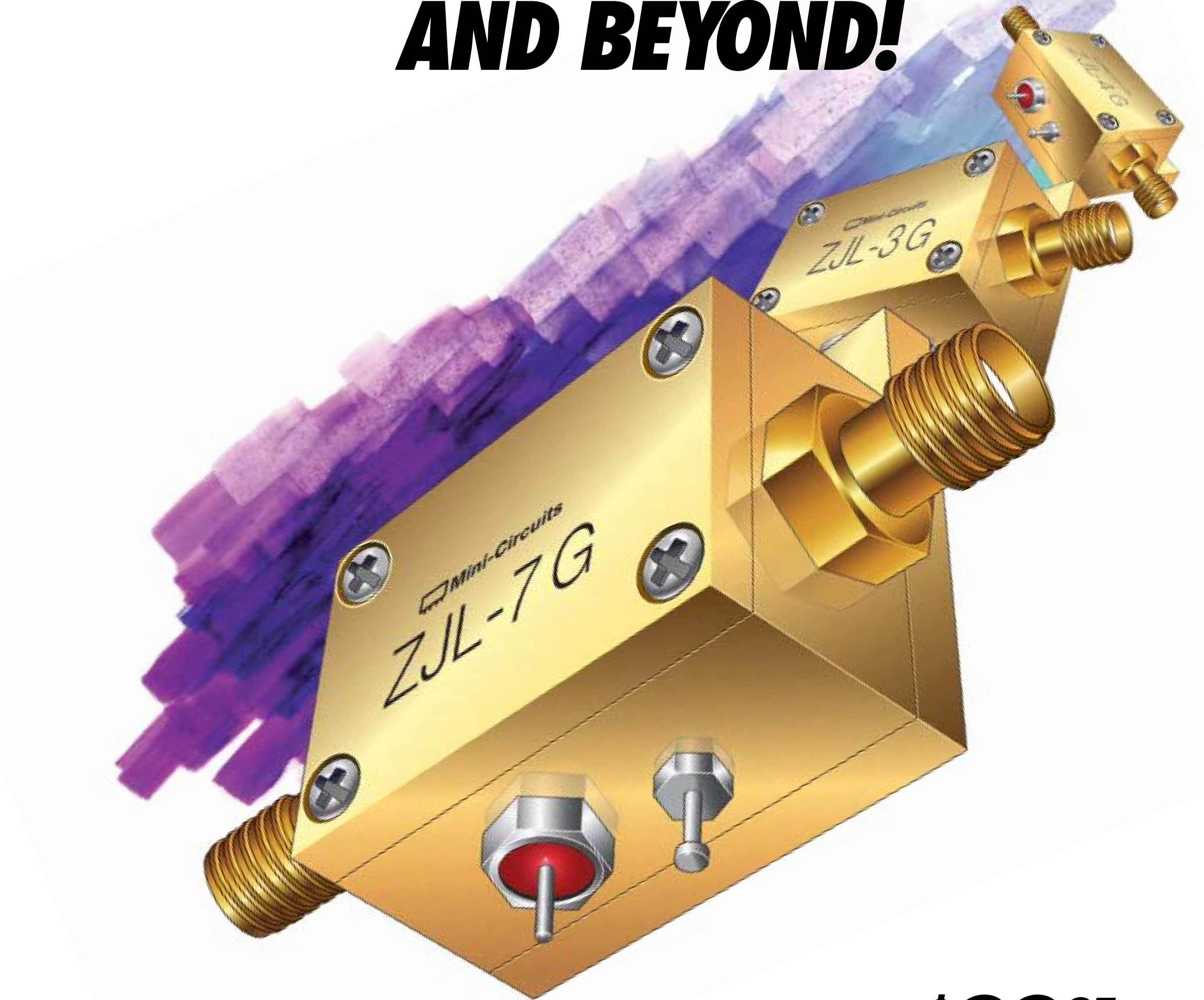

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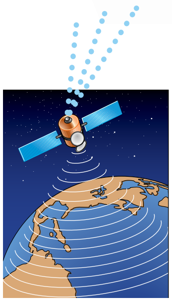

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SPECIFICATIONS

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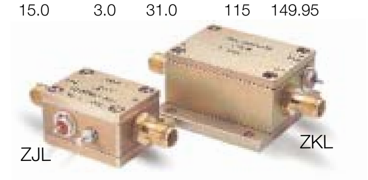
ZJL-5G	20-5000	9.0	±0.55	15.0	8.5	32.0	80	129.95
ZJL-7G	20-7000	10.0	±1.0	8.0	5.0	24.0	50	99.95
ZJL-4G	20-4000	12.4	±0.25	13.5	5.5	30.5	75	129.95
ZJL-6G	20-6000	13.0	±1.6	9.0	4.5	24.0	50	114.95
ZJL-4HG	20-4000	17.0	±1.5	15.0	4.5	30.5	75	129.95
ZJL-3G	20-3000	19.0	±2.2	8.0	3.8	22.0	45	114.95
ZKL-2R7	10-2700	24.0	±0.7	13.0	5.0	30.0	120	149.95
ZKL-2R5	10-2500	30.0	±1.5	15.0	5.0	31.0	120	149.95
ZKL-2	10-2000	33.5	±1.0	15.0	4.0	31.0	120	149.95
ZKL-1R5	10-1500	40.0	±1.2	15.0	3.0	31.0	115	149.95

NOTES:
1. Typical at 1 dB compression.
2. ZKL dynamic range specified at 1 GHz.
3. All units at 12V DC.



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MILLIMETER-WAVE AUTOMATED NOISE PARAMETER MEASUREMENT SYSTEMS

There is an increasing demand for wireless commercial applications operating at millimeter-wave frequencies. The emergence of millimeter-wave wireless applications such as LMDS, WLAN and automotive anti-collision radar has brought new requirements on device technology and the systems used to characterize these devices at higher frequencies. Many researchers specifically require the noise properties of the emerging millimeter-wave transistors. Fortunately, a new line of noise parameter measurement systems from Maury Microwave provides such a fully dedicated automated test system with frequency capabilities up to 110 GHz.

Noise parameters are used to describe noise behavior of a linear two-port device and are essential in designing low noise amplifiers (LNA) and transceivers. Manufacturers do not usually provide noise parameters obtained directly at mm-wave frequencies. When they are provided, they are most likely derived by extrapolation from values measured at microwave frequencies. Clearly, more accurate mm-wave noise parameter measurements are needed in device characterization as well as in the development and verification of device dependent equivalent circuit models.

By providing state-of-the-art device characterization, this new series of millimeter-wave noise parameter measurement systems allows designers to improve overall circuit performance for a given fabrication process by enhancing transistor operating range and linearity. These test systems encompass a wide range of high performance features designed for on-wafer testing. Specific models and added options offer higher levels of noise measurement capabilities and system integration, in addition to fast and accurate S-parameter measurements. This article describes the complete measurement solutions that are now available with frequency coverage up to 110 GHz.

MEASUREMENT SYSTEM SPECIFICS

The typical measurement setup for the fully automated wideband noise parameter measurements is shown in ***Figure 1***. This setup is illustrated using the functional blocks and connectivity that comprise the system. Among the functional blocks, there is a network analyzer for S-parameter measurements, a noise source, an input tuner, an input switch, a noise receiver module and a noise figure analyzer

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Model	Freq. Range (GHz)	Small Signal Gain (dB)	Noise Figure (dB)	Power Output at 1dB Compression (dBm)	Reverse Isolation (dB)	Intercept Point 3rd/2nd (dBm)	VSWR Max. 0/50C (In/Out)	D.C. Typ. (Volts)	(mA)
Microwave Amp in Standard One-stage High Frequency CougarPak™.									
ACP14012	6.0-14.0	10.5	3.0	+14.5	20	26/45	2.0	5	43
ACP14016	6.0-14.0	11.2	3.2	+16.0	21	26/35	2.0	5	65
ACP16012	6.0-16.0	9.5	3.5	+15.2	23	27/40	2.0	5	45
ACP16021	8.0-16.0	9.5	3.4	+24.0	25	30/45	2.0/1.7	12	117
ACP16025	8.0-16.0	7.5	4.3	+29.0	20	42/65	2.0/1.6	12	253
ACP18012	8.0-18.0	8.5	4.0	+15.0	23	25/38	2.0	5	45
ACP18015	8.0-18.0	9.2	4.0	+15.5	25	23/31	2.0	5	63
ACP20015	2.0-20.0	10.0	4.5	+16.0	30	26/29	2.0	5	76

Specifications are typical. See individual data sheets for details.

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(NFA) for noise parameter measurements. A solid-state noise source is used as a hot/cold noise reference needed in the noise figure measurement. Additionally, the system includes a DC power supply and bias tee to supply DC power to the device under test.

A key component in this measurement system is the automated electromechanical tuner that is used to change the reflection coefficient of the network connected to the input of the DUT. The reflection coefficient at the input reference plane of the DUT is controlled by the changing position of a moveable probe inside of a slab line or a waveguide section. Probe motions are precisely controlled using stepper motors. The system is capable of providing a maximum source reflection coefficient greater than a 0.9 magnitude at the DUT input reference plan. The available automated electromechanical tuners (see ***Table 1***) used in the millimeter-wave noise parameter measurement systems are categorized by their frequency range and corresponding waveguide connector dimensions.

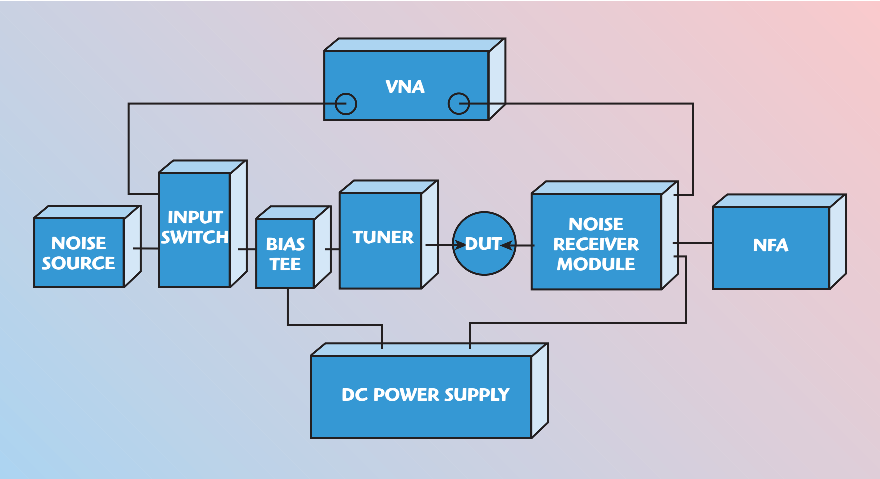

Fig. 1 The Noise Parameter Measurement System.

TABLE I

AUTOMATED ELECTROMECHANICAL TUNERS

Model	Frequency Range (GHz)	Connector Type	Designation	Mates With
MT979A	75.0 to 110.0	WR10	MPF10	UG385/U
MT978A	60.0 to 90.0	WR12	MPF12	UG385/U
MT977A	50.0 to 75.0	WR15	MPF15	UG385/U
MT976A	40.0 to 60.0	WR19	MPF19	UG383/U
MT984A	8.0 to 50.0	coax	2.4 mm	—

TABLE II

NOISE RECEIVER MODULE SPECIFICATIONS

Model	Frequency Range (GHz)	Connector In/Out (mm)	Optional Bias Tee	NF Max* (dB)
MT7553B	0.01 to 50.0	2.4/3.5	yes	18
MT7553B02	0.01 to 67.0	1.85/3.5	yes	18
MT7553M02	50.0 to 75.0	WR15/3.5	no	12
MT7553M	60.0 to 90.0	WR12/3.5	no	12
MT7553M03	75.0 to 110.0	WR10/3.5	no	12

*Noise Figure measured at the input of the noise receiver module including the N8975A Agilent Noise Figure Analyzer

TYPICAL ELECTROMECHANICAL TUNER SPECIFICATIONS

The typical tuner specifications include a minimum matching range of 20:1, a maximum VSWR of 1.06, maximum insertion loss of 0.65 dB, worst case repeatability > 50 dB and CW power handling of 20 W. Another key component of this highly accurate system is the noise receiver module. This module allows automatic switching at the DUT output between S-parameter measurements from the network analyzer and noise power measurements provided by the

Fig. 2 A 50 GHz Noise Parameter Measurement System.

Fig. 3 A WR12 Noise Parameter Measurement System combined with a load-pull system.

noise figure analyzer. The noise figure analyzer includes a low noise downconverter block to increase the system's sensitivity across the entire frequency bandwidth and an optional bias tee. The noise figure analyzer is used only to measure noise power levels up to 26.5 GHz. ***Table 2*** contains the specifications for the different models of the noise receiver module.

ATS version 4.0 software is used to control the measurement setup and to perform all the computations. Prior to the actual DUT noise parameter measurements, the passive network between the noise source and the noise receiver must be carefully characterized. The system performs the task of determining the unilateral transducer gain (kBG) as well as the noise parameters of the receiver during calibration using a thru calibration standard. In the multi-impedance measurement method only one hot noise power measurement with a minimum of four cold noise power measurements is taken during the noise figure measurements. After calibration, the thru standard is replaced by the DUT and at least four noise power measurements are made using different values for source reflection coefficient at the input.

Besides developing the necessary key hardware to perform noise parameter measurements over a broadband frequency range (up to 110 GHz), the system has also successfully integrated the Cascade Microtech automated probe stations for direct wafer testing. ***Figures 2*** and ***3*** illustrate system integrations for a 50 GHz noise parameter system and a 60 to 90 GHz noise parameter and load-pull system.

CONCLUSION

Maury Microwave's new fully integrated millimeter-wave noise parameter measurement systems are a unique solution addressing the increasing demand for mm-wave device impedance and noise characterization. The systems provide completely automated measurements, reducing expensive engineering set-up time while delivering an exceptionally high level of accuracy. Its ease-of-use and flexibility enables engineers to measure a broad range of high performance, leading-edge components, including very low noise transistors and amplifiers. This level of accurate device information is critical for transistor development at higher frequencies, active model generation and, perhaps most critically, circuit optimization. The features available in the new series of Maury Microwave's noise parameter measurement systems are ideal for addressing the challenges facing today's R&D engineers developing millimeter-wave frequency components for the broadband wireless communications industries. Additional information may be obtained at www.maurymw.com.

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Model	Freq. (MHz) f_L - f_U	Gain (dB) Typ.	Max. P_{OUT} (dBm) @ Compression 1 dB	3 dB	Dynamic Range NF (dB) Typ.	IP3 (dBm) Typ.	DC Pwr. Volt (V) Nom.	Current (A) Max.	Price $ea. Qty. 1-9
With Heat Sink/Fan									
ZHL-5W-2G	800-2000	49	+37	+38	8.0	+44	24	2.0	995.00
ZHL-10W-2G	800-2000	43	+40	+41	7.0	+50	24	5.0	1295.00
• ZHL-20W-13	20-1000	50	+41	+43	3.5	+50	24	2.8	1395.00
• ZHL-50W-52	50-500	50	+46	+48	4.0	+55	24	9.3	1395.00
• ZHL-100W-52	50-500	50	+47	+48.5	6.5	+57	24	9.3	1995.00
▲ ***Without Heat Sink/Fan***									
ZHL-5W-2GX	800-2000	49	+37	+38	8.0	+44	24	2.0	945.00
• ZHL-10W-2GX	800-2000	43	+40	+41	7.0	+50	24	5.0	1220.00
• ZHL-20W-13X	20-1000	50	+41	+43	3.5	+50	24	2.8	1320.00
• ZHL-50W-52X	50-500	50	+46	+48	4.0	+55	24	9.0	1320.00
• ZHL-100W-52X	50-500	50	+47	+48.5	6.5	+57	24	9.0	1920.00

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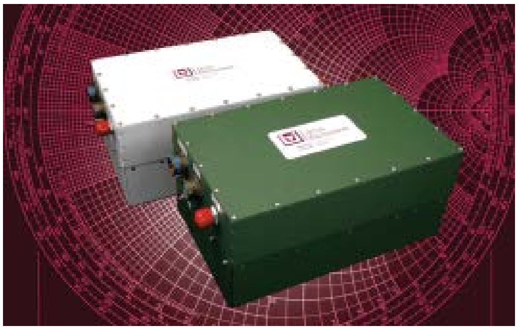

AN X-BAND BLOCK UP-CONVERTER IN A SMALL, LIGHTWEIGHT, RUGGED PACKAGE

In modern "on the move" military communications there is an increasing emphasis on performance in adverse conditions requiring compact, efficient and ruggedized packaging with a cost-effective price tag. With this philosophy in mind, Locus Microwave Inc. introduces the UB61000 series medium power X-band Block Up-converter (BUC) featuring an L-band input interface with X-band (7.9 to 8.4 GHz) power output ratings at 30 or 50 W.

This X-band BUC utilizes innovative packaging technology that combines rugged durability, compact size and low weight. The dimensions of the UB 61000 series are 11.0" × 6.8" × 5.25". The package is designed for outdoor military communication applications where it is critical to maximize use of limited space without sacrificing performance or durability. The UB61000 is a single assembly, which eliminates the need for what would traditionally require a separate frequency converter and solid-state power amplifier. This entire unit tips the scales with a total weight of 13.6 pounds, which is believed to be the lowest weight and least volume of any similar unit on the market today.

The advanced packaging used by the UB61000 is also weatherized for the most rugged of conditions, including resistance to rain, sand and temperature extremes, making it an extremely reliable amplifier/frequency conversion solution. The UB61000 series includes precise thermal management based on forced air cooling over a custom designed heat sink assembly, keeping operating temperatures low within the unit.

The reliability and convenience of an integrated amplifier/up-converter along with a price comparable to a multi-unit approach makes the UB61000 an attractive solution for any commercial or military system integrator or other end user.

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  - XC2500A-03: 3dB – 2300-2700MHz – 150W
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  - XC3500P-20: 20dB – 3300-3800MHz – 20W
- Micro package measures .20 x 40" (5.08 x 10.16mm)
  - XC3500M-03: 3dB – 3300-3800MHz – 60W
  - XC3500M-20: 20dB – 3300-3800MHz – 60W
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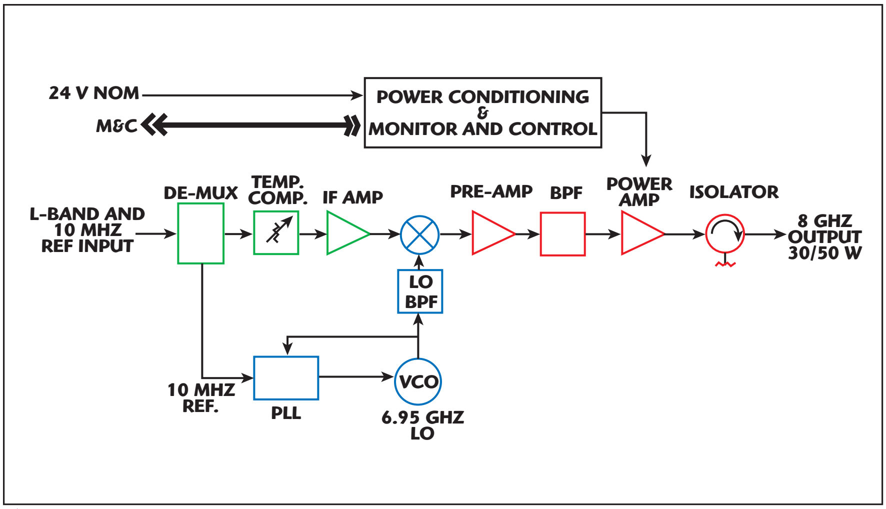

Fig. 1 System block diagram.

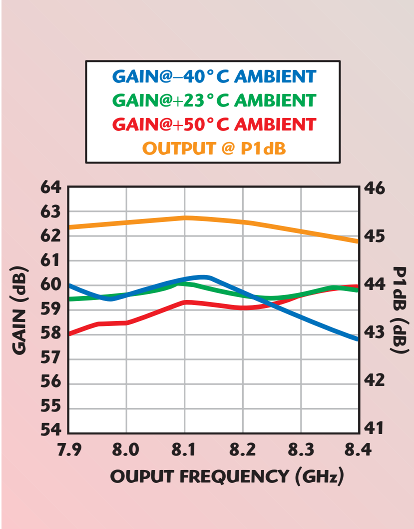

Fig. 2 Gain and output power vs. frequency.

TECHNICAL PARAMETERS

The Locus UB61000 series converts the L-band, 950 to 1450 MHz, input frequency range to the X-band, 7.9 to 8.4 GHz range using a phase-locked 6.95 GHz local oscillator and mixer, as illustrated in the system block diagram (see ***Figure 1***). Amplification is provided at both the L-band IF frequency range and the 8 GHz output range, wherein a gain of 59 dB is typical. Key performance specifications for the UB61000-045 30 W Block Up-converter are shown in ***Table 1***. In addition to the 30 W unit highlighted in the table, a 50 W version is available as well.

Figure 2 provides actual test data covering a variety of different performance parameters. The UB61000 series features temperature compensation included in the IF section of the converter to hold a nearly constant gain level over an approximate 100°C operating range. As illustrated in the figure, the output of the 30 W version of the UB61000 series at 1 dB compression is typically 45 dBm.

TABLE I

UB61000-045 SPECIFICATION SUMMARY

Input frequency (MHz)	950–1450
Output frequency (GHz)	7.90–8.40
LO frequency (GHz)	6.95
External reference (MHz)	10
Gain (dB)	57 min/59 typ
Phase noise (dBc/Hz)	
@100 Hz offset	–62 max/–73 typ
@1 kHz offset	–72 max/–73 typ
@10 kHz offset	–82 max/–85 typ
@100 kHz offset	–92 max/–104 typ
@1 MHz offset	–102 max/–110 typ
Power @1 dB compression (dBm)	44 min/45 typ
Third-order distortion @3 dB backoff (dB)	–25 max/–32 typ
Operating voltage (VDC)	+18 to +36
Power consumption (W)	230 nom
Size	11.0" × 6.80" × 5.25"
Weight (lbs)	13.6 typ
Cooling	forced air

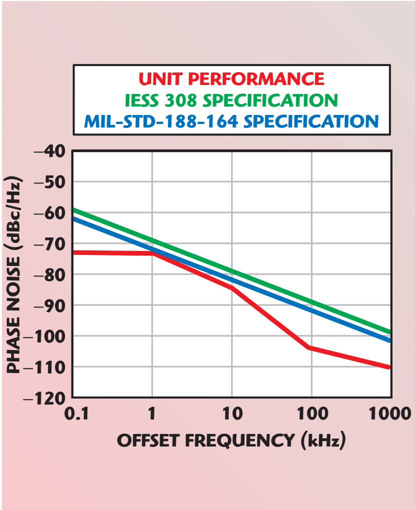

Fig. 3 Phase noise performance.

APPLICATIONS

The X-band frequency range is generally considered the "military band." The intended application for the Locus UB61000 series X-band Block Up-converter is military field operations. The phase noise, as shown in ***Figure 3***, exceeds the standards of both MIL-STD-188-164 and IESS-308 requirements. Due to a combination of package durability, size and weight this unit is ideal for "on the move" applications as well as any satellite or point-to-point communications within the 7.9 to 8.4 GHz transmit frequency.

CONCLUSION

The Locus Microwave UB61000 series medium power X-band Block Up-converter offers a cost-effective solution for military communications where the transmit band is between 7.9 and 8.4 GHz. The industry leading size and weight coupled with cutting-edge performance provide an excellent alternative to traditional multi-unit solutions for satellite signal amplification. Additional information on the UB61000 or any Locus Microwave product may be obtained via e-mail at sales@locusmicrowave.com.

Locus Microwave Inc., Boalsburg, PA (814) 466-6275, www.locusmicrowave.com.

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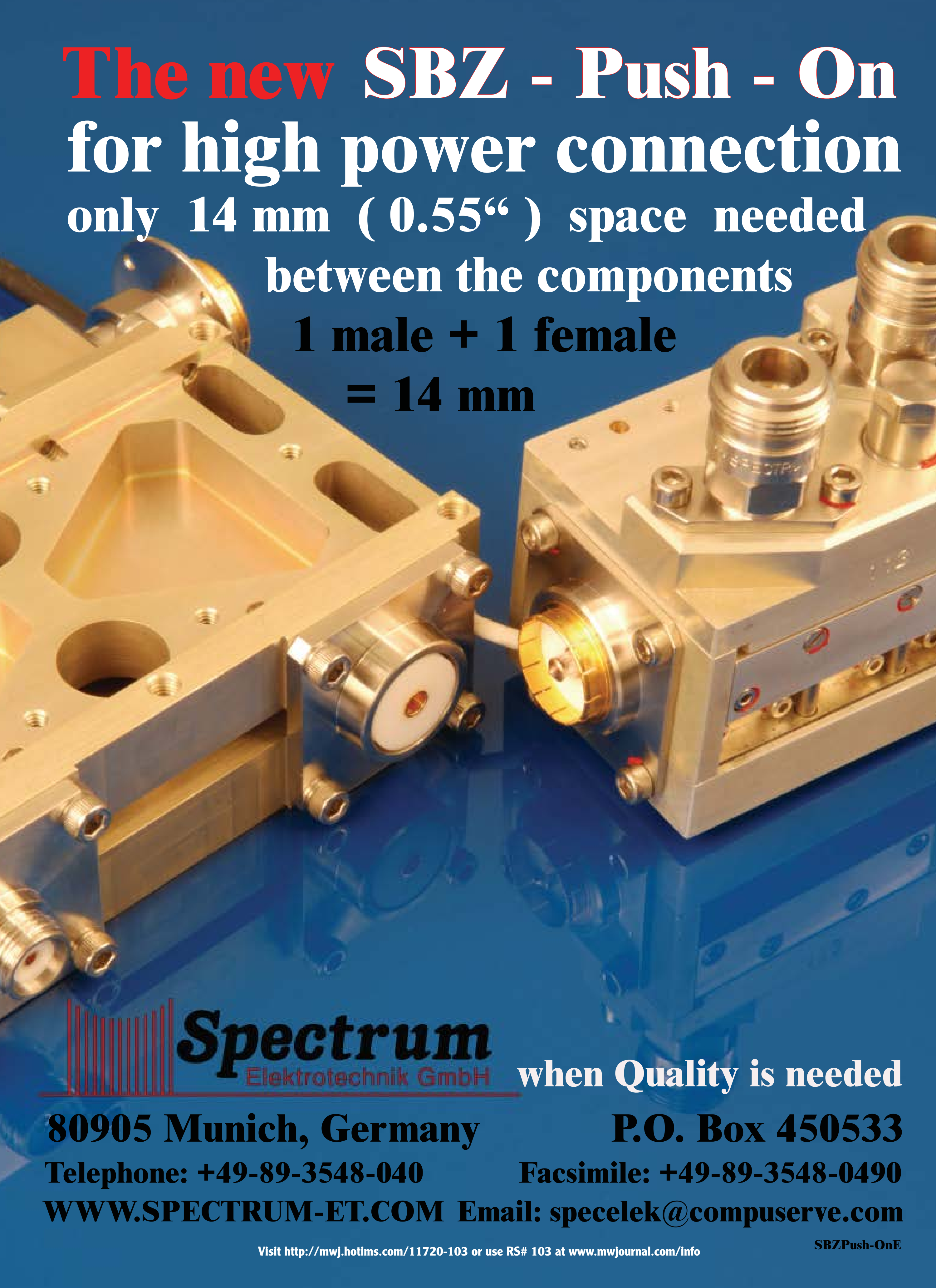
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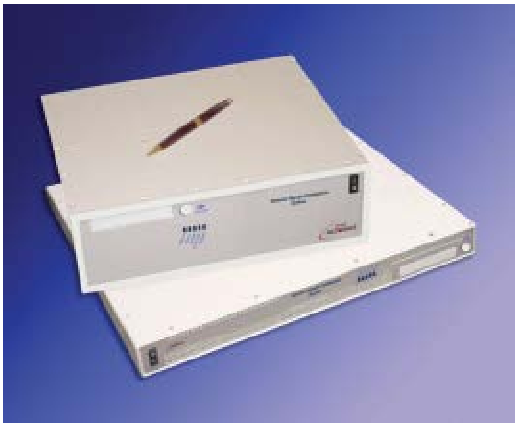


REMOTE SIGNAL INTELLIGENCE MONITORING SYSTEMS

Remote signal intelligence monitoring systems must combine high speed signal acquisition, signal classification and monitoring functionality all within a platform that is compact in size, lightweight and rugged in construction for deployment in the harsh environments common to most military applications. The Tampa Microwave RV3500 system combines multiple software-defined radio and energy detectors with AM/FM/SSB detection and real-time digital audio for operation as a stand-alone system or integrated into a larger system. The RV3500 hardware includes a tuner, digitizer, multi-channel signal processors, system controller and communications controller, all contained in a single 19" 1RU rack-mountable package that is suitable for manpack, ground vehicle, shipboard and airborne real-time signal collection assignments. For more power, several RV chassis can be integrated into a single system by simply interconnecting the chassis via a network data cable. When ready to deploy, the RV hardware is designed to meet demanding field use requirements.

The RV3500 platform is configurable for specific mission requirements, providing rapid high frequency (HF) band spectrum sweeps, proprietary interfaces for analyzer control and data display. The platform empowers multiple users to remotely and simultaneously view different portions of the spectrum. As a development platform, the RV product provides developers with the hardware and software components they need to configure powerful, multi-functioned SIGINT systems. The RV3500 software allows users to develop applications down to the component level of the RV system. Additionally, software development tools are provided to support the development of user interfaces on a client computer, integration of the RV3500 product with other systems and development of custom DSP applications. The software development tools also provide built-in functions for rapid spectrum sweeping, I/Q signal capture, remote communications, multi-channel streaming digital audio, modulation recognition, software-defined radios, multi-chassis integration, as well as many others.

ENERGY DETECTION: HIGH SPEED SIGNAL CAPTURE

Designed with FFT-based sweeps and multiple parallel processing units, the RV3500 monitors frequency ranges of up to 50 GHz/sec. within the instantaneous stare bandwidth (ISB). The system is capable of achieving sweep speeds up to 7.5 GHz/sec., as well as the entire span, in approximately 0.5 seconds. This rapid energy detection facilitates the use of lower resolution bandwidth (RBW) to separate tightly grouped signals without sacrificing speed, and ensures signals of interest are never missed.

Software-defined radio (SDR) gives the RV3500 the power and versatility of commonly used separate hand-off receivers, in a significantly reduced size/weight package. The RV3500 supports multiple channels and can hand-off signals within the ISB to any SDR for

TAMPA MICROWAVE INC.
Tampa, FL

demodulation and recording. Users can access up to 16 streams of real-time, streaming digital audio via TCP/IP from one or multiple authorized PCs around the world.

OPTIMIZED FOR REMOTE OPERATION AND INTEGRATION

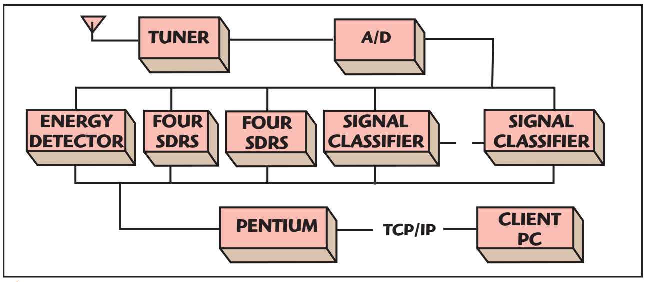
The RV system's core design provides strong support for deployment of the RV hardware at sites remotely located from the operators and analysts. The RV system is optimized to support remote real-time access to data such as spectrum survey data, multi-channel streaming digital audio and I/Q data from captured signals. The system allows multiple operators and analysts to remotely access the RV system simultaneously. Also, each operator and analyst can access multiple RV systems. The RV products provide extensive user control of the system by way of Application Programming Interfaces (API). This makes it easy to integrate an RV system into a larger customer system.

In addition to supporting the development of new SIGINT systems, the RV system is also particularly useful in upgrade programs. Typically the mission of such a program involves replacing a legacy system with newer hardware that is smaller and more powerful, while keeping as many of the existing interfaces as possible. With the RV software development tools, the developer is given the ability to control the RV system using the legacy interfaces. This can save countless hours of retraining operators on the use of a new user interface.

MOBILE OPERATION

The RV3500 platform is designed to support mobile platforms including ground-based, airborne and naval applications. RV products are currently used in Hummer platforms, naval vessels and aircraft. The success of RV systems in these space-limited environments is due to three specific packaging and construction factors:

- The highly integrated RV products provide a complete SIGINT system in a single 1RU rack-mountable chassis or an optional compact chassis. The system can also be packaged per a customer's specifications.
- RV systems are designed to operate in mobile environments subject to shock, vibration and humidity. For instance, the RV system has successfully passed RTCA/DO-160 compliance, the Environmental Conditions and Test Procedures for Airborne Equipment.
- The RV systems support operation on both AC and DC power sources—using either 24 VDC and 28 VDC power sources, as well as any of the standard international AC power sources. Additionally, other sources can be supported per customer specifications.



▲ *Fig. 1 Multiple SmartCells may be arbitrarily arranged to meet the requirements of many diverse signal intelligence monitoring systems.*

DYNAMIC SIGINT RECONFIGURATION WITH SMARTCELLS™

The RV3500 platform offers SmartCells™—a single or multiple set of intelligent hardware processing modules that can be added to any SIGINT system (see ***Figure 1***). Each SmartCell has the ability to perform one of several functions depending on the software selected. For example, up to four SDRs can be loaded into any one SmartCell, allowing four channels of simultaneous signal analysis. Alternatively, a SmartCell may be loaded with software to make it function as a rapid energy detector. Up to seven SmartCells may be added to each system, and the software may be dynamically loaded and changed as needed under software control. SmartCells can be dynamically configured for each mission's critical needs and/or multiple embedded SmartCells can be configured to form a complete signal intelligence system. SmartCells support simultaneous demodulation of multiple radio channels, or can be configured to achieve increased energy detection speeds.

The RV3500 system allows each SmartCell to be reprogrammed on-the-fly as operational requirements change. For instance, multiple SmartCells can be configured for very rapid spectrum survey sweeps, and then reconfigured as needed for modulation recognition or software-defined radios.

All the data and software in the RV3500 are stored on the system's disk drive. Since the disk drive is the only non-volatile storage in the RV hardware, the system is rendered unusable when the drive is not present in the system. The disk drive is easily removed in a matter of seconds from the front panel.

COMPACT, SCALABLE, CUSTOMIZABLE

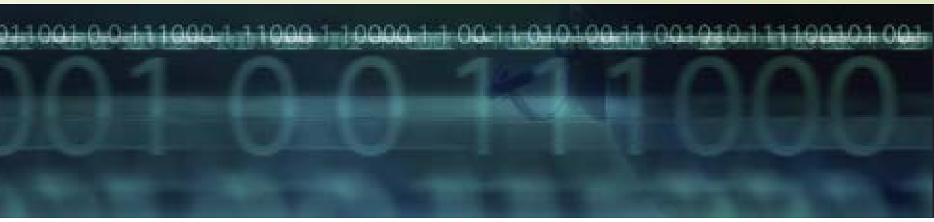
The RV3500 product provides a complete SIGINT spectrum survey and collection system in a package much smaller than traditional systems with the same or less capability. Virtually any RV3500 hardware or software component can be customized or developed to meet a particular customer's requirements. This includes packaging, tuner frequency range, interfaces to third party hardware (such as tuners, handoff receivers, etc.), graphic user interfaces, system integration, DSP software modules, GPS and communications interfaces.

The RV product is available in either the standard 19" 1RU rack-mountable package or in an optional 10" × 11.75" × 3.75" compact chassis package style. The system can also be adapted to a custom package to satisfy specific application requirements.

Each RV3500 product has the ability to function simultaneously as both a signal survey device and a signal collection device. When more capability is required in a system, several RV chassis can be integrated into a single system by simply interconnecting the chassis via a network data cable. The RV software development kit (SDK) allows a multi-chassis RV system to be treated as a single integrated system.

Tampa Microwave Inc.,
Tampa, FL (813) 855-2251,
www.tampamicrowave.com.

RS No. 300



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LINC2 FILTER SYNTHESIS SOFTWARE

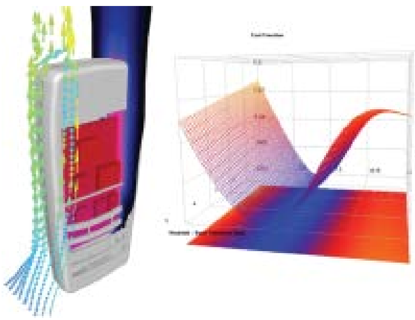
LINC2 Filter Pro version 1.14 adds a new line of space-efficient RF and microwave filters to its filter design and synthesis software. Compact, space-saving interdigital filters can now be designed in microstrip or stripline materials using LINC2 Filter Pro. These and other microstrip and stripline filters can automatically be rendered in both schematic and layout windows. For layout file transfer to other programs, DXF export capability is available from the layout viewer. LINC2 DXF layout files can be translated to Gerber format for PCB fabrication. Microstrip and stripline filters can be analyzed with the built-in circuit simulator or exported to Sonnet's® EM simulation program for accurate electromagnetic simulation. The wizard-like GUI guides the user through the process of entering the specifications for the automatic synthesis of a wide variety of filters.

Applied Computational Sciences,
Escondido, CA (760) 612-6988, www.appliedmicrowave.com.
RS No. 310

CST MICROWAVE STUDIO

CST MICROWAVE STUDIO® (CST MWS) is the leading-edge tool for the fast and accurate simulation of high frequency (HF) devices such as antennas, filters, couplers, planar and multi-layer structures, and SI and EMC effects. It helps designers solve even the most exacting of electromagnetic problems, utilizing unrivalled solver technology, sophisticated import filters, and automated optimization and parametric studies. CST MWS offers considerable product to market advantages including shorter development cycles, virtual prototyping before physical trials and optimization instead of experimentation. This facilitates the design of new products of excellent quality, at minimum cost and to extremely tight deadlines.

CST of America Inc.®,
Wellesley Hills, MA (781) 416-2782, www.cst.com.
RS No. 311



ELECTRONICS THERMAL ANALYSIS SOFTWARE

Version 7 of its Flotherm electronics thermal analysis software features a new Response Surface Optimization capability that Flomerics believes is unrivalled in computational fluid dynamics (CFD) analysis software. Earlier versions of Flotherm included a sequential optimization capability allowing users to specify combinations of design parameters and iterate sequentially towards the best design. The new Response Surface Optimization goes further by fitting a 3D surface to the entire design space, enabling engineers to visualize the complete interaction of the design parameters with the design goal as well as identifying the optimum to a greater degree of accuracy.

Flomerics Inc.,
Marlborough, MA (508) 357-2012, www.flomerics.com.
RS No. 312

PARAMETRIC PRODUCT SEARCH TOOL

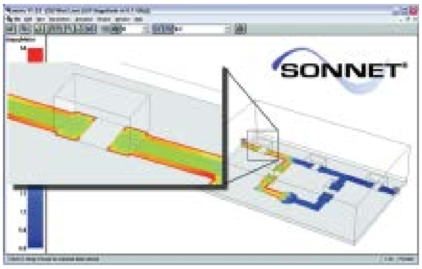
The parametric product search tool is designed for the RF engineer to specify important product parameters and view the company's products that match a specific requirement in a specification-compliance format. Unlike conventional search engines that eliminate products that narrowly fall outside of specification, the parametric product search tool can show these products allowing the engineer to make intelligent design trade-off decisions to "fine tune" the requirement to specific needs. View this and other product software support tools including Product Cross Reference, PLL Phase Noise and Mixer Spur Chart Calculators on the company's site.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343, www.hittite.com.
RS No. 313

FILTER SYNTHESIS AND SELECTION TOOL

Filter Wizard[SM] has been enhanced to incorporate tubular filters in bandpass and low pass search results and to improve the low pass and high pass search interface. The web-based selection tool's bandpass search results now include tubular filters, chip and wire filters, ceramic filters, cavity filters (combline and interdigital), high-Q ceramic puck filters, and waveguide filters, as well as KeL-fil, KeL-com, Mini-Max and Mini-Pack options. Filter Wizard accelerates user progress from specs to RFQ for RF and microwave filters spanning an ever-increasing range of response types, bandwidths and unloaded Q values from 500 kHz to 50 GHz.

K&L Microwave Inc.,
Salisbury, MD (410) 749-2424, www.klfilterwizard.com.
RS No. 314



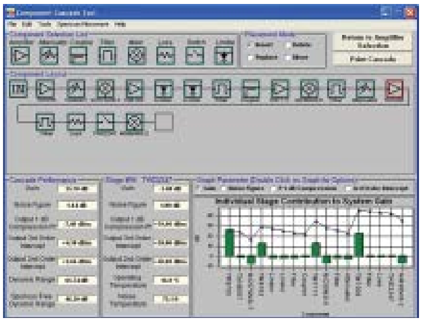
HIGH FREQUENCY EM SIMULATION SOFTWARE

The newly released Sonnet® Suites Release 11 offers perfectly calibrated internal ports that can be used for highly accurate attachment points for active or passive components. These Co-calibrated™ Ports enable full co-simulation within the EM analysis environment. Release 11 also includes a totally redesigned Agilent ADS Interface with a new GUI interface and a new 64-bit EM analysis engine.

Sonnet Software,
North Syracuse, NY (315) 453-3096, www.sonnetsoftware.com.
RS No. 315


MODERN • ART

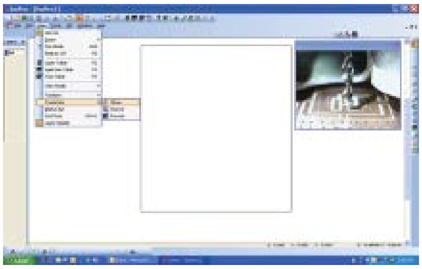

RFMD
RF5198



CASCADE SOFTWARE SUITE FOR DESIGN OPTIMIZATION

CASCADE is a free program whereby engineers can quickly predict a system response by either selecting standard components (Drag and Drop) or typing in their unique values. The software then calculates the chain's performance in both numerical and graphical results, as well as graphs showing each individual component's contribution to gain, noise, output power and intercepts (individually and cumulatively). Engineers can efficiently visualize a block diagram concept and optimize their design by viewing individual component contribution to overall system performance and quickly evaluate trade-offs in component selection and their impact on system performance. CASCADE is available as a CD or as a download at www.spectrummicrowave.com/cascade.

Spectrum Microwave,
Palm Bay, FL (888) 553-7531, www.spectrummicrowave.com.
RS No. 316

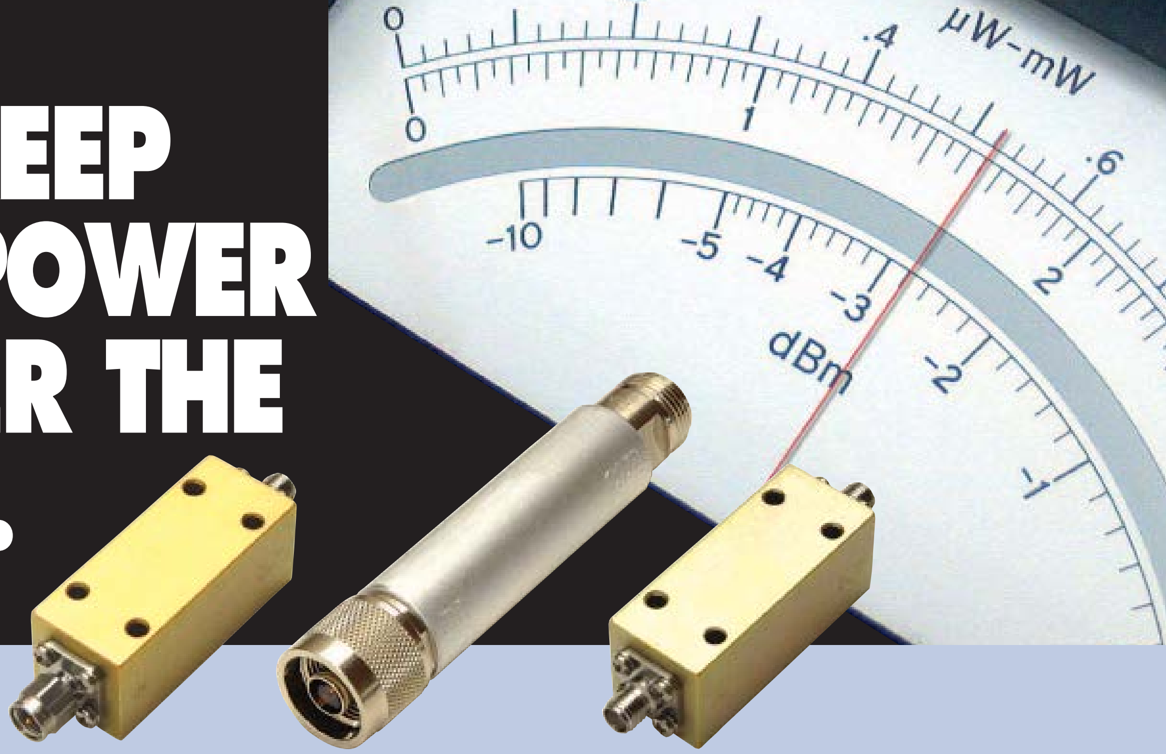


ISOPRO 2.7 SOFTWARE PROGRAM

This major software release improves the drive control of the Quick Circuit milling machine directly from Isopro. One of the many new features of the software is the new TraceCam™ product. It provides the individual viewing access directly from a user's computer. The TraceCam feature greatly enhances the isolation/milling process by displaying an image in real time. These features, with the theoretical mill path viewing, allow an excellent opportunity to compare the quality of a circuit board as it is being cut. Another new feature of the IsoPro 2.7 software is the addition of Iso$_2$NC,™ which produces an NC Code file format. Iso$_2$NC allows a customer to use its software in conjunction with CNC machining center. This will allow the customer to manufacture a circuit board on a system other than a Quick Circuit.

T-Tech Inc.,
Norcross, GA (770) 455-0676, www.t-tech.com.
RS No. 317

WE KEEP THE POWER UNDER THE LIMIT.



High Power RF Limiters

Frequency Range (MHz)	Part Number	Peak Input Power (kW)	CW Input Power (Watts)	Maximum Flat Leakage (CW Power +dBm)	Maximum Insertion Loss (+dB)	Maximum VSWR
0.5 - 30	ACLM-4869H	1	100	14	0.1	1.25:1
30 - 100	ACLM-4870H	1	100	14	0.1	1.25:1
10 - 500	ACLM-4827H	1	100	14	0.1	1.25:1
100 - 1300	ACLM-4871H	1	100	14	0.2	1.25:1
2 - 1500	ACLM-4932H	1	100	14	0.25	1.25:1
0.1 - 2000	ACLM-4897H	1	100	14	0.3	1.25:1
0.1 - 3000	ACLM-4896H	1	100	13	0.4	1.25:1
600 - 3100	ACLM-4891H	1	100	13	0.5	1.25:1
2000 - 4000	ACLM-4943H	1	100	13	1.2	2.0:1

* 60 W Version Also Available

RF & Microwave Limiters

Frequency Range (GHz)	Part Number	Peak Input Power (W)	CW Input Power (Watts)	Maximum Flat Leakage (CW Power +dBm)	Maximum Insertion Loss (+dB)	Maximum VSWR
0.5 - 2	ACLM-4538	100	2	18	0.4	1.4:1
0.1 - 4	ACLM-4637	100	2	17	0.5	1.4:1
1 - 4	ACLM-4581	100	2	17	0.5	1.4:1
2 - 4	ACLM-4531	100	2	17	0.5	1.4:1
1 - 8	ACLM-4597	100	2	17	0.9	1.5:1
2 - 12	ACLM-4535	100	2	18	1.5	1.6:1
2 - 18	ACLM-4537	100	1	18	1.8	1.9:1
18 - 26	ACLM-4765	100	1	21	2.5	2.0:1

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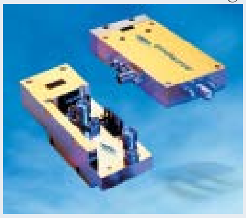
611 Industrial Way West, Eatontown, NJ 07724 • Tel 732 460-0212 • Fax 732 460-0214 www.advanced-control.com

Celebrating our 25th ANNIVERSARY

Millimeter-wave Receivers

These custom-designed millimeter-wave receiver modules are designed for radiometer applications. Two downconverter models have been custom-designed to operate at K-band (20 to 40 GHz) and V-band (50 to 75 GHz).



Gain calibration is accomplished using an internal K- or V-band noise source, a noise injection coupler and a precision temperature sensor. Using a +2.0 dBm Ku-band local oscillator (LO) input to each module, both units employ a sub-harmonic mixer topology to down-convert from the millimeter-wave input frequency to an IF output under 1 GHz, providing 30 dB of nominal gain to the input signal. The V-band module utilizes an additional diode-based frequency doubler on the LO input, allowing a common local oscillator to drive both modules. Overall, the receiver noise figure is under 4 dB for the K-band model and under 6 dB for the V-band receiver.

Endwave Corp.,
San Jose, CA (408) 522-3180,
www.endwave.com.

RS No. 216

Drop-in Isolators

Responding to the exploding market for Ku- and X-band drop-in isolators, Renaissance introduces the R-Series. These flange mount drop-in isolators are ideal for military, SATCOM, space, intelligence and air surveillance radar systems. Covering frequencies of 7.2 to 8.4 GHz, 9.5 to 10.5 GHz, 12.7 to 14.5 GHz and 14 to 15.5 GHz, these temperature stable devices offer a typical loss of < 0.4 dB and return loss and isolation > 20 dB in an industry standard footprint.

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

RS No. 220

Silicon CMOS Switch Matrix

This 4 × 2 switch matrix combines a digital decoder with the RF switching network and tone/voltage detect designed for European- and Asian-market applications including Direct Broadcast Satellite (DBS) Low Noise Block (LNB) – the SKY13292-365LF. DBS is a service that allows households to receive television programming directly from a satellite transponder. The LNB is located on the satellite dish antenna and amplifies/downconverts to a 0.7 to 2.15 GHz IF. The switch matrix is responsible for connecting four of the satellite signals to two indoor set-top controllers, selectable by the viewer's channel choice. The switch is packaged in a lead (Pb)-free and RoHS-compliant, QFN 4 × 4 mm plastic package.

Skyworks Solutions Inc.,
Woburn, MA (781) 376-3000,
www.skyworksinc.com.

RS No. 221

7/16 DIN Terminations

The model 555-142-100 is a 50 Ω, 100 W termination with a 7/16 DIN male connector (other impedance values, power ratings and connector types are available). These units offer low intermodulation distortion and VSWR for improved system performance. These high power terminations are ideal for antenna, base station, broadcast, laboratory, SATCOM and wireless applications. The devices operate DC to 3 GHz in a –40° to +70°C temperature range. The heat sink is a 3 × 3 inch finned square 6.10 inches long. Smaller conduction cooled units are also available up to 500 W average power.

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

RS No. 223

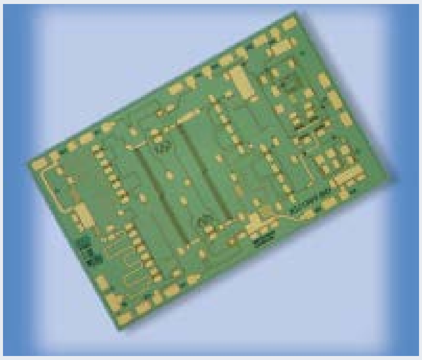
Four-way In-phase Splitter

This L-band, four-way in-phase splitter is designed for SATCOM applications. The low loss splitter spans the frequency band of 900 to 2100 MHz maintaining tight phase and amplitude tracking, typically within 3 degrees and 0.2 dB of signal unbalances respectively within the specified frequency band. The splitter is well matched for applications in 50 Ω systems. This product replaces stripline splitters and saves critical board space when splitting local oscillator signals and when used as receiver antenna combiners. The splitter model SPD-90-210 is packaged in a small surface-mount RoHS-compliant package, measuring 0.8 × 0.4 × 0.2. Prices start at $20.00 for low quantities, with deliveries ranging from stock to six weeks.

Synergy Microwave Corp.,
Paterson, NJ (973) 881-8800,
www.synergymwave.com.

RS No. 234

GaAs MMIC Transmitter

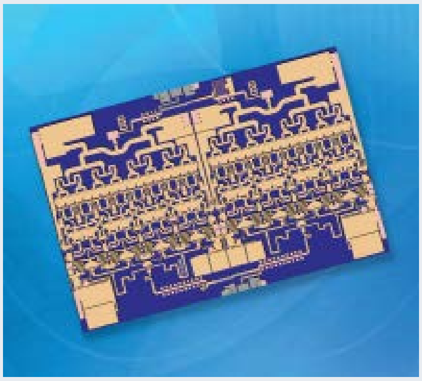


The model XU1009-BD is a gallium arsenide (GaAs) monolithic microwave integrated circuit (MMIC) transmitter that delivers +25 dBm OIP3, 35 dB gain control and 9 dB conversion gain. Using 0.15 micron gate length GaAs pseudomorphic high electron mobility transistor (PHEMT) device model technology, the transmitter covers the 18 to 36 GHz frequency bands and includes a balanced resistive mixer followed by a distributed amplifier, an LO doubler and an LO buffer amplifier. This device is well suited for point-to-point radio, LMDS, SATCOM or VSAT applications.

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

RS No. 251

SATCOM High Power Amplifiers

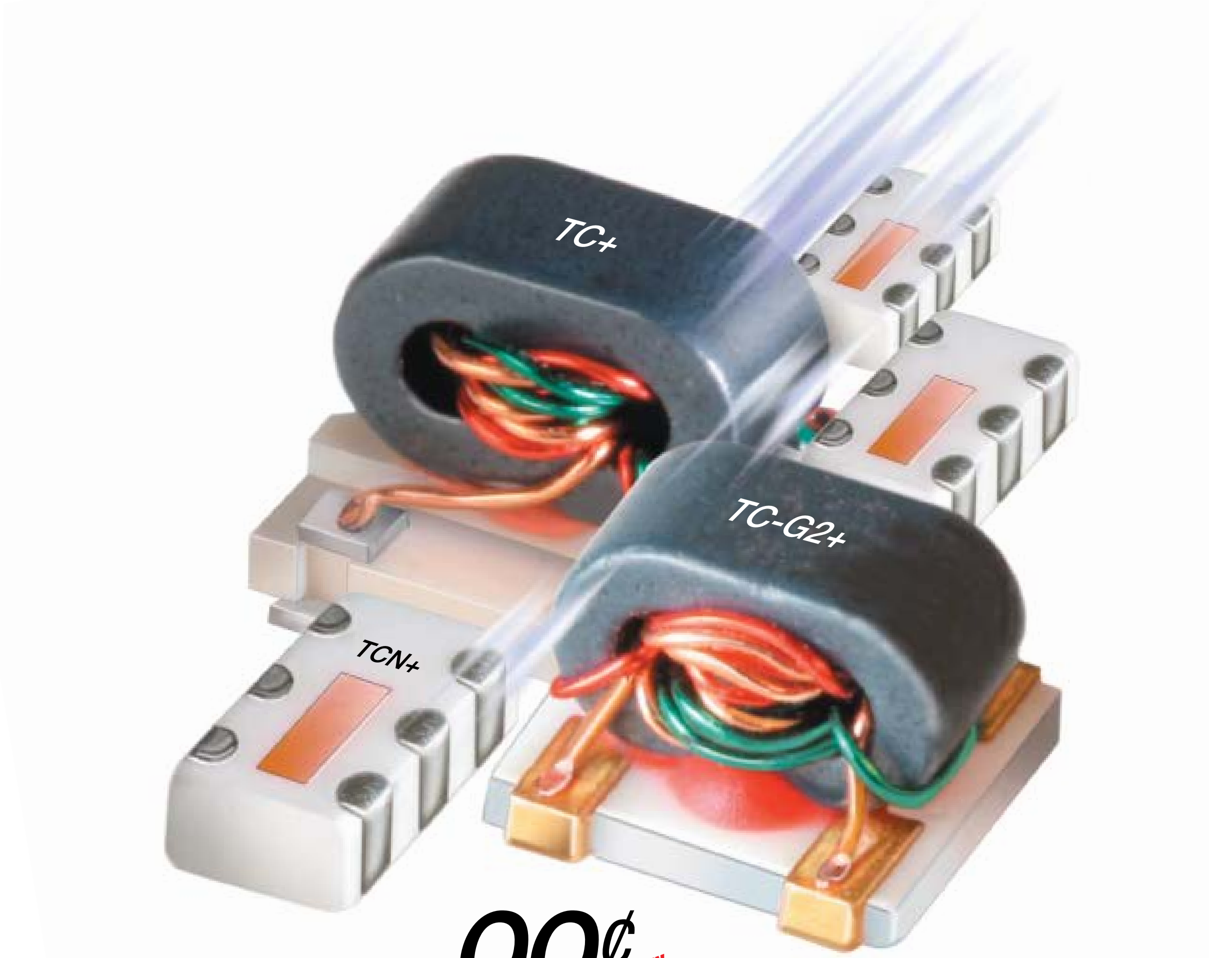


The release of these two new satellite communications (SATCOM) high power amplifiers (HPA) lead the industry in performance and overall size reduction. The new die-level products, TGA4916 and TGA4906, are the latest example of TriQuint's leadership in the evolution of ground terminal SATCOM RF amplifiers. These two new products address OEM needs for smaller, more highly integrated designs and will be offered as packaged devices later this year. TriQuint's new TGA4916 leads the industry with its compact, single-chip architecture. The TGA4916 is a Ka-band, fully monolithic 7 W HPA ideally suited for VSAT ground terminal applications. The TGA4906 is a 'half-chip' version of the TGA4916.

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

RS No. 252

TINY RF & MICROWAVE
TRANSFORMERS



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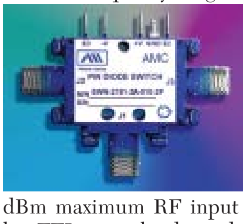
RF/IF MICROWAVE COMPONENTS

377 Rev L

COMPONENTS

SP2T Absorptive Switch

This SP2T, absorptive, PIN diode switch operates in a frequency range from 1.9 to 2.1 GHz.



The isolation is 55 dB with an insertion loss of 2 dB and a VSWR of 1.8. The switching speed is 50 ns rise/fall and 100 ns on/off at +20 dBm maximum RF input power. The switch has TTL control independent for each arm and a DC power supply of +5 VDC at 65 mA maximum and –5 VDC at 50 mA maximum.

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

RS No. 222

EMI Filter

This Interpoint EMI filter is designed to operate with the new Interpoint MPE and MWR DC/DC converters and provides compliance with MIL-STD-461C, CE-03, MIL-STD-461D, CE-102 and MIL-STD-461E, CE-102. The FMT filters have a maximum throughput current of 3A. The full operating temperature range is –55° to +125°C. The hermetically sealed case measures 1.460" × 1.130" × 0.330". Screening levels of standard, /ES and (after qualification) /883 (referenced to MIL-STD-883 and MIL-PRF-38534) are offered. The FMT is available now with prices starting at $310 each for OEM quantities.

Crane Aerospace & Electronics,
Electronics Group,
Redmond, WA (425) 895-4053,
www.craneae.com.

RS No. 224

High-Q Capacitor Kits

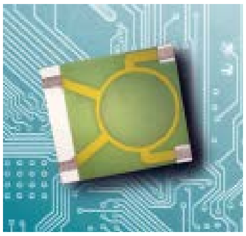
Six new Hi-Q capacitor design kits are now available. 10 Series A case (case size: 0.055 × 0.055) including: DKDLC10A01 contains 16 values ranging from 0.1 pF thru 2.0 pF; DKDLC10A02 contains 16 values ranging from 1.0 pF thru 10 pF; and DKDLC10A03 contains 16 values ranging from 10 pF thru 100 pF. 10 Series B case (case size: 110 × 0.110) including: DKDLC10B01 contains 16 values ranging from 1.0 pF thru 10 pF; DKDLC10B02 contains 16 values ranging from 10 pF thru 100 pF; and DKDLC10B03 contains 16 values ranging from 100 pF thru 1000 pF.

PassivePlus/Dalicap Corp.,
Huntington Station, NY (631) 425-0938,
www.passiveplus.com.

RS No. 225

Power Divider

This thick film SMT two-way Rat Race power divider is available with 180° outputs. The model IMD2417 operates at 10 GHz with a 20 percent bandwidth with less than 0.5 dB insertion loss. Alumina construction and proprietary high conductivity films provide a compact low loss device, which exhibits a high level of unit-to-unit performance repeatability not found in multiplayer devices. The IMS Rat Race device is contained within a 0.322" × 0.354" package and its input power rating is 20 W with a 100°C baseplate.

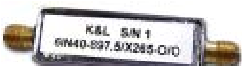


International Manufacturing Services Inc.,
Portsmouth, RI (401) 683-9700,
www.ims-resistors.com.

RS No. 226

Wideband Notch Filter

The model 6IN40-897.5/X265-O/O is a wideband notch filter that uses elliptic response lumped element design techniques to enhance broadband communications, from DC to 765 MHz and 1030 to 3500 MHz, while blocking out wireless communication traffic. Configurations for this product include surface-mount, cables or connectors. Small sizes and custom packages are also available.



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

RS No. 248

Bandpass Filter

The model 7BP5-185/X50-S is a highly selective bandpass filter with SMA-Female connectors. The filter features a 2.0 shape factor from 57 to 0.5 dB bandwidth. Insertion loss is 1.5 dB maximum at a center frequency of 185 MHz. The 0.5 dB bandwidth is 160 to 210 MHz minimum. Rejection is 57 dB minimum at 140 and 240 MHz. The VSWR is 2.0 maximum. Physical size is 4.5 × 1.25 × 1.0 excluding connectors.

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

RS No. 249

PCS Receive Filter

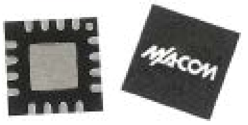
The part number 8C9-1880-X60N11 is a PCS receive band filter. This unit is centered at 1880 MHz with a flat passband of 60 MHz. Passband insertion loss comes in at less than 0.8 dB, with a passband return loss of greater than 16 and 60 dB of attenuation at 1930 to 1990 MHz. This unit sized at only 1.75" high × 2.75" wide × 5.5" long has Type N connectors, but can be fitted with most any RF connector.

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

RS No. 231

SP2T 8 W Switch

The model MASW-000822-12770T is a new SP2T broadband PIN diode switch for 0.5 to 6 GHz applications. The switch is ideal for higher power WiMAX base station and military radio applications and features high linearity and power handling. The device provides over 8 W (CW) power handling coupled with 65 dBm IIP3 for maximum performance. The MASW-000822-12770T is a SP2T, high linearity, common anode, asymmetrical PIN diode switch in a 3 mm PQFN package. It is ideal for use in the 2.3 to 2.7 and 3.3 to 3.8 GHz WiMAX base station applications, where LNA protection is required. Price: $1.98 (10,000).



M/A-COM Inc.,
Lowell, MA (800) 368-3277,
www.macom.com.

RS No. 227

High Power Combiners

MECA expands its H series, 100 W, Wilkinson high power combiner/divider line by adding 7/16 DIN Female connector models in two- and four-way configurations covering all wireless bands between 0.800 to 2.200 GHz. These high power combiners offer high isolation of 25 dB, VSWR of 1.15 and low insertion loss of less than 0.3 dB. This series is essential for combining unbalanced signals in base station applications. The series is made in the USA and available from stock.

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

RS No. 228

Directional Couplers

These directional couplers operate in a frequency range from 800 to 2500 MHz with models able to handle up to 200 W. SMA and Type N connectors are standard with coupling values of 6, 10, 20 and 30 dB.

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

RS No. 247

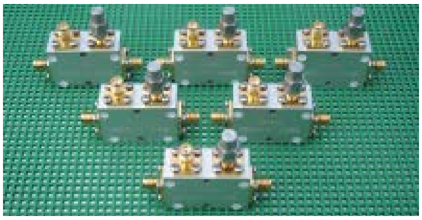
Band Stop Filter

The model BSF-108+ is a surface-mount band stop filter that operates in a frequency range from 88 to 108 MHz. This model features good VSWR of 1.3 typical at passband and high FM frequency rejection. Applications include: FM radio rejection, receivers and transmitters. Price: $39.95 (1–9).

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

RS No. 229

Directional Coupler



This new application specific series of economical directional couplers is designed for power sampling and VSWR monitoring in WiMAX applications. The new couplers operate at 2.5 and 3.5 GHz and are available in coupling values of 10, 20 and 30 dB nominal. Electrical performance offers typical insertion loss of 0.5 dB, isolation of 18 dB minimum, VSWR of 1.25 typical and directivity of 15 dB maximum. Forward power handling is 50 W CW. The new devices are available with N and SMA female connectors standard, and alternate interfaces, including reverse polarity, upon request. The package size is 1.38" × 0.95" × 0.59", plus connectors. Units accommodate environmental extremes from –35° to +80°C.

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

RS No. 232

Coaxial to Waveguide Adapters

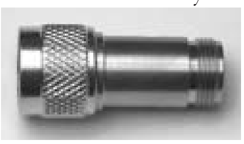
These coaxial to waveguide adapters are available in a variety of configurations for a specific application. Option A includes broadband adapters whose excellent electrical specs are maintained over the entire adapter bandwidth, while option B offers enhanced performance over a specific band of the adapters' bandwidth. Computer design and the latest in RF techniques coupled with precision assembly ensure optimal electrical performance in the recommended frequency ranges.

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

RS No. 233

Type N Fixed Attenuator

The model 3082-7001-XX is an 18 GHz Type N attenuator. This military/aerospace grade product provides excellent performance at a remarkably low price. Housed in a small stainless steel package, this durable 2 W attenuator is a great value in a broad range of applications. The 3082-7001-XX is available in 16 standard dB values (00-12, 15, 20, 30). Non-standard dB values and custom configurations are available upon request.



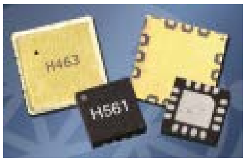
XMA Corp.,
Manchester, NH (603) 222-2256,
www.xmacorp.com.

RS No. 235

AMPLIFIERS

×2 Active Frequency Multiplier and Low Noise Amplifier

The model HMC463LH250 is a GaAs PHEMT MMIC low noise distributed amplifier with gain control that operates from 2 to 20 GHz. This amplifier provides 13 dB of gain, 3 dB noise figure and 18 dBm of output power at 1 dB compression, while drawing only 60 mA from a +5 V supply. Housed in a hermetic surface-mount package, the HMC463LH250 exhibits excellent gain flatness of ±0.5 dB from 2 to 14 GHz, making it ideal for EW, ECM, radar, test equipment and other high reliability applications.



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

RS No. 237

1 kW Pulse Microwave Power Amplifier

The M1270 series of 1 kW X-band microwave power modules (MPM) is designed for air borne radar applications in a high density 11" × 6" × 2" package that weighs in at less than 9 lbs. The M1270 MPM features a new advanced traveling wave tube (TWT)-based design with solid-state preamp that offers RF power efficiency operating from standard 28 VDC bus consuming less than 275 W of operating prime power and less than 40 W at standby.

L-3 Communications Electron Devices,
San Carlos, CA (650) 591-8411,
www.l-3com.com/edd.

RS No. 238

GaN Broadband Power Amplifier

The model SSPA 0.020-0.520-125 is a high power, broadband, gallium nitride (GaN) RF amplifier that operates from 20 to 520 MHz. This PA is ideal for broadband military platforms as well as commercial applications because it is robust and offers high power over a multi-octave bandwidth. This amplifier was designed for broadband jamming and communication systems platforms. The amplifier operates with a base plate temperature of 85°C with no degradation in the MTBF for the GaN devices inside. It is packaged in a modular housing that is approximately 3.4" (width) by 6.4" (long) by 1.0" (height).

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

RS No. 236

Adjustable Threshold Detector Log Amplifier

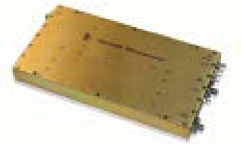
The PMI model TA-SDLVA-0120-70 option 105F is an adjustable threshold detector log amplifier that operates from 1.3 to 1.7 GHz (other frequencies are available), and are designed using GaAs technology, which provides stunning performance and reliability in a compact package. TSS is –60 dBm minimum and a logging range of –60 to +5 dBm. Input VSWR at –23 dBm is 1.8 maximum with an adjustable threshold. Size: 3.75" × 1.50" × 0.50".

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

RS No. 230

Ultra Linear RF Amplifier

The model SM4450-43L is a GaAs FET amplifier designed for various military and commercial applications demanding high performance. The unit operates from 4.4 to 5 GHz with a P1dB of +43 dBm and OIP_3 of +62 dBm. Small-signal gain is 55 dB with a flatness of ±0.5 dB across the band. Standard features include a single +12 VDC supply, thermal protection with auto reset and over/reverse voltage protection. In module form, the unit measures 7.5" × 3.97" × 0.79"; an integral heatsink is also available. This amplifier is also available in lab unit and 19" rack configurations.



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

RS No. 239

ANTENNAS

Broadband Blade Antenna

The model 11D28500-10 is broadband blade antenna designed for airborne applications. This new blade antenna offers ultra-broad bandwidth from 480 to 2400 MHz. This antenna has peak gain of 4 dBiL, with a nominal gain of 2.5 dBiL, includes built-in lightning protection and has 200 W CW power handling capability. Dimensions are 5.25 max base width, 5.55 total height, 0.59 blade thickness and 1.75 max base width inches and weighs only 9 ozs.

Nurad Technologies Inc.,
Baltimore, MD (410) 542-1700, www.nurad.com.

RS No. 218

Microwave Antenna Technology

This new CloakWave™ technology is designed for point-to-point microwave antennas. CloakWave is a unique disguise technique for microwave antennas that allows the antenna to match the aesthetic look of the environment where it is mounted. The new CloakWave technology is currently available in three styles that include: sand camo, green camo and brick.

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

RS No. 219

DEVICE

High Power GaN Transistors

The RF393X family of 48 V gallium nitride (GaN) power transistors offers power performance from 10 to 120 W and wide tunable bandwidth—demonstrating the superior combination of high power and bandwidth offered by RFMD's GaN technology versus competing GaAs and silicon LDMOS technologies. The RF393X product family is comprised of five 48 V GaN unmatched power transistors, each of which deliver gain in the range of 14 to 16 dB and high peak drain efficiency of greater than 65 percent at 2.1 GHz. The superior performance characteristics of RFMD's GaN power transistors make them ideal for wideband, high efficiency power amplifier applications, such as broadcast television, wireless infrastructure, high power radar, aerospace and avionics.

RF Micro Devices Inc. (RFMD),
Greensboro, NC (336) 664-1233, www.rfmd.com.

RS No. 240

INTEGRATED CIRCUIT

Power Solution Modules

The Microsemi Power Solution Module Series consists of three model types: the 1214-800P, 1214-700P1 and 1214-550P. These models provide a "50 Ohms IN-50 Ohms OUT" fully matched across the 1200 to 1400 MHz band, high power amplifier stage for pulsed radar systems. These high performance, Class C modules are designed for unparalleled performance, delivering peak power outputs greater than 550, 700 and 800 W at 50 percent collector efficiency, under a pulse format of 300 microseconds, 10 percent long-term duty cycle. Their user-friendly design provides customers with plug-and-play capability that requires no additional tuning or complicated impedance matching. These modules are designed for high power L-band pulsed radar applications.

Microsemi Corp.,
Irvine, CA (800) 713-4113,
www.microsemi.com.

RS No. 241

PROCESSING EQUIPMENT

Precision Milling System

The FP21T Precision milling system offers micro fine 50 µm capabilities and uses state-of-the-art processing technology and experience in PCB prototyping to deliver accuracy, longevity and reliability. The system is equipped with the company's advanced 'air-ride' milling head, five-phase stepper motor and DC gear driven Z-axis. In addition to copper foil, the FP21T Precision can process traditionally difficult materials such as alumina, Teflon, strontium oxide and silicon wafers.

MITS Electronics,
Tokyo, Japan +81 42 388 1051, www.mitspcb.com.
RS No. 253

SOURCES

High Speed Frequency Synthesizers

This new series of miniature, wideband, high speed frequency synthesizers operate in a frequency range from 2 to 18 GHz, with switching speeds of < 3 µsec and power consumption < 16 W DC. The fast switching speeds of the new synthesizer permit extremely fast receiver tuner acquisition of emitter signals, which therefore permits them to be used as local oscillators (LO) in fast-tuning superheterodyne receivers. For this application, the synthesizers provide substantial improvement in tuning times and spurious signal generation, with excellent phase noise and frequency accuracy. As a result the synthesizers are also ideal for many new ATE systems used for a variety of microwave test applications.
Wide Band Systems Inc.,
Rockaway, NJ (973) 586-6500, www.widebandsystems.com.
RS No. 250

Temperature-compensated Crystal Oscillator

The T1220 series temperature-compensated crystal oscillator (TCXO) offers OCXO-like temperature stabilities as low as $\pm 7 \times 10^{-8}$ and the operating temperature range can be specified as wide as –50° to +95°C. The T1220 features current consumption of less than 30 mA. The T1220 has been designed for applications that require tight stability, low input power (virtually no heat dissipation) and no warm-up time. The T1220's compact, industry-standard package measures 0.8" × 0.5" × 0.33". With a rugged package and excellent g-sensitivity, the T1220 series TCXO is ideal for portable as well as airborne applications with demanding environments.

Greenray Industries Inc.,
Mechanicsburg, PA (717) 766-0223, www.greenrayindustries.com.
RS No. 217

YIG-tuned Oscillators

The MLXS-T series of broadband switched YIG-tuned oscillators are signal sources covering the frequency range from 2 to 20 GHz. These oscillators are two YIG circuits assembled under a single magnetic structure. The circuits share a single MMIC amplifier to guarantee +14 dBm over 2 to 18 GHz and +13 dBm over 2 to 20 GHz. A MMIC switch is used to switch between bands, the switch point occurring at 8 GHz with a 200 MHz overlap. A TTL signal is required to switch the low band or high band into operation. Standard units incorporate an internal driver (option T) to turn off the unused band, conserving power consumption and elimination of unwanted leakage. Guaranteed noise performance is –123 dBc/Hz at 100 kHz offset over the 2 to 20 GHz band.

Micro Lambda Wireless Inc.,
Fremont, CA (510) 770-9221, www.microlambdawireless.com.
RS No. 242

Wideband Voltage-controlled Oscillator

The model V844ME24-LF is a C-band (3250 to 3700 MHz) voltage-controlled oscillator (VCO) designed for WiMAX applications. This model offers a low phase noise performance of –86 dBc/Hz at 10 kHz offset from the carrier. This new model combines linear tuning with superior harmonic suppression. It provides an average tuning sensitivity of 165 MHz/V and typical harmonic suppression of –20 dBc. It also guarantees O/P power of 5 dBm ±2 dB over the extended operating temperature range of –40° to 85°C. Size: 0.50" × 0.50" × 0.22". Price: $18.95/VCO (5 pcs min). Delivery: stock to four weeks.

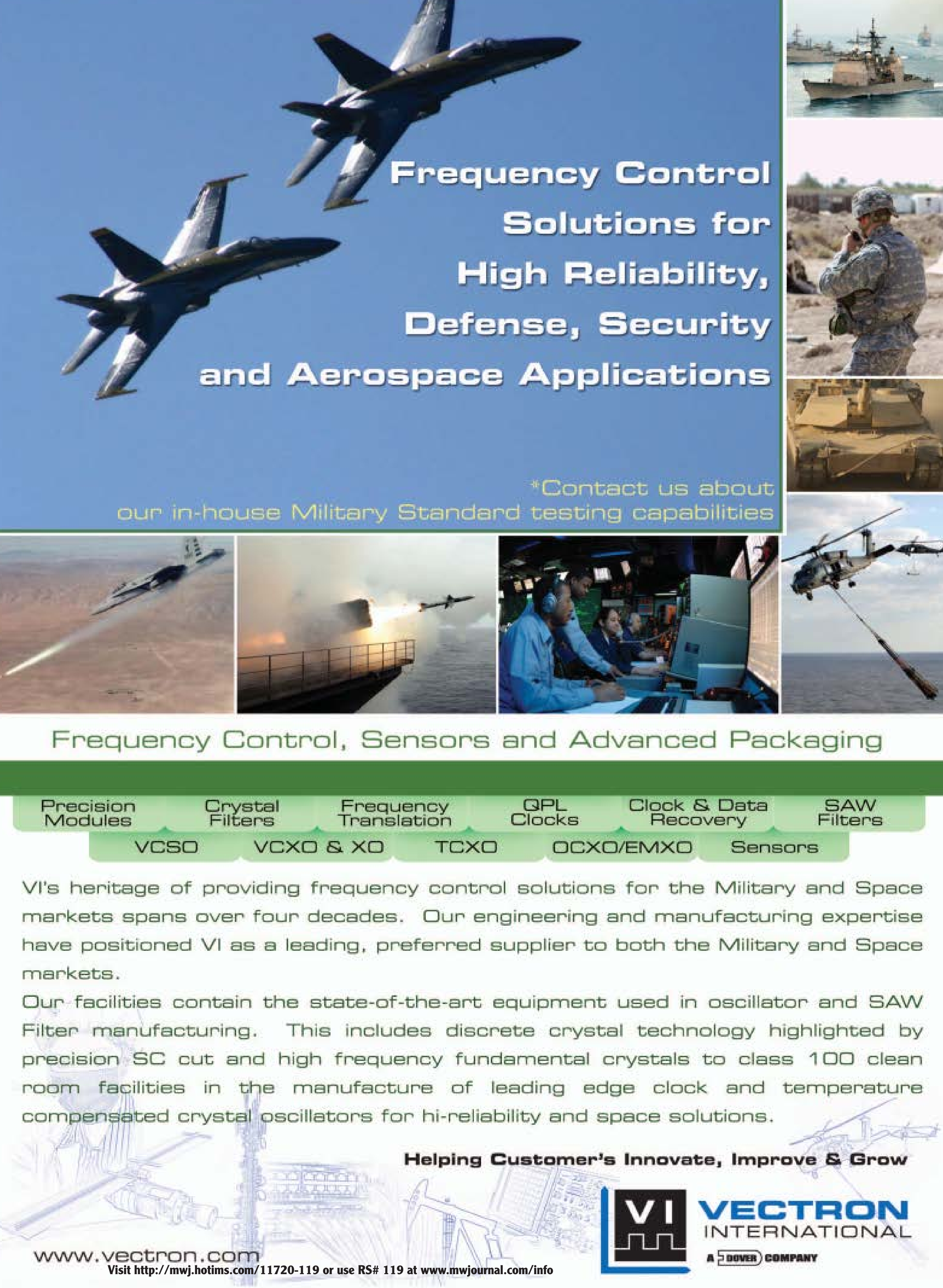
Z-Communications Inc.,
San Diego, CA (619) 621-2700, www.zcomm.com.
RS No. 243

TEST EQUIPMENT

Low Power Digitizer

The Acqiris DP1400 high speed digitizer features a compact design and highly integrated technology for extremely low power consumption as well as a unique simultaneous multi-buffer acquisition and readout (SAR) mode that significantly improves measurement throughput. Designed in a standard short PCI card format, the compact Acqiris DP1400 combines data converter ASIC technology with a high level of component integration for significantly reduced power consumption of less than 15 W. It can be used in all standard PCI bus slots, whether long or short, and is ideal for a variety of test applications, including semiconductor component test, hard disk drive production test and industrial non-destructive testing. Price: starts at $9490. Delivery: eight weeks after receipt of order.

Agilent Technologies Inc.,
Santa Clara, CA (800) 829-4444, www.agilent.com.
RS No. 245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New Products

Radio Test Set

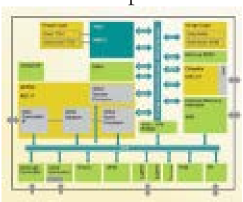
This new 3920 digital radio test set is designed for analog, TETRA and P25 technologies. The 3920 features new enhancements that provide test professionals with more test capabilities integrated into one system, as well as extended analysis range and file management functions. The next generation of the Aeroflex 3900 series, the 3920 replaces the 3901 and 3902 radio test sets. While providing new features and functions, the 3920 continues to perform all the tests previous capable with the 3901 and 3902, including TETRA mobile station, base station and direct mode test features.

Aeroflex,
Wichita, KS (800) 835-2352,
www.aeroflex.com.

RS No. 244

Low Power Kit

This kit enables engineers of different experience levels to adopt advanced low power techniques with minimized risk and deployment effort. The Cadence low power kit provides a working end-to-end methodology covering logic design, functional verification and physical implementation. This kit contains a generic wireless application design, implemented using multi-supply voltage and power shut-off methods, and all associated command scripts and technology files needed to carry the design through the entire end-to-end flow.

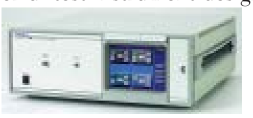


Cadence Design Systems,
San Jose, CA (408) 943-1234,
www.cadence.com.

RS No. 254

Jitter Test System

The Noise Com J7000 jitter test system is a powerful test instrument designed to alter serial signal streams through injection of Gaussian noise in a way that reflects real world signal behavior. To evaluate performance of components and systems, the J7000 is capable of adding precise amounts of white noise to the signal stream that allows the measurement of signal-to-noise ratio (SNR), carrier-to-noise ratio (CNR) and bit-error-rate (BER). J7000 systems are available in different frequency bands ranging from 1 MHz up to 5 GHz. A very high crest factor of greater than 18 dB guarantees optimal distribution of random events to evaluate low BER. The J7000 series provides a frequency dependent output power that ranges from –131 dBm/–66 dBm to –3 dBm and provides an ultra low distortion signal path.



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

RS No. 246

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Call for Papers

The IEEE MTT-S International Microwave Symposium 2008 (IMS 2008) will be held in Atlanta, Georgia, Sunday, June 15 through Friday, June 20, 2008, as the centerpiece of Microwave Week 2008. Technical papers describing original work in research, development, and application of RF and microwave theory and techniques are solicited.

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

Electronic Paper Submission: Technical papers for this symposium must be submitted via the IMS 2008 website, www.ims2008.org. Complete information on how to submit a paper and register for the conference, as well as other important information, can be also found at the IMS 2008 website.

Proposals Invited: Workshop (Tutorial through Expert level), Special Session (Focused and Honorary), and Panel/Rump Session proposals are invited. To suggest topics, or to volunteer to help organize or participate in a Workshop, Special Session, or Panel Session, contact the appropriate committee member listed on this page.

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Electronic Submission Deadlines

Proposals for short courses, workshops, panels, and special sessions:	September 14, 2007
Manuscripts for review:	December 7, 2007
Final manuscripts:	March 7, 2008
All submissions must be made through the IMS 2008 portal:	www.ims2008.org

ALL SUBMISSIONS MUST BE IN PDF FORMAT **Hard copies not accepted**

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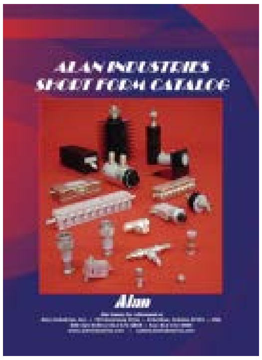

This 12-page, full-color short form catalog features the company's complete range of products that are ideal for test and measurement, SATCOM, telecom, commercial and military applications. Products include: programmable attenuators, variable step attenuators, terminations, loads, DC blocks, bias tees and RF detectors. In addition, the catalog provides an overview of custom design and manufacturing capabilities.

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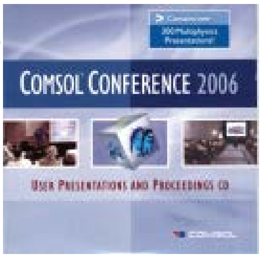

The COMSOL Conference CD is a compilation of user contributed slides, papers and models presented at multiphysics conferences worldwide. CD highlights include: 272 papers from the proceedings, 153 user presentations, 32 keynote presentations and 30 ready-to-run COMSOL models. Applications include: AC/DC systems, acoustics, electrostatics and magnetostatics, MEMS and microfluidics, RF and microwave engineering.

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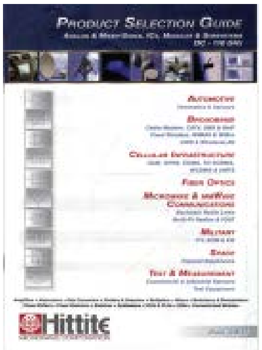

The June 2007 product selection guide summarizes over 500 of the company's products. Newly redesigned are dedicated sections for connectorized modules, designer's kits, application circuits and a competitor cross-reference table. This new selection guide contains new products released in 2007, which are not included in the 2007 designer's guide catalog. In addition, an updated version of Hittite's popular 2007 designer's guide CD-ROM is now available.

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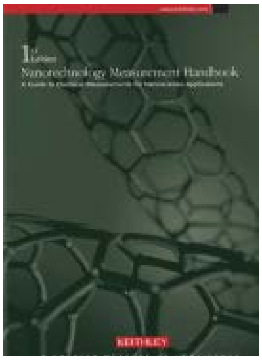

This 124-page guide to electrical measurements for nanoscience applications offers practical assistance in making precision low level DC and pulse measurements on nanomaterials and devices and provides an overview of the theoretical and practical considerations involved in measuring low currents, high resistances, low voltages and low resistances.

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PRODUCT SELECTION GUIDE

This product selection guide provides a simple overview of the company's new and existing RF devices for engineers. Products detailed in the guide are designed for a wide range of applications in wireless base stations, WiFi, WiMAX, GPS, cellular, digital cable, satellite and optical communications systems. Get the guide by visiting www.triquint.com/rf to receive a .pdf download or to order a printed copy.

TriQuint Semiconductor Inc.,
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RS No. 204

IDENTIFICATION AND LABELING CATALOG

This new identification solutions product catalog includes technical specifications and other information for wire and harness identification products, label identification products, hardware, printers and software. The identification and labeling products in the catalog are suitable for general-purpose commercial applications as well as many industrial applications.

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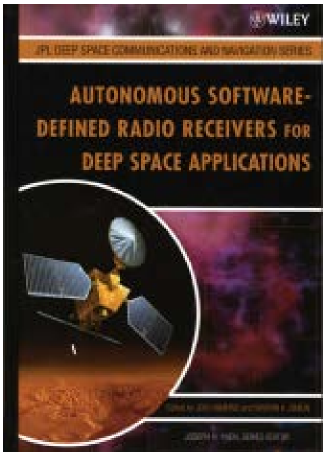
RS No. 205

Autonomous Software-defined Radio Receivers for Deep Space Applications



Jon Hamkins and Martin K. Simon, Eds.
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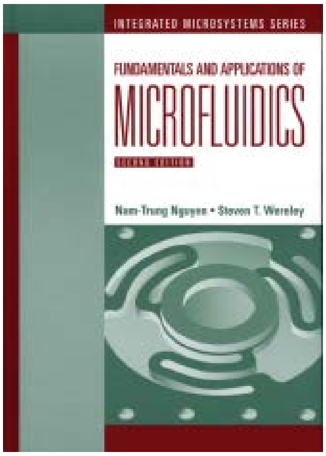
The purpose of this book is the development of techniques to autonomously configure an all-digital software-defined radio (SDR) receiver for whatever type of signal happens to hit its antenna. The automatic identification of the carrier frequency, modulation index, data rate, modulation type and pulse shape, based on observation of the received signal, is described. These are functions that are typically configured manually by the user of an SDR, prior to reception, based on prior knowledge. How the conventional receiver estimators for the signal-to-noise ratio, carrier phase and symbol timing require knowledge of the modulation type, data rate, etc. and how these conventional functions can be implemented in the absence of this information, are also described. Chapter 1 is an overview of the architecture of the autonomous radio receiver, describing what each module does and how the modules interact to produce the desired effect. A general model for a received signal, which will be used throughout the book, is described and many parameters one might desire to estimate from the signal are defined. Chapter 2 provides an overview of the Electra radio, the first programmable software radio that has been developed for space missions. Chapters 3 to 10 cover Modulation Index Estimation, Frequency Correction, Data Format and Pulse Shape Classification, Signal-to-noise Ratio Estimation, Data Rate Estimation, Carrier Synchronization, Modulation Classification and Symbol Synchronization, respectively. In each of these chapters, a method is proposed to estimate a given signal parameter, based on observations of the received signal. How the algorithms of the previous chapters may be incorporated into a single, practical and operational autonomous radio is explained in Chapter 11.

Fundamentals and Applications of Microfluidics: Second Edition



Nam-Trung Nguyen and Steven T. Wereley
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With microfluidics reaching a more advanced stage and given the dynamic nature of this field of study, the materials presented in the second edition of this book are intended to bring the reader to a thorough understanding of the current state-of-the-art of microfluidics. The book can serve as an introductory course for upper-level undergraduate and graduate students in microelectromechanical systems (MEMS) and its organization is clear and suitable for classroom use. It is divided into two sections: Fundamentals and Applications. In the Fundamentals section, Chapter 1 introduces the field of microfluidics, including its definition and commercial and scientific aspects. Chapter 2 discusses when to expect changes in fluid behavior as the length scale of a flow is shrunk to microscopic sizes. Chapter 3 provides the technology fundamentals required for making microfluidic devices, ranging from silicon-based microfabrication to alternative non-batch techniques appropriate for small-scale production and prototyping. Chapter 4 presents experimental characterization techniques for microfluidic devices with a concentration on full-field optical techniques. In the Applications Section, Chapter 5 describes the design of microdevices for sensing and controlling macroscopic flow phenomena such as velocity sensors, shear stress sensors, microflap, microballoons, microsynthetic jets and microair vehicles. Chapters 6 to 8 present design rules and solutions for microvalves, micropumps and microsensors. Chapters 9 to 13 discuss a number of tools and devices for the emerging fields of sciences and chemical analysis in microscale, such as needles, mixers, dispensers, separators and reactors.


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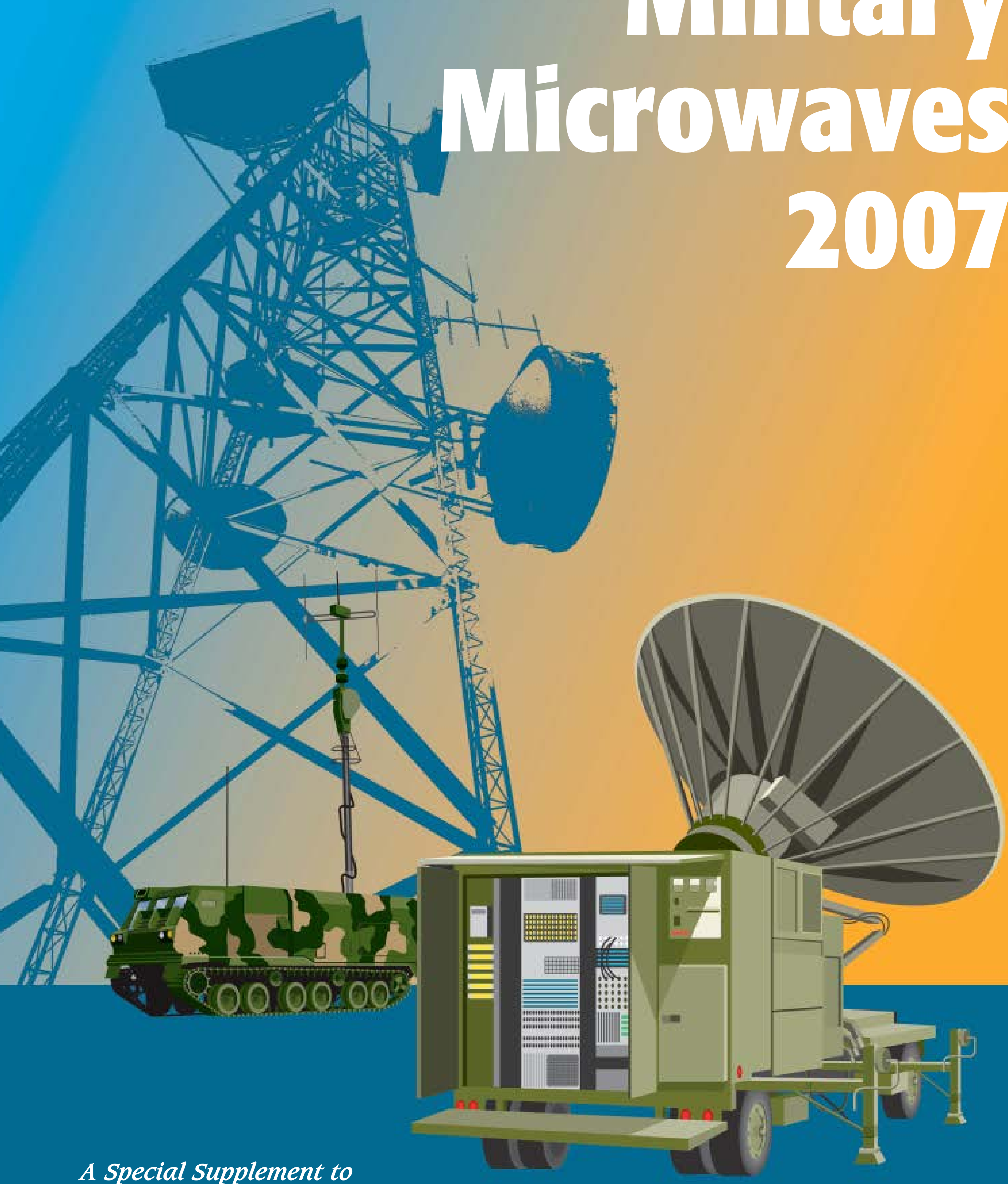

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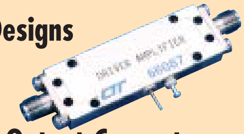

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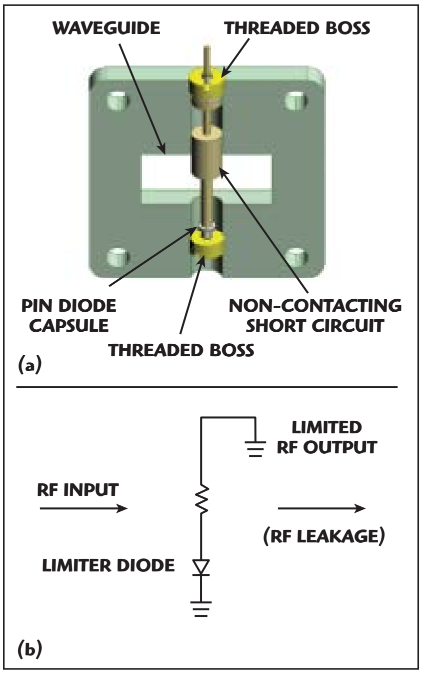
Radar Receiver Protection Technology

Brian Coaker
e2v Technologies Ltd.
Chelmsford, Essex, UK

This article introduces the solid-state microwave technologies and techniques employed in modern radar receiver protector designs. A wide range of device examples are used to illustrate the technology and design concepts.

Receiver protection in modern radars is playing an increasingly vital role in order to meet the challenges of new interference threats and electromagnetic environments. Receiver protectors (RP) are utilised across a broad spectrum of military and commercial platforms, encompassing airborne fixed and rotary wing, missile seeker, maritime and ground-based applications.

Fig. 1 The e2v waveguide PIN limiter's (a) construction and (b) equivalent circuit.



Solid-state receiver protection (SSRP) has broadened in complexity and achieved greater operating power capability in recent years, but fundamentally the waveguide SSRP designs incorporate a PIN (or NIP) diode mounted at the end of a post-coupled coaxial line. ***Figure 1*** illustrates a simple waveguide PIN limiter structure, with a packaged PIN diode mounted with a sliding short-circuit choke, secured between two (threaded) boss structures within the waveguide wall.

By cascading a number of these diode stages within the receiver protector body, an increased level of RF attenuation and low magnitude of RF leakage can be achieved. For each application, the protector design and diode selection is optimized to provide low quiescent loss, with high attenuation in the limiting state, resulting in minimum power absorption by the limiter diode(s), enabling very high peak and mean power handling.

Receiver Protector Architectures

Depending on the application, the protector diodes can be driven (biased) in a number of ways:

- self-biased within the limiter, or self-biased from an integrated detector module (passive)
- active switching triggered by a system command (TTL logic level, for example) input (active)
- active switching circuit triggered by a system command input, or a trigger signal derived from a detector module coupled into the waveguide (quasi-active)
- a quasi-active driver, driven from a system command trigger or self-biased from a detector module, with power-down bias functionality from a detector module within the limiter structure (quasi-passive)

Consider these four styles of receiver protector in turn. First, the passive receiver protector (or 'limiter') relies upon self-bias of the protector diode within the waveguide, rectifying its own bias current from the incident RF pulse. Passive limiters require neither external power supplies nor command signals from the radar system, and offer protection against

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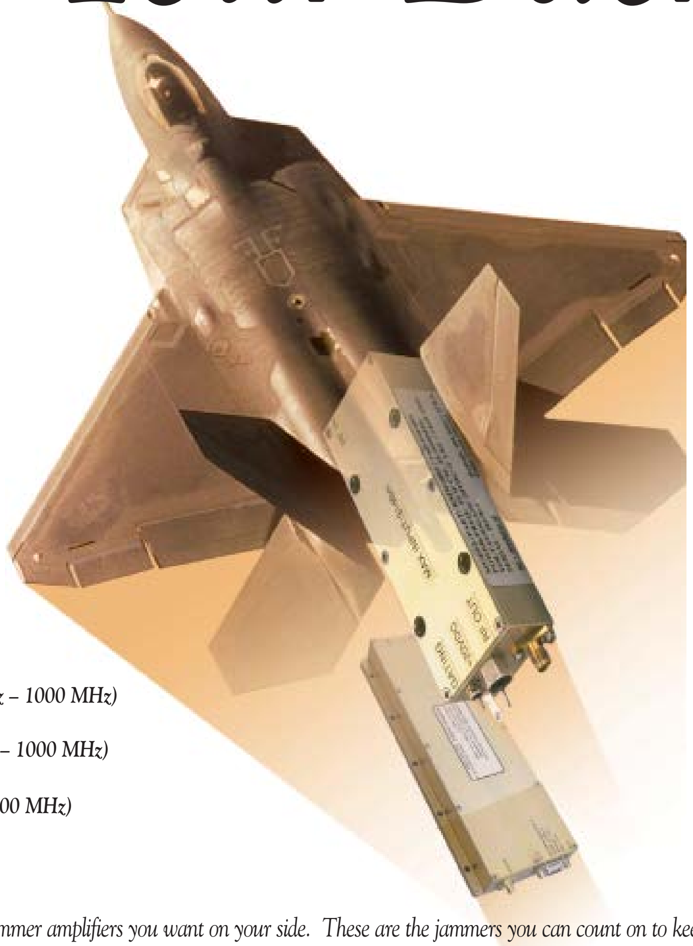

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TABLE I

SSRP ADVANTAGES AND LIMITATIONS

SSRP Architecture	Advantages	Limitations
Passive limiters	✓ Limiting of all incident in-band RF pulses ✓ No power supplies required ✓ No command signal required ✓ Compact mechanical outline ✓ Very high MTTF ✓ No inherent safety hazards ✓ No inherent fire risk or airworthiness issues	✗ Leakage performance inferior to driven SSRPs ✗ Inferior recovery performance at higher incident power levels – negative DC supply needed to optimise insertion loss and recovery performance
Active receiver protectors	✓ Limiting of synchronous RF pulses ✓ Optimum low power (loss) characteristics ✓ Optimum (low) RF leakage performance to synchronous RF ✓ High MTTF ✓ No inherent safety hazards ✓ No inherent fire risk or airworthiness issues	✗ No limiting of non-synchronous RF pulses ✗ Physical size and mass (c.f. passive device) ✗ DC power supplies required ✗ Command signal required ✗ No functionality when powered down ✗ Impact on predicted reliability from driver circuit components
Quasi-active receiver protectors	✓ Limiting of all incident in-band RF pulses ✓ Optimum low power (loss) characteristics ✓ Optimum (low) RF leakage performance ✓ High MTTF ✓ No inherent safety hazards ✓ No inherent fire risk or airworthiness issues	✗ Physical size and mass (c.f. passive device) ✗ No functionality when powered down ✗ Impact on predicted reliability from driver circuit components
Quasi-passive receiver protectors	✓ Limiting of all incident in-band RF pulses ✓ Optimum low power (loss) characteristics ✓ Optimum (low) RF leakage performance ✓ Limiter function when powered-down ✓ High MTTF ✓ No inherent safety hazards ✓ No inherent fire risk or airworthiness issues	✗ Physical size and mass (c.f. passive device) ✗ Impact on predicted reliability from driver circuit and control electronics components

synchronous (own transmitter) and non-synchronous (external interference) signals in low/medium power applications.

The passive limiter may be enhanced by the addition of a protected detector module, mounted 'upstream' within the waveguide structure of the limiter. The self-bias of the limiter diode (in response to the incident RF pulse) is then boosted by the additional bias current sourced from this detector diode.

Again, protection is afforded against synchronous and non-synchronous signals, with improved (reduced) leakage performance when compared to a simple 'diode-only' passive limiter, owing to the additional bias drive provided by the detector module.

Recovery performance of the simple diode-only self-biased passive limiter may be further improved if a negative DC electrical supply is available. Negative bias can be integrated within the limiter to 'sweep' charge carriers from the PIN diodes in between RF pulses, and enable a faster recovery time from the limiting condition back to the insertion loss condition, and also improve the insertion loss through the limiter.

Moving on to active receiver protectors, they can provide synchronous protection of the radar receiver from its associated transmitter. The protector diode(s) are biased using an on-board driver circuit, powered from the host equipment, and commanded by a logic pulse from the host radar system.

Here, too, the performance of the active limiter may be improved if a negative DC electrical supply is available. Negative bias can be integrated within the drive circuitry of the device to enable faster recovery and improved insertion loss.

Since they are driven by a gated pulse from the host system transmitter, active receiver protectors do not provide protection against non-synchronous (external interference) signals, unless driven by an RF detector circuit located elsewhere within the radar system.

Additionally, very little 'quiescent' protection is provided in the power-down state, with DC supplies removed as the protector diodes will self-bias to a small degree.

This power-down condition may therefore leave the powered-down receiver protector and the system receiver susceptible to damage or degradation caused by non-synchronous RF.

Quasi-active receiver protectors, though, can offer both synchronous and non-synchronous protection of the radar receiver from its associated transmitter. The protector diode(s) are driven by bias current from an on-board driver circuit, powered from the host equipment, with a command input derived from both the synchronous logic command pulses from the host radar system and an integrated detector module, which provides a command input to the on-board driver circuit derived from synchronous or non-synchronous RF pulses.

Negative bias is routinely used with the quasi-active receiver protector in order to optimise recovery and insertion loss through the device. Again, very little power-down protection is provided (some protection arises solely from the degree of self-bias in the PIN diodes), which potentially leaves the receiver and the receiver protector susceptible to degradation or damage from non-synchronous RF when the receiver is switched off.

Lastly, consider quasi-passive receiver protectors. Ultimately, the qua-

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si-active SSRP architecture can be modified to incorporate a power-down relay switch, which (in the powered-down state) will route the on-board detector module output away from the driver circuitry, and directly into the protector diodes.

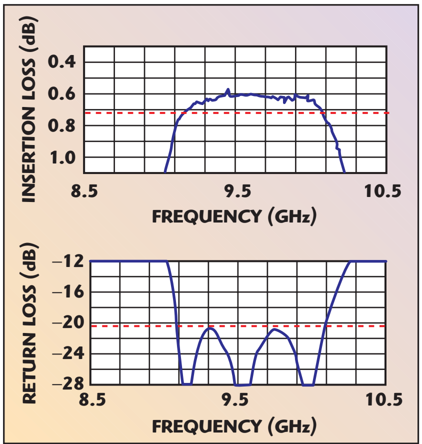
Consequently, when powered, the quasi-passive receiver protector offers equivalent performance to that of the quasi-active device. When powered down, however, the limiter can continue to function in a passive mode, and so continue to provide protection of the receiver from both synchronous and non-synchronous RF, which may enter the radar receiver system.

SOLID-STATE RECEIVER PROTECTION

The range of SSRP functionalities, their advantages and limitations, are summarised in ***Table 1***. Dependent upon available power supplies and electrical interfaces, built-in-test (BIT) can also be implemented within the SSRP unit.

However, a key limitation of any SSRP, when compared to a gas-discharge protector (TR cell), is that the SSRP is a tuned structure, designed to operate in a specific frequency band. This is illustrated in the example of a waveguide SSRP pass-band insertion loss characteristic, shown in ***Figure 2***.

Whereas the operating TR cell would offer an effective short-circuit across a very broad band (from its plasma discharge), the biased-on SSRP will only present a high loss attenuation within the specified frequency band, as shown in ***Figure 3***.



▲ *Fig. 2 Example of an X-band three-stage limiter's broadband loss characteristics.*

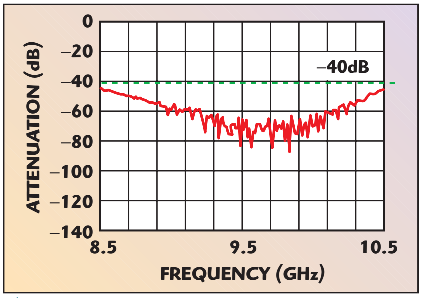
Consequently, the required filtering is routinely fitted within the radar system where out-of-band and/or harmonic RF levels may be present, in order to protect the receiver and the receiver protector from out-of-band transients.

MULTI-FUNCTION RECEIVER PROTECTOR

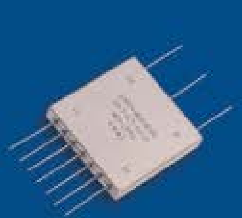
Alongside the limiting or protection functionality of the PIN diode structure of the SSRP, additional functionality may also be integrated within the protector, to provide an integrated multi-function component. The front section of the protector generally contains a high power diode, or doublet of two diodes in parallel, which requires sufficient bias current to enable the stage to handle the incident RF power. The subsequent diode stages are usually less critical in terms of current demand, and generally provide enhanced spike leakage performance as they operate more quickly at intermediate RF power levels.

Consequently, the rear diode stage(s) may be provided with an additional DC bias supply, and driven to provide controlled attenuation for the radar system receive channel. A time-swept attenuation may be provided, enabling precise sensitivity time control (STC) of the radar receiver. In addition, the attenuation stage may be configured to be driven with a simple 1-bit command, to provide (synchronous) blanking attenuation (often termed 'bang snuff') within the receiver channel. This shared functionality of limiting and STC attenuation within the rear stages of the RP means that a distinct, separate attenuator block is not required within the receiver chain.

Radar system requirements increasingly demand the suppression of out-of-band signals, both for protection of the receiver and to address radiated EMC requirements of the



▲ *Fig. 3 The X-band three-stage limiter's broadband attenuation (biased-on).*





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▲ *Fig. 4 An X-band active limiter with STC attenuation and integral out-of-band rejection filter assembly.*

system itself. An input filter can be incorporated into the SSRP to provide rejection to out-of-band interference.

Where a broader-band response is required of the protector, then some of this filtering may also be integrated within the SSRP itself. An example of this integrated unit is shown in ***Figure 4***. Also, a noise source may be incorporated within the waveguide structure of the SSRP, typically located behind the PIN diode stages. A calibrated excess noise ratio (ENR) signal may then be injected into the receive path (often with blanking/full STC attenuation applied to the limiter, in order to prevent interference from the antenna path), thereby providing a receiver system calibration function.

Built-in-test functionality can be incorporated into the SSRP driver electronics to provide a BIT signal return to the radar receiver controller. For example, window detectors can be added to each of the limiter diode stages, and their outputs AND-ed together, enabling a 'good' BIT return provided the limiter diodes are biasing correctly, and remain healthy. Such a BIT scheme is shown in ***Figure 5***.

Another consideration is to maintain system pressurization in an airborne radar system, and prevent moisture/debris ingress into the waveguide of any radar receiver. To this end, a pressure window may be incorporated at the input of the SSRP. A dielectric material panel is fabricated to fit within a frame recess in the input waveguide aperture, and is then bonded into the body of the SSRP.

A pressure window introduces a frequency-dependent additional insertion loss into the SSRP, typically 0.05 dB at X-band (9 to 10 GHz), while offering an aperture seal with hermeticity better than 1×10^{-3} mBar ls^{-1}.

These additional SSRP features and functionality are illustrated in the product example shown in ***Figure 6***, depicting a 500 MHz bandwidth X-band receiver protector, incorporating Ka-band rejection filter, waveguide pressure window, STC attenuation and integrated noise generator. This solid-state passive receiver protector has a waveguide input, SMA coaxial output and a digitally controlled attenuator giving an STC attenuation function from 0 to 60 dB.

It includes four PIN diode stages, with the front stage comprising a PIN doublet. An integrated noise generator is incorporated (14 dB ENR) for system calibration. Its frequency range is 8.7 to 9.2 GHz, with an operating temperature range of –20° to +85°C.

HIGH POWER DUPLEXING/FAULT PROTECTION

Some high power radar systems present peak power levels and duty cycles beyond the capability of the solid-state receiver protector. In such applications, whether high power is incident in normal operation or only in a fault condition, then a gas tube element can be incorporated at the input of the receiver protector.

Classically, a gas tube element is embodied at the protector input to handle high power levels during normal operation. Incident RF energy first activates the PIN diode stages that provide optimum protection during the RF pulse leading edge, and optimum spike leakage performance.

The increasing E-field level across the waveguide then causes ionization of the gas fill in the tube element, leading to a plasma discharge in the gas tube at a high power threshold level. This discharge presents an effective short-circuit to the incident RF pulse, protecting the receiver across a wide frequency bandwidth from incident high power threats.

The routine use of the gas tube element (within the limiter) for receiver protection or duplexing under normal operation high power conditions is termed a pre-TR configuration. This arrangement is illustrated in ***Figure 7***, showing the pre-TR tube (located in H-plane configuration in this case) within an iris tuning structure across the waveguide input, in front of the solid-state limiter section.

In some applications, the solid-state protector can readily handle all of the normal RF operational power

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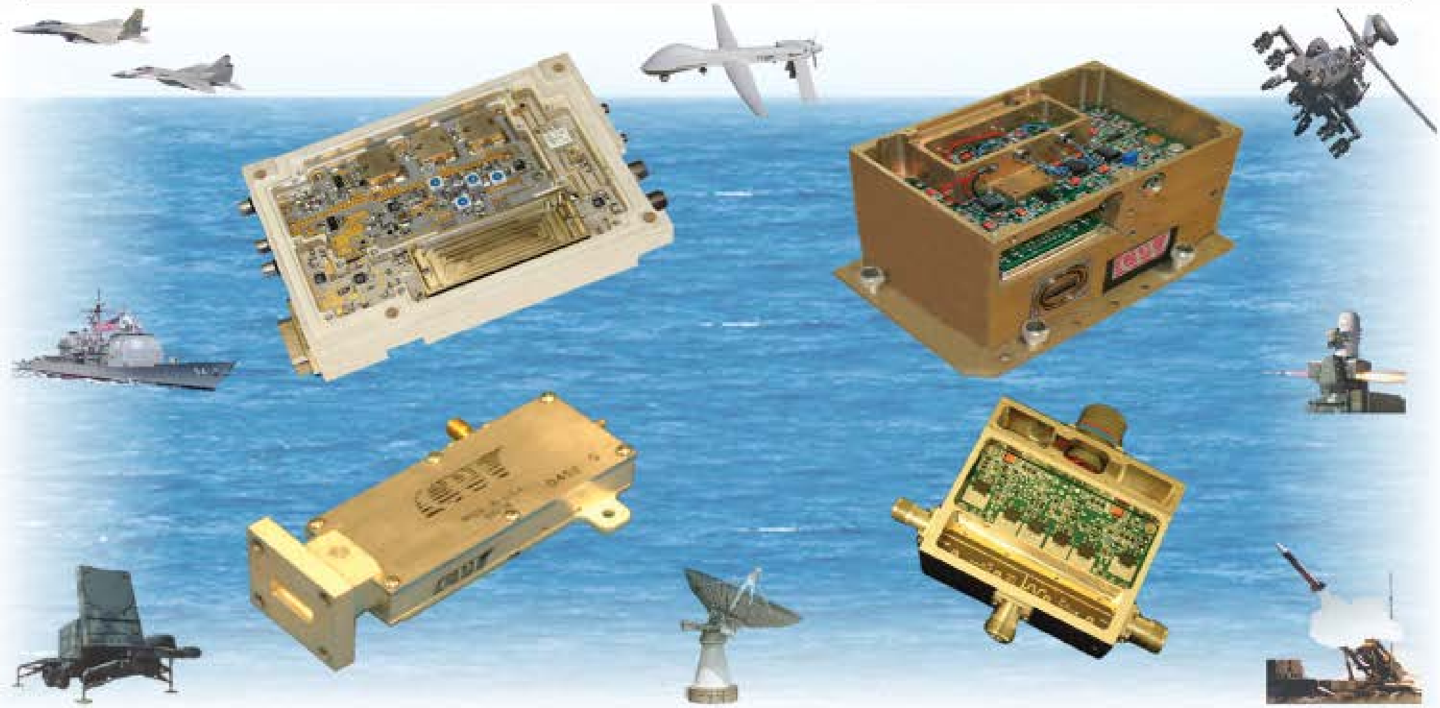

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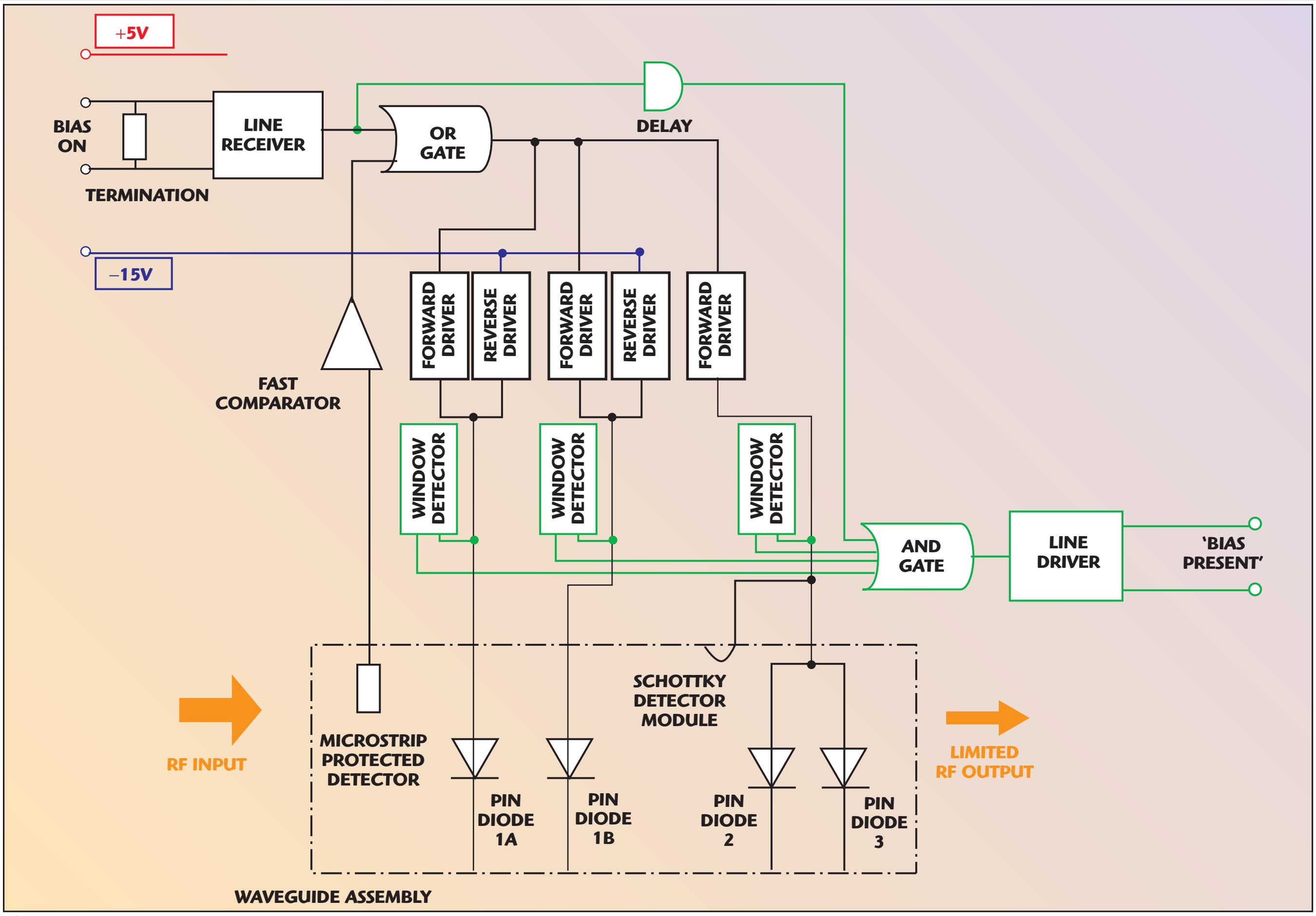


Fig. 5 Functional block diagram of a quasi-active receiver protector with built-in-test.

modes, but a very high level fault condition may also be present. In this scenario, the SSRP can be designed with the solid-state limiter optimised for normal RF operation, delivering optimum loss and limiter responsiveness. For the (intermittent) fault scenario, a gas tube can be incorporated at the SSRP input, and used as a gas switch to deal only with any incident fault pulses (synchronous or asynchronous) on an intermittent basis.

With the development of solid-state limiter capabilities to increase peak and mean power handling levels, former TR cell requirements are increasingly being addressed using a solid-state receiver protector. In many cases, the stand-alone SSRP can address the protection requirement, or may be integrated with a gas switch or pre-TR tube in high power fault or high power duplexing applications.

The TR limiter has traditionally been used for duplexer applications with a magnetron-based RF source. Here the limiter typically sees a short pulse, low duty signal, but with high peak power—often many hundreds of kilowatts at S-band or many tens of kilowatts at X-band.

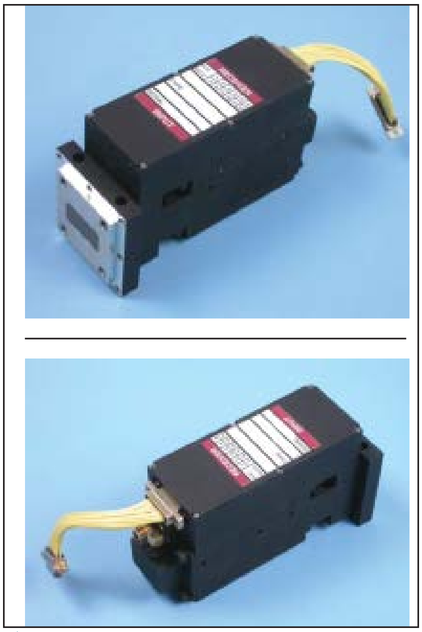


Fig. 6 The e2v X-band four-stage solid-state receiver protector.

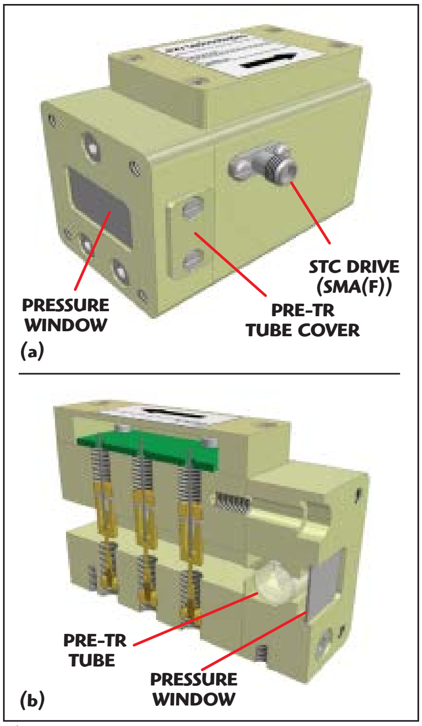
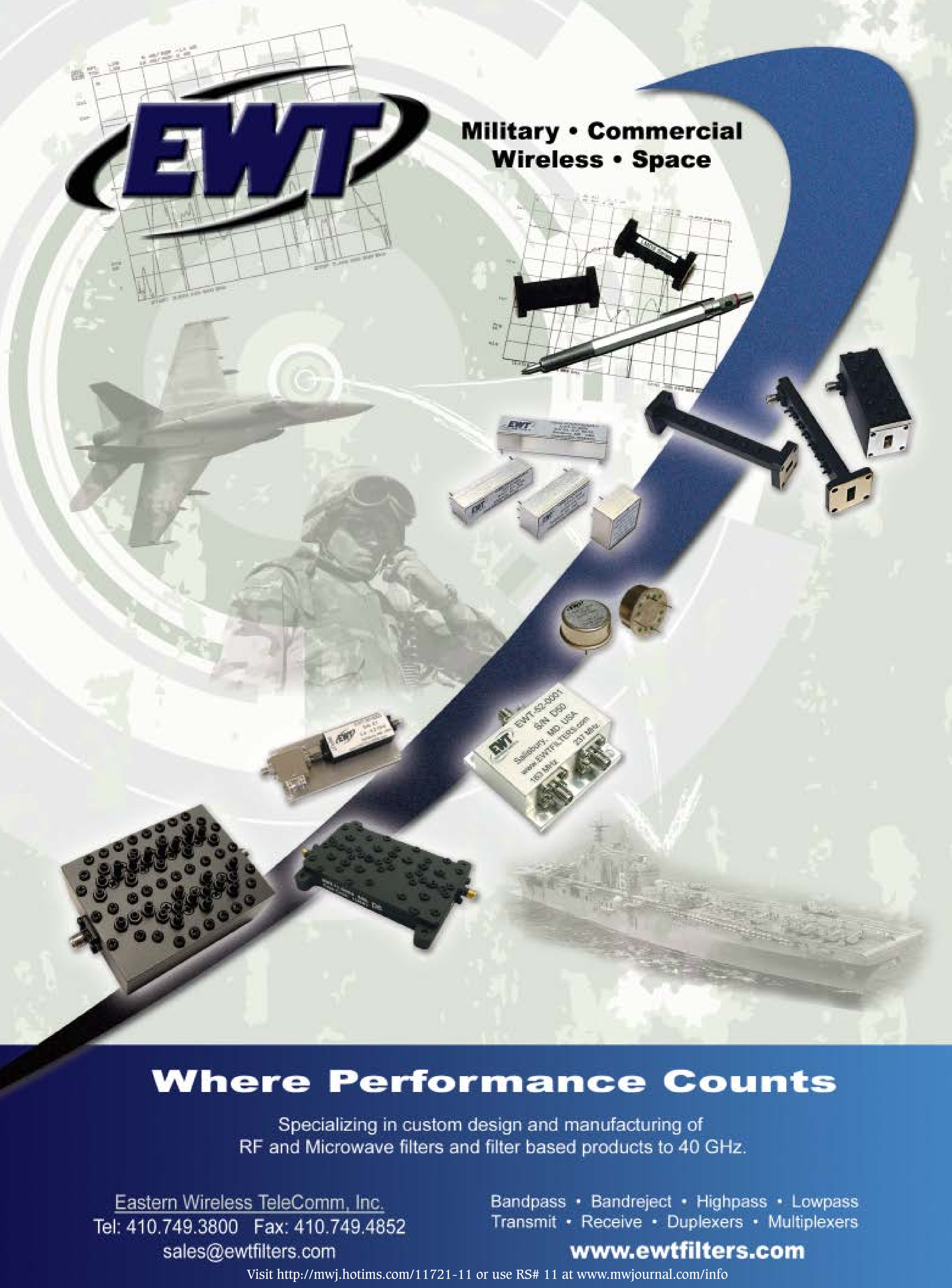


Fig. 7 General arrangement (a) and internal detail (b) of the X-band passive limiter with integral pressure window and pre-TR limiter.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However, the continued use of the TR tube-based TRL has become challenging, owing to the use of radioactive primers to achieve fast response in the gas filling, and the need for a high voltage power supply infrastructure to support the high voltage primer ('keep-alive') on the TR tube.

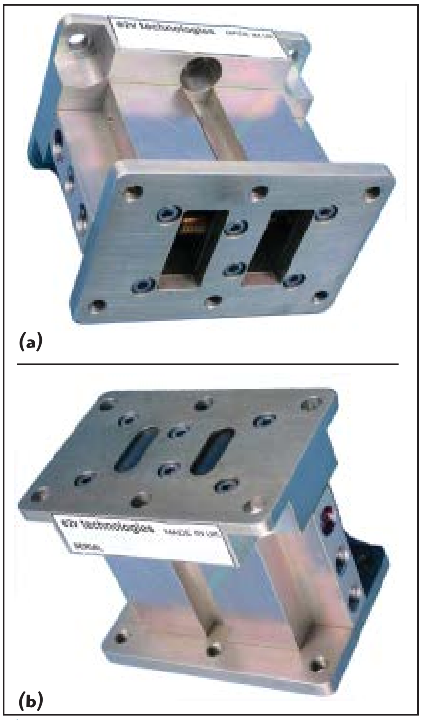
There are three main options for replacing the TR limiter. These include:

- a solid-state diode limiter
- gas tube (pre-TR tube) plus diode limiter
- gas tube (gas switch) plus diode limiter

Utilising a solid-state diode limiter, the operation requirements fall entirely within the capabilities of a modern SSRP. With a gas tube (pre-TR tube) plus diode limiter, the gas tube operates under normal conditions. In this scenario the gas tube is usually referred to as a pre-TR tube. It is used in systems where the pulse conditions (duration, duty) may be more severe at lower power levels, and the recovery specification is not as demanding.

With the gas tube plus diode limiter, the gas tube operates only under fault conditions. The gas tube is often referred to as a gas switch, which is usually fitted when the normal operating conditions require the fast response performance of a diode limiter, plus the high level protection of a gas tube under a high power fault condition. This fault condition is usually present for a short duration. With the protection that this limiter/gas switch configuration offers, the diodes for the limiter can be optimised to meet other operating pa-

▲ *Fig. 8 Legacy X-band dual 50 kW TR limiter.*



▲ *Fig. 9 The updated X-band dual 50 kW pre-TR limiter, showing the input (a) and output (b).*

rameters without the high fault power levels being a concern.

An example of a recent X-band duplexer development entails the replacement of a dual-channel 100 kW TRL unit (shown in ***Figure 8***) with a twin pre-TR limiter (shown in ***Figure 9***). In this application the dual-channel TRL unit is mounted between 3 dB hybrid couplers, so the incident power is split equally between the two channels. Therefore, the power handling requirement per channel, allowing a reasonable margin, is approximately 60 kW peak.

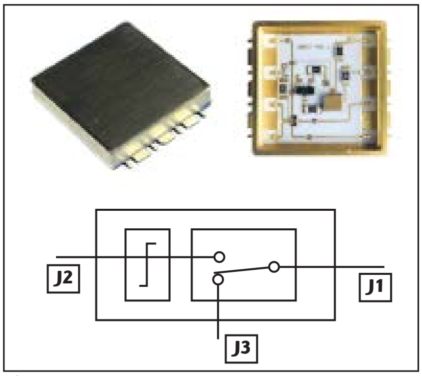
The updated protector design includes a gas tube in each limiter channel in an H-plane orientation. This tube orientation is chosen in order to minimise the arc-loss in the gas tube. Since the device operates continuously at the high power levels, low arc-loss is a requirement for RF and thermal efficiency. The gas switch input section is then followed by a three-stage solid-state limiter.

RECEIVER PROTECTOR PACKAGING AND INTEGRATION

Alongside waveguide units, receiver protectors may also be packaged and configured in strip-line, microstrip and also as coaxial structures. e2v Technologies has taken the microstrip limiter design approach into surface-mount and 'drop-in' packaged devices, which are particularly suited to phased-array radar modules, and developed a surface-mount S-band (E/F band) SPDT reflective switch with limiter protection on its input (J2), as shown in ***Figure 10***.

The limiter section utilises proven diode limiter technology, providing protection at power levels up to +36 dBm CW/+40 dBm peak, and recovery times better than 200 ns. An integrated SPDT switch circuit within the module offers in excess of 40 dB isolation, with a switching speed better than 2 µs.

The microwave integrated circuit tile is mounted within a surface-mount package, having a 20.5 by 20.5 mm



▲ *Fig. 10 An S-band 10 W passive limiter with SPST switch.*

▲ *Fig. 11 An S-band coaxial passive limiter.*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footprint and a height of 3.8 mm. The packaged device is hermetically sealed, and is designed for reflow soldering onto a circuit substrate. The unit operates from a +5 V DC supply, typically drawing a maximum 20 mA. The SPDT switch control is from a –8 V/0 V complementary pair, drawing 1 mA maximum bias current.

Receiver protector topologies can also be realised in a coaxial line structure and an example of a passive S-band coaxial limiter is shown in ***Figure 11***. This low loss S-band coaxial limiter (insertion loss < 0.4 dB, VSWR better than 1.3) is designed for long pulse, high duty operation (100 µs/10 percent duty) at moderate peak power levels. The unit is completely passive, fitting in a compact physical outline with N-type coaxial connectors at input and output.

Alongside receiver protectors, integrated subsystems can facilitate optimum RF system performance, enabling an optimised combination of the receiver protector with other microwave modules and components, into a single integrated package. For example, ***Figure 12*** shows an integrated Ku-band duplexer/receiver protector/low noise amplifier (LNA) for a man-portable military radar system, which comprises a two-piece integrated microwave package assembly. The integrated unit incorporates a quasi-active receiver protector, circulators, bandpass filter and waveguide probes for BITE signal injection and monitor, with the LNA added at the receiver protector output flange.

From the device schematic, the port 1 connector is a 90° swept male SMA, port 2 is identified, port 3 is the straight SMA female on the LNA and port 4 is the right-angled SMA female with integral 6 dB pad attenuator. The LNA has a waveguide input and SMA coaxial output.

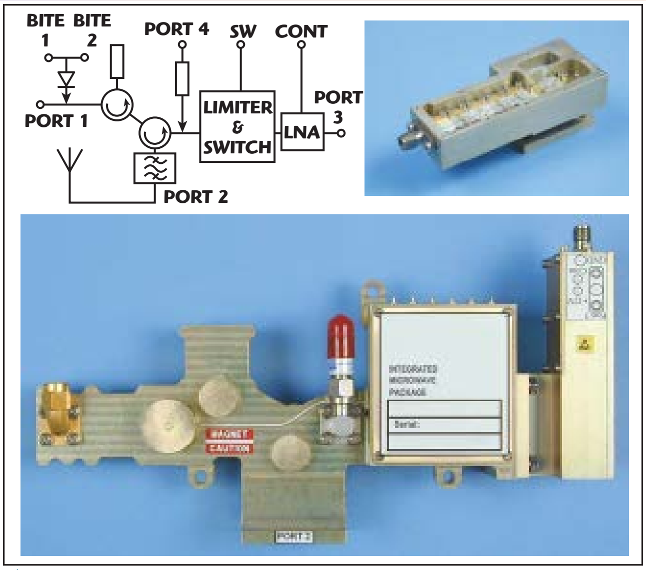
Another example of integration is a Ka-band RF head, comprising a pulse magnetron, four-port circulator, active limiter, LNA mixer pre-amplifier with image rejection, and integrated Gunn oscillator for airborne radar and millimetric imaging applications. The head delivers 1.7 kW peak output power at a nominal 35 GHz, presenting an antenna port match of 1.5 maximum.

The mixer offers a conversion gain of at least 23 dB, down to a nominal IF of 70 MHz. Integration of the receiver protector (in this case an active limiter) within the RF head allows the overall noise figure (from antenna port to the IF output) to be optimised, and is better than 7 dB.

CONCLUSION

Solid-state receiver protection techniques have been deployed across a wide range of conventional and phased-array radar system architectures, providing low loss protection elements that are capable of withstanding high incident powers from local and remote radar transmitters, along with other EMC threats.

Ongoing development of power-handling capability in the solid-state RP, achieved through diode design, packaging and detector-drive schemes, has enabled SSRPs to replace gas-filled TR cells in the majority of radar systems. Where a high power fault condition persists, and while the solid-state limiter



▲ *Fig. 12 The e2v integrated Ku-band duplexer/LNA unit, with the RF subsystem schematic and cut-away view of the LNA assembly.*

can typically handle all normal operating power levels, then a (non-radioactive) gas switch may also be incorporated in the RP, to operate under fault power levels.

Solid-state receiver protection has also been developed in an emerging series of planar circuit configurations, for integration in receiver circuit board architectures to provide low loss protection elements. The integration of further system functionality within the receiver protector assembly supports a further optimisation of the system receiver chain performance and loss, while providing an overall reduction in the radar system mass, size and cost. ■

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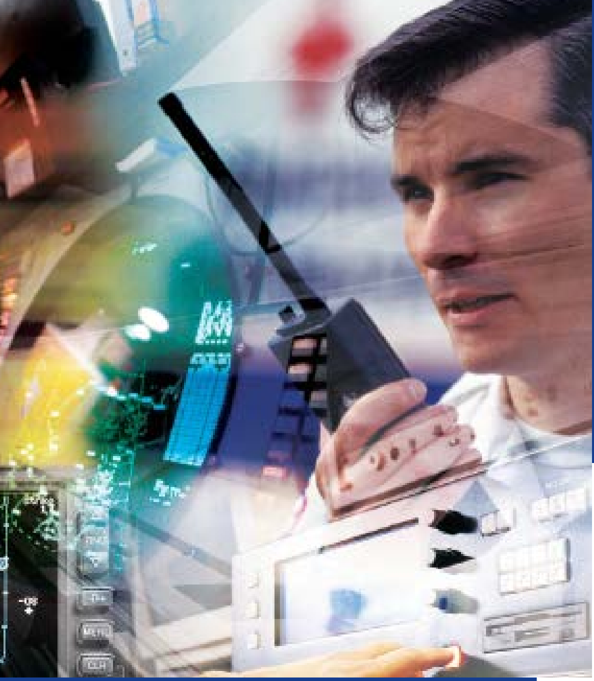

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Multi-gigabit, MMW Point-to-point Radios: Propagation Considerations and Case Studies

Military surveillance and commercial high definition TV have joined carrier "backhaul" to drive development of lower cost, multi-gigabit millimeter-wave (mmW) radios, and the wildly differing system requirements, while challenging, are being met right now. This article provides a basic overview of the unique benefits provided by mmW radios at V-band (57 to 64 GHz) and E-band (71 to 76/81 to 86 GHz) followed by a discussion of the severe operating challenges presented by two radically different deployments (high resolution airborne surveillance video and carrier/enterprise "backhaul") and two case studies of how those challenges were met. Typical system performance, as well as some performance vs. cost trade-offs, will also be presented.

Tom Rosa
Terabeam-HXI
Haverhill, MA

Communications at mmW frequencies offers several unique and very potent advantages as well as some sizable disadvantages. In order to develop cost-effective, high performance links a solid understanding of the issues and in particular how to benefit from the advantages while mitigating the disadvantages is crucial. Reduced hardware size and wider bandwidths are among the leading advantages for radios operating at mmW frequencies. For instance, mmW radios utilize smaller high gain antennas, waveguide and RF front ends than do their lower frequency counterparts. Reasonably priced mmW MMICs are readily available for all small-signal active functions—LNAs, mixers, LO multipliers, etc. The availability of very wide, contiguous bandwidth (7 GHz in V-band, two 5 GHz bands in E-band) allows low cost modulation/demodulation architectures for multi-gigabit data rates.

These advantages are somewhat offset by several disadvantages at mmW, including a higher attenuation vs. precipitation rate (rain, snow and hail) in comparison to lower frequency radios having the same Tx power and Tx/Rx antenna gain product. Lower frequency radios often address their lower gain antennas by using higher power amplifiers in the transmitter. Unfortunately, high power amplifiers

are very expensive at mmW frequencies, thereby limiting their use as a practical solution. Some factors are "wild cards" in terms of being advantages or disadvantages. For instance, the high atmospheric attenuation peak centered at 60 GHz (≈16 dB/km at sea level and dropping to ≈5 dB/km at 4 km above sea level) would seemingly discourage use, but is actually a benefit to secure military systems and has therefore been utilized for decades.

Additional considerations relate to unlicensed versus registered bands. Unlicensed radios (FCC 15.255 compliant radios operating in the 57 to 64 GHz band, for example) can be deployed/re-deployed wherever/whenever desired, without government coordination. Registered radios (that is, those in the 71 to 76, 81 to 86 GHz band) must pass an interference analysis for a specified installation site as part of the FCC registration process; a fee must be paid. (Government agencies register their links with the NTIA.) Registration provides some protection from an interfering radio in the future.

HIGH QUALITY LINKS

Successful communication necessitates reception of a high quality signal despite the presence of adverse conditions like inclement weather, platform movement, extraneous signals (multipath and EMI, for example) and perhaps even denial-of-service attacks. Quality is typically quantified by bit error rate (BER); the maximum acceptable BER is usually established by the signal use (voice, video, or data). For example, voice communication might require a maximum BER of 1×10^{-3} or 1000 ppm, whereas video and gigabit Ethernet might require maximum BERs of 1×10^{-8} and 1×10^{-12}, respectively.

Ideally, BER is a function only of the signal-to-noise ratio (S/N) for a given radio modulation type (OOK, BPK, QPSK, or QAM). For example, a BER = 1×10^{-12} for OOK requires a received S/N ≈15.3 dB; a higher S/N results in a lower BER until a residual minimum level is reached. Therefore, successful communication boils down to achieving the necessary S/N. For most installations, this ultimately requires successful navigation through a minefield of non-RF issues like modeling the weather, or maintaining boresight alignment in spite of a platform in constant motion, perhaps by utilizing a combination of global positioning, inertial navigation, or video alignment systems controlling a positioner.

THE COMMUNICATIONS LINK EQUATION

$$\text{The link S/N} = P_r - N_{ein}$$

where

P_r = received signal
N_{ein} = receiver equivalent input noise

The received signal =

$$P_r = P_t\, G_t\, G_r\, \lambda^2\, L/(4\pi R)^2$$

where

P_t = transmitted signal power
G_t = transmit antenna gain
G_r = receive antenna gain
λ = carrier wavelength
L = loss factor (includes losses due to the weather, polarization or bore-sight alignment errors, etc.)
R = distance between the antennas

The receiver equivalent input noise =

$$N_{ein}(\text{dBm}) = kTBW_nF$$

where

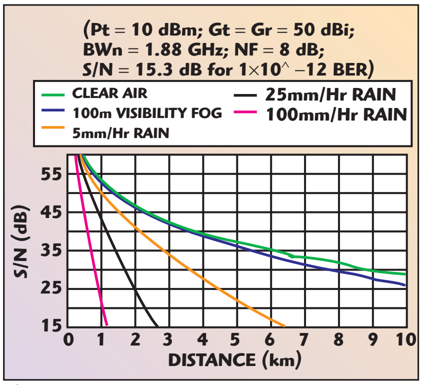
k = Boltzmann's constant (1.38×10^{-23} J/K)
T = temperature (K)
BW_n = receiver noise bandwidth
F = noise factor (note that noise figure =10 log F)

As an example consider a Gigabit Ethernet 71 to 76 GHz (E-band) radio with P_t = 10 dBm, 2ft. dia. antennas ($G_t = G_r$ = 50 dBi), operating under clear air weather conditions, with no bore-sight or polarization errors, 1.88 GHz detection noise bandwidth and 8 dB noise figure, using OOK modulation. This radio will require 15.3 dB S/N to achieve 1×10^{-12} BER and will therefore have a maximum theoretical operating distance of R_{max}, approximately equal to 22 km (see ***Figure 1***).

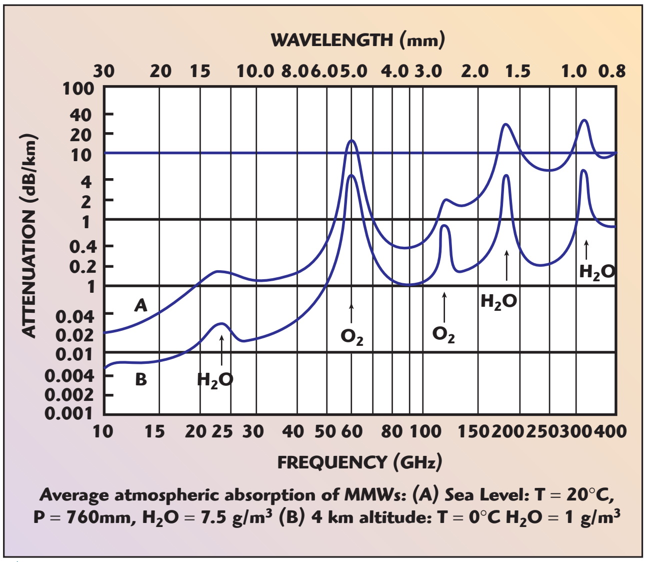
In 100 m-visibility fog, or uniformly distributed rain falling at the rates of 5 mm/Hr (medium), 25 mm/Hr (heavy), or 100 mm/Hr (very heavy), R_{max} drops to ≈17, 6.4, 2.6 and 1.1 km, respectively. To complicate matters, high rain rates are generally localized events (rain cells) with varying sizes (inversely proportional to rain rate) that result in varying attenuation along the link path, hence the probable need to develop a rain attenuation model for long (vs. rain cell size) link paths.

ATMOSPHERIC PROPAGATION LOSSES

It is obvious from the figure that propagation losses due to the various weather conditions can dramatically impact operating range. In the communications link equation, the sum total of all the propagation losses (from "clear air" plus the effects of



▲ *Fig. 1 Link S/N vs. distance for a 1.25 Gbps, 71 to 76 GHz radio.*

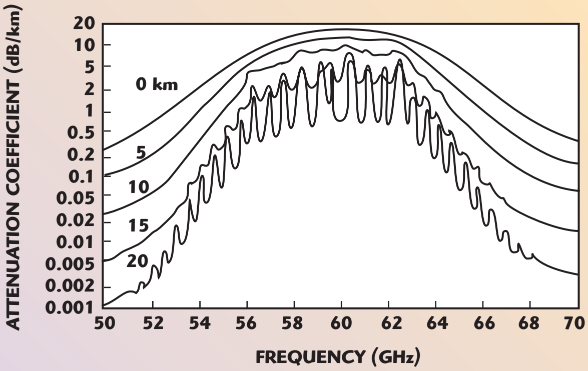


▲ *Fig. 2 Clear air atmospheric attenuation vs. frequency.*[1]

rain, snow, etc., when applicable) are lumped into L for calculation of the received power.

Except for 60 GHz, the common radio frequencies (27, 38, 74, 84 and 94 GHz) appear in atmospheric windows for minimum propagation losses. As mentioned earlier, the relatively opaque region at 60 GHz at low altitudes has been exploited for military satellite-to-satellite communications for decades since it provides eavesdrop and jam-proof protection from terrestrial terminals. Since these propagation losses are critical to developing a successful link, they are quantified below in more detail.

Figure 2 shows the clear air atmospheric attenuation from 10 to 400 GHz at both sea level (top curve) and at 4 km above sea level. In particular, note the high attenuation peaks at 60 GHz (≈16 dB/km at sea level; ≈5 dB/km at 4 km) and the windows from < 71 to > 86 GHz (≈0.5 dB/km at sea level; < 0.2 dB/km at 4 km above sea level). These attenuation levels are significantly higher than those in the 27 and 38 GHz bands.



Altitude-dependent variations of specific attenuations due to atmospheric gases in the 50 to 70 GHz band range. ([ITU-R,1996],© ITU).

▲ *Fig. 3 Clear air atmospheric attenuation vs. altitude (ITU-R, 1996©ITU).*

Figure 3 details the attenuation from 50 to 70 GHz, revealing the greater than 30 oxygen molecule resonances which become increasingly distinct at higher altitudes; this is a consequence of the oxygen molecule having a magnetic moment due to an unpaired electron spin, and the loss of energy (due to electron-spin realignment) by an RF field propagating through it. Under higher pressure conditions (which exist at lower altitudes), collisional broadening increases, the resonance lines smear together, and a relatively wide and smooth attenuation characteristic results, centered at 60 GHz.

Table 1 details the operating distances of identically configured 60 GHz (V-band) and 71 to 76 GHz (E-band) radios under various weather conditions. Note that in clear air at sea level, the atmospheric attenuation due to oxygen drastically reduces the operating distance of the V-band radio; also note that operating distances become comparable in very heavy rain, where attenuation due to rain predominates.

If low probability of intercept and/or resistance to jamming are paramount, the attenuation due to oxygen can be beneficial. The extent to how secure communications

TABLE I

MAXIMUM OPERATING DISTANCE: V-BAND vs. E-BAND RADIOS

Weather Condition	*V-Band*	*E-Band*
Clear Air	1.93 km	22 km
100 m – visibility fog	1.90 km	17 km
5 mm/Hr – rain	1.72 km	6.4 km
25 mm/Hr – rain	1.30 km	2.6 km
100 mm/Hr – rain	0.82 km	1.1 km

1.25 Gbps, Pt = 10 dBm, 2 ft. dia. antennas, BWn = 1.88 GHz
NF = 8 dB, S/N = 15.3 dB for 1×10^–12 BER; altitude: sea level

at 60 GHz can be is illustrated in ***Figure 4***. The total attenuation through the atmosphere looking towards the zenith (that is, straight up) is > 200 dB, and the attenuation looking towards the horizon is even higher. For this reason eavesdropping or denial-of-service attacks of a satellite-to-satellite communications link from a land-based terminal is virtually impossible.

Figure 5 details the attenuation due to rain rate. Caution should be exercised when calculating path attenuation due to high rain rates since these events become highly localized for increasing rates (see also ***Figure 6***, which details rain cell diameter vs. rain rate). If the entire link path is not within the rain cell, then the calculated losses will be too high.

For example, according to Figure 1, the maximum link distance for a uniform 5 mm/Hr rain rate is 6.4 km, but ***Figure 7*** shows that the rain cell diameter for a 5 mm/Hr rain rate is typically less than 3 km as defined by the distance where the rain rate has dropped by 50 percent. Given the diversity of rain rate over a relatively short distance (well within the range of many communication links), the uncertainty in path loss is considerable. Raindrops are not uniform for a given rain rate, but instead have a rather broad distribution, as is evident in Figure 7. This further complicates the loss calculations. This distribution is considered responsible for the discrepancy between the theoretically predicted attenuation resonance at mmW frequencies and the observed attenuation resonance. Note the theoretical resonance would occur when the circumference of the raindrop is equal to the wavelength.

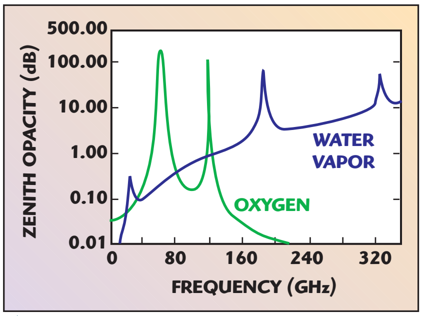
Very little published data exists for attenuation due to snow, but it is generally accepted that light, dry snow has about 10 dB less attenuation than rain at the same rate of precipitation, and that the attenuation due to heavy, wet snow approaches that of rain with the same rate of precipitation, due to the high water content. The attenuation from small diameter hail, since it is composed almost entirely of ice, would be expected to be about the same as that from rain with the same rate of precipitation.

CASE STUDIES

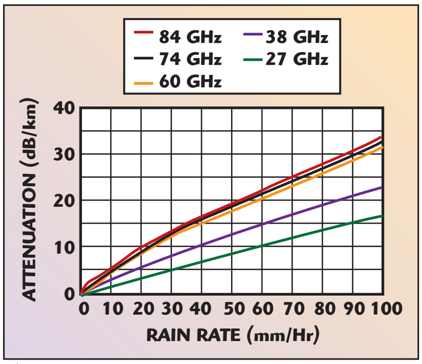
Developing the optimum link frequently requires a trade-off of various parameters. Insight into optimum design choices can usually be gained by reviewing relevant case studies with an eye toward the network challenges and the solutions employed. Towards that end, two radically different case studies are considered.

CASE STUDY 1: AIRBORNE SURVEILLANCE VIDEO DOWN-LINK

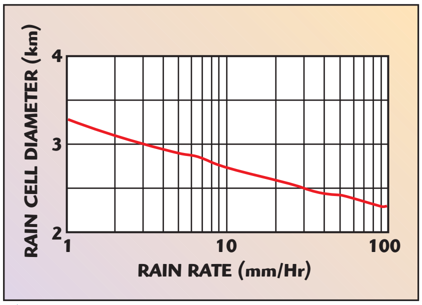
The installation depicted in ***Figure 8*** required a very high data rate (> 1 Gbps) video down-link from an airborne platform. The high data rate



▲ *Fig. 4 Atmospheric attenuation towards zenith.*

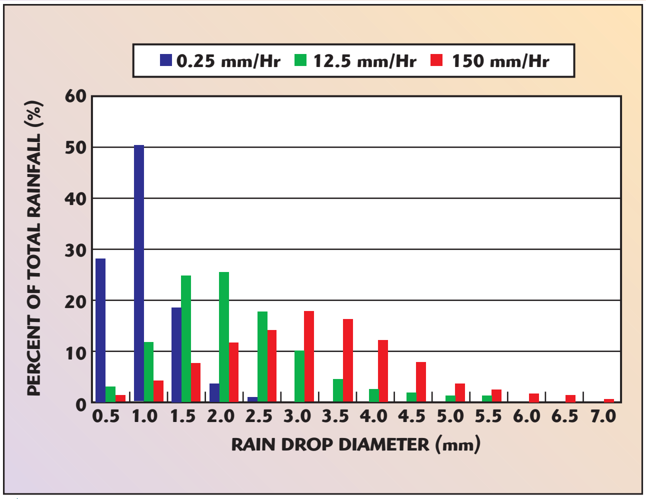


▲ *Fig. 5 Attenuation due to rain.*

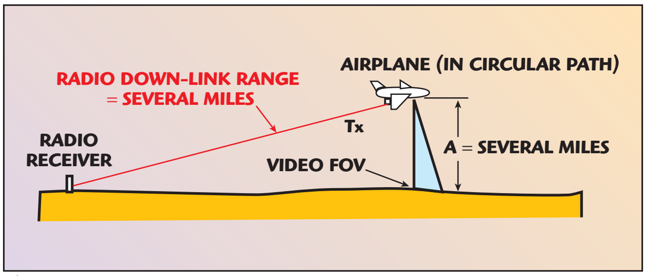


▲ *Fig. 6 Rain cell diameter vs. rain rate.*


CAUTION
HIGH POWER
25
dBm
at 20 GHz
pushing limits



▲ *Fig. 7 Rain drop diameters vs. rain rate.*



▲ *Fig. 8 Airborne surveillance video down-link.*

is required to support the transmission of data from a very high resolution camera along with a high frame update rate to eliminate "blind time." Additionally, the cruising altitude must be sufficiently high in order to ensure pilot safety (avoiding enemy fire) in a dry environment (that is, no significant rain). The airborne environment requires antennas with high gain to maximize the operating distance, as well as small size to fit within the gimbaled yoke. The airborne terminal is gimbaled for tracking over a very wide arc because of the circular flight path. Unfortunately, the very narrow antenna beamwidth (less than a degree) initially challenged the beam-pointing accuracy of the stabilized platform.

While the airplane cruises at sufficiently high altitude for safety from a variety of weapons, it is not high enough to preclude buffeting from wind or pressure gradients. So, while the flight is fairly smooth overall, there are intermittent bumps, which the gimbaled radio mount must be able to compensate for. Ideally, the beam-pointing error would be only a small fraction of the antenna's –3 dB beamwidth to minimize signal loss or amplitude modulation.

Unlike the airborne radio terminal, the ground-based terminal presents much less tracking challenge because the radius of the circular flight path is much less than the link distance.

This particular installation illustrates some thorny antenna trade-offs, namely:

- The need for higher gain to guarantee sufficient standoff distance, in spite of the fact that higher antenna gain results in narrower beamwidth
- The desire for a wide beamwidth (thereby reducing gain) to reduce the pointing accuracy demands on the airborne gimbaled mount and its control loop complexity
- The desire for smaller antenna/radio size/weight for the airborne platform

Because of the non-negotiable requirement for very high data rate and small size, a mmW radio with its advantage in size and bandwidth was the clear choice.

CASE STUDY 2: ENTERPRISE INSTALLATION

The second case study considers an installation that typifies the most common use of mmW point-to-point radio links. These are wireless extensions of high data rate communications from existing fiber-fed buildings to other buildings, eliminating the need to "pull" building permits and dig trenches across parking lots or erect poles (see ***Figure 9***).

As shown previously, the link S/N is calculated to determine if the required BER can be achieved with the anticipated weather conditions (for the continental US, FCC OET Bulletin 70 provides a Crane map showing the maximum rain rates for various system availability times; ITU rain charts are available for other countries). GigaLink® radio availability for various standard data rates are detailed in ***Table 2***.

One of the biggest issues affecting the viability of a link using high gain/narrow beamwidth antennas is the need for mount stability. The widest beamwidth accepted by the FCC for an E-band antenna is approximately 1°. Many E-band radios use antennas with approximately 0.5°

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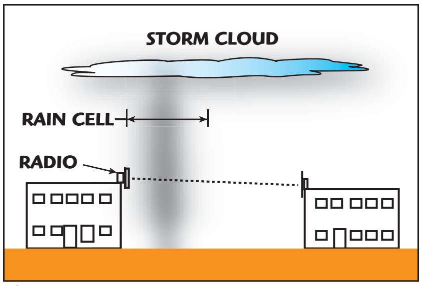
beamwidth. For such narrow beamwidths, it is critical that the transmitting and receiving antennas maintain their locations relative to each other. In other words, the structure that the antenna is mounted to must exhibit enough stability to maintain the antenna's position within a small fraction of the antenna beamwidth.

Accommodating 0.5° beamwidth antennas is routinely achieved when mounting to the relatively short masonry/steel buildings typically found in office parks. However, modern high-rise buildings are often designed to sway when stressed from high winds or earthquakes. This is clearly problematic for narrow beam antennas. Radios based on top of these structures might only accommodate wider beamwidth antennas or the antennas may need to be mounted below mid-height where structure sway is within acceptable levels.



▲ *Fig. 9 Typical enterprise installation.*

COST VS. PERFORMANCE TRADE-OFFS

For most installations, the type of payload (voice, video, or data) determines the required BER. For example, voice might require a BER = 1×10^{-3}, while Ethernet might require a BER = 1×10^{-12}. Other considerations for quality of service include the operating distance, the propagation losses (note: the rain rate which is used to calculate the propagation loss is determined from a Crane rain map and the required system up time) and the preference for unlicensed use or registered use, thereby leading to different operating bands: 57 to 64 GHz vs. 71 to 76/81 to 86 GHz.

TABLE II
GIGALINK RADIO AVAILABILITY

# of Independent Channels	Maximum Data Rate per Channel (Gbps)	Total Throughput (Gbps)	Application	Availability
2	1.25	2.5	Gigabit Ethernet	Standard
4	1.25	5.0	Gigabit Ethernet	Custom
2	1.42	2.84	n/a	Standard
2	1.49	2.98	HDTV SMPTE 292M	Standard
4	1.49	5.96	HDTV SMPTE 292M	Custom

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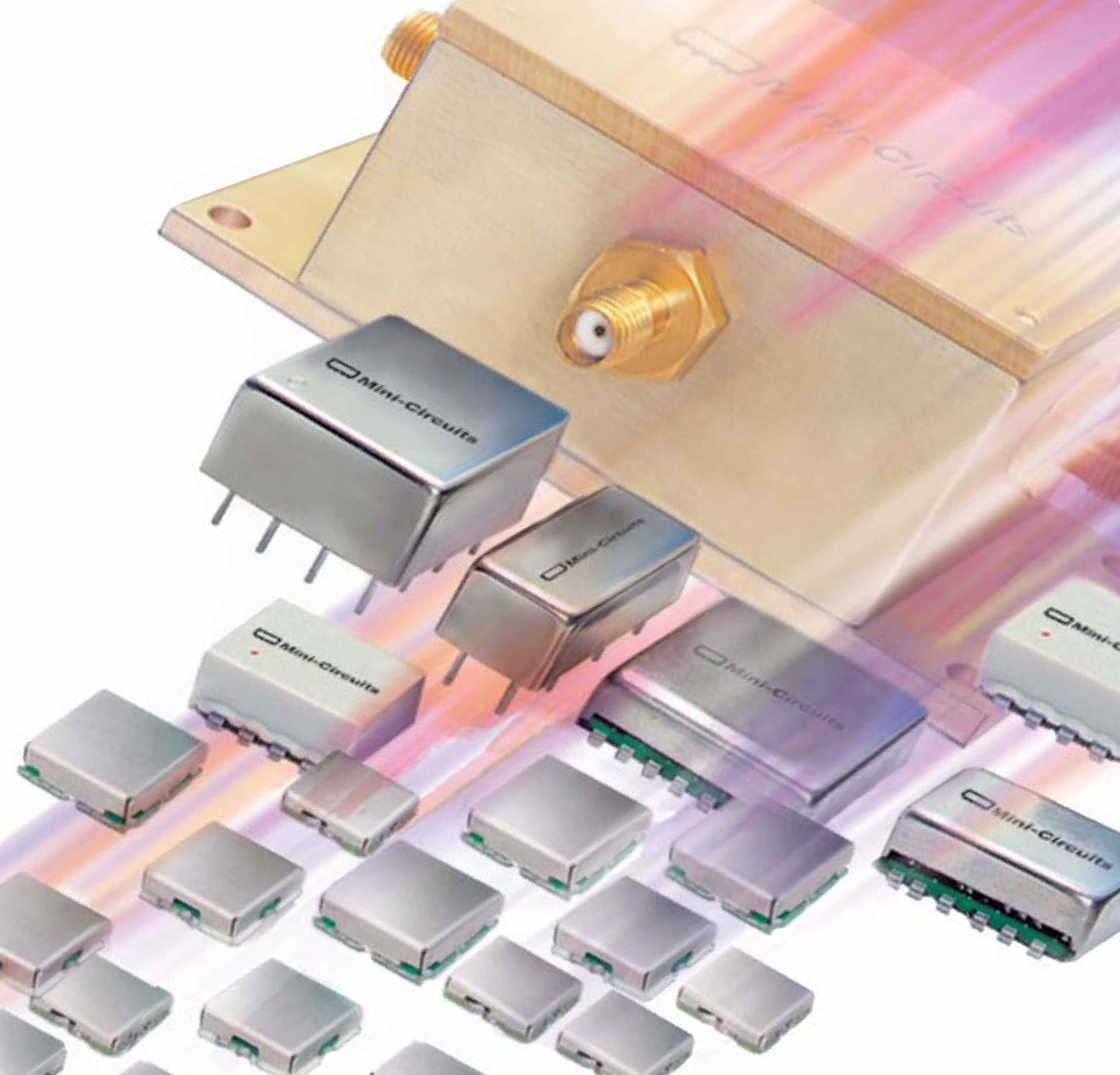

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Often, the only "choices" available to increase performance and/or extend operating distance include increasing the transmitter power level, increasing the antenna size (which increases the gain while narrowing the beamwidth) and/or reducing the receiver noise figure.

In general, if a narrower beamwidth is not a problem, it is much less expensive to use a higher gain antenna to increase range than it is to increase the transmitter power. For example, increasing the antenna size from 1 ft. dia. to 2 ft. dia. increases the S/N by 12 dB for relatively little additional cost as compared to increasing the transmitter power by 12 dB. Unfortunately, only 1 ft. and 2 ft. diameter antennas are presently available at reasonable cost. Because the receiver noise figure can only be marginally improved at very high cost, this option is limited.

Fortunately, innovation and market drive will help drive down the cost of these mmW systems. For example, the first FCC 15.255 certified (unlicensed use), 60 GHz 1.25 Gbps radios were introduced by Terabeam/HXI in 2003. Today the cost for that product with improved performance is approximately 67 percent less. This is the result of increased sales due to the market's appetite for low cost, high data rate wireless products. Additionally, the allocation by the FCC of an additional 10 GHz of bandwidth in E-band, combined with much higher allowable EIRP levels than at 60 GHz and the protection provided by link registration, allows longer distance solutions for high bandwidth needs.

CONCLUSION

While millimeter-wave radios must overcome a number of environmental challenges ranging from adverse weather conditions to unstable mounting surfaces, they do offer considerable benefits in terms of available bandwidth and relative size. This bandwidth capacity is ideal for addressing a number of hot applications. While the original need for multi-gigabit, wireless last-mile connectivity still exists, a new need for multi-gigabit wireless connectivity providing mobile high definition video is growing. This need is shared by both military (surveillance) and commercial (HDTV) sectors. Driven by this growing market demand and made possible through innovative engineering, mmW-based point-to-point and point-to-multipoint networks will continue to deliver more wireless bandwidth for less. ■

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MICROWAVES IN THE MILITARY

SHAUN MCFALL
Harris Stratex Networks, San Jose, CA

In the 21st Century the provision of secure, reliable communications and data is paramount in maintaining national and global security and the safe deployment and operation of military forces. This article outlines the vital role that microwave technology plays, giving examples that illustrate the practical deployment of microwave systems and the logistical, climatic and operational environments they operate in.

Mirroring every other organization in this computer age, today's armed forces are totally dependent on data. A constant supply of rich information is fundamental to the success of any form of military action, from peacekeeping and border control, to combined air and ground assault. Voice communications on the battlefield have always required robust networks, but modern communications networks have to carry much richer data. In addition to reliability, modern battlefield communications require high bandwidth to deliver video, high resolution images and graphical intelligence.

What would generally be viewed as boardroom tools are being deployed on the battlefield. For example, the Norwegian military is a heavy user of video conferencing, deploying 180 consoles throughout its bases, command centers and mobile outposts. With a geographically distributed force, such a system enables the chief of defense to ensure good communication down the chain of command.

Other modern communications may not be quite so accessible to the military in the field of operations. Unlike most organizations, the armed forces cannot rely on ready access to a mobile network, leased line, or other broadband connection. In many of their operating environments, there is little or no infrastructure. And even where the infrastructure exists, it may not offer the requisite levels of reliability and security. In a fast-paced environment, armed forces need networks that can be deployed quickly, whatever the geographical, weather, or security conditions.

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▲ *Fig. 1 The link is able to cope with the ship's pitch and roll.*

MEETING THE CHALLENGES

One ally in this struggle is microwave technology, which has proven to be a reliable solution to the problem of quickly delivering secure voice and data services in the toughest of environments. High capacity links can be deployed in a matter of hours, spanning all manner of terrain, and surviving the most intense weather conditions.

For example, in Afghanistan the Canadian armed forces have deployed a dedicated microwave network to support in-country operations and connect troops back to the command structure in Canada. Afghanistan is a country of weather extremes, with the northern lowlands reaching almost +50°C in summer, while bitter northerly winds from Russia and Kazakhstan can drive the temperatures down to –50°C in the mountains in winter. In a country with only one phone line for every hundred people, microwave has quickly provided a secure, reliable system of communications.

Also, in French Guiana, the French military has deployed a software-configurable microwave radio system that overcomes the challenges posed by the country's dense jungles and river systems. The system links teams securing common borders with Suriname and Brazil, providing communications much more cost-effectively and at higher bandwidths than alternatives such as satellite.

NAVAL DEPLOYMENT

These are just some of the many examples of land-based uses for microwave radio systems in military applications. A more unusual example is the US Navy's deployment of microwave radios to command the world's largest remote control battleship.

In March 2003 the decommissioned Spruance-class destroyer USS Paul F. Foster was handed over to the Naval Surface Warfare Center (NSWC) Port Hueneme Division to serve as the Navy's new Self Defense Test Ship (SDTS) on the waters of the Pacific Sea Test Range off the coast of Southern California. The SDTS, which operates unmanned and under remote control, is used as a test platform for various US Navy defensive weapon systems.

The SDTS provides a flexible test platform with reduced safety constraints compared with manned ships. During a typical live fire test, various threats are aimed at a decoy barge towed 150 ft. behind the unmanned SDTS, protecting the ship and its assets. Clearly, control of such an asset must be reliable; losing control of a remotely operated battleship would be problematic to say the least.

To address this issue NSWC Corona Division Telecom Engineering designed a state-of-the-art 45 Mbps (DS3) ship-to-shore, line-of-sight communications link for the SDTS to transfer control commands in one direction and send back telemetry. Spanning up to 50 miles, this would be one of the longest ship-to-shore microwave links in the world.

The US Navy wanted to use cost-effective commercially available microwave systems, but needed to be able to support a complex path-protection scheme to increase link reliability. The system also needed to integrate with a stabilized antenna pointing system to enable communications to be maintained with the test ship, regardless of its position and attitude within the test range. This would enable constant remote control of the ship's maneuvering and weapon systems during operations at sea.

Working with the Navy and its chosen contractors, Harris Stratex Networks provided an Eclipse Nodal Wireless system. This system is able to select the best signal operating between four independent links that are separated spatially and by frequency to ensure a high availability communications link over 50 miles of water.

The four microwave links operate in two parallel sets comprised of two frequency-diverse links operating in the 5 and 7 GHz bands. Traffic is duplicated over each link, with the best quality signal being selected at the remote site. Frequency diversity operates on this premise: since each link operates on a different channel frequency (in this case, in entirely different frequency bands) the propagation characteristics of each will be very different, with fading in each link uncorrelated to the other.

Consequently, when the signal received from one radio (the 5 GHz link, for example) is degraded, the signal from the diversity link (the 7 GHz link) will be less affected. The selection between the two available paths is performed automatically by an external switch/router.

Microwave radio systems are traditionally designed to operate on fixed links between two fixed sites, so special arrangements were made to ensure that the antennas at each end of the link remained aligned while the SDTS moved around the test range.

To achieve this, the ship and shore antennas and RF outdoor units (ODU) were mounted on special stabilized pedestals of the type that have been used for ship-based satellite communications systems. Each diversity ODU set is mounted on a separate pedestal, which remains locked onto the signal received from the corresponding set at the far end of the link.

The pedestal is able to automatically lock onto and track the signal using a combination of the radio received signal level (obtained from the ODU AGC monitoring point) and the ship's GPS positioning system. This enables free, 360° movement and also allows the link to cope with changes in elevation and azimuth caused by the pitch and roll movement of the ship (see ***Figure 1***).

A single shore communications tower hosts both sets of links, while the ship-based equipment is split between

the forward mast and aft masts, respectively (see ***Figure 2***). This enables the link to be maintained during ship maneuvering when either of the two ship-mounted sets is obscured from the shore site by the ship infrastructure. The system automatically switches between the fore and aft diversity radio ODU set when blockage or path failure occurs.

MISSION-CRITICAL MICROWAVE

This is just one example of the use of microwave technology. Because of the critical nature of their activities, military organizations often require rapid access to secure, reliable and flexible high bandwidth communications systems, even when there is little or no infrastructure available. Microwave is a proven technology capable of delivering these mission-critical attributes, and as such, can deliver high value solutions that meet the objectives of any military organization in extreme conditions, regardless of climate or terrain.

Wireless microwave networks are inherently less vulnerable and more reliable than networks using buried or pole-mounted copper or fiber. Since cable is a solid medium, wireline networks rely on a continuous connection deployed and physically secured every inch of the way between termination points. Overhead cables are vulnerable to extreme conditions, such as wind, rain, flood waters, falling and flying objects, and other hurricane conditions. Buried cables are primarily vulnerable to construction excavation (back hoe fade, in industry terminology) and tampering.

Microwave technology uses the air as the transmission medium, so networks need only be secured and protected at each end of the links or hops within the network. In contrast, a cabled network, with miles of space in between, requires installation and maintenance across the full extent of the network. With a microwave system, network operators can dedicate their resources to making certain each site is fully secured against the most extreme elements, sabotage or attack.

These advantages make microwave systems a logical choice for military communications as they need only protect the links. For reasons of security, flexibility and rapid deployment, microwave systems can clearly be one of the most valued communications tools in military applications. ■

▲ *Fig. 2 The ship-based equipment is mounted on the forward and aft masts for diversity.*

As vice president, marketing at Harris Stratex Networks, **Shaun McFall** *provides overall direction for programs to position the company in its focus markets. He has been with the company since the formation of its UK subsidiary in 1989, when his initial assignment was in new business development, first in the UK and later the European market. In 1994 he relocated to the company's headquarters in San Jose, CA, assuming responsibility for worldwide product marketing. He has accumulated over 20 years of experience in the wireless telecommunications industry, holding prior positions with two UK-based companies: Ferranti International Signal plc and GEC Telecommunications Ltd. He holds a BS degree in electrical and electronic engineering from the University of Strathclyde, Glasgow, UK.*

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ITAR: What Does it Mean for You?

Joe Chandler
Millitech Inc., a Smiths Interconnect business
Northampton, MA

My initial reaction to the International Trade in Arms Regulations (ITAR) several years ago was, "What a nightmare. I don't want anything to do with it." I quickly learned that there is no choice—the law is clear. Within those regulations resides the United States Munitions List (USML) beginning on page 473, which provides all of the definitions of what constitutes a defense article.

Coming to terms with the reality of complying with ITAR for many can mirror the often quoted five stages of grief. First is denial ("This can't apply to me/my company!"). Second is anger ("This is ridiculous! Don't they realize how this will kill us? We're not doing it!"). Third is rationalizing or bargaining ("Maybe I don't have to deal with it or it's no big deal because it only really means this or that."). Fourth is depression ("We're doomed."). And, finally, acceptance, even if reluctantly, when you get educated and implement proper policy. If your approach is to relegate/delegate all responsibility to only a few, it is probably a big mistake. The more widely understood ITAR is within your organization the better off you will be.

As stated, the law and what it means is quite clear. The part that isn't always clear is what makes a particular item subject to ITAR. In the microwave industry, you probably do not typically provide actual weapons or military equipment per se. However, according to the USML, within nearly every major category there is a sub-category described as follows: "Components, parts, accessories, attachments and associated equipment specifically designed or modified for use…" This definition means that a commercial off the shelf (COTS) item that you modify in the slightest way so it can be used for a military application becomes a defense item. Another subcategory is for technical data, which includes documentation of design and development activity.

What about non-military satellites? A product designed or modified for use on a research satellite including those for NASA, JPL, ESA or JAXA missions is subject to ITAR control. These are included on page 485 in Category XV of the USML.

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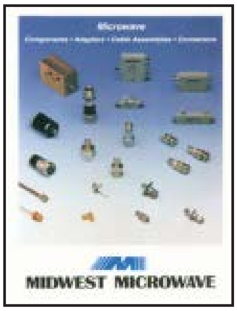

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There are of course situations that may still restrict your item.

Upon review of this brief overview it is pretty clear that if you are exporting a defense item then you must obtain a license from the United States Department of State (US DoS). But your responsibility for compliance with ITAR is much more involved because you are required to identify defense items that you supply to US customers as well. This is known as a destination control statement. However, there is one more way that a seemingly commercial item may actually be subject to ITAR. A product you design for commercial use that contains even a single ITAR part is also subject to ITAR control; it is in effect "tainted" for lack of a better term. Therefore, if your supplier fails to inform you that this part is a defense item, then you or your customer run the risk of illegally exporting a defense item, albeit inadvertently. Unfortunately, many suppliers are utilizing a simply bogus destination control statement in an attempt to cover themselves, which in effect says that it "might be ITAR" by stating that either EAR or ITAR applies. This, of course, is useless to us. If a part is ITAR then say so and if it's not, please don't say that it might be. If you do not know, then you should stop shipping the part and confirm its status. You absolutely need to put the correct destination control statement on all of your shipping documentation.

If your organization is not registered with the US DoS then you need to determine if you should be. I recommend that you open it up for discussion among your colleagues and carefully read the USML to be sure. It may be a good idea to get expert legal counsel that specializes in international trade compliance issues to assist you. However, if you are reading *Microwave Journal*, you are probably not in the food service, garment, agriculture or consumer electronics industry. Your company or university probably has received development funds that somehow originated from the government, which means that it is very probable that you, on occasion, provide defense articles. Answer this question: Is there anything that you make or sell that constitutes a defense article, data or service? The pivotal question is, what was the original platform or design purpose? Phrased differently, why does this particular item exist or what was the motivation for creating it? Remember that it does not matter if you do not export.

If you find that you need to be registered then you should do it immediately. It is required by law. Start at http://www.pmddtc.state.gov/registration.htm. Remember, you cannot apply for an export license without first being registered.

In my experience, some of the particular challenges of ITAR are listed as follows:

1. You must have the order BEFORE you can apply for a license. This presents risk in the event that a license is denied. Even if approved, it can also affect your ability to deliver to a firm schedule.
2. Approval or denial depends a lot on policy that may not be obvious or make sense to you.
   a. Policy can change abruptly. An identical license granted six months ago could be denied today.
   b. Conversely, a license previously denied could be approved today.
3. The license processing time can be quite long. Preparing the license can take just as long, especially if it is new and unique.
   a. Plan for three months. If it is taking longer, that's not a good sign.
4. Business opportunities can be lost and foreign competitors can gain competitive experience, which may not otherwise have happened.
5. A single ITAR part within an otherwise commercial item makes that item a defense article and is forever subject to ITAR restrictions.
   a. You can petition the DoS for a change of jurisdiction, but that is a lengthy and often costly endeavor and the outcome is difficult to predict.
6. The DoS reserves the right to categorize an item as subject to ITAR controls if it poses significant strategic importance EVEN if it doesn't meet ANY criteria of the USML. While this doesn't occur often, it could happen.

My experience also shows that once you have it fairly well figured out, it's not so bad.

1. It's about National Security and protecting and controlling Strategic Technology.
2. There is not much gray area so with proper research you can quickly establish confidence of approval and save the frustration of getting denied after expending lots of effort.
3. Experience counts. An accurate and well-written license application can get approved more quickly, particularly if you can reference precedent license approvals. Two weeks is possible for a repeat application.

There are many ITAR related resources available and they often emphasize the liability for penalties, which can be very severe and is very much a reality. I hope you find this discussion constructive and useful in understanding your obligations with respect to ITAR.

This editorial content does not constitute official advice or training. It is strictly the opinion of the author and does not represent any official opinion or policy of Smiths Group or any of its businesses. Obtain your own training and legal advice for your ITAR related matters from an expert in the international trade compliance field. ■

Joe Chandler *is currently vice president and MMW Products Division manager of Millitech Inc., a Smiths Interconnect business.*

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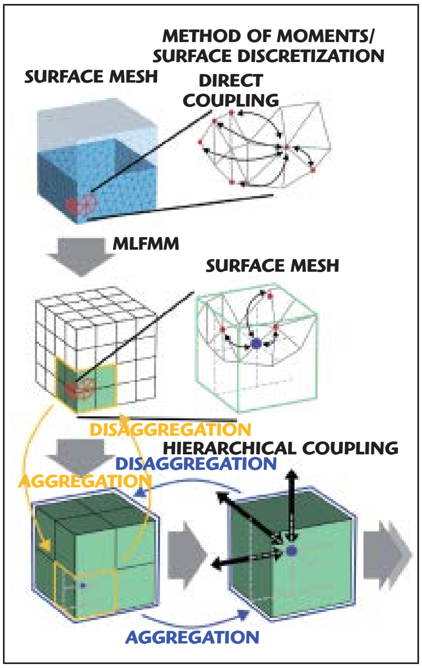
Fig. 1 From MoM to MLFMM: The improvement of numerical complexity.



Tackling these problems is quite simply not feasible using standard volume discretization methods. CST has addressed these problem classes with the introduction of the Integral Equation solver (I-solver) for its CST MICROWAVE STUDIO® (CST MWS). It enables the user to perform accurate 3D full-wave analysis of electrically large structures, which is particularly useful in military microwave applications. The I-solver is seamlessly integrated in the CST DESIGN ENVIRONMENT™ (CST DE). Engineers can take advantage of this easy to use interface and the sophisticated imports from a large variety of CAD formats to set up the models. The selection of the right solver is then just a mouse-click away.

The I-solver features a Method of Moments (MoM) discretization using a surface integral formulation of the electric and magnetic field integral equations. Due to the surface integral formulation the new solver uses far fewer elements than common volume methods for the described problem classes. Nevertheless, the numerical complexity of MoM is high and is not applicable to electrically large structures.

This problem is solved by applying the multi-level fast multipole method (MLFMM), as described in ***Figure 1***. This figure shows that MoM considers the direct coupling between all elements of a mesh. In MLFMM the domain is first subdivided into separate blocks. Inside each block only the coupling to one point is considered, representing the coupling effect of the elements grouped together (aggregation). On the next level the coupling between blocks is considered. In this way a multi-level hierarchy is built-up. The coupling information is fed back through the hierarchy levels to the individual elements (disaggregation).

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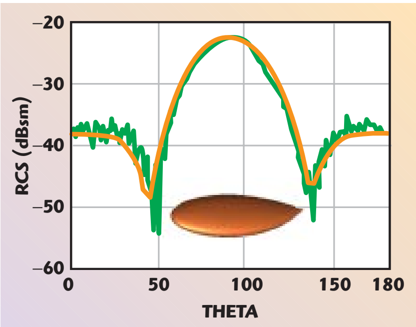
electrically large structures. One of its key strengths is the combination of higher order discretization elements with an iterative or direct solver. The higher order discretization increases accuracy compared to standard first order methods.

To reduce the numerical complexity, the built-in discretization is also capable of applying so-called mixed order discretization, where the polynomial order of the discretization function is chosen adaptively, according to the size of the mesh elements, which the automatic mesh generator chooses with respect to the structure's features.

This means that in regions where many elements are required to resolve small details (an antenna mount, for example), a lower order discretization is used, whereas on the smooth surface of the platform or aircraft body a higher order discretization reduces the number of necessary surface elements and is ideal for military applications.

An additional feature of the I-solver is the flexible MLFMM accuracy control. It adjusts the MLFMM parameters to the individual model and, together with the powerful preconditioner, optimizes simulation time and memory requirements. However, the I-solver is not restricted to perfect electric conductor (PEC) surfaces. It can also take into account lossy metals and (lossy) dielectric materials.

The open space boundary condition best meets the demands of most antenna and RCS calculations. In addition, it features electric boundary conditions for simulating conducting grounds. The available field sources are discrete port and plane wave excitations, and waveguide ports and imported far fields will soon be available to drive simulations. The latter provides an efficient means to use the results of a high detail transient or frequency domain simulation on a large structure.



▲ *Fig. 2 Mono-static RCS for the NASA almond for the vertical polarization at 1.19 GHz.*

THEORETICAL BACKGROUND

Electromagnetic field scattering by three-dimensional objects can be computed numerically using the electromagnetic field integral equations where the unknown function is the induced current distribution J(r). The integral equations can be discretized into a matrix equation system by the MoM discretization.[2,3]

The resulting discrete equation system is then solved by an iterative method, which usually takes N^2 operations per iteration (for N unknowns). However, using a multi-level fast multipole method the numerical complexity can be reduced to Nlog(N), so that many large scale problems can be solved efficiently.[2]

For conducting objects, the electric field integral equation (EFIE) in three space dimensions is given by

$$t\int_S G(r,r')J(r')dS' = \frac{4\pi i}{k\eta} tE^i(r) \quad (1)$$

for r on the surface S, where t is any unit tangent vector on S and

$$G(r,r') = \left(1-\frac{1}{k^2}\nabla\nabla'\right)\frac{\exp(ik|r-r'|)}{|r-r'|} \quad (2)$$

For closed conducting objects, the magnetic field integral equation (MFIE) is given by

$$2\pi J(r) - n\times\nabla\times\int_S dS' \frac{\exp(ik|r-r'|)}{|r-r'|} J(r') = 4\pi n\times H^i(r) \quad (3)$$

for r approaches to S from outside, where n is an outwardly directed normal.[1,2] In general, either EFIE or MFIE can be used for closed conducting objects but the formulation can break down due to interior cavity resonance problems. A solution is to create the combined field integral equation (CFIE), which has numerically been proven stable for any kind of resonance effects. The CFIE for 3D-conducting objects is a convex linear combination of the EFIE and the MFIE according to

$$CFIE = \alpha EFIE + (1-\alpha)\frac{i}{k}MFIE \quad (4)$$

The parameter α varies from 0 to 1 and can be any value within this range. In the literature it is considered that α = 0.2 is an appropriate choice.

The MLFMM is used for solving the MoM discretization of the CFIE on a surface mesh (see Figure 1). Therefore, unlike standard MoM techniques, the I-solver reduces full coupling to one within multiple small cubic volumes of the model. These are then coupled in a similar way to a larger volume and so on recursively, until one volume remains, and scaling for numbers of cells is vastly improved at Nlog(N).

To apply the MoM to the CFIE, the unknown current J(r) is expanded using an appropriate set of N basis functions into a series according to a standard Galerkin discretization.[2,3] As a result, a linear algebraic equation system is obtained, which reads

$$\sum_{i=1}^{N} A_{ji}a_i = b_j \quad j=1,2,\ldots,N \quad (5)$$

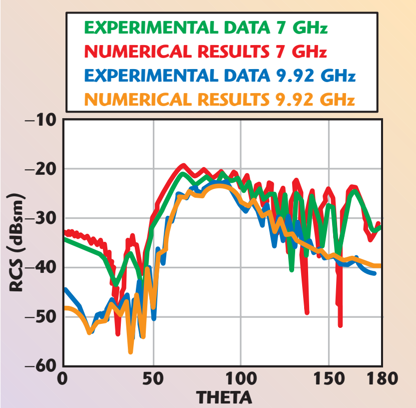
The matrix entries of A are simply given by the inner product of the selected basis functions and the integral operator of the CFIE.[1] Consequently, the integral equations are approximated by matrix equations using the MoM. These linear equations can be evaluated efficiently by the fast multipole method (FMM), applying a splitting in terms representing the interactions from nearby regions.

The detailed formula is shown in Reference 1. The multilevel fast multipole method is the recursive extension of the FMM, where the matrix vector multiplication is implemented in a hierarchical or multi-level multistage fashion, which can be written as

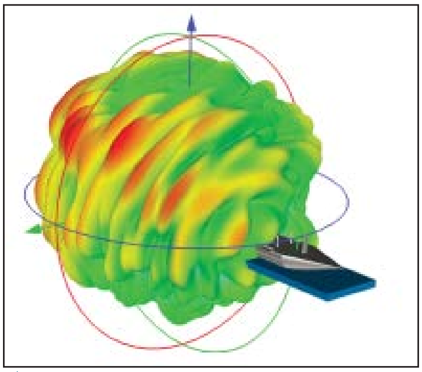
$$Aa = A_{near}a + U^t_{NL}T_{NL}V_{NL}a + \sum_{i=2}^{NL-1} U^t_i T_i V_i a \quad (6)$$

where V_i, T_i and U_i represent the matrix of aggregation, translation and disaggregation, respectively, at the ith level, and NL is the total number of

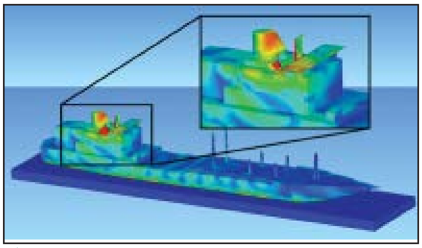
levels. These matrices as well as A_{near} are sparse. In the MLFMM, V_i



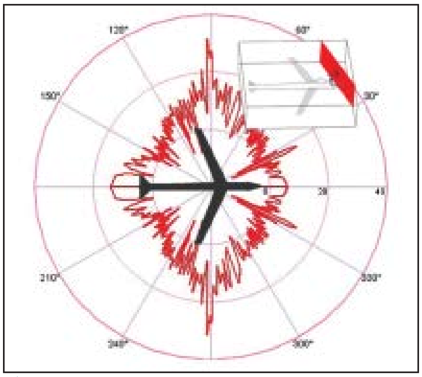
▲ *Fig. 3 Mono-static RCS for the NASA almond for the horizontal polarization at 7 GHz and for the vertical polarization at 9.92 GHz.*



▲ *Fig. 4 Far-field antenna simulation of a large ship including sea water with a relative permittivity of ε = 80 at 25 MHz.*



▲ *Fig. 5 Surface currents on the large ship at 25 MHz.*



▲ *Fig. 6 Mono-static RCS analysis for an aerial vehicle at 0.5 GHz using a fully automatic built-in function of CST's I-solver.*

and U_i ($i < NL$) are computed by interpolation and anterpolation techniques. For N unknowns, the computational complexity in memory and simulation time is the order Nlog(N).

APPLICATIONS

Moving on to the applications of the I-solver, the NASA almond is a well known benchmark for RCS calculations due to its stealth properties.[4] The almond is a doubly curved surface with a pointed tip (see ***Figure 2***). It has a low RCS when viewed in the tip angular sector. Elsewhere, a surface normal is always pointing back toward the radar, creating a bright high level specular RCS return.

In addition to specular mechanisms, surface traveling waves and creeping waves contribute to the scattering. The almond is 9.936 by 3.84 by 1.26 inches in length, width and thickness, respectively.[4] Experimental data are available for a set of frequencies up to 9.92 GHz with horizontal and vertical polarizations of the plane wave excitation.

Figure 2 shows the NASA almond and displays the results of the mono-static RCS analysis for the vertical polarization at 1.19 GHz. ***Figure 3*** shows the plot for the mono-static RCS at 7 and 9.92 GHz for horizontal and vertical polarization, respectively. The numerical results of the Integral Equation solver agree very well with the experimental data. The simulation of a complete RCS study for a single frequency and 180° angle sweep takes less than one hour and 160 MB of memory on a PC with an Intel® Xeon™ (3 GHz) CPU.

LARGE SHIP SIMULATION

The I-solver can be used to realistically simulate an antenna placement on, or radar illumination of a large transport ship, including the effects of sea water, which is modeled as a dielectric layer (see ***Figures 4*** and ***5***). The watercraft is modeled using PEC, and the dimensions are 132.8 by 20 by 20 m. The simulated monopole antenna is mounted on top of the stern.

The sea water, where the ship is embedded, is modeled as a loss free dielectric with a relative permittivity ε = 80. The dimensions of the water block are 143 by 30 by 3.5 m. In total, the surface of the geometry including the ship and water covers about 77 by 77 square wavelengths at 25 MHz. Figures 4 and 5 show the numerical results for the simulation of the full geometry at 25 MHz using a discrete port excitation for the monopole antenna. The simulation of the antenna on the watercraft including the sea water takes less than 45 minutes and 5.2 GB memory. The simulation without the sea water takes less than one hour and 1.7 GB memory at a frequency of 150 MHz.

RCS ANALYSIS OF AN AERIAL VEHICLE

The mono-static RCS for an aerial glider is calculated in the horizontal plane at 0.5 GHz with a 1° step size. The length of the glider and the wingspan is 14 m. ***Figure 6*** displays the polar plot of the resulting absolute RCS value as a function of the incident plane wave direction. The total simulation time is less than 14 hours and 420 MB memory is consumed. I-solver features a built-in function to perform such a mono-static RCS analysis fully automatically.

CONCLUSION

The Integral Equation solver is a specialist full-wave solver, which applies MLFMM using a MoM discretization. Its use of higher order discretizations and a flexible accuracy control, combined with a powerful preconditioner, result in outstanding performance and efficiency. The I-solver is dedicated to the accurate 3D analysis of the electromagnetic fields in electrically large structures, and is therefore ideally suited for some problem classes of particular interest to engineers in the military microwave field.

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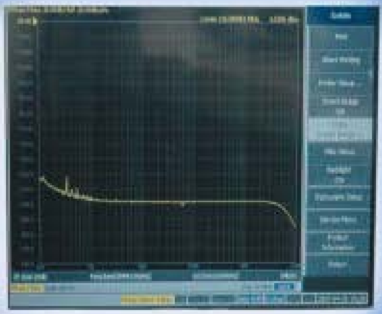

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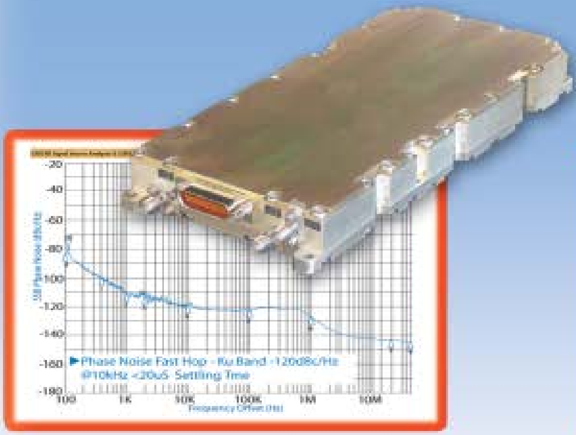

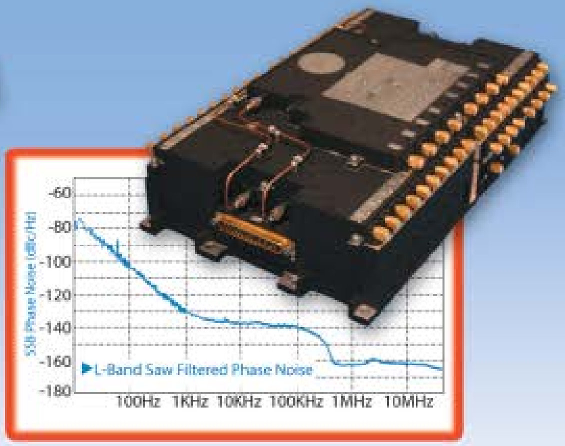

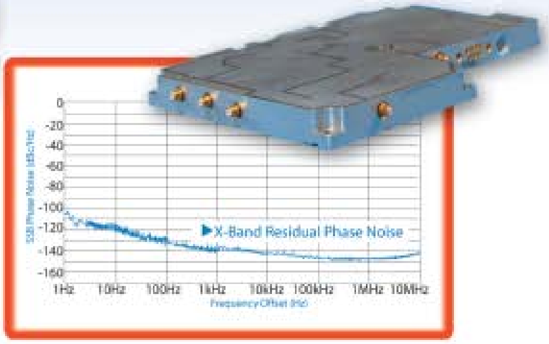

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A Water Dielectric Load Assembly for Testing Radar Transmitters

Credowan Ltd.
Chichester, UK

In the mid-1990s, the market clearly indicated a desire for more fully integrated waveguide related components and a development program to meet this need was begun. Credowan was in a strong position to offer key components in this development, particularly loop couplers and flexible waveguide. This article focuses on that development and particularly on the evolution of the 10-HW-9065 water dielectric load assembly and the associated product family used for testing high power radar transmitters.

Starting with loop couplers, they offer a small compact option for the monitoring of forward and reverse power and/or frequency. The relatively low specification directivity in such couplers and a relatively narrow bandwidth is not normally a hindrance compared to the cost-effective and robust long-term solution they provide for high power microwave testing in general, and the radar industry in particular.

Add to that flexible waveguide, which offers two substantial advantages. First, the positioning of waveguide components can be versatile at the S-band 3 GHz frequency with typically 3 to 5 mm of displacement in three dimensions being quite achievable. They also offer excellent survivability against applications where shock and vibration are key factors.

POWER HANDLING

However, care must be taken to look at true power handling, as traditional flexible/twistable waveguide has considerable limitations, especially in long-term use. Options of seamless waveguide have been developed to offer a significantly higher powered option. In the particular subsystem we are considering it was not necessary to have a flexible assembly, although commonly it is.

Other coupler options would include both broad-wall and cross guide, where perhaps higher directivity is required, or coupling val-

ues lower than the traditional 50 dB that radar dual couplers are designed for.

The core technology to the 10-HW-9065 is the novel and unique method of configuring a high power waveguide load utilizing water both as the absorber and the coolant. The use of water dielectric loads dates back as far as the 1960s, but these original designs incorporated glass water containment features, which were far from robust in application. A combination of glass, extremely hot water and mobile radar systems set an impossible challenge for engineers tasked with establishing real confidence and real high power test regimens.

UPDATED TECHNOLOGY

For the new unit this technology was updated by replacing the glass elements with Teflon elements. Similarly, the manufacture of a hollow precision cone to extremely accurate angular and surface finish specifications paved the way for a high performance device and also provided a water pressure differential of 10 Bar (1 MPa).

The basic principle of water dielectric loads (illustrated in ***Figure 1***) is that a conical taper-shaped cavity is created for the high power microwave energy to enter, while a highly specialized waveguide window allows the RF energy to pass in a controlled way into a continuously recycling water heat sink.

In simple terms cold water is pumped into this cavity, which becomes heated by the microwave energy and is expelled. When used in controlled conditions for military applications, the water can be recycled and cooled through a chiller. On board ship, this may well be the ship's chilled water supply.

The use of relatively low quality water is quite acceptable in most instances and coolant such as Glycol can be added to constitute up to 60 percent of the total fluid content. That is provided scaling and other contaminants are carefully monitored and the loads are cleaned and flushed through with suitable solvents after each sustained use. For systems where continuous water flow is used with no possibility of a maintenance period then cleaned and de-scaled water must be used.

PRODUCT DEVELOPMENT

Taking these constraints into consideration the 10-HW-9065 was developed after a major customer approached the Credowan engineering team with a view to a complete subsystem, which is shown in ***Figure 2***. The capabilities for this sub-system included the need to monitor both the power and frequency, which entered the load and for it to be configured on a number of different waveguide flange configurations. More of a challenge, though, was the requirement to use the load in two different orientations.

With the need to keep the coolant output at the highest point of the load itself and the cooling port configuration not being a field adjustable option and therefore remaining static, the waveguide input had to be variable. Also, the use of flexible/twistable waveguide was not an option because the power level of the system under test was too high. The use of seamless flexible (non-twistable) waveguide would overcome the power problem, but analyzing the amount of regular bending and the required bend radii to keep the overall unit as compact as possible would certainly mean regular replacement of the flexible section, making it not a cost-effective or reliable solution.

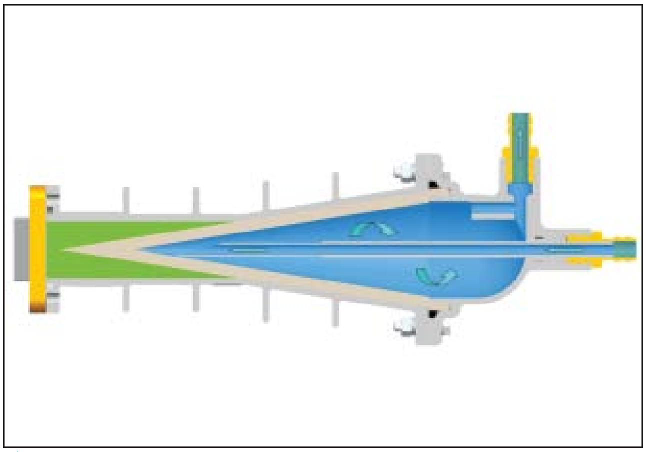
However, simply adding a rigid 90° bend in conjunction with the adjustable stand gives the orientations needed and by the addition of a 90° twist instead of the bend provides a third orientation if it were ever required.

Water dielectric loads are fundamentally extremely small for the equivalent power handling, and power levels of 20 kW+ average power are readily achievable at 3 GHz for S-band radar applications, determined primarily by the coolant flow rate, which is typically 10 litres per minute for a 16 kW rating. Also, if the specific heat and the flow rate of the coolant are known, the difference between the input and output temperature can provide a calorimetric measurement of the power.

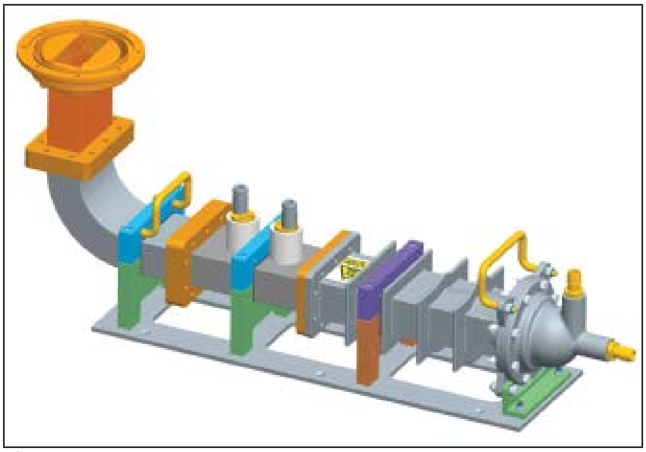
FLOW MONITORING

It is fundamental to the operation that the absorber taper is entirely full with water/coolant; not only for the power performance, but also because an air blockage or pocket could limit or stop the flow. It is recommended that all users of water cooling devices monitor the flow and ensure that there is no air in the system.

Therefore, two of the important factors in designing such a product are the back pressure of the cooling system and ensuring that the orientation with the flow out-



▲ *Fig. 1 A cut-away diagram showing water flow.*



▲ *Fig. 2 High power load system.*

put is always uppermost on the system. Peak powers can rise above a megawatt should the radar system require it, and the waveguide can typically handle a 3 Bar (300 kPa) pressure differential to achieve high power levels.

Keeping within these parameters, a fundamental design for the water dielectric load assembly was established, offering a robust subsystem, combining a standard dual-loop coupler, with a relatively standard water dielectric load. This was fitted into a robust and versatile frame including a series of waveguide flange adaptors to suit the range of requirements. The end application for this product is for the field testing of large mobile S-band radar transmitter systems, monitoring their power curves and ensuring frequency consistency.

Although geared towards S-band radar applications, it is also suitable for higher or lower frequency needs and designs within the product range including devices at 1.6 and 5.4 GHz, covering L-band and C-band radar applications.

CONCLUSION

In essence, this type of water dielectric load assembly is based on established technology that is proven to meet the strict and robust requirements of radar applications. One of the great attractions of this technology is that should the unit receive any kind of mechanical or systemic abuse, such as an interruption of water supply, while the failure may be catastrophic at the time, the repair cost will be minimum as the unit is designed for quick disassembly and refurbishment.

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An Ultra-wideband Phase-matched Balun

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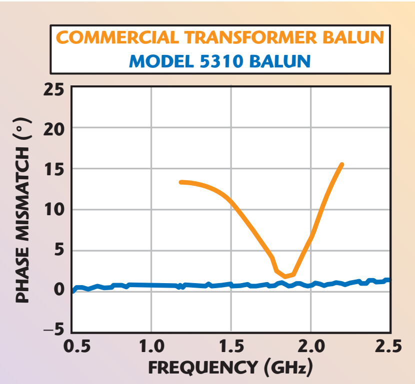
Boulder, CO

Picosecond Pulse Labs has introduced a new phase-matched balun. The Model 5310 uses proprietary technology that provides exceptional phase and amplitude matching (±0.5° phase match from 500 MHz to 2 GHz; ±0.1dB amplitude match from 100 MHz to 3.5 GHz). This performance represents a significant improvement over traditional transformer-based balun designs (see ***Figures 1*** and ***2***). Note that the phase and amplitude matched performance of the Model 5310 is not only significantly better, it also covers a frequency range that is approximately double that of a transformer-based balun.

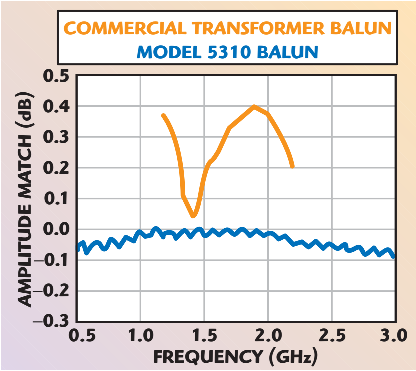
Fig. 1 Phase match comparison.



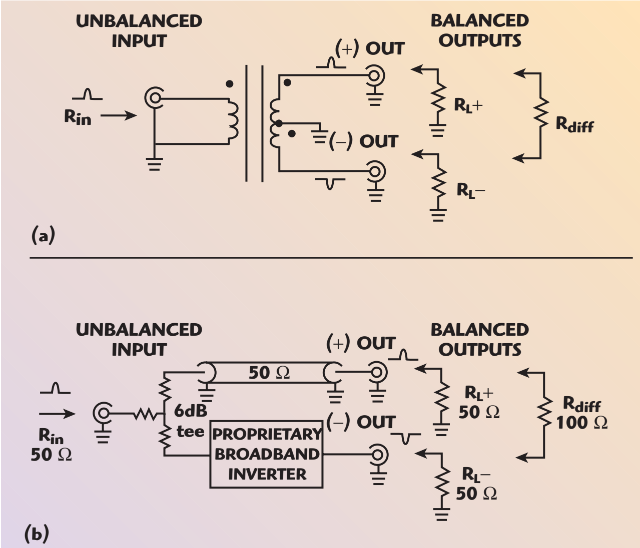
Single-ended-to-differential conversion has historically been achieved with either a transformer-based balun or an active part such as a single-ended-to-differential amplifier. Both of these approaches have deficiencies. Transformer-based baluns have an inherent limitation due to the frequency dependant performance of the transformer core materials used (phase and amplitude matching is a function of frequency). In addition, transformer-based baluns have a performance roll-off that makes them unusable at higher frequencies. Active parts such as amplifiers introduce jitter and noise that also cause performance issues.

Picosecond Pulse Labs' products are designed with a very different approach. The company has extensive design and manufacturing experience with ultra-broadband techniques and has applied this knowledge to design the Model 5310 to address the deficiencies of transformer-based baluns. The Model 5310 uses a novel, proprietary balun structure that is extremely well matched. This balun structure differs from traditional transformer-based baluns in that it splits the signal into two paths with a resistive broadband power divider and utilizes a proprietary inverter design comprised of a hybrid of coax cable and conventional transformer designs (see ***Figure 3***).

This matched broadband inverter design leverages techniques originally developed by Picosecond Pulse Labs for the inversion of fast pulse signals. Inverting fast pulse signals requires design considerations (ultra-broadband performance) that cannot be achieved with traditional transformer-based baluns. It should be noted that since the Model 5310 uses a resis-



▲ *Fig. 2 Amplitude match comparison.*



▲ *Fig. 3 Comparison of a conventional transformer-based balun design (a) and the PSPL proprietary balun design (b).*

tive power divider, the insertion loss is greater than with transformer-based baluns, approximately 7 dB instead of 1 dB. However, this can be compensated for with gain at other points in the system architecture. Another important point is that this architecture requires that the impedance ratio be 2:1, that is, 50 Ω at the input and a 100 Ω differential output.

Baluns and single-ended-to-differential conversions are key functions in many electronics applications. For example, state-of-the-art analog-to-digital converters (ADC) are designed for use with differential inputs. Utilization of differential signals with these ADCs improves key performance parameters such as linearity and spurious free dynamic range (SFDR). Consequently, when the available input is single-ended, some mechanism of converting the signal to differential with a minimum amount of distortion is required. If significant distortions are introduced, such as phase or amplitude mismatches, they will degrade the differential signal and the analog-to-digital conversion process. In general, phase mismatch is a greater problem than amplitude mismatch. This is because transformer-based baluns typically have poor phase mismatch and good phase matching is needed to suppress undesirable harmonics. For example, a phase mismatch reduction from 10° to 1° will result in an improvement of second harmonic suppression of approximately 30 dB.

Baluns also play an important role in test and measurement. Differential test equipment (signal sources, vector network analyzers and oscilloscopes, for example) is typically expensive and frequently unavailable. Therefore, an accurate means of single-ended-to-differential conversion and vice versa is very useful for the characterization of differential signals and components with more commonly available single-ended test equipment. Good matching of phase and amplitude produces excellent signals for applications such as serial data testing where distortions show up as artifacts in eye diagrams and similar measurements. It should be noted that for serial data testing, the low frequency performance limitations of a balun must be considered since long strings of consecutive ones or zeros require good low frequency performance.

In addition to the Model 5310, Picosecond Pulse Labs offers two ultra-broadband balun products with greater bandwidths at the expense of moderately reduced matching performance. These two products, the Model 5315A and the Model 5320B, have bandwidths of 200 kHz to 17 GHz and 5 kHz to 11 GHz, respectively.

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Fig. 1 The unique double-helix channel design. ▼

A UNIQUE AND VERSATILE DESIGN

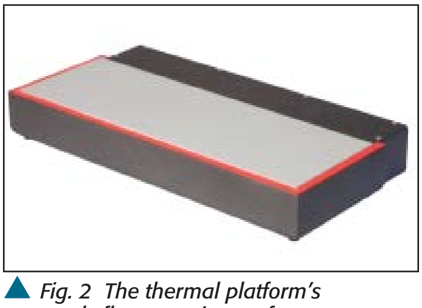
In an effort to diminish operating costs by decreasing test times and facility resources, thermal platforms were developed as a cost-effective alternative to using large chambers for thermal conditioning of flat package and micro-electronic devices. Since Sigma Systems first introduced the thermal platform over 30 years ago demand for supporting faster cycling, higher frequency tolerance, larger wattage dissipation and a host of custom fixture applications has driven this product to adapt to an industry that is constantly evolving. Sigma Systems has grown with this industry by never forgetting the fundamentals of what it takes to make a properly designed thermal platform.

Properly designed thermal platforms are cooled by injecting high pressure liquid nitrogen (LN2), carbon dioxide (LCO2), R507, or R508B (SUVA95) through a small diameter tube into a coolant channel that is physically imbedded within the platform. The injection capillary tube acts as a throttling device. The refrigerant passes through the capillary tube and transitions from high to low pressure in much the same way a pressurized fluid passing through the nozzle of a spray bottle will atomize and turn to a mixture of vapor and microscopic particles. To fully understand the physics of this process, a thermodynamic analysis of the expendable refrigerant must be made.

FLOW MECHANICS

A properly designed thermal platform should be quiet and efficient. For example, a poorly designed unit using LCO2 will whistle and can sound like a siren. The areas that need to be considered when properly designing a thermal platform is to increase the channel volume proportional to the expansion rate of the refrigerant in order to support a decrease in particle population as the particles sublimate or migrate from a fluid to a gas (depending on the refrigerant). Another area of channel construction that significantly affects the channel geometry is designing a channel that promotes expansion while inhibiting particles bombarding the channel wall. The last area that is taken into consideration is expansion rates of up to 700:1. The channel must be able to support as much expansion as possible in order to harness this cooling energy and at the same time harness the expansion gradient itself to help propel the vapor and remaining particles through the exhaust at the end of the channel. It was this premise that lead to the gentle arcing double-helix channel design that Sigma Systems uses (see ***Figure 1***).

Conversely, a poorly designed plate can have a profound negative impact on performance. For example, if the channel does not inhibit bombardment into the wall, the pressure driving the particulate stream will stabilize. This, in turn, will promote particle accumulation. This effect can result in catastrophic failure as any significant restriction can quickly turn into an extremely high pressure condition or could result in more minimal ways by creating undesirable temperature gradients.



▲ *Fig. 2 The thermal platform's extremely flat mounting surface.*

CONSTRUCTION FEATURES

The Sigma Systems Thermal Platforms are constructed of a high grade aluminum body and feature an extremely flat mounting surface that minimizes thermal transfer losses (see ***Figure 2***). Below the surface is the proprietary milled expanding cross section inverted double-helix design cryogenic cooling channel with a single coolant inlet for maximum cooling efficiency. Added to that is a high resolution temperature sensor and a compact design for maximum accuracy and efficiency. The resulting system provides faster thermal testing and greater accuracy and improved stability, with increased component throughput and efficient use of cryogenic gases and lower overall power consumption.

APPLICATIONS

Applications for these thermal platforms include thermal conditioning and programmed thermal cycling, environmental stress testing (ESS), space temperature and pressure simulation using a bell jar in place over the thermal platform, highly accelerated life testing (HALT), highly accelerated stress testing (HAST), parametric tuning over temperature, component curing and bake out.

CONCLUSION

Many test professionals have found that a well engineered platform is the fastest, quietest and most efficient means to boost product performance while lowering operational costs. Controlling delivery and sublimation rates of the expendable coolant by optimizing path curvature, length and geometry are but some of the methodologies required to design and produce an efficient thermal platform. Constantly refining these basic premises that are over 30 years old attest to Sigma Systems' ability to grow and adapt to the ever-changing face of the defense industry and to provide a product that is of sound design, built from quality materials and tested to ensure reliability for years to come.

Sigma Systems Corp.,
El Cajon, CA (619) 258-3700,
www.sigmasystems.com.

RS No. 307

Military Microwaves

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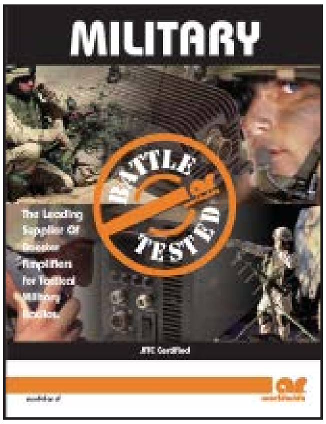
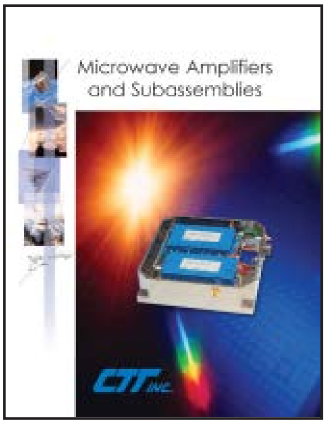


Military Brochure

The revised military brochure from AR Modular RF features a family of booster amplifiers for tactical military radios that covers 30 to 512 MHz and 12 to 40 W. The family features several versions including manpack or vehicular mounted, manual or automatic band switching and a SINCGARS 30 to 88 MHz only version.

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

RS No. 318



Product Catalog

This 36-page catalog includes 175 all-new amplifier products. Products include a new line of low noise solid-state amplifiers for applications in narrowband and wideband frequencies through 20 GHz. These new lightweight and compact LNAs are based on GaAs PHEMT active devices with input and output impedance matching and are available with or without SMA connectors. Catalog listings include: low noise amplifiers, high and medium power amplifiers, commercial power amplifiers and custom engineered options.

CTT Inc.,
Sunnyvale, CA (408) 541-0596, www.cttinc.com.

RS No. 336

Product Catalog

This catalog details the company's capabilities in the design and manufacture of RF microwave connectors and cable assemblies. The company is a provider of high quality, standard and special RF and microwave connectors, adapters, blindmate interconnecting components and cable assemblies for use in military applications and commercial microwave, RF and wireless industry components. Information of quote requests, ordering information and product warranty are also provided.

Dynawave Inc.,
Haverhill, MA (978) 469-0555, www.dynawave.com.

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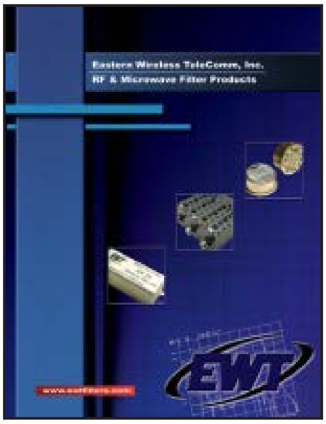
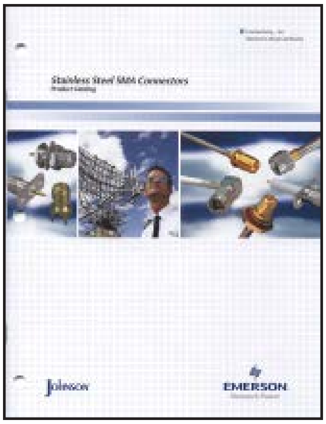


Filter Catalog

This new short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial and wireless applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities.

Eastern Wireless TeleComm Inc.,
Salisbury, MD (410) 749-3800, www.ewtfilters.com.

RS No. 320

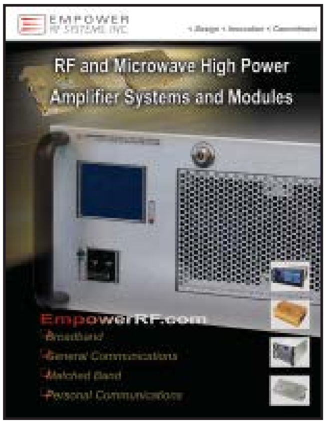


Connectors Catalog

This catalog features the company's Johnson® line of stainless steel SMA connectors that meet or exceed the performance requirements of MIL-PRF-39012. All designs are based on a 50 Ω system impedance per MIL-STD-348 and operate at frequencies up to 26.5 GHz minimum. All contacts are plated with 50 micro-inches of gold for good durability and high frequency performance. Applications include: antennas, base stations, cellular radio, RF and microwave components, radar, SATCOM and aircraft.

Emerson Network Power Connectivity Solutions, Johnson Div.,
Waseca, MN (800) 247-8256,
www.emersonnetworkpower.com/connectivity.

RS No. 321



High Power Amplifier Systems and Modules Catalog

This catalog highlights the company's capabilities in the design, development and manufacture of high power solid-state amplifiers in both modular and rack mount system configurations for the military, aerospace and industrial marketplace worldwide. Frequencies range from 10 kHz to 18 GHz, with output power levels from 1 W to multi kilowatts. Empower's ISO9001:2000 Quality Assurance Program assures consistent performance with the highest reliability.

Empower RF Systems,
Inglewood, CA (310) 412-8100, www.empowerrf.com.

RS No. 337

Military Microwaves

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Short Form Catalog

The 2007 short form catalog highlights the company's latest products and product upgrades offered in 2007. EM Research designs and manufactures high performance frequency sources for hi-rel and military applications. The company specializes in surface-mount and modular phase-locked oscillators and synthesizers from 4 MHz to 18 GHz.

EM Research Inc., Reno, NV (775) 345-2411, www.emresearch.com.

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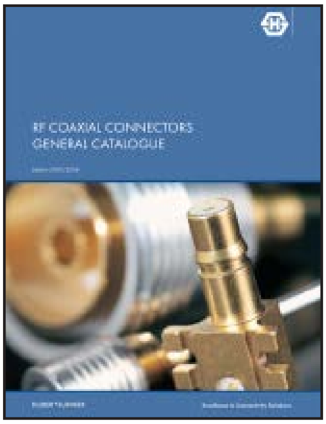

RF Coaxial Connectors

The new HUBER+SUHNER coaxial connectors general catalog 2007/2008 is available now and replaces the 2003/2004 edition. The actual edition displays more than 400 pages of the company's connector series. With its technical information and glossary, a reference to the RF connector guide is made. The catalog is now also available in German.

HUBER+SUHNER AG, Herisau, Switzerland +41 71 353 4111, www.hubersuhner.com.

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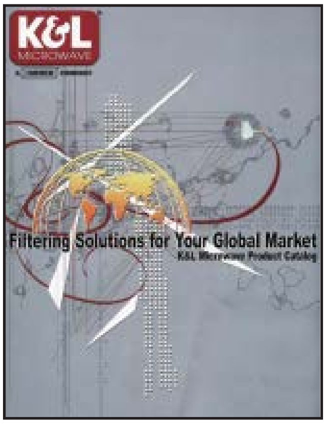
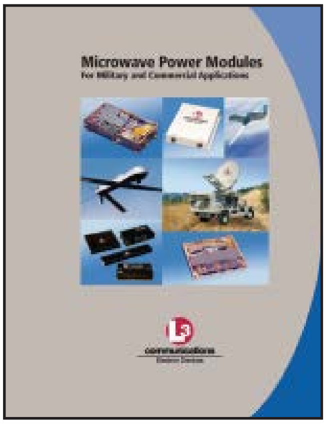


Product Catalog

As homeland security and defense systems become more advanced, K&L Microwave offers a broad range of RF and microwave filter products for defense electronics and telecommunications. Integrated assemblies and a wide assortment of lumped component, cavity, ceramic and suspended substrate filters are among the many types of products featured in this 123-page catalog.

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

RS No. 324

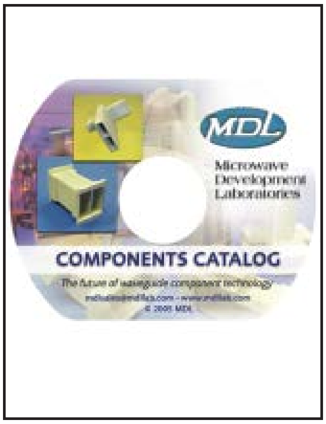


Microwave Power Module Brochure

This brochure offers detailed specifications on a wide variety of microwave power modules currently available for military and commercial applications. The newest offering is the M1270 capable of delivering up to 1 kW of X-band pulse power for airborne radar applications in a high density 11" × 6" × 2" package that weighs in at less than nine pounds. L-3 EDD now offers a full range of MPM products from S-, X-, Ku- and Ka-band to enable lightweight, high performance communication and radar systems.

L-3 Electron Devices, San Carlos, CA (650) 591-8411, www.l-3com.com.

RS No. 325



Components Catalog CD-ROM

This catalog CD-ROM features the company's cast components and other passive waveguide products. The CD also highlights the company's commitment to total control for perfection, engineering capabilities, quality manufacturing capabilities and guaranteed reliability.

Microwave Development Laboratories (MDL), Needham Heights, MA (800) 383-8057, www.mdllab.com.

RS No. 326

RF Amplifier Data Sheet

MILMEGA is a leading specialist in the design and manufacture of high power, solid-state, wideband microwave amplifiers. Developed around a unique upgradeable topology, allowing upgrades in both power and frequency, microwave amplifiers are backed with a fully expensed five-year warranty. The latest innovation from MILMEGA sees the launch of the 200 MHz to 1 GHz silicon carbide RF range of amplifiers.

MILMEGA Ltd., Ryde, Isle of Wight, UK +44 (0) 1983 618004, www.milmega.co.uk.

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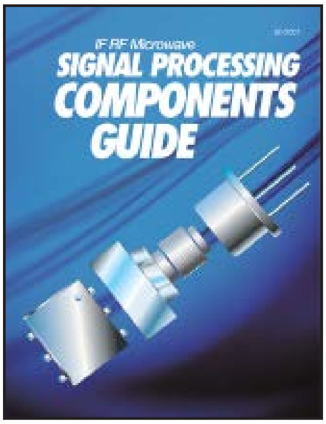

Components Guide

The 2007 IF/RF Microwave Signal Processing Components Guide is available for free from Mini-Circuits. The 144-page catalog offers the RF/microwave industry's most comprehensive listings of RF, IF and microwave components with essential performance specifications for each product. In addition to the extensive component data, the catalog also provides a listing of Mini-Circuits' patents and the product model numbers to which they apply.

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

RS No. 328

Short Form Catalog

In addition to the company's standard low noise, low cost amplifiers, this new short form catalog details the company's new line of PET-VI Configurable System Platforms. Also listed in this catalog is its full line of Portable Test Bench amplifiers and System Grade Rack Mount amplifiers. Custom platforms, racks and assemblies are available.

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

RS No. 330

Military Microwaves Supplement Archive

Visit www.mwjournal.com and click "archives" to access our three previous Military Microwaves supplements, all of which contain in-depth interviews with industry experts, high-quality technical articles and groundbreaking product features.

Microwave Journal

Norwood, MA (781) 769–9750, www.mwjournal.com.

Military Microwaves

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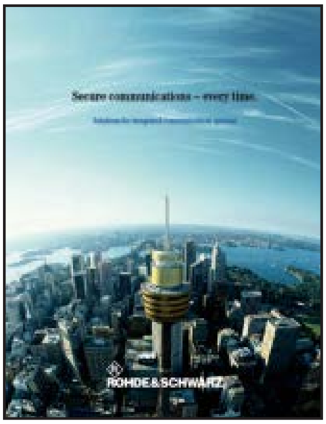

Product Brochure

This brochure features the company's solutions for integrated communications systems. Any organization tasked with protecting its country or company—as well as the people and goods entrusted to it—from threats has clear structures of responsibility. This includes a reliable, secure communications network that makes the effective command and control of all participating forces possible. Rohde & Schwarz offers military, governmental and civil forces the right solutions that have been customized for these tasks.

Rohde & Schwarz GmbH and Co. KG,
Munich, Germany +49 89 4129 0, www.rohde-schwarz.com.

RS No. 338

Selection Guide

Sirenza Microdevices' new 2007 Aerospace, Defense and Homeland Security product selection guide features a variety of solutions ranging from wideband and high level mixers to hybrid VCOs, power dividers and wideband transformers. Custom and COTS solutions are available.

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

RS No. 332

Product Catalog

L-3 Communications Narda Microwave-West designs and manufactures active and passive products for the military, space (requiring high reliability), commercial and service provider markets. Narda West's active product offering includes amplifiers, channel and linearized channel amplifiers, multipliers and multifunction assemblies. Passive products include filters, diplexers/multiplexers, circulators/isolators, space power dividers/combiners and multifunction assemblies.

Narda Microwave-West,
Folsom, CA (916) 351-4500, www.nardamicrowave.com.

RS No. 329

Push-on Connector Catalog

Push-on connectors are mating with regular connectors of the same series, SMA, N, TNC and 7/16. Eliminating time consuming tightening, torqueing and loosening of regular connectors, Spectrum E.T. developed push-on connectors and adapters. Push-on male connectors do not use threaded coupling nuts, sliding directly onto any female connector of the same series, allowing quick and easy connection and disconnection, guaranteeing repeatable performance.

Spectrum Elektrotechnik GmbH,
Munich, Germany +49-89-3548-040, www.spectrum-et.com.

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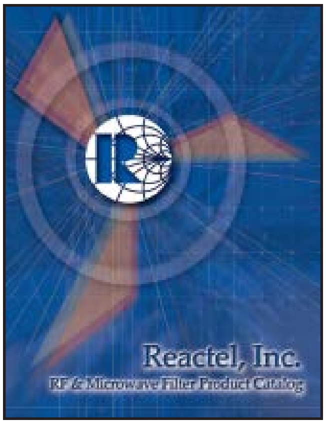

RF and Microwave Filters

This catalog features the company's full line of RF and microwave filter products. The catalog highlights high reliability filters, multiplexers and switched filter banks that cover DC to 50 GHz and are tailored to meet the military market. To request a complimentary copy, e-mail: catalog@reactel.com.

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

RS No. 331

Semi-rigid Data Sheet

This new data sheet features the company's Maximizer™ line of high performance semi-rigid cable products, available as custom assemblies, straight lengths, or coils. Options include phase stable, low loss Maximizer Gold products and low loss, RG replacement Maximizer Silver products. The data sheet includes mechanical and electrical product specifications; IL, Phase vs. Temp and Power Handling graphs; and design considerations.

Storm Products–Microwave,
Woodridge, IL (630) 754-3300, www.stormproducts.com.

RS No. 334

Military Microwaves

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EUROPEAN MICROWAVE WEEK 2007

Sign up to this year's unmissable event

Munich, the home of the famous Oktoberfest, will also celebrate the very best in Microwaves and RF technology when the city plays host to the 10th European Microwave Week. To mark its first decade the Week covers FIVE days and will provide an intoxicating mix of FOUR strong and challenging conferences, complemented by ONE healthy exhibition featuring international players. Europe's premier RF and Microwave event will showcase the industry's latest trends and developments at the ICM (Munich International Congress Centre) from 8 October through to 12 October.

THE MUST GO SHOW

Concentrating on the needs of engineers the event showcases the latest trends and developments that are widening the field of application of microwaves. Pivotal to the week is the **European Microwave Exhibition**, which offers YOU the opportunity to see, first hand, the latest technological developments from global leaders in microwave technology, complemented by demonstrations and industrial workshops. **Registration to the Exhibition is FREE!**

- **International Companies** - catch up with the premier industry names from across the globe
- **Leading-edge Technology** - exhibitors will showcase the latest product innovations, offering demonstrations and the chance to talk technical with experts
- **The Venue** - in the beautiful city of Munich and with good international access, The ICM (International Congress Centre) is one of the most modern congress centres in the world
- **Technical Workshops** - get first hand technical advice and guidance from the experts
- **Four Conferences** - The European Microwave Conference (EuMC), European Conference on Wireless Technology (ECWT), European Microwave Integrated Circuits Conference (EuMIC), European Radar Conference (EuRAD)

BE THERE

Exhibition Dates	**Opening Times**
Tuesday 9th October	09.30 – 17.30
Wednesday 10th October	09.30 – 17.30
Thursday 11th October	09.30 – 16.30

EUROPEAN MICROWAVE EXHIBITION REGISTRATION FORM

Please complete the following:

First Name: ______________________ Last Name: ______________________

Company/University: ______________________

Dept: ______________________

Address: ______________________

City: ______________________

Country: ______________________ Postal Code: ______________________

Tel: ______________________

E-mail: ______________________

☐ Yes, I would like to receive information by email from EuMA/Horizon House

☐ Yes, I would like to receive information by email from microwave/wireless industry companies

What is your job title? (please tick box)

Corporate Management ☐ Technical Management ☐ Technical Engineering ☐

Which market does your company serve? (please tick box)

Industrial / Commercial ☐ Government / Military ☐ Academia ☐

REGISTRATION INFORMATION

Attending the Exhibition is **FREE**! You can Pre-register on-line at **www.eumweek.com** and click on 'Registration'.
Alternatively, complete this form and fax to +44 (0) 20 7596 8749. Registration deadlines: 3 September, 2007 for advance fax or mail; 10 September, 2007 for advance website.
On-site registration is available at the event.
Please note that ALL visitor badges to the exhibition can be collected on-site.
Badges will NOT be mailed to visitors prior to the event.

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Munich
8-12 October 2007
www.eumweek.com

EUROPEAN MICROWAVE WEEK 2007
CONFERENCE REGISTRATION

Don't miss Europe's premier microwave conference event. The 2007 week consists of four conferences and associated workshops:

- **The European Microwave Integrated Circuits Conference (EuMIC) – Monday & Tuesday**
- **The European Conference on Wireless Technology (ECWT) – Monday & Tuesday**
- **The European Microwave Conference (EuMC) – Tuesday, Wednesday, Thursday**
- **The European Radar Conference (EuRAD) – Thursday & Friday**

From more than 1000 submissions, the Technical Program Committees have built a high-level program covering all aspects of microwave and wireless techniques, components, and applications, with some 450 oral and 150 poster presentations.

For a detailed description of the conferences, workshops and short courses please visit www.eumweek.com. The full conference programme can be downloaded from there.

REGISTRATION

- ADVANCE REGISTRATION at reduced rates via the web at www.eumweek.com or by fax or mail - see form overleaf for details. Deadlines are 3rd September (fax/mail) and 10th September 2007 (website).
- After these dates you must register ON-SITE at the conference at the higher rates listed below.

ON-SITE REGISTRATION FEES

For advance registration, fees are approx. 30% lower. See reverse for details.

CONFERENCES	*Society Member (*any listed over)*		*Non-Member*	
(available options - choose one)	**Standard**	**Student/Sr.**	**Standard**	**Students/Sr.**
EuMC Only	€ 490	€ 130	€ 630	€ 160
ECWT Only	€ 380	€ 120	€ 490	€ 150
EuMIC Only	€ 380	€ 120	€ 490	€ 150
EuRAD Only	€ 260	€ 110	€ 340	€ 140
EuMC & ECWT	€ 780	€ 250	€ 990	€ 310
EuMC & EuMIC	€ 780	€ 250	€ 990	€ 310
EuMC & EuRAD	€ 670	€ 240	€ 860	€ 300
EuMC & ECWT & EuMIC	€ 960	€ 370	€ 1240	€ 460
EuMC & ECWT & EuRAD	€ 870	€ 360	€ 1130	€ 450
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EuMC & EuMIC & ECWT & EuRAD	€ 980	€ 480	€ 1270	€ 600
EuMIC & ECWT	€ 680	€ 240	€ 880	€ 300
EuMIC & EuRAD	€ 570	€ 230	€ 740	€ 290
EuMIC & ECWT & EuRAD	€ 780	€ 350	€ 990	€ 440
ECWT & EuRAD	€ 570	€ 230	€ 740	€ 290

One Day Conference Ticket
Pay one fee and attend all conferences on the specified day. The price for society members* is €340 and for non-members €440.

Workshop and Short Course Prices	*Society Member (*any listed overleaf)*		*Non-Member*	
	Standard	**Student/Sr.**	**Standard**	**Students/Sr.**
Full Day WITH conference registration	€ 120	€ 90	€ 150	€ 110
1/2 Day WITH conference registration	€ 80	€ 60	€ 100	€ 80
Full Day WITHOUT conference registration	€ 160	€ 120	€ 190	€ 140
1/2 Day WITHOUT conference registration	€ 110	€ 80	€ 130	€ 100

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