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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

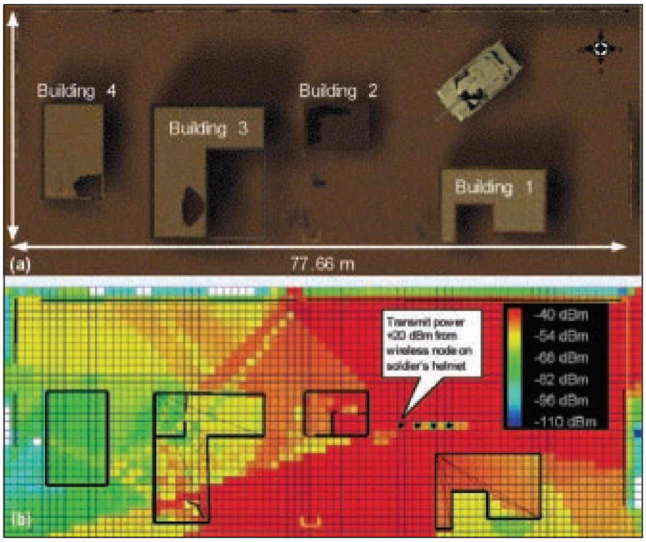
dier-mounted radios are expected to be extremely power efficient and ultra-reliable, mechanically robust and easy to operate, non-inhibitive to movement and capable of providing high data bandwidths. At the same time, they must be compact, lightweight and have a stealth mode of operation. With the widespread 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

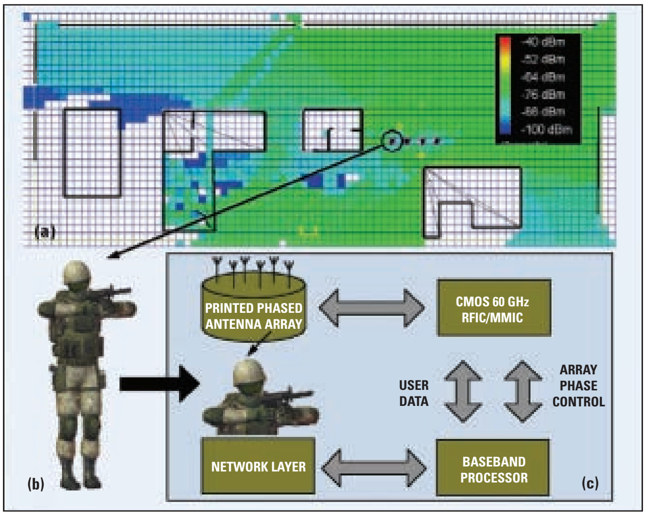
To achieve optimal network-centric operations, tactical information must be effectively distributed among soldiers while maintaining a low probability of detection and intercept. This places two distinct requirements on the air interface technology used: it must be capable of high data rates (when required) 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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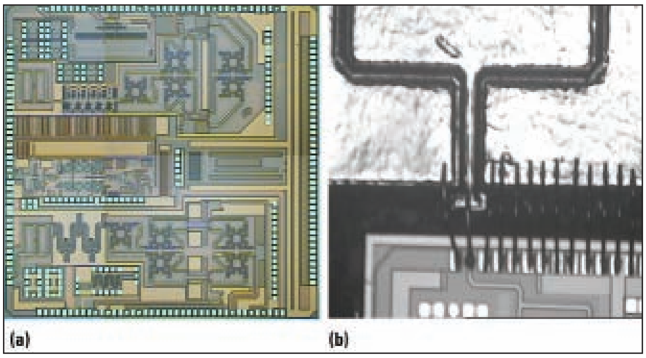

Fig. 3 An integrated 60 GHz transceiver on 130 nm CMOS[2] (a); wire-bond attached antenna to CMOS transceiver[9] (b).

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.

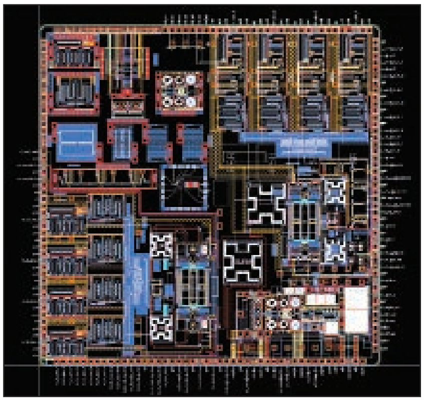

Fig. 4 Phased array 60 GHz transceiver on 65 nm CMOS incorporating 4 transmit and 4 receive chains.[8]

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

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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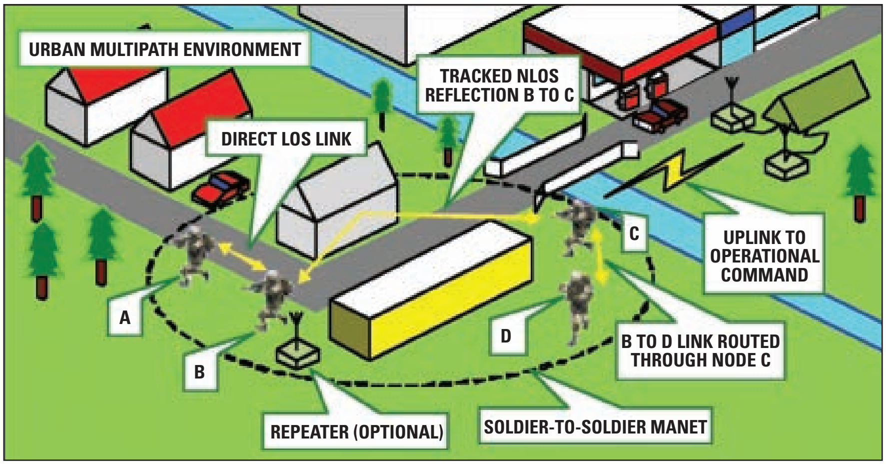

▲ *Fig. 5 Millimeter-wave soldier-to-soldier communications system.*

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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References

1. S.K. Reynolds, et al., "A Silicon 60 GHz Receiver and Transmitter Chipset for Broadband Communications," *IEEE Journal of Solid-State Circuits*, Vol. 41, No. 12, December 2006, pp. 2820-2831.
2. C. Ta Minh, et al., "Wireless Communications at 60 GHz: A Single Chip Solution on CMOS Technology," *Mobile and Wireless Communications*, Eds. S.A. Fares and F. Adachi, In-Teh, Vokuvar, Croatia, 2010.
3. C. Park and T.S. Rappaport, "Short-range Wireless Communications for Next-generation Networks: UWB, 60 GHz Millimeter-wave WPAN and ZigBee," *IEEE Communications Magazine*, August 2007, pp. 70-78.
4. S.L. Cotton, W.G. Scanlon and B.K. Madahar, "Millimeter-wave Soldier-to-soldier Communications for Covert Battlefield Oerations," *IEEE Communications Magazine*, Vol. 47, No. 10, October 2009, pp. 72-81.
5. "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements. Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPAN) Amendment 2: Millimeter-wave-based Alternative Physical Layer Extension," *IEEE Std 802.15.3c-2009* (Amendment to *IEEE Std 802.15.3-2003*), pp.c1-187, Oct. 12, 2009.
6. D. Falconer, S.L. Ariyavisitakul, A. Benyamin-Seeyar and B. Eidson, "Frequency Domain Equalization for Single-carrier Broadband Wireless Systems," *IEEE Communications Magazine*, Vol. 4, No. 40, April 2002, pp. 58-66.
7. C.H. Doan, S. Emami, D.A. Sobel, A.M. Niknejad and R.W. Brodersen, "Design Considerations for 60 GHz CMOS Radios," *IEEE Communications Magazine*, Vol. 42, No. 12, December 2004, pp. 132-140.
8. E. Skafidas, et al., "Integrated Phased Array 60 GHz Transceiver on 65 nm CMOS," manuscript in preparation.
9. G. Felic and E. Skafidas, "Flip-chip Interconnection Effects on 60 GHz Microstrip Antenna Performance," *IEEE Antennas and Wireless Propagation Letters*, Vol 8, May 2009, pp. 283-286.
10. S. Collonge, G. Zaharia and G.E. Zein, "Influence of the Human Activity on Wideband Characteristics of the 60 GHz Indoor Radio Channel," *IEEE Transactions on Wireless Communications*, Vol. 3, No. 6, November 2004, pp. 2396-2406.

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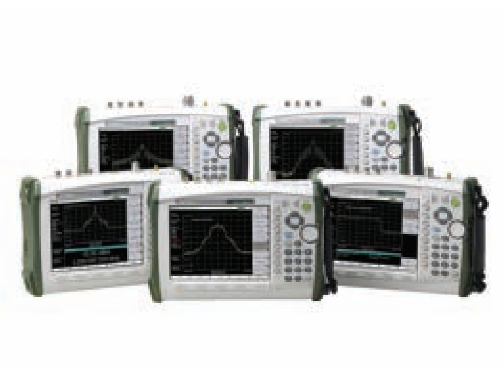

First 43 GHz Handheld Spectrum Analyzer Family

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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***).

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TABLE I

FREQUENCY RANGES FOR SPECTRUM MASTER MS272xC SERIES MODELS

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Spectrum Master MS2724C	9 kHz to 20 GHz
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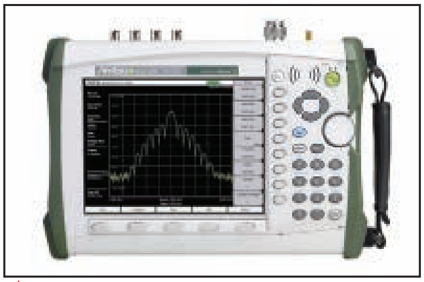
and No FFT—are available in the MS272xC series. In the Fast sweep mode, the handheld spectrum analyzers deliver sweep speeds that are virtually the same for resolution bandwidths from 10 MHz down to 30 kHz. Performance mode allows sweeps to be conducted in the traditional method, with sweep speed changing 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


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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

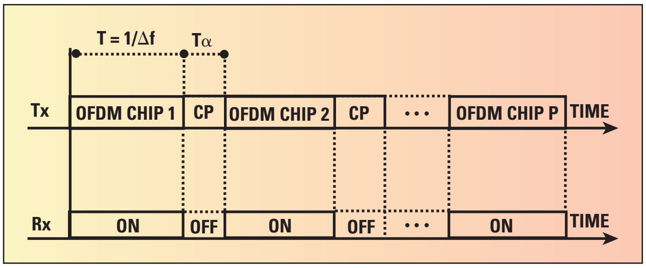

Fig. 1 Long OFDM chip.

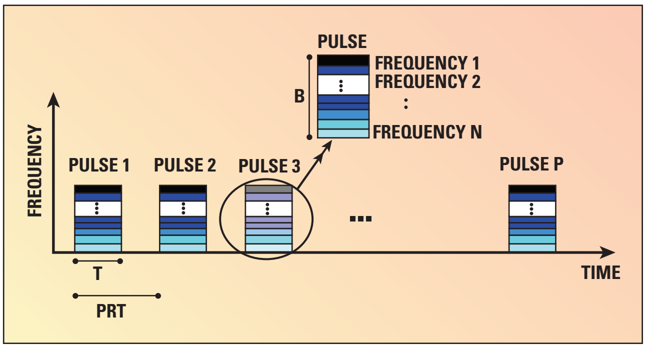

Fig. 2 Short OFDM chip.

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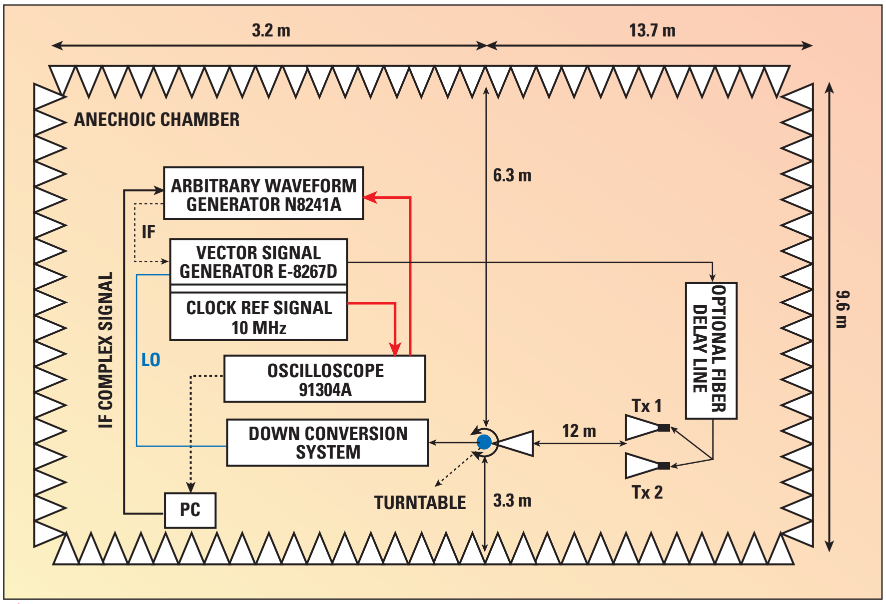

▲ *Fig. 3 Anechoic chamber: map and equipment (not to scale).*

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

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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.

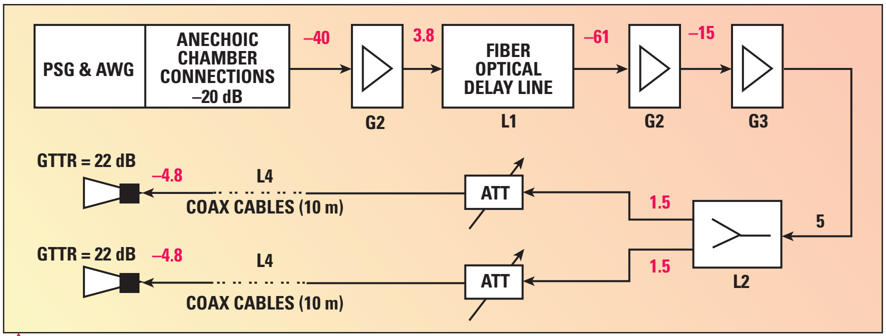


Fig. 4 Transponder block diagram and signal level 1 (dBm).

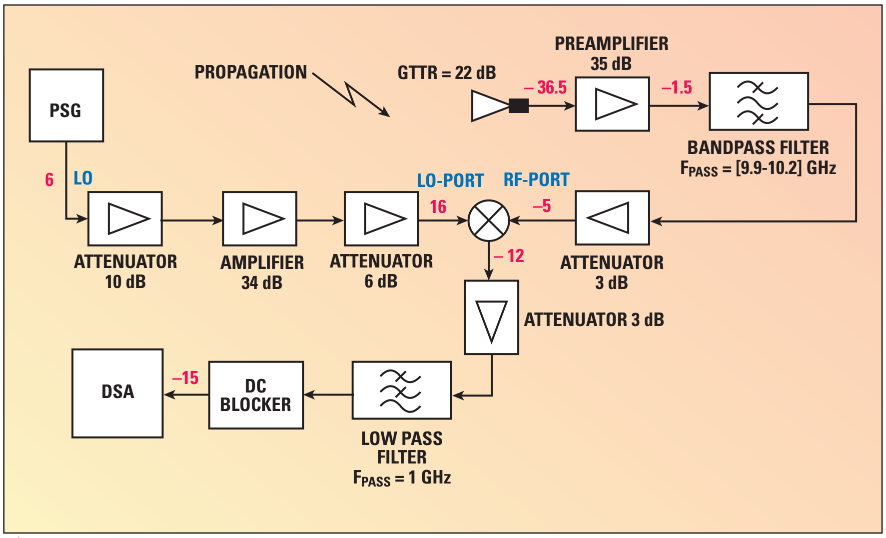


Fig. 5 Down-converter scheme with both LO and OFDM signal levels (dBm).

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/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

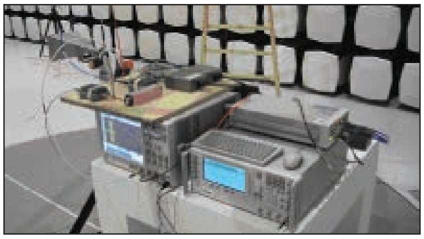


Fig. 6 Down-conversion system, DSA, AWG and PSG.

- 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.

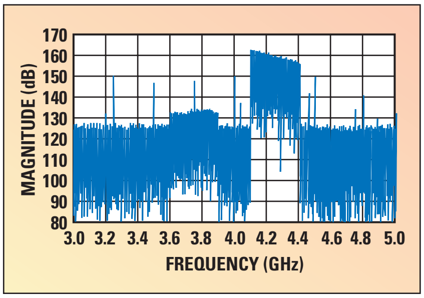
The double sideband mixer is used to down-convert the RF signal to IF. For that purpose, the LO signal from the PSG is directly connected to the mixer. The mixer also converts the noise from both 9.4 to 9.7 GHz and 9.9 to 10.2 GHz bands to the 100 to 400 MHz IF output, where the noise powers add up. 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.



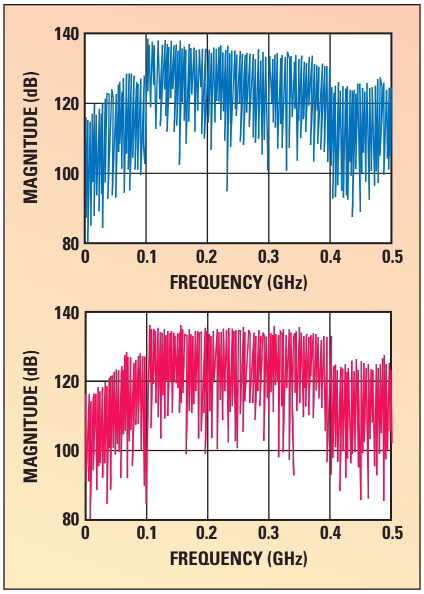
▲ *Fig. 7 RF 300 MHz long chip OFDM spectrum (LO = 4 GHz).*

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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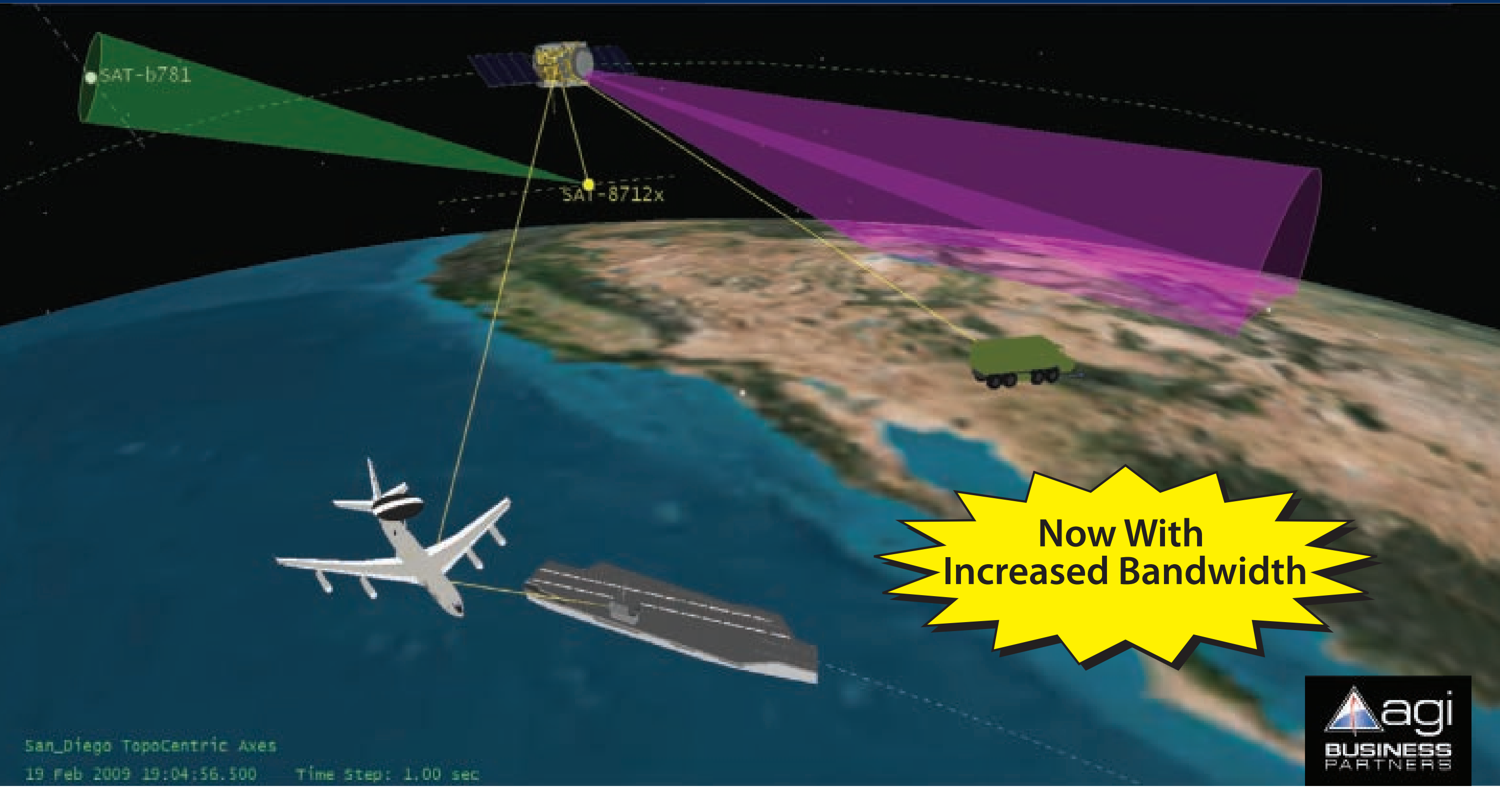

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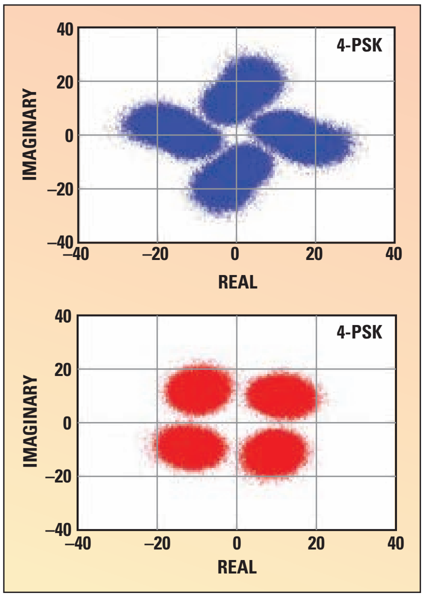
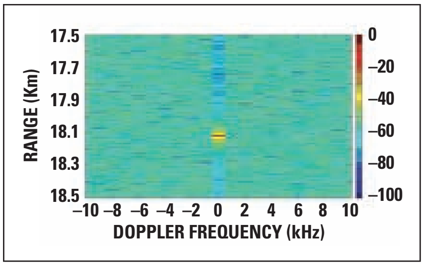
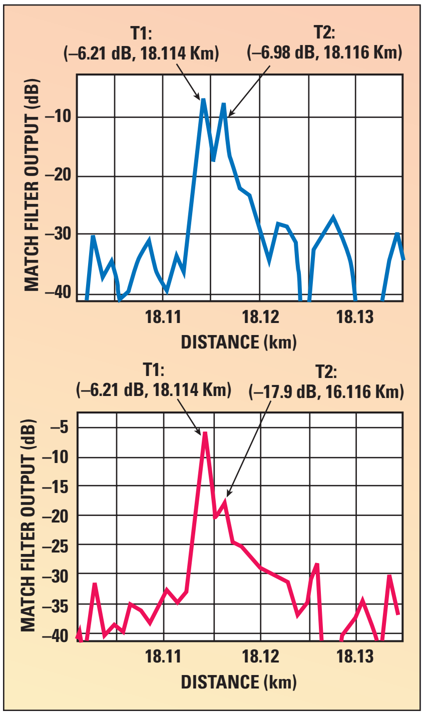


▲ *Fig. 9 Received constellations.*



▲ *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. ■

ACKNOWLEDGMENTS

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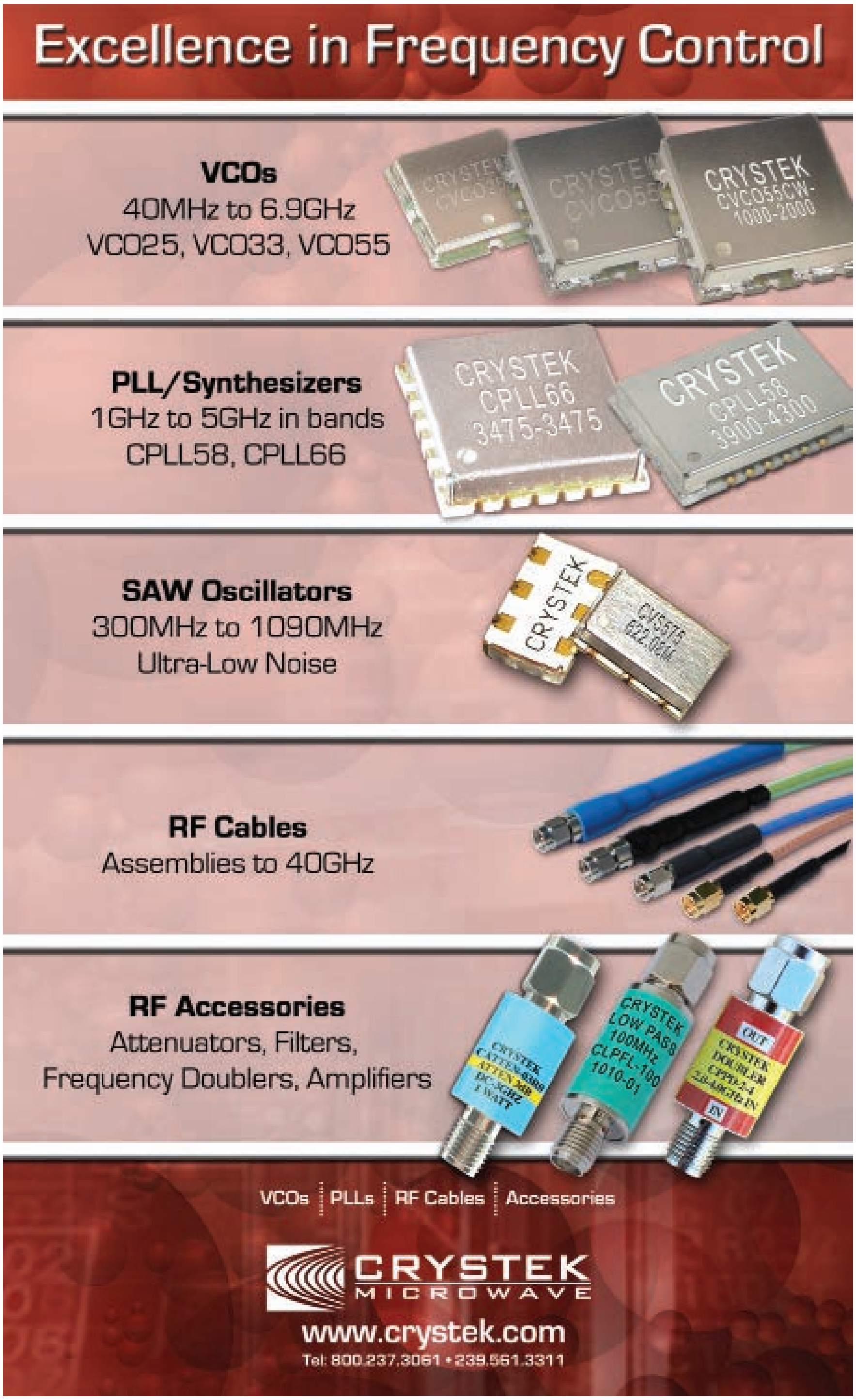
References

1. R.A.M. Fens, M. Ruggiano and G. Leus, "Channel Characterization Using Radar for Transmission of Communication Signals," *2008 European Wireless Technology Conference Proceedings*, pp. 127-130.
2. G. Lellouch and H. Nikookar, "On the Capability of a Radar Network to Support Communications," *2007 IEEE Symposium on Communications and Vehicular Technology in the Benelux Digest*, pp. 1-5.
3. O. Edfords, et al., "An Introduction to Orthogonal Frequency-division Multiplexing," *Luella University of Technology, Div. of Signal Processing*, September 1996, www.teleamerica.net/reference/Science/IntroToOrthogonalFreqDivisionMultiplexing.pdf.
4. Y. Li and G. Stüber, *Orthogonal Frequency Division Multiplexing for Wireless Communications*, Springer, Berlin, 2006.
5. R. Prasad, *OFDM for Wireless Communications Systems*, Artech House, Norwood, MA, 2004.
6. H. Schulze and C. Lüders, *Theory and Applications of OFDM and CDMA, Wideband Wireless Communications*, John Wiley and Sons Ltd., Chichester, UK, 2005.
7. J.G. Proakis, *Digital Communications*, Fourth Edition, McGraw-Hill, New York, NY, 2001.
8. R.F. Tigrek and P. van Genderen, "A Golay Code-based Approach to Reduction of the PAPR and Its Consequence for the Data Throughput," *2007 European Radar Conference Digest*, pp. 146-149.
9. R.F. Tigrek, W.J.A. de Heij and P. van Genderen, "Multi-carrier radar Waveform Scheme for Range and Doppler," *2009 IEEE Radar Conference Digest*, pp. 1-5.
10. G. Lellouch, P. Tran, R. Pribic and P. van Genderen, "OFDM Waveforms for Frequency Agility and Opportunities for Doppler Processing in Radar," *2008 IEEE Radar Conference Proceedings*, pp. 1-6.
11. Agilent Technologies, "Agilent N8241A/N8242A Arbitrary Waveform Generators," 2006, http://cp.literature.agilent.com/litweb/pdf/N8241-90001.pdf12; Agilent Technologies, "Agilent E8257D/67D PSG Signal Generators, User's Guide," 2004-2008, www.photonics.umd.edu/umd/manuals/E8257D/users-guide.pdf.
13. Agilent Technologies, "Agilent Infiniium DSA/DSO 90000A Series Data Sheet," http://cp.literature.agilent.com/litweb/pdf/5989-7819EN.pdf.
14. M. Ruggiano, E. Stolp and P. van Genderen, "Resolution and Unmasking of CLEAN and LMMSE Algorithms Using Coded Waveforms," *2008 International Conference on Radar Digest*, Adelaide, SA, pp. 592-597.

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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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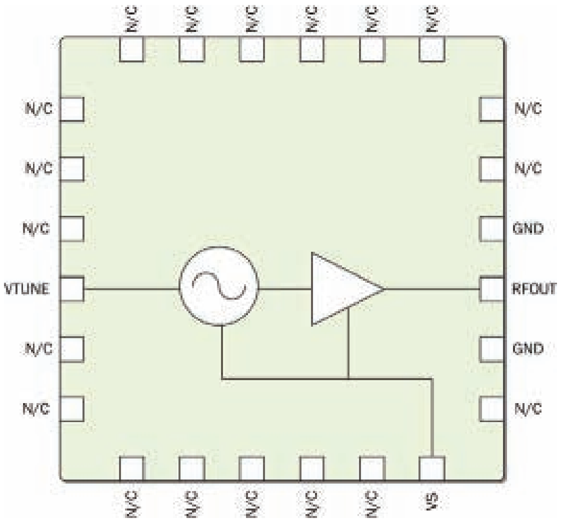
RFVC-1801	5000	10000	3.0	72.0	96.0	18	6	5 V at 55 mA
RFVC-1802	4000	8000	3.5	74.0	99.0	16	4	5 V at 55 mA
RFVC-1803	6000	9000	3.5	73.0	97.0	22	–	5 V at 52 mA



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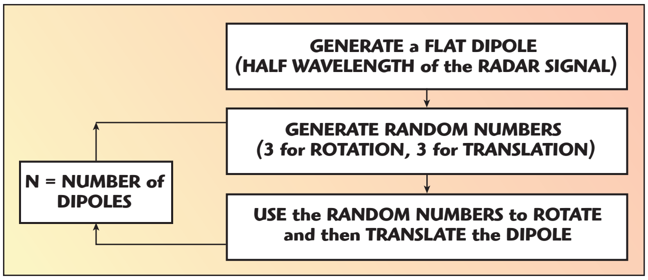

Fig. 1 Schematic of the VBA code to model the chaff cloud.

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-

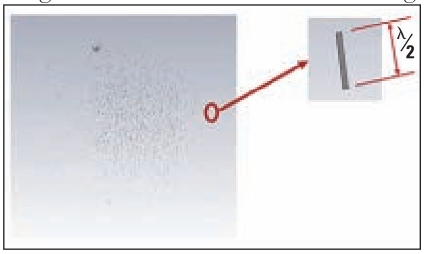


Fig. 2 Scenario of a metallic sphere and a chaff cloud.

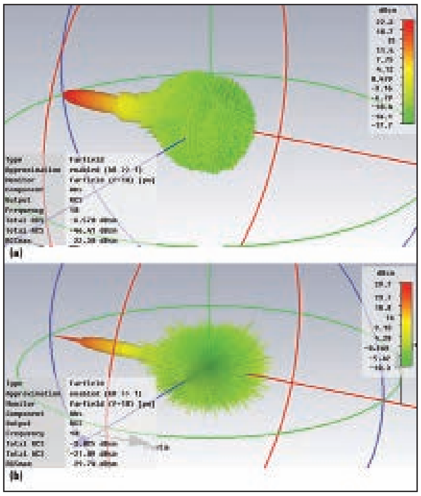


Fig. 3 3D plot of the absolute RCS value for the sphere alone (a) and for the sphere and chaff cloud (b) .

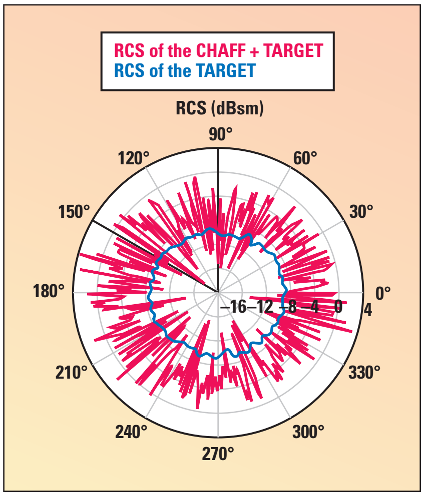
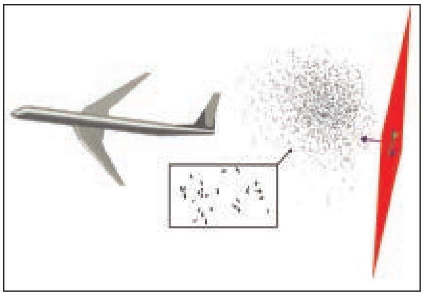
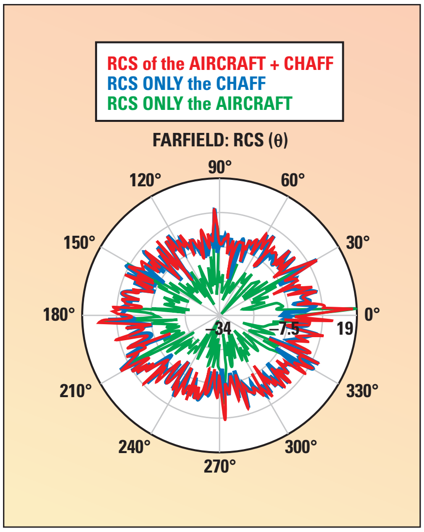


Fig. 4 Monostatic RCS absolute value for the cases with and without the chaff cloud.



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



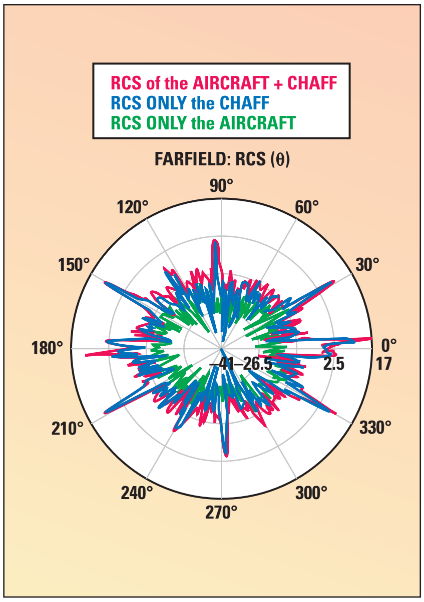
▲ *Fig. 6 Comparison of the absolute values of RCS for three different situations at 5 GHz.*

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



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

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.

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. ■

References

1. F. Neri, *Introduction to Electronic Defense Systems*, Second Edition, Artech House Inc., Norwood, MA, 2001.
2. CST MICROWAVE STUDIO® 2009, www.cst.com.
3. G. Curry, *Radar System Performance Modeling*, Second Edition, Artech House Inc., Norwood, MA.
4. C.L. Mack and B. Reiffen, "RF Characteristics of Thin Dipoles," *Proceedings of the IEEE*, Vol. 52, No. 5, May 1964, pp. 533-542.
5. R.P. Fray, "Simulation of Chaff Cloud Signature," Master Thesis, Naval Postgraduate School, 1985.
6. R.J. Garbacz, "Chaff Radar Cross Section Studies and Calculations," *Technical Report*, Ohio State University, 1978.

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

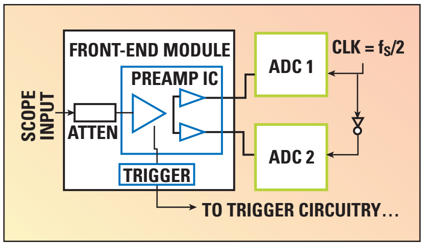
Chris Rehorn
Agilent Technologies Inc., Santa Clara, CA

As serial data speeds increase, instrumentation for characterizing and debugging the next generation of protocols is required. A real-time oscilloscope family with 32 GHz of bandwidth and the lowest reported jitter and noise floor has been developed, providing engineers superb signal integrity for characterizing and debugging the fastest interfaces.

The oscilloscope incorporates a new architecture for signal acquisition and a new chipset delivering the performance. It features a new analog front-end chipset developed in an InP HBT process. This process has a number of features allowing for the implementation of broadband circuits operating at very high frequencies. It features several ICs designed in this process: A new preamplifier IC reaching frequencies from DC to 32 GHz, a new sampler IC, a new trigger IC and a new calibration IC.

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.



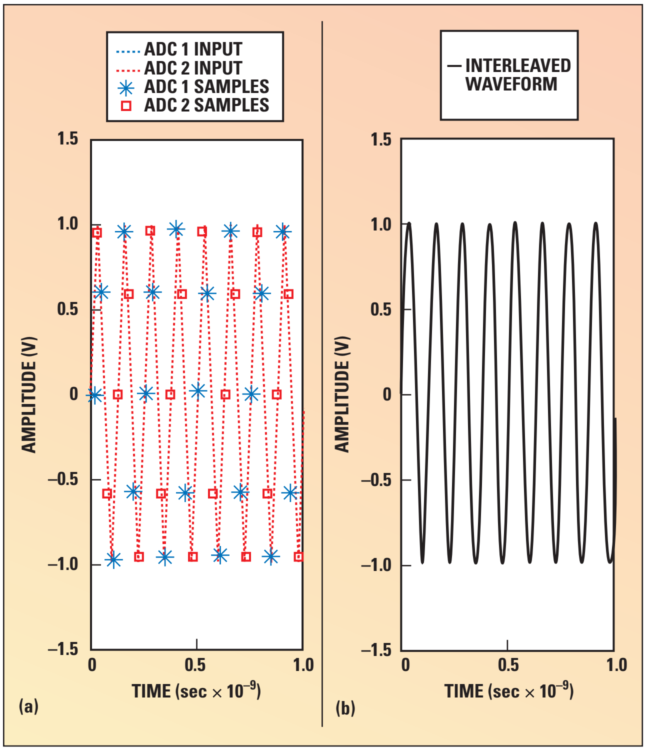
▲ *Fig. 1 Block diagram of a traditional oscilloscope front-end.*

This architecture has several limitations:

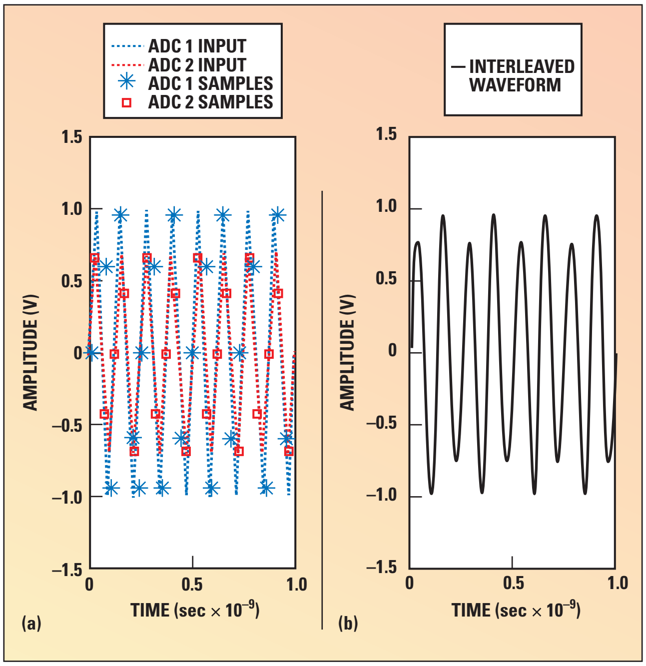
- The ADC input bandwidth and sampling aperture must be at least the full RF bandwidth of the oscilloscope
- The preamplifier must drive multiple ADCs (in this case two), with the full RF bandwidth preserved at the interface
- Mismatch associated with the fan-out will manifest as error in the measurement

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.

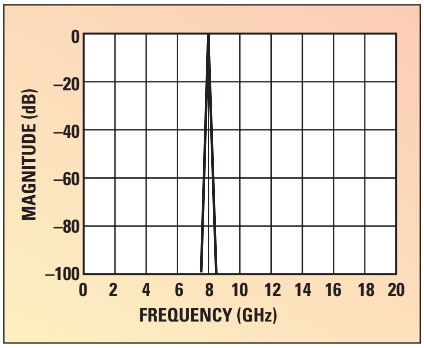
A Fast Fourier Transform (FFT) of the result in Figure 2 is shown in ***Figure 3***. Note the single



▲ *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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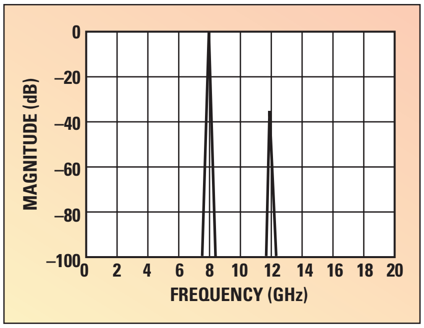
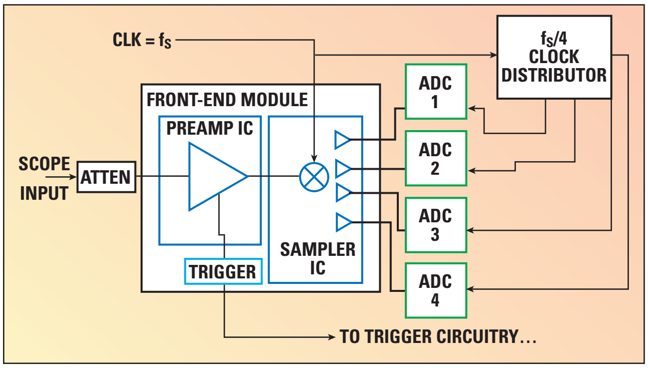


▲ *Fig. 5 The FFT of the interpolated waveform with ADC input signals mismatched shows a tone at 8 GHz and a new tone at 12 GHz as a result of the mismatch.*



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

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.

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.

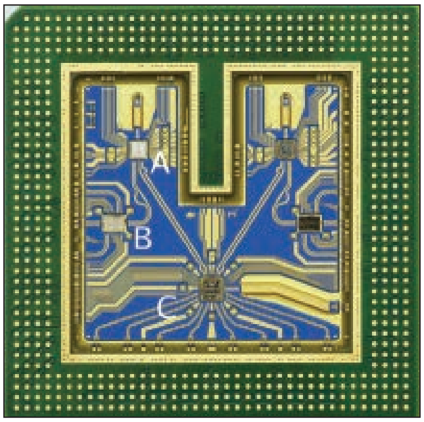
Thirdly, because the first ranks of sampling are contained in one proprietary IC, the ADC must no longer accept full-bandwidth to its input. The requirements on the ADC aperture, therefore, are much less, allowing the previous generation of ADC to be used in the new design, and lowering the effective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

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.

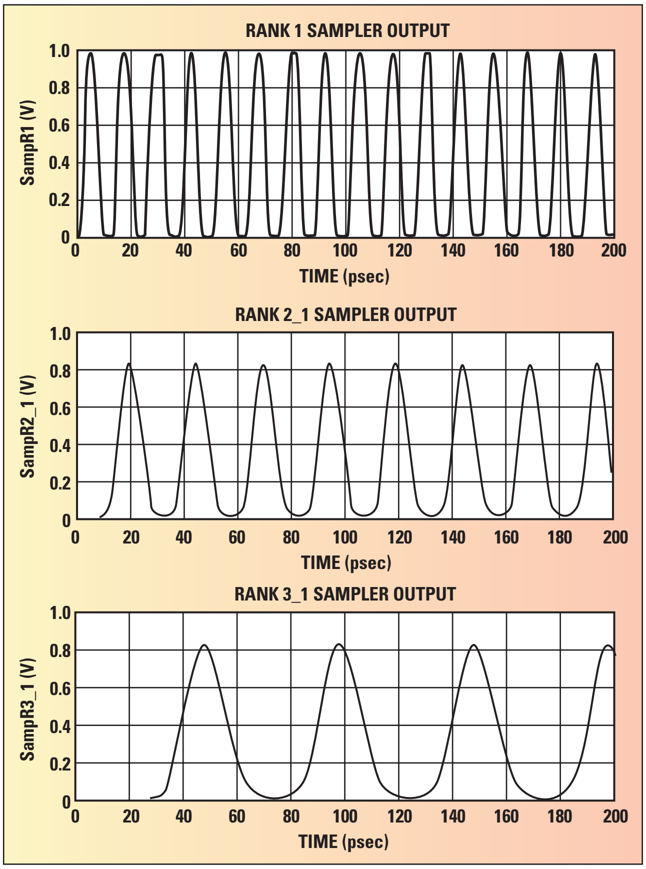
Unlike silicon-based HBT processes, the HB2B process has an insulating InP substrate, with a dielectric constant of 12.4. The substrate is 90 um thick. This allows for low parasitic capacitance interconnect and the ability to design spiral inductors with high inductance/length, for input T-coil matching circuits and on-chip filters.



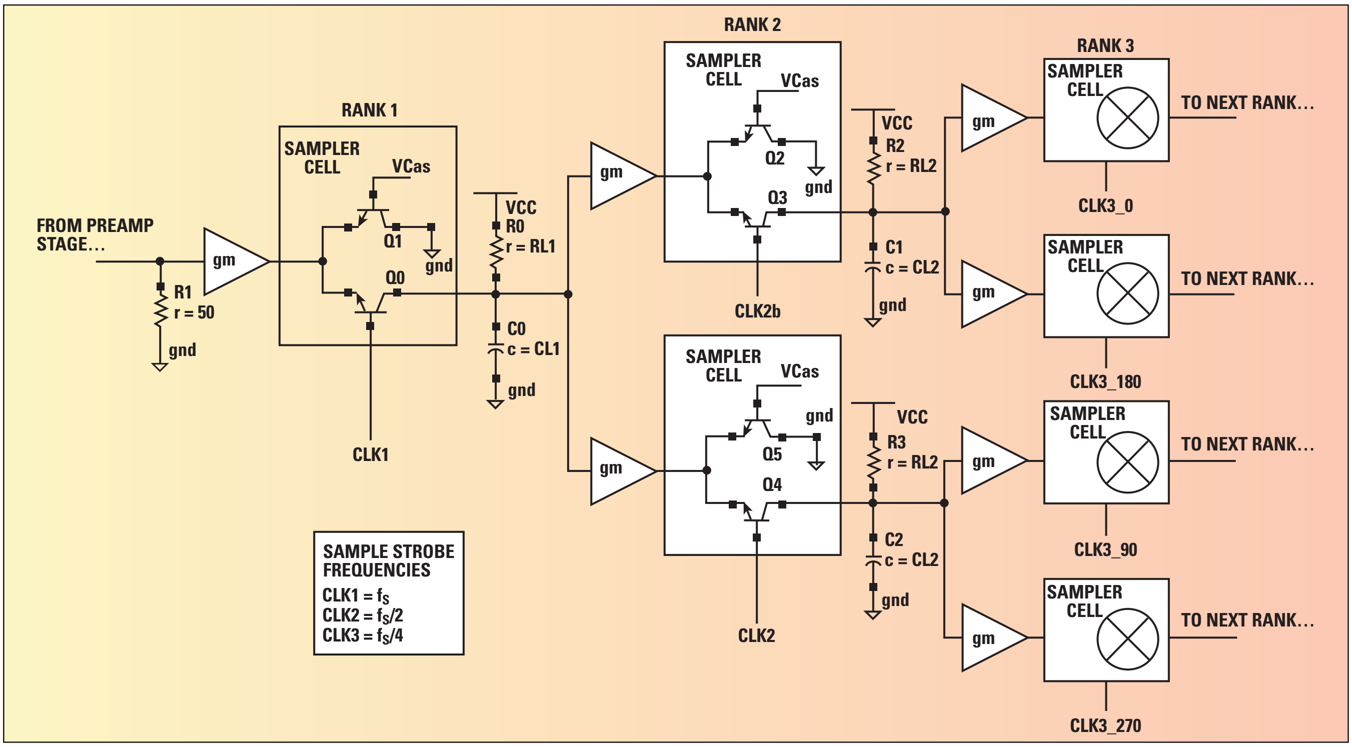
▲ *Fig. 7 The DSO-X front-end module with preamp (A), trigger (B) and sampler IC (C).*

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.*

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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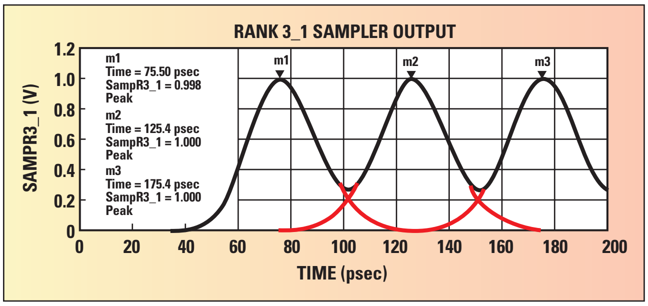

Fig. 10 *Gaussian IF response of Rank 3.*

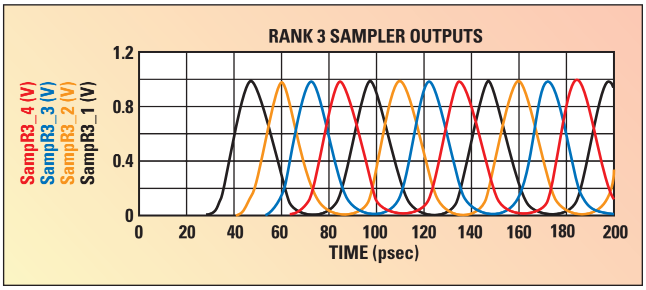

Fig. 11 *Rank 3 sampler outputs for all Rank 3 samplers shown in Figure 8.*

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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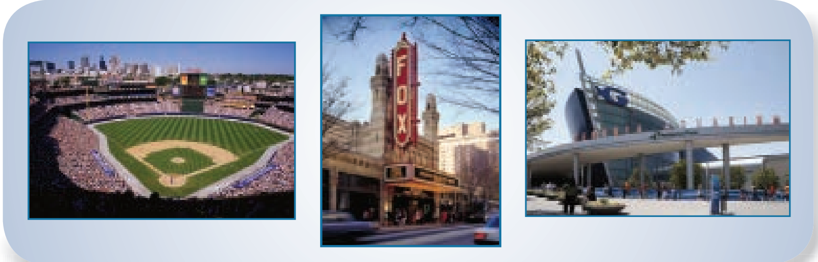

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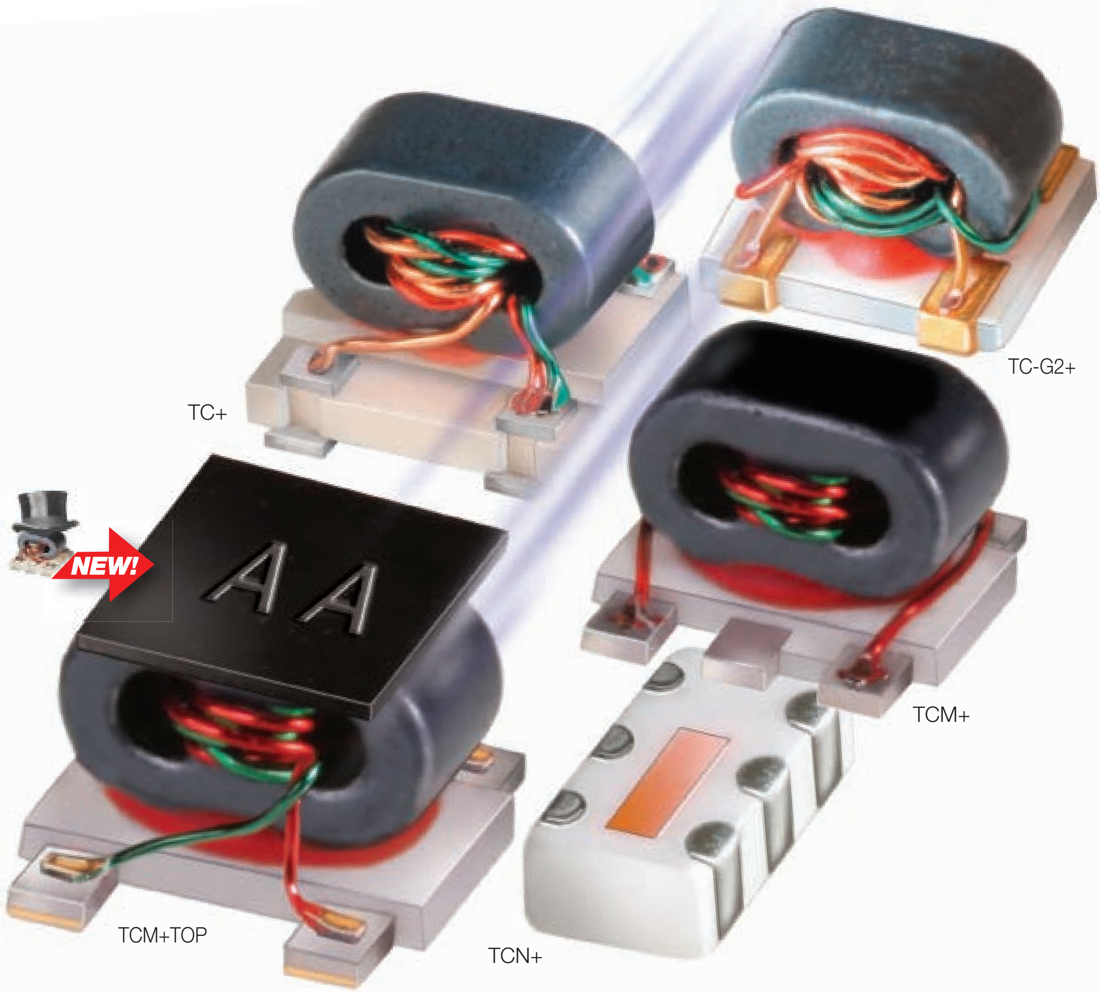

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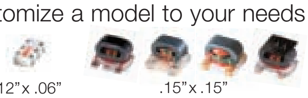

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Applications of Time Domain Processing in Antenna Measurements

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-

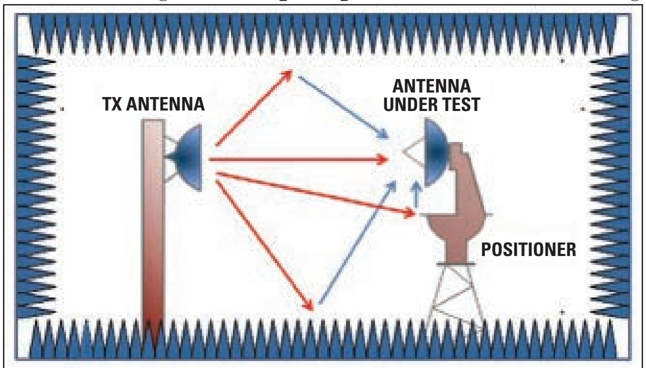

Fig. 1 Antenna measurement system in an anechoic chamber.

Mark Winebrand, John Aubin and Russell Soerens
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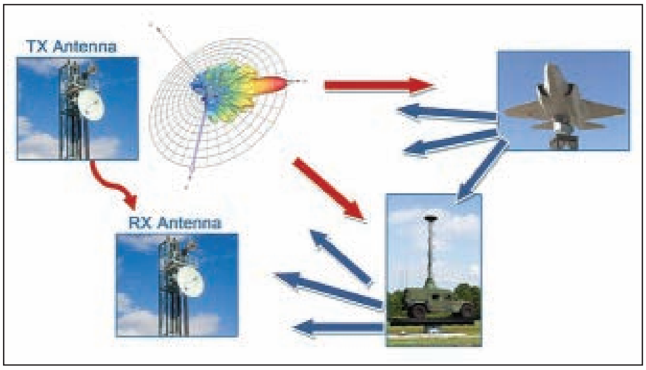

Fig. 2 Typical radar operation diagram.

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

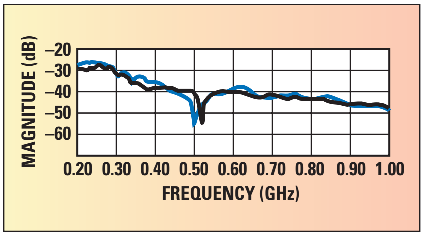

Fig. 3 Frequency domain vertical (blue) and horizontal (black) co-polarized signals in the quiet zone of an anechoic chamber of UHF.

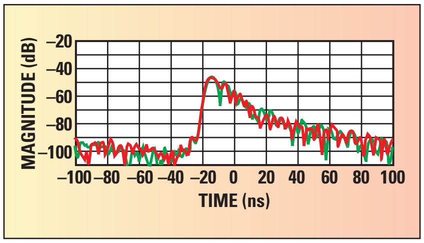

Fig. 4 Time domain vertical (red) and horizontal (green) co-polarized signals in the quiet zone of an anechoic chamber at UHF.

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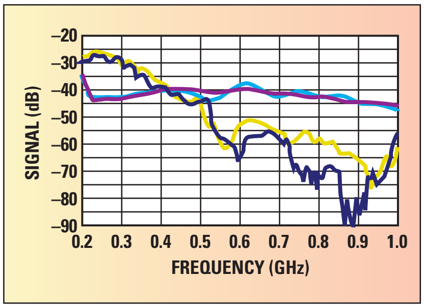
times, the difference becomes pronounced, so that this time interval can be attributed to the direct illumination and the rest of the responses from -10 to 100 ns to multiple reflections. Performing the time-gating and transforming the data back to the frequency domain, the direct and reflected time-gated 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.

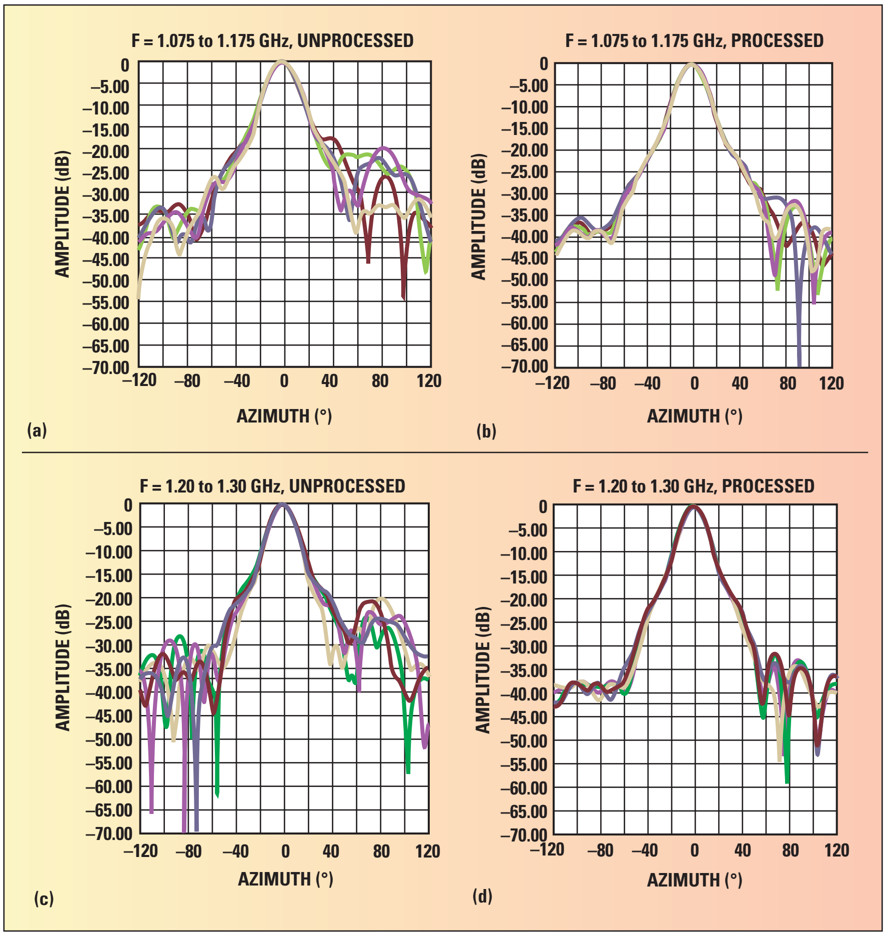
ACCURATE CYLINDRICAL NEAR-FIELD ANTENNA MEASUREMENTS

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.

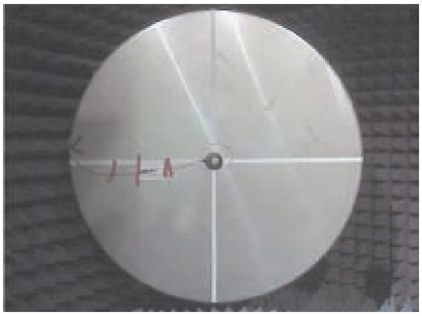
SHORT RANGE FAR-FIELD ANTENNA MEASUREMENTS OF A LOW GAIN ANTENNA ON A GROUND PLANE

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:

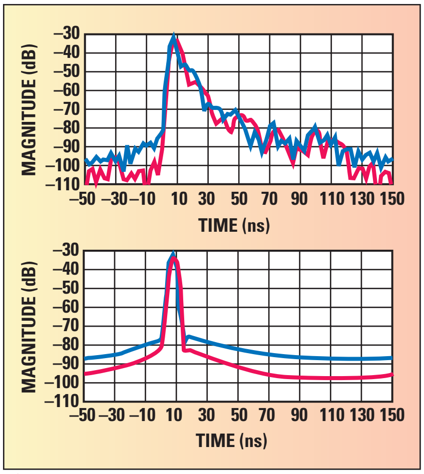
- What size metallic plate is to be considered to minimize the edge diffraction associated with the ground plane? This is important in order to isolate the antenna performance from the edge effects introduced by a terminated (finite size) ground plane, as well as to extrapolate the measurement results 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



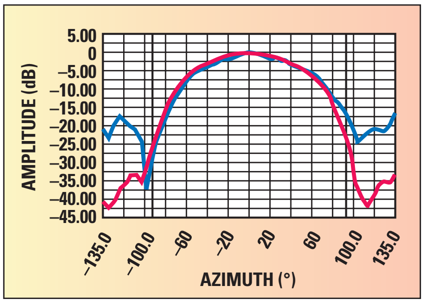
▲ *Fig. 7 Satellite radio antenna on a metallic ground plane.*



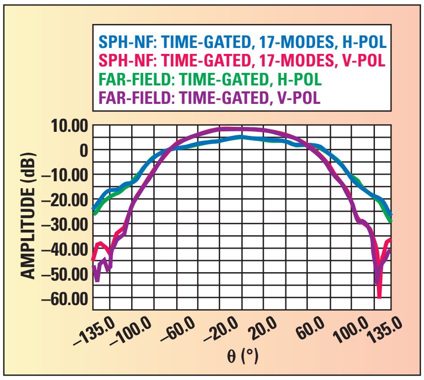
▲ *Fig. 8 Measured SNF-FF ungated and gated time domain response for vertical (red) and horizontal (blue) polarizations.*

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. ■

References

1. J. Aubin and M. Winebrand, "Test Zone Performance in Low Frequency Anechoic Chambers," *2008 Antenna Measurement Techniques Association Annual Symposium Proceedings*, pp. 482-488.
2. M. Winebrand, R. Soerens and J. Aubin, "Measurements of Low Gain Antennas on a Ground Platform Using a Short Range Time-domain Far-field Technique," *2007 Antenna Measurement Techniques Association Annual Symposium Proceedings*, pp. 357-361.
3. J. Aubin, M. Winebrand, R. Soerens and V. Vinogradov, "Accurate Near-field Measurements Using Time-gating," *2007 Antenna Measurement Techniques Association Annual Symposium Proceedings*, pp. 362-367.

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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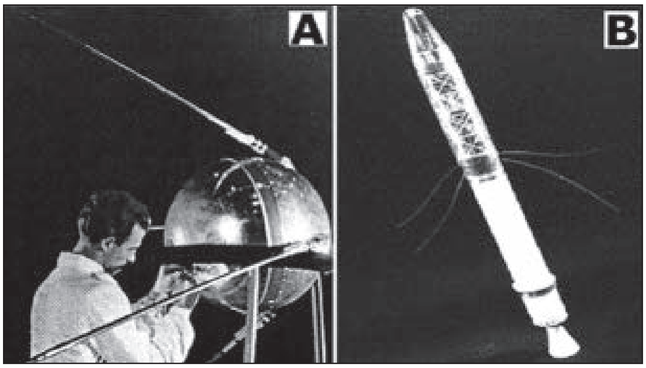


▲ *Fig. 1 (A) Sputnik 1 and (B) Explorer 1 (courtesy of* Never Beyond Reach *(A) and NASA (B)).*

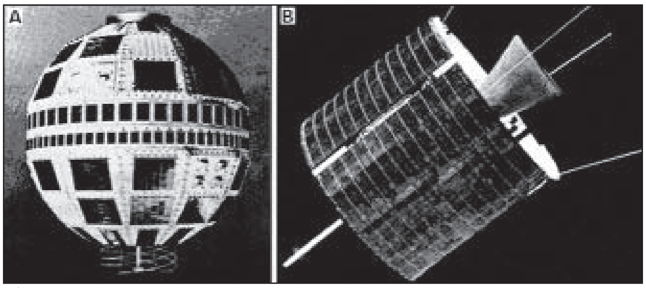
communications began to unfold. Russian scientist Konstantin Tsiolkovsky (1857–1935) published a scientific book on virtually every aspect of space rocketing. He propounded the theoretical basis of liquid propelled rockets, put forward ideas for multi-stage launchers and manned space vehicles, space 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. ■

Sources

1. R.M. Gagliardi, *Satellite Communications*, Van Nostrand Reinhold, New York, NY, 1984.
2. B. Gallagher, "Never Beyond Reach," Inmarsat, London, 1989.
3. R. Galic, *Telekomunikacije satelitima*, Skolska knjiga, Zagreb, 1983.
4. *Utilisation des Satellites pour les Recherches et le Sauvetage*, Cepadues-Editions, Toulouse, France, 1984.
5. A.A. Huurdeman, *Guide to Telecommunications Transmission Systems*, Artech House Inc., Norwood, MA, 1997.
6. St. D. Ilcev, *Global Mobile Satellite Communications for Maritime, Land and Aeronautical Applications*, Springer Publishing, New York, NY, 2005.
7. St. D. Ilcev, "History of Maritime Radio Communications," *Our Sea* (Nase More), No. 5-6, Dubrovnik, Croatia, 1987 (http://www.nasemor).
8. E. Kadish, et al., *Satellite Communications Fundamentals*, Artech House Inc., Norwood, MA, 2000.
9. G. Maral, et al., *Satellite Communications Systems*, John Wiley & Sons Ltd., Chichester, UK, 1994.
10. V.A. Zhilin, "*Mezhdunarodnaya sputnikova sistema morskoy svyazi – Inmarsat*," Sudostroenie, Leningrad, 1988.
11. Webpages: "History of Satellite Communications" - Explorer 1 (history.nasa.gov/sputnik/expinfo.html) - Intelsat 1 (http://space.skyrocket.de/index_frame.htm?http://space.skyrocket.de/doc_sdat/intelsat-1.htm), 2000 – 2010.

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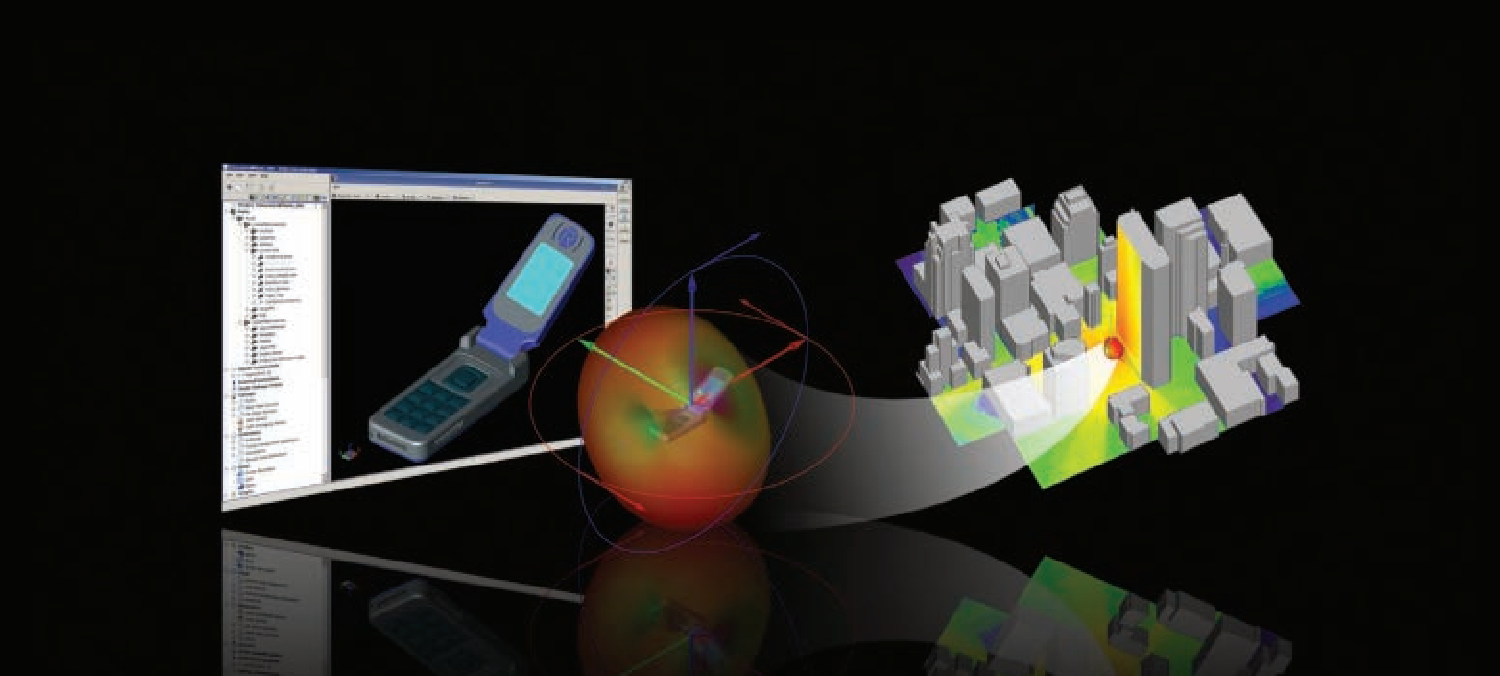

Ka-band Traveling Wave Tube: 500 W Peak, 350 W CW

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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High Frequency Performance Worldwide

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.

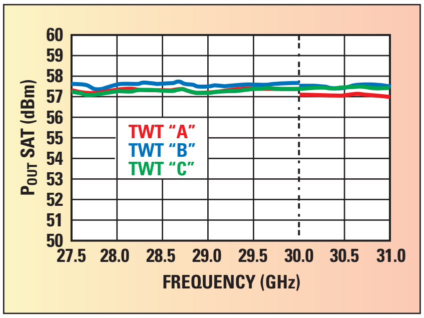
The advantage of the four-stage collector is that it reaches typical overall efficiency of 55 percent at saturation and 45 percent at 350 W output power (as shown in ***Figure 3***). The dissipated power is lower than 460 W and very constant across the full range of RF output power (see ***Figure 4***). 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

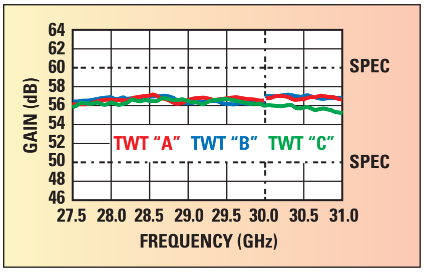
TABLE I

TH 4092 CHARACTERISTICS

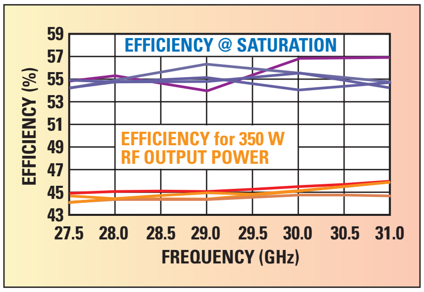
Parameter	Unit	Typical data
Frequency range	GHz	27.5-30 & 30-31
Rated output power (CW)	W	350
Saturated power (peak)	W	550
Drive power @ 350W	dBm	1
Gain @ 350W	dB	54
Small signal gain	dB	56
Helix voltage	kV	16.5 & 16.3
Anode voltage (A0)	V	-2000
Col.1 voltage	% Vk	41
Col.2 voltage	% Vk	34
Col.3 voltage	% 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



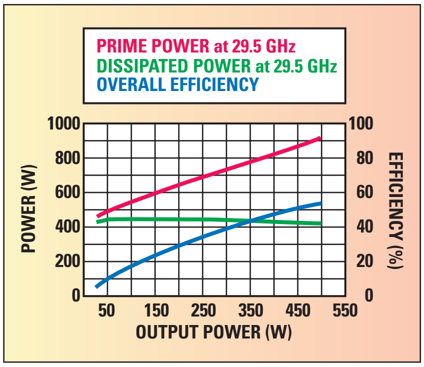
▲ *Fig. 1 RF saturated output power.*



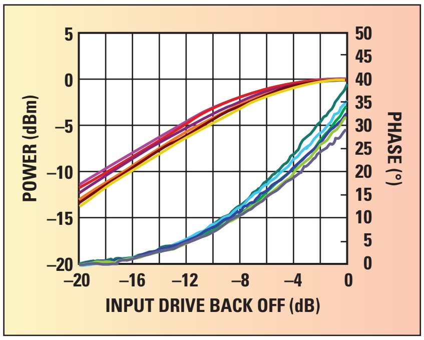
▲ *Fig. 2 Small-signal gain.*



▲ *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.

Thales Electron Devices,
Paris, France,
Tel: +33 (0)1 30 70 36 40,
www.thalesgroup.com.

RS No. 301

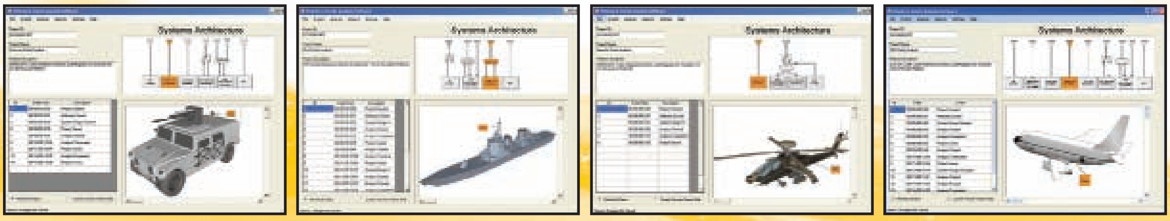
CROWD CONTROL

Is your RF equipment its own worst enemy?

The complex missions of the modern warfighter require a variety of critical communication links. Multiple transmitters and receivers in close proximity must operate simultaneously and without degradation from self-generated (cosite) interference. Pole/Zero can provide a comprehensive evaluation of your platform's cosite communication vulnerabilities, ensuring full range communications performance in the most crowded electromagnetic environments.

Optimize Your Equipment with a Detailed Cosite Analysis

Pole/Zero is an industry leader in high dynamic range RF communications solutions with over 20 years of experience. We will partner with your team to analyze the communications environment at any point over the entire life cycle of your platform, providing the information necessary to cost-effectively maximize the availability of your communication links/channels.



Use Pole/Zero Cosite Interference Analysis Results to Determine:

- Optimal communications hardware selection
- Minimum channel frequency separation determination
- Optimal platform antenna placement
- Minimum link budget margins

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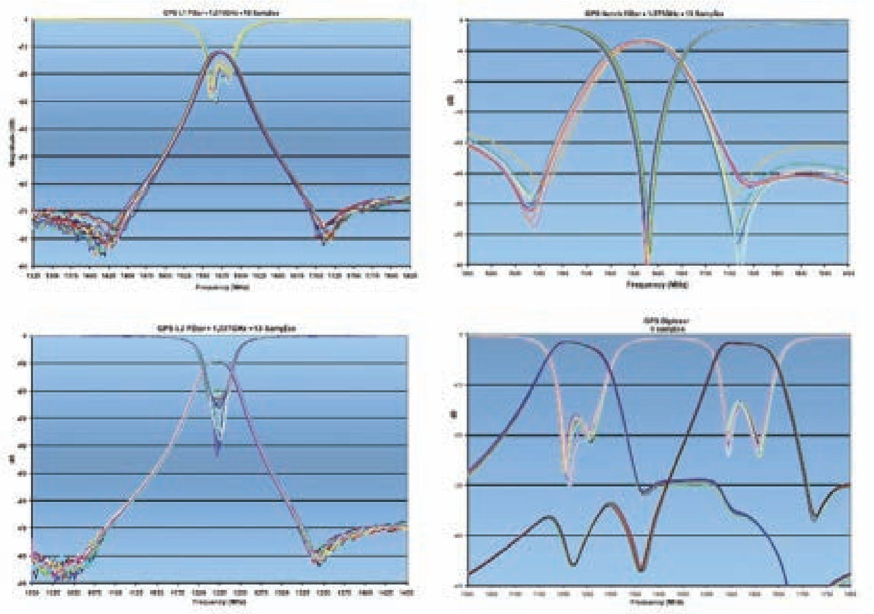
GPS Filters



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.

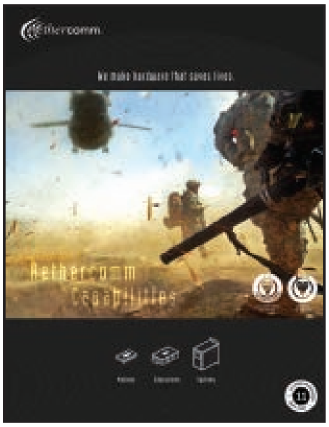
Dielectric Laboratories Inc. (DLI), Cazenovia, NY (315) 655-8710, www.dilabs.com.

RS No. 306

MILITARY MICROWAVES SUPPLEMENT

LITERATURE SHOWCASE

FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE FEATURING VENDORVIEW STOREFRONTS

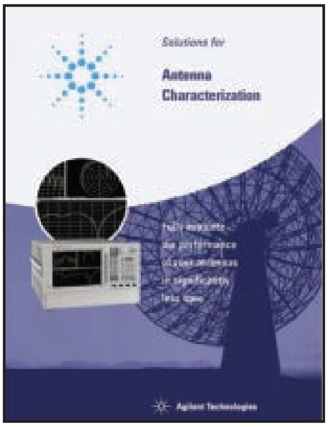


Capabilities Brochure

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



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

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.

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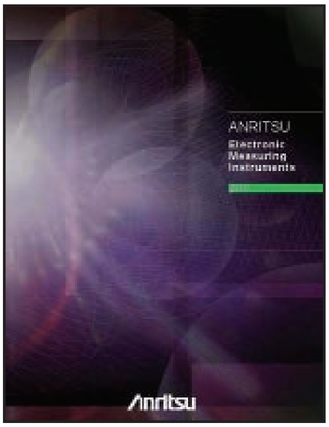


Electronic Measuring Instruments Catalog

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

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

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

MILITARY MICROWAVES SUPPLEMENT

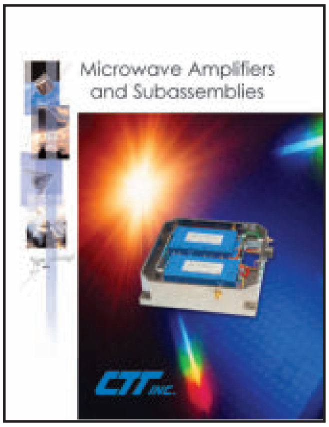
LITERATURE SHOWCASE

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.

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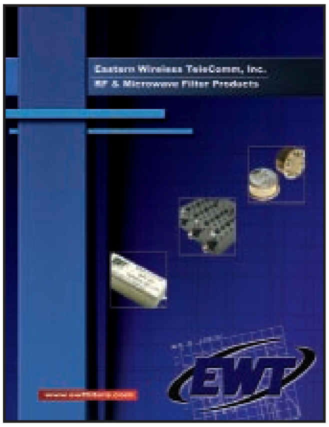

Filter Catalog

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

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

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MILITARY MICROWAVES SUPPLEMENT

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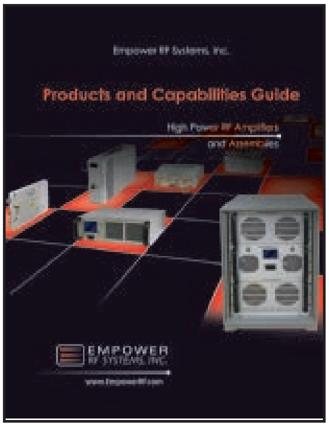


High Power Broadband RF Amplifiers

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.

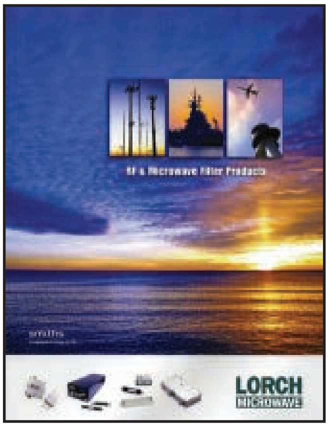
RS NO. 328

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

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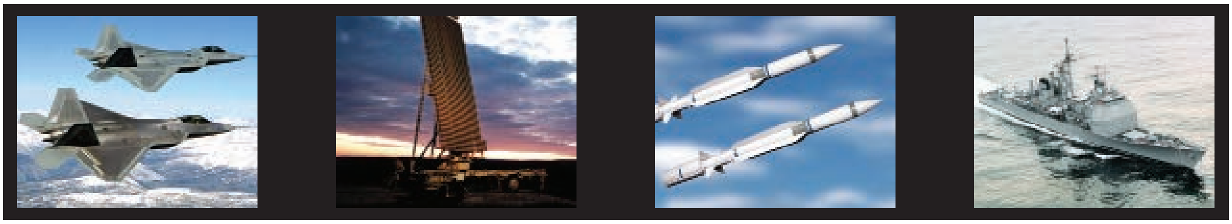

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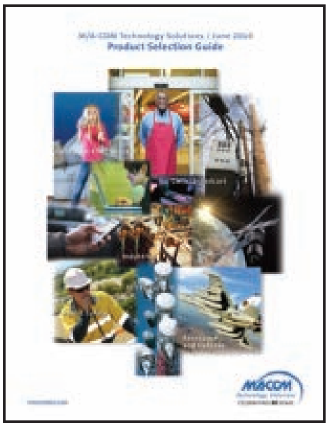

Product Guide

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.

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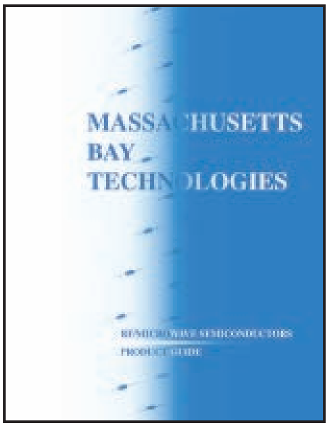

Product Guide

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.

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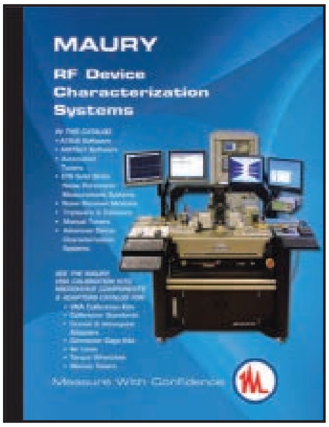

RF Device Characterization Systems

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.

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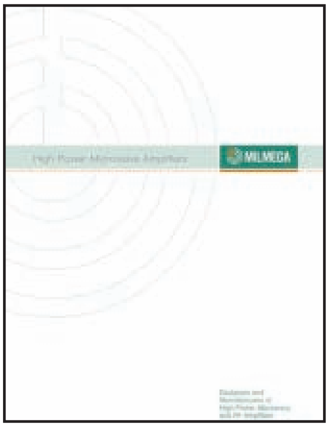

Microwave Amplifiers Catalog

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.

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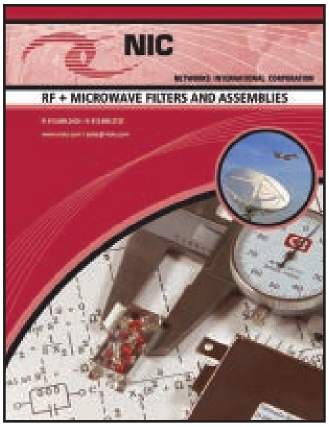


Capabilities Brochure

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

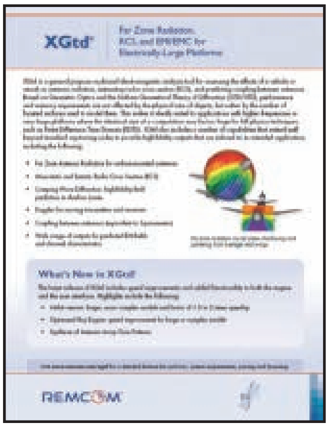
MILITARY MICROWAVES SUPPLEMENT
LITERATURE SHOWCASE

Filters, Multiplexers and Multi-function Assemblies

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

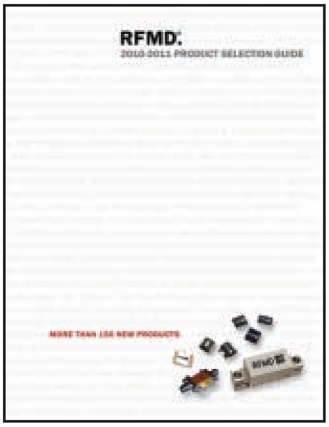


Product Brochure

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

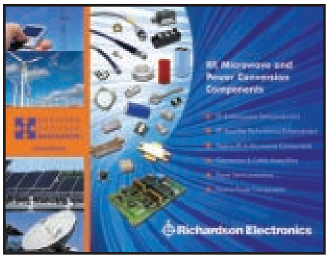


Product Selection Guide

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

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

MILITARY MICROWAVES SUPPLEMENT

LITERATURE SHOWCASE

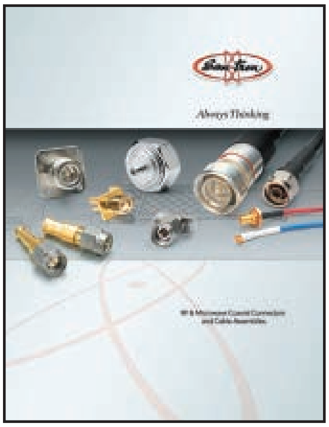
Product Brochure

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.

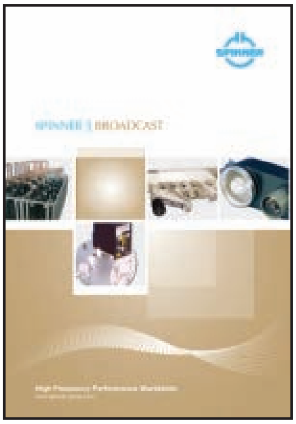
RS NO. 343

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

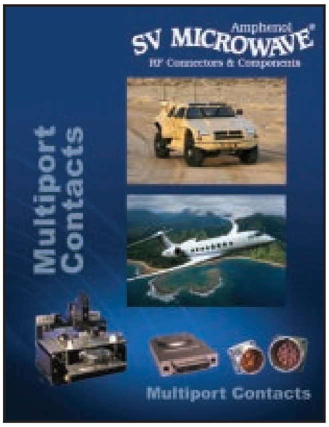
The catalog presents the complete SPINNER broadcast product portfolio, which includes its multi channel combiners, bandpass filters, patch panels, parallel switching units, coaxial switches, RF-lines and monitoring and coaxial loads. The new catalog includes all available information on the numerous 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

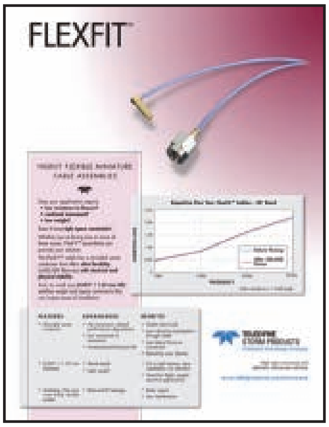


Multiport Contacts Catalog

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

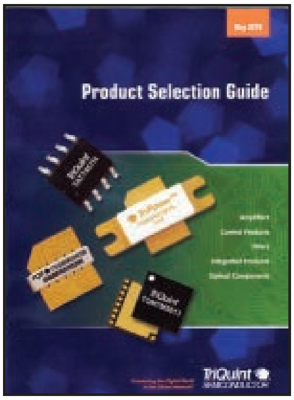


Highly Flexible Assemblies

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



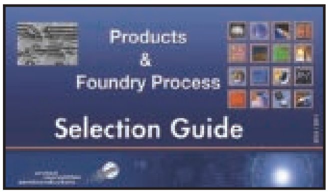
Product Selection Guide

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

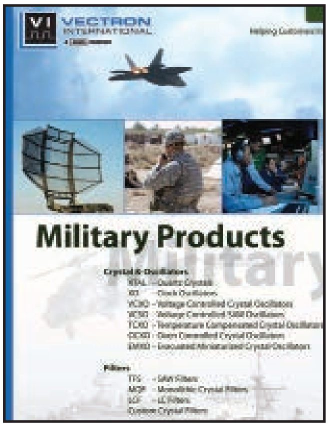
Aimed especially at buyers, sales reps and engineers, this guide highlights the company's products and foundry processes, covering a broad range of markets and applications up to 100 GHz. It highlights that the company targets its main market segments – Military (radars), Telecommunication (backhaul) 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),
Paris, France +33 1 69 33 02 26, www.ums-gaas.com.

RS NO. 349

MILITARY MICROWAVES SUPPLEMENT

LITERATURE SHOWCASE



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,
Hudson, NH (603) 598-0070, www.vectron.com.

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.

IMT,
Hackettstown, NJ (908) 852-3700, www.imt-solutions.com.

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

The Defence/Security Executive Forum
at European Microwave Week 2010

This premier live event features leading representatives from European defence agencies, market analysts and industry leaders discussing current initiatives, market trends and strategies impacting the European Defence/Security sector.

Wednesday, September 29, 5:00-7:00 pm ■ CNIT Conference Centre, Paris

Free admission for registered attendees.
Space is limited, sign-up today.

Agency Perspectives:

Francois Murgadella, Direction Generale pour L'Armement **(DGA)** & Agence Nationale de la Recherche **(ANR)**

NATO – Speaker to be confirmed

Simon Attila, R&T Project Manager, European Defence Agency **(EDA)**

Market Perspective:

Asif Anwar, Program Director for **Strategy Analytics**

Industry Round Table:

Prof. Dr. Heinrich Daembkes,
VP Systems & SW Engineering
EADS

Dr. Lorenzo Mariani,
Senior VP
Selex Sistemi Integrati

Pierre Fossier,
VP, Technical Director
Thales

Also with Dr. Barry M. Alexia, Director Strategy Technology, Rockwell Collins

Registration/Sponsorship information online at:
www.mwjournal.com/euro_execforum2010

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