Vol. 53 • No. 8
August 2010

Microwave Journal

THE MASTERS OF MIMO

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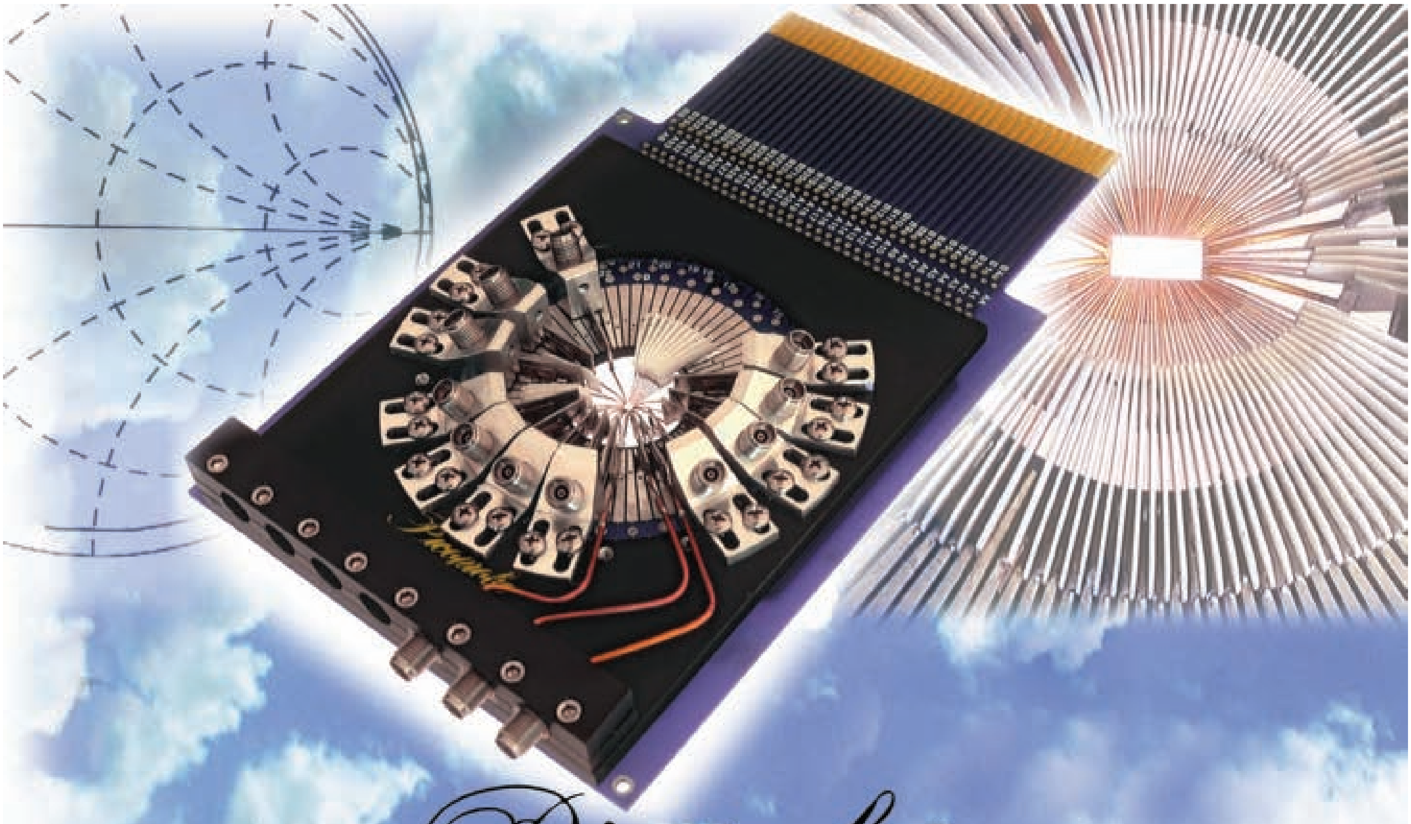

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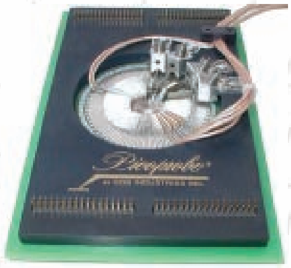

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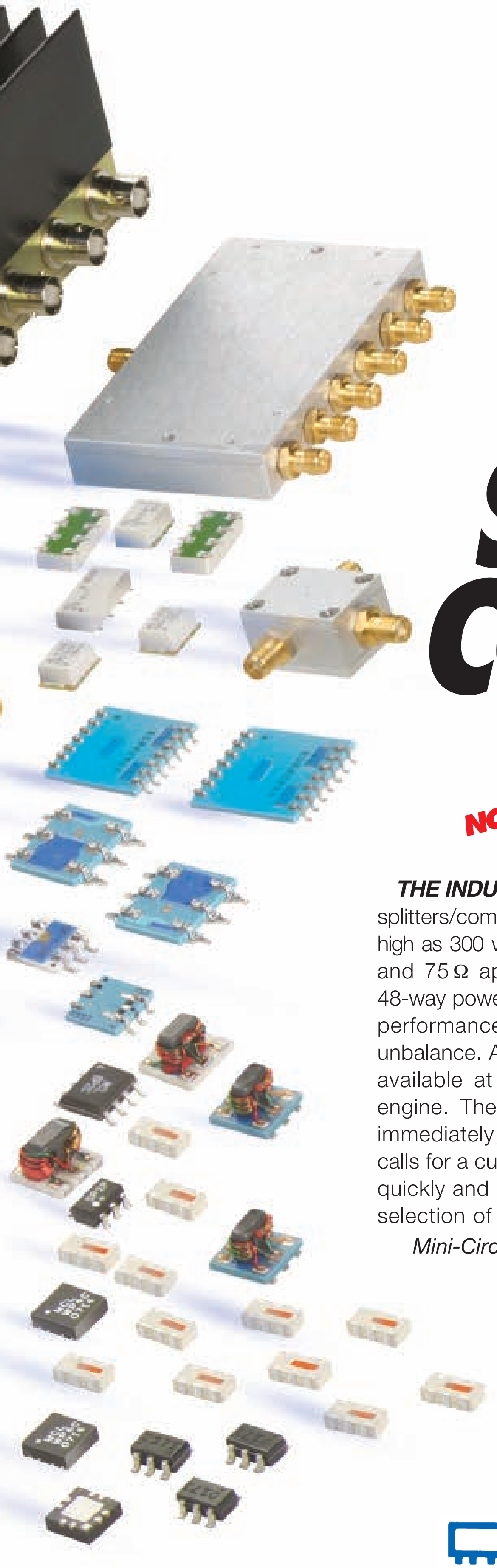

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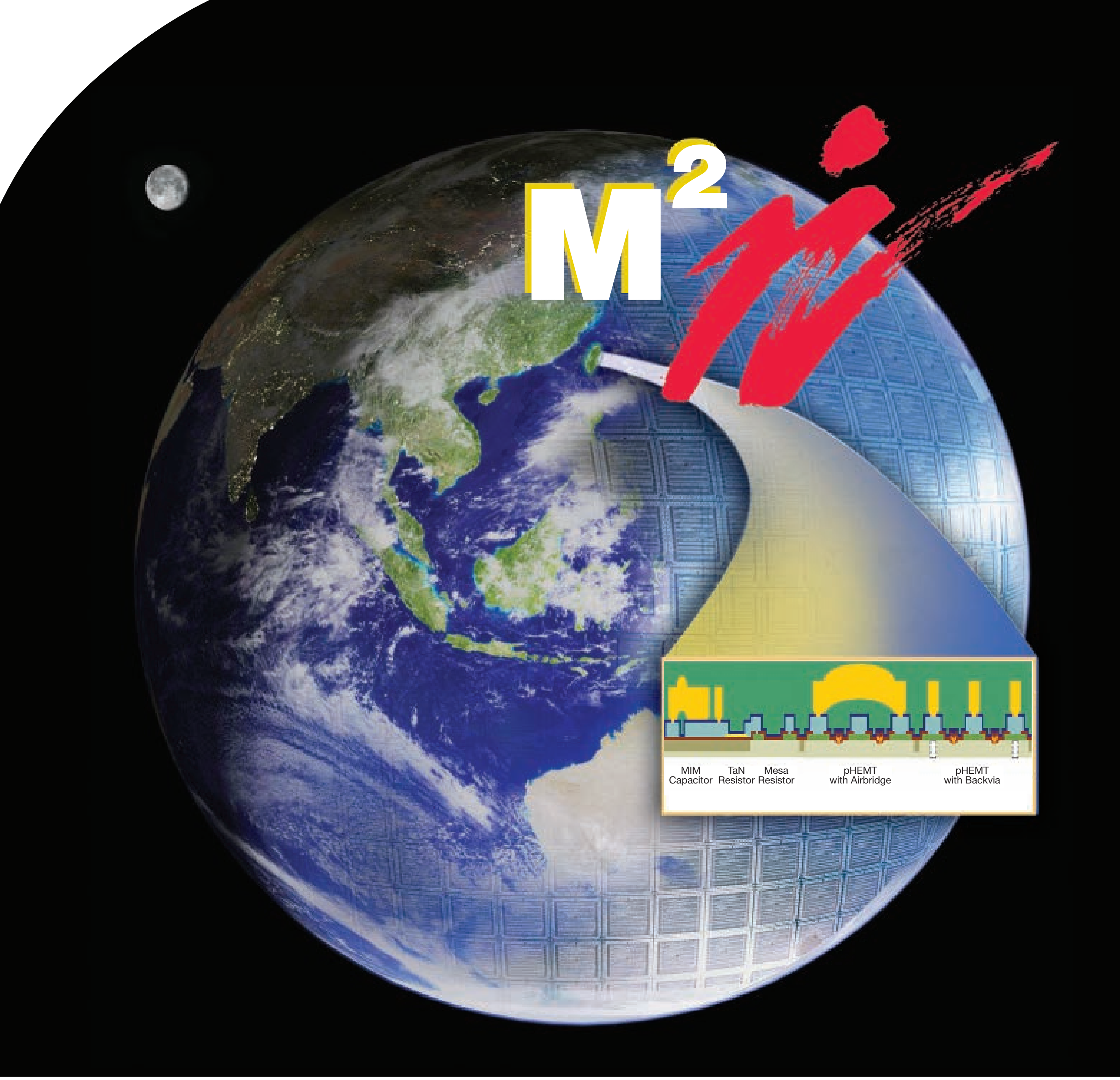
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FEATURES

COVER FEATURE: THE MASTERS OF MIMO

TECHNICAL FEATURE

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Online Technical Papers

Time-saving Technologies to Simulate and Tune Conformal Antennas for Modern Mobile Devices
Chris Hults, Jim Stack and M. Jeffrey Barney, Remcom Inc.

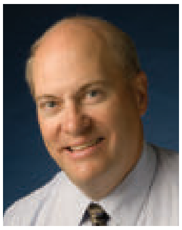
The Pros and Cons of Dual-band RF Amplifiers
Jason Smith and Pat Malloy, AR Worldwide

Improving IED Countermeasure Technology with RF Capture/Playback Solutions
White Paper, X-Com Systems

Seven Practices to Prevent Damaging Power Meter and Power Sensors
White Paper, Agilent Technologies Inc.

Executive Interview

Donn Mulder, Vice President/General Manager of Microwave Measurements Division at **Anritsu**, talks about his company's research, development, manufacturing, and marketing in light of evolving wired and wireless communication systems.



Expert Advice

THE MASTERS OF MIMO

The Masters of MIMO (technologists from Agilent, Spirent, SATIMO, ETS-Lindgren and MI Technologies) respond to questions about Multiple-In, Multiple-Out (MIMO) antenna systems and Over-the-Air (OTA) testing procedures.

TestBench

SATIMO, solution providers for measuring antenna performance, extend our "Masters of MIMO" coverage with a look at "OTA Throughput Measurements by Using Spatial Fading Emulation Technique." The authors employ a Spatial Fading Emulation technique and the use of an anechoic chamber, a channel emulator, and a mapping of geometry-based stochastic channel model (GSCM) by the channel emulator.

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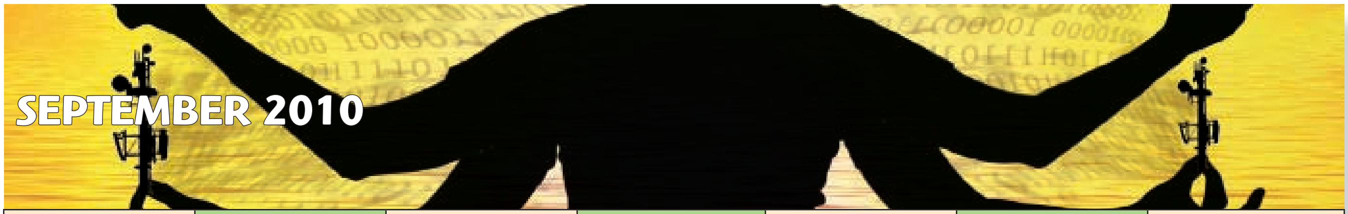

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
29	30	31 **Call for Papers Microwave Update (MUD)** Deadline: August 31, 2010	1	2	3	4
5	6	7 **MWJ/Strategy Analytics Webinar: MilSatcom Electronic Market Trends Through 2020**	8	9	10 **AWR Users Group Meeting** Tokyo, Japan	11
12	13 **Call for Papers ISSCC 2011** Deadline: September 13, 2010	14 **Webinar: MMIC Product Line** Presented by: endwave **CST MICROWAVE STUDIO® Microwave and Antenna Training** Darmstadt, Germany	15	16 **IEEE Great Lakes Technology Symposium** Ann Arbor, MI	17 **MOS-AK/GSA ESSDERC/ ESSCIRC Workshop** Seville, Spain	18
19	20	21 **MWJ/Besser Webinar: Passive Components** **Antenna Applications Symposium** Monticello, IL	22	23	24	25
26 **EUMW 2010 European Microwave Week** Paris, France	27 **EuMIC 2010** Paris, France **EuWiT 2010** Paris, France	28 **EuMW Exhibition** Paris, France **EuMC 2010** Paris, France	29	30 **EuRAD 2010** Paris, France	1	2

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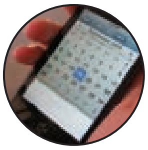

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Microwave Update (MUD)
Deadline: August 31, 2010

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WAMICON 2011
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AUGUST

10TH Mediterranean Microwave Symposium (MMS)
August 25–27, 2010 • Guzelyurt, Turkey
www.mms.ncc.metu.edu.tr

SEPTEMBER

IEEE Great Lakes Technology Symposium
September 16–17, 2010 • Ann Arbor, MI
www.ieeegreatlakes.org

Antenna Applications Symposium
September 21–23, 2010 • Monticello, IL
www.ecs.umass.edu/ece/allerton/

EuMW 2010
European Microwave Week
September 26–October 1, 2010 • Paris, France
www.eumweek.com

OCTOBER

AOC 2010
47TH Annual AOC International Symposium and Convention
October 3–6, 2010 • Atlanta, GA
www.crows.org

Bipolar/BiCMOS Circuits and Technology Meeting
October 4–6, 2010 • Austin, TX
www.ieee-bctm.org

MWP 2010
International Topical Conference on Microwave Photonics
October 5–9, 2010 • Montreal, Canada
www.mwp2010.org

COMSOL Conference 2010
October 7–9, 2010 • Newton, MA
www.comsol.com/conference2010/usa/

AMTA 2010
Antenna Measurement Techniques Association
October 10–15, 2010 • Atlanta, GA
www.amta2010.com

IEEE International Symposium on Phased Array Systems & Technology
October 12–15, 2010 • Waltham, MA
www.array2010.org

4G World
October 18–21, 2010 • Chicago, IL
http://4gworld.com

Microwave Update (MUD)
October 21–24, 2010 • Cerritos, CA
www.microwaveupdate.org

Microwave Antenna Design, Testing and Wireless Propagation
October 26–29, 2010 • Ottawa, Canada
www.nearfield.com/shortcourses.htm

MILCOM 2010
October 31–November 3, 2010 • San Jose, CA
www.milcom.org

DECEMBER

APMC 2010
Asia Pacific Microwave Conference
December 7–10, 2010 • Yokohama, Japan
www.apmc2010.org

JANUARY

RWS 2011
Radio Wireless Week
January 16–20, 2011 • Phoenix, AZ
http://rawcon.org

MEMS 2011
IEEE International Conference on Micro Electromechanical Systems
January 23–27, 2011 • Cancun, Mexico
www.ieee-mems2011.org

FEBRUARY

MWC 2011
Mobile World Congress
February 14–17, 2011 • Barcelona, Spain
www.mobileworldcongress.com

ISSCC 2011
IEEE International Solid-State Circuits Conference
February 20–24, 2011 • San Francisco, CA
http://isscc.org

Nate 2011
National Association of Tower Erectors
February 21–24, 2011 • Oklahoma City, OK
www.natehome.com

APRIL

WAMICON 2011
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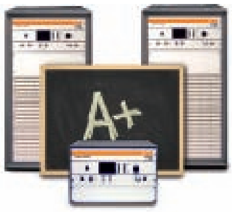

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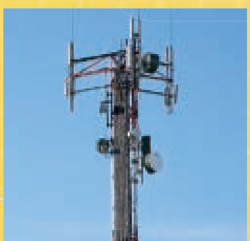

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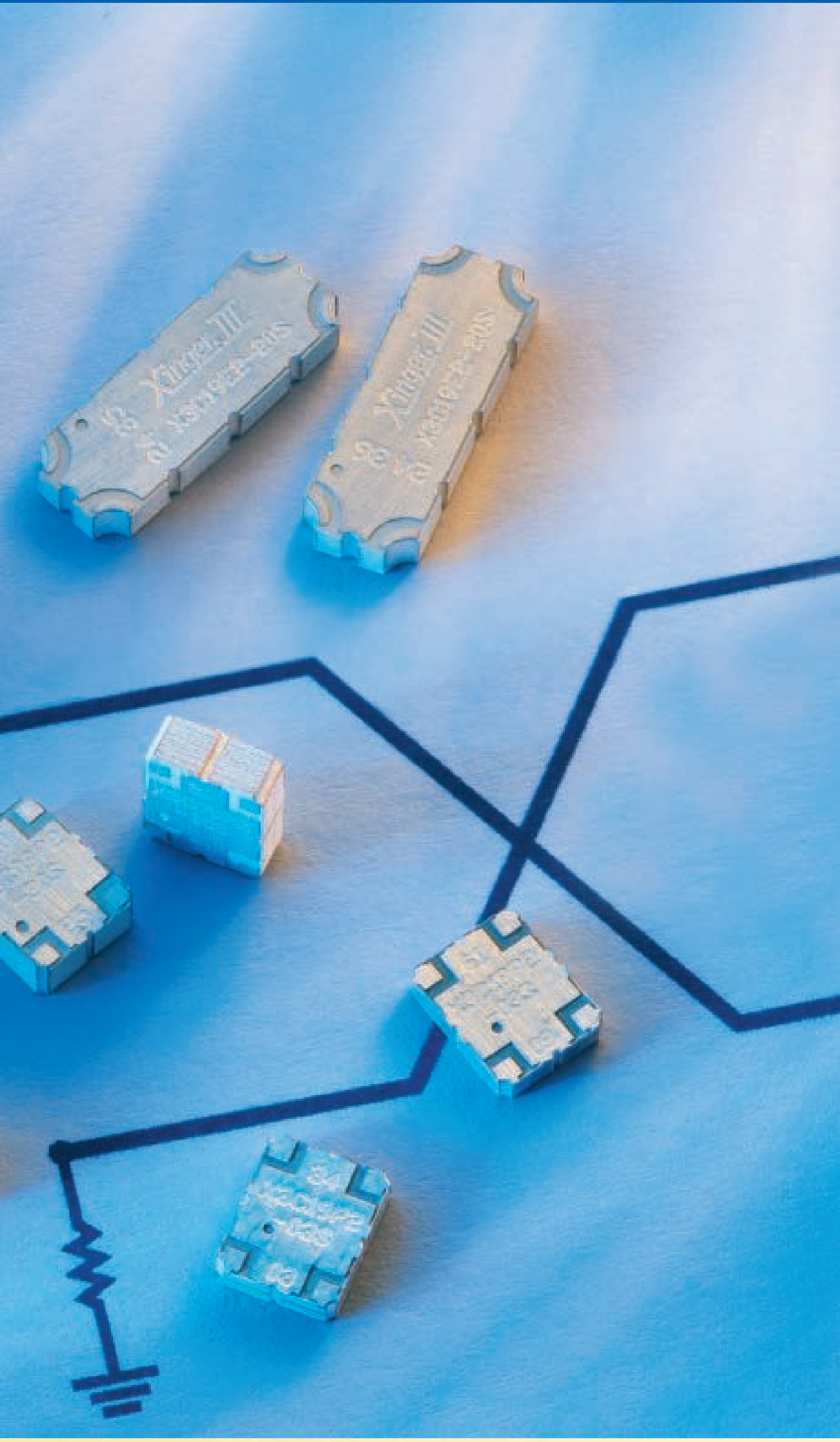

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COVER FEATURE
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THE MIMO ANTENNA: UNSEEN, UNLOVED, UNTESTED!

Multiple input/multiple output (MIMO) systems have shifted from theory through design to development and are now entering the testing and deployment phases. The MIMO articles in this issue are focused on performance testing in real world conditions, which is the validation of MIMO performance that the industry has long been waiting for.

This first article covers the standardization efforts for MIMO "Over the Air" (OTA) testing. MIMO is used here to refer to any multi-antenna technique including Rx and Tx diversity, beamsteering and spatial multi-plexing. When this work started a couple of years ago, I quickly concluded that MIMO OTA was the biggest test challenge facing the industry that I had seen in 20 years of standards involvement. By the end of this article I hope you will appreciate why. Following this article are four related articles focused on specific aspects of the test process. Dr. Michael Foegelle of ETS-Lindgren explains the classical anechoic chamber method for creating the required spatially diverse test signals, while Derek Skousen of MI Technologies and Charlie Orlenius of Bluetest describe how to use a reverberation chamber for the same purpose. Madhu Gurumurthy of Spirent describes the spatial correlation properties of real radio channels and the importance of realistically modeling them. Finally, Azimuth Systems, as a part of the product feature section, presents a drive test solution for measuring real channels so they can be replayed in the lab.

THE MIMO ANTENNA: UNSEEN

When mobile phones first appeared on the scene, the antenna was very much in evidence. These early phones typically operated in the 900 MHz band and were often "graced" with a folding or pull-out whip antenna whose length was optimized for the frequency of operation. Over time the whip antenna gave way to much smaller helical designs and then in 1994 we saw the first of the integral "patch" antennas that became widespread by 1998. Thus, in a few short years the antenna has transitioned from its traditional, highly visible form to being nothing short of invisible.

THE MIMO ANTENNA: UNLOVED

The transition from seen to unseen was clearly a gift to the industrial designer, who was now freed from the need to design around this functional "wart." Seen through the eyes of fashion, the integration of the antenna represents huge progress, but from an antenna design and performance perspective, the opposite

MORAY RUMNEY
Agilent Technologies Inc., Santa Clara, CA

is true. In the clash between industrial and antenna designers, suffice it to say that for the sake of a millimeter here or there, fashion often triumphs over function.

THE MIMO ANTENNA: UNTESTED!

And now for the reckoning—Single input/single output (SISO) OTA standards have existed since 2001, but nothing yet exists for MIMO. The factors affecting MIMO antenna performance are much more complex than SISO and today's antenna designers are under huge pressure. They have had to deal with the transition from external to integrated design as well as the change from single to multiple ports. The volume required for one good antenna can easily be divided up to make room for two bad antennas—and without standard test methods, who is to know? A similar challenge comes from the huge increase in the number of supported frequency bands, with hex band devices now being common. Each band imposes unique demands on the optimal receive and transmit antennas resulting in the need for separate antennas for some bands. And although the focus here is cellular, there are further antenna demands for the support of Wi-Fi, Bluetooth, GPS, FM radio, DVB, etc. Before getting into the specific challenges of MIMO OTA testing, it is important to first have a working understanding of SISO.

A BRIEF HISTORY OF RADIATED TESTING

Most handset testing is done using conducted methods; that is, by connecting a cable to what is known as the "temporary antenna connector," which bypasses the DUT antenna to provide direct access to the transceiver. The requirements at this port are based on an assumption that the DUT antenna can be fairly represented by an isotropic antenna with 0 dB gain. In the days when the antenna was a dipole tuned to the single band of interest, this assumption was not unreasonable. However, with the advent of multi-band integrated antennas, the 0 dBi assumption is no longer safe. This being the case it is easy to see how the results from conducted tests for requirements such as reference sensitivity and maximum output power may no longer represent the radiated performance of the device in a real network.

TABLE I

TRP AND TRS TEST REQUIREMENTS FOR UTRA (W-CDMA) FDD POWER CLASS 3 (24 dBm)

Band	Uplink-Mobile transmit (MHz)	Downlink-BS transmit (MHz)	Total Radiated Power			Total Reference Sensitivity*		
			Avg.	Min	Rec. Avg.	Avg.	Min	Rec. Avg.
I	1920 - 1980	2110 - 2170	+14.3	+12.0	+17.3	-100.1	-96.8	-103.1
II	1850 - 1910	1930 - 1990	+14.3	+12.0	+17.3	-98.1	-94.8	-101.1
III	1710 - 1785	1805 - 1880	+14.3	+12.0	+17.3	-97.1	-93.8	-100.1
IV	1710 - 1755	2110 - 2155	+14.3	+12.0	+17.3	-100.1	-96.8	-103.1
V	824 - 849	869 - 894	+10.3	+8.0	+13.3	-95.1	-91.8	-98.6
VI	830 - 840	875 - 885	+10.3	+8.0	+13.8	-95.1	-91.8	-100.1
VII	2500 - 2570	2620 - 2690	+14.3	+12.0	+17.3	-98.1	-94.8	-101.1
VIII	880 - 915	925 - 960	+11.3	+9.0	+14.3	-95.1	-91.8	-99.1
IX	1749.9 - 1784.9	1844.9-1879.9	+14.3	+12.0	+17.3	-99.1	-95.8	-102.1

* The check for self-blocking, the TRS must be met while the mobile station is transmitting at max power

Radiated testing for regulatory purposes started with Electromagnetic Compatibility (EMC) testing for spurious emissions, and more recently both a hearing aid compatibility and a safety test were added for specific absorption ratio (SAR) to assess how much of the DUT radiated power is absorbed by a phantom head. However, these tests do not assess the desired radio performance of the DUT for the purpose of communication. The CTIA published its "Test Plan for Mobile Station Over the Air Performance" in 2001, and beginning in 2006 3GPP published Technical Report (TR) 25.914, Technical Specification (TS) 25.144, and finally in 2008 the associated test specification TS 34.114.

SISO OTA FIGURES OF MERIT

SISO OTA is conceptually simple, comprising one figure of merit (FOM) for the DUT transmitter called Total Radiated Power (TRP) and another for the DUT receiver called Total Reference Sensitivity (TRS). For TRS, the CTIA uses the term Total Isotropic Sensitivity (TIS). The TRP is defined as the integral of the power transmitted in different directions over the entire radiation sphere. TRS is a similar measure, but it represents the reference sensitivity of the DUT receiver. With these two FOMs agreed upon, the bulk of the standards work for SISO was in defining the method, the test system uncertainty and finally the performance requirements.

The test method was initially developed using an anechoic chamber. Substantial theoretical analysis of the measurement uncertainty was performed by CTIA and the European COST273 project, resulting in an error model with over 20 terms. The requirement for overall test system uncertainty was calculated to be in the region of ±2 dB; this figure has since been validated using a golden radio by the majority of the nearly 50 CTIA accredited labs. Further work on an alternative test method using a reverberation chamber has also been done and test results indicate a similar level of uncertainty.

SISO OTA TEST REQUIREMENTS

A summary of DUT minimum test requirements for UTRA (W-CDMA) from TS 34.114 is given in ***Table 1***. The figures in Table 1 are the test requirements, which have been relaxed from the minimum requirements in TS 25.144 by an amount known as the test tolerance, which is a function of the maximum allowed test system uncertainty. 3GPP normally relax the minimum requirements by the full test system uncertainty, but since the OTA test uncertainty is quite high (±1.9 dB for TRP and ±2.3 dB for TRS), the relaxation is limited to about half of the allowed test system uncertainty. This choice prevents the requirements from becoming too relaxed and allowing bad DUTs to pass, but it does slightly increase the risk that a good DUT might fail the test. In the pursuit of improved user experience and network performance, a non-mandatory recommended target is also defined.

The figures presented in Table 1 conceal the details of the actual tests, which are quite thorough. Both TRP

and TRS are the average of measurements made across a sphere typically using steps of 15 degrees for TRP and 30 degrees for TRS in both azimuth φ (Phi) and elevation θ (Theta). At each point, measurements are made at the low, middle and high channels of all the frequency bands supported by the DUT and at two orthogonal RF polarizations; e.g., vertical and horizontal. The DUT has to be tested in its primary mechanical mode, and may involve sliding or folding open the DUT. Testing in other mechanical modes is not part of the minimum requirement, although some carriers require all modes to be tested.

The final consideration is the physical environment. Tests are carried out in free space or in the proximity of a Specific Anthropomorphic Mannequin phantom head, better known as SAM. Tests are carried out on both the left and right sides of the head, which is filled with different liquids to match the frequency-dependent RF loading effect of the human head. In order to ensure repeatability across labs, detailed guidelines on how to align the DUT to the test environment are provided. The latest CTIA test plan has added a phantom hand, which can take four positions depending on the DUT design: monoblock, fold, narrow data and PDA. The hand may be used on its own for "data" positions or in conjunction with the head to emulate a more realistic speech position than the head-only tests. Currently, the hand tests are limited to the right hand. Testing may be extended to the left hand since the interaction between device and hand can be highly asymmetric.

From this brief overview of the scope of SISO OTA testing it is easy to see that characterizing one multi-band device requires thousands of measurements. Testing can take up to two weeks in an expensive anechoic facility.

DEVELOPMENT OF THE SISO OTA TEST REQUIREMENTS

The normal process in standardization is to simulate the desired performance and provide design targets for developers. Since OTA performance requirements are very much retrospective, simulation was not an option. Also, the sheer complexity of trying to simulate a realistic performance target was considered out of scope. However, with the creation of a repeatable test method, the requirements were instead developed through a series of measurement campaigns using real devices. This is clearly not ideal, but under the circumstances was the only practical solution. A typical set of free space TRP and TRS measurements from a variety of commercial devices is shown in ***Figure 1***. Each point defines the TRP and TRS for one DUT.

Note the variation of performance covering approximately 7 dB for TRS and 4.5 dB for TRP. With the addition of head and hand loading the figures will spread significantly further. All of these devices will have passed the conducted tests, which have a narrower spread, suggesting that the increased variation is due to the previously untested antenna. A carrier company choosing devices for a network will want to see a high TRP and low TRS. The availability of standardized OTA measurements gives the carrier for the first time a deterministic and repeatable way (compared

to field measurements) of selecting the best handsets, which in turn will directly improve end-user quality of experience (QoE). In the conducted domain many a battle has been fought over a tenth of a dB here or there, but in the radiated domain there are dBs of performance at stake, which is why the recent introduction of OTA testing is long overdue and so important.

Agreeing to minimum requirements in 3GPP was by no means straightforward. Carriers naturally wanted to set high targets, while vendors had to protect the installed base of handsets and existing designs from being classed as non-compliant and to protect design margins for the ever-decreasing size of future handsets. The end result was a compromise. Figures were agreed on for average and minimum performance that allowed the bulk of legacy devices to remain compliant. Carriers accepted tougher, though non-mandatory, "recommended" average performance—

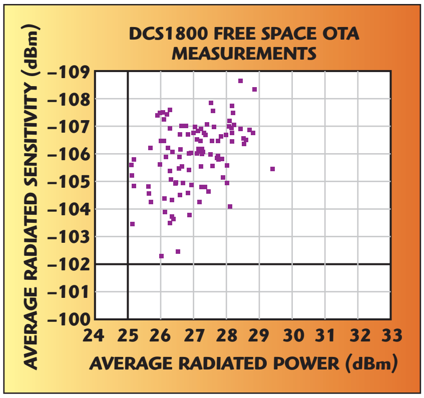

Fig. 1 TRP vs. TRS for GSM 1800 commercial devices.[1]

typically 3 dB better—to give the industry something to aim for. Even then the recommended TRP performance is some 6 dB below the nominal power for the conducted test, suggesting that there is still considerable scope for improvement, although with the continual downward pressure on device size further improvement may not be realistic. To date, figures for GSM OTA requirements have not yet been reached and many CTIA requirements are still to be defined.

MOVING FROM SISO TO MIMO

MIMO OTA standardization started a couple of years ago in CTIA and 3GPP along with the European COST2100 project that succeeded COST273. We saw that SISO OTA is conceptually simple, with just one primary test method and two figures of merit based on existing conducted measurements in order to provide the missing insight into the antenna performance. With the exception of the phantom head and hand, the SISO measurements are independent of the external radio environment.

The situation for MIMO OTA is very different. The desired FOM for MIMO OTA is end-to-end data throughput in realistic conditions, which provides a direct measure of QoE. MIMO is all about taking advantage of instantaneous spatial diversity in the radio channel, and thus the measured performance is tightly coupled to the radio propagation, noise and interference conditions in which a device is tested. This extends to the closed loop behavior of the end-to-end system; that is, the real-time interaction between how the DUT measures the radio environment and the

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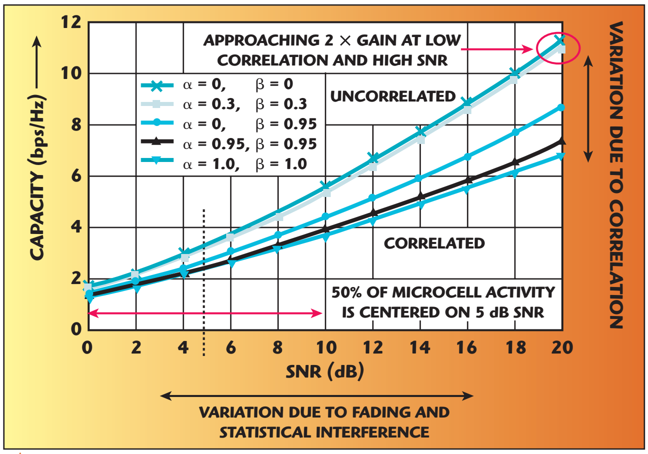
The state of play of MIMO OTA standardization in 3GPP is summarized in TR 37.976, which documents the progress of the study phase prior to formal standardization. Much of the discussion has been on methods for creating spatially diverse signals. A table contrasting the seven different proposals runs to 25 criteria, with most of the objective data still to be provided and agreed upon. Throughput is the main FOM, but six others are also being considered.

MIMO OTA TEST METHODS

The test methods for MIMO OTA can be broadly grouped into three categories: reverberation chamber (with and without external channel fading), anechoic chamber (using from 2 to 32 antennas) and multi-stage. The articles that follow from ETS-Lindgren and MI Technologies/Bluetest will cover the first two categories and so will not be discussed here other than to draw attention to the robust debate that exists over which method is viable or affordable.

Two methods are classed as multi-stage. The first and simpler method involves antenna pattern measurement[2] from which various FOM such as correlation and gain imbalance can be developed, making it possible to compute the antenna impact on theoretical throughput. Since this method measures only part of the DUT and does not measure end-to-end throughput, the impact of secondary factors such as self-blocking (desensitization) are excluded. That said desensitization is largely covered by the SISO OTA tests. To accurately measure the antenna pattern on an unmodified handset requires the definition of a non-intrusive method. The CTIA has developed a standard format for documenting pattern information for GPS devices, but techniques used for pattern measurement are currently device-specific and proprietary. From a test perspective, the ideal solution for handsets would be to standardize a non-intrusive device test mode that allows the measurement of antenna relative gain and phase using the same anechoic chamber as for SISO OTA tests. This approach would require some development work but would be highly useful.

The other multi-stage proposal is called the two-stage method.[3,4] The first stage is the same radiated antenna pattern measurement just described, although the calculation of FOM and theoretical throughput is not required. The second stage is a conducted test that combines the measured antenna pattern with any desired radio propagation environment using a channel emulator. The two output signals are then injected into the standard, temporary antenna ports used for conducted testing, and a throughput measurement is made with a signal that consists of the fading channel modified by the antenna pattern. The main advantage of the two-stage method is that it can reuse the existing simple SISO anechoic chamber for the antenna measurement and then, using only a two-port channel emulator, can emulate arbitrarily complex spatial channel conditions without the need for a large anechoic chamber and multiple probe antennas. With this brief overview of the proposed test methods we will now look at the primary FOM, MIMO throughput.



▲ *Fig. 2 Shannon-bound spectral efficiency for rank 2 spatial multiplexing as a function of antenna correlation and SNR.*

THEORETICAL MIMO PERFORMANCE GAINS

The SISO OTA requirements were defined retrospectively, so there could be no preconceived expectations. However, for MIMO to have any value, it has to demonstrate a gain over SISO. ***Figure 2*** plots the spectral efficiency versus SNR for five different combinations of transmit (α) and receive (β) antenna correlation, showing how the theoretical spatial multi-plexing gain varies with SNR. Low antenna correlation is much easier to achieve at high frequencies e.g., above 1.7 GHz. In reality, the end-to-end correlation is continually varying due to the additional impact of the radio channel. Spirent's paper discusses this in more depth. The correlation can also vary widely within one channel bandwidth; to get the optimum MIMO gain out of the system, frequency-selective scheduling is required to target the best part of the channel. This is something that OFDM systems can do but CDMA systems cannot.

When MIMO performance is discussed, it is common to highlight the potential 100 percent spatial multiplexing gains over SISO without mentioning that this only occurs with high SNR and low correlation. In real loaded networks, however, the median SNR is in the vicinity of 5 dB. Combining this median SNR with a realistic correlation value (which includes the impact of all antennas and the channel) gives realizable gains over SISO nearer to 20 percent than 100 percent. This performance difference is problematic for testing.

EFFICACY OF TEST

The whole point of testing is to differentiate good performance from bad. If in realistic conditions the theoretical gain is limited, then the figure for acceptable performance needs to be somewhat lower. The challenge is to devise a test that can distinguish between SISO performance and limited MIMO gain. We know that the SISO OTA radio conditions can be controlled within ±2 dB and there are no obvious reasons why the more complex MIMO environment will be more accurate. If we then look at the impact of a possible 4 dB change in conditions on theoretical throughput, we see that the subtle gains we are trying to measure could easily be swamped.

Indeed, calibration of multi-probe test environments is proving to be a significant challenge, and failure to understand the factors that influence uncertainty always results in underestimation of their contribution. If five thermometer

manufacturers independently predict the accuracy of their devices as less than 1 degree, but when the thermometers are exposed to the same environment the range of readings spans five degrees, you know there is a problem even if the theory does not yet exist to explain the cause. This is why the CTIA golden radio validation exercise was so important for the new discipline of OTA measurement.

It is reasonable to assume that 3GPP will relax the MIMO OTA minimum requirement by some proportion of the test uncertainty. With the figures suggested here, it would be easy to see how a DUT operating in SISO mode could then pass a MIMO test requirement, completely negating the efficacy or usefulness of the test.

The problem can be alleviated by testing under more extreme conditions (high SNR and low channel correlation) to maximize the expected gain, but there is no guarantee that the results obtained in near ideal conditions would correlate with those in real life conditions. Consider this analogy: If you were trying to differentiate the demodulation accuracy of two optical character recognition systems, would you use large, high contrast, uncorrelated characters such as WOXI or small, low contrast, correlated characters such as OCQD? My hunch is that if the demodulation target is easy, it is not useful as a performance differentiator. If for measurement accuracy reasons MIMO throughput gain turns out to be problematic as an FOM, an alternative option is to consider an antenna-only metric such as correlation or gain imbalance. The timeliness, cost and lower scope of such an approach need to be weighed against the alternatives.

SELECTING MIMO OTA TEST METHODS AND FIGURES OF MERIT

One practical way to distinguish useful FOM and test methods from the not so useful is to define two reference DUTs, one with known, agreed-upon good performance and the other with some controlled impairment such as a deliberate gain imbalance or highly correlated antenna pattern. The goal of any candidate FOM and supporting test method would then be to demonstrate repeatable and accurate differentiation of the good DUT from the impaired one. It would also be necessary to define more than one type of impairment since many DUT capabilities can impact performance in a closed loop MIMO system; for example, the timing and accuracy of the reporting of channel state information.

We might expect such capabilities to be covered by the conducted receiver tests, but for reasons of simplification these tests are executed primarily open loop, i.e., with fixed channel coding, regardless of radio conditions. Any optimized system relies on unspecified scheduling algorithms in the network. If tests are to be realistic, they need to be closed loop, but then it becomes necessary to precisely define the behavior of network algorithms so that differences in test equipment implementation do not impact the measured DUT performance. With the air interface becoming ever more complex, the gap between the simplified open loop testing we have become used to and real closed loop performance continues to grow.

BP
SP
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SCN, QCN

Take LTE as an example. LTE supports seven different downlink transmission modes ranging from SISO through six forms of MIMO with transmit diversity and beam steering to fully precoded spatial multi-plexing. Each mode is designed to offer the best system performance for particular network conditions. When the radio conditions vary, a fully optimized system has to configure the DUT to measure the channel in the best way; then interpret the results to select the correct transmission mode and subsequent coding gain and rank.

Another teasing issue is the definition of noise. Some test scenarios are done without noise in order to highlight the issue of desensitization, while other tests are performed under realistic noise levels as seen in loaded networks. But what is this noise? Uniform Gaussian white noise is easy to generate and is relevant for testing CDMA systems, but due to frequency dependency scheduling in no way represents reality for OFDM systems. A real UE will be faced with statistically varying narrow band frequency hopping interference coming from different directions to that of the signal. If the test environment uses spatially uniform interference, a good DUT with low correlation will gain no advantage. This is unrealistic and unfair.

CONCLUSION

The big issue facing MIMO OTA test development is the laudable but hugely challenging goal of measuring realistic end-user performance. Considerable work lies ahead to determine what level of sophistication is required in the test system to differentiate between a good MIMO DUT and one that is undesirable. SISO OTA standardization had the advantage that every DUT on the planet was a potential measurement candidate, but the lack of wide availability of a rich diversity of MIMO devices will limit the rate at which progress can be made towards a final MIMO OTA standard. Everyone agrees that testing needs to be no more complex, time consuming, or expensive than necessary, but it is clear from current proposals that the industry is still some way from agreeing on reference performance in specific conditions and the associated accuracy and method of test. ■

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Moray Rumney *joined Hewlett-Packard/Agilent Technologies in 1984 after receiving a BSc degree in Electronics from Heriot-Watt University in Edinburgh. His career has spanned manufacturing engineering, product development, applications engineering, and most recently technical marketing. His main focus has been the development and system design of base station emulators used in the development and testing of cellular phones. Rumney joined ETSI in 1991 and 3GPP in 1999 where he was a significant contributor to the development of type approval tests for GSM and UMTS. He currently represents Agilent at 3GPP RAN WG4, developing the air interface for HSPA+ and LTE. His current focus is on radiated testing of MIMO devices. Rumney has published many technical articles and is a regular speaker and chairman at industry conferences.*


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Defense News

Dan Massé, Associate Technical Editor

Multi-band Trends in Tactical Military Radios Increasing Component Demand

The next generation of military tactical radios will serve as nodes and hubs in mobile ad hoc networks. These networks will connect ground, naval, airborne and satellite assets into an interactive mesh of battlefield information and decision-making. The Strategy Analytics Advanced Defense Systems (ADS) service report, "Electronic Component Demand Scenarios for Land Based Military Tactical Radios," forecasts the annual military radio market will grow from under \$3 B in 2009 to almost \$5 B in 2020.

Strategy Analytics predicts the electronic content from the current generation of single-band and multi-band radios will decline, as their capability no longer meets the emerging network-centric requirements. The next generation of military tactical radios, including those from the JTRS program in which companies like Harris and Thales are involved, will be capable of performance in several frequency ranges and enhanced data throughputs. These multi-mode radios will significantly upgrade capabilities and serve as the critical components needed to provide "network-centric" battle space resources.

"The development of multi-mode, multi-band radios will provide significantly upgraded capabilities with frequencies extending to 2.7 GHz," observed Asif Anwar at Strategy Analytics. "Multi-mode, multi-band will mean multiple transceivers, fueling an increase in the number of RF components. Together with digital and other passive components, the resulting radio electronics market will grow to over \$1 B."

...the annual military radio market will grow... to almost \$5 B in 2020

Anwar concluded, "The increasing sophistication of base band processing and encryption requirements, coupled with traditionally low frequency military radio operating ranges, will mean that silicon semiconductors will remain seated as the dominant technology. However, increasing operating frequencies and bandwidths will open the doors for compound semiconductor technologies such as gallium arsenide and gallium nitride."

Lockheed Martin Team Completes Requirements Milestone for GPS IIIB Program

Lockheed Martin announced that it has successfully completed a key requirements review for the Global Positioning System (GPS) IIIB satellite series under the US Air Force's next generation GPS III Space Segment program. GPS III will improve position, navigation and timing services and provide advanced anti-jam capabilities yielding superior system security, accuracy and reliability for users around the globe.

GPS III will improve position, navigation and timing services...

Lockheed Martin Space Systems, Newtown, PA, is working under a \$3 B development and production contract to produce up to 12 GPS IIIA satellites, with first launch projected for 2014. The contract, which features a "back to basics" acquisition approach to low-risk constellation sustainment and technology insertion, includes a capability insertion program (CIP) designed to mature technologies and perform rigorous systems engineering for the future IIIB and IIIC increments planned for follow-on procurements.

The Lockheed Martin-led team, which includes ITT, Clifton, NJ, and General Dynamics of Gilbert, AZ, recently completed a two-day GPS IIIB system requirements review (SRR) with the US Air Force at Lockheed Martin's facilities in Valley Forge, PA. Over 170 attendees participated in the SRR, including representatives from the US Air Force's GPS Wing, Air Force Space Command, the Defense Contract Management Agency, the OCX Ground Segment team, the Federal Aviation Administration and user communities.

"The GPS IIIB SRR was a success," said Lt. Col. Don Frew, GPS III Squadron Commander. "Lockheed Martin demonstrated to the government that the team is working to a solid requirements baseline and developing a mature design beyond what we normally see at a SRR. I want to thank the GPS III team for all their hard work and dedication." The successful review demonstrated to the customer and user community the Lockheed Martin team's understanding of the inherent product development and technology maturity risks, how they will be met, and the program's readiness to continue to the GPS IIIB System Design Review.

The GPS IIIA satellites will deliver significant improvements over current GPS space vehicles, including a new international civil signal (L1C) and increased M-Code anti-jam power with full earth coverage for military users. GPS IIIB will enable a cross-linked command and control architecture, allowing these GPS III vehicles to be updated from a single ground station instead of waiting for each satellite to orbit in view of a ground antenna. GPS IIIC will include a high-powered spot beam to deliver greater M-Code power for increased resistance to hostile jamming.

The team, which is progressing in the GPS IIIA Critical Design Review (CDR) phase of the program, has completed more than 80 percent of the planned CDRs and is well on its path to the overall space vehicle CDR in August, two months ahead of the planned schedule. Successful completion of the space vehicle CDR will allow the team to enter the production phase of the program.

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Northrop Grumman Completes System Development, Demonstration Phase of B-2 Radar Modernization

Northrop Grumman Corp. has helped the US Air Force improve the mission availability of its fleet of B-2 stealth bombers by successfully completing the system development and demonstration (SDD) phase of the B-2 Radar Modernization Program (RMP). SDD includes the design, development, test and installation of the new radar system in a B-2 test aircraft, plus several operational bombers. Installation of the new radar in this first group of B-2s was completed at Whiteman AFB with final spares delivered. Northrop Grumman is the US Air Force's prime contractor for the B-2, the flagship of the nation's long range strike arsenal.

The Northrop Grumman-led B-2 industry team is currently producing the radar units authorized under the low rate initial production phase (LRIP) of the RMP program, which began in December 2008; and the full rate production phase, which began in November 2009. Installation of the LRIP radar units is expected to begin in mid 2010, with completion of all B-2 RMP radar installations expected to be complete in 2012. The B-2 radar modernization program replaces the aircraft's original radar system with one that incorporates technology improvements that have occurred since the B-2 was originally designed in the early 1980s.

Raytheon Space & Airborne Systems, El Segundo, CA, developed a significant portion of the new radar hardware under contract to Northrop Grumman. The units include a new advanced electronically scanned array antenna, a power supply and a modified receiver/exciter. Other key RMP subcontractors include Lockheed Martin Corp., Owego, NY, and BAE Systems Information and Electronic Systems Integration, Greenlawn, NY.

Northrop Grumman is the US Air Force's prime contractor for the B-2...

The B-2 is the only US aircraft that combines stealth, long range, large payload and precision weapons in a single platform. In concert with the Air Force's air superiority fleet, which provides airspace control, and the Air Force's tanker fleet, which enables global mobility, the B-2 helps ensure an effective US response to threats anywhere in the world. It can fly more than 6,000 nautical miles unrefueled and more than 10,000 nautical miles with just one aerial refueling, giving it the ability to reach any point on the globe within hours. The 20-aircraft fleet of B-2s is operated by the 509th Bomb Wing from its headquarters at Whiteman AFB, MO.

Richard Mumford, International Editor

Industry Leaders Establish MIFARE4Mobile Industry Group

Seven leading players in the Near Field Communication (NFC) ecosystem, Ericsson, Gemalto, NXP, Oberthur Technologies, STMicroelectronics, Venyon (a company in the Giesecke & Devrient Group) and ViVOtech, have joined forces to form the MIFARE4Mobile™ Industry Group.

MIFARE4Mobile is a technology, which has been developed by NXP and is used to manage MIFARE-based services in NFC mobile devices, from the over-the-air installation to the end-user interaction via the user interface of the mobile phone. By bringing together some of the key players in the NFC ecosystem, the group will act as a platform to provide future direction, discuss experiences and share best practices to ensure evolution, interoperable development and implementation of the MIFARE-4Mobile technology.

"…this new industry group provides further impetus to the development of NFC applications for mobile phones…"

The aim of the group is to enable its members to collaborate and work together to standardize and advance the uniform management of MIFARE™ applications on NFC-enabled secure elements, such as mobile phones and SIM cards. Over the next few months, the MIFARE4Mobile industry group will further develop the specifications supporting MIFARE DESFire™ technology and multiple Trusted Service Managers.

"The creation of this new industry group provides further impetus to the development of NFC applications for mobile phones especially given MIFARE's reach as a key contactless platform," said Jonathan Collins, Principal Analyst, ABI Research. "As SIM-based NFC phones come to market, greater collaboration by all stakeholders to remove development and interoperability barriers in existing contactless infrastructures will help drive NFC adoption."

Nav Bains, Senior Director Mobile Money, GSM Association, commented, "Increased collaboration by some of NFC's most influential stakeholders will support the creation and facilitate the integration of business for the mobile network industry related to NFC-based services."

ETSI's Standard for A-CDM Reaches for Single European Sky

ETSI's newly-published European Standard for Airport Collaborative Decision Making (A-CDM) has been declared a European 'Community Specification' as a consequence of being listed in the Official Journal of the European Union (OJEU). It is the first standard from a European Standards Organisation to be listed as a Community Specification and provides essential requirements in support of the Single European Sky Interoperability Regulation for Air Traffic Management.

This specification (EN 303 212), one of a series being developed in support of the European Union initiative to enhance the capacity and safety of European airspace, is a significant first step towards achieving the goals of the Single European Sky Air Traffic Management Research (SESAR) initiative: a three-fold increase in capacity with a safety performance improvement by a factor of 10, a 10 percent reduction in environmental impact and a 50 percent reduction in costs.

The objective of the regulation is to ensure interoperability of the European Air Traffic Management Network…

Under the terms of the European Commission's Interoperability Regulation 552/2004 (amended by Regulation 1070/2009) for the Single European Sky, systems, procedures and constituents that meet this Community Specification are presumed to be compliant with the essential requirements of the regulation and the relevant implementing rules. The publication of this European Standard, and its reference in the OJEU as a Community Specification, will therefore facilitate the deployment of the A-CDM concept in Europe's airports.

The Single European Sky legislation is based on a framework of four regulations, the Interoperability Regulation being one of them. The objective of the regulation is to ensure interoperability of the European Air Traffic Management Network (EATMN), consistent with air navigation services.

TRS Wins NATO Contract to Enhance Ballistic Missile Defence Capabilities

ThalesRaytheonSystems (TRS) has been awarded a contract by NATO's Active Layered Theatre Ballistic Missile Defence (ALTBMD) Program Office to provide the alliance commanders with real-time interim ballistic missile defence capabilities for deployed forces by the end of 2010.

The company will deliver the Air Command and Control System (ACCS) Theatre Missile Defence (TMD) component of NATO's ALTBMD Interim Capability Step 2 Real-Time (InCa 2 RT). This program will enhance the alliance's command and control capabilities by integrating the alliance nations' contributions in areas such as space-based Shared Early Warning, Early Warning Frigates and weapons systems.

Under the direction of ALTBMD Program Office, Tha-

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"ThalesRaytheonSystems is proud to deliver a theatre air and missile defence system to ensure the future security of NATO deployed forces"

ThalesRaytheonSystems will work in close cooperation with NATO's C3 Agency to field InCa 2. This deployment will be the first operational use of NATO's ACCS LOC1 software, currently being developed by ThalesRaytheonSystems as the prime contractor.

Jack Harrington, Chief Executive Officer, ThalesRaytheonSystems, stated, "ThalesRaytheonSystems is proud to deliver a theatre air and missile defence system to ensure the future security of NATO deployed forces. Our commitment is to use our experience in NATO and national studies, air C4I, exercises and programs to develop effective integrated air and missile defence solutions."

£8.4 M Investment in UK Plastic Electronics Technologies

A range of specialist plastic electronics businesses in the UK are to benefit from a total of £8.4 M investment in research and development into new technology that will lead to the creation of a range of new products. Thirteen projects, involving more than 30 industrial and academic partners, will benefit from the funding allocated as a result of two competitions run by the UK government-backed Technology Strategy Board.

£7.4 M has been offered to eight projects to help build the supply chain and to overcome the barriers to UK exploitation of plastic electronics technology, including over £800,000 from the Engineering and Physical Sciences Research Council (EPSRC). A further £1 M has been offered by the Technology Strategy Board to five projects to encourage UK businesses to use plastic electronics in their product development by producing demonstrators with potential for real commercial value.

"The funding… is important in supporting UK businesses to be world leaders in one of the key industries of the future"

When announcing the initiative, the UK Minister for Universities and Science, David Willetts, said, "The global market for Plastic Electronics is now worth almost $2 B (£1.337 B) and is forecasted to grow to as much as $120 B (£80.19 B) by 2020. The funding I've announced is important in supporting UK businesses to be world leaders in one of the key industries of the future. Commercially exploiting the outputs of the UK's world-leading science and research base has a vital role to play in helping our economy to grow."

Dan Massé, Associate Technical Editor

MarketWatch

EMITE Ing (Murcia, Spain) presented at both CTIA RCSG and 3GPP RAN#4 standardization committees the Sample Selection technique for the MIMO Analyzer. The novel technique allows standardized MIMO channel fading measurements using mode-stirred chambers for the first time. Successful emulation of standardized IEEE 802.11n models and measured throughputs were presented. The MIMO Analyzer E Series provides the unique measurement capabilities of Correlation, Diversity gain (ADG, EDG, IDG), MIMO capacity, loss effect due to the presence of the user or the efficiency (DGL, CLMIMO), number of resolvable multipath components (MPC), Angle of Arrival (AoA), Mean Effective Gain (MEG) and Effective MEG (EMEG), Total Radiated Power (TRP), Total Isotropic Sensitivity (TIS), Active Antenna Gain (AAG), LTE MIMO TRP and LTE MIMO TIS for an extended bandwidth covering the recently-auctioned 700 MHz spectrum range and a wide variety of Rayleigh, Rician, isotropic and non-isotropic environments, all united in one single and intuitive interface. The new facilities also include a novel deembedding-based autocalibration technique, avoiding the cumbersome use of reference antennas. For more information, visit www.emite-ing.com or e-mail sales@emite-ing.com.

GaN and SiGe MMICs to Progressively Invade GaAs MMIC Territory

According to a recently released industry and market report from Engalco—MMICs2—which analyzes the compound semiconductor MMICs market to 2015, GaAs MMICs will remain important, while GaN and SiGe MMICs will progressively invade these markets. Although the overall worldwide total markets are forecasted to reach \$6.26 B in 2015, this total continues to be dominated by the commodity markets of cell phones (over \$3 B) and both intelligent cruise control and mobile WiMAX (\$1.2 B each). After these end-users have been considered, the remaining market segments of defense, ISM, microwave radio, millimeter-wave radio, SATCOM and SATNAV, all come in with much lower market shares. Of these, microwave radio accounts for a market worth approximately \$280 M in 2015 and millimeter-wave radio exhibits exceptionally high (double-digit) growth to reach \$420 M in the same year. The latter market is driven by the exploding capacity requirements of multi-Gbit links. In the defense segment North America (principally the US) leads, but both Europe and Asia (especially) are increasingly important. This report indicates in quantitative depth of detail how both GaN- and SiGe-based MMICs will progressively invade many market segments. The utility of GaN MMICs for high-power/high-efficiency RF amplification is becoming well known and the application will also be extended to other functions in RF modules. SiGe-based MMICs are already being implemented in low-power signal processing roles—mainly in receivers and switches. In this report, average selling prices and shipments are provided—again with forecasts to 2015. A total of 64 MMIC manufacturing and "fabless" companies are identified and discussed. The industry structure is critiqued in detail. For further information, e-mail: enquiries@engalco-research.com.

...microwave radio accounts for a market worth approximately \$280 M in 2015...

Provigent and BridgeWave Partner to Provide 4G Mobile Backhaul Solution

BridgeWave Communications, a supplier of gigabit wireless solutions for 4G network backhaul, and Provigent, a provider of System-on-a-Chip (SoC) solutions for the broadband wireless transmission market, announced a strategic partnership enabling BridgeWave to extend its market leading millimeter-wave solutions to the edge of 4G networks.

Provigent will collaborate with BridgeWave to develop a chipset that provides increased spectral efficiencies supporting multi-gigabit rates in up to 1 GHz RF channel bandwidth. As part of this strategic cooperation, BridgeWave will pay non recurring engineering (NRE) to Provigent and Provigent will grant BridgeWave favorable terms. This partnership supports Provigent's mission to provide advanced chipsets to the broadband wireless market and BridgeWave's mission to offer a complete set of backhaul solutions including edge and aggregation, utilizing the 70/80 GHz spectrum. BridgeWave's experience as the leading millimeter-wave solution provider, combined with Provigent's cutting-edge technology, will enable BridgeWave to deliver a broader range of cost-effective, highly integrated systems with advanced functionality.

Provigent will collaborate with BridgeWave to develop a chipset that provides increased spectral efficiencies...

"Mobile operators require flexible products that address scalability and capacity needs with a low total cost of ownership," said Amir Makleff, CEO at BridgeWave. "The level of silicon integration offered by Provigent will enable BridgeWave to offer 70/80 GHz solutions at price points similar to lower frequency microwave products, without taking shortcuts that will adversely affect the usefulness of this spectrum in the future."

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"The 70/80 GHz FDD approach we are implementing is critical as it is mandated by existing regulatory agencies and best preserves spectrum for future dense 4G deployments," added Idan Bar-Sade, SVP of Engineering and Product Management at BridgeWave.

"Mobile backhaul capacity requirements continue to grow and carriers are planning their networks to meet future needs," said Dan Charash, CEO of Provigent. "Our System-on-a-Chip solutions enable our customers to provide cost-effective high capacity solutions for these needs, across all frequency bands. Adding 70/80 GHz technology in partnership with BridgeWave to our portfolio further strengthens Provigent's position as the industry's leading SoC provider."

More Than 80 Million USB Modems to Ship

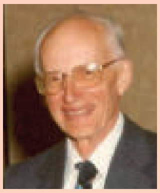
Wireless modem devices come in a variety of form factors including USB modems, PC cards, embedded modules and wireless routers. Among the external devices, USB modems have become the most popular products—so popular that ABI Research forecasts shipments of nearly 81 million this year.

Today, the majority of wireless broadband subscribers enjoying portable connectivity use USB ports. The alternative, the PC Card slot, has rapidly been displaced since USB's introduction in 2006. "The main reason for USB modem popularity is versatility at a low price," says Jeff Orr, Principal Analyst, mobile devices at ABI Research.

According to ABI Research's Cellular Modem Product Tracking Database, more than 50 percent of the modem models now available in the market utilize the ubiquitous USB interface. Adds Orr, "USB dongles connect the subscriber to a specific network rapidly and without installing drivers. As new networks using the latest 3G or 4G protocols emerge, the USB modem is ready to update the installed base of portable and mobile computers." The question remains whether embedded modem modules in new computers or the recent interest in personal hot-spot routers connecting multiple Wi-Fi devices to a single wireless WAN connection can overtake the popularity of USB dongles. Research associate Khin Sandi Lynn points out that, "In the long run, more devices are looking for a network to connect to. The wireless modem market can solve this in many ways—different form-factors, air interface protocols, and increased attention to style and cultural interests." He said mobile broadband modems available in the market today support a variety of air interface technologies. According to ABI Research's database, approximately 50 percent wireless modems in the market support GSM, GPRS, EDGE or HSDPA.

"The main reason for USB modem popularity is versatility at a low price"

INDUSTRY NEWS



Henry J. Riblet, inventor and microwave pioneer, passed away on June 25, 2010, less than a month short of his 97th birthday. He was one of the last surviving staff members of the MIT Radiation Laboratory of WWII. Born in Calgary, Canada, on July 21, 1913, he grew up in Erie, PA. He matriculated at Yale University in the early '30s where he concluded his studies with a PhD in mathematics in 1939. He credited microwave pioneer William W. Hansen with obtaining a staff position for him at the Rad Labs, which had recently opened in 1941. When the Rad Labs closed at the end of 1945, he was hired by Harold Hart, the manager of the microwave department of the Submarine Signal Co. in Boston. When Sub Signal was acquired by Raytheon in 1948, he and several other employees (including Theodore Saad and Nathanial Tucker) decided to form a new company, Microwave Development Labs (MDL). A large order from Hughes Aircraft and several of his patents helped sustain MDL through the 1950s. The most important of these were the sidewall and topwall waveguide hybrid. In the 1960s, he played a major role in the founding of Ferrotec and Americon. Later these companies became part of M/A-COM. In 1976 he was awarded the Microwave Career Prize by the MTT-S section of the IEEE. Dr. Riblet held a total of 67 patents. The first of these was applied for in 1938 while he was still a student. The last of these was issued in May 2010, just a month before his passing. He briefly held academic appointments at Adelphi College, Harvard University and Hofstra University. He is survived by his wife, Virginia, of 69 years, two sons and four grandchildren.

Aeroflex Inc. announced the execution of a definitive agreement to acquire **Advanced Control Components Inc.** (ACC) from **EMRISE Corp.** for $20 M in cash. The closing of the acquisition is subject to the approval of EMRISE's stockholders, as well as certain customary closing conditions. The purchase price is subject to a working capital adjustment if the adjusted net working capital at the date of closing is less than the target set forth in the purchase agreement.

Teledyne Technologies Inc. and **Intelek plc** jointly announced that they have reached agreement on the terms of a recommended cash offer to be made by Teledyne for the entire issued and to be issued ordinary share capital of Intelek (the "Offer"). Under the terms of the Offer, Intelek's ordinary shareholders will receive 32 pence in cash for each Intelek share valuing the entire existing issued ordinary share capital of Intelek at approximately £28 M.

Spectrum Control Inc., a designer and manufacturer of custom electronic products and systems, announced that **Spectrum Microwave Inc.**, its wholly-owned subsidiary, has acquired substantially all of the assets and assumed certain liabilities of **Sage Laboratories Inc.**, a wholly-owned subsidiary of Ceralta Technologies Inc. The total purchase price of the acquisition was approximately $6.5 M. Current annualized revenues of Sage Labs' products are approximately $12 M.

Platronics Seals announced the purchase of the ceramic packaging group formally called **Tech-Ceram Corp.** from **M/A-COM Technology Solutions** located in Lowell, MA. Platronics Seals is a 44 year-old electronic packaging company located in Spartanburg, SC. Under the purchase agreement Platronics has acquired all ceramic manufacturing equipment, processes and raw material inventory. The ceramic operation has been consolidated into a state-of-the-art 36,000 square feet Spartanburg facility leveraging the existing in-house plating capabilities. With the acquisition, Platronics Seals will broaden the product offering to include glass to metal and ceramic microwave, optical and RF packages.

QuinStar Technology Inc. has acquired **Passive Microwave Technology** (Pamtech). Pamtech is operating as a wholly owned subsidiary of QuinStar Technology Inc. George Grund, founder of Pamtech and a recognized leader in the field of cryogenic isolators and circulators, passed away in May of this year. The company has been relocated from Camarillo, CA to QuinStar. Pamtech employees have made the change in location, and are currently working in a 44,000 S.F. with complete fabrication and plating facilities. For more information, contact: sales@quinstar.com or call (310) 320-1111.

TowerJazz, a specialty foundry leader, announced it was selected by **Toppan Technical Design Center Co. Ltd.** (TDC) as its preferred specialty foundry supplier. TowerJazz has successfully engaged in multiple specialty design projects in Japan with TDC in the area of Silicon Germanium (SiGe) BiCMOS technologies used for high speed RF applications. This partnership enables TowerJazz to strengthen its penetration in the Japanese market, particularly TDC's customers targeting RF, high speed analog, power management, high voltage, CMOS image sensors and MEMS.

Agilent Technologies Inc. and **picoChip** announced a high volume manufacturing test solution for 3G femtocell products. The jointly developed solution is based on picoChip's picoXcell semiconductors and software, and Agilent's N7310A chipset software. The new integrated manufacturing test solution delivers rapid calibration and verification testing capabilities for original design manufacturers (ODM) and contract manufacturers (CM).

Polaris Wireless, a leader in high accuracy, software-based wireless location solutions, and **Globecomm Systems Inc.**, a provider of satellite and terrestrial communications infrastructure solutions and services, announced a partnership designed to enable US wireless operators to more quickly, easily and cost effectively meet Federal Communications Commission (FCC) E911 Phase II requirements. As part of its menu of offerings, Globecomm is introducing a managed E911

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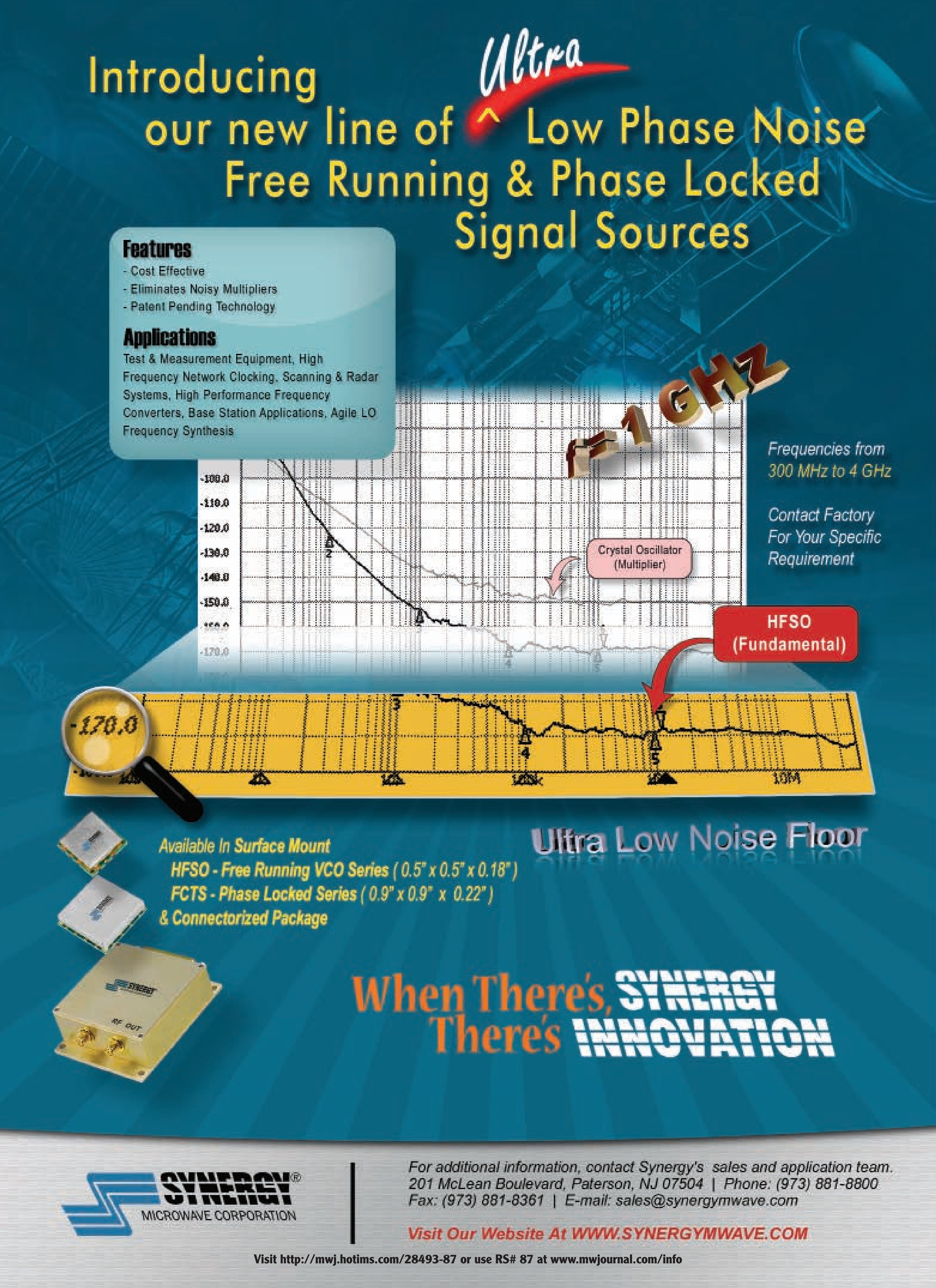

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Phase II service that leverages Polaris's proven E911 Phase II software solution for rapidly locating mobile-device users.

NXP Semiconductors announced the opening of a high performance radio frequency (RF) product creation center (PCC) in Billerica, MA (US). This new NXP facility, located near Boston, will focus on the design of RF and microwave integrated circuits (IC) used in demanding applications such as defense & aerospace, Industrial, Scientific and Medical (ISM) satellite receivers and broadband communications.

Empower RF Systems announced the opening of its second Regional Design Center located in Lake Forest, CA. The investment in the Orange County Regional Design Center is part of the company's strategic growth plans and focuses in three primary areas—attracting and retaining additional engineering resources residing in Southern California, providing sales and technical support to targeted communications customers, and supporting advanced technology development activities. Further, the Orange County Regional Design Center is coming online within a year of the opening of the company's first Regional Design Center located in Holbrook, NY.

Aviat Networks Inc., a wireless expert in advanced IP migration solutions, announced that it has opened a new 128,000-square-foot facility at 5200 Great America Parkway in Santa Clara, CA, and will now be the location of its corporate headquarters. The relocation follows the company's global re-branding effort as Aviat Networks Inc., formerly known as Harris Stratex Networks Inc. The name change took effect on January 28, 2010.

Tektronix Inc. and **Fluke Corp.** announced that they have donated $100,000 to DeVry University for a five-year scholarship program. In the program, $20,000 will be awarded each year in $1,000 scholarships to 20 students each in the name of Tektronix and Fluke.

RF Micro Devices Inc. (RFMD), a leader in the design and manufacture of high performance RF components and compound semiconductor technologies, announced the successful qualification of RFMD's second high power Gallium Nitride (GaN) process technology, expanding the company's industry-leading portfolio of compound semiconductor technologies.

Rogers Corp. recently received two award honors from the Chinese government. The first award, "Level A Credit Company for Labor Security," was given to Rogers for its labor compliance and positive management of its employees. The award is based on Rogers having met or exceeded labor compliance requirements during the last two years, including cooperation with the local Chinese labor union and the high audit scores Rogers received related to labor compliance audits. The second award, "Jiangsu Provincial May 1, 2010 Honorary Labor Medal," was given to Rogers' Vice President of Asia, Michael Sehnert, by the Jiangsu Labor Union Bureau for outstanding performance, achievement and contribution to society in Jiangsu Province.

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Skyworks Solutions Inc., an innovator of high reliability analog and mixed signal semiconductors enabling a broad range of end markets, announced that it has received the Technology Support Award from **Huawei**, a telecom solutions provider, in recognition of its excellence in base transceiver station (BTS) radio frequency (RF) customized devices.

CONTRACTS

Harris Corp., an international communications and information technology company, has been awarded a five-year, $140 M contract by **General Dynamics** to modernize the ground segment of the satellite communications network used by the National Aeronautics and Space Administration.

Comtech Telecommunications Corp. announced that its Orlando, FL-based subsidiary, **Comtech Systems Inc.**, received an order for $11 M from an international prime contractor for transportable troposcatter systems to be used by a middle eastern government. This is the first material troposcatter equipment contract with this foreign government.

Micronetics Inc. announced that its New Jersey based subsidiary, **Microwave Concepts** (Micro-Con), has received orders valued at over $4 M from a major defense OEM for highly integrated microwave subassemblies. These subassemblies are used as part of a high performance airborne jamming system. The anticipated period of performance on this program is approximately 24 months.

Giga-tronics Inc. announced that it received a $1.1 M order from the Naval Air Warfare Center in Lakehurst, NJ, for its Model 8003 Precision Scalar Analyzer. The Giga-tronics Model 8003 Precision Scalar Analyzer combines a 90 dB dynamic range with the accuracy and linearity of a power meter in a single instrument.

PERSONNEL

▲ *Harold Aikins*

Channel Microwave, a Smiths company, announced that **Harold Aikins** has joined the company as Vice President of Sales and Marketing. Aikins brings with him over 20 years of experience with component sales. Prior to joining Channel, Aikins worked as a manufacturing representative with Thorson Desert States Inc. and Regional Sales Manager with K&L Microwave. He is also a former Signal Corps officer with the US Army Reserve.

Microsemi Corp. has announced the appointment of **Russell Garcia** as Executive Vice President of Marketing and Sales. Garcia, who will be responsible for corporate marketing, worldwide sales and the development of product, market and technology roadmaps, comes to Microsemi with more than 25 years of semiconductor industry experience, most recently as Chief Executive Officer of WiSpry Inc. and u-Nav Microelectronics. He also has held senior marketing management positions with Texas Instruments and Silicon Systems.


▲ Kevin Strack

Anatech Electronics announced that **Kevin Strack** has been promoted to Director of National Sales, responsible for managing all sales activities, developing new business opportunities, and maintaining customer relationships throughout the US. He was previously Technical Sales Manager for the Southeastern US. Strack has more than three decades of experience in marketing and sales of RF and microwave products. He joined Anatech from Meggitt Safety Systems Inc., where he held a similar position. He can be reached at (407) 234-6359 or by e-mail at kevin.strack@anatechelectronics.com.


▲ Paul Leo

Micro Lambda LLC, a mid-Atlantic-based manufacturer's rep firm, has announced the addition of **Paul Leo** to the company's sales team. Leo recently served as the Director of Business Development for Microwave Business Units and Business Development Manager for Antenna Products with Cobham.

REP APPOINTMENTS

Maury Microwave Corp. and **AMCAD Engineering** have signed an exclusive development and distribution agreement with regards to AMCAD's advanced measurement suite, IVCAD and its PIV/PLP family of pulsed IV systems. Development of IVCAD, which is currently available for sale, will continue over the upcoming year as a complement to Maury's long-standing ATS device characterization software. IVCAD will support multiple load pull techniques including traditional load pull using external instrumentation, VNA-based load pull, active load pull and hybrid load pull.

MITEQ Inc. announced the appointment of **Micro Sales** as the company's exclusive sales representative in Ohio, Indiana, Michigan, Kentucky, West Virginia and western Pennsylvania. Micro Sales will represent MITEQ's Component division of products, which includes amplifiers, mixers, frequency multipliers, passive power components, switches, attenuators, limiters, phase shifters, IF signal processing components, oscillators, synthesizers, integrated multi-function assemblies and fiber optic products. Micro Sales can be contacted at sales@micro-sales.com.

Paciwave Inc., a supplier of microwave solid-state switches, attenuators, DLVAs and custom integrated microwave assemblies, announced the expansion of the company's network of regional sales representatives with the following new representative appointments: **Biggs and Associates** of Plano, TX (972) 679-5871 will be representing the company in Texas (except El Paso), Louisiana and Arkansas; **Coastal Marketing Inc.** of Ocean Beach, NY (631) 583-8604 will be representing the company in Long Island, Metro NYC and northern New Jersey; and **Microwave Component Sources** of Sorrento, FL will be representing the company in Florida, Alabama, Georgia and the Carolinas.

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THE MASTERS OF MIMO

CREATING A COMPLEX MULTIPATH ENVIRONMENT SIMULATION IN AN ANECHOIC CHAMBER

Techniques for measuring over-the-air (OTA) performance of wireless devices with single antennas do not work as well for multiple antennas because they assume that the radiation pattern of the device is fixed such that the measured result is a snapshot of the device performance at any given instant in time. However, on a device with multiple antennas, software algorithms can change the relationship between the antennas, essentially adapting the radiation pattern to suit the environment in which the device is used. Such adaptation alters the quantity being measured during the measurement process, thus invalidating the test.

OTA metrics such as total radiated power (TRP) and total isotropic sensitivity (TIS) are used to evaluate SISO performance of wireless devices, representing the static properties of the device under test (DUT), independent of the environment in which the device is used. On the other hand, the ability of MIMO devices to adapt to their environment implies that the radiated performance of the device is a function of both the DUT and the environment in which it is evaluated. Since it is impractical to evaluate device performance in the wide range of real-world environments, a laboratory technique for simulating those environments is required.

Conducted test methods can evaluate radio performance for a variety of standardized channel models, yet they make assumptions about the radiated performance of the DUT, leaving out the impact of variations in antenna pattern, spacing, etc., as well as platform interference and antenna loading. OTA testing is required to properly evaluate all these critical factors together.

However, typical radiated test environments such as anechoic chambers or reverberation chambers are not directly suited to this type of testing either. In the traditional single antenna OTA measurement system in an anechoic chamber, the goal of the test is to evaluate the DUT performance from each direction around the device without extraneous reflections. Thus, the chamber is lined with RF absorber to prevent these reflections and ensure that the only RF energy measured is that transferred line-of-sight (LOS) between the DUT and the measurement antenna.

For accurate measurement, the system is intentionally designed so that the entire test volume around the DUT (the quiet zone) will produce nearly the same measurement result no matter where the DUT antenna is located within the test volume. Increasing the number of measurement antennas for the purpose of an N × N MIMO link would still result in N LOS signals between each source antenna and the corresponding N receivers. The resulting channels are all highly correlated, since all antennas on the DUT essentially see the same signal; there is no way such a system could transfer multiple unique data channels across the wireless link. The environment simulated here is the worst case behavior for MIMO, which is a LOS only environment.

Conversely, the reverberation chamber is a system that is designed to take advantage of reflections to measure the power radiated from a device. The measurement antenna becomes the only sink of power in the closed cell, so conceptually the idea is that all energy radiated by the DUT reaches the measurement antenna and vice-versa. Any RF energy introduced in the chamber bounces around within the entire chamber, with some loss each time it encounters a surface. Eventually some portion of that energy reaches the target antenna and is received. The remainder continues reflecting within the environment until absorbed or until it reaches the antenna again. Various "stirring" techniques are used to randomize the field structure to ensure that there are no standing wave resonances within the test volume. The result is a statistical distribution that relates the received power to the transmit power through the net losses of the chamber itself.

The pattern information of the DUT antenna(s) has been averaged out since the direction of propagation between the DUT and measurement antenna has been intentionally randomized. The result is a completely uniform spatial channel that appears as though reflections are coming from all directions (because, of course, they are). While the loading of the chamber can be tweaked somewhat to alter the power delay profile (PDP) seen at the DUT, the actual delays involved are a function of the size of the chamber itself, since larger chambers will have longer delays. In either case, the delays induced by the chamber itself are more typical to equivalent room sized environments than those of an urban cellular network.

From a spatial correlation standpoint, the reverberation chamber produces a test volume with an extremely low correlation, meaning that if a MIMO device is going to work anywhere, it will work in a reverberation chamber; assuming of course that the created PDP corresponds to something the DUT is designed to handle. While the environment produced in a reverberation chamber can be used to test MIMO, the usefulness of the resulting data is unknown, as the environment being generated does not look much like typical real world environments either.

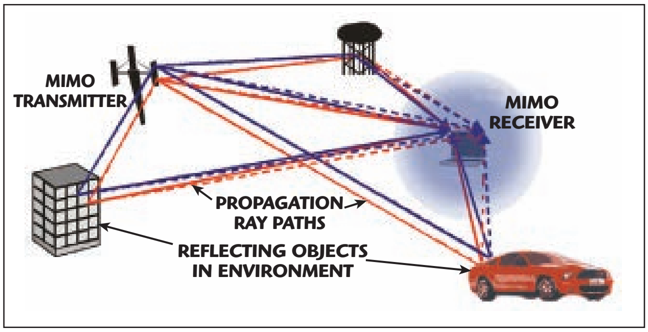
SPATIAL ENVIRONMENT SIMULATION

In order to properly evaluate performance of MIMO devices in an over-the-air configuration, what is needed is a configurable RF environment simulator that allows emulation of an entire spectrum of RF environments. As noted above, the anechoic chamber and reverberation chamber represent two ends of a broad spectrum of environmental conditions. Most of the real world environments in which devices will be used lie somewhere in between these two extremes. The obvious question becomes: What changes can be made to either of the systems to approximate other environments? Since in general it is easier to add RF

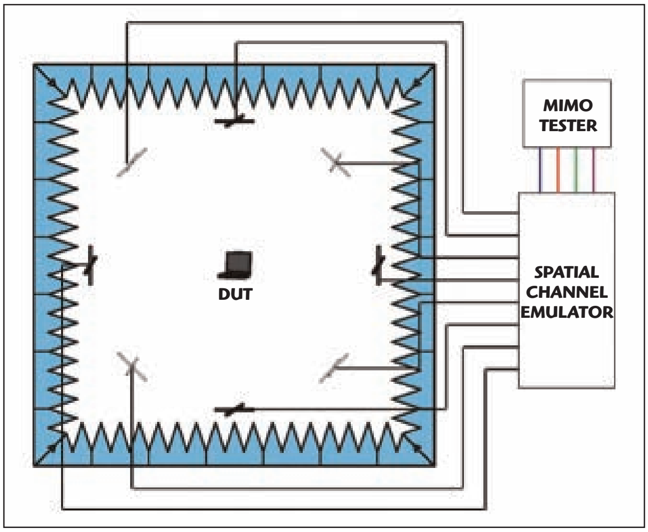
MICHAEL D. FOEGELLE
ETS-Lindgren, Cedar Park, TX

signals than to take them away, adding simulation of spatial multipath behavior to an anechoic environment is more feasible than removing multipath from an inherently multipath environment.

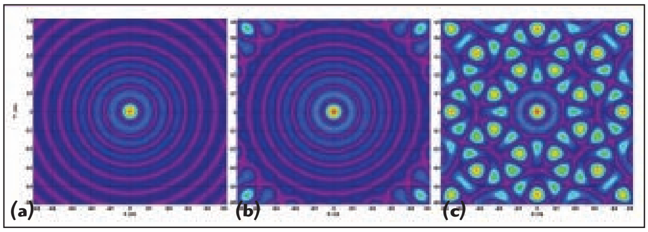
Figure 1 illustrates a typical real world environment encountered by a wireless device. Reflections from scatterers in the environment arrive at the device from various angles of arrival (AOA) and with varying PDPs and angular spreads. If one were to isolate a spherical surface around the device, the conditions within that sphere can be replicated by reproducing the conditions on the surface of the sphere. For the purpose of our environment simulator, we would take the contents of the sphere, including any near field effects such as the impact of head, hands, etc., and recreate those within the isolated environment of a fully anechoic chamber. Events at the boundary of the sphere can then be approximated through the use of an array of antennas, as shown in ***Figure 2***, where each antenna simulates a general AOA relative to the DUT.



▲ *Fig. 1 The OTA environment simulator isolates the area around the DUT and simulates everything outside that region.*



▲ *Fig. 2 An array of antennas in an anechoic chamber simulate reflections from different directions and a channel emulator simulates the propagation of communication signals.*



▲ *Fig. 3 Illustration of field structure produced by a perfect circular array (a), an array of 24 antennas on a 15° spacing (b), and an array of eight antennas on a 45° spacing (c).*

Each antenna is fed by the output of a spatial channel emulator that simulates the remainder of the environment outside the sphere. The quality of the boundary condition, and thus the resulting simulated environment, is a function of the number of antennas used to create the boundary. Physical constraints such as physical size, reflections and mutual coupling limit the number of elements that can be used in the array. The cost of the channel simulation required to drive each antenna may further limit the number of antennas used. Since elevation behavior is of secondary interest, typical implementations use a circular array arranged in a plane rather than a full spherical arrangement. ***Figure 3*** illustrates the impact of angular resolution of the array on the quality of the simulated field structure. This translates directly to the size of DUT that can be tested for a given array relationship.

SPATIAL CHANNEL EMULATION

Radios with multiple receivers are often tested in conducted mode using

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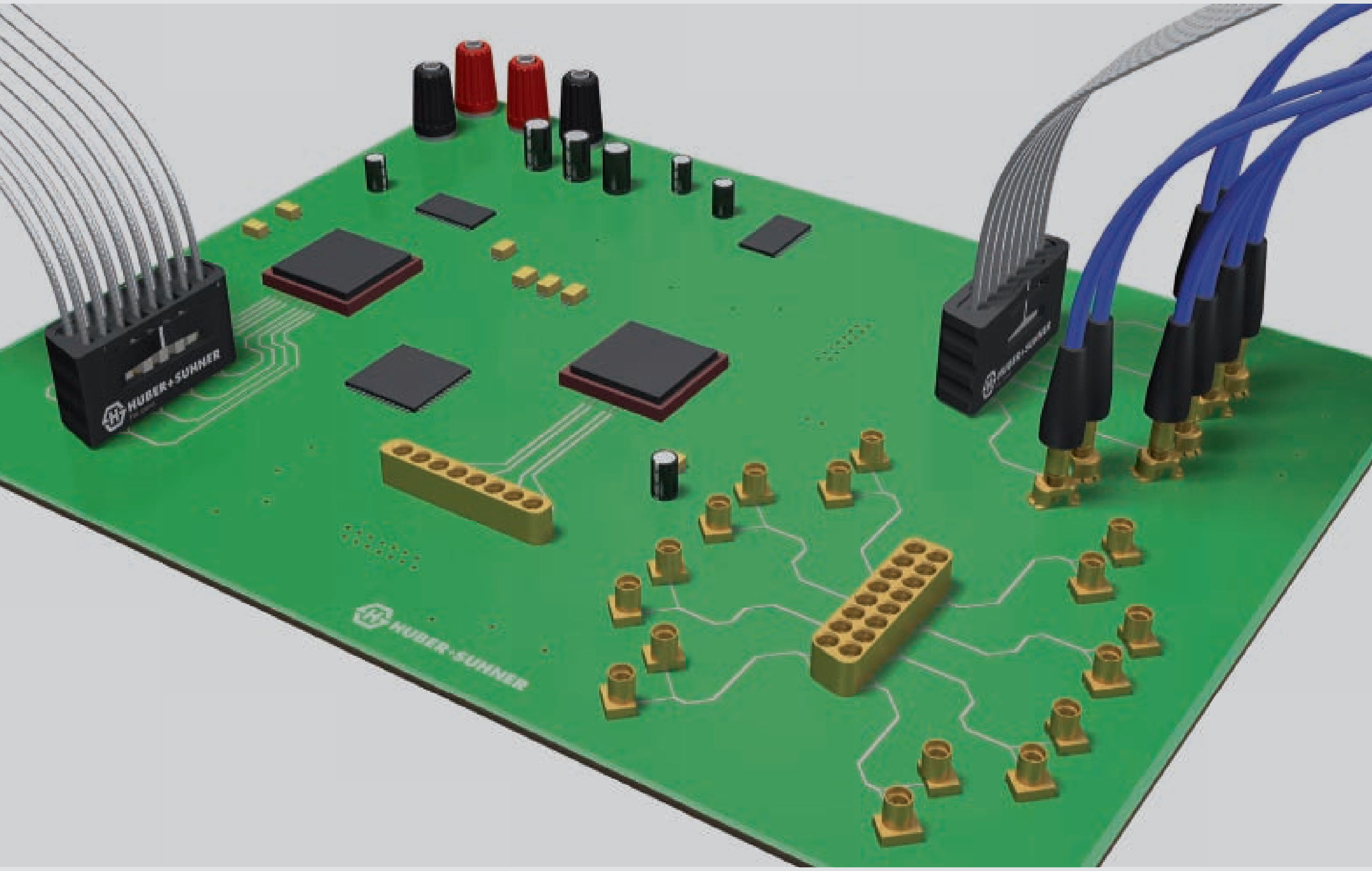

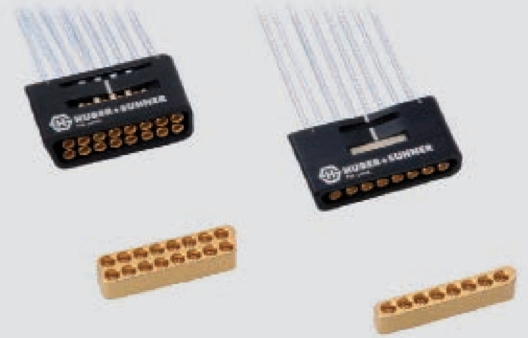

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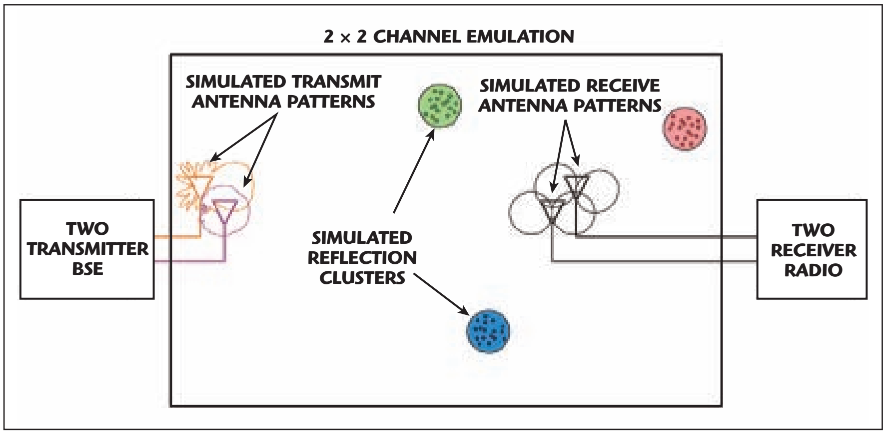
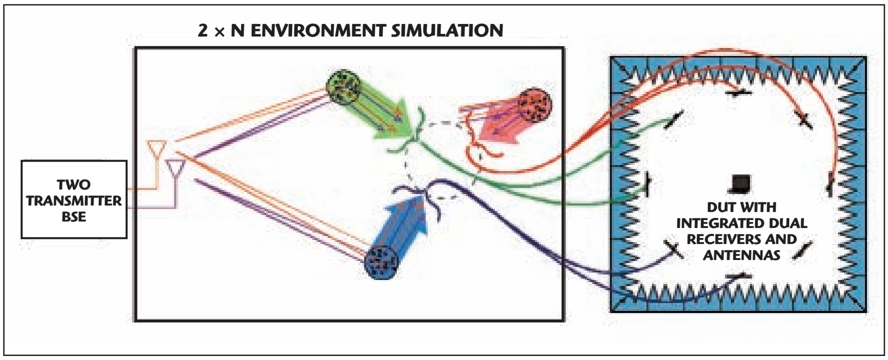


▲ *Fig. 4 A channel emulator typically simulates the entire propagation channel between a transmitter and receiver, including the behavior of the antennas on the DUT.*



▲ *Fig. 5 For the environment simulator, the DUT antenna models are removed from the channel emulator and use the directional information from the model to feed an antenna array within the chamber with appropriate signals.*

channel emulators to apply appropriate fading simulation. In the most advanced cases, the channel models used contain information on angles of departure (AOD) and AOA, as well as the antenna patterns assumed for both the transmit and receive sides of the channel. ***Figure 4*** illustrates such a case for a 2 × 2 MIMO channel emulation. These spatial channel models can easily be adapted for OTA environment simulation by modifying these models, as shown in ***Figure 5***.

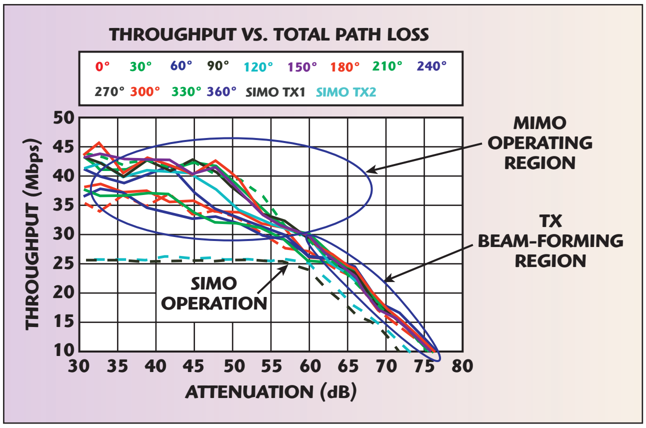
The receive antenna information is removed from the model and instead the AOA spread information is used to feed the matrix of OTA antennas with a statistical distribution representing the various clusters within the model. The DUT is then free to use its antennas to integrate the field structure thus generated just as it would with real-world signals. The impact of antenna placement and orientation, as well as the effects of the platform itself, can be readily evaluated. Near-field phantoms can be used to simulate the impedance changes and pattern variations introduced by objects usually found in the vicinity of the device in normal operation. While there are other ways of creating a faded channel between the DUT and any test equipment, this spatial channel emulator concept provides the most versatile way of creating a repeatable, reproducible OTA multipath environment simulation that can mirror a wide variety of real-world environments.

SOME EXPERIMENTAL RESULTS

Data throughput is the logical metric of interest of MIMO performance. ***Figure 6*** shows the results of a set of throughput vs. attenuation (throughput vs. power) tests on an 802.11n access point that supports 2 × 2 MIMO. The data was acquired for a range of device orientations within the simulated environment. This was also compared to the device operation in SIMO mode, where only one of the two downlink channels from the reference device outside the chamber was enabled.

The effect of MIMO behavior of the link is clearly visible over that of simple spatial diversity when in SIMO operation. For high signal to noise ra-

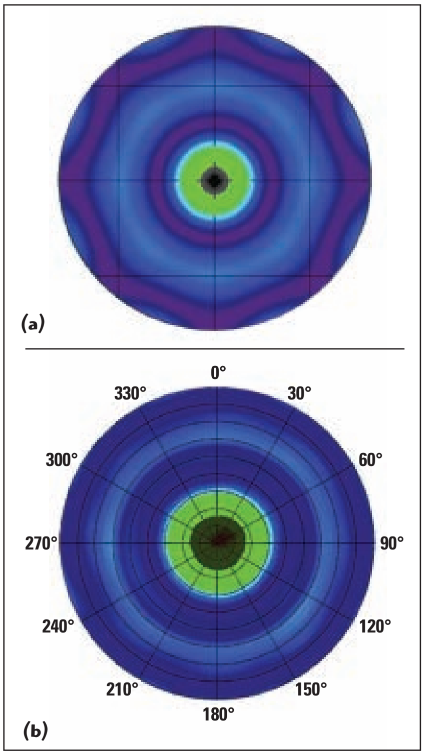
tio (SNR) regions, the throughput is considerably higher than that possible for a single channel. The variation in throughput as a function of device orientation can also be seen. Note that this is not just radiation pattern variation, as the simulated environment is transmitting signals to the DUT from multiple directions simultaneously. This variation is a more complicated relationship that includes the correlation of the antennas due to their spacing and orientation, in addition to their patterns.



▲ *Fig. 6 Tests of an 802.11n device in the multipath environment simulator show the difference between MIMO operation (upper curves) and simple RX diversity (lower curves).*

In addition to the obvious MIMO throughput performance, there are also notable differences in the performance at low SNR when both transmit sources are active. While the general shape of the "waterfall" curve remains constant, the increase in gain over the SIMO case would indicate the presence of transmit beam forming in this particular implementation. Otherwise, the low SNR portions of the curves would be expected to follow the SIMO curves.

The curves contain a considerable amount of useful information about the wireless device's overall performance. However, this amount of detail comes at the cost of test time. A variety of metrics may be extracted from the data. Wireless carriers or network designers will want to know the link budget necessary to maintain a certain level of throughput to the end user. If the network density was well defined, such that the expected minimum field levels could be applied to a target channel model, then the simplest approach would be to perform a simple pass/fail test on the device to determine if it could meet a target average throughput under those conditions. However, that approach provides little information about the relative performance of devices. It is more likely that carriers will want to know the average power level that produces a target minimum throughput—essentially a throughput-based sensitivity test or a MIMO TIS.



▲ *Fig. 7 Comparison of the theoretical field structure (a) and that generated in an actual environment simulator (b) for an eight antenna circular array.*

SYSTEM VALIDATION

To ensure that the system produces the desired field structures within the test volume, and thus to have confidence that other target environments can be simulated with appropriate channel models, a number of system validation tests have been performed. These tests are intended to compare actual measured results with theoretically predicted behaviors based on the chosen channel model. Such tests include evaluating the quality of the test volume to evaluate chamber induced

ripple, measuring the spatial correlation across the test volume to verify the expected relationship, performing time domain analysis to evaluate the generated PDP, measuring the Doppler spread induced by the faded channel, evaluating the angular distribution of the generated channel(s), and mapping the field distribution within the test volume.

Figure 7 illustrates an example of the last case for an eight antenna system with 45° spacing, where a precision sleeve dipole was rotated through the test volume on even angular steps, with 1 cm steps in radius between angular cuts. Since the linear spacing between points increases as the radius increases, the resolution is lower near the edge of the measured data, but the breakdown of the field pattern due to the coarse boundary condition is clearly visible.

CONCLUSION

In evaluating MIMO performance, it is not sufficient to just create a test that can measure MIMO; the system must be capable of measuring MIMO in a way such that the results predict the expected performance experienced by the user in everyday life. This requires a reconfigurable environment simulator capable of generating a wide range of user scenarios, rather than static test systems that test edge cases that may never be seen in the real world. ■

For more information on this topic, view the free, on Demand Webinar, "Understanding MIMO OTA Testing," presented by ETS-Lindgren and EB on the *Microwave Journal* website at www.mwjournal.com/MIMO_OTA_Webinar.

ACKNOWLEDGMENTS

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Michael D. Foegelle *received his PhD degree in physics from the University of Texas at Austin, where he performed theoretical and experimental research in both condensed matter physics and electromagnetic compatibility (EMC). In 1994 he began working for EMCO in Austin, TX (now ETS-Lindgren, Cedar Park, TX), where he is currently the Director of Technology Development. He has been involved in numerous national and international standards committees on EMC and wireless.*

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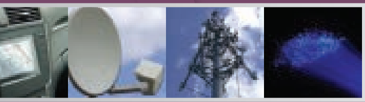

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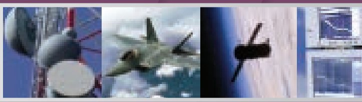

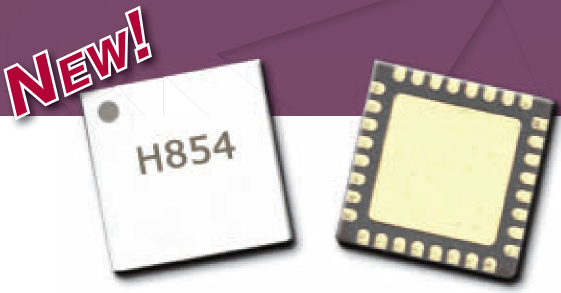

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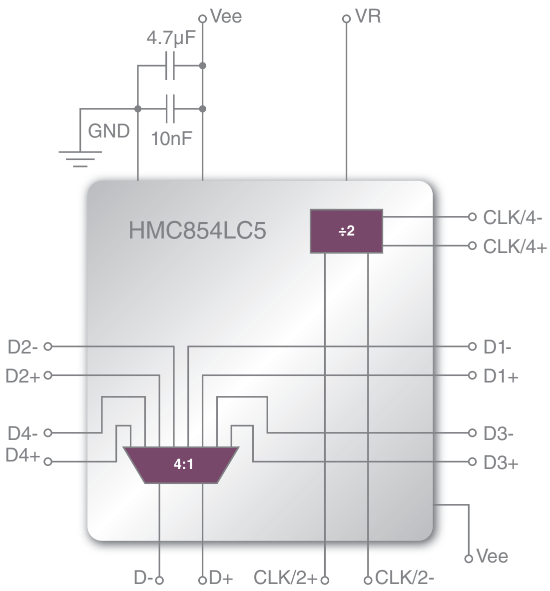

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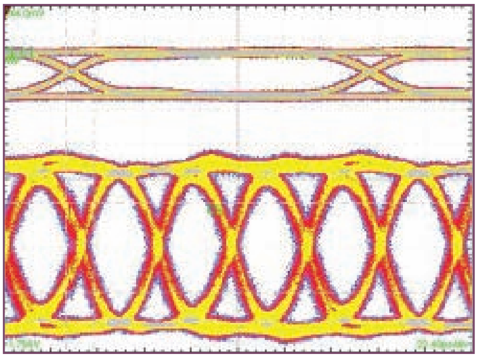

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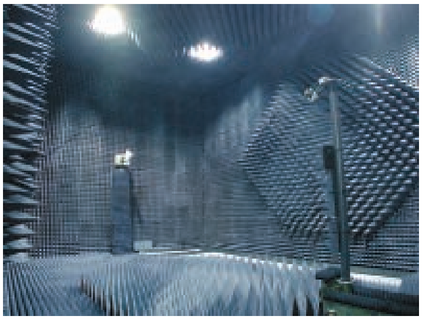
Embracing Complexity: MIMO Over-the-Air Testing with the Reverberation Chamber

This article describes a repeatable reference environment for over-the-air (OTA) testing of multiple input multiple output (MIMO) devices and why the reverberation chamber is uniquely suited to provide insight into MIMO device performance. The importance of reference environments and the characteristics of the reverberation chamber in the context of 4G wireless systems are reviewed. Statistically based measurements are described and compared with the line-of-sight solutions implemented in an anechoic chamber environment.

MIMO systems are specifically designed to create efficiency gains in the spatial domain. Diversity gain is fundamentally affected by the configuration and design of the multiple antennas inside these devices. Ideally, the antennas should be maximally efficient and fully independent of each other, but today's wireless trends of reduced size and higher complexity make this increasingly difficult. In short, the entire physical structure of the final phone design, combined with the hands and body of the user, will strongly affect MIMO performance. For this reason, MIMO makes testing the entire device including antennas and chassis, etc., more important than ever. Unlike breakthroughs in wireless modulation and system design, which could largely be diagnosed with conductive tests, spatial diversity gain is more difficult to predict without physically measuring the OTA performance of the complete device.

IMPORTANCE OF WIRELESS REFERENCE ENVIRONMENTS

One of the greatest challenges of OTA testing is getting repeatable measurements independent of location. Antenna test engineers have traditionally used large outdoor ranges where distance alone reduces the power of potential interfering signals or spurious reflections. The anechoic chamber (see ***Figure 1***) does the same thing in an even more controllable way. By eliminating extraneous signals and absorbing transmitted signals, the anechoic chamber creates a reference environment with a controlled "quiet zone" that zeros out all the signal channel variables. This is an excellent solution to the repeatability problem for direct transmit-receive systems. This quiet, unreflecting, line-of-sight measurement system is naturally associated with the spatial pattern data that is the traditional base for spatial antenna information.



▲ *Fig. 1 Typical anechoic chamber.*

▲ *Fig. 2 Typical reverberation chamber.*

By definition, the anechoic chamber carefully eliminates multipath reflections, but in order to test for MIMO, the effects of multipath must somehow be added back to the measurement system. A new kind of reference environment must be implemented to test these new devices. There are various ways to do this with and without anechoic chambers.

The reverberation chamber, shown in ***Figure 2***, takes the opposite approach to an anechoic chamber in creating an OTA test environment.[1] While both can provide high isolation from outside signals, the reverberation chamber is a highly reflective cavity. These reflections fill the chamber with standing waves, which are mechanically stirred to expose the device under test (DUT) to a full distribution of this highly variable propagation environment. At any given moment, the DUT could see a large variation in signal, but across many samples, the statistical response of the DUT to this controlled reflective environment can be accurately characterized.

Instead of trying to avoid the noisy complexity of multipath reflections, the reverberation chamber takes the opposite approach and embraces multipath completely. This highly reflective chamber, combined with a thorough mode stirring and sampling process, essentially creates a general multipath environment. With proper calibration of the chamber, a highly repeatable reference environment can be created that encompasses exactly the kinds of conditions that are challenging wireless devices today.

MIMO OTA MEASUREMENTS

The complexity of testing in a rapidly changing channel is absorbed into the statistics of the measurement process, allowing designers to focus on the performance of the device and its network. ***Figure 3*** shows the basic measurement setup for both passive and active MIMO tests in the reverberation chamber. The OTA MIMO link is established with the DUT via two or more fixed antennas in the reverberation chamber. The fixed antennas are connected to either a vector network analyzer (VNA) or a base station simulator, depending upon whether the DUT is a passive multi-element antenna or an active MIMO handset. The system software coordinates the data collection with the integrated mode stirring to provide a rich multipath dataset.[2]

This reverberation chamber setup is not used for MIMO measurements alone. The basic multipath reference environment is also ideal for rapidly characterizing single antennas and

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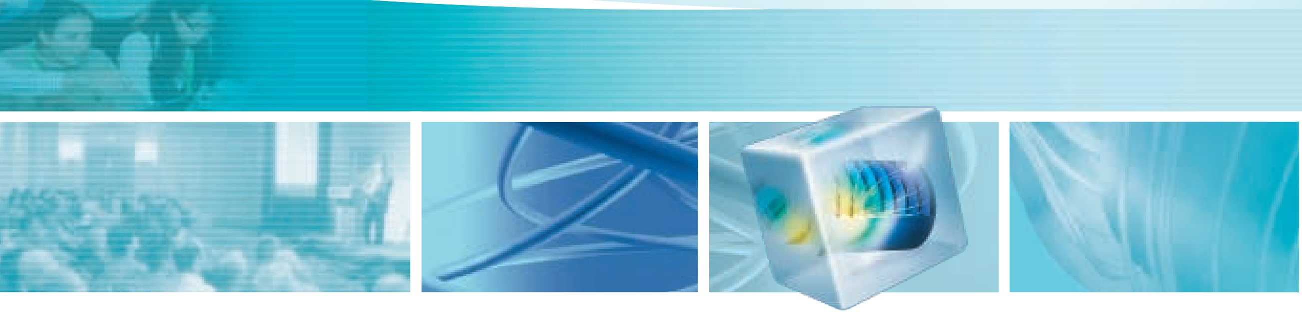
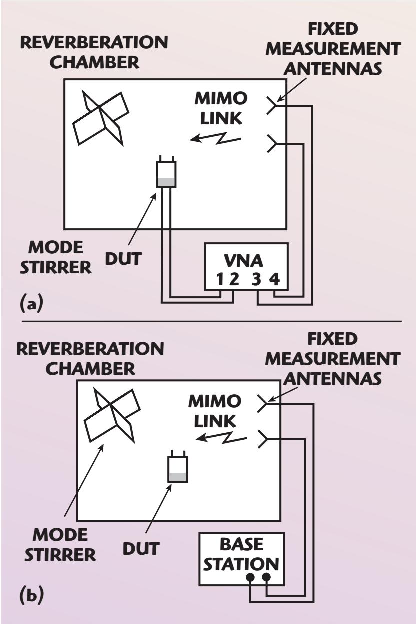
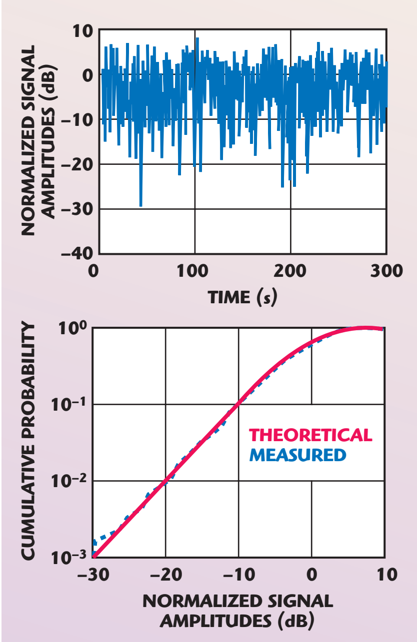




▲ *Fig. 3 Set up for measurement of passive multi-element antennas (a) and of multi-antenna user terminal (b) in reverberation chamber.*



▲ *Fig. 4 Theoretical Rayleigh fading response (red) and measured in reverberation chamber (blue).*

SISO systems in both active and passive tests. These tests are also important for diagnosing and optimizing complex MIMO network interactions, including measurements such as antenna efficiency and correlation, impedance mismatch, element isolation, diversity gain, throughput/capacity, total isotropic sensitivity (TIS), total radiated power (TRP) and average fading sensitivity (AFS).

Many of these are the same measurements that have traditionally been made in an anechoic chamber. Despite the process difference in acquiring this data, the results are repeatable across both chamber methods as confirmed in multiple laboratories.[3-5] The basic reverberation chamber principle is that once the complete device or single antenna is measured against the rich modal multipath, the resulting power transmission parameters can be summarized in a variety of traditional ways. In fact, the only common wireless antenna measurement that is missing from this list is the gain pattern. This lack of pattern information makes the reverberation test method less suited for point-to-point antennas, where directionality is a functional requirement, but entirely relevant to today's small wireless devices. For these devices, there is no inherent directional orientation and the constantly varying uses of the device make the measurement of patterns irrelevant compared to overall transmission efficiency in a challenging channel environment.

CHARACTERISTICS OF THE REVERBERATION CHAMBER ENVIRONMENT

How realistic is this multipath reference environment? Obviously channel models of the real world are infinitely unique and variable and the industry has gone to great lengths to enumerate channel variables and build descriptive models. The opportunities for channel modeling are endless; from a static point-to-point unimpeded channel to a highly reflecting, rapidly changing, multi-source source environment. What does the reverberation chamber emulate and how much can it be varied and controlled?

The reflective cavity of the reverberation chamber, with its multiple stirred modes, creates a near-ideal isotropic Rayleigh fading distribution. It maximizes the multipath and measures the signal fades throughout the mode stirring. As seen in ***Figure 4***, the chamber replicates a statistical sampling of as many fades and modes as possible. The Rayleigh distribution is the generalized distribution of a complex random variable, so it reflects the central limit theorem of combined random variations in phase and am-

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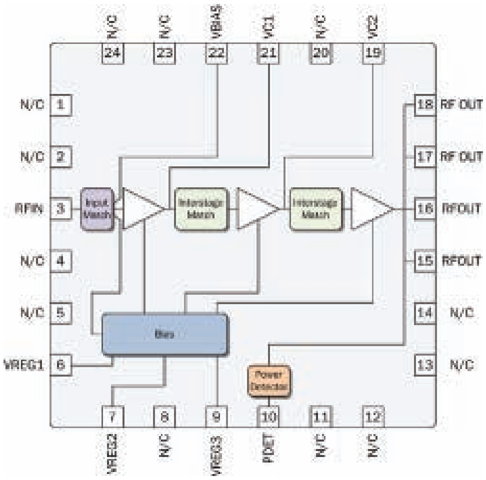
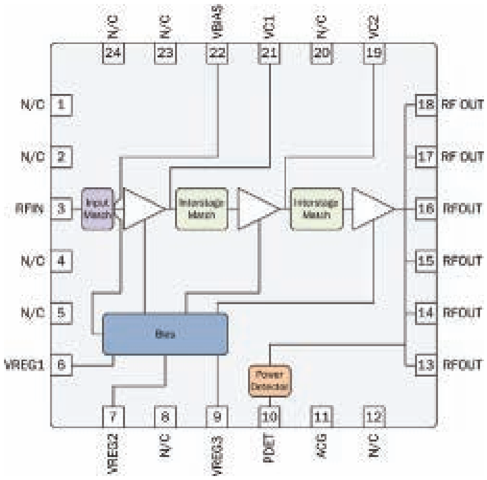


RF5632 block diagram



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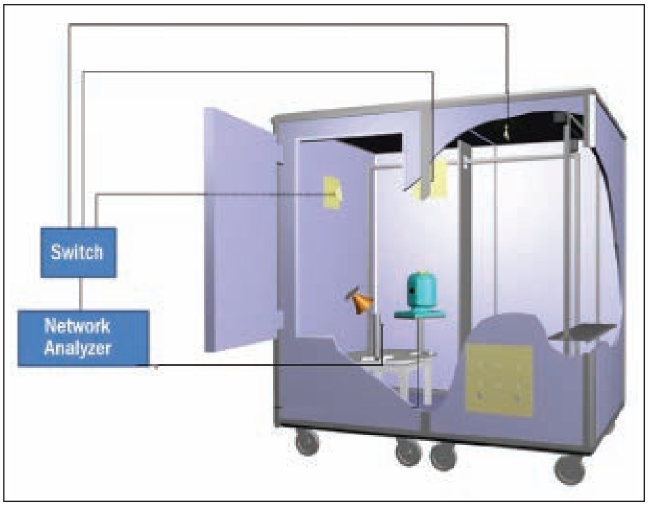
plitude. In other words, if all channel models of the world were to be combined, the statistical result would be this isotropic Rayleigh distribution. The reverberation chamber then, tends toward creating the general case channel model.[6]



▲ *Fig. 5 Calibration setup block diagram.*

The isotropic nature emphasizes that the environment in the reverberation chamber is a full 3D multipath environment. Unlike anechoic systems, there are no discrete measurement planes or angles that segment the physical reference environment. There has been some research into selectively modifying the reflectivity of reverberation chambers to change the isotropic profile into a more directional one. This would shift the fading statistics from a general Rayleigh environment to a Ricean fading distribution with stronger line-of-sight components. However, this increases uncertainty for some tests and also narrows the range of environment scenarios covered by the test.[6] Ultimately, the full 3D environment is a critical requirement in the world of portable devices that are expected to operate with unknown orientation.

DEFINING A CALIBRATED REFERENCE ENVIRONMENT

Calibration of the chamber is performed by measuring all S-parameters through the chamber during a complete stirring sequence, thereby deriving the transfer function of the chamber. Then connector and cable insertion losses to the chamber are added to the calibration for a full characterization.

Since the transfer function in this resonant cavity will be sensitive to frequency, to make the calibration straightforward in practice, a broadband measurement antenna and swept VNA is used. With optimized system software, this setup makes chamber calibration almost as fast as a simple conducted fixture calibration. ***Figure 5*** shows the calibration setup block diagram.

Due to the large sample sets over the spatial signal diversity in the chamber, a calibrated chamber can obtain highly repeatable measurements for an OTA system. Due to the large number of variables and uncertainties in traditional OTA testing, it is much more difficult to obtain the same kinds of measurement uncertainties without significant post-processing of large quantities of acquired scanner data. In contrast, the reverberation chamber test system can quickly gather the significant data sets needed for repeatable measurements.

Although the ideal reverberation chamber only generates the theoretical isotropic Rayleigh fading environment, in practice, these chambers can exhibit non-idealities such as leakage, loading, insufficient modality and under-stirring. The effects of these non-idealities can be either calibrated out of the desired measurement or, to a limited extent, manipulated to create a desired modification to the reference environment:

Leakage: Adds to the measurement uncertainty by limiting the potential dynamic range of the mode peaks and nulls. It can also allow signals into the chamber that may interfere with the measurement.

Loading: Absorbs energy that would normally resonate within the chamber. Loading, as recent research is uncovering, also influences the power delay profiles within the chamber.[10] Loading effects are an important consideration in the chamber calibration process.

Size: The number of modes in the chamber is a function of the chamber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size and test frequencies. Lower test frequencies require a larger chamber to generate a sufficient number of standing waves to provide a repeatable measurement distribution. A typical measurement chamber for most wireless frequencies is less than 2 m in height and length and 1.5 m wide.

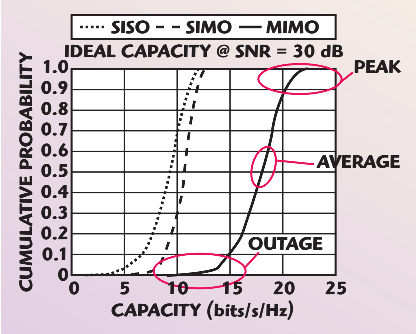
By adding a channel emulator to the input signal path, even more variables to the channel environment in a reverberation chamber can be added, simulating different distributions of spatial multipath for testing the robustness of diversity hardware and algorithms.[8,9] New research involving linked reverberation chambers also shows some interesting testing opportunities.[10] The amount of flexibility is still limited by the hard realities of the reflective cavity walls and the statistical, not deterministic, measurement process. In the end, the chamber will primarily emulate the isotropic Rayleigh fading environment.

It should be emphasized how this isotropic Rayleigh fading environment is considered increasingly useful for testing today's wireless devices. Measurements of digital wireless signal profiles in urban environments show that channel multipath characteristics are very similar to the Rayleigh fading environment and the exponential power delay profile seen in the reverberation chamber.[11,12] This is different from the Ricean distributions that have been traditionally considered in wireless systems with strong line-of-sight components. For highly portable devices, used in any orientation and where direct line-of-sight paths to a base station is the exception (rather than the rule), the typical environment of the reverberation chamber becomes an increasingly realistic reference environment.

STATISTICALLY BASED MEASUREMENTS

The primary conceptual shift in measuring in a reverberation chamber versus traditional anechoic methods is in the statistical extraction of measurement results, instead of the deterministic extraction of results based on angle-of-arrival (AoA). The reason this statistical method is being used so much more today is due to the complex and varied use models of today's wireless devices.

The statistical method builds in a



▲ *Fig. 6 Distribution of throughput capacity for ideal SISO, SIMO and MIMO systems.*

wide distribution of link conditions into common MIMO metrics such as throughput—and does so very rapidly. Since a distribution of multipath conditions in a 3D environment can be characterized in less than a minute,[4] large sets of information about device response can be quickly obtained under varying signal types, configurations and power levels.

MIMO devices, in particular, can leverage the distribution of signal modes to quickly measure and plot the throughput capacity of the device link. Naturally, this throughput capacity will vary, often dramatically, with the changing channel conditions.[13] A common way to visualize this is by plotting the cumulative probability of throughput capacity. ***Figure 6*** clearly shows the potential of a MIMO system that strongly shifts the capacity to higher throughput rates for the same uncertainty levels compared to SISO and SIMO. Testing in a reverberation chamber quickly generates such a capacity plot showing device performance over a range of peak, average and outage capacity channel conditions. This kind of statistical description of a throughput measurement provides wide insight into device performance over the range of conditions today's devices will regularly experience.[14]

CONCLUSION

Despite the usefulness of these reference environments, both the anechoic and the reverberation chamber fail to be sufficiently "realistic" for complete and detailed recreation of specific wireless channels. With the success of test equipment that can generate accurate channel simulations in a conducted test environment (even replaying drive test data), there is an expectation for an over-the-air test chamber that can accurately and

dynamically replicate a full 3D RF signal channel. Currently, such a test system would be prohibitively complex and costly. Even if this was not the case, the question would remain: Which of all real-world environment simulations should be used across labs to compare test results? This reemphasizes the need for simplified reference environments. Engineers can reference both extremes of signal environments: A rich multipath reference in the reverberation chamber and a directional quiet-zone reference in the anechoic chamber.

The reverberation chamber creates a fixed multipath reference environment that is analogous, but complimentary, to the anechoic chamber's fixed line-of-sight reference environment. By making multipath an inherent physical property of the test chamber and providing a calibrated response to that property, a new approach to testing wireless devices can be developed. This approach offers particular insight into the challenges of MIMO and small, complex, radiating systems. ■

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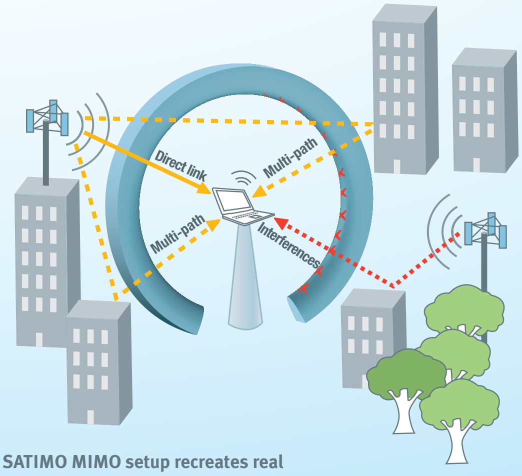


THE MASTERS OF MIMO

DYNAMIC CORRELATION IN VIRTUAL DRIVE TESTING

One of the least-understood aspects of the real-world RF environment is the effect of real-time motion on radio receivers. This becomes especially interesting in modern radio technologies, which are quickly converging on Multiple-In Multiple-Out (MIMO) antenna techniques as a means of increasing data rates without sacrificing temporal or spectral resources.

While much has been written regarding MIMO performance in static conditions, this article addresses time-varying channel conditions, such as those caused by movement of a mobile device, on MIMO performance.

Toward that end, some discrete topics are discussed: the relationship between channel correlation and the capacity of a system; the effect of motion on correlation; and the sensitivity of correlation to orientation and design.

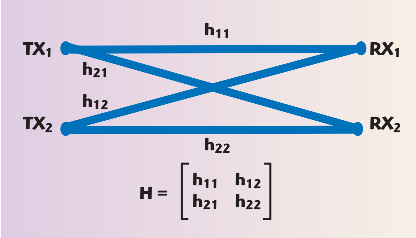
Finally, measured data shows some unanticipated effects on throughput as the result of varying correlation caused by motion, emphasizing the need to test mobile device designs under dynamically varying correlation conditions.

CORRELATION IN MIMO SYSTEMS

Consider two transmit antennas sending distinct data signals to two receive antennas at the same time and in the same frequency band. These signals undergo multiple reflections that traverse diverse paths between the transmitter and the receiver. As a result, multiple copies of the transmitted signal combine to produce multipath fading at each antenna. The multipath components from various angles of arrival combine to form a composite signal.

The composite signals seen by the two receive antennas are different as a result of their phase relationships due to the physical environment surrounding the device. The quantitative measure of this similarity in received signals is called spatial correlation.

The focus of this article will be 2 × 2 MIMO systems, since this configuration will be commonly deployed in initial LTE systems.



▲ *Fig. 1 MIMO path gains represented as an H matrix.*

The MIMO channel is represented by H, a matrix of complex path gains (see ***Figure 1***).

The correlation observed in a MIMO channel depends on a variety of factors such as device geometry (orientation, antenna pattern, antenna spacing) and scattering environment. In the real world, many of these factors constantly vary due to motion, resulting in varying correlations as well.

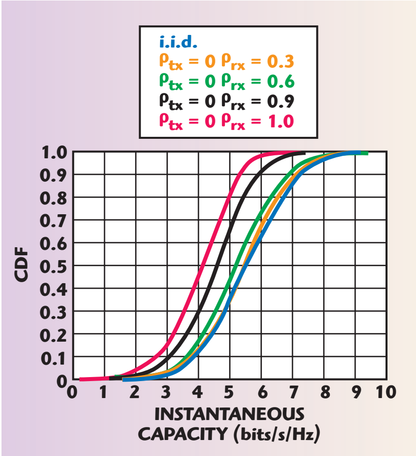
IMPACT OF CORRELATION ON MIMO PERFORMANCE

MIMO systems take advantage of the spatial domain to realize increased spectral efficiency. In order to understand MIMO performance, it is important to understand how MIMO systems realize throughput gains by exploiting RF channel conditions.

One important metric in understanding MIMO system performance is the rank (R) of the MIMO channel. For a MIMO system with M transmit and N receive antennas, the rank is R <= min (M, N). As an example, for a 2 × 2 MIMO system rank can be either 1 or 2. In a full rank channel realized in rich scattering (low correlation) environments, R = 2. Other environments (high correlation) will result in R = 1.

MIMO systems realize capacity gains by decomposing the spatial channel into independent orthogonal streams. The number of useful streams with sufficient signal-to-noise is always less than or equal to the rank, R. Independent data is then multiplexed onto these orthogonal streams to achieve data rates that are up to R times that of comparable single-stream systems.[3]

Under full rank conditions, a 2 × 2 MIMO system can essentially be decomposed into two streams, thereby offering twice the throughput of a SISO system. When R = 1, the MIMO system offers much lower capacity gain. The best MIMO performance will be realized when R = 2.



▲ *Fig. 2 Capacity curves showing the effect of correlation on capacity.*

The theoretical bound on the capacity of a MIMO system with full channel knowledge at transmitter and receiver is given by

$$C = \log_2 \left[\det \left(I + \frac{\Phi}{m} HH^H \right) \right] \text{bps/Hz}$$

where Φ is the signal-to-noise ratio seen at the receiver, m is the number of transmit antennas, I is the 2 × 2 identity matrix and H is the MIMO channel matrix.[1]

Based on this information, ***Figure 2*** illustrates the dependence of the theoretical maximum capacity on correlation between receive antennas for a constant signal-to-noise ratio (SNR) = 10 dB. Here, ρ_{tx} refers to the correlation between transmit antennas, set to 0 in these plots. ρ_{rx} refers to the correlation between receive antennas and is varied from one plot to another. Hence, any change in capacity from curve to curve is as a result of the variation of ρ_{rx}.

The red curve shows the cumulative

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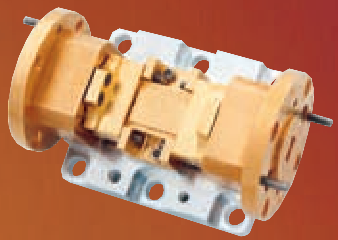
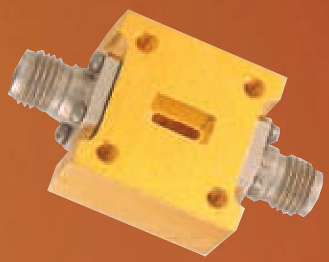


AMPLIFIERS

Model Number	Frequency (GHz)	Gain (dB, Min.)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	In/Out VSWR (Max.)	Output Power at 1dB Comp. (dBm, Typ.)
JSW4-18002600-20-5A	18-26	34	1.5	2.0	2.0:1/2.0:1	5
JSW4-26004000-28-5A	26-40	25	2.5	2.8	2.2:1/2.0:1	5
JSW4-18004000-35-5A	18-40	21	2.5	3.5	2.5:1/2.5:1	5
JSW4-33005000-45-5A	33-50	21	2.5	4.5	2.5:1/2.5:1	5
JSW5-40006000-55-0A	40-60	18	2.5	5.5	2.75:1/2.75:1	0

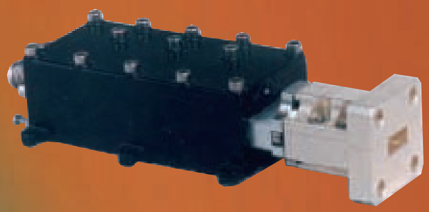
Higher output power options available.



MIXER/CONVERTER PRODUCTS

Model Number	Frequency (GHz)			Conversion Gain/Loss (dB, Typ.)	Noise Figure (dB, Typ.)	Image Rejection (dB, Typ.)	LO-RF Isolation (dB, Typ.)
	RF	LO	IF				
LNB-1826-30	18-26	Internal	2-10	42	2.5	25	45
LNB-2640-40	26-40	Internal	2-16	42	3.5	25	45
IR1826N17*	18-26	18-26	DC-0.5	11	9.5	25	25
IR2640N17*	26-40	26-40	DC-0.5	11	9.5	25	25
SBW3337LG2	33-37	33-37	DC-4	-7.5	8	N/A	25
TB0440LW1	4-40	4-42	.5-20	-10	10.5	N/A	20
DB0440LW1	4-40	4-40	DC-2	-9	9.5	N/A	25
SBE0440LW1	4-40	2-20	DC-1.5	-10	10.5	N/A	20

* For IF frequency options, please contact MITEQ.



MULTIPLIERS

Model Number	Frequency (GHz)		Input Level (dBm, Min.)	Output Power (dBm, Min.)	Fundamental Feed Through Level (dBc, Min.)	DC current @+15VDC (mA, Nom.)
	Input	Output				
MAX2M260400	13-20	26-40	10	10	18	160
MAX2M200380	10-19	20-38	10	10	18	200
MAX2M300500	15-25	30-50	10	10	18	160
MAX4M400480	10-12	40-48	10	10	18	250
MAX3M300300	10	30	10	10	60	160
MAX2M360500	18-25	36-50	10	10	18	160
MAX2M200400	10-20	20-40	10	10	18	160
TD0040LA2	2-20	4-40	10	-3	30	N/A

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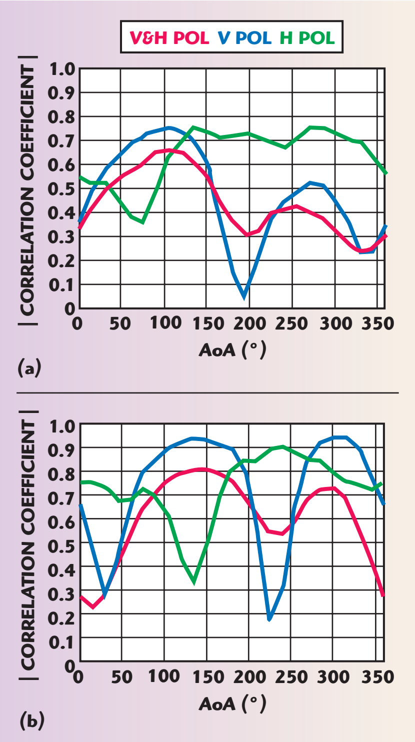
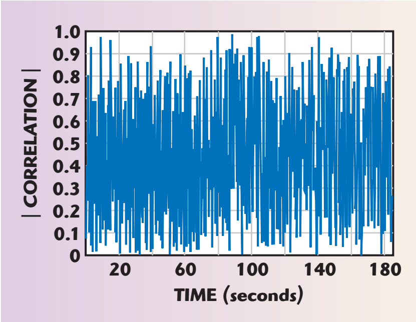


▲ *Fig. 3 Correlation responses to SCME Urban Micro (a) and Single Cluster (b) channel models.*



▲ *Fig. 4 Receive correlation reported by an LTE device during drive test.*

distribution function (CDF) of capacity for a fully-correlated MIMO channel, while the blue curve shows the CDF for an independent identically distributed (i.i.d.) MIMO channel (essentially a MIMO channel with correlation equal to zero). It is clear that the higher the correlation in the MIMO channel, the lower the capacity.

VARIABILITY IN CORRELATION

In order to investigate the variation of correlation under real conditions, two illustrative examples are provided. The first demonstrates variation resulting from slight changes in the mobile device's orientation. The second uses data logged from an LTE device prototype during live drive testing to show a real-world example of variations in correlation.

CORRELATION VARIATION AS A FUNCTION OF MOBILE DEVICE ORIENTATION

Antenna patterns of realized mobile devices are quite varied. Typically they are functions of frequency and external factors (e.g. the user's hands and head). In ***Figure 3***, spatial correlation is calculated for an actual handset device in response to the SCME Urban Micro and Single Cluster models. The SCME Urban Micro model is considered to be a typical urban micro-cell scenario, while the Single Cluster model is encountered less often, typically 10 to 20 percent of the time in the real world. Three polarizations are shown in the plots: vertical, horizontal, and an equal combination of the two.

It is clear from these examples that there is significant variation in spatial correlation as the device observes different orientations with respect to the incoming signal. From the plots below, a 70 to 80 percent correlated signal can easily drop to 20 percent with a minimal change in orientation, such as a user turning his head. This clearly indicates that a MIMO system must be able to react to rapid changes in spatial correlation in normal situations with typical user behaviors.

CORRELATION IN LIVE DRIVE TEST SCENARIOS

Figure 4 illustrates the receive correlations reported by an LTE device from a live drive test scenario at typical urban driving speeds. This device reported correlation several times per second. It can be seen that the correlation varies rapidly. The plot reveals that correlation can vary from 0.9 to 0.1 in as little as 200 ms. This points to the fact that the correlation varies significantly in real-world conditions and MIMO systems need to be designed to adapt to the same.

THE EFFECT OF CORRELATION ON LTE SYSTEMS

LTE is arguably the most widely anticipated wireless technology in many years. Feedback mechanisms have

been refined and optimized for efficiency in LTE. In the connection between a base station and an LTE mobile device, there are three key feedback parameters, collectively called Channel State Information (CSI):

- Channel Quality Indicator (CQI) – this feedback is used by the adaptive modulation and coding (AMC, also called "link adaptation") process
- Precoding Matrix Indicator (PMI) – in closed-loop (feedback) systems, the mobile device must make frequent recommendations to the base station regarding each transmit antenna's optimal signal power and phase. LTE uses a pre-defined set of "codeword" matrices, and the PMI indexes whichever matrix is most appropriate at the moment
- Rank Indicator (RI) – This reports the rank value described earlier

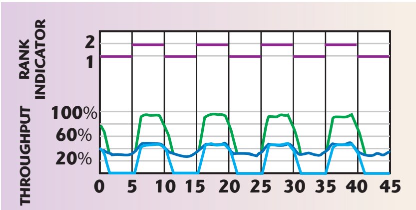
While LTE is quite efficient in calculating and transmitting these parameters, they still require processing time and packaging/transmission time. If the MIMO scenario changes significantly in the time it takes the system to process feedback and adjust, performance can be impacted. A MIMO system that can quickly process and respond to feedback will offer better performance.

THE EFFECT OF VARYING CHANNEL CONDITIONS ON MIMO PERFORMANCE

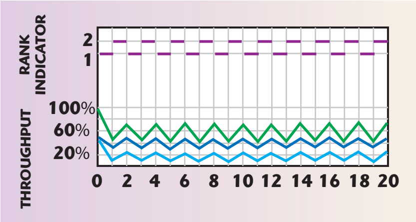
In order to understand the true impact of varying channel conditions on the performance of an actual MIMO system, some procedures were performed in the laboratory. A lab-based emulated LTE network was connected through an SR5500 Wireless Channel Emulator (to control the RF environment) and then to an LTE UE (User Equipment, or mobile device). The SR5500 was set up to toggle between two channel conditions: rank 1 (minimum rank) and rank 2 (full-rank) channels.

In a rank 2 channel, maximum MIMO throughput is expected, while minimum throughput (that of a single stream) is expected in a rank 1 channel. While the SR5500 can be used to create any dynamically varying correlation conditions, this investigation used two channel correlation conditions. This relatively simple case was chosen to examine the effects of correlation. Performance was measured as Physical Downlink Supplementary Channel (PDSCH) Layer 1 throughput.

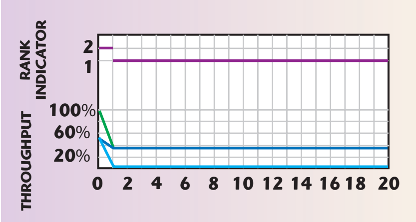
Figure 5 shows the rank as reported by the device and the system throughput as a percentage of the nominal maximum. The dark blue and light blue curves represent the throughput contributions of two streams; the green curve represents overall system throughput. When channel conditions were toggled at five-second intervals, the system was able to adapt between the expected data rates, although it is clear from the graphical presentation of the data that the transition time was significant.



▲ *Fig. 5 Throughput while toggling correlation models at 5 s intervals.*



▲ *Fig. 6 Throughput while toggling correlation modes at 1 s intervals.*



▲ *Fig. 7 Throughput while toggling correlation modes at 500 ms intervals.*

By inspection, the UE takes roughly 900 ms to fully adapt to the variation in channel conditions. The average throughput (not shown in Figure 5) is a little above 70 percent of the maximum system throughput. Note that a calculation assuming insignificant transition time would produce an expected value of about 75 percent.

When channel conditions are toggled more frequently, the throughput range and mean drop. When toggling occurs every second (see ***Figure 6***), average throughput drops to roughly 60 percent of maximum.

When the channel conditions are toggled every 500 ms, the system essentially offers the throughput of a single stream system, as shown in ***Figure 7***. Note that there is no effective MIMO throughput gain even though the system offers an ideal MIMO channel 50 percent of the time.

CONCLUSION

This article explores the relationship between variations in correlation in a cellular MIMO system and data throughput. Results show that:

- Slight changes in the orientation (movement) of a mobile device can cause significant variations in correlation
- Correlation measured in actual drive testing shows that correlation varies rapidly and significantly in live conditions
- Data throughput is affected not only by changes in channel conditions, but by the rapidity with which those changes take effect. In one case, it was shown that with frequent rapid movement, a MIMO system might offer no throughput gain over a single stream system, even though MIMO conditions are ideal half of the time. Accounting for all the aspects of adjustment (feedback, processing, etc.) can often point out that data capacity is being wasted

These factors point out the importance of designing MIMO system components (base stations and mobile devices) that can dynamically respond to varying correlation. The potential pitfalls can be uncovered and mitigated by using equipment to emulate controllable dynamic correlation conditions in the design laboratory. ■

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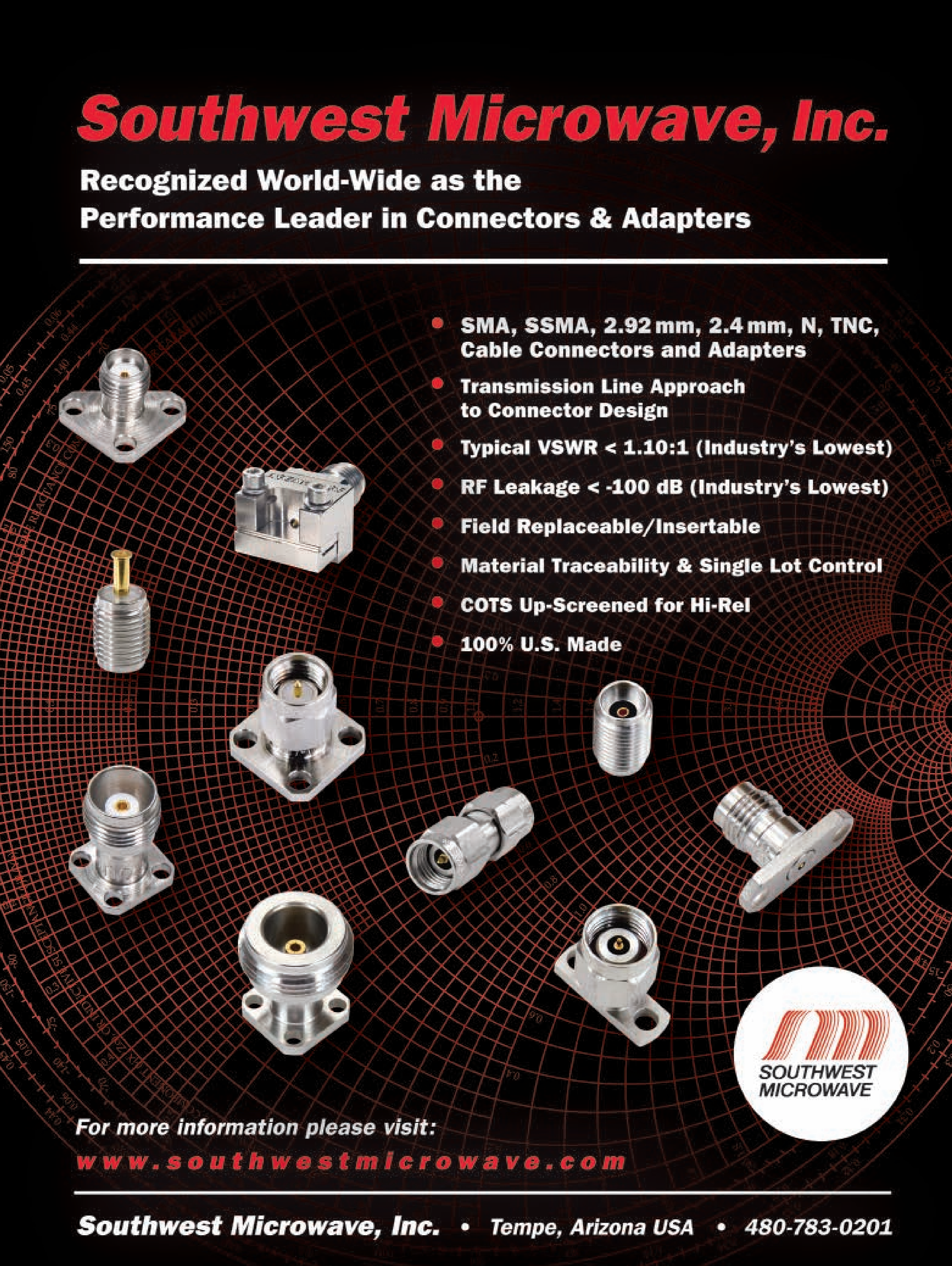
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INTERNAL PIFA PERFORMANCE EVALUATIONS FOR A SATELLITE-TERRESTRIAL HANDSET

The performance of several internal PIFA prototypes for a satellite-terrestrial handset is evaluated for multipath fading channels. The fade margins are provided by the system reliability requirements. The user's head and hand have a large effect on the PIFA antenna patterns as well as the receive and transmit power statistics and fade margins.

Antenna performance evaluation is a key step to understanding the performance behavior of an antenna design. Planar inverted-F antennas (PIFA) are often applied in terrestrial cellular phones. At EB, the first GMR-1 3G satellite-terrestrial smartphone was designed, using an internal PIFA antenna configuration for the satellite mode. The handset also integrates the radio technologies of GSM/WCDMA, GPS and WLAN/Bluetooth. The satellite RF front-end is designed for open and remote areas in the case where no cellular network is available. ***Figure 1*** shows the picture of the handset, which has a similar size and weight as a standard cellular smartphone. In antenna design for a specific communication system, a number of prototypes must be built and their antenna gain performance measured in an anechoic chamber. To select the best antenna prototype for the system, the performances of the prototypes should be evaluated by passing a multipath fading channel, which is typically characterized by slow or fast Rician fading channels in GMR-1 3G standards.[1] A Rician channel is independent on the transmit and receive antennas. Here, the Rician slow fading channel weighted by the patterns is applied to evaluate the performance of the prototypes and to estimate the fade margin for the system design. The preferred elevation angles are from 20° to 50° and the interested frequency is at S-band.

▲ *Fig. 1 TerreStar GENUS™ Smartphone.*

ANTENNA MEASUREMENTS

The PIFA is located at the upper right corner of the handset from the front view. Several prototypes were built and measured in an anechoic chamber with approximately 3° angular steps in both the azimuth and elevation planes. The phone and hand positions are shown in ***Figure 2***, where the phone is tilted by an angle θ = 60° from the zenith direction to the centre axis of the handset in the head-hand measurements. Three hand positions (HP1, HP2 and HP3) are selected for both the right and left one. They are defined respectively by 3, 5 and

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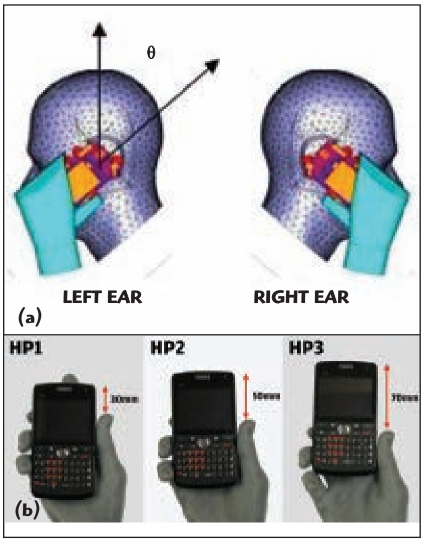
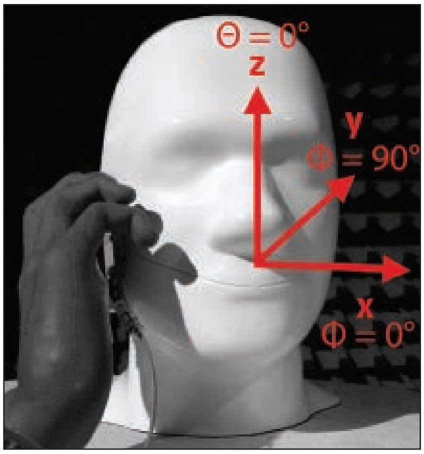


▲ *Fig. 2 Phone and hand position in the antenna measurements: (a) phone position and (b) HP1, HP2 and HP3 hand positions.*

7 cm distances from the thumb to the upper edge of the phone.

Figure 3 shows the coordinate system for the phantom head with hand measurements. The handset beside the right and left ear, using both the right and left hand, was measured. For free space (FS) measurement coordinates, the head shown is replaced by the handset with the keyboard towards the Z axis. Many different setups were also measured, such as data mode and other real user cases. In this article, the free space and the handsets beside the right ear with right hand are investigated without loss of generality.



▲ *Fig. 3 Measurement coordinate system.*

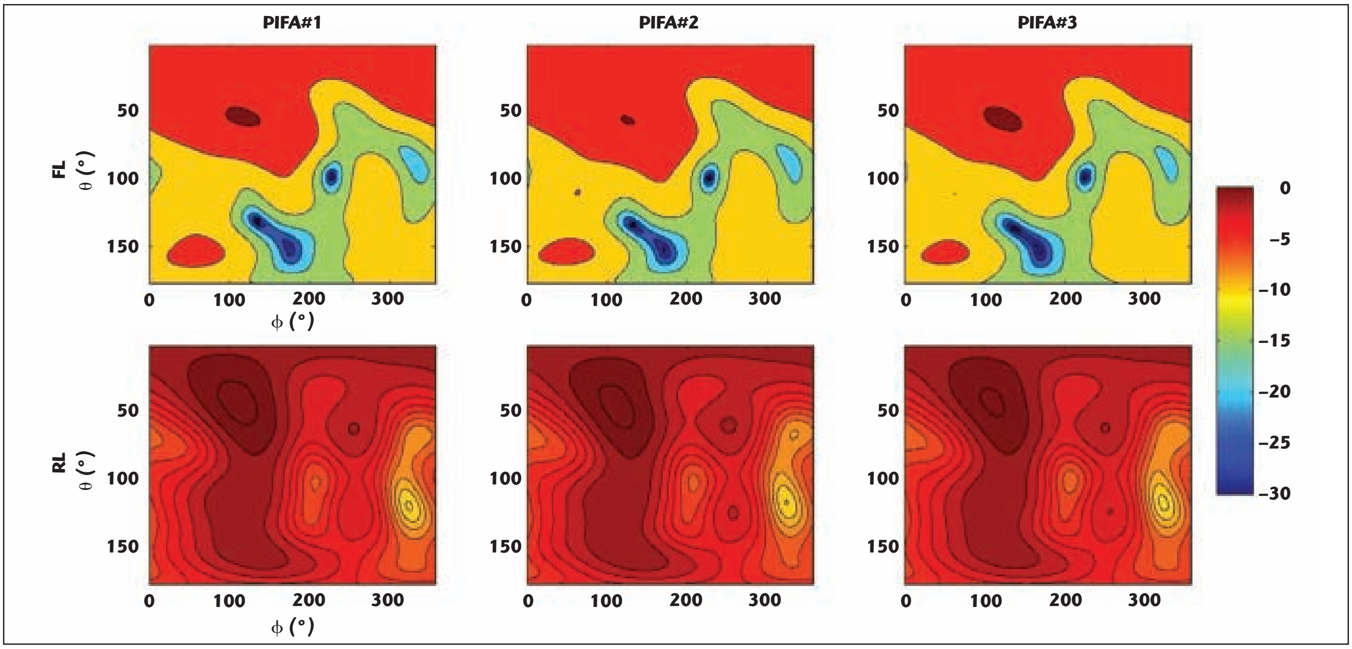
INTERNAL PIFA PATTERNS

The PIFA patterns were measured on both the forward link (FL) and return link (RL). The FL is defined as the signals from the satellite to the handset; the RL is defined as vice versa. LHCP (left-hand circular polarization) and linear polarization are applied in the FL and RL, respectively. For all the setups, the three dimensional patterns are plotted by using the measured PIFA gains with approximately 3° angular resolution in both the azimuth and elevation plane. ***Figure 4*** shows the patterns for the FL and RL of the three prototypes under test. It is seen that the patterns of the three prototypes are very close. The RL patterns are better than the FL patterns due to the gains contributed by the total transmitted power. The FL patterns are also very good in the required elevation angles.

Figure 5 shows the PIFA patterns for the FL with the phantom head and hand. It can be seen that the head as well as the hand have a large effect on the PIFA gain patterns. The phantom head has more of an effect compared with the different hand positions (HP1 ~ HP3). HP1 is the worst because the thumb and the hand are closer to the PIFA location. HP2 and HP3 look comparable. In the back cover of the handset, a warning line is plotted to remind the users to hold the handset correctly.

MULTIPATH FADING CHANNEL

Multipath propagation is the key characteristic in mobile communications and causes channel fading. The typical multipath fading channels are Rician and Rayleigh channels. In GMR-1 3G,[1] slow and fast fading Rician channels are recommended to be applied in the system and link level simulations. The slow fading channel is defined with a Doppler shift of 10 Hz and 9 dB Rician factor, while the fast fading channel is with a 100 Hz Doppler shift and 12 dB Rician factor. ***Figure 6*** shows the slow and fast fading Rician and Rayleigh channels, where the Doppler shift and sampling time are 10 Hz and 0.001 s, respectively, and the Rician factor 9 dB is taken for Rician channel simulations. It is seen that the Rayleigh channels



▲ *Fig. 4 The FL and RL PIFA pattern for FS.*

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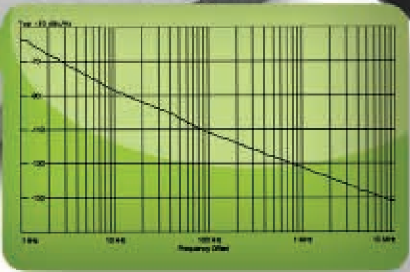
DCO50100-5	500 - 1000	0.3 - 15	+5 @ 26 mA	-100	0.3 x 0.3 x 0.1
DCO7075-3	700 - 750	0.5 - 3	+3 @ 10 mA	-108	0.3 x 0.3 x 0.1
DCO80100-3	800 - 1000	0 - 3	+3 @ 15 mA	-105	0.3 x 0.3 x 0.1
DCO80100-5	800 - 1000	0.5 - 8	+5 @ 21 mA	-111	0.3 x 0.3 x 0.1
DCO100200-5	1000 - 2000	0.5 - 24	+5 @ 30 mA	-95	0.3 x 0.3 x 0.1
DCO1198-8	1195 - 1205	0.5 - 8	+8 @ 24 mA	-115	0.3 x 0.3 x 0.1
DCO170340-5	1700 - 3400	0.5 - 24	+5 @ 24 mA	-90	0.3 x 0.3 x 0.1
DCO200400-5 DCO200400-3	2000 - 4000	0.5 - 18	+5 @ 35 mA +3 @ 35 mA	-90 -89	0.3 x 0.3 x 0.1
DCO300600-5 DCO300600-3	3000 - 6000	0.5 - 18	+5 @ 35 mA +3 @ 35 mA	-80 -78	0.3 x 0.3 x 0.1
DCO400800-5 DCO400800-3	4000 - 8000	0.5 - 18	+5 @ 35 mA +3 @ 35 mA	-78 -76	0.3 x 0.3 x 0.1
DCO432493-5 DCO432493-3	4325 - 4950	0.5 - 11	+5 @ 17 mA +3 @ 17 mA	-88 -86	0.3 x 0.3 x 0.1
DCO450820-5	4500 - 8200	0.5 - 14	+5 @ 22 mA	-77	0.3 x 0.3 x 0.1
DCO473542-5 DCO473542-3	4730 - 5420	0.5 - 22	+5 @ 20 mA +3 @ 20 mA	-88 -86	0.3 x 0.3 x 0.1
DCO490517-5 DCO490517-3	4900 - 5175	0.5 - 5	+5 @ 22 mA +3 @ 22 mA	-88 -86	0.3 x 0.3 x 0.1
DCO495550-5 DCO495550-3	4950 - 5500	0.5 - 12	+5 @ 22 mA +3 @ 22 mA	-87 -85	0.3 x 0.3 x 0.1
DCO579582-5	5780 - 5880	0.5 - 10	+5 @ 27 mA	-91	0.3 x 0.3 x 0.1
DCO608634-5 DCO608634-3	6080 - 6340	0.5 - 5	+5 @ 22 mA +3 @ 22 mA	-86 -84	0.3 x 0.3 x 0.1
DCO615712-5 DCO615712-3	6150 - 7120	0.5 - 18	+5 @ 22 mA +3 @ 22 mA	-85 -83	0.3 x 0.3 x 0.1

Model	Frequency Range (GHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Typ.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]	Size (Inch)
DXO Series					
DXO810900-5 DXO810900-3	8.1 - 8.925	0.5 - 15	+5 @ 26 mA +3 @ 26 mA	-82 -80	0.3 x 0.3 x 0.1
DXO900965-5 DXO900965-3	9.0 - 9.65	0.5 - 12	+5 @ 22 mA +3 @ 22 mA	-80 -78	0.3 x 0.3 x 0.1
DXO10701095-5	10.70 - 10.95	0.5 - 15	+5 @ 21 mA	-82	0.3 x 0.3 x 0.1
DXO11441200-5	11.44 - 12.0	0.5 - 15	+5 @ 23 mA	-82	0.3 x 0.3 x 0.1
DXO11751220-5	11.75 - 12.2	0.5 - 15	+5 @ 24 mA	-80	0.3 x 0.3 x 0.1

Features

- Exceptional Phase Noise
- Dimensions: 0.3" x 0.3" x 0.1"
- Excellent Tuning Linearity
- Models Available from 4 to 12 GHz
- High Immunity To Phase Hits
- Lead Free RoHS Compliant
- Patented Technology



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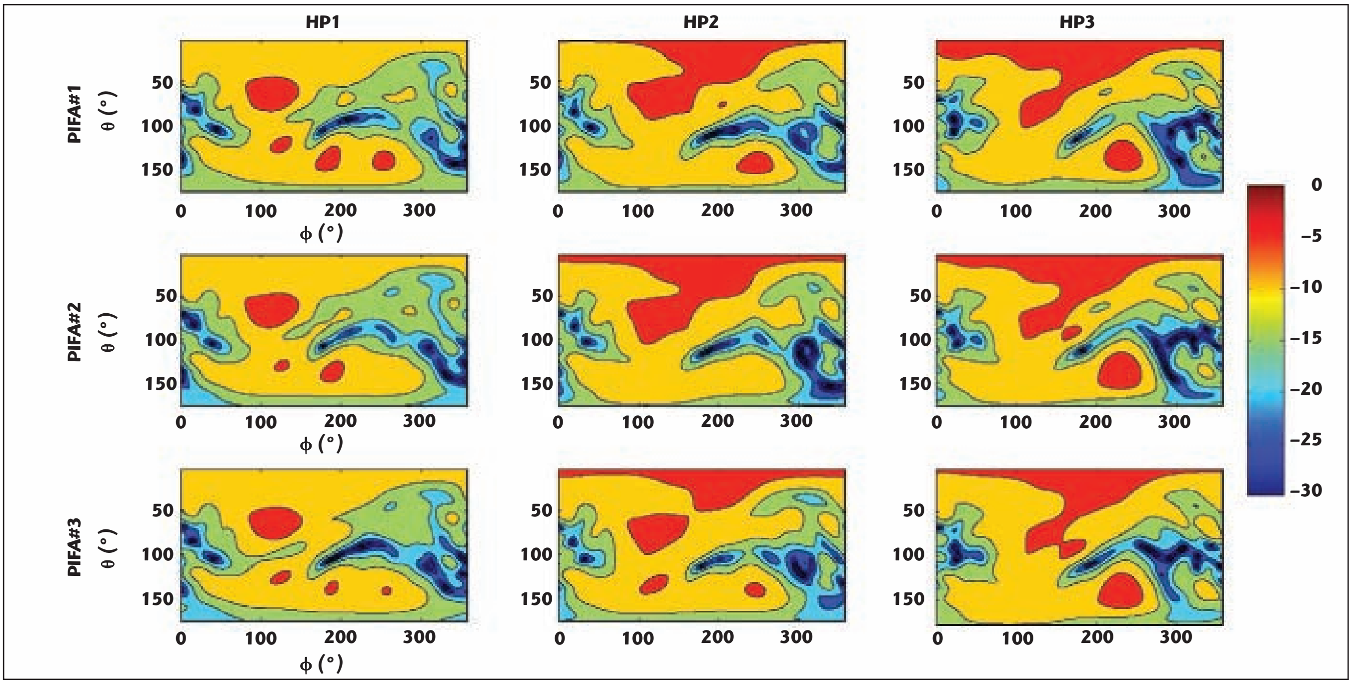
RoHS COMPLIANT



▲ *Fig. 5 The FL patterns for the PIFA prototypes; handsets held in the right hand beside the right ear with HP1, HP2 and HP3.*

TABLE I

POWER STATISTICS FOR THE PIFA PROTOTYPES: FL AND RL

		Power statistics (elev: 20 ~ 50 deg.)						
FL	PIFA#	min	CDF1%	CDF10%	mean	median	CDF90%	max
FS	#1	-22.2	-16.2	-11.2	-4.6	-3.8	0.5	4.7
	#2	-23.1	-16.5	-11.8	-5.0	-4.1	0.4	4.6
	#3	-25.3	-16.7	-11.9	-4.9	-4.0	0.6	5.4
BHR, HP1	#1	-33.5	-20.2	-15.2	-9.8	-9.7	-4.3	1.5
	#2	-38.0	-21.0	-15.7	-10.2	-10.2	-4.5	1.8
	#3	-36.4	-21.0	-15.6	-10.1	-10.0	-4.5	1.4
BHR, HP2	#1	-30.3	-19.5	-13.9	-8.3	-7.9	-3.3	2.3
	#2	-32.3	-18.8	-13.5	-8.2	-7.9	-3.3	2.2
	#3	-33.1	-19.2	-13.8	-8.7	-8.4	-4.0	1.9
BHR, HP3	#1	-30.9	-19.6	-13.4	-8.6	-8.3	-4.0	2.3
	#2	-33.6	-19.0	-13.8	-8.8	-8.6	-4.0	1.7
	#3	-31.2	-20.1	-13.9	-8.9	-8.6	-4.4	2.4
RL	PIFA#	min	CDF1%	CDF10%	mean	median	CDF90%	max
FS	#1	-7.7	-7.4	-5.1	-1.9	-1.8	0.8	1.3
	#2	-8.1	-7.8	-5.6	-2.1	-1.8	0.8	1.3
	#3	-8.0	-7.7	-5.6	-2.1	-1.8	0.7	1.1
BHR, HP1	#1	-19.4	-17.1	-11.7	-5.7	-4.4	-1.6	-0.8
	#2	-20.1	-17.5	-11.6	-6.0	-4.9	-1.9	-0.8
	#3	-20.0	-18.2	-12.1	-6.1	-4.9	-2.0	-1.2
BHR, HP2	#1	-14.1	-12.9	-9.2	-4.1	-3.3	-0.6	-0.1
	#2	-13.9	-13.1	-8.9	-3.9	-3.0	-0.4	0.3
	#3	-13.3	-12.7	-8.9	-3.9	-3.0	-0.4	0.6
BHR, HP3	#1	-11.7	-10.4	-8.0	-3.7	-3.3	0.2	1.2
	#2	-12.1	-10.3	-7.7	-4.1	-4.0	0.0	1.3
	#3	-12.3	-10.6	-7.8	-4.0	-3.8	-0.1	1.0

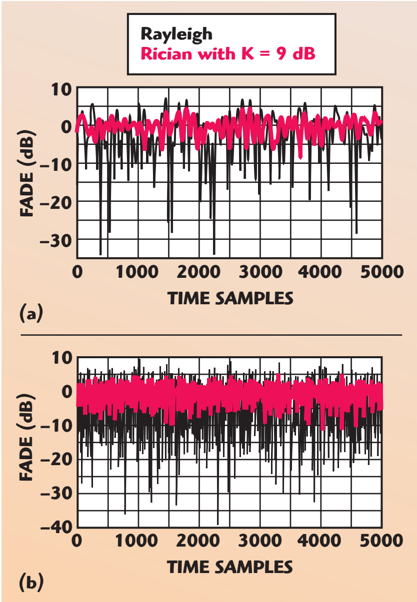
have a deeper fast fading and Rician channels are much better. When the mobile terminal is moving fast, 100 Hz Doppler shift, the channel fading rate will increase, which makes the channel worse. In this work the slow Rician channel will be used in simulations and the fast fading channel can be done in a similar way.

ANTENNA PERFORMANCE EVALUATIONS

Assuming that $G_T(\theta, \phi)$ and $G_R(\theta, \phi)$ are the antenna patterns for the transceiver, respectively, and H denoting the fading channel gain by multipath, the received power can be calculated by

$$P_r = G_T(\theta,\phi) \cdot H \cdot G_R(\theta,\phi) \qquad (1)$$

For antenna performance and fade margin estimation purposes, the handset can be taken either as a transmitter or receiver and the satellite gain pattern is assumed to be unknown. The received power statistics can be tabulated using the values of the minimum, CDF 1 percent (CDF: Cumulative Distribution Function), CDF 10 percent, mean, median, CDF 90 percent and the maximum. From the power statistics of the prototypes, the best prototype can be selected for mass production. Moreover, the fade margins required in both the forward and return links can be seen and further checked to see if they meet the system requirements.



▲ *Fig. 6 Rayleigh and Rician (k = 9 dB) fading channels for a moving terminal with a Doppler shift: (a) 10 Hz and (b) 100 Hz.*

Figure 7 shows the receive/transmit power distributions in the FL and RL for PIFA#1, from which the fade margins can be found by using the slow Rician channel weighted by the patterns. Moreover, it is seen how much the antenna patterns in free space as well as the head-hand setups can affect the power distributions, and how much deviations for the fade margin compared with the only Rician channel. In the figure, the fading caused by only the Rician and only the Rayleigh channels are plotted for the sake of comparison. It is seen that the antenna patterns have a big effect on the power distributions. Therefore, the measured power cannot be used directly to obtain the corresponding fading channel before removing the effect of antenna patterns. ***Table 1*** shows the specific power statistics at different CDF points for the prototypes. The elevation angles are from 20° to 50° as the system required. In the phantom head

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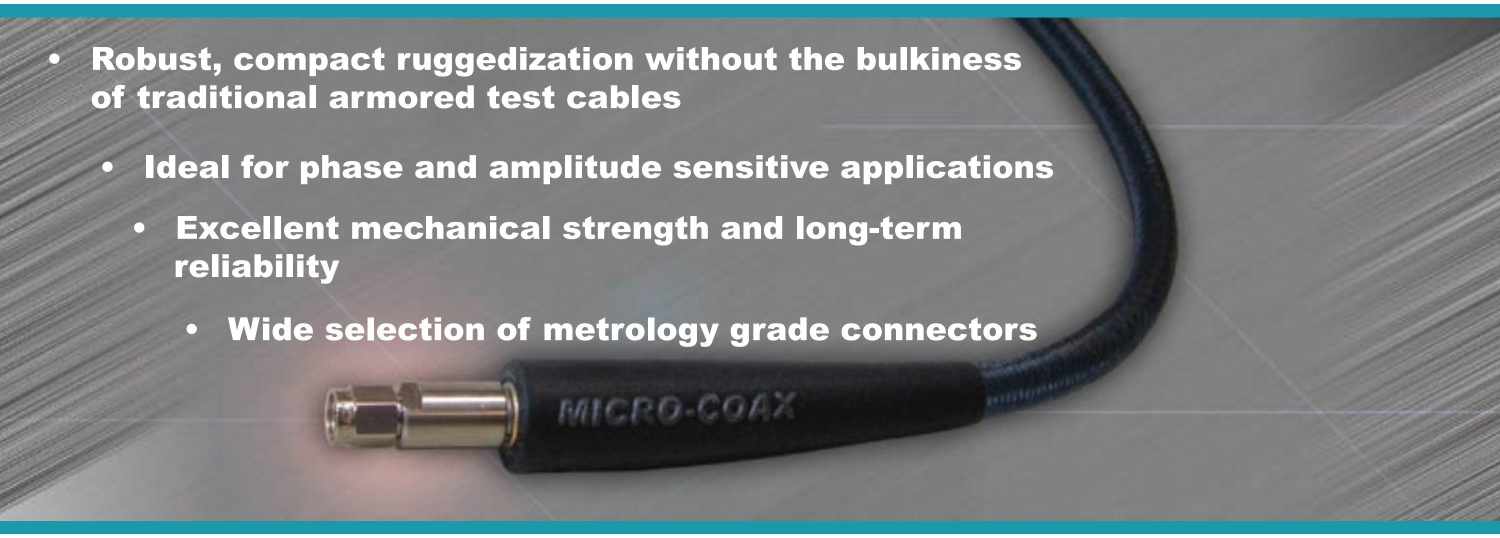

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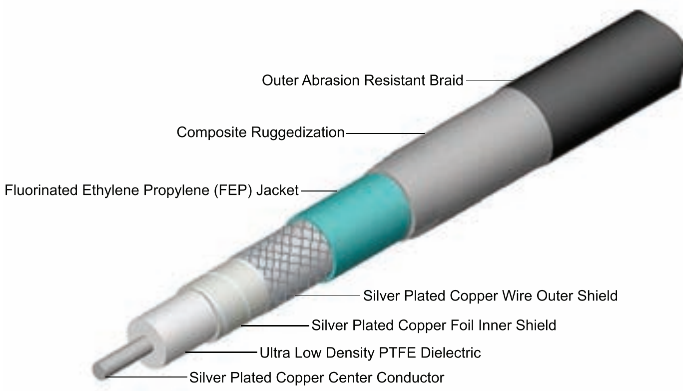
5 GHz	0.23	0.20
10 GHz	0.33	0.28
18 GHz	0.45	0.38
26.5 GHz	0.55	0.47
40 GHz	0.68	—



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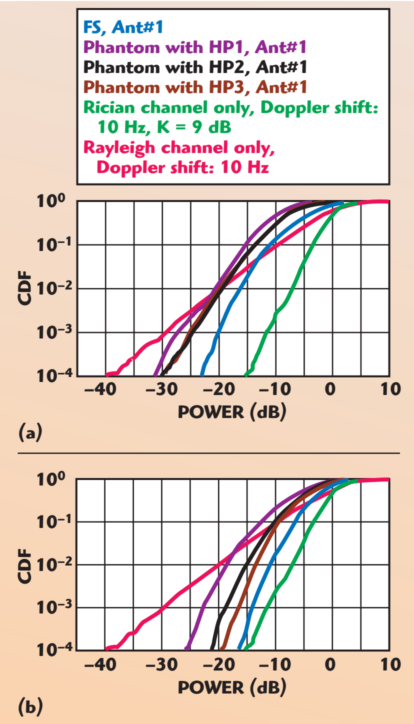
with hand setups, the measurements of the handset beside the right ear (BHR) are analyzed. It is seen in the Table that the FS setup has the best performance. For the phantom with hand setups, HP1 has worst performance. HP2 and HP3 results are almost identical in the FL, but HP3 is found better in the RL. Overall, the RL performance is better than FL. From the Table, it can be seen that:

- At CDF1 percent, the HP1 power statistics are worse than HP2 and HP3 by approximately 2 dB in the FL. In the RL, HP3 is approximately 2.5 dB better than HP2 and HP2 is approximately 5 dB better than HP1.
- Compared to the FS, the head-hand setups are approximately 4 dB lower in the FL. In the RL HP1 case, the power is approximately 10 dB lower at CDF1%.
- The RL is with less fade margin.
- By different system reliability requirements, the fade margins are available.



▲ *Fig. 7 Receive/transmit power distributions: (a) FL and (b) RL.*

CONCLUSION

The internal PIFA prototypes for a satellite-terrestrial handset are evaluated by multipath Rician channels. Moreover, the fade margins are provided for the FL and RL by the system reliability requirements. The head and hand have a large effect on the antenna gain patterns and further affect the final power statistics. One cannot tell what the exact channel is without taking out the effect of the antenna pattern(s). ■

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Reference

1. "Radio Transmission and Reception," GMR-1 3G 45.005, ETSI TS 101 376-5-5, v3.1.1 (2009-07).


360° @ 1 GHz
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HIGH-PERFORMANCE OSCILLOSCOPES WITH BANDWIDTHS UP TO 2 GHZ

The new Rohde & Schwarz RTO oscilloscopes are available as two- and four-channel models with a bandwidth of 1 or 2 GHz and a sampling rate of 10 Gsample/s per channel (see ***Figure 1***). Crucial factors for optimum use of an oscilloscope include how quickly it helps find errors and how accurately it displays the signal trace. This fact makes this new family of R&S scopes of particular interest as their very short 'blind times' make it possible, for the first time, to analyze and display one million waveforms per second.

▲ *Fig. 1 The R&S RTO offers high signal fidelity, good measurement dynamics, an acquisition rate of 1 M waveforms/s and a digital trigger.*

BLIND AMBITION

A digital oscilloscope measures signals in two steps. First, it samples the signal for a defined period and stores the acquired data. It then processes the data and displays the waveform. During this signal processing phase, digital oscilloscopes are 'blind' to the measurement signal. Any errors that arise at the test point during this period go undetected (as illustrated in ***Figure 2***). The effects of this blind time are the most critical at the highest sampling rate. When measuring at a sample rate of 10 Gsample/s and a record length of 1,000 samples, conventional oscilloscopes are blind for 99.5 percent of the acquisition cycle.

Consequently, measurements only take place during less than 0.5 percent of the cycle. These new oscilloscopes, on the other hand, look at the signal 20 times more often. This is made possible by the instruments' highly integrated ASIC. The use of multiple parallel processing paths drastically reduces blind time. The result is a speed of one million displayed waveforms per second. Simultaneously, all instrument settings and measurement analysis functions remain available.

DIGITAL TRIGGER SYSTEM

With an analog trigger system, the trigger path runs parallel to the signal acquisition path.

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Due to the different characteristics of the paths, a time and amplitude offset arises in the signal display at the trigger point. This causes measurement inaccuracies (trigger jitter), which post-processing can only partially correct. In what is believed to be the world's first purely digital trigger architecture, the trigger and measurement data share a common signal path, and thus have the same time base. The result is very low trigger jitter in real time and precise allocation of the signal to the trigger point.

In addition to trigger jitter, analog trigger systems also have to cope with long 're-arm' times. During this period, the system does not react to additional trigger events. This means that signal characteristics that users want to trigger on are masked. The digital trigger system, on the other hand, has no re-arm mechanism, and therefore responds reliably to trigger events that occur in rapid succession. No events are lost.

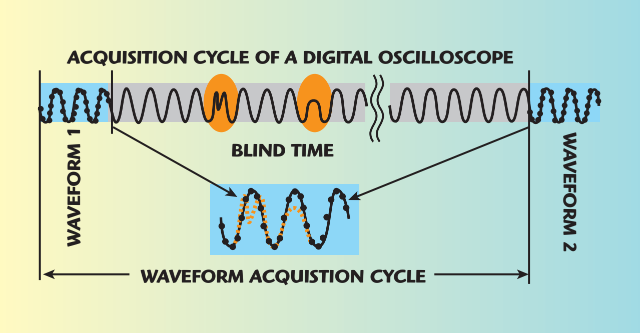
SIGNAL FIDELITY

The accuracy of the measurement signal's representation depends heavily on the front-end's bandwidth and noise floor. Consequently, Rohde & Schwarz has developed BNC-compatible broadband inputs, very low-noise front-ends and precise analog-to-digital converters (ADC). The result is a very low inherent noise.

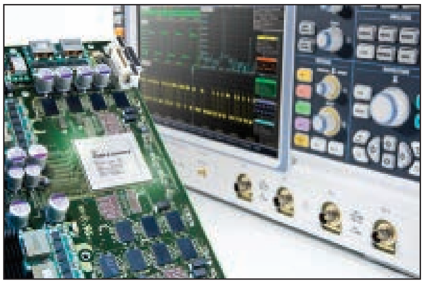
Stringent accuracy requirements are especially needed in the case of low signal amplitudes for digital interfaces and signal analysis in the frequency domain. The accuracy of the signal digitization depends on the ADC's effective number of bits (ENOB). Typically, the ADCs used in digital oscilloscopes consist of several interleaved, time-delayed, slow converters. The higher the number of such interleaved components, the larger the errors caused by the non-uniform behavior of the individual converters. For this reason, a monolithic 8-bit ADC with a sampling rate of 10 Gsample/s has been developed. This module's single-core architecture minimizes signal distortion. With more than seven effective bits, it achieves excellent measurement dynamics, significantly improving accuracy.

Even at low vertical resolution (down to 1 mV/div), the new scopes are highly accurate, because their sensitivity levels are not implemented with software-based zooming; they are implemented with switchable amplifiers in the front-end. For accurate measurements, the full measurement bandwidth is available in all sensitivity ranges down to 1 mV/div.

Compensation for the amplifiers and attenuator pads in the front-end is very precise, and a sophisticated temperature control system ensures excellent temperature stability within the instrument. Furthermore, the channel-to-channel isolation of more than 60 dB up to 2 GHz ensures that the measurement signal from one channel has the lowest possible influence on signals from the other channels.



▲ *Fig. 2 Compared to a conventional oscilloscope, the blind time of R&S RTO oscilloscopes is up to 20 times shorter.*



▲ *Fig. 3 All signal processing takes place in the recording trigger control ASIC.*

HARDWARE-ACCELERATED SIGNAL PROCESSING

A highly integrated ASIC handles all signal processing. This ASIC also contains hardware support for measurement and analysis functions, such as spectrum display, mathematical operations, cursor measurements, histograms and mask tests. Even during complex signal analysis, the ASIC's high degree of parallel processing ensures a high acquisition rate (as illustrated in ***Figure 3***).

The various methods for reducing the number of samples—such as Sample, Peak Detect, High Res and RMS as well as arithmetical operations on waveforms, such as Envelope and Average functions—are important tools for signal analysis and troubleshooting. The new oscilloscopes simultaneously display up to three waveforms per measurement channel in different ways. It is possible to combine the type of data decimation and the waveform arithmetic.

Fast Fourier Transformation (FFT) is particularly fast with these oscilloscopes, with the high acquisition rate conveying the impression of a live spectrum on the screen. Combined with the persistence mode, it is possible to see even rarely occurring events in the spectrum. For R&S RTO instruments, the mask test was implemented in the ASIC so that the acquisition rate remains at a very high level (more than 600,000 waveforms/s). The otherwise very time-consuming mask test can be performed quickly.

USER-FRIENDLY INTERFACE

An intelligent user interface with convenient touch screen operation makes work processes easier; the user is able to maintain a clear overview of what is going on, even during complex measurements. The user-friendly screen design with semi-transparent dialog boxes, signal icons to preview waveforms in real time and a configurable toolbar help users perform even complex test and measurement tasks quickly.

The handy, compact instrument comes with a 10.4 inch touch screen and the straightforward menus at the bottom of the screen make it possible to reach any of the settings with no more than two clicks. The flat menu structures and cross-links to logically associated settings simplify navigation. Signal flow diagrams in the dialog boxes visualize the progress of signal processing, and the toolbar at the top of the screen offers fast access to frequently used functions, such as Zoom, Undo/Redo, Histogram and FFT.

CONTROL USING A PROBE

Suitable active and passive probes for use with the new R&S RTO oscilloscopes are also offered. With an input resistance of 1 MΩ, the R&S active probes put only a minimum load on the signal source's operating point. The vertical dynamic range is very large even at high frequencies (for instance, 16 V peak-to-peak at 1 GHz), preventing signal distortion.

Measurements also do not have to be interrupted for compensation processes, because the offset and gain errors of the probes are almost completely independent of temperature. For example, the zero error is less than 90 µV/°C. In addition to solid test and measurement characteristics, the active probes feature two innovations: The micro button on the probe, which can be assigned various functions, such as Run/Stop or Autoset, enabling the user to control the oscilloscope directly from the probe. And the R&S ProbeMeter, an integrated voltmeter that allows precise measurements of the DC voltage regardless of the oscilloscope's current channel settings.

CONCLUSION

By encompassing digital technology, the new R&S RTO oscilloscopes bring a new dimension to the market. The instruments' highly integrated ASIC and the use of multiple parallel processing paths drastically reduces blind time facilitating a speed of one million displayed waveforms per second. Rohde & Schwarz developed a monolithic 8-bit ADC with a sampling rate of 10 Gsample/s the digital trigger architecture, providing very low trigger jitter in real time and precise allocation of the signal to the trigger point. Other key features include low inherent noise and a user friendly touch-screen interface.

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RS No. 305

TELEMETRIX 400 REAL TIME CHANNEL SIMULATOR

A member of the RT Logic Telemetrix® product line, the Telemetrix 400 Real Time Channel Simulator (T400CS) addresses a broad range of IF and RF hardware-in-the-loop R&D, test, operational, and training applications. The T400CS creates RF and IF signals that precisely match those that occur when transmitters and receivers are in motion with respect to one another. By accurately duplicating the effects of motion and RF channel physics on an RF link, the T400CS allows bench testing of what once required actual motion and distance between a transmitter and receiver.

The T400CS enables comprehensive test and training activities without actual flights of the satellites, missiles, UAVs, targets and aircraft carrying the transmitters or receivers under test. T400CS channel effects include physics-compliant, phase-continuous, real-time, carrier and signal Doppler shift, range delay, range attenuation, fading, and noise. In addition, multiple test and/or interference signals can be generated with the optional multi-channel signal source. A comprehensive selection of RF up-converters and down-converters are also available, allowing signals to be generated or received in frequency bands of interest.

The T400CS client/server software architecture facilitates a wide range of local and remote control options. Local control is provided by an easy-to-use RT Logic Graphical User Interface (GUI). Users can also create their own channel simulation profiles from a comma separated listing of RF effects values versus time. Programmatic control capabilities include a well documented control protocol and an optional RT Logic Plug-in for the Analytical Graphics Inc. (AGI) STK software. This provides a seamless real-time connection between the motion and RF modeling included in STK, and T400CS real-world, hardware-in-the-loop creation of fully physics compliant channel effects.

APPLICATIONS

The T400CS is a general purpose RF and IF test and measurement instrument for communications system- and component-level testing and verification, both in the laboratory and in the field. Key applications include a wide variety of flight and ground system testing of satellites, UAVs, aircraft, missiles and ground stations.

CHANNEL SIMULATOR

The RT Logic T400CS generates physics-compliant, phase-continuous, real-time carrier and signal Doppler shift, range delay, range attenuation, and Additive White Gaussian Noise

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(AWGN). These effects can be applied singly or in combination. Together they precisely duplicate propagation effects encountered in LEO, MEO, HEO and GEO satellite applications, as well as aircraft, UAV, missile, target and range test scenarios.

The T400CS is designed to be user-expandable, allowing the system to cover a wide range of channel counts and frequencies. One channel simulator card is typically configured in a T400CS system in order to emulate a single communication path, for example, an uplink or a downlink path. This same configuration can also be used for a single direction or half duplex up and downlink path if emulating a link through a "bent pipe" satellite transponder. When emulating a bi-directional or full duplex communication link, the T400CS system is typically configured with two channel simulator cards. Signal recorders/players, signal generators and spectrum analyzers can also be included in the T400CS system, further expanding its testing capabilities.

The T400CS can be inserted into a system under test in multiple ways, including direct cabling or utilizing amplifiers, signal conditioners and antennas connected over the air. The T400 Channel Simulator is an important addition to any communication system designer's test bench, with flexibility that reaches much further to quality assurance and training.

KEY SPECIFICATIONS

- Instantaneous bandwidth, 40 MHz or 85 MHz (model dependant)
- Signal Doppler shift, 0 kHz ±500 kHz, phase-continuous, 1 Hz resolution
- Carrier Doppler shift, 0 kHz ±20 MHz or 0 kHz ± 42.5 MHz (model dependant), phase-continuous, 1 Hz resolution
- Range delay, 3 μs to 2.5 s or 3 μs to 1.25 s (model dependent), phase-continuous, 1 ns resolution
- Fading/range attenuation, up to 60 dB, phase-continuous, 0.5 dB resolution
- AWGN, -168 dBm/Hz to -102 dBm/Hz
- Receiver noise, -168 dBm/Hz to -102 dBm/Hz
- Amplitude response, ±0.5 dB
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- Internal and external trigger
- Input Bands, Intermediate Frequency (IF), 70/160/266 MHz, RF input/output frequencies (with optional converters) UHF-band, L-band, S-band, C-band, X-band and Ku-band
- Compatible with most non-RT Logic 70/160/266 MHz IF converters
- Signal Generation (with optional signal generator cards)
- Channels, eight (8) per card
- Standard modulation types: BPSK, QPSK, OQPSK, SOQPSK-TG, SOQPSK-MIL 8PSK, MSK, FSK, AM, FM, CW
- Data rates, modulation type dependent
- Frequency offset, 0 kHz ±20 MHz or 0 kHz ±42.5 MHz (model dependant).

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RS No. 303

BRIDGING THE GAP BETWEEN MIMO LAB AND FIELD TEST RESULTS

Testing mobile devices involves many phases, including the validation of the devices in the actual field conditions where subscribers will use them. However, field testing in the diverse conditions of terrain, population density, physical location and motion of devices is extremely time-consuming and costly.

As the wireless industry works to introduce 4G LTE and WiMAX products and solutions, field testing will be particularly important. The MIMO technology used to enhance system performance and achieve the high data rates expected will cause product performance to vary substantially depending on the RF environment.

SOLUTION

The Azimuth Field-to-Lab solution allows service providers and equipment manufacturers to take real-world channel conditions collected from drive testing, performed in many ecosystems in different sites around the globe, and replay this data in the ACE™ MX MIMO channel emulator in any lab, at any phase of the design and qualification cycle.

Field conditions in laboratory product testing have typically been recreated with channel emulation using industry-approved and standardized channel models. These statistical representations of channel conditions are very useful in characterizing generalized RF environments for testing and certification, but they do not capture the unique and specific conditions experienced by a device as it moves through RF conditions in an actual wireless network. The Azimuth Field-to-Lab solution can augment current test conditions with actual field data collected from locations of interest.

Using the Azimuth Field-to-Lab solution involves three phases:

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- Conditioning the data for playback
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MODELS (Add Prefix BW-)

2 W SMA $29.95	5 W SMA $44.95	5 W Type-N $54.95	Attenuation (dB) Nominal	Accuracy*
S1W2	S1W5	N1W5	1	±0.40
S2W2	S2W5	N2W5	2	±0.40
S3W2	S3W5	N3W5	3	±0.40
S4W2	S4W5	N4W5	4	±0.40
S5W2	S5W5	N5W5	5	±0.40
S6W2	S6W5	N6W5	6	±0.40
S7W2	S7W5	N7W5	7	-0.4, +0.9
S8W2	S8W5	N8W5	8	±0.60
S9W2	S9W5	N9W5	9	-0.4, +0.8
S10W2	S10W5	N10W5	10	±0.60
S12W2	S12W5	N12W5	12	±0.60
S15W2	S15W5	N15W5	15	±0.60

RoHS COMPLIANT

To order Attenuators as RoHS, add + to base model No. Example: BW-S1W2+
Adapters available as RoHS, see web site.

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P.O. Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661

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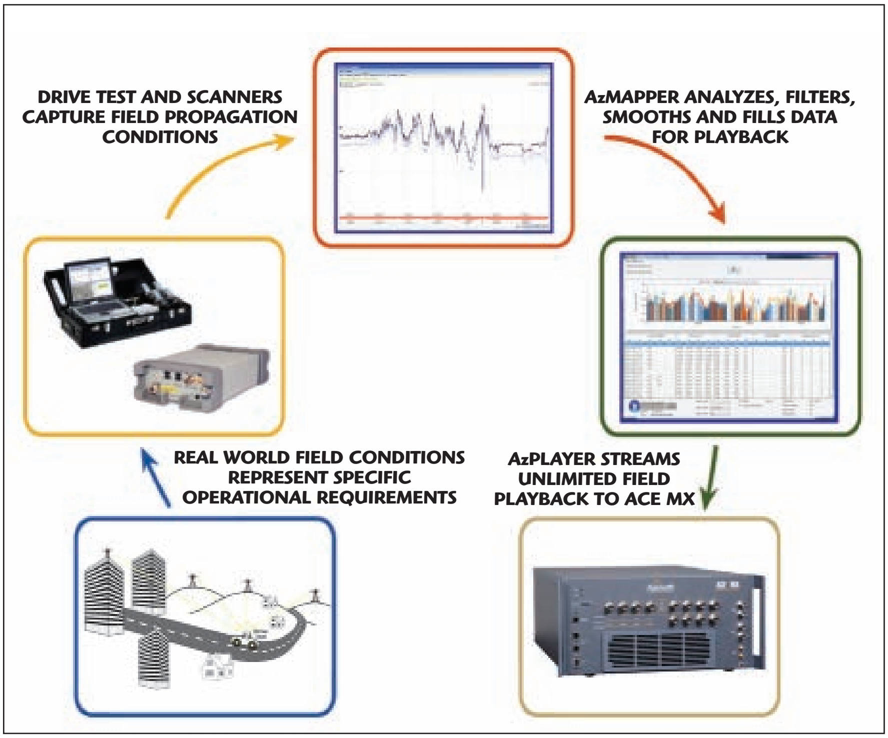
U.S. patent 7739260

IF/RF MICROWAVE COMPONENTS

331 rev P



▲ *Fig. 1 Mobile device testing process with Azimuth solution.*

standard drive testing software allowing the re-use of data from drive tests. Drive test data is converted into a playback file for a given number of base stations. The data can be filtered, smoothed and filled to ensure realistic playback conditions. The data is played back on the channel emulator. A playback control tool configures the ACE MX MIMO channel emulator and streams the playback conditions to the signal path of the channel emulator between the mobile device (e.g. UE) and the base station (e.g. eNodeB).

COMPONENTS

ACE MX MIMO Channel Emulator

The flexible, scalable ACE MX wireless channel emulator has been designed for MIMO- and OFDM-based systems, delivering a range of configurations for MIMO and/or SISO system testing. The intuitive and easy-to-use configuration and control interface enables efficient, automated and repeatable testing of 2G, 3G WiMAX, LTE and other 4G infrastructure equipment and devices.

AzMapper Application

AzMapper software analyzes drive test logs and automatically recreates these channel conditions for playback.

First, the field data is filtered to extract the useful and significant data from the mass of collected information. The data is then smoothed to make sure that the behavior of the playback best imitates the time varying nature of the real world. Finally, the data is analyzed for missing segments, which can be filled or closed with interpolated data to ensure continuity. All the parameters of the filtering and mapping are configurable to the user's preferences.

Any components that are removed (filtered out) and interference that is detected in the field data is added back to the environment in the form of AWGN to ensure operating conditions identical to those in the field. In addition, the velocity of the mobile device is added based on either information from the GPS coordinates over time or as a fixed velocity. The application provides advanced visualization views to help the user interpret both the source data and output data before creating the playback file.

AzPlayer Application

The ACE MX MIMO channel emulator, together with the AzPlayer application, supports real-time streaming of playback files for unlimited playback to channels on one or more ACE MX wireless channel emulators. With the easy-to-use play control, the data can be played back, paused, looped and even coupled with other playback files, accurately replicating real-world conditions.

Figure 1 shows the complete process flow and components.

TARGETED APPLICATIONS

By utilizing measurements of field data and playing them back through a wireless channel emulator, R&D and QA engineers and operators can test device performance against the dynamics of the field before ever deploying products in these environments. Operators can troubleshoot and optimize system performance, introduce field-trial support for qualification of devices in the lab, reproduce known trouble spots in the lab for analysis, provide throughput performance metrics on devices before deployment and allow qualification for specific markets and environments. Semiconductor and device manufacturers are able to characterize expected performance in real-world environments, reproduce and verify field issues, benchmark performance with other devices and optimize algorithms for best performance. Infrastructure manufacturers are able to test interoperability with devices under real-world conditions, benchmark system performance, characterize enhancements or improvements under real conditions and test algorithms such as soft handover in life-like conditions.

Azimuth Systems,
Acton, MA (978) 263-6610,
info@azimuthsystems.com,
www.azimuthsystems.com.

RS No. 302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Former ASD/C3I and ASD/NII panel members
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AEROSPACE
AFCEA
IEEE

ROGERS' NEW RO4360™ LAMINATES AND RO4460™ PREPREG FOR MULTILAYER POWER AMPLIFIER DESIGNS

Rogers Corp. recently introduced two new products: RO4360™ laminates and RO4460™ prepreg, developed for use in compact, multilayer power amplifier designs. These new materials feature a matched dielectric constant (ε_r) of 6.15 and dielectric loss (Df) of approximately 0.003 at 2.5 GHz. Building on the successful legacy of the company's RO4000® series materials, RO4360 laminates and RO4460 prepreg allow designers to reduce the overall size of their circuit boards (typically estimated between 20 and 30 percent) and save valuable real estate on passive board features.

RO4360 laminates and RO4460 prepreg provide the performance and reliability designers need in a lower total PCB cost solution. The materials are based on a ceramic-filled, thermoset resin system reinforced by glass fiber for excellent mechanical stability. The new products feature a low dissipation factor and generous power-handling capability; the thermal conductivity of the RO4360 laminate is 0.8 W/m-K. The matched-dielectric constant prepreg allows low-cost, homogenous, multilayer designs that were previously challenging due to the limits of competitive PTFE material options. RO4360 laminates may also be used with epoxy-based materials in hybrid designs.

The environmentally friendly RO4360 and RO4460 materials are RoHS compliant and compatible with standard PCB processing methods. The materials exhibit a high glass transition temperature (Tg) of greater than 280°C and a low coefficient of thermal expansion (CTE) in the z-axis, necessary for reliable plated through holes (PTH) in multilayer circuits. Drilling and plating of vias are less costly than PTFE-based materials and do not require time-consuming and expensive plasma hole-wall preparation processes.

When size and cost reduction are critical to a design, RO4360 laminates and RO4460 prepreg materials with their 6.15 dielectric constant represent a technological breakthrough. As the first high Dk, RF grade thermoset resin system available, they are an optimal choice for engineers working on designs including power amplifiers, patch antennas and other commercial high-frequency applications.

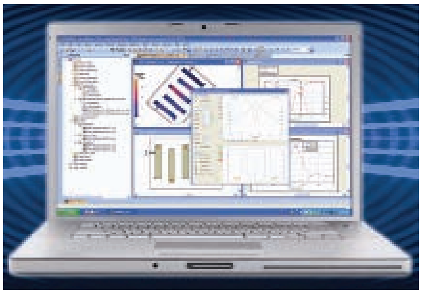
Rogers Corp., Advanced Circuit Materials Division (480) 961-1382, www.rogerscorp.com/acm.

RS No. 300

SYSTEM SIMULATION SOFTWARE

A new version of the LINC2 VSA (Visual System Architect) system simulation software has recently been released by ACS. Version 1.03 adds new system components and behavioral models to the VSA's Components menu. A new bandpass filter model with ideal selectivity is now part of the list of available components. The Visual System Architect offers the flexibility and ease of use of schematic-based system simulation combined with a comprehensive array of analysis methods and graphic displays for designing at the system level. More information about the Visual System Architect and other LINC2 products from ACS can be found on the ACS web site.

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

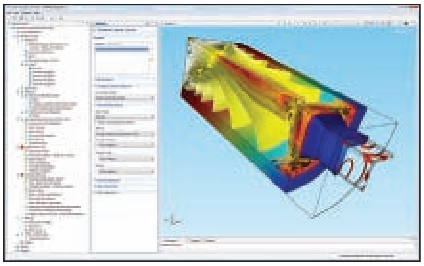


IFILTER SOFTWARE

VENDORVIEW

AWR Corp. announced its new iFilter technology, which was developed specifically for synthesis of lumped-element and distributed filters. iFilter's intuitive user interface enables users to quickly and easily design filters, connect them directly to circuitry, and make optimization trade-offs that positively impact their designs. It operates seamlessly within AWR's Microwave Office® high-frequency design software, allowing filter designs and their evolution to be part of the entire circuit design project. iFilter's physical layouts are automatically generated for distributed filters, while lumped-element filters can be realized using an extensive library of manufacturers' components (inductors, capacitors, etc.).

AWR Corp.,
El Segundo, CA (310) 726-3000, www.awrcorp.com.
RS No. 312



MULTIPHYSICS SIMULATION SOFTWARE

VENDORVIEW

COMSOL Inc. announces that version 4.0 of its multiphysics simulation software is now shipping. First unveiled at the 2009 users conference in Boston, COMSOL Multiphysics version 4.0 features an all-new user interface that makes the power of multiphysics simulation available to a wider audience of scientists and engineers. Both expert analysts and non-experts alike will benefit from the organized layout and streamlined model-building process. Along with the release of version 4.0, COMSOL also announces the release of a series of new LiveLink™ options that tightly integrate COMSOL Multiphysics into the mainstream product design workflow. New LiveLink products are now shipping for Autodesk® Inventor®, Pro/ENGINEER®, SolidWorks® and MATLAB®.

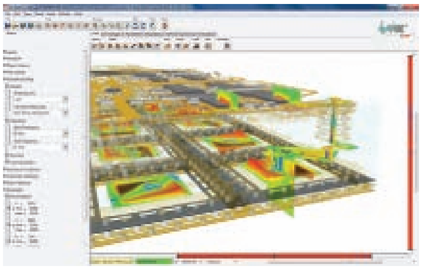
COMSOL Inc.,
Burlington, MA (781) 273-3322, www.comsol.com.
RS No. 313

USB DESIGNER'S KIT

VENDORVIEW

The HMC-DK008 Serial/Parallel USB Interface Designer's kit has been expanded to provide a user friendly interface for programming Hittite's family of interface driver/controllers, digital attenuators and variable gain amplifiers. This kit allows the designer to set desired attenuation and gain states, toggle between serial and parallel control modes, and construct custom serially clocked input signals. The HMC-DK008 Designer's Kit includes a Serial/Parallel USB Interface Board, custom USB and ribbon cable assemblies, and software CD-ROM.

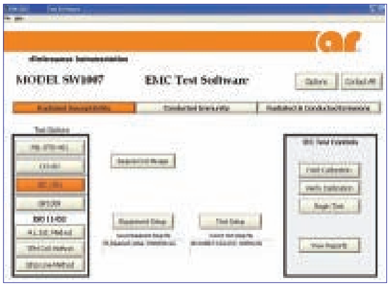
Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343, www.hittite.com.
RS No. 316



EM SIMULATION

Version 5.40 of EMPIRE XCcel™ software enables one simulation job to be distributed on multiple, networked PCs. This almost infinite extension of memory-space, based on the resources of the PC-network available, increases the complexity of tasks the software can tackle, i.e. higher resolutions and/or larger dimensions. Other features of version 5.40 include: the completely automated distribution of files and data throughout the simulation run, easy configuration capability for multiple hosts, transparent job-management by visualization of configuration and processes, and performance and simulation-speed is scaled linearly with the number of PCs.

IMST GmbH,
Kamp-Lintfort, Germany +49 2842 981 0, www.empire.de.
RS No. 317

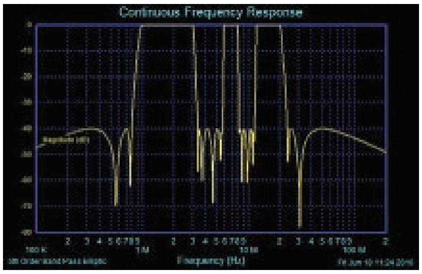


SOFTWARE FOR COMPLIANT TESTING

VENDORVIEW

AR's SW1007 software is a standalone program that combines conducted immunity test software and radiated susceptibility test software into one user-friendly package suitable for corporate to professional test lab users. The software automatically performs both calibration and immunity testing in full compliance with IEC 61000-4-3, 4-6; MIL STD 461/462 RS103, CS114 and RTCA/DO160 Section 20 specifications. The new version has an updated user interface including a tab system and organizes all the features for quick, easy access and makes selecting test standards much easier. The SW1007 also has the ability to control more equipment and the report generating feature has been enhanced to offer more control and customization.

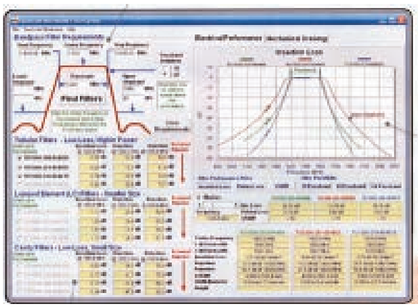
AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181, www.ar-worldwide.com.
RS No. 318



FILTER TOPOLOGY SOLUTION

As a new feature in its flagship product, Filter Solutions®, Nuhertz Technologies® has introduced a solution for the synthesis of "Multiple-Band™" filter networks. The term describes the construction of a cascade of an arbitrary number of pass and stop bands in a single lumped LC, active, or digital IIR filter. This robust feature adds to the power of the versatile and unique filter solutions. The "Multiple-Band" solution solves the design problem for "N-band" filters wherein "N" is an arbitrary integer. In network designs wherein cascades of individual passive filters are needed, the individual filters will necessarily interact, thus altering the desired network response. Such design problems are common in multiple passband VDSL or other filters used in data communications over telephone lines. The design solution synthesizes the geometric asymmetries in the various required pass and stop bands.

Nuhertz Technologies LLC,
Phoenix, AZ (602) 279-2448, www.nuhertz.com.
RS No. 314



FILTERXPRESS

FilterXpress does not deliver simulated filters like other programs. FilterXpress delivers thousands of real designs, real fast. Spectrum Microwave's database of thousands of Cavity, Lumped Element and Coaxial-Tubular Filters lays the groundwork for matching your unique requirements with a real filter design. By entering your filter's unique requirements, FilterXpress responds with up to 12 designs from Spectrum Microwave's exhaustive library of filter designs.

Spectrum Microwave Inc.,
State College, PA (888) 553-7531, www.spectrummicrowave.com.
RS No. 315

Components

2 to 6 GHz Limiter

The model ACLM-4805FM15 is a microwave limiter that combines high RF power handling ability of 10 W CW with a broad frequency range of 2 to 6 GHz and a compact surface-mount package. The ACLM-4805FM15 is designed to keep the RF input signals experienced by low noise amplifiers and front-end components of receivers to safe levels by attenuating signals above a specific threshold. While there are many limiters available in the marketplace, the ACLM-4805FM15 is highly unusual in its ability to handle such high power over a broad frequency range within the confines of a package with a very small footprint.

Advanced Control Components,
Eatontown, NJ (732) 460-0212,
www.advanced-control.com.

RS No. 216

Low Pass Filters

Crystek has introduced a new line of low pass filters, the CLPFL Series. Encased in a rugged SMA housing, this filter line is designed for test equipment and general lab use. Five models, with frequency ranges from DC to 100 through 500 MHz, compose the CLPFL line. The Crystek CLPFL low pass filter line has excellent out-of-band rejection, and features 7th Order Butterworth Response and 50 ohm SMA connectors. All filters in the CLPFL family are rated at +36 dBm (4 W), with an operating temperature of -40° to 85°C and storage temperature of -55° to 100°C.

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

RS No. 217

High Power Diplexer

Model EWT-52-0069 is a high power diplexer capable of handling 100 W CW over the passbands 30 to 390 MHz and 410 to 500 MHz. This unit features 1.25 dB maximum insertion loss over both passbands and a minimum of 30 dB channel to channel isolation. Overall size is 3.0" × 3.5" × 0.81". Shown with TNC connectors. Other connector styles are available upon request.

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

RS No. 218

Single and Dual Junction Isolators

VENDORVIEW

MECA Electronics introduced a new line of single and dual junction isolators enclosed in an IP67 housing and suitable for outdoor long-term use. The isolators are available in both cellular and PCS frequency bands. The dual junction models feature isolation performance of 45 dB with 50 W power handling capability when used with a properly sized external heat sink. Made in the USA with a 36-month warranty.

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

RS No. 219

RF Step Attenuator

VENDORVIEW

The model 743-60 step attenuator provides attenuation of 0 to 60 dB in 10 dB steps via a thumb-wheel and direct readout, and covers DC to 18 GHz. The model 743-60 is extremely precise, with attenuation deviation of ±1 dB or less from 0 to 40 dB, and no more than ± 1.5 dB to 60 dB of attenuation. Resetability is less than 0.05 dB, VSWR is less than 1.5:1 and temperature stability is 0.0001 dB/deg. C. The attenuator can handle RF input power of 2 W average and 200 W peak, and uses Type-N female connectors. The model 743-60 measures 1.43" × 1.75" × 0.5" and can be panel mounted with an optional kit available from Narda.

Narda,
Hauppauge, NY (631) 231-1700,
www.nardamicrowave.com/east.

RS No. 221

Directional Coupler

Pulsar model CS20-53-436-13 is a new 20 dB coupler covering the frequency range of 1 to 40 GHz with 1.6 dB insertion loss. Directivity is greater than 10 dB and flatness is ±0.6 dB, 1 to 20 GHz and ±1.5 dB, 1 to 40 GHz. The VSWR is 1.80:1 maximum and the unit can handle 20 W into a 1.20:1 load. Connectors are 2.92 mm female.

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

RS No. 222

Series of Connectors

The new cost-effective MML Series connector solutions include plugs, receptacles, jacks, adapters, pigtails and cable assemblies. These connectors address the market demand for smaller miniaturized connectors for applications such as Wi-Fi access points, GPS and other mobile terminals. With an operating frequency range of DC to 6 GHz and a typical VSWR of 1.35, the series features two types of PCB receptacles and three corresponding types of space saving plugs with mated heights of 2.5, 2.0 and 1.5 mm. Also offered is a variety of MML Series cable assemblies with three RoHS compliant 50 ohm high-performance cables.

Radiall USA Inc.,
Chandler, AZ (480) 682-9400,
www.radiall.com.

RS No. 223

Directional Couplers

RLC Electronics' high power directional couplers offer accurate coupling, low insertion loss and high directivity in a compact package. The standard units are optimized for two octave bandwidths and are available with a choice of coupling values. These units are ideal for sampling forward and reflected power with a negligible effect on the transmission line and very low intermodulation products.

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

RS No. 224

Four Tuning Bandpass Filter

The four tuning helical bandpass filter offers high attenuation, meets broadband needs with a bandwidth greater than 100 M, insertion loss is < 2.0 dB and group delay is < 20 to 40 ns. In particular the filters are suitable for this special project design, such as for digit-mixer RF/IF conversion, MDS, mine communication system, Project 25 wireless systems, the data radio of two-way radio, etc. The company can also install the four tuning bandpass filter into module filters and provide SMA, N and F connector for selection.

Temwell Corp.,
Taipei, Taiwan 886-2-25652500,
www.temwell.com.tw.

RS No. 225

Amplifiers

Broadband Power Amplifier

Aethercomm model number SSPA 0.5-2.5-50 is a high power, broadband, Gallium Nitride

(GaN) RF amplifier that operates from 500 to 2500 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. It is packaged in a modular housing that is approximately 3.4" (width) by 6.4" (long) by 1.06" (height). This amplifier has a typical P3dB of 40 to 50 W at room temperature. Noise figure at room temperature is 10.0 dB typical.

Aethercomm,
Carlsbad, CA (760) 208-6002,
www.aethercomm.com.

RS No. 226

100 and 200 W Power Amplifiers

Models C090105-50 and C090105-53 are X-band high power rack mount amplifiers that operate over the 9 to 10.5 GHz bandwidth. The model C090105-50 amplifier delivers 100 W minimum of output power across the entire bandwidth with greater than 52 dB of small-signal gain. The model C090105-53 amplifier delivers 200 W minimum of output power across the entire bandwidth with greater than 52 dB of small-signal gain. These amplifiers can be factory tuned to provide 100 or 200 W for adjacent bands including 8.5 to 9.6 GHz and 10.7 to 11.7 GHz. Enclosure size: 19" wide × 24" depth × 8.75" panel height.

AML Communications Inc.,
Santa Clara, CA (408) 727-6666,
www.amlj.com.

RS No. 227

Hybrid Power Amplifier Modules

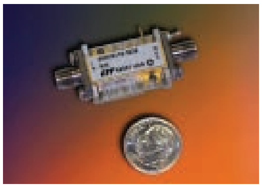
VENDORVIEW

AR's new line of wideband, hybrid power amplifier modules (HPM) covers the 6 to 18 GHz frequency range, and are the result of combining microelectronic technology with the latest developments in thin film substrates. These hybrid modules require a single DC voltage source and are 50 ohm cascadable building blocks with output powers up to 37 dBm. AR has the in-house capabilities to create custom HPM design solutions with frequencies from DC to 40 GHz. Bring AR your requirements and they will work with you to create a solution.

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

RS No. 228

Low Noise Amplifiers

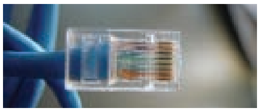


CTT Inc. announced a new family of compact, low noise amplifiers (LNA) operating in the 1 to 18 GHz frequency range for a wide variety of RF and microwave applications. CTT's family of LNAs offers noise figures of less than 2.5 dB (typical) over an instantaneous bandwidth of more than four octaves (1 through 18 GHz). These compact LNAs will find use in a wide range of applications including radar imaging, spread-spectrum, and a myriad of ultra-wide bandwidth applications including the related instrumentation for each. CTT's AMX family of LNAs is based on GaAs PHEMT technology with input and output impedance matching. The compact LNAs are available as a drop-in package or with SMA connectors.

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

RS No. 229

Amplifier Systems User Interface



The Ethernet option builds on the strong features of the LCD Controller and allows the end user to control the amplifier over a LAN using any common Web browser. This function is especially useful when connecting to several amplifiers because each amplifier can be individually addressed. The Ethernet connectors can be placed in the front or rear panel according to your design requirements.

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

RS No. 230

Double-balanced Mixer Pre-amplifier

VENDORVIEW

MITEQ's new X-band double-balanced mixer with integral IF amplifier for radar, communications, and related test systems applications provides 25 dB conversion gain for low level, 20 to 40 MHz and IF signals. Model DA0812/3010 mixer with pre-amplifier covers from 8 to 12 GHz and provides a noise figure of 9.5 dB with conversion gain to a RF output level of 9 dBm at P1dB. This model meets rugged environmental MIL specs, operates over a -54° to +85°C temperature range, and is ideal for rugged military systems applications.

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

RS No. 231

Variable Gain Amplifiers

VENDORVIEW

RFMD announced a new family of high linearity, 6-bit digitally controlled variable gain amplifiers (DVGA). The innovative RFDA family of

DVGAs expands RFMD's portfolio of infrastructure grade components that target the cellular base station, point-to-point and CATV end markets. RFMD's RFDA DVGA product family leverages RFMD's industry leadership in laminate multi-chip modules (MCM) to integrate high linearity amplifiers from multiple technologies with a digital step attenuator (DSA) and an optional serial to parallel converter. RFMD's DVGA products deliver multi-function features and performance while requiring few external components. As a result, designers of infrastructure transceivers can design radios with smaller size, higher assembly yields and lower cost. The RFDA product family offers a selection of components with gain up to 38 dB, OIP3 up to 43 dBm and a maximum operating frequency up to 4 GHz.

RFMD,
Greensboro, NC (336) 664-1233,
www.rfmd.com.

RS No. 232

Antenna

Omni-directional Antenna

The EM-6857 ultra-wideband, omni-directional, passive antenna performs over a frequency range from 20 MHz to 40 GHz and is the ideal antenna for TSCM and many SIGINT applications. The light 2.5 pound, 4 ½ inch diameter, 17 ½ inch long antenna reduces the number of antennas required to cover the spectrum and eliminates the need for batteries that a broadband active antenna would require. It is perfect for applications demanding rugged design and where size, weight and system configuration complexity must be kept to a minimum. The exceptionally broad and consistent frequency response with nominal gains above 0 dBi from 200 MHz to 40 GHz is the result of the continuing development of Electro-Metrics' proprietary technology.

Electro-Metrics, Johnstown, NY
(518) 762-2600,
www.electro-metrics.com.

RS No. 245

Semiconductors/ICs

PIN Diodes

Skyworks Solutions Inc. has introduced new PIN diodes in an industry standard 0402 packaging technology for handset, WLAN, CATV, SATCOM, land mobile radios, infrastructure, T/R and switching applications. These new PIN diodes provide designers with a small form factor, low-profile and low inductance, all in a plastic surface-mount technology (SMT) package. Additional benefits include low capacitance, resistance and thermal impedance.

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

RS No. 233

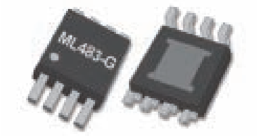
94 GHz ×12 Active Multiplier

Model A940-12XW-8 is a ×12 active frequency multiplier intended to extend a 10 dBm low frequency input signal at 7.833 GHz up to 94 GHz with a minimum output power of 4 dBm. While maintaining excellent rejection of unwanted harmonics, the A940-12XW-8 contains a series of amplifier and multiplier stages designed to achieve optimum power levels at all stages.

Spacek Labs Inc.,
Santa Barbara, CA
(805) 564-4404,
www.spaceklabs.com.

RS No. 234

High Linearity Converter

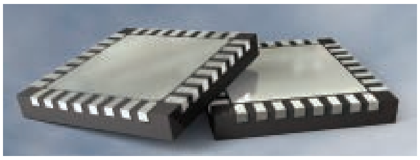


The ML483 is a high linearity converter combining a passive GaAs FET mixer with an integrated LO driver in an ultra small MSOP-8 package for wireless base stations and repeaters. The RFIC is able to operate across a 0.7 to 1.0 GHz frequency range to achieve +36 dBm input IP3 while drawing a very low 50 mA current from 0 dBm of LO drive level. The ML483 is footprint compatible with its high-band sister product, the ML485.

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

RS No. 235

QFN Packages



Endwave Corp. has an advantage when housing its high-performance monolithic-microwave-integrated-circuit (MMIC) products in a surface-mount package. By re-engineering the widely accepted QFN, or Quad Flat No-leads surface-mount-technology (SMT) package, Endwave has more than doubled the usable frequency range of the housing, increasing its upper-frequency limit to 50 GHz and higher. A standard QFN package is a micro-lead-frame-type SMT housing designed to provide protection for MMICs and other semiconductors while also simplifying their attachment to printed-circuit boards (PCB).

Endwave Corp.,
San Jose, CA (408) 522-3100,
www.endwave.com.

RS No. 236

Sources

Voltage-controlled Oscillator

These new coaxial-based VCOs are available from 800 to 4000 MHz and there are plans to expand to 7000 MHz. This new line of CROs offers superior electrical performance such as stable output power and excellent phase noise over harsh operating temperatures (-40° to +85°C) of today's system demands. These CROs feature up to 10 percent bandwidths with moderate output levels up to +8 dBm.

MICA Microwave Inc.,
Manteca, CA (209) 825-3977,
www.mica-mw.com.

RS No. 237

PLL Synthesizer

Peregrine's PE33361 is a high performance integer-N PLL capable of frequency synthesis up to 3500 MHz. The device is designed for superior phase noise performance with a direct, serial and parallel programming option. The PE33361 features a 10/11 dual modulus prescaler, counters and a phase comparator. Counter values are programmable through either a serial or parallel interface and can also be directly hard wired. The PE33361 is available in a 48-lead QFN and is manufactured on Peregrine's UltraCMOS™ process, a patented variation of silicon-on-insulator (SOI) technology on a sapphire substrate, offering excellent RF performance.

Peregrine Semiconductor Corp.,
San Diego, CA (858) 731-9400,
www.psemi.com.

RS No. 238

Oven-controlled Crystal Oscillator

Valpey Fisher Corp. introduces the VFOV600, the newest addition to its OCXO product line. The VFOV600 utilizes AT-Cut crystal technology to provide excellent performance at prices below conventional oven oscillators. At 600 milliwatts the VFOV600 consumes significantly less power than most standard OCXOs. It is built in a space saving DIL 14 pin package and generates frequencies up to 100 MHz. The VFOV600 has stability performance of Stratum 3 or better and has a phase noise floor of -160 dBc/Hz.

Valpey Fisher Corp.,
Hopkinton, MA (508) 435-6831,
www.valpeyfisher.com.

RS No. 239

Fixed Frequency Synthesizer

The model SFS3900A-LF is an RoHS compliant fixed frequency synthesizer in S-band. The SFS3900A-LF is a single frequency synthesizer that operates at 3900 MHz. This synthesizer features a typical phase noise of -88 dBc/Hz at 10 kHz offset and typical sideband spurs of -65 dBc. The SFS3900A-LF is designed to deliver a typical output power of 3 dBm with a VCO voltage supply of 5 VDC while drawing 33 mA (typical) and a phase-locked loop voltage of 3 VDC while drawing 15 mA (typical) over the temperature range of -40° to 85°C. This fixed frequency synthesizer features typical 2nd harmonic suppression of -20 dBc and comes in Z-Comm's industry standard PLL-V12N package measuring 0.60" × 0.60" × 0.13".

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

RS No. 240

Systems

Dichroic Subreflector

Cobham Sensor Systems - Baltimore announces the latest in Cobham's composite offerings. The solid laminate constructed dichroic subreflector is made from low loss high performance composite material. The subreflector has a three-dimensional geometry and contains a Frequency Selective Surface (FSS) embedded for dual band application. The subreflector is used for ship-based applications.

Cobham Sensor Systems – Baltimore,
Baltimore, MD (410) 542-1700,
www.cobham.com.

RS No. 241

Test Equipment

RF Signal Generators

AnaPico offers a range of RF signal generators designed to match different customer requirements and to provide a lightweight, compact and low cost alternative to high end laboratory grade instruments. Featured in the new catalog are: the APSIN3000 and APSIN6000, which are true handheld, low noise, fast switching instruments; the APSIN 6010 (9 kHz to 6,100 MHz), the company's fastest-switching analog signal generator; the APGEN 3000 (9 kHz to 3,000 MHz), with 0.1 Hz frequency resolution, good signal quality and powerful trigger capabilities; and the APPH 6000, a fully automated phase noise test system to 6 GHz. The company's modules and customized solutions for OEMs are also outlined.

AnaPico Ltd.,
Zurich, Switzerland +41 44 440 0051,
www.anapico.com.

RS No. 242

HSPA Evolution Test Solution

VENDORVIEW

Anritsu Co. introduces additional Release 8 HSPA Evolution software for its MD8480C Signaling Tester that builds on existing Dual Carrier downlink capability to create a more comprehensive Release 8 HSPA Evolution test solution. The new software includes features for testing Uplink Continuous Packet Connectivity (CPC), including Improved Layer 2 and Enhanced Cell FACH support, and provides developers of 3GPP protocol stacks, chipsets, and application software with an efficient test tool to verify performance, reduce cost of test, and improve time to market. The MD8480C Signaling Tester is a modular base station/network simulator with support for up to two RFs, four W-CDMA cells and two GERAN cells. The platform enables a full range of UE testing from physical layer to application and protocol testing, including tests requiring maximum downlink throughput of 42.2 MB/s or 2×2 MIMO.

Anritsu Co.,
Richardson, TX (800) 267-4878,
www.us.anritsu.com.

RS No. 243

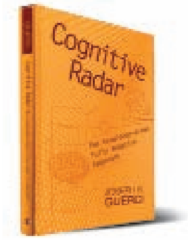
RF Peak Power Sensor

Boonton announced the extension of the fast 593xx peak power sensor family, the 59340. This RF peak power sensor is optimized for Boonton's high end peak power meter series 4500B and 4540. It provides dynamic input power ranges from -24 to +20 dBm in Peak mode and -34 to +20 dBm in CW mode. With frequencies of up to 40 GHz, its rise time of less than 10 ns and a bandwidth of up to 35 MHz, the new 59340 can even handle the most complex signal forms. Due to its high speed, the sensor is ideal for statistical measurements with high dynamic signal content.

Boonton,
Parsippany, NJ (973) 386-9696,
www.boonton.com.

RS No. 244

THE BOOK END



Cognitive Radar: The Knowledge-Aided Fully Adaptive Approach

Joseph R. Guerci

Cognitive Radar: The Knowledge-Aided Fully Adaptive Approach addresses major new developments in optimal and adaptive MIMO radar and knowledge-aided processing, yielding an entirely new dynamic radar architecture that possesses unprecedented capabilities for adaptation in challenging real-world environments. It covers important breakthroughs in advanced radar systems, and offers new and powerful methods for combating difficult clutter environments. In addition, there are details on specific algorithmic and real-time high-performance embedded computing (HPEC) architectures. This practical book is supported with numerous examples that clarify key topics, and includes more than 370 equations.

After a brief introduction to cognitive radar, the book covers optimal and adaptive MIMO radar including several examples from various systems. The optimization chapter covers transmit and receive functions along with MIMO target identifications and radar. Knowledge-aided adaptive radar is covered next with a final chapter on combining all the material for cognitive radar. Each chapter includes several examples and references to assist in understanding the material.

The author uses his many years of experience in the areas of research from work pioneered by experts from the Air Force Research Laboratory (AFRL) and Defense Advanced Research Projects (DARPA), where he led major new radar developments. Although this subject area has been researched for many years, it is still in its infancy so this book only briefly covers the subject as an introduction. Therefore, it is only intended to present key concepts as an overview to the field and further reading is needed for comprehensive coverage of this subject.

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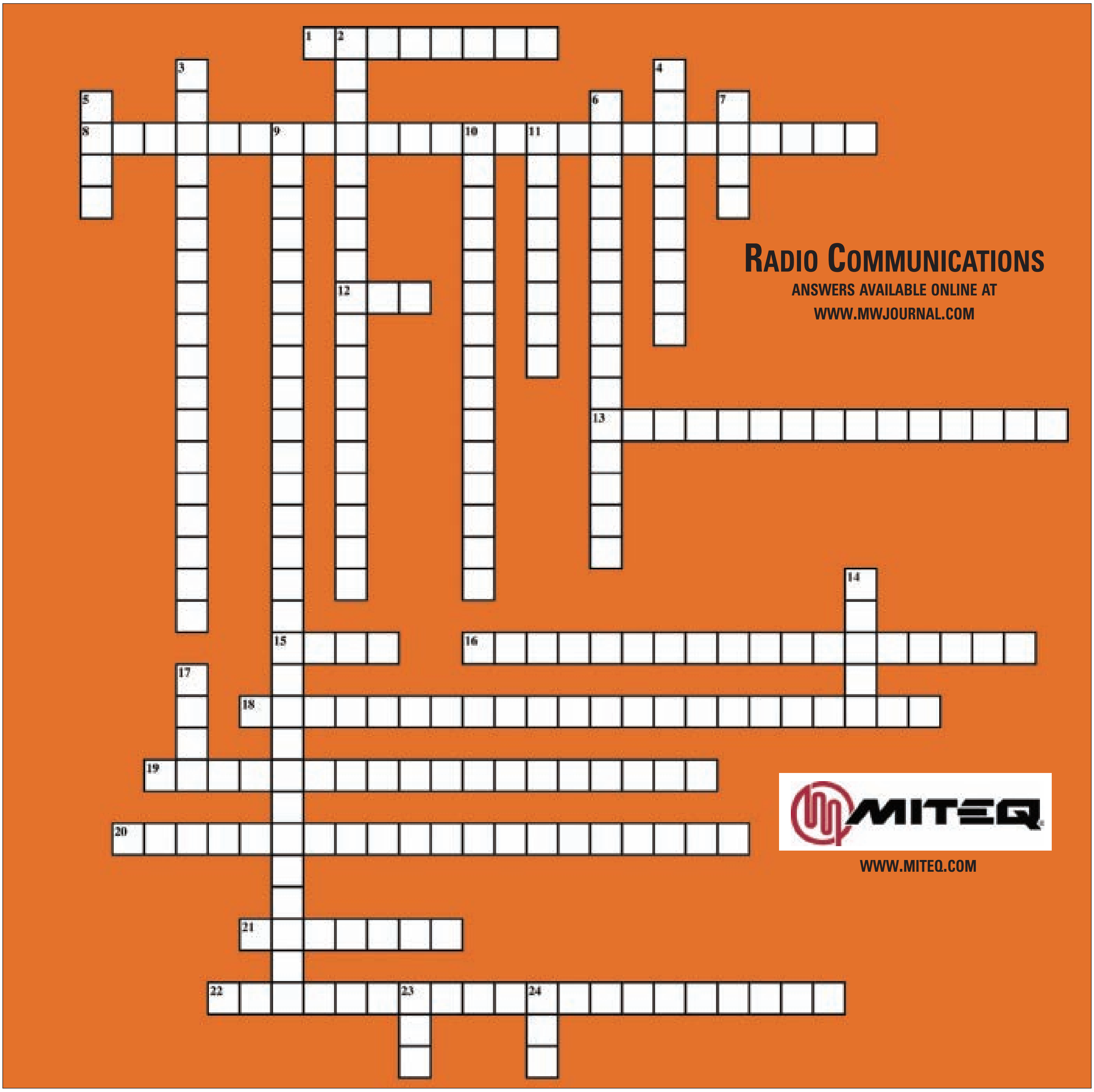

ACROSS

1 The state of play of MIMO OTA standardization in 3GPP is summarized in this document, which is in the study phase prior to formal standardization

8 The CTIA uses the term Total Isotropic Sensitivity (TIS) for this figure of merit (3 words)

12 Signal to noise ratio

13 AOA (3 words)

15 A method of digital modulation in which a signal is split into several narrowband channels at different frequencies

16 TRP (3 words)

18 The parameter used to assess how much of the DUT radiated power is absorbed by the human body (3 words)

19 MIMO systems take advantage of the spatial domain to realize increased ______________ (2 words)

20 A system that is designed to take advantage of reflections to measure the power radiated from a device (2 words)

21 Multiple-input multiple-output over-the-air (2 words)

22 The generalized distribution of a complex random variable that reflects the central limit theorem of combined random variations in phase and amplitude (2 words)

DOWN

2 Fading distribution with stronger line-of-sight components than a combination of all the random variations (2 words)

3 The quantitative measure of this similarity in received signals in a MIMO system (2 words)

4 An anechoic chamber creates a reference environment with a controlled ____________ that zeros out all the signal channel variables (2 words)

5 International Association for the Wireless Telecommunications Industry

6 A test system that is lined with RF absorber to prevent these reflections and ensure that the only RF energy measured is that transferred line-of-sight (2 words)

7 Single-input single-output

9 EMC (2 words)

10 A system for air interface testing, replacing the real-world radio channel between a transmitter and a receiver (2 words)

11 Techniques used to randomize the field structure to ensure that there are no standing wave resonances within the test volume

14 Wideband Code Division Multiple Access

17 3rd Generation Partnership Project

23 The most widely used standard for mobile telephony systems

24 Specific Anthropomorphic Mannequin phantom head nickname

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Millimeter-wave Stealth Radio for Special Operations Forces

For Special Operations Forces, an important attribute of any future radio will be the ability to conceal transmissions from the enemy while transmitting large amounts of data for situational awareness and communications. These requirements will mean that military wireless systems designers will need to consider operating frequencies in the mm-wave bands. The high data rates that are achievable at these frequencies and the propagation characteristics at this wavelength will provide many benefits for the implementation of 'stealth radio'. This article discusses some of the recent advances in RF front-end technology, alongside physical layer transmission schemes that could be employed for millimeter-wave soldier-mounted radio. The operation of a hypothetical millimeter-wave soldier-to-soldier communications system that makes use of smart antenna technology is also described.

The continuation of worldwide peacekeeping operations by the United Kingdom, United States and coalition allies has placed a continued reliance upon the use of Special Operations Forces to perform information-harvesting and security-based activities such as covert reconnaissance and surveillance, and directed counter-terrorism strikes. Key to the success of these operations is the ability of the Special Forces to work undetected well behind enemy lines. While visual concealment can often be achieved through the cover of darkness, masking of other potential sources of detection such as soldier-to-soldier radio communications is not as straightforward. In fact, given the recent influx of technology at the disposal of today's soldier, such as miniaturized Global Positioning System (GPS)-based navigational aids and multi-megapixel video cameras, and the need to share data for improved situational awareness, this is a task that will become increasingly difficult. It is clear that mission success could benefit quite significantly from a 'stealth radio'.

Designing wireless devices that are capable of meeting the stringent demands of the special operations soldier is a challenging task. Sol-

Simon L. Cotton and William G. Scanlon
Queen's University of Belfast, UK
Efstratios Skafidas
University of Melbourne, Australia
Bhopinder K. Madahar
Defence Science and Technology Laboratory, Ministry of Defence, UK

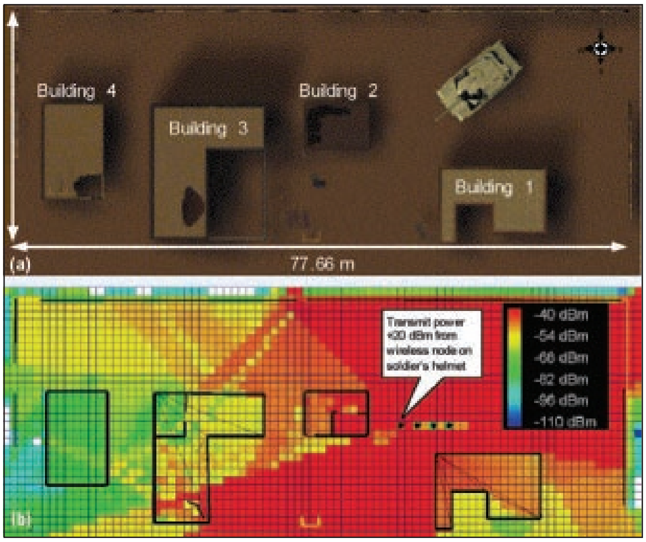
dier-mounted radios are expected to be extremely power efficient and ultra-reliable, mechanically robust and easy to operate, non-inhibitive to movement and capable of providing high data bandwidths. At the same time, they must be compact, lightweight and have a stealth mode of operation. With the widespread use of wireless technology, they must also be resilient to interference from both co-located spectrum users and malicious jamming by enemy forces. These are formidable challenges, but may be surmountable using both recent developments in millimeter-wave (mm-wave) transceiver technology,[1,2] and the 5 to 7 GHz of contiguous bandwidth currently being made available throughout the world in the 60 GHz mm-wave band.[3]

BENEFITS OF 60 GHZ TECHNOLOGY

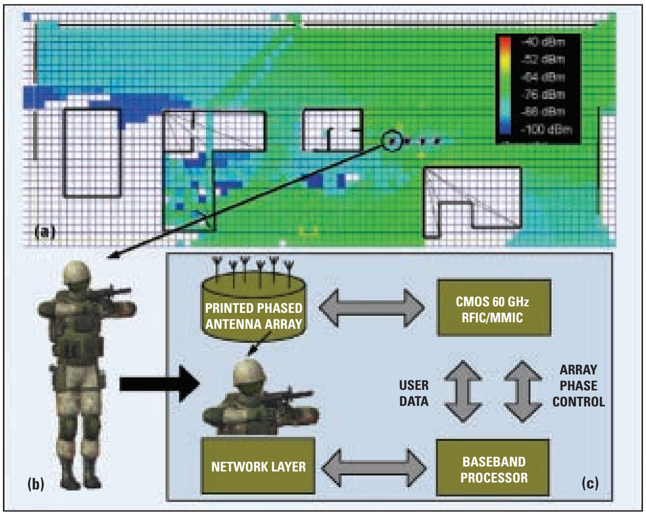
To achieve optimal network-centric operations, tactical information must be effectively distributed among soldiers while maintaining a low probability of detection and intercept. This places two distinct requirements on the air interface technology used: it must be capable of high data rates (when required) and have desirable propagation characteristics. Although there are a number of candidate air interface technologies that could be used to implement soldier-to-soldier communications such as ultra-wideband (UWB) in the 3.1 to 10.6 GHz band and Wi-Fi in the 2.45 and 5.2 GHz bands, this article focuses on 60 GHz communications. Operating soldier-mounted radios at this frequency will offer a number of key benefits compared to the other competing lower frequency technologies. For example, 60 GHz millimeter- wave communications will operate in currently under-utilized spectrum space and will provide high data rates of up to several gigabits per second for short-range applications.[3] Furthermore, factors that would generally be considered to hinder traditional radio communications can be exploited to provide the desirable signal propagation characteristics required for short-range military communications. These include: increased covertness, high frequency reuse and reduced risk of interference, which may be attributed to higher path loss, increased atmospheric oxygen (O_2) absorption and the narrow antenna beamwidth inherent with high-gain arrays.

Shorter wavelength mm-wave frequencies are also subject to much greater losses caused by electromagnetic (EM) interactions with everyday objects (e.g., building structures and personnel) when compared to longer wavelength microwave frequencies. This effect can be observed in ***Figure 1***, which shows the power received by a square grid (resolution 1 m^2) of isotropic antennas placed at a height of 1 m above ground level, in a Computer Aided Design (CAD) model of a Middle Eastern compound, from a wireless node operating at 2.45 GHz positioned on the protective helmet of a soldier. For this simulation, the antenna associated with the node had an omnidirectional radiation pattern and was configured to operate with a transmit power of +20 dBm. The results were obtained using a ray tracing EM simulation tool, simple material models of the building structures, and human body models generated using the Poser 7 animation software as described in the literature.[4]

It can be seen quite clearly that the signal transmitted from this node illuminates the majority of the outdoor environment with a received power generally greater than -70 dBm. This high degree of signal coverage is clearly undesirable for the proposed stealth mode of radio operation. In contrast, ***Figure 2*** shows a much less extensive coverage pattern for the same node when operated with an identical transmit power at 60 GHz. Here, the level of signal illumination is significantly reduced. For a considerable region of the outdoor environment, particularly within and in the immediate shadow of the buildings, virtually no signal is received at all, as shown by the white squares indicating levels below -100 dBm.



▲ *Fig. 1 CAD model of hypothetical Middle Eastern compound (dimensions 29.08 × 77.66 m) (a) and signal coverage at a height of 1 m from a 2.45 GHz wireless node positioned on the protective helmet of soldier (b) [see Figure 2 (b)] .*



▲ *Fig. 2 Signal coverage at a height of 1 m throughout hypothetical Middle Eastern compound (dimensions 29.08 × 77.66 m) (a), from a 60 GHz wireless node positioned on the protective helmet of soldier operating (b) and system level view of smart antenna hardware operation (c).*

Another important feature of mm-wave frequencies is the small-size of product that may be achieved. At 60 GHz, it is possible to construct a cylindrical antenna array with 32 elements placed half-wavelength apart, all within a radius of 13 mm (close to the size of a US quarter). This will permit the development of compact, wearable smart antenna technology that could use technologies such as adaptive beam steering to dynamically adjust the array pattern by altering the am-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plitude and phase of a feed network. A system level view of the smart antenna hardware operation is shown in ***Figure 2c***, where information passed down through the network layer is used to control the phase at the input of an antenna array. This will allow antenna gain to be focused in the required directions, helping to counteract eavesdropping, improving resilience to jamming and provide a lower probability of detection by enemy forces.

60 GHZ STEALTH RADIO: THE PHY LAYER

Transmission Schemes: There are a number of different transmission schemes that could be adopted for soldier-to-soldier communications. These include the single carrier (SC) and orthogonal frequency-division multiplexing (OFDM) schemes specified in the IEEE 802.15.3c standard for high rate wireless personal area networks.[5]

OFDM is well known for its ability to mitigate against frequency selective fading due to multipath, by turning the transmission channel into a series of suitably modulated (e.g., quadrature amplitude modulation) orthogonal sub-carriers. This has the effect of greatly reducing the complexity of transceiver design through the use of IFFT and FFT signal processing stages for signal transmission and reception respectively, and negates the need for intricate wideband equalizers.

While OFDM may be resilient to multipath effects, it is prone to a high peak-to-average power ratio (PAPR), phase noise and carrier offset. High PAPR will be a particular problem for soldier-mounted radios, as it will cause nonlinear distortion and low-power efficiency in the power amplifier[3] directly impacting upon battery life. The complexity of time-domain channel equalization in wideband SC systems is regarded as its main drawback for use in high data rate mobile radio channels. However, this challenge can be overcome through the use of frequency domain equalization (FDE). Single carrier systems with FDE (SC-FDE) typically use transmission blocks with a cyclic prefix to prevent inter-block interference. Signal recovery at the receiver is then performed through FFT processing with equalization followed by an IFFT stage. SC-FDE will then deliver performance similar to OFDM, with essentially the same overall complexity,[6] but because SC modulation uses a single carrier it has the added advantages of lower PAPR and less sensitivity to both phase noise and carrier offset.[7]

RF Front-end Technology: The choice of 60 GHz RF front-end technology for a soldier-mounted radio will introduce a tradeoff between performance and cost. Traditionally group III-IV semiconductor technologies such as GaAs and InP have been used for mm-wave radios. While they offer superior noise characteristics and high gain at mm-wave frequencies, they also suffer from a high cost per unit, poor integration and low power efficiency. CMOS technology on the other hand will offer lower-cost mass production, improved integration and increased power efficiency; however, CMOS front-end circuits will also have to address issues in power amplifier output, local oscillator phase noise and low-noise amplifier design as discussed in the literature.[7]

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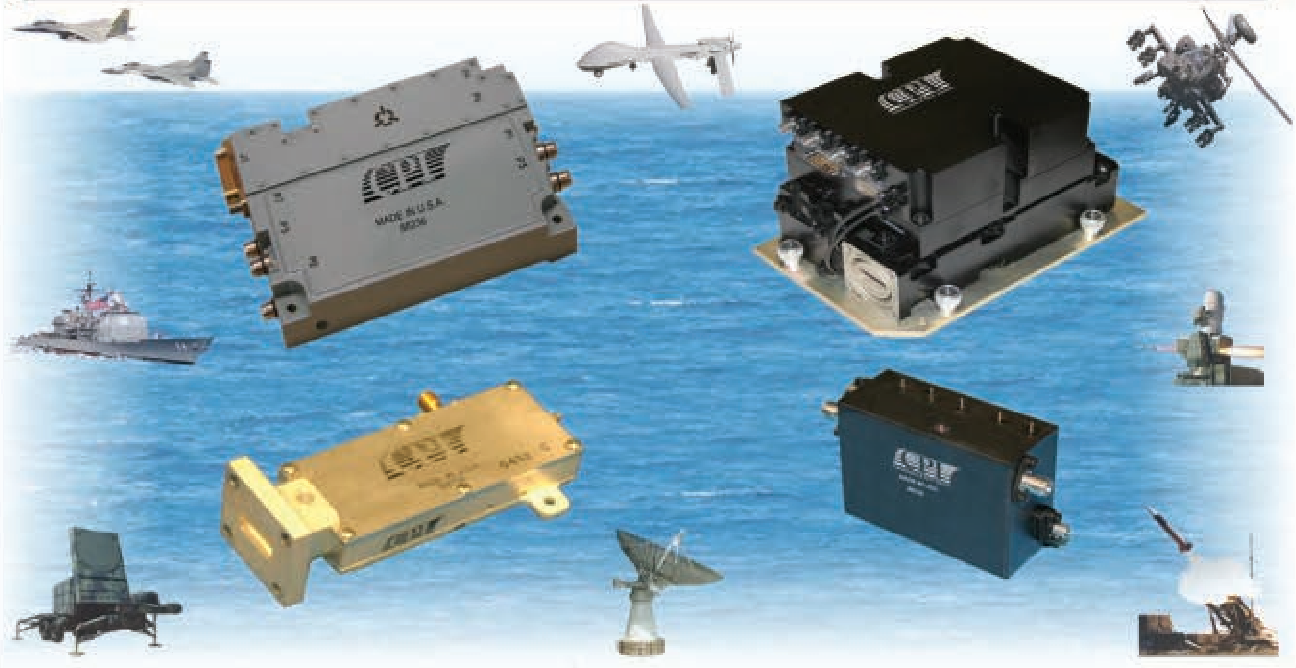

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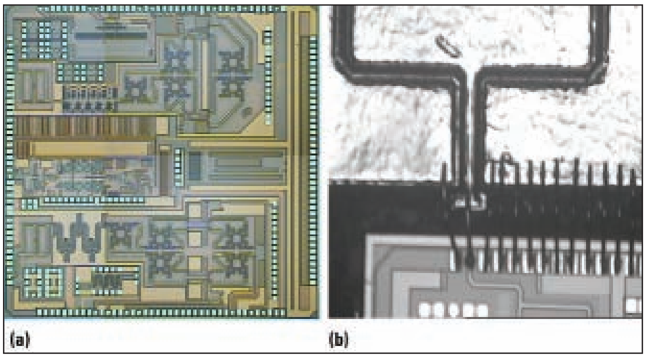
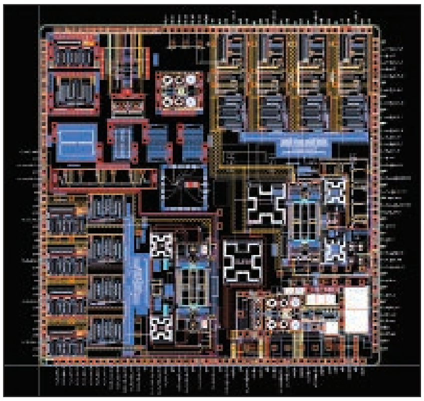


▲ *Fig. 3 An integrated 60 GHz transceiver on 130 nm CMOS[2] (a); wire-bond attached antenna to CMOS transceiver[9] (b).*

As a compromise, more recent advances in silicon germanium (SiGe) technology have now made it possible to build miniaturized, low-cost mm-wave radio devices, such as the 60 GHz, 0.13 μm SiGe BiCMOS double-conversion superhetrodyne receiver (Rx) and transmitter (Tx) chipset recently developed by IBM.[1] Here, data rates of up to 630 Mbps have already been demonstrated for this chipset over a 10 m indoor Line of Sight (LOS) link using folded-dipole antennas for both Tx and Rx modules. Based upon link budget calculations, the IBM authors also state that increasing the receiver gain by 12 dBi (e.g., using smart antenna technology) could increase the range by a factor of four assuming free space propagation. Undoubtedly, even greater operating distances may be attained by sacrificing bandwidth and data rates or improving overall system gain.

In Reference 2 a single chip multi-gigabit transceiver on CMOS is described; the architecture of this device is illustrated in ***Figure 3a***, while ***Figure 3b*** shows the device with an integrated antenna. In ***Figure 4***, a 4 × 4 phased array transceiver implemented on 65 nm CMOS is shown.[8] The measured receiver noise figure is 5.5 dB and the output P1dB of each transmit chain is 7 dBm. This device, including 4 transmit and receive chains, consumes a total of 650 mW.



▲ *Fig. 4 Phased array 60 GHz transceiver on 65 nm CMOS incorporating 4 transmit and 4 receive chains.[8]*

MM-WAVE SOLDIER-TO-SOLDIER COMMUNICATIONS

One of the greatest challenges to ensuring the success of a 60 GHz-based special operations radio will be the system's ability to cope with the unpredictable nature of its operating environment. Everyday obstacles like buildings, cars, vegetation and even humans, which can limit the propagation of microwaves, will have a much greater

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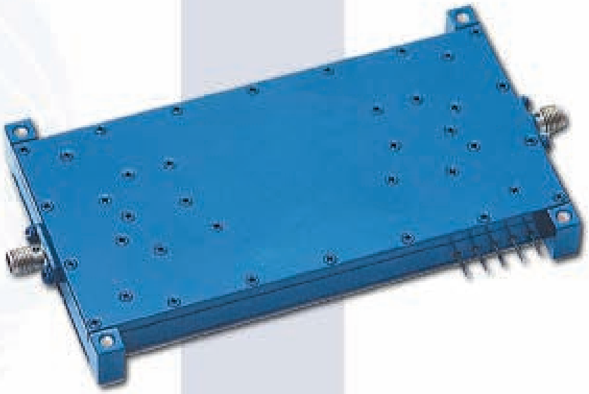

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impact on mm-wave systems. For example, in Reference 10 it is reported that human body shadowing can cause attenuations of greater than 20 dB on indoor 60 GHz device-to-device links. Field trials performed by the authors investigating human body shadowing events on indoor point-to-point links found similar results (attenuations of 20 to 25 dB), with the greatest shadowing events occurring when a person moved in close proximity to a 60 GHz node, blocking the LOS. In military operations, the continual movement of soldiers in high-tempo urban (i.e. cluttered) environments is likely to lead to frequent loss of LOS links between two soldiers. Hence, the wireless link will become dependent upon multipath contributions from signals scattered, reflected and diffracted from the surrounding environment.

To overcome channel impairments and exploit multipath propagation, 60 GHz soldier-mounted radios will have to make innovative use of beam steering hardware, time of arrival (TOA) and direction of arrival (DOA) information, digital navigation aids such as GPS (e.g. soldier's digital assistant) and inertial navigation systems as well as smarter routing tables and strategies. The positional information needs to be readily shared among squad members during communications packet exchange so that internal calculations may be performed to estimate relative geometries (these methods of DOA estimation may not be as effective in indoor environments or when the direct LOS is obstructed). All of this information will form the basis of an internal positioning table used to administer and manage connections between soldiers.[4] The success of the system will also depend on a bespoke directive medium access layer (MAC). As the focus of this article is on the PHY technologies, required MAC operation is not discussed. Instead the interested reader is referred to Reference 4 and the references therein for a full description of its functionality. However, the reader should note two important points, vital to the understanding of the proposed system operation. Firstly, when a node is in idle mode, or during random back-off intervals in contention periods, it should listen to the channel omnidirectionally, that is, without beam steering. Secondly, all other operations associated with channel access, set up and data transfer (both transmit and receive) should be performed directionally.

To illustrate how 60 GHz communications could be achieved, consider single hop communications between soldiers B and C, as shown in ***Figure 5***. If it is assumed that successful communications between these two soldiers have occurred very recently and hence they have good estimates of their relative locations or DOAs of significant multipath components, soldier C uses the last known 'good' directional entry for soldier B in his internal positioning table to initiate communications (not necessarily the LOS link). All nodes that may overhear the transmission (e.g., soldiers A and B who are in idle states) then update their internal positioning tables with the incoming signal's DOA and adjust the elapsed time of arrival information. This will include tracking and storing all major multipath components as well as the most significant


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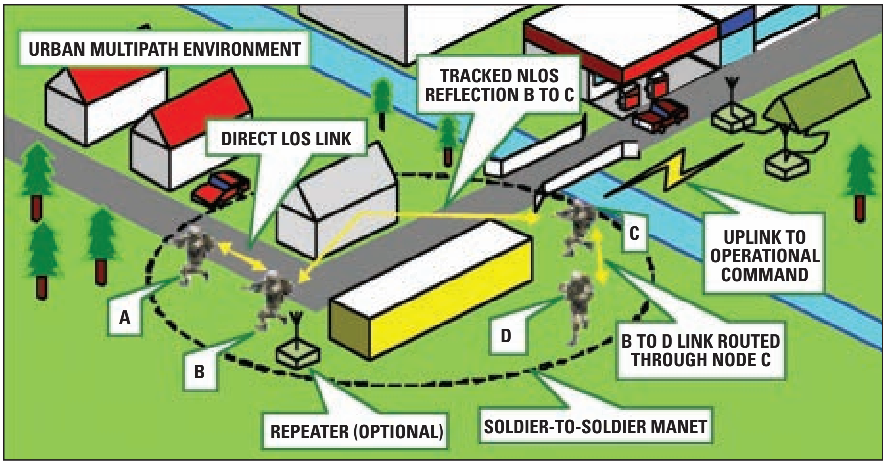

▲ *Fig. 5 Millimeter-wave soldier-to-soldier communications system.*

path, as shown in Figure 2.[4]

Assuming unhindered channel set up, soldier B then uses the information stored in his positioning table to beam steer in the direction of soldier C. Meanwhile, soldier C also beam steers in the direction of soldier B and begins the directional transmission of data. Throughout this process, all nodes that can hear the exchange, continuously update their positioning tables. In the case of soldiers B and C, this will provide the maximum opportunity of re-establishing the link should it unexpectedly go into outage, before abandoning transmission and handing the problem to the network layer for routing as outlined in the 'packet transmission' flowchart (see Figure 2).[4] Link sustainability can also be guaranteed by dropping repeater nodes as the team progress through the theater of operations. As these nodes simply capture and repeat packet transmissions, they carry no information on encryption methods used and therefore can be safely discarded.

To further enhance the stealth mode of operation, the system could also use adaptive power control. Here, radio transmit power is adjusted on a packet-by-packet basis to the minimum level required for operation with a given capacity and error probability. These schemes are often desirable in mobile wireless systems for the purposes of reducing interference and prolonging battery life.

Overall, this is only a brief overview of how directional 60 GHz communications could work between soldiers. However, it will be particularly susceptible to many of the common issues associated with wireless networking such as the hidden node problem, deafness and gain asymmetry.

CONCLUSION AND FUTURE WORK

Previous sections outlined the innovative developments that are taking place at mm-wave frequencies that can help realize 'Stealth Radio' for the benefit of covert applications such as Special Operations Forces. By fusing a 60 GHz operating frequency with smart antenna technology it will be possible to build short-range body-centric networks that are virtually undetectable to the enemy. Not only will these systems provide covert communications, but they will also provide the bandwidths required to simultaneously transmit real-time streaming video, voice, health and location related data.

Current work is focused on developing the low cost, power efficient integrated beam steering transceivers needed for these systems and characterizing their performance in realistic scenarios and environments that represent the difficult propagation conditions expected for these systems. While today's state-of-the-art systems, implemented on 65 nm CMOS, consume approximately 650 mW, next generation 60 GHz systems, implemented on 45 nm and 32 nm CMOS, will reduce power consumption to less than 300 mW and substantially improve in receive sensitivity by incorporating better beam steering as well as MIMO receivers. Future work is aimed at the engineering and integration of a wearable prototype research system. This will be used for an assessment of mobile ad hoc networking between dismounted combat troops and channel performance using a combination of representative real and virtual environments. ■

ACKNOWLEDGMENTS

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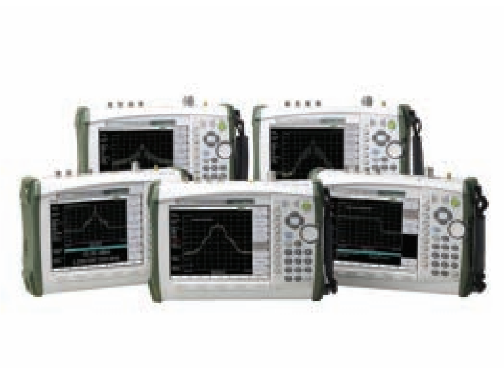

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Executive Interviews

As the spectrum grows more crowded, higher and higher frequencies are being used. One example is microwave backhaul for cell sites in the 38 GHz range, although there are many others as well. The new Spectrum Master™ MS272xC series from Anritsu Co., which includes the industry's first 32 and 43 GHz handheld spectrum analyzers, has been developed for these higher frequency applications.

Five models—the MS2722C, MS2723C, MS2724C, MS2725C and MS8726C—are included in the series. In addition to the wide frequency coverage, as shown in ***Table 1***, these instruments deliver excellent phase noise of -95 dBc/Hz at 10 kHz offset at 1 GHz and dynamic range of 101 dB. The instruments include a broadband preamplifier that operates all the way to 43 GHz.

A new fast sweep selection feature of the handheld spectrum analyzers gives them unprecedented sweep speed of about 27 seconds for a 43 GHz span with 30 kHz RBW. Similar analyzers need more than an hour to conduct the same sweep. Additionally, those analyzers are large, heavy and require AC power. The MS272xC weighs less than eight pounds and employs a long-life rechargeable battery that can be field-swapped without tools (see ***Figure 1***).

Three sweep modes—Fast, Performance

TABLE I

FREQUENCY RANGES FOR SPECTRUM MASTER MS272xC SERIES MODELS

Model	Frequency Range
Spectrum Master MS2722C	9 kHz to 9 GHz
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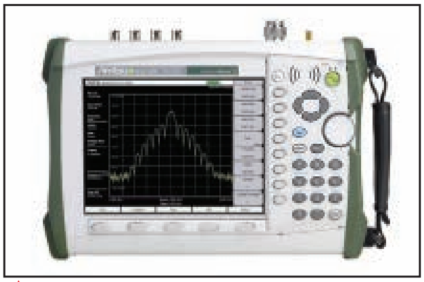
and No FFT—are available in the MS272xC series. In the Fast sweep mode, the handheld spectrum analyzers deliver sweep speeds that are virtually the same for resolution bandwidths from 10 MHz down to 30 kHz. Performance mode allows sweeps to be conducted in the traditional method, with sweep speed changing as the RBW is changed. The No FFT mode allows users to see the line spectrum of pulse modulated signals.

COMMERCIAL AND AEROSPACE/ DEFENSE APPLICATIONS

The MS272xC series can be configured with a 140 MHz IF output option that is 30 MHz wide, which is ideal for signal monitoring agencies since they often have their own proprietary signal processing tools. The small size coupled with SCPI programmability makes these products ideal instruments for incorporation in flight line test systems.



▲ *Fig. 1 MS272xC spectrum analyzer.*

A number of 3G/4G options can be easily incorporated into the handheld spectrum analyzers to measure LTE, HPSA+, W-CDMA, CDMA/EVDO, GSM/EDGE, TD-SCDMA and WiMAX signals. The many available options enable users to purchase the exact capability they need at the moment while providing the flexibility to add measurements when/if requirements change. Further, the instrument can be equipped with a GPS receiver that allows location stamp measurements to be made, as well as enhances time base accuracy to 50 ppb.

EASE OF USE

The MS272xC family employs the same familiar Spectrum Master user interface. Some evolutionary changes have been added to the interface, such as larger, easy-to-read text for data entry and a very large marker data display choice. Other benefits of the new user interface include logical grouping of set-up parameter annotations and simultaneous display of x-axis annotations—start, stop, center and span frequencies.

All measured data can be extracted and the instruments can be remotely operated using Anritsu Master Software Tools (MST), which provide users with the capability to conduct detailed evaluation of measurement data. Interference sources can be easily identified using built-in reporting tools, mapping, folder spectrograms and 3D Spectrograms. These tools eliminate the need for more expensive, larger, heavier benchtop instruments, as well as third-party spectrum monitoring software.

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Experimental Set Up Demonstrating Combined Use of OFDM for Radar and Communications

Orthogonal Frequency Division Multiplexing (OFDM) waveforms are viable alternative signals to be used for a new generation of radar networks. A network of radars using OFDM signals enhances the information acquired in the detection process when compared with that obtained by a single station. A set of experiments have been performed to demonstrate and verify OFDM-radar signals allowing communications among radar stations taking into account both the current electronic capabilities and signal parameters needed for a proper radar-communication synergy.

Both radar and communication systems are RF systems that can be combined with a partially shared technology basis. The challenge is to combine them with the aim of improving radar performance. A network of radar stations, where each station would operate either mono-statically or bi-statically, could be used to ensure that targets are viewed from different aspect angles, allowing classification of objects. The abundance of different information about the targets has to be communicated by the individual radar stations. The information exchange is possible by using a centralized or distributed solution by wireless transmission from one station to the other. The communications among multiple radar units can be embedded in the radar signal without extra infrastructure, allowing in this way the exchange of communication messages between radar stations, including the reports of detected targets, for example.

However, there are fundamental differences between communications and radar systems. Communication needs higher signal-to-noise ratios (SNR) at the receiver for proper recognition of the transmitted symbols, while radar systems can integrate over a specified number

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of transmitted pulses. Time-varying multipath channels pose problems to the communication systems due to moving objects, while for radar this is a basic feature for recognition of moving targets.[1] In this way, the proper selection of a specific waveform can alleviate those issues and facilitate the combination between communications and radar.

According to the waveform, both systems typically desire a large time-bandwidth product and an efficient use of the spectral resources. Nevertheless, radar systems also have other challenges due to their frequent operation in more complex environments; for example, unmasking weaker targets in a multi-target scenario or solving range/Doppler ambiguities.

This article is focused on a monostatic single radar station belonging to a certain network, where the communication signal is embedded in the radar transmit waveform, in this case OFDM. Range and Doppler processing schemes proposed by some of the authors will be tested to evaluate the radar operation with such a signal. Moreover, the feasibility and demonstration that OFDM waveforms can provide both communications among radar stations and radar operation, even when high computational complexity appears in the processing schemes, will be shown and verified with the results obtained from an extensive set of measurements. Synchronization among stations, network structure and physical-layer assessment is beyond the scope of this report; information on these topics can be found in the literature.[2]

WAVEFORMS GENERATED

The concepts described in the following are developed in the context of a study of the viability and the opportunities rising from a wireless network of radars supporting an integrated communication link on the radar transmit signal. The objective is to prove the double usage (radar and communications) of specifically designed radar waveforms, such as OFDM, taking the limitations of current electronic devices and equipment capabilities into account.

The waveform selected for the synergy between radar and communication is OFDM. Recently, there has been a lot of interest in OFDM signals, not only for communication but also for radar. For this, OFDM has been studied extensively.[3-6] Wideband radar systems are easily obtained with OFDM, where the spacing between carriers can be chosen to be large enough, obtaining in this way a large instantaneous bandwidth to provide the radar with a higher resolution capability (ability to distinguish between two or more targets on the same bearing at different ranges).

OFDM is a digital multi-carrier transmission technique that allows an efficient use of the bandwidth and a simultaneous large instantaneous bandwidth for the radar operation. This modulation scheme maps the digitally encoded symbols over several frequencies (subcarriers) to achieve robustness against fading in a multipath radio channel. Even though the spectra of the individual subcarriers overlap, the information can be completely recovered without any interference from other subcarriers as a consequence of the orthogonality of the base functions of the Fourier series.[6] In a multipath scenario, orthogonality is kept among subcarriers by inserting a cyclic prefix (usually a cyclic extension of the current transmit symbol). However, the addition of this prefix, which mitigates the effects of link fading and inter-symbol interference (ISI), increases the bandwidth and introduces some loss in efficiency since no new information is carried. Moreover, for communications purposes, OFDM permits frequency diversity improving the reliability of a message signal by using two or more communications channels with different characteristics. In this way it is possible to combat co-channel interference and avoid error bursts.[7]

Nevertheless, several challenges arise for the novel use of this multi-carrier waveform in radar. The range and Doppler processing are different compared to standard processing schemes in order to benefit from the characteristics that the OFDM waveform offers, such as tunability and individual subcarrier retrieval. The flexibility in the coding of the OFDM waveform for communication purposes requires an ad hoc processing scheme to counteract interference between close-by object targets in the radar processing. The large instantaneous bandwidth required for radar

operation imposes challenges to standard electronic equipment. There are more stringent requirements on the waveform for radar operation than for communication. Signal parameters such as subcarriers spacing Δf, and number of possible subcarriers N inserted in a specified bandwidth, require careful consideration to preserve orthogonality among subcarriers and prevent a high peak to average power ratio (PAPR), since the latter is proportional to the number of subcarriers if their phases were perfectly aligned.

The communication encoding of the OFDM waveform has to be properly designed in order to constrain the inherent high PAPR of this signal. This measure allows the linear operation of the amplifiers in the receive chain to prevent signal distortion and the optimal use of the dynamic range of the global system. The PAPR of the OFDM waveforms was limited by constraining the random phase codes, simulating the communication messages. Golay codes are also a valid alternative to constrain the PAPR in OFDM signals. Nevertheless, a trade off between communication throughput and radar performance comes up.[8] In this way, the PAPR of the OFDM waveforms used along the experiments can be limited to values smaller than 10 dB or even until 3 dB.

In this article, two different 300 MHz bandwidth OFDM waveforms are considered, continuous and pulse version, to test suitable range/Doppler processing techniques for each case.[9,10] The main characteristics and parameters of the OFDM waveforms used along the experiments are the following:

Long OFDM Chip

This waveform consists of OFDM chips that are transmitted consecutively, with cyclic prefixes (CP) inserted in between the chips as guard intervals. A chip is the basic section of the OFDM signal with a length exactly equal to $1/\Delta f$. The receiver is active as long as the actual body of an OFDM chip is being transmitted, while it is turned off during the transmission of the cyclic prefix.[9] The timing is depicted in ***Figure 1***.

The carrier spacing Δf, the guard interval ratio α, and the numbers of carriers N were:

- N= 300000 subcarriers
- α= 0.1
- Δf = 1 kHz

where α is calculated as the ratio of the guard interval duration to the chip length T.[9] The guard interval allows pulse compression for range processing, considering that the maximum range of interest should correspond to a delay smaller than the guard interval.

Short OFDM Chip

This waveform is typically a pulse burst, as depicted in ***Figure 2***. Each pulse is an OFDM chip with short duration. The pulse duration T, and the numbers of carriers N were in three different cases:

- T = 1, 5, 10 µs
- PRT = 100 µs
- N = 300, 1500 and 3000 subcarriers

The pulse repetition time (PRT) values were chosen arbitrarily as for typical medium PRT radar. Nevertheless, it must be considered that the maximum desired unambiguous speed and maximum unambiguous

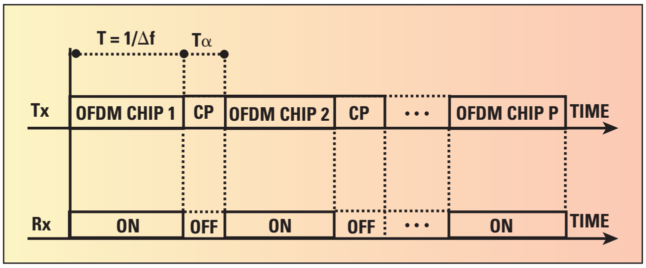


Fig. 1 Long OFDM chip.

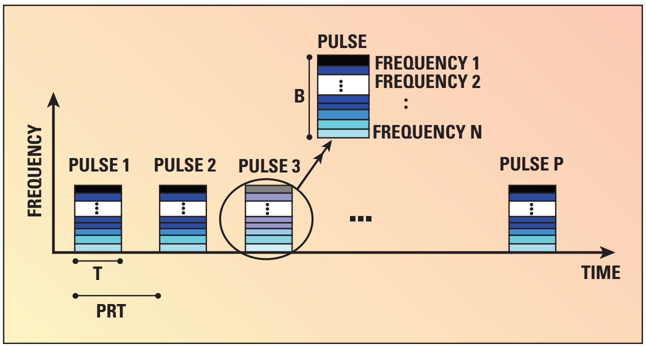
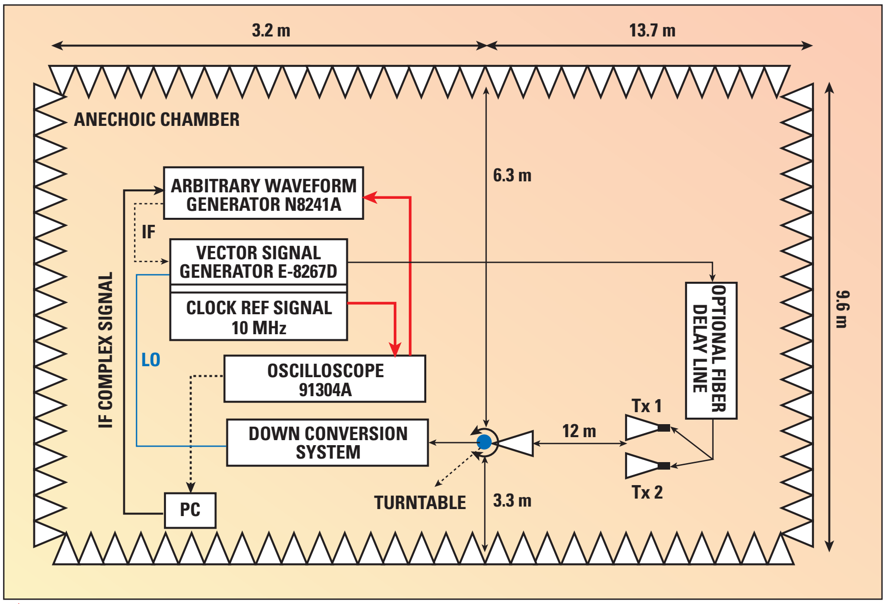


Fig. 2 Short OFDM chip.



▲ *Fig. 3 Anechoic chamber: map and equipment (not to scale).*

range constrain this value.[2] The pulse duration T changes according to the corresponding number of carriers inserted in each chip (T = 1 µs for N = 300, T = 5 µs for N = 1500 and T = 10 µs for N = 3000). To preserve orthogonality among carriers, the carriers spacing Δf must be the inverse of the chip duration T. Multiple chip durations allow different time-bandwidth products. In this case, there is no need for guard interval as will be explained later on.

As the OFDM waveform was developed for communications systems, it is important to verify the effects of electronics (deterioration of the radar performance due to hardware limitations, degradation, loss of functionality, detection capability, distortion effects) from the front-end to down-conversion to sampling, on the waveform for its performance for radar-communications fusion.

EXPERIMENTS AND ELECTRONIC SYSTEMS SET UP

The experiments consisted of one main measurement set up, and were carried out with OFDM signals of 300 MHz bandwidth around a carrier (RF) frequency of 10.05 GHz. From the computer (PC) shown in ***Figure 3***, the intermediate frequency (IF) complex signals are uploaded to the arbitrary waveform generator (AWG), which provides the I and Q signals with 300 MHz bandwidth on a 250 MHz carrier. For signal-conditioning, the AWG uses the differential mode, providing common mode rejection and signal fidelity.[11] The AWG performs an internal sampling of the signal at 1.25 GHz. Subsequently, the I and Q signals are sent to a vector signal generator (Agilent PSG E-8267D Options 520/016) that carries out the up-conversion stage by using a local oscillator (LO) signal with a certain frequency.[12] The PSG Option 520 stands for an LO frequency range of 250 kHz to 20 GHz; Option 016 allows differential wideband external I/Q inputs. Once the RF signal has passed through the transponder system, it can be visualized on an oscilloscope (DSA 91304A). The DSA samples the received signal from the transponder with a certain rate and permits downloading the received signal to the computer where it can finally be processed with MATLAB. To simulate continuous wave (CW) transmission for the long OFDM chip, the DSA is single triggered during a single measurement, whereas for the short chip case the DSA is triggered at the beginning of each pulse to simulate pulse transmission. In the latter case, it must be considered that due to the small duty cycle of this waveform it is not necessary to record the silence periods between successive pulses, and thus no guard interval, decreasing in this way the data needed to be recorded in the internal memory of the DSA.

An external down-converter system was used in front of the DSA to

down-convert the RF signals to IF before sampling in the DSA (IF down-conversion). As an alternative, an RF down-conversion could be performed in MATLAB as long as coherent reception imposed for the modulation-demodulation scheme can be guaranteed for communications purposes. In the experiments campaign, it was not possible to preserve a coherent reception, thus this possibility was discarded in the bench test. The description and purpose of the external down-converter will be presented later.

The anechoic chamber and the main systems mentioned are shown in Figure 3. The DSA-AWG clock rate synchronization is carried out with a reference signal of 10 MHz, taken internally from the DSA (red arrow in Figure 3). This guarantees that the samples taken by the DSA are on the same phase values of the IF signal, and provides the same starting point of the data logging by the DSA relative to the IF signal. Synchronization between PSG and the rest of the equipment is done with a 10 MHz reference signal taken from the PSG to help in the phase-frequency stability of the LO signal when up-converting and down-converting the IF and RF signal respectively, since the same LO signal is used for both operations.

TRANSPONDER AND FIBRE OPTICAL DELAY LINE SET UP

The transponder is intended for use with OFDM radar signals (see ***Figure 4***). It was designed to possibly include variable delay and amplitude between two simulated targets. The transponder system basically consists of:

- Tx gain horn antennas: $\theta_{-3dB} = 11°$, 22.31 dB gain
- AWG & PSG
- 2 amplifiers: G2 (46 dB gain), G3 (20 dB gain)
- Delay line (60.18 µs): 65 dB loss, noise figure 67 dB
- Power combiner (3.5 dB loss)
- 2 variable attenuators
- 2 coaxial cables (10 meters long each): 5 dB loss each

All components are operated at least 10 dB below their 1 dB compression point to create room for the peak to average power excursions. Since it is desired to create both a single and a multi-target scenario, variable attenuators are incorporated in front of the transmitters, to possibly switch on/

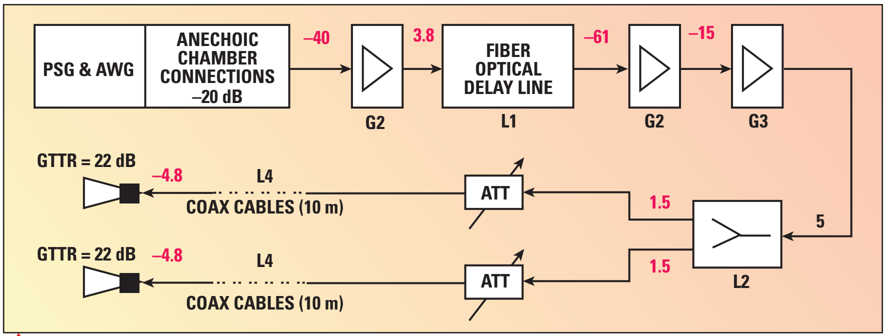


Fig. 4 Transponder block diagram and signal level 1 (dBm).

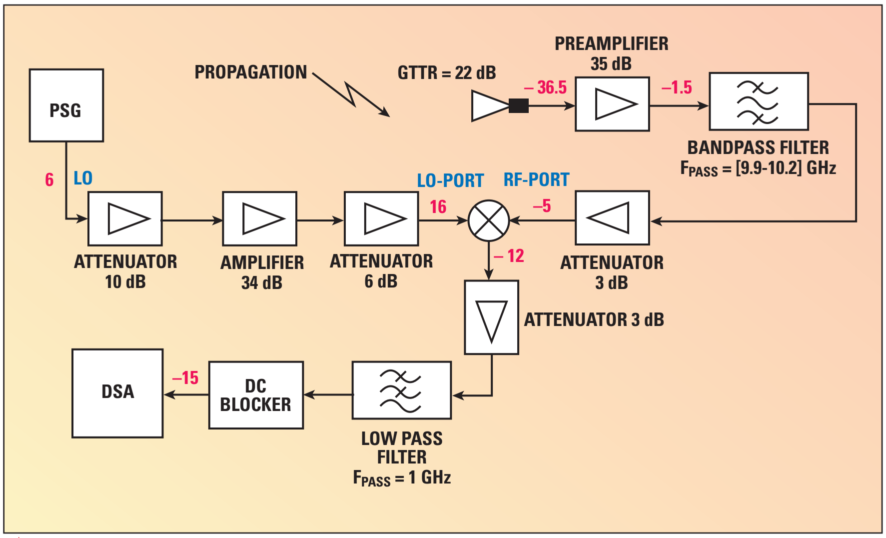


Fig. 5 Down-converter scheme with both LO and OFDM signal levels (dBm).

off one of the simulated targets and perform the difference in amplitude between the two possible targets. G2 and G3 were used to compensate for the losses of the delay line and optimize the use of its dynamic range.

The output power level setting on the PSG was -20 dBm. In the connection from the PSG output to G2 there were 20 dB losses due to the cable-connections of the anechoic chamber; thus, the levels of the signal at each point of the transponder are finally those shown in red in the figure.

EXTERNAL DOWN-CONVERSION SYSTEM SET UP

The external down-conversion system converts the received RF signal from 10.05 GHz to an IF signal at 250 MHz. This system is shown in ***Figures 5*** and ***6***. The down-converter system consists of:

- Rx gain horn antenna: $\theta_{-3dB} = 11°$, 22.31 dB gain
- Preamplifier: 35 dB gain
- Bandpass filter
- Double side band mixer
- Low pass filter

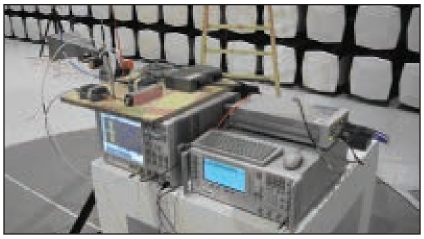


Fig. 6 Down-conversion system, DSA, AWG and PSG.

- 4 attenuators
- DC blocker

The preamplifier is used to improve the level of the signal coming from the delay line and free space propagation. Subsequently, a bandpass filter was placed with a pass-band in the frequency range of 9.9 to 10.2 GHz. The filter presents a negligible attenuation in the band pass of interest, 15 dB attenuation for a LO feed-through at 9.8 GHz, and more than 30 dB attenuation for images in the frequency band 9.4 to 9.7 GHz. The main functionality of this filter is to suppress not only the undesired image frequencies 9.4 to 9.7 GHz coming from the I-Q unbalance of the PSG, but also the

output noise of the preamplifier in the image frequency band. The bandpass filter also permits to improve the SNR by 3 dB.

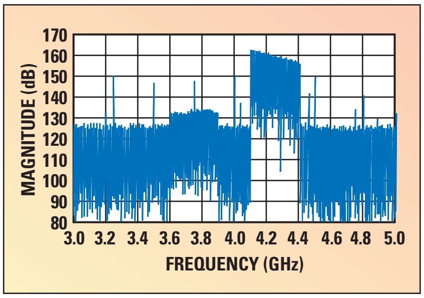
The double sideband mixer is used to down-convert the RF signal to IF. For that purpose, the LO signal from the PSG is directly connected to the mixer. The mixer also converts the noise from both 9.4 to 9.7 GHz and 9.9 to 10.2 GHz bands to the 100 to 400 MHz IF output, where the noise powers add up. The mixer is surrounded by attenuators to prevent image feed back to the filters. Once the down-conversion is done, a low pass filter can be used to reduce the level of the possible undesired signals (multiples of the frequencies ± n 9.8 GHz ± m 10.05 GHz). Furthermore, to suppress the LO leakage to the sampling scope, the low pass filter can also perform a 30 dB attenuation at the LO frequency.

Finally, a DC blocker is used to eliminate the DC component of the signal towards the DSA, where the signal is delivered for visualization and analog to digital conversion. In that way, the sum of all the losses in the down-conversion component chain following the preamplifier is approximately 20 dB. The down-converter will not limit the dynamic range of the global system because the noise power output of this system is -66 dBm (16.5 dB below the noise floor of the DSA).[13]

EXPERIMENT RESULTS AND DISCUSSION

Down-conversion Scheme

The external down-converter system allows for a high over sampling ratio, or the use of a lower sampling frequency, fulfilling the Nyquist-Shannon sampling theorem, since the maximum frequency of the signal is 400 MHz. If a RF down-conversion scheme in MATLAB was possible, a higher sampling frequency should be used to sample the received signal in the DSA before downloading it in the computer, since the maximum frequency of the signal is now around 10.05 GHz. Furthermore, not only the received RF signal but also the LO used to up-convert the IF waveform should be sampled, recorded and downloaded to the computer, allowing subsequently the down-conversion procedure in the computer.



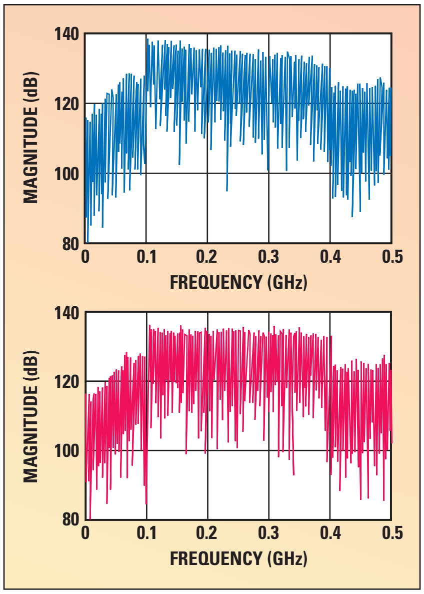
▲ *Fig. 7 RF 300 MHz long chip OFDM spectrum (LO = 4 GHz).*

Therefore, by performing IF down-conversion, the DSA stores only the received IF signal, resulting in a lesser amount of data that has to be transferred to the computer for post processing, which also translates into a faster signal processing. The down-converter can also reduce the level of both the LO and the undesired image band coming from the I-Q unbalance of the PSG output, shown in ***Figure 7***. To plot this figure, a LO central frequency of 4 GHz and a sampling frequency of 40 GHz were used before performing a RF down-conversion scheme realized during the test bench. Notice instead, that for IF down-conversion the PSG generates a 9.8 GHz LO signal and the DSA sampling rate is 5 GHz.

Distortion Effects

During the measurement campaign, distortion effects were affecting the signals. Thus, an efficient solution to correct them was done by calculating a series of coefficients to be applied in the transmitted waveform. A variation in the magnitude and phase of the output response of the internal filers of the AWG as a function of frequency is mostly responsible for the difference between the signal at the input of the AWG and the signal obtained at the input of the PSG. This variation is the result of the sine x/x (sinc) roll-off of the internal DAC and the frequency response of the reconstruction filter used for the 500 MHz channels output of the AWG.[11] Therefore, the series of pre-distortion coefficients can compensate for this effect and prevent loss of functionality due to the phase modification introduced in the signal and thus a possible critical phenomenon for communication purposes.

Nevertheless, distortion effects coming from other components inserted in both the transponder and ex-



▲ *Fig. 8 3000 carriers OFDM waveforms.*

ternal down-conversion systems were considered (cables, bandpass filter, low pass filter, mixer). For that purpose, a 300,000 carrier OFDM signal covering the band 100 to 400 MHz, giving a finer carrier spacing of 1 kHz and random phase coding, was transmitted and received to calculate the whole system distortion effects for the operating bandwidth. This procedure was performed on the test bench, without the transponder.

Figure 8 shows in blue a received 3000 carriers OFDM chip without using pre-distortion coefficients in transmission; shown in red is the same OFDM chip, when pre-distortion coefficients are applied to the corresponding OFDM transmitted waveform.

To verify the use of OFDM waveforms communicating radar stations, a 4-PSK constellation was used to encode two bits per symbol in the transmitted message. The received constellations are shown in ***Figure 9*** for both cases: absence (blue) and presence (red) of pre-distortion coefficients. When no pre-distortion coefficients are used, the constellation experiences a rotation due to the variations in phase introduced mainly by the response of the AWG filters. Therefore, the effectiveness and improvements achieved through correcting the distortion feature of the global system has been proven. The residual rotation observed in the red case can be due to the distortion introduced by

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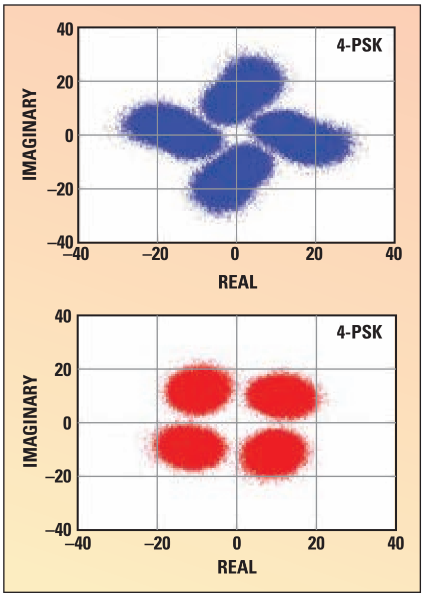
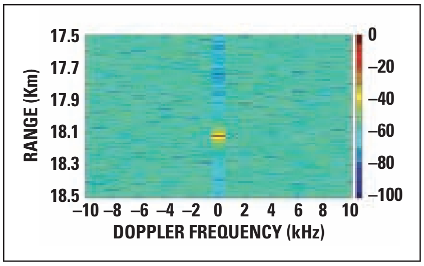
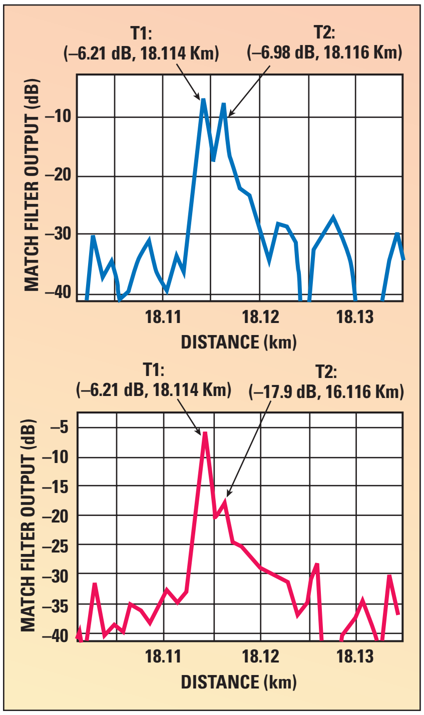


▲ *Fig. 9 Received constellations.*



▲ *Fig. 10 Ambiguity diagram power spectrum for one target scenario for a long chip 300,000 carriers OFDM signal.*



▲ *Fig. 11 Two-target scenario. Pulse compression output of a short chip 300 OFDM signal with phase Golay coding.*

other extra components like the delay line, attenuators and extra cables used in the final set up, so a possible slight inaccuracy of the distortion coefficients could still be present.

To verify the radar operation, range/radial velocity detection, the ambiguity diagram obtained with a long OFDM chip is illustrated in ***Figure 10***. The diagram is obtained with a novel signal processing technique[9] for a single target case scenario. As no Doppler shift was introduced, the target appears in the zero Doppler trench. The fiber optical delay line introduces a time delay of 60.18 µs, which translates into a one-way trip distance of 18.054 km in free-space propagation conditions. The target is detected at 18.12 km, which corresponds with a time delay of 60.4 µs. The difference in the time delay is explained by the presence of the coaxial cables in the global system (transponder and down-converter) and extra cables used to perform the measurements inside the anechoic chamber. These cables introduce an extra time delay of 0.22 µs in the global system that is added to that performed by the optical delay line itself.

To test the detection capability of the radar, range resolution and masking effect of close-by targets a short chip OFDM (300 carriers, time duration of 1 µs, with pre-distortion correction) was utilized in a two-target scenario. Both targets were simulated by using two identical antenna gain horns separated by two meters in range. In the anechoic chamber, the first and second gain horn were placed at 10 and 12 meters from the receiver, respectively. A 4-PSK Golay code was implemented and tested in this waveform to constrain the PAPR. The matched filter output for this waveform is shown in ***Figure 11***. The variable attenuators determining the individual target level were set to 4 dB for both targets (blue), and 4 and 14 dB for the first and second target, respectively (red).

From the figure, both targets are easily recognized and identified according to their respective positions and levels. The x-axis has been adapted to show the match filter output around the region of interest. It should be considered that the chip OFDM waveform presents high side lobe levels at the output of the match filter, so it is necessary to apply specific signal processing techniques (out of the scope of this paper) to suppress the side lobes and allow unmasking of close-by targets with different radar cross sections.[14]

CONCLUSION

A measurement campaign was carried out to demonstrate and confirm the dual use of OFDM signals for radar operation as well as for communication purposes among radar stations. OFDM signals have a large instantaneous bandwidth and also the specific coherency requirements needed for coherent radar processing imposed by the communications scheme. The experiments provided a compelling insight into the effects of the current electronic devices on the waveforms, such as amplitude and frequency distortion on the signal. Those effects were overcome to keep both the radar and communication capabilities.

The inherent high PAPR of the OFDM waveforms was limited by constraining the random phase coding, or by applying Golay codes, allowing the linear operation of the amplifiers in the receive chain and an optimal use of the dynamic range of the system.

The OFDM-radar detection capability was verified for both single- and two-target scenarios. For the multi-target scenario, the capability of coping with weak-strong targets was also shown. Recent processing techniques can be applied in the matched filter output for reduction of the side lobes level in order to unmask weak targets. Due to the flexibility of the OFDM signal, high range resolution (HRR) and frequency agility can be utilized with the aim of improving the radar operation.[10] The experiments described in this article constitute a first step in the development of a new generation of radars, which can be operated in a network, using the same waveform for both radar and communications. ■

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3D Electromagnetic Evaluation of a Chaff Cloud

The importance of electronic warfare in the area of defense is becoming increasingly emphasized. More than the well-known "stealth" concept, a thorough understanding of available techniques in this discipline helps to increase the survival rate on the battlefield. One such technique is the chaff cloud, a system where thousands of small printed dipoles are thrown from military vehicles to create a false radar signature, making the correct identification of the target by the enemy more complicated. This article illustrates the analysis of a chaff cloud, without simplifications, using a 3D electromagnetic solver. The cloud is simulated in an environment with other objects (targets), including a metallic sphere and a simplified fighter model.

A chaff cloud is made of metallic strips cut to obtain a resonant length. They are dispensed by a vehicle in the air to create a false signature in the enemy radar, masking the real vehicle return signal. Therefore, the detection and tracking become more complicated.

The impact of chaff has recently been reduced due to new technologies such as Doppler filters. However, chaff has been used with a high degree of success by misleading radar guided missiles. After launching a chaff cloud, the incoming missile tends to track on the chaff because of its higher RCS signature. The aircraft can then perform a fast, sharp maneuver, deviating from the missile path.

The issue of chaff cloud modeling has been addressed several times.[1,4-6] Usually the RCS of a unitary strip is computed and later the statistics of a chaff cloud (that is normal or Gaussian distribution) are taken into consideration, in order to evaluate its global electromagnetic characteristics. Although the modeling is fast, since its computation relies on analytical formulae, it does not consider the coupling among adjacent strips and does not include the target in the scenario.

This work involves the modeling of a chaff cloud, with strips randomly distributed. It was computed with two different targets. The simulation is done with a 3D full wave electromagnetic simulator, using its Integral Equation Solver on a surface mesh.[2] The results can provide much more realistic and conclusive results to address issues such as the necessary number of dipoles (the weight is a key issue in fighters), the frequency response of the strip and also the wind dispersion. Due to the intrinsic confidential status of these studies and the complicated actual measurements, the virtual evaluation is of vital importance.

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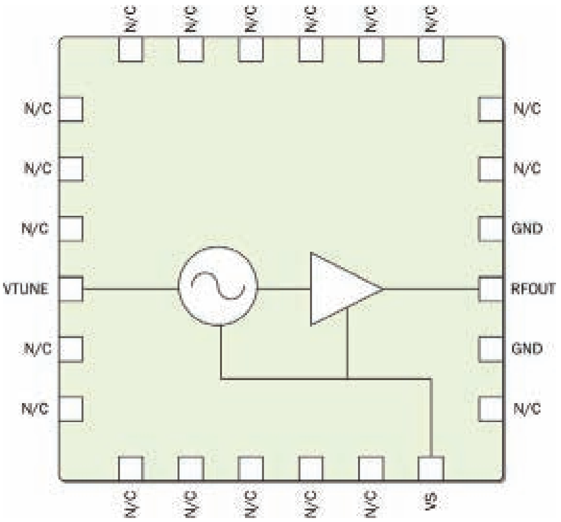
RFVC-1802	4000	8000	3.5	74.0	99.0	16	4	5 V at 55 mA
RFVC-1803	6000	9000	3.5	73.0	97.0	22	–	5 V at 52 mA



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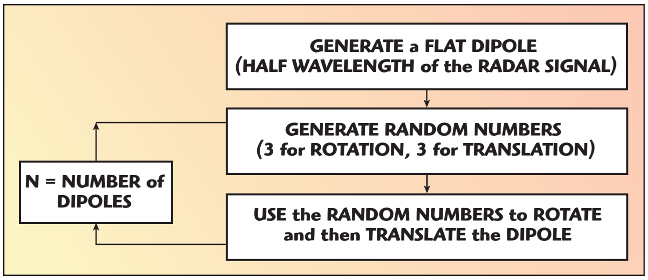

▲ *Fig. 1 Schematic of the VBA code to model the chaff cloud.*

MODELING SCHEME

The first example considers a pure monochromatic radar wave of 10 GHz (X-band), which is a frequency commonly used by the missile radar. The strips are then cut to a half wavelength (which is equivalent to 15 mm). It is considered that the operational range of these strips is approximately 10 percent of the center frequency, in this case from 9.09 to 10 GHz.[3] Common ways to achieve the operation in higher bandwidths and/or other frequency bands basically involve the use of strips of several lengths. The second example, due to its higher complexity, was simulated at 5 GHz (C-band).

Since the number of individual strips is in the thousands, an automated modeling scheme is necessary. In this study, the integrated Visual Basic Interface (VBA) interpreter was used to create the chaff cloud automatically. ***Figure 1*** illustrates the VBA code flowchart.

The main parameters used are:

- N = Number of Dipoles
- Translation set (tx, ty, tz) indicates the individual dipole translation distances
- Rotation set (rx, ry, rz) indicates the individual dipole rotation angles
- Only the number of dipoles (N) is set by the user; the other parameters are randomly set for each dipole.

SIMULATION ENVIRONMENT

Once the 3D model is ready, the electromagnetic conditions of the environment are set. Here the models are excited by a plane wave with a certain frequency to model the incoming wave from a radar transmitter placed in the far field, so that the electromagnetic wave can be considered plane (equal-phase condition).

The used solver is the Integral Equation (I). It uses a surface instead of a volumetric mesh, which means the problem becomes tractable with moderate computer resources. The I-solver possesses options where the problem can be solved with the iterative Method of Moments (MoM), or multilevel fast multipole method (MLFMM). The MLFMM uses a numerical scheme, where the original MoM matrix is manipulated to increase its sparseness, making the computation easier. It is suitable for situations where the number of elements and complexity are high. In the following sections two different cases are analyzed.

CASE I: CHAFF AND A METALLIC SPHERE

The first case considers a metallic sphere as a target, with a diameter of 0.2 m (13.4 λ at 10 GHz) as depicted


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in ***Figure 2*** where the zoomed area shows one metallic strip. The chaff cloud is made of 1800 resonant metallic strips. This problem is solved with the I-solver option called iterative MoM, since the number of variables is high but the overall complexity is not so critical. The incoming wave strikes the sphere after it goes through the chaff cloud, which means that the total scattering by a wave incident from a single direction is considered.

Figure 3 shows both the 3D plots of the absolute RCS for the cases with only the sphere and the sphere plus the chaff cloud. One clearly sees that the chaff creates several peaks where the RCS exceeds the normal sphere signature. Another option is the use of a monostatic RCS simulation. It simulates the structure being hit by a plane wave incident from different directions and it gets only the signal reflected back into the transmitter. It is a more realistic situation, where both the radar transmitter and receiver are in the same spatial position. The monostatic option offers an interesting feature, since it maintains the basis matrix for the different angles, enabling a faster computation. The monostatic (360° in steps of 1°) RCS polar plot is shown in ***Figure 4***. From the figure, it is possible to see the chaff cloud effect—it creates several peaks of strong scattered signal, whereas the target alone has a more constant sig-

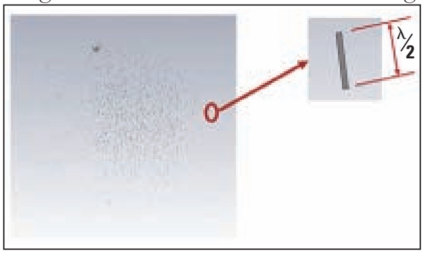


Fig. 2 Scenario of a metallic sphere and a chaff cloud.

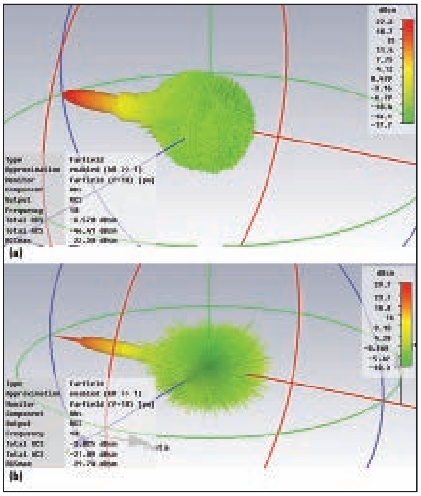


Fig. 3 3D plot of the absolute RCS value for the sphere alone (a) and for the sphere and chaff cloud (b) .

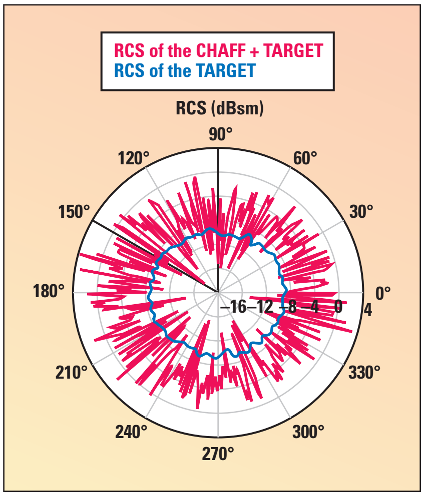
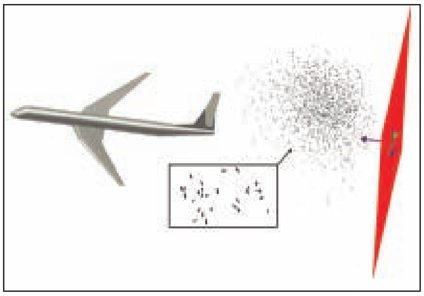
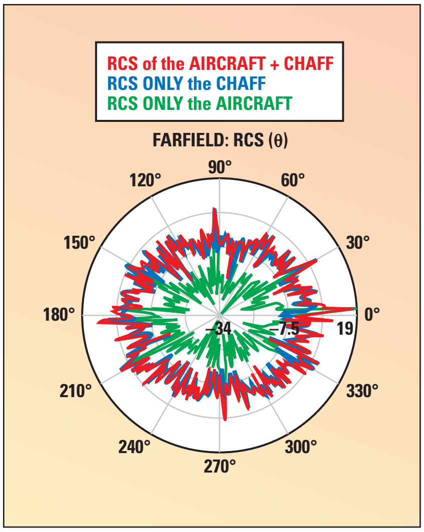


Fig. 4 Monostatic RCS absolute value for the cases with and without the chaff cloud.



▲ *Fig. 5 Scenario of an aircraft plus a launched chaff cloud both illuminated by a 5 GHz plane wave.*



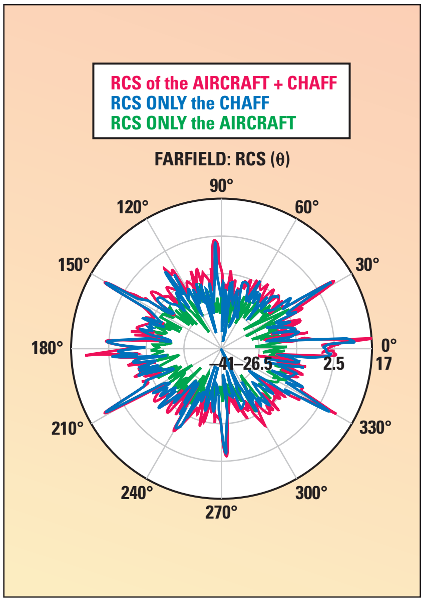
▲ *Fig. 6 Comparison of the absolute values of RCS for three different situations at 5 GHz.*

nature, with lower amplitude. Thus, the chaff cloud makes target detection much more complicated.

CASE II: CHAFF AND A FIGHTER

This case involves a more realistic environment. It uses a fictitious aircraft (16 m long and wingspan of 14.5 m) hit by a plane wave at the frequency of 5 GHz. Although the frequency of interest is 10 GHz, the complete scenario with the plane was chosen for 5 GHz to make the simulation feasible with the available computer resources. The whole scenario took 32 hours in a Sun Fire X4600 machine with 2 AMD 2.8 GHz processors and a total RAM memory of 64 GB. The MLFMM solver was used, since the number of elements and the complexity were both high. The peak RAM used by the simulation was 46 GB. ***Figure 5*** illustrates the problem. In the simulated case, the plane is detected by radar, modeled by a plane wave, which is positioned in the back of the plane.

The absolute RCS results for a 5 GHz plane wave are presented in ***Figure 6***. Three different simulations were taken into account: the chaff alone, the aircraft alone and finally both together. It is possible to see that the chaff-only response has a much higher scattered electric field than that from the airplane. Therefore, the chaff cloud can, under these circumstances, be used to help an aircraft escape from a fired missile, even though the missile had already locked on the jet alone. Similar results for a 3 GHz plane wave can be seen in ***Figure 7***. Since the strips are resonant at 5 GHz, the chaff cloud at 3 GHz is not so effective in comparison to the designed frequency. This is why strips of different lengths are used, covering a broader range of radar frequencies.



▲ *Fig. 7 Comparison of the absolute values of RCS for three different situations at 3 GHz.*

CONCLUSION

The full 3D electromagnetic modeling of a chaff cloud was undertaken to demonstrate that it is possible to simulate complicated and difficult real-world problems without simplifications. The chaff model was created using a VBA script and numerically simulated using commercial software. The strips were modeled as thin resonant metallic strips, randomly distributed. The results show that a complicated and difficult real-life problem can be analyzed without simplifications, in a relatively short time, using the Integral Equation solver. In this way, much more realistic and conclusive results can be derived to address issues such as the required number of dipoles, frequency response of the strips and also the wind dispersion. ■

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InP HBT Chipset, Enabling High-bandwidth, Real-time Oscilloscope Architecture

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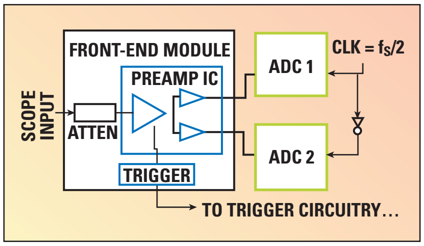
TRADITIONAL ARCHITECTURE

Figure 1 illustrates the traditional architecture used in the previous generation Agilent oscilloscopes. The input signal passes through a variable attenuator, followed directly by a preamplifier IC, responsible for scaling the signal properly, applying offset, and buffering the signal to the analog to digital converters (ADC). To provide enough sample rate to not violate Nyquist, two ADCs sampling at $f_S/2$ are interleaved in the architecture described by Figure 1, where f_S represents the full sample rate of the acquisition channel.



▲ *Fig. 1 Block diagram of a traditional oscilloscope front-end.*

This architecture has several limitations:

- The ADC input bandwidth and sampling aperture must be at least the full RF bandwidth of the oscilloscope
- The preamplifier must drive multiple ADCs (in this case two), with the full RF bandwidth preserved at the interface
- Mismatch associated with the fan-out will manifest as error in the measurement

To clarify item 3, a sine wave operating at one-fifth the sample rate is presented in ***Figure 2***. The outputs from the ADCs are interleaved to reconstruct the waveform at full sample rate, shown by the interpolated waveform (b). Sin(x)/x interpolation is used to reconstruct the signal from the sampled data. In this example, f_S is 40 GS/s and the input waveform is an 8 GHz sine wave. ADC 1 input cannot be seen clearly because it is overlapped by the ADC 2 input waveform. ADC indices in this figure correlate to the ADC indices in Figure 1. By forcing the ADCs to sample 180° out-of-phase, the effective sample rate of the system can be twice that of a single ADC.

A Fast Fourier Transform (FFT) of the result in Figure 2 is shown in ***Figure 3***. Note the single

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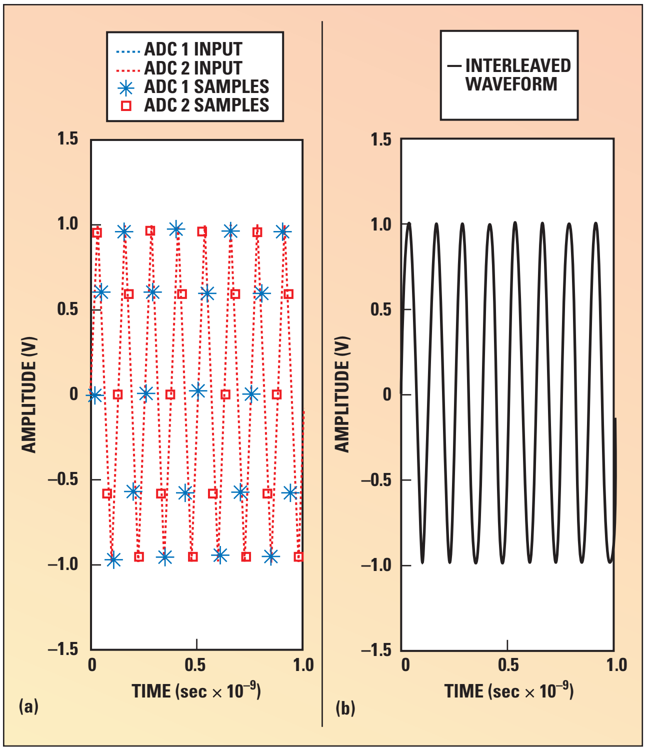
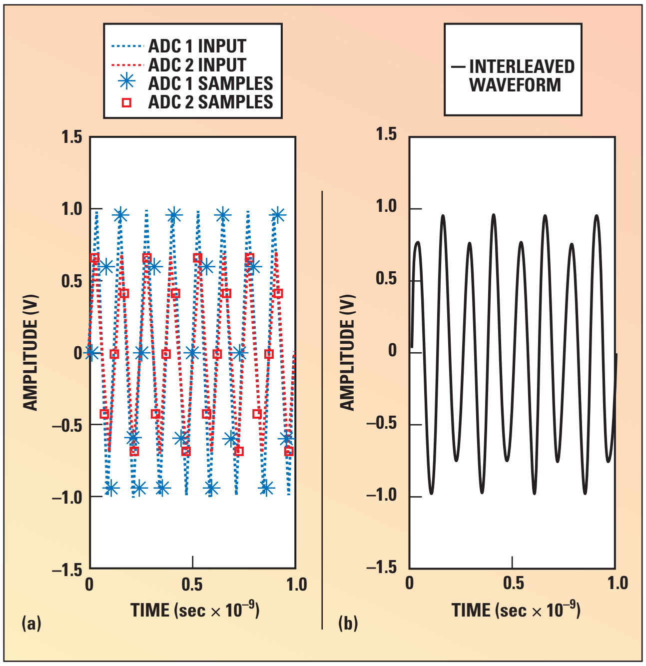
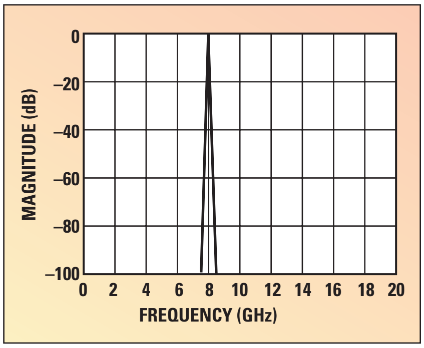


▲ Fig. 2 Sine wave of $f_S/5$ inserted into oscilloscope (a). The waveform is then reconstructed from the interleaved samples of ADC 1 and ADC 2 using sin(x)/x interpolation (b).



▲ Fig. 4 The ADC 2 input is now attenuated by 3 dB (a). ADC 1 and ADC 2 no longer digitize the same signal. This causes error in the interpolated waveform (b).



▲ Fig. 3 An FFT of the interpolated waveform in Figure 2b.

tone at $f_S/5$, indicating that the waveform is properly reconstructed by the system. Because the preamplifier must drive both ADC blocks, the interface between them is important to match. Mismatch in the interface will cause error in the acquired waveform. As an example, consider the case where the second preamp output channel has less bandwidth than the first output buffer. In this example, 3 dB of loss is added to the second ADC input signal. This is illustrated in ***Figure 4***.

When the samples are interleaved, a new signal is created, which manifests as distortion in the reconstructed waveform, not present in the signal when presented to the oscilloscope input. An FFT of the reconstructed waveform is given ***Figure 5***. The FFT of the interpolated waveform shows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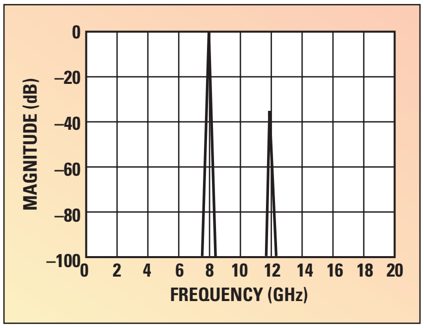
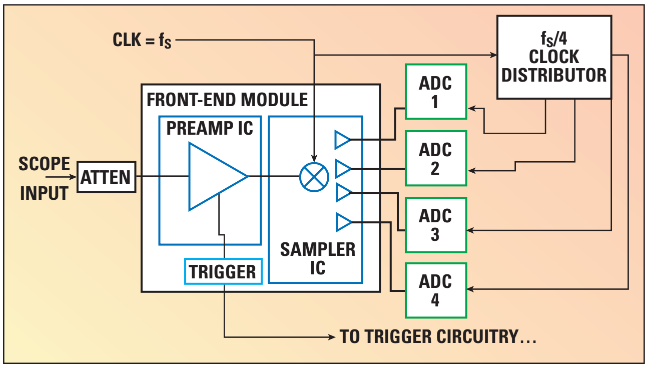


▲ *Fig. 5 The FFT of the interpolated waveform with ADC input signals mismatched shows a tone at 8 GHz and a new tone at 12 GHz as a result of the mismatch.*

a new tone at 12 GHz, not present in the first example, where ADC inputs were well matched.

ADC mismatch is another potential source of the error seen in Figure 4. Because two ADCs are used, any mismatch between the two components due to process variation, packaging differences or assembly anomalies will create errors in the user's signal if not addressed properly. To avoid such problems, careful design of the preamplifier/ADC interface is critical. As the frequency capability of the oscilloscope increases, the design becomes more challenging.



▲ *Fig. 6 The new DSO-X architecture.*

As an example, suppose this architecture were used in a system with twice the bandwidth. This requires a sample rate of $2f_S$. Assuming the same ADC converter technology is used, the system now requires four ADCs per acquisition channel, and requires a fan-out of four from the preamplifier module. This fan-out would require twice the bandwidth as the previous generation. With higher input bandwidth also comes more complexity and power in the ADC block itself. Maintaining signal integrity in a system like this is difficult. The new architecture was developed to avoid these issues in high-bandwidth oscilloscopes.

THE DSO-X ARCHITECTURE

Figure 6 is a drawing of the new DSO-X architecture. Although very similar to the original architecture, the DSO-X includes a number of new components:

- A full-bandwidth, low-noise preamp, responsible for signal scaling and offset injection
- A high-bandwidth trigger IC
- A new sampler IC, inside the preamp module

As seen in Figure 6, the first ranks of sampling are now contained inside the preamp module, instead of on the CMOS ADC. This is advantageous for a few important reasons. Firstly, the full-bandwidth preamplifier IC now provides only one output to the sampler, instead of fanning-out to multiple ADCs with full channel bandwidth. Because the preamp IC is contained in the same micro-circuit module as the sampler IC, the interface distance is short and does not require long PCB traces, lossy at high frequencies. The RF traces inside the microcircuit can be printed on a low-loss dielectric material, optimizing the interface for high-frequency transmission.

Secondly, because the RF sampling occurs in one IC, mismatch in sampled responses is smaller. In the previous architecture, RF sampling occurred in the ADC technology blocks themselves. Because the ADC samplers exist on separate die, the potential mismatch between the sampling apertures is much greater than the new architecture, where samplers coexist on one die.

Thirdly, because the first ranks of sampling are contained in one proprietary IC, the ADC must no longer accept full-bandwidth to its input. The requirements on the ADC aperture, therefore, are much less, allowing the previous generation of ADC to be used in the new design, and lowering the effective noise bandwidth at the input to the ADC.

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THE DSO-X ANALOG FRONT END

At the heart of the new DSO-X is a new analog front-end module containing three new ICs designed in Agilent's HB2B InP semiconductor process. The module is shown in ***Figure 7***. It contains a new DC to 32 GHz low-noise preamplifier that feeds a 20 GHz trigger IC and a 32 GHz sampler IC. The sampler IC accepts full bandwidth to its input, and drives the four CMOS ADC converters outside of the analog front-end module, after sampling.

The HB2B InP HBT process enables the performance levels achieved. The HBTs available in the process have maximum f_τ frequencies of 185 GHz at 2 mA/um^2 bias current levels. The process incorporates two varieties of thin-film resistor material for low parasitic passive components. Resistive materials available are a 22 ohm/square thin-film material and a 250 ohm/square thin film material. High-density MIM capacitors are also available, with 0.59 fF/um^2.

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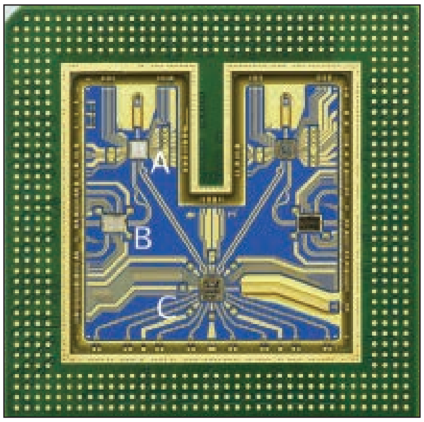
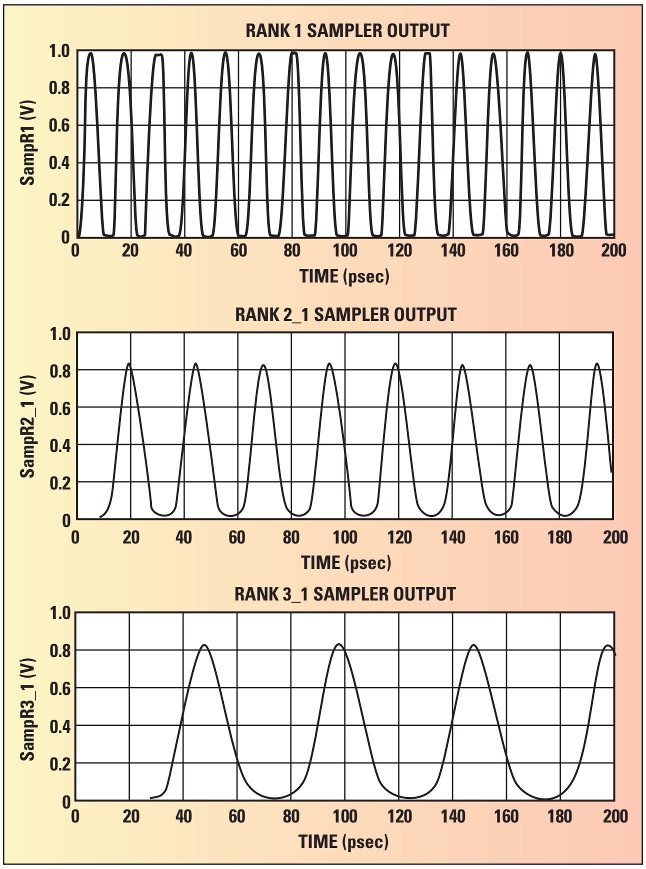


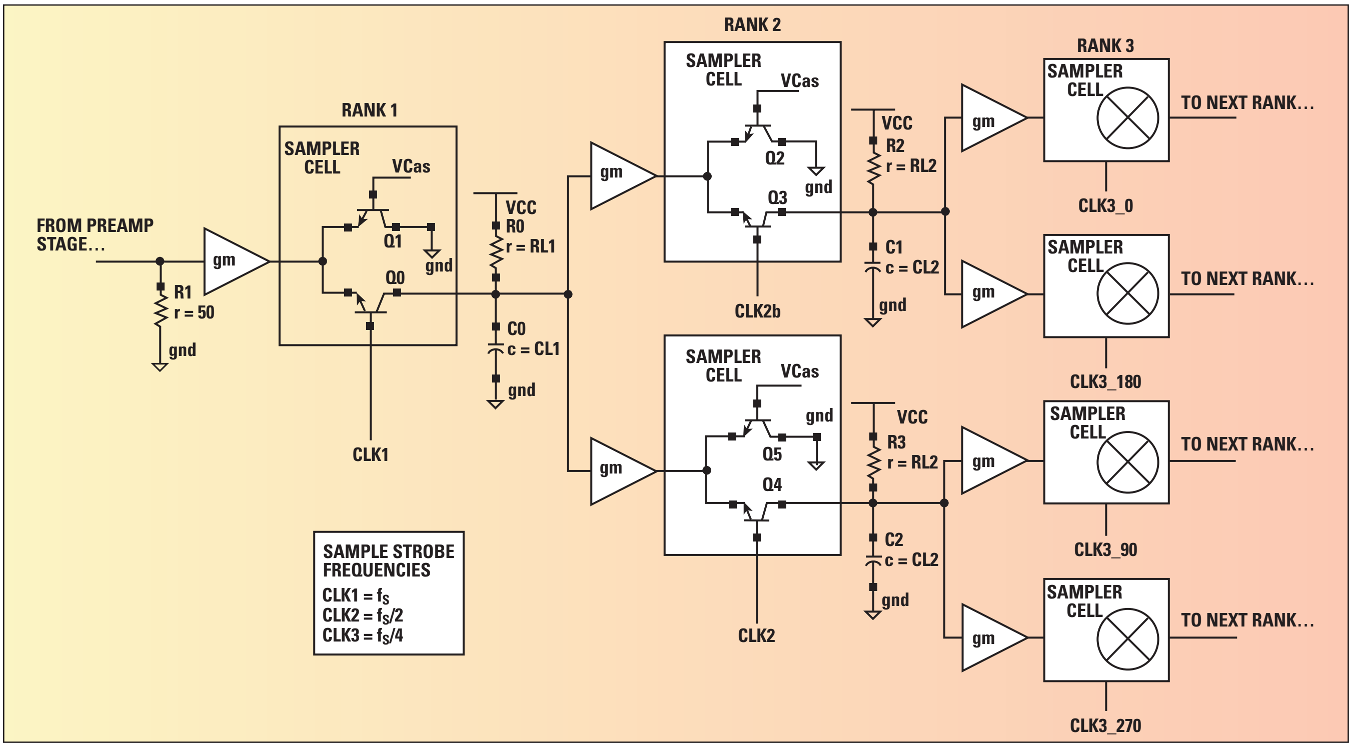
▲ *Fig. 7 The DSO-X front-end module with preamp (A), trigger (B) and sampler IC (C).*

MULTI-RANK SAMPLING

As discussed previously, multiple ranks of sampling are required in the DSO-X architecture to achieve high-bandwidth response. High-frequency sampling is handled by the InP



▲ *Fig. 9 Multi-rank sampler outputs.*



▲ *Fig. 8 An example of a multi-rank sampling architecture.*

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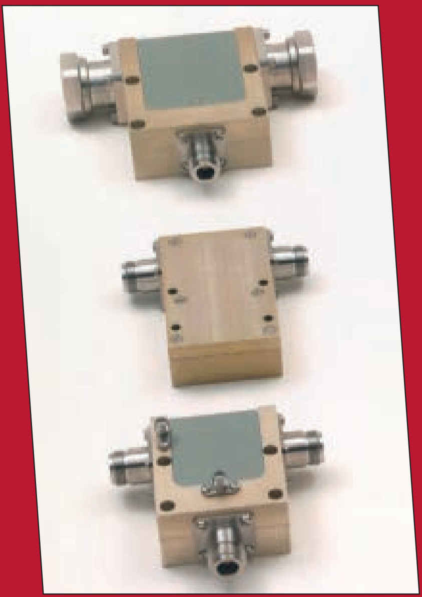

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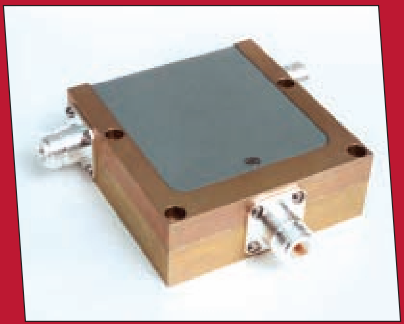

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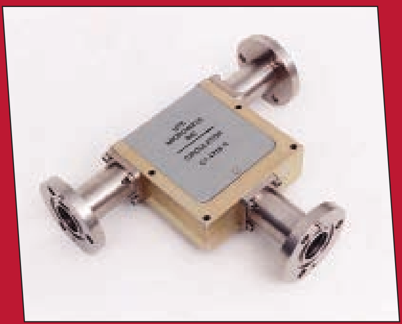

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HBT sampling IC in the analog front-end module, while final digitization of the samples is performed in the Agilent CMOS ADC used in previous oscilloscope designs. ***Figure 8*** is an example of how multi-rank sampling can be used to leverage lower-speed ADC technology for a high-bandwidth system.

In this figure, a tranconductance amplifier is used to convert the voltage signal from the preamplifier into a current. This amplifier is responsible for buffering the preamp's output into the first sampler, and must accept full RF bandwidth to its input and drive full RF bandwidth on its output. This output signal, in the form of a current, is fed into an HBT sampling switch labeled "Sampler Cell" in Figure 8. The HBT switch is driven by a sample pulse driver that drives the base of the HBT switch. When the switch is "off", the "VCas" bias voltage shown in Figure 8 is higher than the "clk1" signal, and the RF current is shunted. When the sample pulse fires, the HBT switch conducts current into the output load. The RF current travels through the cascode sample device and is imposed on an impedance to convert the sampled current into a voltage.

The load impedance defines the pulse-shape of the sampled signal, and the first IF bandwidth, once it is converted to a voltage. The IF of the first sampler output requires the previous sample be settled before the peak of the next sample. Therefore, the sampled output of the first IF in Figure 8 must reach its final value in no less than T_S, where T_S is $1/f_S$, the sampling frequency. While this does not relax bandwidth requirements to the next sampler rank, it does allow for very low jitter sampling and proper response matching. Because all samples pass through a single sampler, all samples are referenced to a single clock. Furthermore, the RF response of the Rank 1 sampler affects all samples in the system, eliminating susceptibility to RF sampler response mismatch, seen previously in Figure 4.

The first IF output drives additional transconductance stages. The output of each buffer drives a sampler. These cells sample out of phase, each operating at $f_S/2$. Because the sample rate is lower, the IF output of each sampler has more time to settle before the next sample. This is demonstrated in ***Figure 9***. In this figure, the sample pulse output from the Rank 2 sampler can be broader than the original sample stream. The Rank 2 samplers behave as "switches" that route alternating Rank 1 sample outputs to Rank 2 outputs. Because the pulses have more time to settle in the higher ranks of sampling, the bandwidth requirement of the IF is reduced.

Finally, the "Rank 3_1" output shown in Figure 9 indicates that Rank 3 output pulses have a longer time to settle than Rank 2 outputs. In the limit, each sample pulse must return to zero just before the next pulse reaches its final value. In Figure 9, the IF bandwidth for each sampler rank has been augmented to make sample location more obvious.

Figure 10 portrays the Gaussian IF response of Rank 3 if the bandwidth is reduced by a factor of 2. The dashed lines in Figure 10 indicate the trajectory of the sample pulses. Note that each pulse settles before the peak of the next pulse in the IF, even with reduced bandwidth.

Figure 11 portrays all sampled outputs from the Rank 3 samplers in Figure 8. The separation of each

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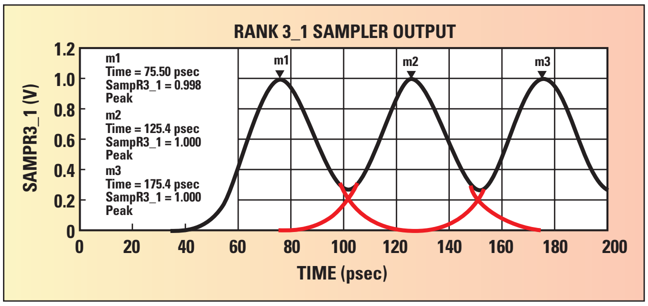
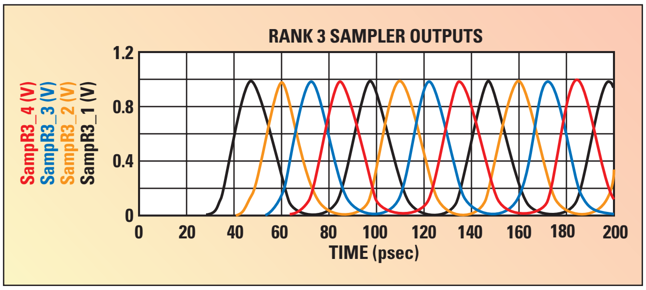


▲ *Fig. 10 Gaussian IF response of Rank 3.*



▲ *Fig. 11 Rank 3 sampler outputs for all Rank 3 samplers shown in Figure 8.*

pulse is exactly $1/f_S$, but because the pulses exist on four separate IF channels, they each have much longer to settle than the Rank 1 sample outputs.

Reduced IF bandwidth is advantageous to the design for several reasons: Lower-power circuits can be used after the sampler, because the bandwidth requirements on circuits following sampling are relaxed; as multiple ranks are used in the sampling process and IF bandwidth requirements are relaxed, driving signals off of the IC using standard PCB traces becomes less challenging than at full RF bandwidths; lower IF bandwidth from the HBT integrated circuit results in lower frequency content to the ADC, reducing susceptibility to high-frequency mismatch, and allowing the architecture to leverage existing CMOS ADC technology.

Many sampling ranks can be used, to the point where IF bandwidth is slow enough for CMOS ADC digitization. Once digitization occurs, the samples must be interleaved properly in time with one another, to reconstruct the waveform at full sample rate, as discussed previously.

CONCLUSION

As the industry demands high bandwidth measurement capability, it is important test and measurement equipment manufacturers provide solutions for characterizing high-speed signals. The DSO-X achieves high performance levels with a unique sampling architecture, featuring fast HBT-based circuits partnered with CMOS ADC technology. The new architecture provides the industry's lowest reported noise and jitter in the highest bandwidth real-time oscilloscope available. ■

ACKNOWLEDGMENTS

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Applications of Time Domain Processing in Antenna Measurements

Antenna measurements involve recording the radiated coupling between a measurement antenna and the antenna under test (AUT). ***Figure 1*** shows an example set up inside an anechoic chamber, in which the measurement antenna acts as the transmitter and the AUT operates in reception. The goal is to record the direct coupling. Indirect coupling via scattering from walls and surrounding structures in the chamber results in an error on the measured data. This unwanted scattering can be eliminated from the measurements by taking advantage of time domain techniques commonly used in radar.

A typical radar application, which uses two separate antennas for transmission (Tx) and reception (Rx) of the signals, is illustrated in ***Figure 2***. The Tx antenna radiates a signal into open space (red arrows). The signal (straight red arrows) illuminates different objects arbitrarily distributed in space, as shown in the figure. The randomly spaced objects reflect the illuminating signal, and the reflected signals (blue arrows) in turn illuminate the Rx antenna, which are often located in close proximity to the Tx antenna. The received signal is to be processed, and the resulting information is used to indicate the presence of objects in the surrounding space, to identify the objects, and to track or characterize them, if necessary. Clearly, the better the radar system dynamic range and sensitivity, the longer the useful range. As is also shown in the figure, a concurrent direct leakage signal radiated by the Tx antenna in the direction of the Rx antenna (curved red arrow) is typically present and thus can also contribute to the total received signal. This concurrent signal is often comparable or even stronger than the received signal contributions from reflections from the objects.

Clearly, the leakage signal (curved red arrow) is a disturbing factor to normal radar operation and should be either separated from the desired reflected signals (blue arrows), reduced as compared to the reflected signals, or eliminated completely. In order to accom-

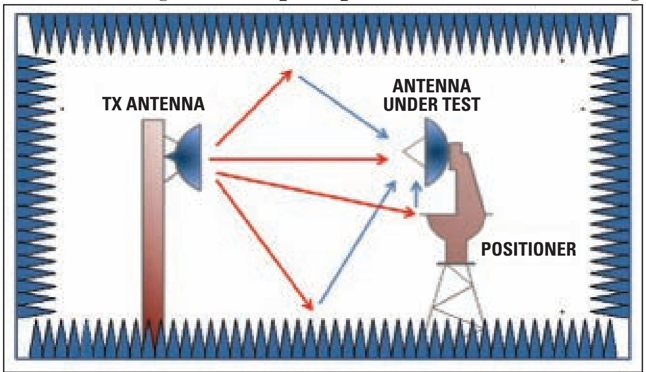

Fig. 1 Antenna measurement system in an anechoic chamber.

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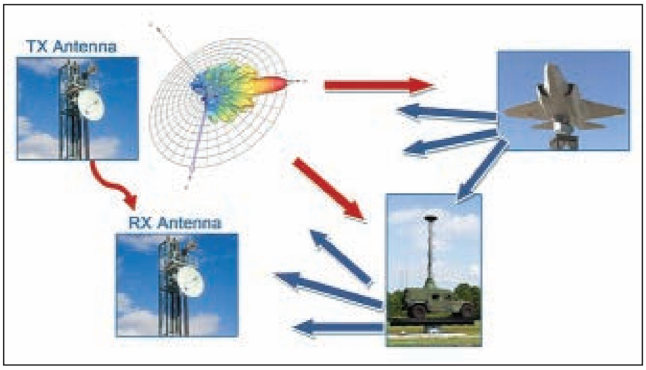


Fig. 2 Typical radar operation diagram.

plish this, it is necessary to consider parameters that would differentiate these signals. The time of arrival is the most distinguishing characteristic differentiating these signals. Since the Tx and Rx antennas are typically located much closer than the distance to the detected objects in space, the leakage signal arrives at the Rx antenna sooner in time than the signals reflected from the detected objects.

Various techniques are used in radar applications to differentiate signals based on their different times of arrival, including utilization of specialized Tx signal modulation and/or time-gated Rx software/hardware processing. Gated time-domain techniques have been in use for years in many radar installations. Time-gating is a hardware feature or computer processing algorithm capable of transferring the data acquired in the frequency domain to the time domain, where the time response allows one to observe the time sequence of multiple received signals and to subsequently discriminate between them. When the desired signal is selected from the sequence of time distributed signals, it can be time-gated by applying the proper mathematical pass band filter (which again can be realized either in hardware or software). The filtered data can then be transformed back to the frequency domain, providing the required time-gated data. The extrapolation of this technique to radar cross section (RCS) measurements is straightforward, and as such has been implemented in many RCS measurement systems.

Alternatively, another set of applications requires the use of the direct signal, while requiring the reflected signal to be negligible. Such applications include wireless communications (where the Tx and Rx antennas can be directed toward each other in order to improve signal to noise ratio); antenna measurements, where unwanted reflections can occur from objects surrounding the measurement range in outdoor far-field (FF) antenna measurement ranges; and from the absorbing walls in indoor anechoic antenna measurement chambers. In antenna measurements, the antenna locations and pointing directions may vary during the measurement, and thus any reflections (including multiple reflections in anechoic chambers where the walls are treated by absorbing materials) may affect the antenna measurement accuracy. Similarly, the reflections reduce the antenna measurement accuracy in near-field (NF) antenna measurement systems. Time-gating techniques can be very useful to eliminate unwanted reflections, and thus to improve antenna measurement accuracy. A few interesting examples are described, which are intended to illustrate the effectiveness and usefulness of time-gating techniques in the antenna measurements.

REFLECTIVITY ASSESSMENT IN A FAR-FIELD ANTENNA MEASUREMENT CHAMBER AT UHF FREQUENCIES

Unsatisfactory quiet zone performance can be found in rectangular chambers designed for operation in the UHF band using a classic 60° side wall incidence angle approach. In this design, the ratio of the width (W) or height (H) of the chamber to the separation distance between the source antenna and the antenna under test (L) satisfies the relationship $W/L \approx H/L \leq 0.5$. The approach has been successfully implemented in hundreds of anechoic chambers operating at frequencies higher than 2 GHz. However, extrapolation of this design down to frequencies as low as 200 MHz, where the chamber cross section becomes electrically small (such as 3 to 4λ), fails to perform as well as at L-band and higher frequencies. This despite the fact that higher grade absorbing materials (taller than 48") are often utilized to treat the chamber metallic walls at UHF, and the free space VSWR test procedure (the classical method for chamber validation) performed at the discrete UHF frequencies often shows satisfactory reflectivity during the testing. However, thorough investigation reveals that, at UHF, the VSWR procedure can lead to incorrect quiet zone performance interpretation.[1]

Figure 3 shows measurement results in a chamber where log periodic dipole (LPD) antennas were used as both a source and a probe antenna. The antennas were installed such that their boresights coincided with the chamber central line. The two curves correspond to the cases where the polarizations of both antennas are identical and are either vertical (V) or horizontal (H). In theory, these two curves should coincide. In a well designed chamber, the difference may be on the order of 1 dB or so at UHF. However, in the figure, the difference reaches 3 dB or more across some frequency intervals. The difference in polarizations at 200 and 300 MHz (discrete frequencies where the free space VSWR test was executed) were acceptable.

Figure 4 shows curves of the time-domain data for these cases. It can be seen that the strongest and virtually equal signals for both polarizations are received in the time interval from approximately -30 to -10 ns. At later

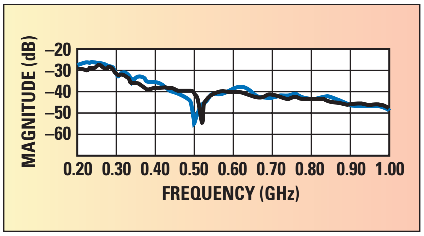


Fig. 3 Frequency domain vertical (blue) and horizontal (black) co-polarized signals in the quiet zone of an anechoic chamber of UHF.

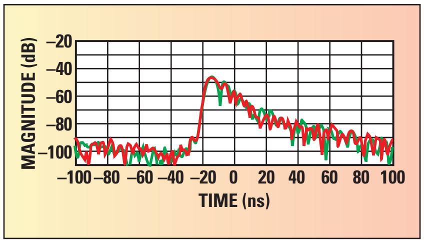


Fig. 4 Time domain vertical (red) and horizontal (green) co-polarized signals in the quiet zone of an anechoic chamber at UHF.

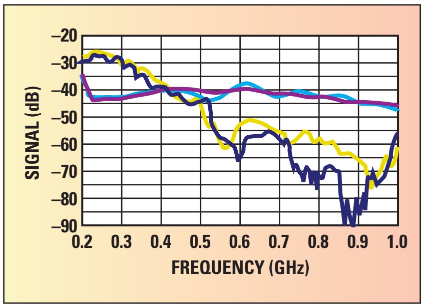
times, the difference becomes pronounced, so that this time interval can be attributed to the direct illumination and the rest of the responses from -10 to 100 ns to multiple reflections. Performing the time-gating and transforming the data back to the frequency domain, the direct and reflected time-gated frequency signals for both polarizations are obtained and are shown in ***Figure 5***. The vertical (blue) and horizontal (pink) time-gated co-polarized direct illumination signals in the quiet zone are shown as well as the vertical (yellow) and horizontal (navy blue) time-gated co-polarized quiet zone signal reflected from the walls of the chamber. This shows that the reflected signals actually exceed the direct signal at 200 to 300 MHz by more than 12 dB. The reason the free space VSWR results appeared acceptable at these frequencies is that the VSWR processing inevitably interpreted the dominant reflected signals as the direct one, leading to incorrect conclusions regarding chamber performance.

In addition, the figure explains a less than desirable chamber performance in the range of 400 to 600 MHz (see the V and H polarization differences in Figure 3) and shows that the chamber can be used for high quality conventional far-field antenna measurements, starting from 700 MHz and above, where the reflected signals are well below the direct illumination signal.

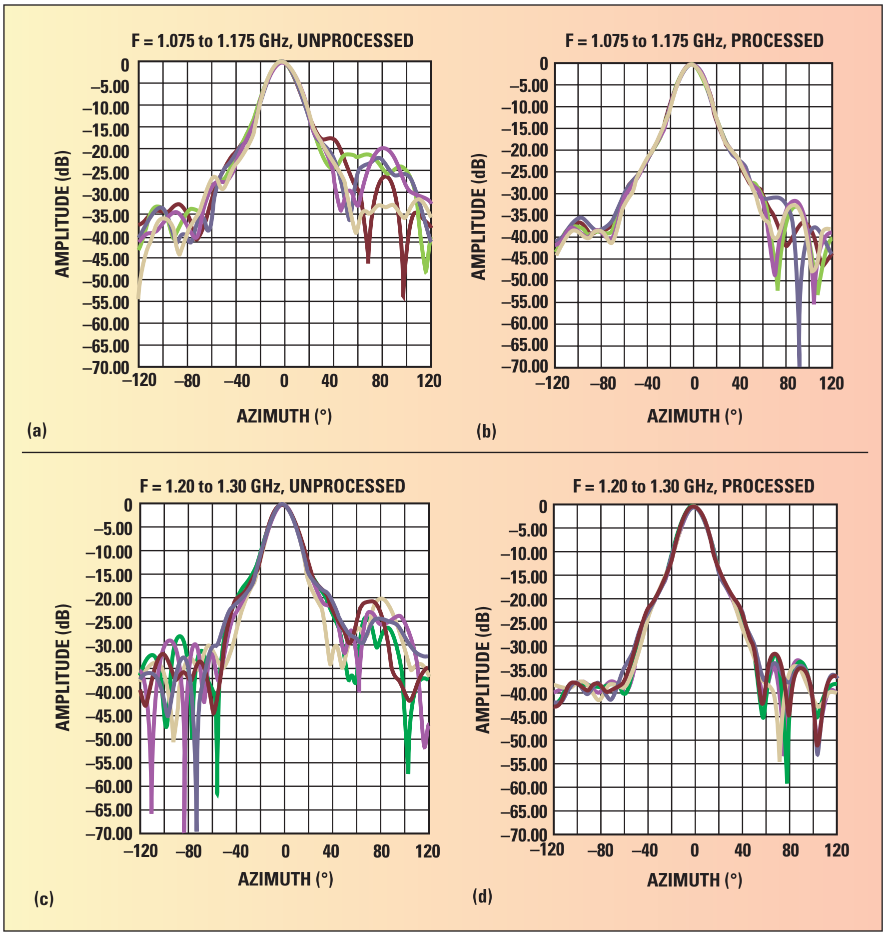
ACCURATE CYLINDRICAL NEAR-FIELD ANTENNA MEASUREMENTS

A broadband dual ridge diagonal horn antenna (ORBIT/FR model FR6417) operating in the frequency range of 950 to 3000 MHz has been tested using a cylindrical near-field measurement system. The size of the aperture along its diagonal is approximately 3.5 feet, and the gain is more than 15 dBi over the frequency band considered. The test set up includes a vertical scanner for the probe vertical motion and an azimuth positioner for the antenna under test (AUT) rotation. The dimensions of the measurement room were such that the measurement set up barely fit within the room confines. Twelve inch absorbing material was used to cover all of the side walls and floor of the room. Moreover, as a part of the test program, and in order to evaluate the efficiency of the time-gating algorithm, a "window" on one side wall was left bare without absorber treatment.

All the measurements were accomplished in two sub-bands using two standard open ended rectangular waveguide (OEWG) probes—WR650 and WR430—covering a frequency band of 0.95 to 3.0 GHz in frequency



▲ *Fig. 5 Direct and reflected time-gated frequency signals for both polarizations.*



▲ *Fig. 6 Far-field patterns obtained using cylindrical NF-FF transformation with and without time-gating algorithm.*

increments of 25 MHz. The primary measurement goal was to eliminate the room scattering error in the measurements with the aid of the time-gating algorithm. In order to accomplish this, the measured raw near-field data was "pre-processed" by time-gating, and the two sets of raw data—"pre-processed" and "unprocessed"—were transformed to far-field patterns using a standard cylindrical near-field to far-field transformation algorithm. The far-field patterns were then compared. The measurement results are presented in ***Figure 6***. The far-field patterns obtained with the use of raw, unprocessed cylindrical near-field data are presented in the left column. The patterns obtained using the raw but pre-processed set of data prior are presented in the right column. As can be seen from the left column, the presence of the window "uncovered" by absorber on the right side wall of the chamber can be clearly identified by a high level of ripple in the large sector of pattern angles on the right [+30° to +120°]. Moreover, there are noticeable perturbations seen at negative angles on the patterns. This is explained by the insufficient absorption provided by using only 12" high absorbing material at frequencies in the vicinity of 1.0 GHz in the "small" anechoic chamber utilized for the tests. As seen in the right column, the side lobes and perturbations are significantly reduced. Also, the patterns in the right hand column show better symmetry around its bore sight, indicating improved measurement accuracy.

SHORT RANGE FAR-FIELD ANTENNA MEASUREMENTS OF A LOW GAIN ANTENNA ON A GROUND PLANE

In many commercial applications, the performance of low gain antennas is closely associated with and depends on the geometry and size of the device the antenna is attached to, mechanically connected to, or the properties of the skin in which the antenna is embedded. Some antennas, such as satellite radio antennas used in automobiles, are attached to the roof. The vehicle roof acts as a large ground plane and is an essential part of the antenna that influences the antenna pattern. In order to accurately measure such antennas in an anechoic chamber, a large metal plate is frequently used to simulate the ground plane. A number of questions should be answered in order to make sure that the measurements of the low gain antenna on a ground plane are accurate. These questions include:

- What size metallic plate is to be considered to minimize the edge diffraction associated with the ground plane? This is important in order to isolate the antenna performance from the edge effects introduced by a terminated (finite size) ground plane, as well as to extrapolate the measurement results to "ground bodies" of different geometries.
- What size metallic plate is to be considered to evaluate the dimensions of the "effective" metallic plate that functionally participates in the formation of the far-field antenna pattern?
- What measurement facility and measurement technique are to be used to accurately predict the antenna pattern?

A low gain antenna typically does not require large and expensive anechoic chambers for far-field antenna pattern measurements. However, the addition of a metallic ground plate increases the effective size of the antenna under test and, accordingly, increases the required size of the anechoic chamber, which results in a more expensive test facility. An alternative solution is to implement a spherical near-field (SNF) testing technique. This technique, although the data acquisition is identical to conventional far-field antenna measurements, does not require a large anechoic chamber. With this technique in mind, a two-step procedure can be implemented to answer the first two questions above.

- Time-gated pre-processing of "raw" SNF data, which reduces the edge diffraction, effects and delivers a "true" far-field pattern. Note

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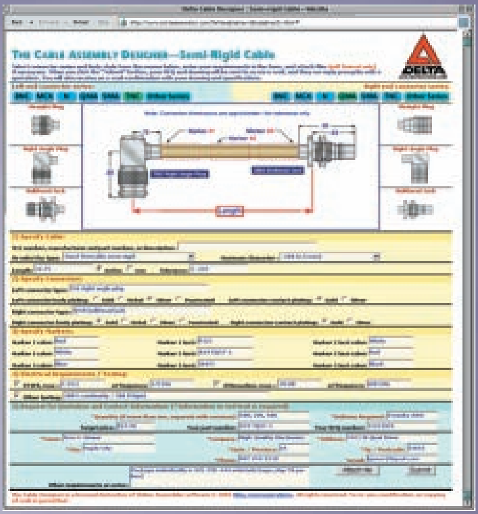

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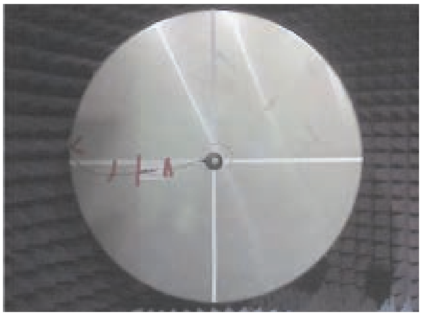
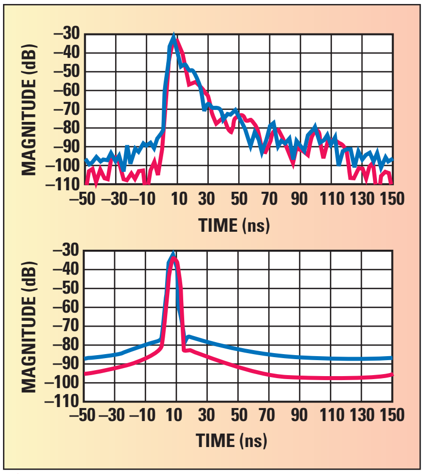


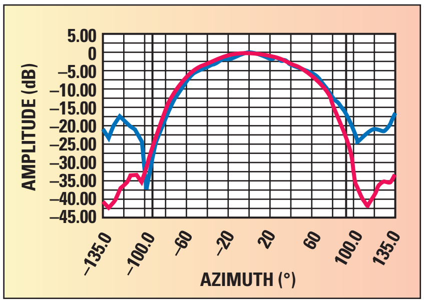
▲ *Fig. 7 Satellite radio antenna on a metallic ground plane.*



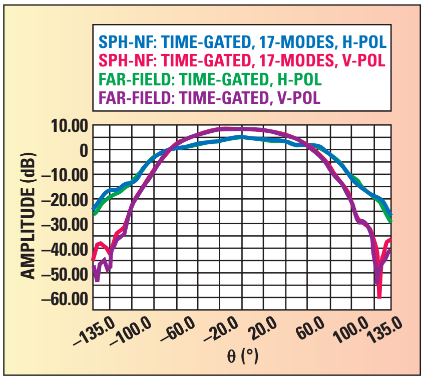
▲ *Fig. 8 Measured SNF-FF ungated and gated time domain response for vertical (red) and horizontal (blue) polarizations.*

that the application of time-gating for a narrow band antenna (a satellite radio antenna, for example) means using test frequencies outside the designed operational band of the antenna. As long as the antenna radiates (or receives) at a level above the noise floor, information may be extracted to create the time-domain response of the test antenna, which may then be time-gated to remove unwanted scattering sources.

- Compare the pre-processed SNF field with the corresponding far-field pattern. If the SNF pattern coincides with or closely resembles the far-field pattern, this indicates that the separation between the SNF probe and the AUT (in this case a low gain antenna with a metallic ground plane) used during the SNF "raw" data acquisition was at the minimum required far-field separation. This information can be applied to estimate the "effective" size of the ground plane, and effectively replaces longer (in time) near-field measurements with a far-field measurement at a near-field probe to AUT separation. In particular, two principal plane pattern cuts can be acquired significantly faster, and without the post-processing complexity.



▲ *Fig. 9 Measured SNF-FF ungated (blue) and gated (red) azimuth pattern for vertical polarization.*



▲ *Fig. 10 Comparison of time-gated SNF and time-gated FF azimuth patterns for vertical and horizontal polarizations.*

The low-gain antenna used for this measurement is less than ½-inch thick with a two-inch diameter, using an 8-inch coaxial feed line. The operating frequency was approximately 2.3 GHz. The antenna is mounted in the center of a 38-inch diameter metallic ground plane, as shown in ***Figure 7***.

A WR-430 rectangular open-ended waveguide was used as a probe antenna. The separation used for the measurements was 33 inches. The test bandwidth was extended to ±15 percent of the nominal bandwidth of a WR-430 rectangular waveguide. This provided a useable 1.56 GHz bandwidth, or 7.7 inch resolution, for the tests.

The far-field distance for the test antenna is only approximately two inches. However, if the largest aperture is assumed to be determined by the size of the metallic ground plane to which the test antenna is attached, then the minimum far-field distance becomes over 61 feet.

Figure 8 shows the ungated and gated time-domain response of the measured far-field data for both horizontal (blue) and vertical (red) polarization. A 10 ns time-gate was used to filter the response. ***Figure 9*** shows the result of gating the time-domain response of the far-field data on the azimuth pattern. The ripple in the main beam is reduced or eliminated. In addition, the scattering lobes beyond 90° (behind the metallic ground plane) are reduced to better than 30 dB below the peak of the main beam, clearly indicating that the edge diffraction effect is significantly reduced.

Figure 10 compares the time-gated SNF and time-gated far-field azimuth patterns. As can be seen, any differences between the patterns is virtually absent in the forward hemisphere, and are well within practical tolerances (only a few dB at the -40 dB pattern level) in the back hemisphere, indicating that the antenna with metallic ground plane can be effectively tested using a time-gated far-field antenna measurement scenario with the source (probe) antenna separated from the AUT on as short a distance as 33 inches instead of the predicted 61 feet.

CONCLUSION

A series of examples presented above has demonstrated that the time-gating technique, either as a stand-alone process, or in combination with other widely used techniques, can be effectively applied to enhance a broad range of practical measurement applications ranging from classical radar to a number of diversified antenna measurement situations. In particular, time-gating applications at UHF frequencies or in combination with antenna near-field techniques deliver a high quality result that could not be achieved with other methods. ■

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Technology Refresh –

What Is It and Why a Strategy is Needed

By Duane Lowenstein, *Agilent Technologies*

The concept of Technology Refresh is derived from the idea that people responsible for electronic technology only think about making changes when a change is necessary. In other words, if things are not broke, then why fix them. However, for users of older electronic technology there is a greater risk of failure, greater cost associated with maintaining the equipment and increased cost of repair. Technology Refresh is all about establishing a plan for the future today using a methodical process that invokes a clearly defined strategy when "it" breaks. It is akin to having an insurance policy that is invoked for protection when needed, versus having no protection on a burning structure that will ultimately disrupt all activities and affect all aspects of operation.

Buying a new car, a TV or any significant purchase requires planning, study and comparison. Several attributes drive or influence us in our decision making, such as how familiar we are with a product's controls or operation, discounts for bundling or ease of payments. In almost all cases, we go with the product or service that takes the least change or minimizes the complexity in our decision. The same goes for deciding to buy, migrate or upgrade test and measurement assets; what Agilent defines as Technology Refresh. The other factor that impacts our ability to make change is that electronic technology does not stand still. There is a need to understand the newest technology, as well as its advantages and disadvantages in relation to implementing a Technology Refresh plan.

The decision to refresh technology tends to be a focused initiative on a single instrument, on a single platform, for a specific reason. Although the reasons for change may vary, the critical success factors are the same, these include: measurement capability, code compatibility, physical envelope, and user interface. The underlying factor is usually cost. The ability to remove the obstacles to ensure minimum disruption of the critical success factors is paramount to ensuring the best asset replacement. A key to this is the early identification of those obstacles and their real effect on the success of the migration. To adequately do this takes planning and forethought so that all needed information is vetted on facts rather than emotion or circumstances.

To simplify the decision process, three fundamental strategies can be used to continue operation readiness while minimizing cost and risk: *Extend*, *Migrate* and *Modernize.* Each strategy has both fundamental business and technical advantages and disadvantages. Each of these refresh approaches presents the following advantages:

Extend *(eBay strategy—buy the same replacements cheap)*
- No hardware or software changes
- Low risk, simple
- Least expensive
- Higher downtime
- Eventually the product will go out of support

Migrate *(selective instrument replacement, one at a time)*
- Greater reliability
- Faster test
- Lower cost of ownership
- Minimum hardware and software changes
- Can be expensive
- Risk of software issues
- Possible requalification of automated test equipment (ATE) and software

Modernize *(complete refresh of core system)*
- Greater reliability
- Faster test
- Lowest cost of ownership (excluding acquisition cost)
- Greatest future longevity
- Most expensive
- Greatest risk
- Maximum hardware and software changes

A key assumption which influences the asset upgrade decision is the length of time for which the instrument/test platform will be needed. In very simple terms, if the life expectancy of the product being tested by the instrument/test platform is relatively short, less than 2 years, then by far the most cost-effective approach is the Extend or eBay strategy. Alternatively, if the life of the product-under-test is very long, greater than 10 years, then Modernization becomes the preferred course of action. Unfortunately, the most difficult question to answer is, "How long will the product remain in service?"

For more information and assistance on Technology Refresh go to **www.agilent.com/find/techrefresh-mwj** *or contact your local Agilent Business Development Manager.*

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History of Mobile Satellite Communications

Communication satellites provide the bridges for a number of new, specialized markets in commercial and private telecommunications and create ties between nations. In their more than 40 years existence, they have become fixed satellite communications (FSC). Eventually, mobile satellite communications (MSC), navigation and determination came to serve navies, ground and air forces worldwide and, for economic reasons, also provided commercial MSC. MSC has been used for the past 35 years, particularly because ocean-going vessels have become dependent on mobile satellite services (MSS) for their commercial and safety communications. Although their use in aircraft and land vehicles started before ships, because of many unsuccessful experiments and projects, they have had to follow the evident lead of Inmarsat maritime MSC service and engineering.

The modified ship's mobile Earth stations (MES) are today implemented on land (road or railway) vehicles and aircraft for all civil and military applications, including remote or rural locations and industrial onshore and offshore installations. The GPS, GLONASS and other new global navigation satellite systems (GNSS) provide precise positioning data for vessels, aircraft and land vehicles. Because of the need for enhanced services, these systems will be augmented with satellite communications, navigation and surveillance (CNS) facilities.

EVOLUTION OF SATELLITE COMMUNICATIONS

The first known mention of devices resembling rockets is said to have been made by Archytus of Tarentumin, who invented in 426 B.C. a steam-driven reaction jet rocket engine that flew a wooden pigeon around his room. Devices similar to rockets were also used in China during the year 1232. In the meantime, human space travel had to wait almost a millennium, until the time of Sir Isaac Newton, when it was understood how a projectile launched at the right speed could enter the Earth's orbit. Finally, the twentieth century came with its great progress and the historical age of space

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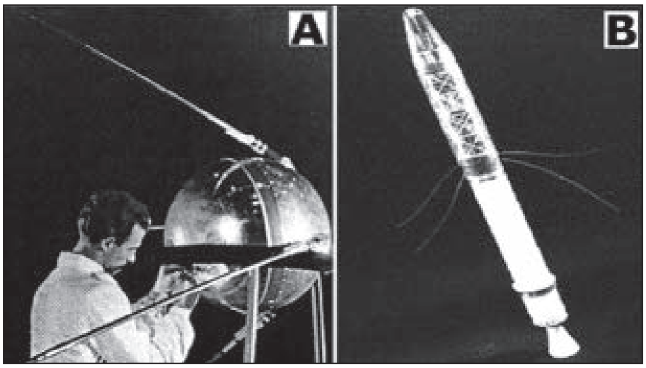

Fig. 1 (A) Sputnik 1 and (B) Explorer 1 (courtesy of Never Beyond Reach (A) and NASA (B)).

communications began to unfold. Russian scientist Konstantin Tsiolkovsky (1857–1935) published a scientific book on virtually every aspect of space rocketing. He propounded the theoretical basis of liquid propelled rockets, put forward ideas for multi-stage launchers and manned space vehicles, space walks by astronauts and a large platform system that could be assembled in space for normal human habitation. A little later, the American Robert H. Goddard launched in 1926 the first liquid propelled rocket engine.

At the same time, between the two world wars, many Russian and former USSR scientists and military constructors used the experience of Tsiolkovsky to design many models of rockets and to build the first reactive weapons, particularly rockets called "Katyusha," which the Soviet Red Army used against German troops at the beginning of World War II. Thus, towards the end of the Second World War, many German military contractors started experiments to use their series V1 and V2 rockets to attack targets in England. In October 1945, the British radar expert and writer of science fiction books Arthur C. Clarke proposed that only three communications satellites in geostationary earth orbit (GEO) could provide near global coverage for TV broadcasting.

The work on rocket techniques in Russia and the former USSR was extended after the Patriotic War. The satellite era began when the Soviet Union shocked the world with the launch of the first artificial satellite, Sputnik I, on 4 October 1957 (see ***Figure 1***). This launch marked the beginning of the use of artificial Earth satellites to extend and enhance the horizon for radio communications, navigation, weather monitoring and remote sensing. That was soon followed on 31 January 1958 by the launch of the US satellite, Explorer I, also shown in the figure. The development of satellite communications and navigation signified the beginning of the space race. The most significant progress in space technology was on 12 April 1961, when Yuri Gagarin, an officer of the former USSR Air Force, lifted off aboard the Vostok I spaceship from Bailout Cosmodrome and made the first historical manned orbital flight in space.

EXPERIMENTS WITH ACTIVE COMMUNICATIONS SATELLITES

After the launch of Sputnik I, a sustained effort by the US to catch up with the USSR started. This was reflected in the first active communications satellite named SCORE, launched on 18 December 1958 by the US Air Force. The second satellite, Courier, was launched on 4 October 1960

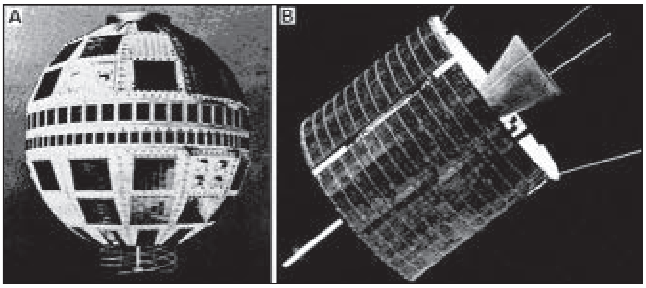

Fig. 2 (A) Telstar 1 and (B) Intelsat 1 (courtesy of Satellite Communications).

in high-inclined elliptical orbit (HEO) with its perigee at approximately 900 km and its apogee at approximately 1,350 km using solar cells and a frequency of 2 GHz. The maximum emission length was between 10 and 15 min for every successive passage. The third such satellite was Telstar I, designed by Bell Telephone Laboratories experts and launched by NASA on 10 July 1962 in HEO configuration, with its perigee at approximately 100 km and apogee at approximately 6,000 km (see ***Figure 2***). The plane of the orbit was inclined at approximately 45° to the equator and the duration of the orbit was approximately 2.5 hours. Because of the rotation of the Earth, the track of the satellite as seen from the Earth stations appeared to be different on every successive orbit. Thus, over the next two years, Telstar I was joined by Relay I, Telstar II and Relay II. All of these satellites had the same problem: they were visible to widely separated LES for only a few short daily periods, so a number of LES were needed to provide full-time service.

On the other hand, GEO satellites can be seen 24 hours a day from approximately 40 percent of the Earth's surface, providing direct and continuous links between large numbers of widely separated locations. The world's first GEO satellite, Syncom I, was launched by NASA on 14 February 1963, which presented a prerequisite for the development of MSC systems. This satellite failed during launch, but Syncom II and III were successfully placed in orbit on 26 July 1963 and 19 July 1964, respectively. Both satellites used the military band of 7.360 GHz for the uplink and 1.815 GHz for the downlink. Using FM or PSK mode, the transponder could support two carriers at a time for full duplex operation. Syncom II was used for direct TV transmission from the Tokyo Olympic Games in August 1964.

These spacecraft operated successfully until some time after 1965 and marked the end of the experimental period. Technically, all these satellites were being used primarily for fixed satellite service (FSS) experimental communications, which were used only to relay signals from fixed Earth stations (FES) at several locations around the world. Hence, one FES was actually located aboard the large transport vessel USNS Kingsport, anchored in Honolulu, HI. The ship had been modified by the US Navy to carry a 9.1 m parabolic antenna for tracking the Syncom satellites. The antenna dish was protected, like present mobile antennas, from the marine environment by an inflatable Dacron radome, requiring access to the 3-axis antenna through an air lock within the ship.

The Kingsport ship terminal was the world's first true MES and could be considered the first ship Earth station (SES). The ITU authorized special frequencies for Syncom communication experiments at approximately 1.8 GHz for the downlink (space to Earth) and approximately 7.3 GHz for the uplink (Earth to space). This project and trial was an unqualified success, proving only the practicality of the GEO system for satellite communications but, because of the large size of the Kingsport SES antenna, some experts in the 1960s concluded that MSC at sea would never really be practical. However, it was clear that the potential to provide a high quality line-of-sight path from any ship to the land and vice-versa, via the satellite communications transponder, existed at this time.

Intelsat was founded in August 1964 as a global FSS operator. The first commercial GEO satellite was Early Bird (renamed as Intelsat I) developed by Comsat for Intelsat (see Figure 2). It was launched on 6 April 1965 and remained active until 1969. Routing operations between the US and Europe began on 28 June 1965, a date that should be recognized as the birthday of commercial FSS. The satellite had 2 × 25 MHz transponder bandwidths, the first with two Rx uplinks (centered at 6.301 GHz for Europe and 6.390 GHz for the US) and the second with two Tx downlinks (centered at 4.081 GHz for Europe and 4.161 GHz for the US), with a maximum transmission power of 10 W for each Tx. This GEO system used several LES located within the US and Europe; the modern era of satellite communications had begun.

In the meantime, considerable progress in satellite communications had been made by the former USSR, the first of which, the Molniya I (Lightning) satellite, was launched at the same time as Intelsat I on 25 April 1965. These satellites were put into an HEO, very different to those used by the early experiments and were used for voice, fax and video transmission from central FES near Moscow to a large number of relatively small receive only stations. In other words, that time became the era of development of the international and regional FSS with the launch of many communications spacecraft in the USSR, US, UK, France, Italy, China, Japan, Canada and other countries. At first, all satellites were put in GEO, but later HEO and polar Earth orbits (PEO) were proposed, because such orbits would be particularly suitable for use with MES at high latitudes. The next step was the development of MSC for maritime and later for land and aeronautical applications. The last step has to be the development of the non-GEO systems of Little and Big Low Earth Orbits (LEO), HEO and other GEO constellations for new MSS for personal and other applications.

EARLY PROGRESS IN MOBILE SATELLITE COMMUNICATIONS AND NAVIGATION

The first successful experiments were carried out in aeronautical MSC. The Pan Am airlines and NASA program, in 1964, succeeded in achieving aeronautical satellite links, using the Syncom III GEO spacecraft. The frequencies used for experiments were the VHF band (117.9 to 136 MHz), which had been allocated for aeronautical MSC (AMSC). The first satellite navigation system, called Transit, was developed by the US Navy and became operational in 1964. The great majority of the satellite navigation receivers has worked with this system since 1967 and has already attracted about 100,000 mobile and fixed users worldwide. The former USSR equivalent of the Transit was the Cicada system developed almost at the same time.

Following the first AMSC experiments, the Radiocommunications Subcommittee of the Intergovernmental Maritime Consultative Organization (IMCO), as early as 1966, discussed the applicability of an MSC system to improve maritime radiocommunications. This led to further discussions at the 1967 ITU WARC for the maritime MSC (MMSC), where it was recommended that a detailed plan and study be undertaken of the operational requirements and technical aspects of systems by the IMCO and CCIR administrations.

A little while later, the International Civil Aviation Organization (ICAO) performed a similar role to that of IMCO (described earlier), by the fostering interest in AMSS for air traffic control (ATC) purposes. The majority of the early work was carried out by the applications of space technology to the requirement of aviation (Astra) technical panel. This panel considered the operational requirements for and the design of suitable systems and much time was spent considering the choice of the frequency band. At the 1971 WARC, 2×14 MHz of spectrum, contiguous with the MMSC spectrum, was allocated at L-band for safety use. Hence, the work of the Astra panel led to the definition of the Aerosat project, which aimed to provide an independent and near global AMSC, navigation and surveillance system for ATC and airline operational control (AOC) purposes.

The Aerosat project unfortunately failed because, whereas both the ICAO authority and world airlines of the International Air Transport Association (IATA) agreed on the operational benefits to be provided by such a system, there was disagreement concerning the scale, the form and potential cost to the airlines. Finally, around 1969, the project failed for economic reasons.

The first experiment with Land MSC (LMSC) started in 1970 with the MUSAT regional satellite program in Canada for the North American continent. However, in the meantime, it appeared that the costs would be too high for individual countries and that some sort of international cooperation was necessary to make MSS globally available. In 1971, the ICAO recommended an international program of research, development and system evaluation. Before all, L-band was allocated for distress and safety satellite communications and 2×4 MHz of frequency spectrum for MMSS and AMSS needs, by the WARC held in 1971. According to the recommendations, Canada, FAA of the US and ESA signed a memorandum of understanding in 1974 to develop the Aerosat system, which would be operated in the VHF and L-bands. Although Aerosat was scheduled to be launched in 1979, the program was cancelled in 1982 because of financial problems. The first truly global MSC system started with the launch of the three Marisat satellites in 1976 by Comsat General. Marisat was a GEO spacecraft, containing a hybrid payload: one transponder for US Navy ship's terminals operating on a government UHF frequency band and another one for commercial merchant fleets utilizing newly-allocated MMSC frequencies. The first official mobile satellite telephone call in the world was established between the vessel-oil platform "Deep Sea Explorer," which was operated close to the coast of Madagascar, and the Phillips Petroleum Co. in Bartlesville, OK, on 9 July 1976, using AOR CES and GEO of the Marisat system.

The IMCO convened an international conference in 1973 to consider the establishment of an international organization to operate the MMSC system. The international conference met in London two years later to set up the structure of the international maritime satellite (Inmarsat) organization. The Inmarsat convention and operating agreements were finalized in 1976 and opened for signature by states wishing to participate. On 16 July 1979, these agreements entered into force and were signed by 29 countries. The Inmarsat officially went into operation on 1 February 1982 with worldwide maritime services in the Pacific, Atlantic and Indian Ocean regions at first, using only Inmarsat-A SES. Moreover, the Marecs-1 B2A satellite was developed by nine European states in 1984 and launched for the experimental MCS system Prodat, serving all mobile applications.

In 1985, the Cospas-Sarsat satellite SAR system was declared operational. Three years later, the international Cospas-Sarsat program agreement was signed by Canada,

France, the US and the former USSR. In 1992, the global maritime distress and safety system (GMDSS), developed by the International Maritime Organization (IMO), began its operational phase. Hence, in February 1999, the GMDSS became fully operational as an integration of Radio MF/HF/VHF (DSC), Inmarsat and Cospas-Sarsat LEOSAR and GEOSAR systems.

The Transit system was switched off in 1996 to 2000 after more than 30 years of reliable service. By then, the US Department of Defense was fully converted to the new Global Positioning System (GPS). However, the GPS service could not have the market to itself; the ex-Soviet Union developed a similar system called Global Navigation Satellite System (GLONASS) in 1988. While both the Transit or Cicada system provides intermittent two-dimensional (latitude and longitude when altitude is known) position fixes every 90 minutes on average and was best suited to marine navigation, the GPS or GLONASS system provides continuous position and speed in all three dimensions, equally effective for navigation and tracking at sea, on land and in the air.

The US Federal Communications Commission (FCC) worked toward private development of the radio determination satellite system (RDSS), which would combine position fixing with short messaging. In 1985, Inmarsat developed the Standard-C system and later examined the feasibility of adding navigational capability. The ESA satellite navigation concept, called Navsat, dates back to the 1980s, but the proposed project has received relatively little attention and even less financial support. In 1988, the US-based company Qualcomm established the OmniTRACS service for mobile messaging and tracking. Soon after, Eutelsat promoted a very similar system named EuroTRACS integrated with GPS and the Emsat communications system.

At the beginning of this millennium, three satellite augmentation systems (SAS) were developed for communications, navigation and surveillance (CNS): the American WAAS, Japanese MTSAT and European EGNOS. Those three operable and future projected SAS will augment the two military Global Satellite Navigation Systems (GNSS), the US GPS and the Russian GLONASS and make them suitable for safety critical applications, such as flying aircraft or navigating ships through narrow channels and port approaches. The last project of the European Union is Galileo second generation of GNSS, which should be operational in 2015.

Finally, several interesting projects are developing in Europe, Japan and the US for new mobile and fixed multimedia stratospheric communication platform (SCP) systems powered by fuel or the sun's energy and manned or unmanned aircraft or airships equipped with transponders and antenna systems at an altitude of approximately 20 to 25 km. At the end of this race, a new mobile satellite revolution is coming, whereby anyone can carry a personal handheld telephone using simultaneously satellite or cellular/dual systems at sea, in the car, in the air, on the street, in rural areas, in the desert, that is to say everywhere and in all positions. These integrated systems will soon be implemented, with new stratospheric platform wireless systems using aircraft or airships. ■

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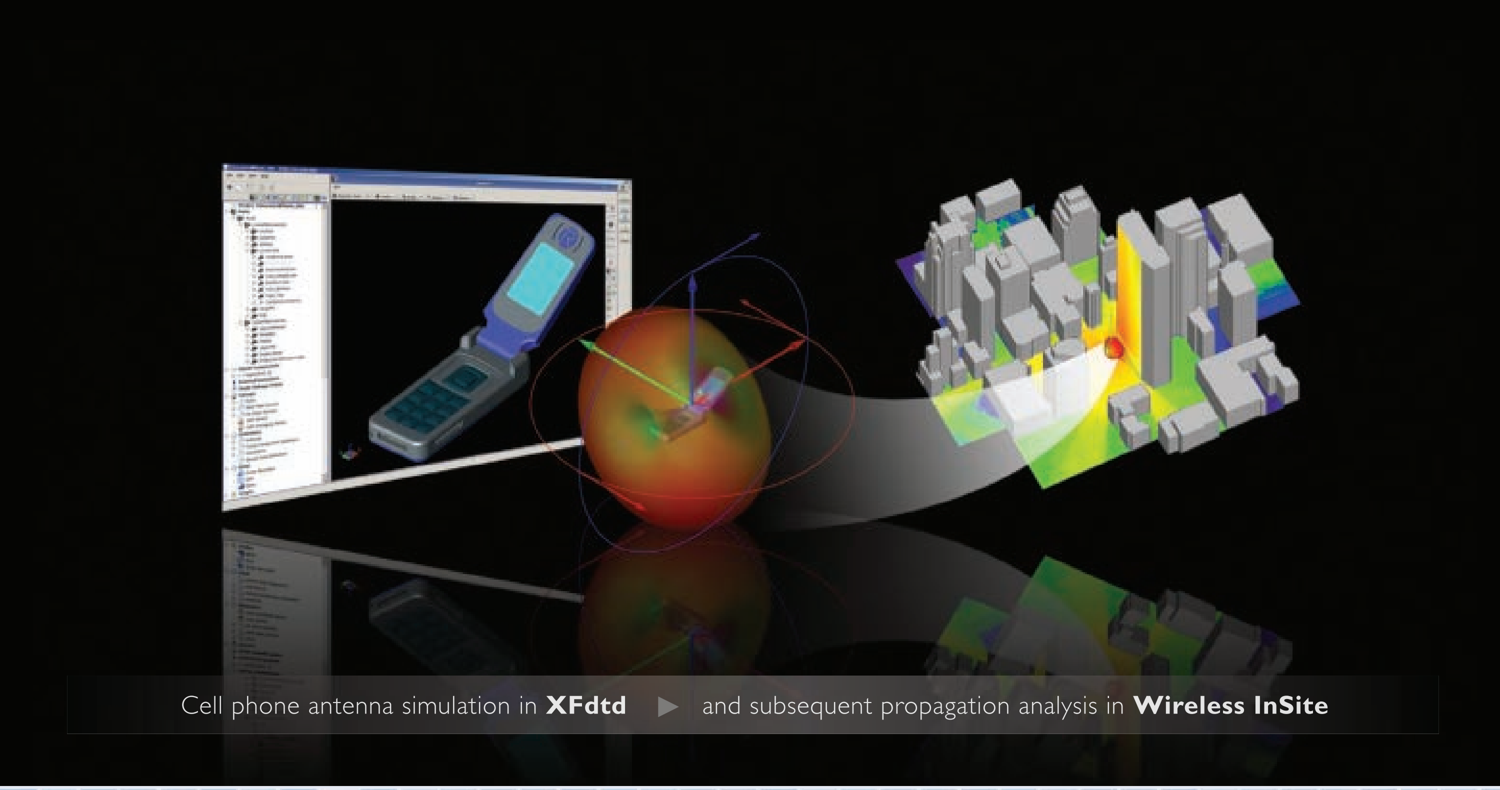
Cell phone antenna simulation in **XFdtd** ▶ and subsequent propagation analysis in **Wireless InSite**

Ka-band Traveling Wave Tube: 500 W Peak, 350 W CW

Taking advantage of over 60 years of experience as a global supplier of traveling wave tubes (TWT) and particular expertise in data transmission via satellite, Thales has introduced the new Ka-band TH 4092. This new introduction continues the company's expansion of its range of high-power TWTs to meet the needs of satellite operators around the world and support growing demand for new communication uplinks, including HDTV, direct broadcast TV, consumer broadband and military missions.

The TH 4092 is a new-generation Ka-band TWT dedicated to large earth-station uplink applications in the millimeter-wave bandwidth. Designed for broadband applications at 27.5 to 31 GHz, this powerful TWT delivers 500 W minimum peak power and 350 W in CW operation, covering market requirements for SATCOM uplinks with enhanced data rates and more available linear power. By leveraging the company's experience in spaceborne TWTs, it increases design margins, using a top-down approach that ensures high reliability.

DESIGN CHARACTERISTICS

The TH 4092 is a conduction-cooled TWT for fast mounting. It is equipped with a four-stage collector, drawing on proven space technologies, for high efficiency and low power dissipation. It is housed in a very rugged, compact package (370 × 72 × 60 mm) weighing only about 3 kg.

It is designed to deliver typical RF output power of 550 W CW, providing sufficient margins under specified operating conditions. The design focused on RF characteristics and the thermal qualities of the new subassemblies. Several prototypes underwent duration and environmental tests, which, combined with computer simulations, demonstrated that the maximum temperature and stress levels remain well below critical limits at the various operating points.

The electrical design of the gun and collector meet standards applied to space TWTs for high-voltage insulation: 'cold' electrodes and a low-power electrical field avoid high voltage arcing and spurious switch-off. The gun is equipped with an anode A0; the adjustment of anode A0 and cathode voltages optimize the tube's electrical and RF performance (linearity, RF output power and gain). A beam forming electrode (BFE) handles beam switch-on/switch-off. The BFE voltage (with respect to cathode voltage) is 0 V beam-on and typically -1,400 V beam-off. This fast switching mode is very safe for such a powerful Ka-band TWT.

A positive ion barrier, A1, protects the cathode and increases tube lifetime, while a new helix-rod layout is used to increase beam efficiency and ensure stable operation.

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The standard WR34 flange is used for the RF input and output to guarantee higher RF peak power margin and better thermal dissipation. Inputs and outputs are matched to achieve VSWR lower than 1.5:1 in a wide frequency band (26 to 32 GHz). The housing is designed to comply with outdoor environmental conditions, electromagnetic compatibility and low magnetic susceptibility requirements.

PERFORMANCE

The typical performance characteristics are given in ***Table 1***. Due to the adjustable cathode and anode voltages, RF performance can be optimized for each frequency band, or it can operate over the entire frequency band (27.5 to 31 GHz) with the same voltages. Saturated output power, gain for 350 W rated output power and small-signal gain responses are flat over the full bandwidth, as shown in ***Figures 1*** and ***2*** for saturated output power and small-signal gain.

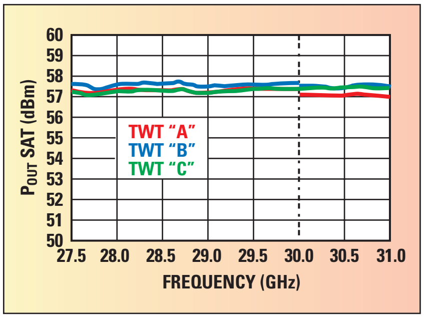
The advantage of the four-stage collector is that it reaches typical overall efficiency of 55 percent at saturation and 45 percent at 350 W output power (as shown in ***Figure 3***). The dissipated power is lower than 460 W and very constant across the full range of RF output power (see ***Figure 4***). Operating at constant dissipation means less thermal stress for the HPA and increased reliability. Even with its high RF output power, the TH 4092 reflects the 'green HPA' concept.

The TH 4092 combines high RF power with high linearity due to a low phase shift over the whole frequency range

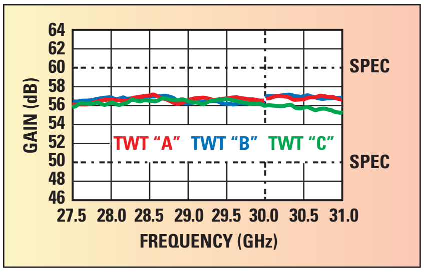
TABLE I

TH 4092 CHARACTERISTICS

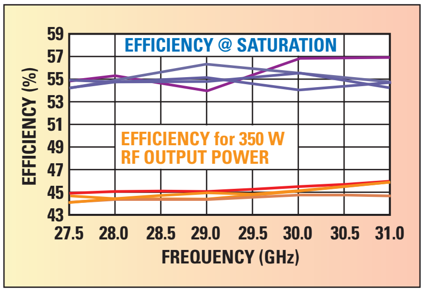
Parameter	*Unit*	*Typical data*
Frequency range	GHz	27.5-30 & 30-31
Rated output power (CW)	W	350
Saturated power (peak)	W	550
Drive power @ 350W	dBm	1
Gain @ 350W	dB	54
Small signal gain	dB	56
Helix voltage	kV	16.5 & 16.3
Anode voltage (A0)	V	-2000
Col.1 voltage	% Vk	41
Col.2 voltage	% Vk	34
Col.3 voltage	% Vk	27
Col.4 voltage	% Vk	10
Helix current no drive	mA	0.5
Helix current @ 350W	mA	1.5
Dimensions L × W× H	mm	370 × 72 × 60
Weight	kg	3



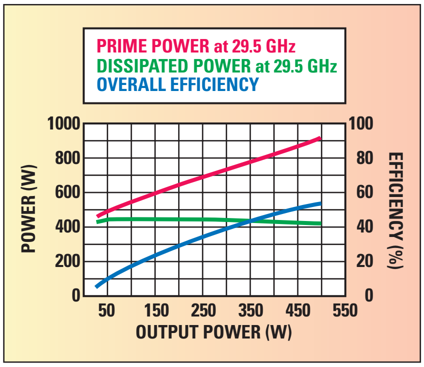
▲ *Fig. 1 RF saturated output power.*



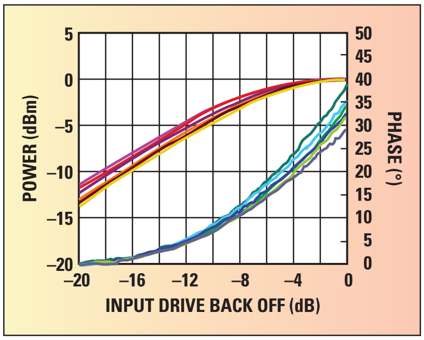
▲ *Fig. 2 Small-signal gain.*



▲ *Fig. 3 Overall efficiency vs. frequency.*



▲ *Fig. 4 Prime power, dissipated power and overall efficiency vs. RF output power.*



▲ *Fig. 5 Phase shift and gain compression vs. drive at different frequencies.*

(as shown in ***Figure 5***). The IM3 product is higher than 30 dBc for two carriers at 10 dB operating in back-off (OBO). Moreover, the smooth AM/AM and AM/PM characteristics support easy linearizer integration for optimum link performance.

The tube's very good linear characteristics offer broad possibilities of adjusting TWT parameters to achieve the best compromise between linear performance and prime power consumption. Moreover, the four collector voltages have been optimized to avoid reflected electrons and thus maintain good linearity up to saturation, a very important characteristic in multicarrier operations.

QUALIFIED FOR SERVICE

The TH 4092 is now fully qualified, with proven state-of-the-art RF characteristics: noise density, phase and output power sensitivities, NPR, EMC, spectral regrowth, etc. Mechanically it has been qualified for random vibrations (10 to 2,000 Hz at 5 g rms) and shock (30 g /11 ms), and operation over a wide baseplate temperature range (-40° to +95°C) has been validated. The variation in gain versus temperature is low (<0.015 dB/°C in linear operation and <0.01 dB/°C for 350 W rated output power). The TWT's compatibility with hot, humid environments (humidity 95 percent, temperature 50°C) and altitude (up to 15,000 m) has also been validated.

MARGINS AND RELIABILITY

The technological choices and design margins on the TH 4092 are compatible with an expected lifetime exceeding 50,000 hours. Thales has carried out a margin test program (using an approach similar to its space TWTs) to underpin confidence in year-long 24 × 7 operation.

On a high-power TWT, thermal management and stability are the keys to good reliability. Therefore, all components in the TH 4092 are designed to operate at 500 W CW RF output power. Each subassembly has undergone margin tests; for example, the collector has been validated at 1 kW dissipated power (i.e., twice the nominal value).

Operation at output power higher than 500 W CW has been successfully tested. The low variation in output power after RF switch-on (< 0.1 dB for 550 W CW) demonstrates the high thermal capability of the delay line. The RF power transient record proves that the helix temperature is well below the maximum allowed threshold. This ensures excellent margins for operation at 350 W CW under all specified environmental conditions.

The TWT's stability has been checked for saturated output power higher than 550 W over the full temperature range, with highly variable helix voltage and cathode current values. The low, constant power dissipation versus output power does, in fact, decrease thermal stress in the HPA, thus increasing subsystem reliability.

The gun is designed for an operating life exceeding 50,000 hours, based on an MM type cathode, an adjustable anode A0 and an ion barrier A1. The MM cathode lifetime is space-qualified, with durations longer than 80,000 hours. Use of the adjustable anode A0 provides broad flexibility in achieving the optimum tradeoff between power and linearity, and also enables stabilization of the cathode current and the maintenance of constant performance (power, gain, etc.) over the TWT's lifetime. Also, the ion barrier avoids any ion bombardment that could damage the emitting cathode surface.

CONCLUSION

The extensive qualification and margin tests performed on the new-generation Ka-band TH 4092 TWT, at 500 W peak/350 W CW, have confirmed the validity of the design choices and technologies used to ensure high reliability. Based on the thermal and stability margins, along with tests on the subassemblies, Thales ensures a service life exceeding 50,000 hours.

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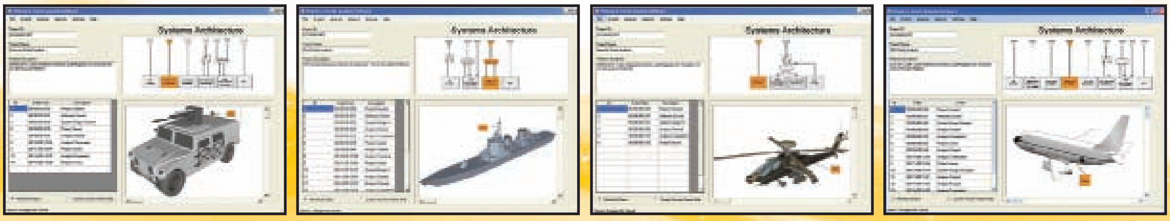

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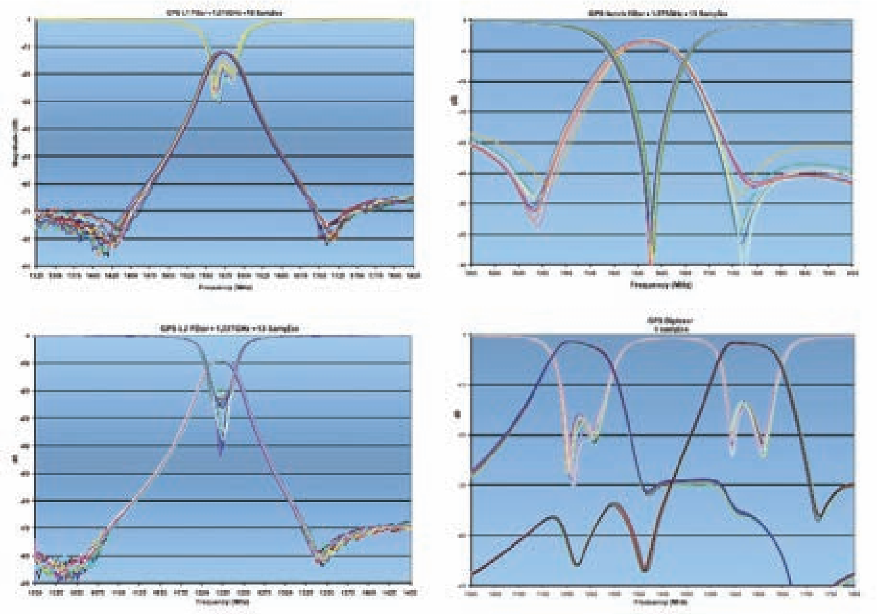

DLI has introduced a family of GPS components that includes two bandpass filters, two diplexers and a notch filter. The bandpass filters and diplexer pass both L1 and L2 frequency bands. The notch filter attenuates the L1 frequency band. Two different versions of the diplexer have been designed and manufactured. The first version has higher insertion loss, but better rejection due to a narrow bandwidth. The bandwidth was widened on the second version to reduce the insertion loss at the cost of eroding the rejection skirts.

The bandpass filters and diplexer incorporate DLI's new printed wired board (PWB) cover technology. The PWB cover provides RF shielding and reduces the possibility of energy coupling from the filters to other components in the circuit. The notch filter incorporates an integral metal cover for RF shielding. All filters employ DLI's high-k ceramic, which allow for great size reduction and superior temperature stability compared to alumina and PWB materials. All components are radiation hardened, do not out gas and are solder surface-mount compatible, making them an ideal, temperature stable drop-in for any GPS application.

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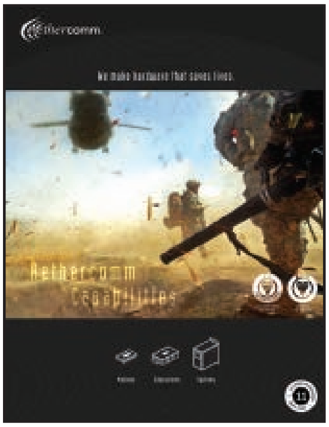


Capabilities Brochure

The 2010 capabilities brochure features Aethercomm's three major product lines: RF amplifier modules, RF subsystems and RF systems. The major classes of RF amplifier modules are broadband high power, linear high power and high power pulsed amplifiers. The products are employed in electronic warfare, radar and communication systems, and other applications that require high power RF energy. Aethercomm offers automated assembly and test capabilities, hybrid and MIC capabilities, custom product design and is ISO 9001:2008 and AS 9100 certified.

Aethercomm Inc.,
Carlsbad, CA (760) 208-6002, www.aethercomm.com.

RS NO. 319

Product Brochure

VENDORVIEW

Akon Inc. offers a complete line of subassemblies/subsystems and components applicable to the needs of the EW-ESM/ECM community. These products and capabilities include transceivers and related subsystems: channelized receiver front-ends, DFD/IFMs, threat simulator RF source/simulators, ERDLVAs (extended-range DLVA) and SDLAs (successive-detection DLVA), and RF front-end amplifiers and assemblies. Designs utilize Akon's more than 30 years of technical expertise, internal active and passive capability, and manufacturing know-how to deliver high performance, reliable hardware.

AKON Inc.,
San Jose, CA (408) 432-8039, www.akoninc.com.

RS NO. 321

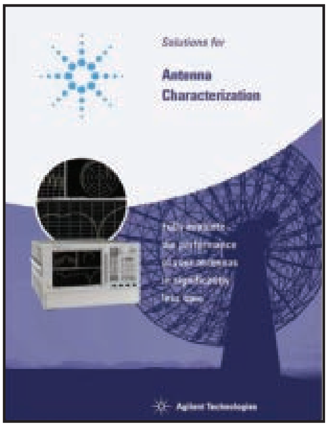
Product Brochure

VENDORVIEW

AWR's AXIEM™ v. 2010 brochure is packed with information on the latest features and technologies in AXIEM EM software, which was developed specifically for 3D planar applications like RF PCBs and modules, as well as LTCC, MMIC and RFIC designs. The brochure highlights AXIEM 2010 antenna analysis and post-processing capabilities, indispensable tools for designers of planar antennas and antenna arrays. For more information on AXIEM and to download a complimentary .pdf of the brochure, visit www.awrcorp.com/axiem.

AWR Corp.,
El Segundo, CA (310) 726-3000, www.awrcorp.com.

RS NO. 323



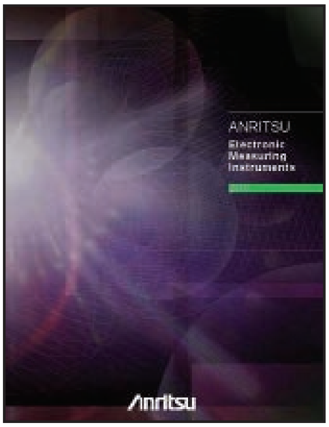
Antenna Test Solutions

VENDORVIEW

Learn about antenna test solutions from Agilent Technologies. See how to lower antenna test times by as much as 80 percent, significantly improve measurement sensitivity or replace existing 8530A-based solutions with higher performance and code emulation. For more information, visit www.agilent.com/find/antenna-mwj.

Agilent Technologies Inc.,
Santa Clara, CA (800) 829-4444, www.agilent.com.

RS NO. 320



Electronic Measuring Instruments Catalog

VENDORVIEW

This 2010 EMI Catalog features Anritsu's full line of products including pulse pattern generators/error detectors, mobile/wireless communication measuring instruments, signal analyzers/spectrum analyzers, network analyzers, signal generators, RF microwave measuring instruments, components, peripheral equipment and optical devices. Anritsu is a leader in the telecommunications, optical and wireless industries, providing a diverse range of test and measurement solutions, high-speed devices and components for use in R&D, production and maintenance. To download the catalog, visit www.anritsu-offer.com/emi-catalog824.

Anritsu,
Richardson, TX (972) 644-1777, www.anritsu.com.

RS NO. 322

Capabilities Brochure

VENDORVIEW

Carlisle Interconnect Technologies is a provider of RF/microwave solutions encompassing every facet of design and production. The company's new RF/microwave and filter interconnect capabilities brochure will give you an idea of all that we can do for you. Take a look at www.CarlisleIT.com today.

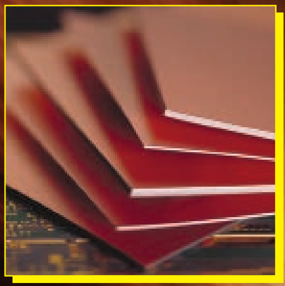
Carlisle Interconnect Technologies,
St. Augustine, FL (904) 829-5600, www.carlisleit.com.

RS NO. 324

Tactical Advantage.

When Reliability Counts.

Mission-critical applications have relied on Rogers' microwave materials for years. The superior electrical and mechanical characteristics of Rogers' military-grade laminates provide the stable, consistent performance over time and temperature that's so critical for aerospace and defense applications.



The rock solid performance of Rogers' microwave materials deliver the high performance and high-reliability demanded by the most mission-critical applications. Can you afford to use anything less?

To learn more about Rogers' aerospace and defense microwave material solutions, visit us at:
www.rogerscorp.com/military

Photos used by permission from Northrop Grumman Corporation.

	Features	Benefits
RT/duroid® 6202PR	Reduced planar resistor variation	Lower manufacturing costs due to decreased tuning
	Low thermal coefficient of dielectric constant	Stable electrical performance versus temperature
	Low coefficient of thermal expansion	High reliability in complex multilayer designs
RT/duroid® 5880LZ	Dielectric constant of 1.96	Lowest dielectric constant microwave PCB material
	Low z-axis coefficient of thermal expansion	Plated through hole capable
	Light weight	Advantage for airborne applications

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MILITARY MICROWAVES SUPPLEMENT

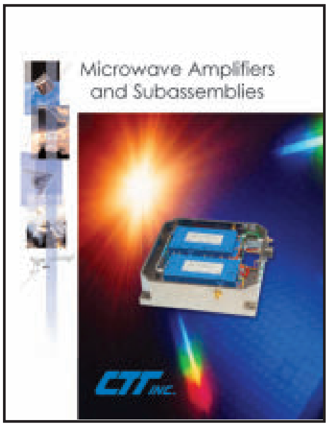
LITERATURE SHOWCASE

Product Catalog

CPI's Beverly Microwave Division (BMD) designs and manufactures a broad range of RF and microwave products for radar, communications, electronic warfare and scientific applications. CPI/BMD is the world's largest manufacturer of receiver protectors and related products. Other product lines include magnetrons, TWTs, CFAs, transmitter assemblies, scientific systems, high power solid-state switches and switch assemblies, pressure windows, and a wide variety of multifunction components and integrated microwave assemblies.

Communications & Power Industries (CPI), Beverly Microwave Division, Beverly, MA (978) 922-6004, www.cpii.com/bmd.

RS NO. 325

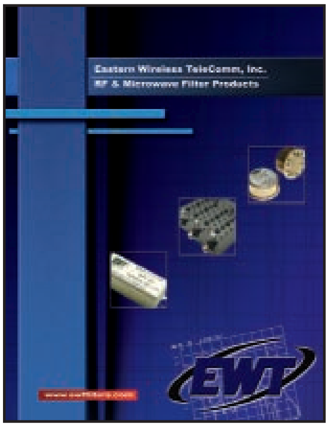


Product Catalog

This 36-page catalog features 175 all-new amplifier products, including lightweight and compact LNAs based on GaAs PHEMT active devices. CTT's extended product offering includes Gallium Nitride (GaN)-based power amplifiers for wideband jammers applications (25 W from 0.5 to 2 GHz), as well as narrowband radar applications (80 W from 8.5 to 9.6 GHz). In addition, several new subsystem offerings have been introduced, including a VMEbus-compatible two-channel IF conditioner.

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

RS NO. 326



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. 327

Massachusetts Bay Technologies, Inc. (MBT) specializes in the design, manufacture and distribution of RF/Microwave semiconductor diodes. MBT is committed to the continuance of innovations in service to its customers, improvement of design, product performance and quality control.

MBT's product frequencies range from 100Hz up to and including millimeter wave; our quality devices are used in various industry applications such as university and laboratory research, consumer products, telecommunications, aerospace and military.

MBT's consistent objective is to provide a superior product with unsurpassed customer service to our clients. Our engineers are available to discuss your specific design and application requirements that are both cost and time effective. We look forward to providing you component expertise and a quality product.

MBT's product line includes but is not limited to the following RF/Microwave devices:

Abrupt Tuning Varactors Diodes
Hyperabrupt Tuning Varactors Diodes
Step Recovery/Multiplier Diodes
PIN/Beam Lead PIN/Limiter Diodes
Point Contact Diodes
Schottky Diodes
MIS Chip Capacitors
Custom Designed Components

Are you looking for a discontinued Alpha Industries, Frequency Sources, Hewlett Packard, M/A-Com, Microwave Associates, MEDL, Motorola, NEC, Philips, Parametric Industries, Siemens, Thomson CSF, Toshiba or Varian part? MBT will cross reference and manufacture your discrete, obsolete or custom RF/Microwave application.

MASSACHUSETTS BAY TECHNOLOGIES

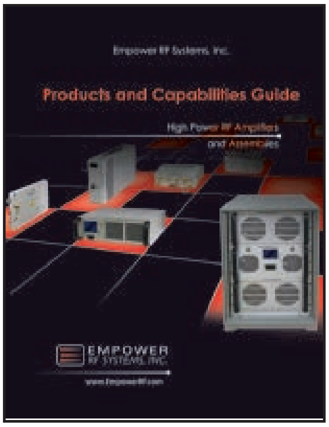
RF/MICROWAVE SEMICONDUCTORS

Motivated By Performance, Focused on Reliability ®

Massachusetts Bay Technologies, Inc. 378 Page Street, Stoughton, MA 02072 • Tele: 781-344-8809 • Fax: 781-341-8177 • Website: www.massbaytech.com • Email: sales@massbaytech.com

MILITARY MICROWAVES SUPPLEMENT

LITERATURE SHOWCASE



High Power Broadband RF Amplifiers

Empower is pleased to present the company's updated products and capabilities guide. The brochure is a comprehensive overview of the company's capabilities and a listing of its most popular amplifier products. With products that cover from 150 kHz to 6 GHz and an extensive library of building block designs, there is an array of catalog standard and semi-custom solutions available to consider. This brochure will be especially useful for buyers, sales reps and engineers.

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

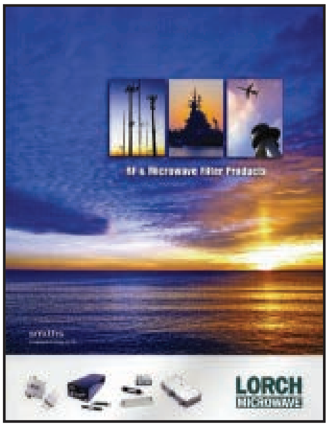
RS NO. 328

Product Catalog

K&L Microwave's 128-page catalog can be used as a desktop reference guide that offers details and specifications to help designers and engineers choose products quickly. 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 catalog.

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

RS NO. 329



Short-form Product Guide

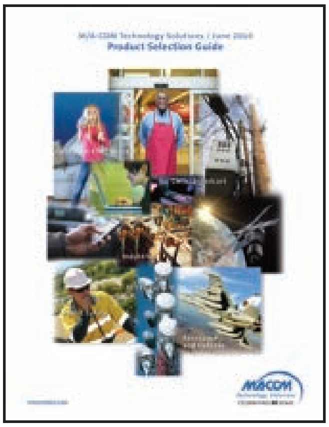
The Lorch Microwave short-form product guide presents the company's complete product range in a clear and concise format. The products featured are used in a wide range of military and commercial applications. Also included are frequency range of operation, photographs and specific application information, charts and tables.

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

RS NO. 330

MILITARY MICROWAVES SUPPLEMENT

LITERATURE SHOWCASE



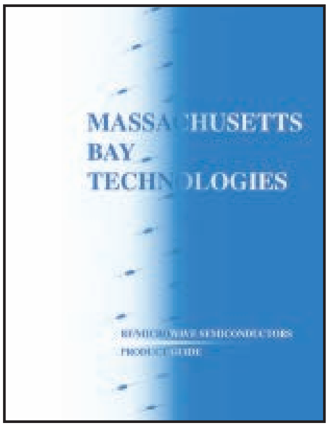
Product Guide

VENDORVIEW

M/A-COM Technology Solutions' Product Selection Guide (PSG) is designed to help microwave and RF engineers select the products they need for their applications in the commercial, aerospace and defense markets. It contains a comprehensive listing of products, in addition to details such as packages available, wavelength and frequency information, Decibels-Volts-Watts Conversion Table, Telecommunications Standards, Part Number index, and application block diagrams. Download a copy today by going to macomtech.com.

M/A-COM Technology Solutions,
Lowell, MA (978) 656-2546, www.macomtech.com.

RS NO. 331

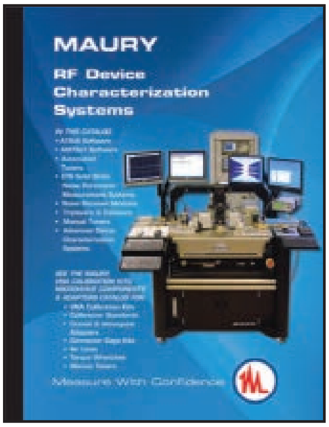


Product Guide

The Massachusetts Bay Technologies (MBT) RF/microwave diode product catalog is the clear choice for the discriminating project engineer. Inside you will find a diverse selection of PIN, Schottky mixer & detector, step recovery and varactor diodes. MBT also has a vast inventory of legacy wafers and an engineering department with a combined experience of over 100 years in the industry. In a further move to be the best, MBT has recently showed its commitment to quality by instituting the quality standard of ISO 9001:2008.

Massachusetts Bay Technologies Inc.,
Stoughton, MA (781) 344-8809, www.massbaytech.com.

RS NO. 332

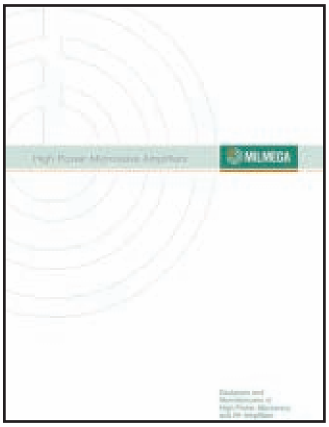


RF Device Characterization Systems

This catalog covers Maury Microwave's full line of device characterization solutions, including information on RF device characterization methods, ATSv5 device characterization software, load pull and noise parameter systems, automated tuners, controllers, manual tuners and test bench accessories; everything you need to make device characterization measurements with confidence. The catalog is available as a free 60-page .pdf download from http://maurymw.com/mmc_catalog/1G-003b.pdf.

Maury Microwave Corp.,
Ontario, CA (909) 987-4715, www.maurymw.com.

RS NO. 333



Microwave Amplifiers Catalog

As well as detailing the company's comprehensive range of products, the 32-page 2010 *High Power Microwave Amplifiers* catalog outlines Milmega's commitment to quality and performance in terms of R&D, manufacture, quality and reliability, sales and continuous improvement. It highlights that Milmega's amplifiers can be used in such diverse applications as communications testing, EMC testing and in the fields of defense, medical and high energy physics research. The catalog also covers performance testing, application guidelines and custom design.

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

RS NO. 334

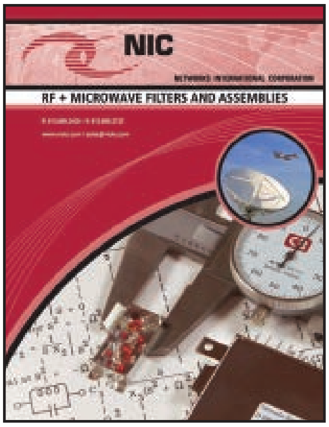
IF/RF Microwave Signal Processing Components Guide

VENDORVIEW

Mini-Circuits' new 164-page catalog includes over 750 new products and is the industry's most comprehensive listing of RF/IF and microwave components and subsystems with more than 4100 products and over 25 product lines, including state-of-the-art amplifiers, mixers, VCOs, synthesizers, filters, test accessories and USB power sensors. Mini-Circuits' website provides additional data, application notes, design tools and its powerful YONI search engine.

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

RS NO. 351



Capabilities Brochure

VENDORVIEW

NIC introduces its new RF and microwave products and capabilities brochure. Products include: cavity, ceramic, crystal and LC filters, multiplexers and diplexers; RF assemblies - filter/amplifiers, switched filter banks, phase shifters; oscillators - TCXOs and VCTCXOs and Space Qualified products. Advanced Environmental Testing capabilities and Filter Design considerations are also included.

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

RS NO. 335

MILITARY MICROWAVES SUPPLEMENT

LITERATURE SHOWCASE

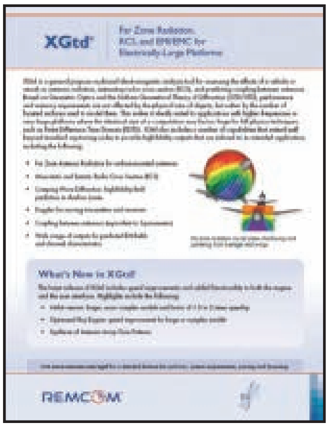
Filters, Multiplexers and Multi-function Assemblies

VENDORVIEW

This new catalog features the company's full line of RF and microwave filters, multiplexers and multi-function assemblies. The catalog contains RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request a copy, please e-mail reactel@reactel.com, or visit www.reactel.com.

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

RS NO. 336

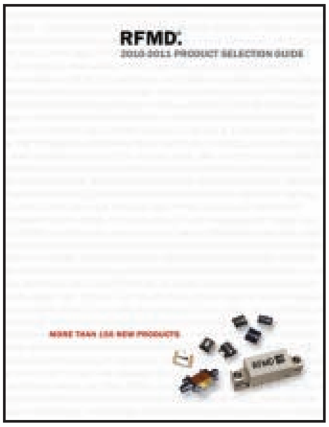


Product Brochure

Remcom announces a new version of XGtd®, a tool for far zone radiation, RCS, and EMI/EMC for electrically large platforms. Performance enhancements such as a 64-bit version, inclusion of an optimized ray engine (ORE), and improvements to graphical displays shorten the time it takes to achieve results. Visit www.remcom.com/xgtd for more information.

Remcom,
State College, PA (814) 861-1299, www.remcom.com.

RS NO. 337



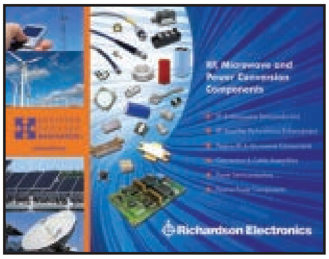
Product Selection Guide

VENDORVIEW

Visit www.rfmd.com to download the new 2010 RFMD Product Selection Guide, which provides specifications for over 850 products. The guide offers a broad portfolio of RF components for the RF industry in an easy-to-use format, and lists products servicing over 20 end-market segments. Individuals can cross-reference and search products using market application diagrams.

RFMD,
Greensboro, NC (336) 664-1233, www.rfmd.com.

RS NO. 338



Updated Line Card

Richardson Electronics recently updated its 16-page line card. The expanded line card is organized as a reference tool to help design in components for RF Active, RF Interconnect, RF Passive and Industrial Power and Passives product categories from leading suppliers. Visit RELL's website to download a .pdf at www.rell.com.

Richardson Electronics,
LaFox, IL (800) 737-6937, www.rell.com.

RS NO. 339

Product Catalog

RLC Electronics is a leader in the design and manufacture of RF and microwave components. The company's product range includes coaxial switches up to 65 GHz, power dividers, couplers, variable attenuators, filters and detector diodes up to 40 GHz. Many components are available in surface-mount construction, designed to meet specific customer requests electrically and mechanically. Those products include filters, switches, couplers and power dividers. New products include programmable attenuators, high power broadband couplers, high frequency broadband power dividers and delay lines up to 40 GHz.

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

RS NO. 340

Test and Measurement Catalog

VENDORVIEW

In the past year, Rohde & Schwarz launched many new product highlights, again proving its innovative strength in RF test and measurement. Now the Rohde & Schwarz T&M Products Catalog 2010/11 is available, presenting solutions for wireless communications, EMC and broadcasting, as well as general-purpose and RF test equipment. Order your copy from customersupport@rohde-schwarz.com.

Rohde & Schwarz,
Munich, Germany +0049 89 4129-13774, www.rohde-schwarz.com.

RS NO. 341

S292™ 2.92mm Connectors


Straight plug, direct solder for .086 semi rigid cable


Straight plug, solder/solder for .047 semi rigid cable


4 hole flange panel receptacle, female, .375" square


2 hole flange panel receptacle, female, .550"


4 hole flange panel receptacle, female, .500" square


4 hole flange panel receptacle, female, .500" x .390" rectangle


4 hole flange panel receptacle, male, .500" square


2 hole flange panel receptacle, male, .625"

Other configurations available.

Performance

Frequency Range:	DC to 40 GHz
VSWR:	DC-12 GHz: <1.04 DC-40 GHz: <1.18
System Impedance:	50 ohms
DWV:	300 Vrms @ 60 Hz (sea level)
Temperature Range:	-65°C to +85°C

Materials

Socket Contact:	BeCu
Body:	SS-303
Insulator:	Delrin

Plating

Bodies:	Passivated
Center Contacts:	Au/Ni

Mechanical

Interface:	MIL-STD-348
Contact Retention:	6 lbs axial
Durability:	500 Cycles


THUNDERLINE-Z®
Feedthrus Available

K-Band for the masses

If you're part of the high frequency movement that's been held back by overpriced or underperforming connectors, let San-tron set you free. S292 connectors offer exceptional VSWR performance through 40 GHz with prices near standard SMAs. Our internal redesign includes an engineered dielectric match to a hermetic 50 ohm Thunderline-Z® feedthru. The result is precise mating and ultra-pure signal transmission.

Looking for a replacement for K-band specific connectors or other SMA, WSMA, 2.92mm or 3.50mm interconnects? Make the move with S292.

San-tron

Always Thinking

ISO 9001:2008 REGISTERED

www.santron.com

978-356-1585

ROHS COMPLIANT

MILITARY MICROWAVES SUPPLEMENT

LITERATURE SHOWCASE

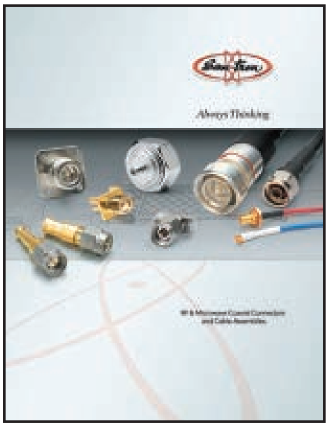
Product Brochure

VENDORVIEW

RT Logic's product overview brochure summarizes the company's broad line of innovative channel simulation, signal, data and network processing systems for the space and aerospace communications industry. Since RT Logic's founding in 1977, thousands of RT Logic systems have been fielded, with 90 percent of America's space missions utilizing RT's products during their test, launch, or on-orbit phase.

RT Logic,
Colorado Springs, CO (719) 598-2801, www.rtlogic.com.

RS NO. 342



Product Brochure

VENDORVIEW

San-tron Inc. has released its new "RF and Microwave Coaxial Connectors and Cable Assemblies" product brochure. The brochure outlines the company's entire connector offering, categorized by connector types, and their cable assembly capabilities. Connectors featured include SMA, MHV, SHV, BNC, TNC, C, SC, HN, LC, Type N and 7/16 connectors. New innovations include: eSMA connectors offering enhanced performance and reinforced sleeves, S292 connectors offering 40 GHz performance at standard SMA prices, and 7/16s with outstanding PIM performance.

San-tron Inc.,
Ipswich, MA (978) 356-1585, www.santron.com.

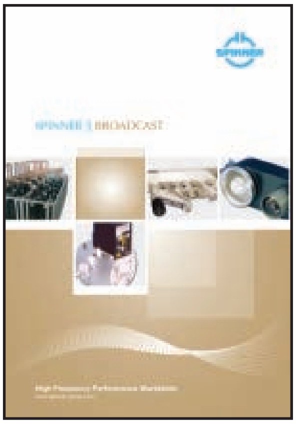
RS NO. 343

Short-form Catalog

This short-form catalog details the company's wide variety of hermetically sealed adapters that operate up to 40 GHz. It illustrates the product's key features such as: a leakage rate of less than 10-8 cc/s at 1 atmosphere Helium per MIL-STD 202, Type N and Type BNC BFJ and four hole flanges to 18 GHz for standard units and for high power applications to 13.5 GHz, and Type 2.92 mm BFJ to 40 GHz. The adapters have a stainless outer conductor, copper beryllium center conductor and both are gold plated.

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

RS NO. 344



Broadcast Catalog

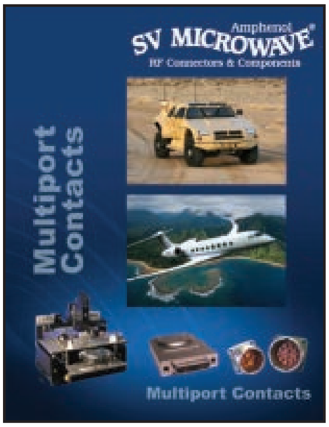
The catalog presents the complete SPINNER broadcast product portfolio, which includes its multi channel combiners, bandpass filters, patch panels, parallel switching units, coaxial switches, RF-lines and monitoring and coaxial loads. The new catalog includes all available information on the numerous new SPINNER products in this field, such as the new components of the Compact Combining and Switching System. It is also the first that has been adapted to the new design, which the SPINNER Group uses to visually underline its leading role in terms of technology and quality.

SPINNER GmbH,
Munich, Germany +49 89 12601-0, www.spinner-group.com.

RS NO. 345

MILITARY MICROWAVES SUPPLEMENT

LITERATURE SHOWCASE

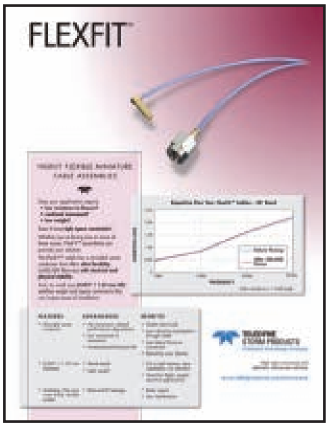


Multiport Contacts Catalog

SV Microwave has released its new Mulitport Contacts catalog featuring information on Size 8, 12 and 16 contacts operating to 18 GHz and fitting into M38999, ARINC, Micro-D and SIM connector cavities. These new contacts have enabled SV to combine RF/microwave and D/C signal in hybrid harnesses, providing simplified interconnection and smaller package size to aid both designers and operators in the field.

SV Microwave,
West Palm Beach, FL (561) 840-1800, www.svmicro.com.

RS NO. 346

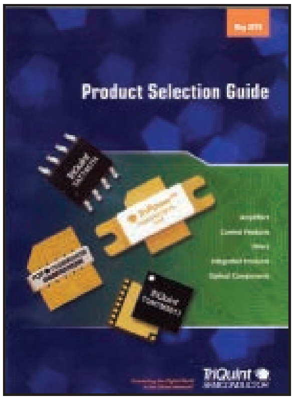


Highly Flexible Assemblies

Applications requiring low resistance to flexure, low weight, continual movement or having tight space constraints will benefit from design-in of Teledyne Storm's new 0.052" FlexFit™ assemblies. A stranded center conductor offers ultra flexibility (>500,000 flexures) while maintaining electrical and physical stability. This provides the advantages of no movement-related performance degradation, low resistance to movement and increased performance life.

Teledyne Storm Products,
Woodridge, IL (630) 754-3300, www.teledynestorm.com.

RS NO. 347



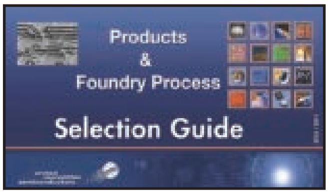
Product Selection Guide

VENDORVIEW

Download TriQuint's new and expanded product selection guide (PSG), which includes hundreds of advanced RF solutions for mobile device, 3G/4G wireless base station, optical, CATV/FTTH, WLAN, GPS/PND, defense and aerospace markets. It contains new components, modules and application block diagrams. Printed copies are also available through area TriQuint sales representatives, or by contacting TriQuint.

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

RS NO. 348



Products and Foundry Process Selection

Aimed especially at buyers, sales reps and engineers, this guide highlights the company's products and foundry processes, covering a broad range of markets and applications up to 100 GHz. It highlights that the company targets its main market segments – Military (radars), Telecommunication (backhaul) and Automotive (SRR and LRR) – by offering high volume capabilities in bare die and surface-mount plastic packages. The guide emphasizes that UMS is ISO TS16949, ISO9001 and ISO14001 certified and that its processes are 'Space Evaluated'.

United Monolithic Semiconductors (UMS),
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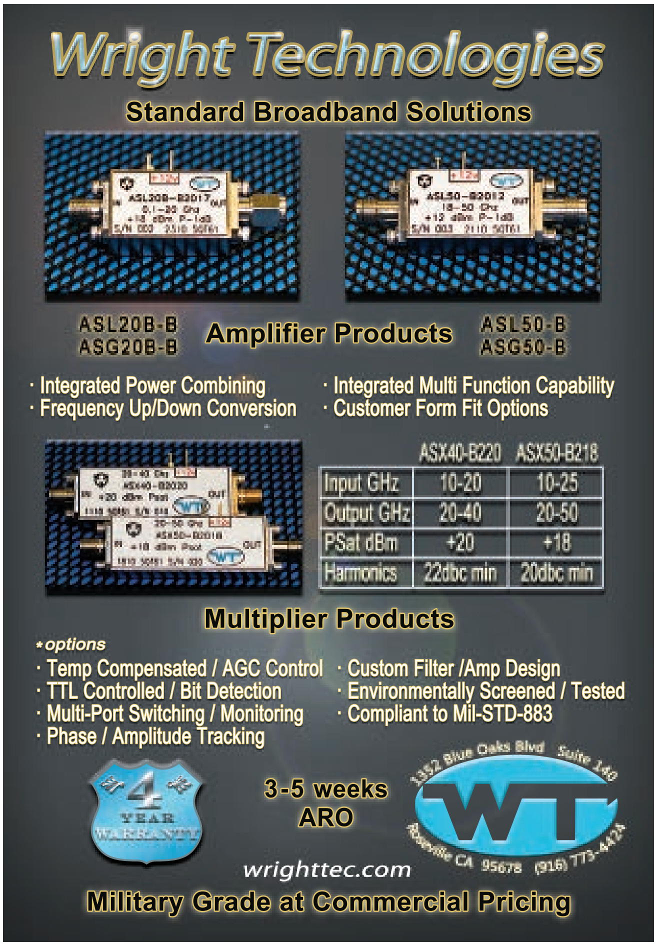

MILITARY MICROWAVES SUPPLEMENT

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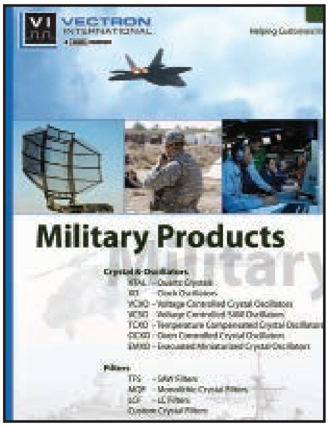

Military Products Brochure

With over 50 years of experience, Vectron is a leader in providing frequency control and hybrid solutions to customers around the world. Vectron's innovative approach to design and manufacture has resulted in the most advanced product offering of any frequency control supplier in the world.

Vectron International,
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RS NO. 350

Product Guide

IMT's state-of-the-art law enforcement and defense products provide critical situational awareness and real-time mission insight in packages you can count on in the harshest of environments. The company makes products that remove the risk of complexity, and get you online painlessly. IMT is the tactical advantage you are looking for.

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RS NO. 352

Tunable RF Filter Catalog

Are you looking for tunable RF bandpass and notch filters? Do you need pre/post-selectors, filter/amplifier cascades or LNAs? In the new 2010 catalog, Pole/Zero offers a complete line of tunable cosite filter products in the 1.5 MHz to 2 GHz range. Call or visit the website to get a copy and solve your tunable filter needs today.

Pole/Zero Corp.,
West Chester, OH (513) 870-9060, www.polezero.com.

RS NO. 353

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