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UAVs Unleashed

They call it the "Hidden War" – the United States' secret use of unmanned autonomous vehicles (UAV) to search out and kill terrorists overseas. It has created a lot of controversy recently and receives increasing mainstream news coverage. Where is the technology heading? What are the risks and business opportunities for RF and microwave companies? This article takes a look at the UAV (or "drone") market, recent progress in the technology and future directions related to the RF and microwave industry.

UAV LANDSCAPE

The most commonly seen UAVs are Unmanned Aircraft Systems (UAS) that include ground stations and other elements besides the actual aircraft. UASs get the most public coverage of all UAVs that also include Unmanned Ground Systems (UGS) and Unmanned Maritime Systems (UMS). The most widely known UAS is the Predator A (see ***Figure 1a***), which began as a reconnaissance platform and was later modified to carry Hellfire anti-tank missiles. The Predator B (Reaper) was a second generation with improved performance capabilities. The third generation Predator C (Avenger, see ***Figure 1b***) is more in line with the fifth generation fighters being deployed by the USAF. The Avenger UAV uses existing Predator ground-based infrastructure so the costs to field it are just the UAV and software itself, avoiding the cost of a full new system. The Avenger has a jet-powered engine and stealth technology that was not used in the previous Predator platforms. The Predator UAV and sensors are controlled from a ground station via a C-Band line-of-sight data link or a Ku-Band satellite data link for beyond-line-of-sight operations. The Avenger is fitted with the General Atomics-developed "Lynx" Synthetic Aperture Radar (SAR) system as well as the AESA Wide-Area Surveillance Sensor.

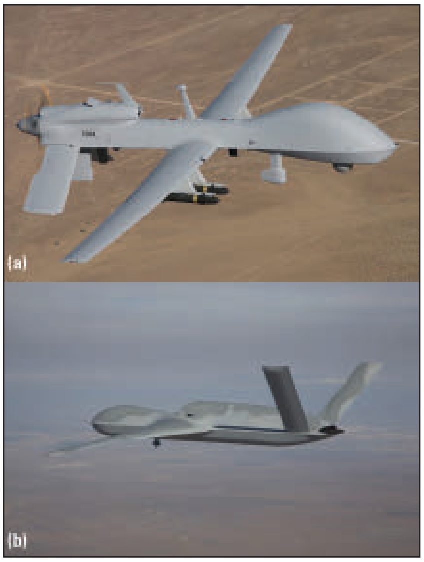

Fig. 1 Predator A (a) and Predator C (b) UAS platforms (courtesy of General Atomics).

Another class of UASs is micro- or mini-UASs. This is a growing area as these are less expensive, easier to deploy and becoming more capable as the software control improves. An example is the Wasp III, which provides real-time direct situational awareness and target information for Air Force Special Operations Command Battlefield Airmen. The Wasp III UAS features the expendable air vehicle, a ground control unit and communications ground station. It is a collapsible lightweight air vehicle with a two-bladed propeller driven by a small electric motor (see ***Figure 2***). It is equipped with an internal GPS and Inertial Navigation System, autopilot and two on-board cameras. The system can function autonomously from takeoff to recovery or be controlled by one operator using a handheld remote control unit.

Fig. 2 Wasp III UAS (courtesy of Aerovironment Inc.).

PATRICK HINDLE
Microwave Journal *Technical Editor*


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Unmanned Ground Systems (UGS) are an over-looked class of UAVs with many thousands of vehicles used in the Iraq and Afghanistan wars to locate and defuse IEDs or explore potentially dangerous buildings. It has been reported that as of 2011, more than 11,000 IEDs were defeated using UGSs. Other UGSs are designed to go into buildings and provide visual images of what is inside while others are designed to carry equipment to support troops. Many UGSs use treads like a tank for movement but DARPA is working on legged UGSs for carrying equipment like a mule. The DARPA project is called the Legged Squad Support System and is shown in ***Figure 3***. It can carry heavy loads and would therefore be able to support troops by hauling equipment.

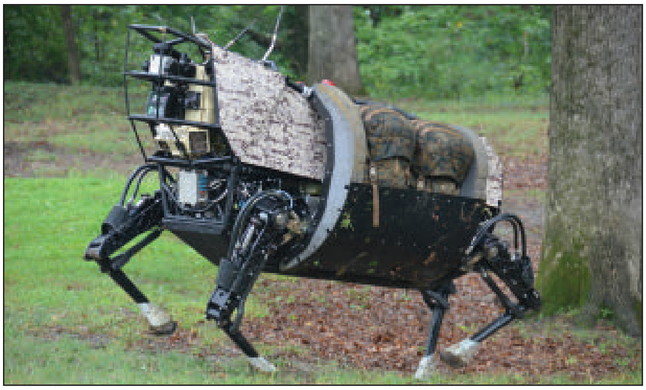

Fig. 3 DARPA Legged Squad Support System UGS (courtesy of DARPA).

For UGS recognizance, there are many kinds of vehicles with cameras and sensors that can enter a building or other areas that pose a risk to humans and take a look remotely at what is there. Some examples are sending UGSs into areas contaminated with chemicals, under bomb threats or radioactive contamination. The UGSs can survey the area for possible problems without endangering humans. An interesting example is the iRobot FirstLook as shown in ***Figure 4***. It is a small, light, throwable robot that provides quick situational awareness, performs persistent observation and investigates confined spaces. One can just toss it into a building (through a window or door) and immediately get images as to what is inside as it is guided around the area. Historically, the emphasis has been on IED and bomb detection and defusing but as the Middle East wars wind down, it is expected that the emphasis will change to other uses such as border security and law enforcement applications.

Fig. 4 iRobot 110 FirstLook "throwable" UGS (courtesy of iRobot).

Fig. 5 SeaFox USV (courtesy of Defence Talk).

Unmanned maritime systems (UMS) consist of unmanned underwater vehicles (UUV) and unmanned surface vehicles (USV). The U.S. government's priorities for UMS include mine countermeasures, anti-submarine warfare, maritime domain awareness and maritime security.[1] UMSs have been widely used in mine sweeping operations in several wars. Examples of maritime security UMSs are the SeaFox USV shown in ***Figure 5*** and the Sea Maverick UUV shown in ***Figure 6***. UMSs are used for military maritime security and border security. With large amounts of illegal drugs entering the U.S. coming from underwater or surface vehicles, border security is expected to be a growing area for all types of UAVs, especially UMSs.

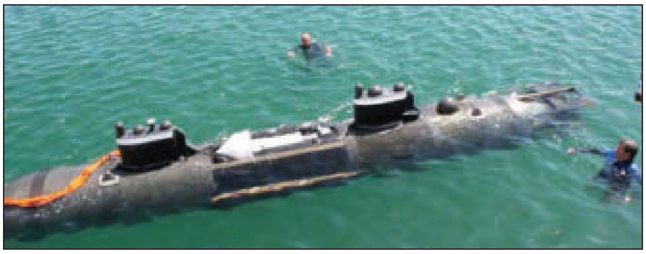

Fig. 6 Sea Maverick UUV (courtesy of Autonomous Undersea Vehicle Applications Center).

UAV MARKET

The UAV sector has recently been called the fastest-growing sector in the aerospace industry by the Teal Group, a defense industry consultant.[2] Current global UAV sales are about $6.6 billion annually and are expected to double over the next decade. The U.S. military UAV market is projected to grow at a CAGR of 12 percent between 2013 and 2018, according to a Market Research Media report.[3] The report says that the U.S. military UAV market will generate $86.5 billion in revenues over the period 2013-2018. Market demand is anticipated to be driven by increased UAV procurement for applications such as persistent surveillance, suppression/destruction of enemy air defense, and communications relays and combat search and rescue.

ASDReports offers another market trend analysis over the next five years. They project that NATO nations (especially the U.S.) will reduce their investment in defense and security UAVs while the non-NATO world will move into those military and police UAVs in a relatively big way. The resultant global market will exceed a cumulative $130 billion over the coming eight years, but the funding profile will change considerably (see ***Figure 7***).[4] The U.S. DoD is changing its focus from Counter Insurgency to a more traditional conflict against a near-peer. That move will reduce the need for expensive UAVs, but will increase the need for fast, stealthy, survivable UAVs.

The U.S. plans to cut spending on unmanned aerial vehicles in fiscal 2014 by one-third of the amount over the previous year, mostly because of the winding down of operations in Afghanistan and the end of the U.S.


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military role in Iraq. While the war on global terrorism initially drove the U.S.'s use of UAVs, it is predicted that there are a wide variety of other uses that will allow the growth to continue including civilian uses. Current civilian applications include Homeland Security, disaster management and border surveillance. The AUVSI Economic Report 2013[5] states that the planned opening up of the national airspace to UAVs in the U.S. by 2015 will affect the market potential between 2015 and 2017 by some $13.6 billion, and $82.1 billion between 2015 and 2025. However, it predicts that if the effort is delayed, it will cost the U.S. billions of dollars in potential revenue. For each year of delay, some $10 billion of potential economic impact is lost. So establishing the guidelines for UAVs to operate in U.S. airspace is critical for domestic growth.

Another obstacle to commercial use is privacy issues which are raising objections in the public's eye. It was revealed for the first time in mid-June that the FBI has been using UAVs in the U.S. for law enforcement activities. About a dozen operations were disclosed including surveillance of a man that was holding a young boy hostage in Alabama. The government stated that they are only used on a very limited basis but this immediately outraged some of the privacy advocate groups.

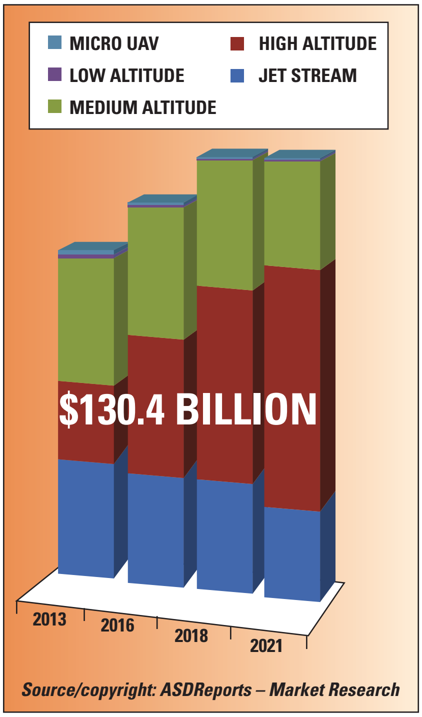

Fig. 7 Projected funding profile for UAV market (courtesy of ASDReports).

While UAVs are already used in a range of civil applications, including wildfire mapping, weather monitoring and telecommunications, the AUVSI report outlined other potential uses that UAVs could carry out, such as precision agriculture and public safety. These applications are thought to make up about 90 percent of the known potential markets. UAVs have many applications in public safety such as search and rescue, surveillance, bomb defusing, surveying dangerous areas (chemical or radiation threats) and following suspects, to name a few. Farmers are already using UAVs to monitor their crops' health from the air to see problems with insects or disease before they become too large to address. This also allows for targeted insectiside application reducing the need to use these chemicals. The report predicts that these two markets will produce approximately 90 percent of the known potential future markets for UAVs.

Outside of the U.S., the demand for UAVs is expected to grow as the technology becomes more widespread. Israel and India are two markets that many analysts are predicting will experience high demand. We have even seen recent use of UAVs by Hezbollah entering into Israeli air space, as they have been shot down by the Israeli defenses. Advanced Defense Technologies Inc. has projected that India is a booming market for micro- and mini-UAVs for civilian and military use.[6] They expect UAVs to be used for reconnaissance and mapping, surveillance, border and maritime patrol.

Israel has been reported to be the largest exporter of UAVs with $4.62 billion from 2005-2012.[7] Britain, India and Brazil are reported to be Israel's leading customers. While the U.S. is constrained with ITAR restrictions that prevent easy export of restricted products, Israel has been able to take the lead in the UAV market. Saudi Arabia recently decided to purchase UAVs from South Africa as the U.S. was reluctant to provide armed UAVs to a Middle Eastern country.

UAV TECHNOLOGY CHALLENGES

There are many challenges to improving UAV capabilities, integrating them into the national airspace and having them cooperate with manned vehicles. These challenges represent opportunities for companies as to the technology needed for future UAV programs. A couple of years ago, the Department of Defense (DoD) released The Unmanned Systems Integrated Roadmap FY2011 — 2036 projecting the U.S. governments priorities and plans for UAVs.[7] It lists the following challenges facing military departments:

- Interoperability: UAVs need to operate seamlessly across domains and with manned systems.
- Autonomy: Pursue technologies and policies that introduce a higher degree of autonomy to reduce the manpower burden and reliance on communications links while also reducing decision cycle time.
- Airspace Integration: Ensure UAS have routine access to the appropriate airspace needed within the National Airspace System working with the FAA.
- Communications: Continue to address frequency and bandwidth availability, link security, link ranges, and network infrastructure.
- Training: Ensure continuation and joint training that will improve basing decisions, training standardization.
- Propulsion and Power: Continue to develop more efficient and logistically supportable sources for propulsion and power.
- Manned-Unmanned Teaming: Continue to implement technologies and evolve tactics, techniques and procedures that improve the teaming of unmanned systems with the manned force.

The interoperability of sensors and improvement in communications bandwidth challenges offer RF and microwave companies the opportunity to develop new technologies that can meet these needs. Standard sensors that can be used across multiple platforms and wideband/high-frequency transmitter/receiver systems are a couple of the solutions that could help meet these challenges.

RF SYSTEM CHALLENGES

Most important to RF and microwave companies, the roadmap discusses many suggested approaches for future developments that are addressed with microwave technology especially in the area of communications. Antennas for UAVs require high-gain, rug-

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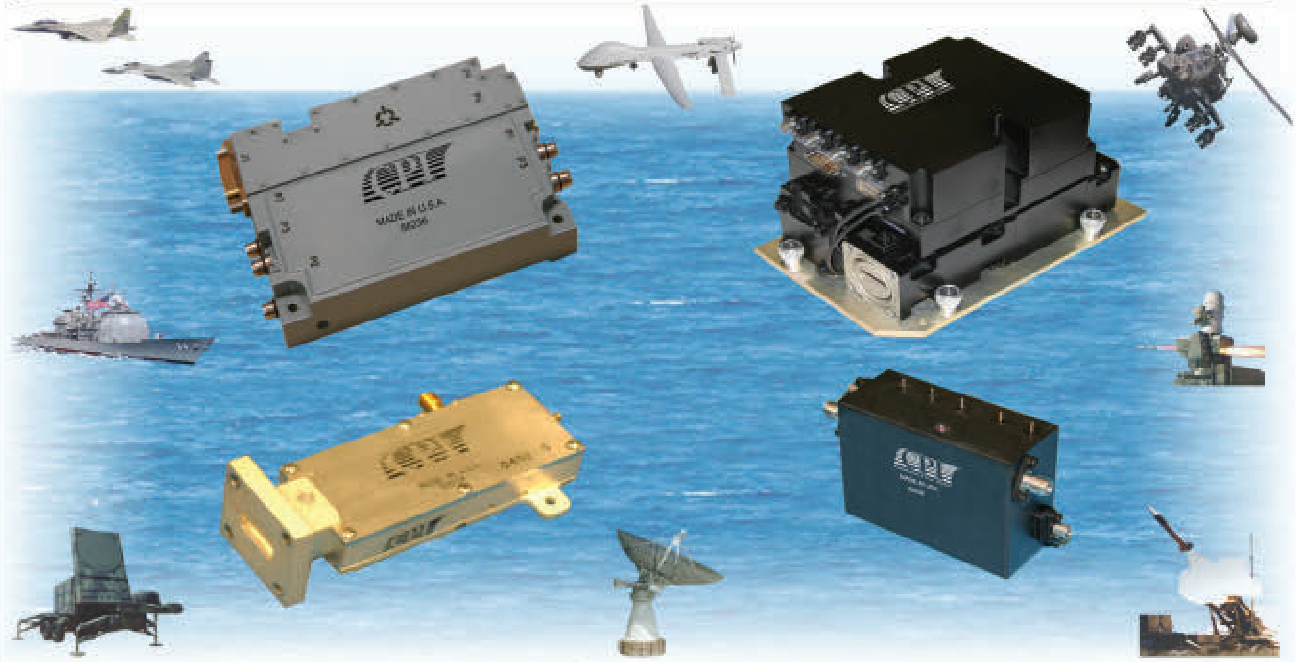

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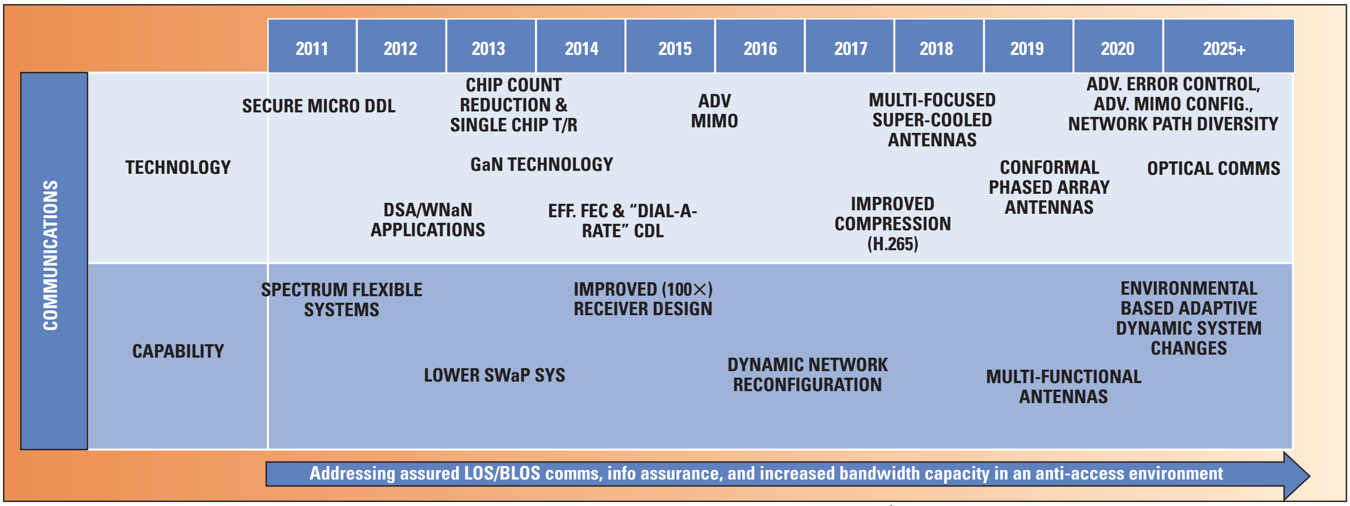

▲ *Fig. 8 Projected communications technologies timeline (courtesy of Department of Defense).*[1]

ged, and low cost multidirectional antennas. It states that phased array antennas and "smart" antennas offer an alternative to traditional dish antenna, but they require tradeoffs among size, weight and power (SWaP). The industry will need to continue developing such techniques as multi-focused and super-cooled antenna systems. The roadmap explains that future antenna systems need to be able to send and receive signals over a broad range of frequencies. While phased arrays are a viable approach, they need to be conformal (e.g., using metamaterial) so that they will be molded within the vehicle surfaces. The utilization of common apertures requires the development of new interference mitigation methodologies that minimize cosite interference effects and improve the potential for achieving simultaneous transmit and receive operations within adjacent frequency bands.

The report also mentions that MIMO is a proven technology currently being used in commercial 4G wireless systems and would utilize multiple paths (although not necessarily independent) with lower data rates on each path; apply space-time coding and capacity optimization to achieve a total high data rate mission; apply power saving to jammer margin; and evaluate performance in benign and stressed conditions.

For transmitter and receiver systems, GaN SSPAs can offer more than double the efficiency of GaAs amplifiers, increased operational bandwidth, and wider frequency range of operation. The high transmit efficiency of GaN systems reduces the cooling requirements. In order to achieve some of these benefits, amplifier designs need to utilize technologies such as predistortion correction, envelope tracking, etc., to improve efficiency and performance. Some of these GaN technologies are currently available for selected frequency bands and plan to be in service in 2014. Instantaneous bandwidth performance and analog-to-digital converter sampling speeds have continued to improve system performance so this should continue to improve systems. The report mentions that improvements in integrated chip fabrication methods have allowed for significant miniaturization and reductions in part counts and for various transmit/receive and antenna functions and components to be integrated on a single chip this year. Most of these improvements are aimed at

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Many U.S. military operations are now taking place in parts of the world where adequate spectrum is not available. Broader bandwidths are needed to deliver timely data to the warfighter and transfer data to UAVs. Additionally, mission areas are becoming more spectrally noisy. DARPA's Next Generation (XG) project and its follow-on Wireless Network after Next (WNaN) program demonstrated the feasibility of dynamic spectrum access (DSA). DSA offers the ability to change frequency band use based on other adjacent spectrum-dependent systems actual use and nonuse of certain bands.

Communication systems need to implement more robust anti-jamming and secure communications techniques. Networking of multiple unmanned systems may be necessary to better ensure connectivity of the systems in non-LOS, urban, hostile, and noisy EMS environments to transfer the collected information. One concept under development with DARPA is the LANdroids program. This program calls for the deployment of small, inexpensive, smart robotic radio network relay nodes that can leverage their mobility to coordinate and move autonomously. ***Figure 8*** shows a summary of the projected communications technologies on a timeline for planned implementation. Most of these improvements involve RF and microwave technology that companies can contribute expertise to developing.

As miniaturization is a growing trend for UAVs, reducing electronics size and weight is becoming more important. RF and microwave companies offering reduced power consumption devices and highly integrated ICs have an advantage in the marketplace. Lightweight cabling and connectors are also an important technology for future systems.

FUTURE DIRECTIONS

Interoperability

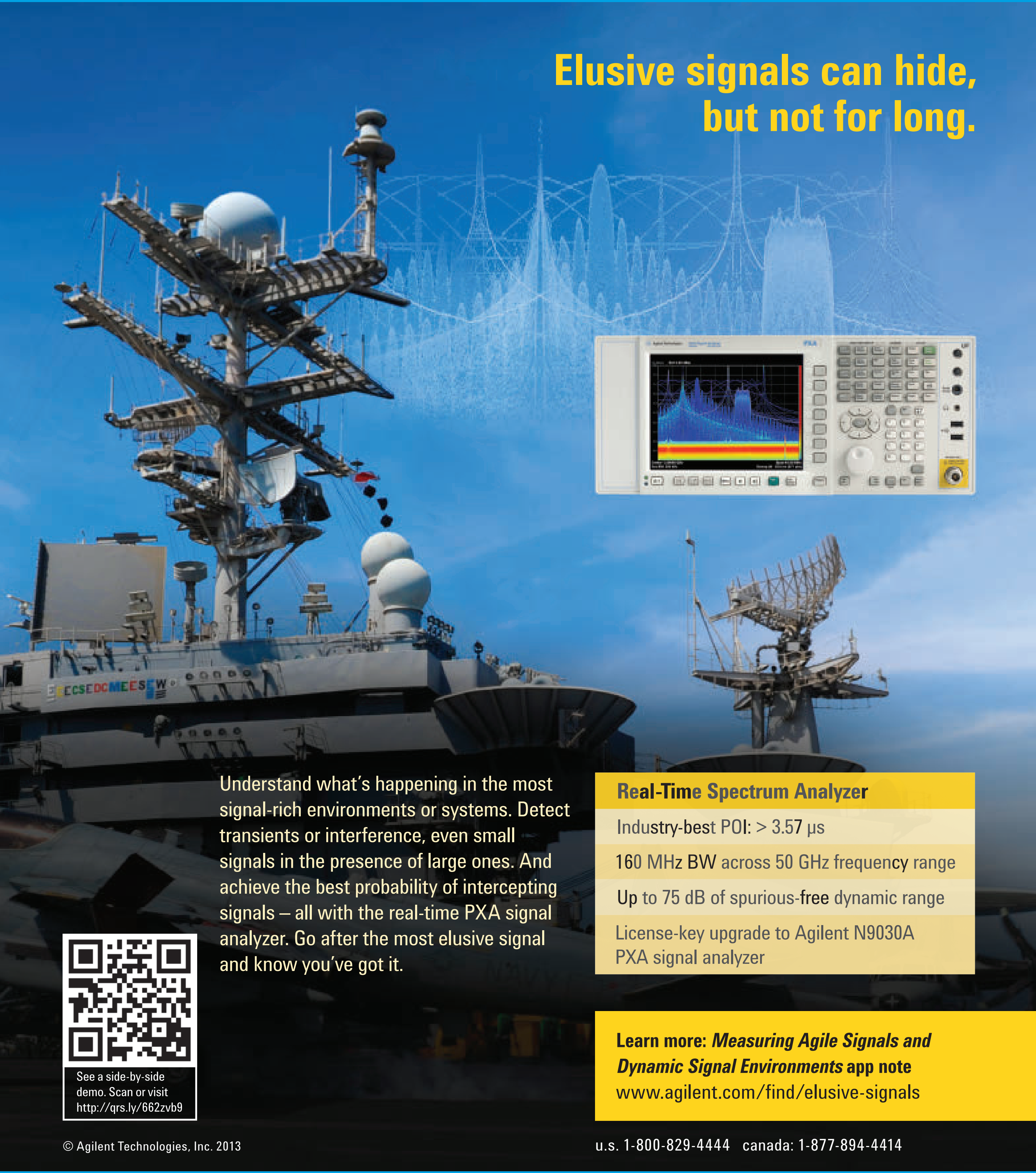
Interoperability is a big challenge to UAVs and the systems that support them. To achieve the full potential of unmanned systems, these systems must operate seamlessly across the domains of air, ground and sea and also operate with manned systems. Initially many of the UAVs were developed as a single system and used as proprietary systems so they are not compatible with each other. Many of them were procured in a rush to meet an immediate wartime need so there was no time to plan for interoperability. Going forward, the U.S. government plans to use an open architecture for systems to operate together and to use common plug-and-play sensors. This extends from sensors to data collection to system controls. Designing sensors and subsystems that can be utilized on many UAV platforms will also be a trend as the government tries to reduce costs and be able to distribute spare parts around the world. These parts could be shared between systems, agencies and maybe even non-military groups.

As a first step in this direction, the Office of Naval Research has recently developed software that can be shared across the range of UAVs in an effort to save money and streamline training. The Unmanned Aerial System Control Segment (UCS) software for the Common Control System has been successfully tested during a dry run on the ground and will be used in a test flight with a UAV later this year.

Airspace Safety

UAVs designers also need to prove that their UAVs can safely operate in the same airspace as piloted aircraft before they will be allowed to fly in commercial airspace. UAVs need to demonstrate a high level of operational robustness and the ability to "sense and avoid" other air traffic. Therefore, NASA has developed the Unmanned Aircraft Systems Airspace Operations Challenge (UAS AOC) that is focused on developing some of the key technologies that will make UAS integration into the National Airspace System possible. This Centennial Challenge will be conducted in two parts: Phase 1 is scheduled to be held in spring of 2014 and Phase 2 will be approximately one year later.[8] Phase 1 focuses on important aspects of safe airspace operations and robustness to system failures, and seeks to encourage competitors to get an early start on developing some of the skills critical to Phase 2.[8]

Another step in this direction of establishing the safety of UAVs in commercial airspace is that the FAA has issued a request for proposal for six ranges that will be used to test UAVs as part of the government's plan to integrate the technology into national



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airspace. Establishing the test sites is a component of the FAA Modernization and Reform Act of 2012 with the goal of fully integrating UAVs into the airspace by 2015.

Autonomy

The next evolution in UAVs is autonomy. UAVs currently perform minimal tasks on their own relying on their operators to make most decisions – some behavior is automatic but not necessarily autonomous. An autonomous system has the ability to be goal-directed in unpredictable situations making its own decisions. Some think taking control from humans and giving it fully to machines is a bad idea (especially after watching Terminator or The Matrix), but in order to take UAVs to the next level to perform more tasks in an efficient manner, autonomy is needed. While many of the challenges to autonomy are software related, inputs to the software regarding the surrounding environment come from sensors. Higher resolution and improved sensors with fast response time will help enable autonomy.

Some UAVs are already starting to incorporate this type of technology into their designs. Britain's new stealth bomber UAV, Taranis, is being designed to self-evade without input from a controller. It can also independently identify targets and would only check back with a human controller before initiating an attack. This UAV is relatively large at with a wingspan of 30 ft and has a shape similar to the B-2 and stealth design (see ***Figure 9***). The UK hopes to replace manned bombers with UAVs such as this one. Some have said that the day of the manned fighter platform is gone after the current fifth generation fighters end their service.

Recently, a similar U.S. designed UAV achieved a very significant milestone. The X-47B (see ***Figure 10***) was catapult launched from the aircraft carrier USS George H.W. Bush for the first time and later made an arrested landing on the carrier. The X-47B design took into account the corrosive saltwater environment, launch and recovery on deck, integration with command and control systems, and operation in an aircraft carrier's high-electromagnetic-interference environment, as well as the ability to perform reconnaissance missions in its design. UAVs are now able to be fully integrated into the Navy on carriers – one of the harshest environments for aircraft to land on and take off from. This marks one of the last areas for UAVs to fully penetrate the armed services and provides better coverage around the world.

Micro- and Mini-UASs

An intriguing aspect of the micro- and mini-UAS space is UAS platforms that are hidden or blend into the environment. Some designs look like birds that sit perched on a tree and survey the area or track a target. Others are insect-like and so small that they are very difficult to observe. As the UAVs become smaller, their agility increases so that they can easily maneuver through small spaces. This allows them to move around inside of buildings without hitting any obstacles.

Researchers have also been working on software that allows these small UAVs to cooperate and fly together in formation and even break formation to go through a small space and then regroup automatically. A February 2012 Technology, Entertainment, Design (TED) video, featuring Vijay Kumar from the University of Pennsylvania, shows the results of cooperation between UAVs as they fly in formation sensing each other to keep a minimal distance in a set pattern.[9] Then as they come to an obstacle too small for the formation, they cooperate by passing through one by one, regrouping in formation after they have each passed through the small space. Developing systems that allow these UASs to communicate with each other and make their own decisions is a big area of research that could allow these vehicles to take the next leap in capability. With this technology, many UAVs can work together to accomplish tasks that a single UAV would not be able to do such as lift a heavy object or perform a coordinated attack from many directions.

Imagine several small UAVs communicating with each other as they fly through a structure and automatically map out the inside using radar sensors and sending the layout information to those that need it. The UAVs make their own decision about which way to roam around the building steering toward the areas that are the most unmapped at the time and communicating which areas they have covered to the other units.

This quickly accomplishes the task without inputs from a controller.

Improved Radars

New radars that can perform through-the-wall sensing and mapping are being developed to improve UAV capabilities. An example of this technology is found at TiaLinx which designs UAVs with sensors that operate at 5 GHz, giving them substantial penetrating capability, even at extremely low power. Some models are designed to detect motion, even a heartbeat or breathing. The company has previously stated that the device can detect people or animals more than 20 feet behind an 8" thick concrete slab. They have models that operate in the V-Band to produce sharper images. But the atmospheric attenuation at 60 GHz means this model cannot penetrate as deeply. Because these devices transmit ultrawideband (UWB) signals, they are able to obtain a more complete view of hidden objects. UWB signals are less affected by environmental factors such as rain, snow and fog that degrade the performance of many radars plus operate at low power (see ***Figure 11***). These types of UAVs' roles could be expanded into internal surveillance as very small form factors that can fly around virtually undetected.

Global Activity

Many other countries are putting a lot of resources into UAV design and development. During the AVIC Cup-International UAV Innovation Grand Prix ceremony (a contest for industry professionals) at the Zhuhai Airshow in China last November, a video was shown of the futuristic "Blue Shark" UUV (see ***Figure 12***) diving for an attack on Russia's Kuznetsov aircraft carrier.[10] Many of the contestant submissions were of near-space UUVs and hovering ground-attack heavy UAVs.[10] A recent report states that China uses UAVs for intelligence, surveillance, and reconnaissance (ISR) missions and communications relay, but likely is developing and operating UAVs for electronic warfare (EW) and lethal missions.[11] China, like the U.S., is incorporating UAVs into non-defense missions such as border security, maritime surveillance, and humanitarian assistance/disaster relief. The Chinese presence is expected to grow in the international market as they have far fewer restrictions than the U.S. for military exports.

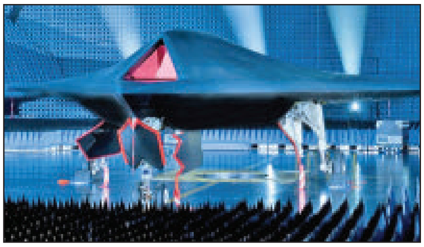

Fig. 9 British UAV Taranis (courtesy of BAE).

Fig. 10 U.S. UAV X-47B preparing for carrier launch (courtesy of U.S. Navy – photo by MC2 David R. Finley, Jr.).

Israel is a major operator and producer of UAVs, with three air force squadrons equipped with Heron, Hermes 450 and Searcher craft, as well as the giant Eitan[12] and as stated previ-

ously, probably is the largest exporter of UAVs globally. Israel is considered to be second to the U.S. in UAV technology. UAVs play a key role in battling Gaza rocket launchers as they perform surveillance and identify rocket launcher positions. They are working on UAVs to take over many tasks that are currently performed by manned aircraft.

CONCLUSION

UAVs are an exciting area of development that is progressing quickly. While the overall market is growing, the U.S. military market will decline in the next few years as the U.S. pulls out of Iraq and Afghanistan. However, the U.S. commercial market is expected to grow significantly as military sales decline providing that legislation is passed to incorporate UAVs into the national airspace. New commercial applications such as border security, public safety and farming are expected to find many benefits from the use of UAVs. Growth is also expected in foreign military markets as the technology becomes more widespread.

RF and microwave companies can participate in this market growth with technologies that reduce SWaP such as GaN amplifiers, highly integrated radio transmitters and receivers, MIMO and conformal antennas, light weight cables/connectors, plug-and-play sensors and low power systems. The market for smaller mini- and micro-UAVs will demand further miniaturization of electronics and other key components as the commercial market expands. ■

Fig. 11 TiaLinx UAV with UWB radar sensor (courtesy of TiaLinx).

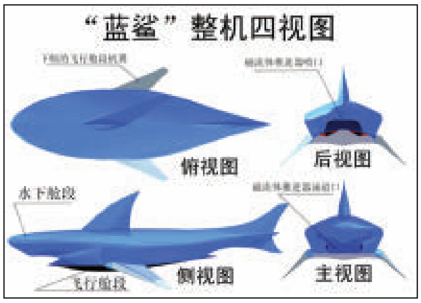

Fig. 12 Blue Shark UUV Chinese concept (courtesy of Defense News).

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Envelope Tracking in Next Generation Military Radios

Existing narrowband military communications systems offer minimal battlefield capability beyond voice communications and relatively low data rate services. The desire for increased combat effectiveness is driving the need for improved interoperability and battlefield communication system features – combat units and individuals are now integrated into a network of data services providing features such as integrated command and control, mapping, real-time video and location-based services providing situational awareness.

Realistically, these services can only be delivered using modern complex high peak to average power ratio (PAPR) modulation schemes that provide high spectral efficiency. For systems supporting both these and legacy constant envelope or low bandwidth/PAPR waveforms, the traditional fixed-supply PA becomes very inefficient when using the new modulation schemes, requiring large power sources for even small RF output powers. The increased peak power needed by a fixed-supply PA to support high-PAPR waveforms also compromises the efficiency when operating with legacy waveforms, resulting in decreased battery life compared with legacy equipment.

Recent advances in envelope tracking (ET) techniques are leading to their adoption for commercial LTE-based 4G cellular systems, enabling insertion into next generation military radio designs. The use of an ET-enabled PA is an effective solution for modern high modulation rate air-interfaces, especially for dismounted soldiers. ET PAs offer improved efficiency and lower power consumption resulting in reduced cooling requirements thereby allowing smaller, lighter batteries to be used or longer battery life to be achieved from a given battery. Less obvious benefits include improved linearity performance, improved tolerance of mismatched antennas and increased output power from a given PA device compared with fixed-supply operation. ET PAs fit in well with software defined radios (SDR) as they are capable of being configured in real time to suit the differing operating modes required under battlefield conditions. In addition, they are forward-compatible with yet to be announced future waveform developments.

This article explains how the key benefits of ET PAs for modern battlefield communications systems – improved PA efficiency and linearity – are achieved, and the types of ET modulator

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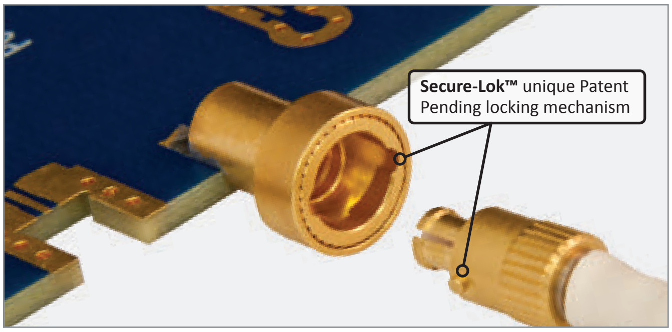

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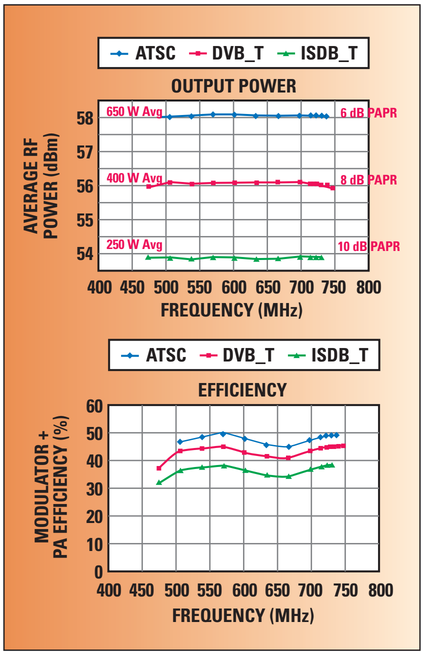


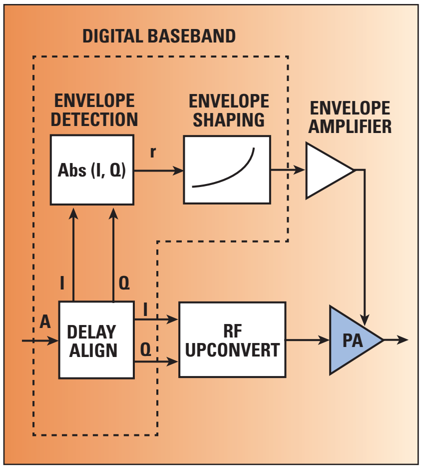
▲ *Fig. 1 Broadband high power ET PA example.*

technology being developed to enable them. The move to networked combat data services is driving demand for higher data rates and there is currently no real alternative to ET-modulated PAs for next generation military radio use.

WHY USE ET FOR MILITARY APPLICATIONS?

Military success has always depended on effective battlefield communications and with the emerging proliferation of radios, sensors and unmanned assets, this has proved to be an increasing technical challenge. In this environment, it is essential to integrate all battlefield communications within a single integrated network to provide seamless access to voice and data traffic. This objective has been pursued in the U.S. under the JTRS program with the result being a complete networking concept enabled by SDR and several new networking waveforms. In order to understand the benefits ET brings to radios operating in this environment, it is useful to review the top level network architecture and associated waveforms.

In concept, the evolving military communications network has three distinct levels; lower, mid-level and upper, with each level having specific functionality and waveforms commensurate with this functionality. The lower level is intended to support the tactical edge and provides voice and low capacity data services including connectivity to other edge devices. Network domains are formed using the Soldier Radio Waveform (SRW) which fully supports self-forming ad hoc IP networking. At this level, domains are generally small geographically and are supported by small form factor handheld radios with RF transmit powers typically in the range 2 to 5 W.



▲ *Fig. 2 ET-enabled system architecture.*

Networking at the mid-level is by means of the Wideband Networking Waveform (WNW) which again supports self-forming mobile ad hoc networks with each radio being a node on an IP-based mesh. The purpose of the mid-level is to provide effective high capacity backhaul. It provides connectivity between the lower level local networks at the tactical edge and integrates all data over a large geographical area. Radios for use in mid-level communications must therefore have an extended range and simultaneously be able to interconnect to both lower and upper levels. Interconnection with the lower level uses SRW whilst upper level interconnection uses the Mobile User Objective System (MUOS) satellite system. Mid-level radios today are generally man portable or vehicle mounted with RF transmit powers in the 20 to 50 W range. Support for SRW, WNW and MUOS waveforms is therefore required in addition to a range of legacy waveforms. Planned upper level integration of the total networked battlespace will use assets that include WIN-T, the MUOS satellite constellation and GIGBE, and consequently, will be global in scale. See JTNC Newsletter for further background on the communications networks and waveforms discussed here.[1]

For the emerging military communications strategy to succeed, next generation radios require certain features which are challenging for the radio designer. Each radio is required to support one or more high PAPR waveforms operating over an extended frequency range. Depending on whether the radio is assigned for operation on the lower or mid-level networks, these modern waveforms may have to operate alongside a range of legacy waveforms, imparting additional demands. These considerations create significant challenges for the transmit chain where efficiency and linearity are crucial. In the future, these challenges will be compounded with the move toward cognitive radios required for the DARPA Wireless Network after Next (WNaN) program.

ET exhibits attributes well suited to meeting these requirements. An example of ET's ability to deliver high efficiency, broadband PAs capable of operating with a wide range of signal PAPRs is shown in ***Figure 1***. This allows the efficiency of broadband PAs to be significantly improved without the inherent RF bandwidth restrictions of RF phasing techniques such as Doherty and Chireix.

ET SYSTEM ANATOMY

A typical ET-enabled transmit system is shown in ***Figure 2***. At the heart of the system is the envelope amplifier (also known as an envelope modulator) that must provide a high efficiency, low noise and high bandwidth dynamic power supply to the PA. Envelope detection and shaping functionality needs to be added to the digital baseband processing in an ET system to generate a reference signal for the envelope amplifier. The envelope shaping determines the relationship between the instantaneous RF power and the PA supply voltage and influences many key metrics of the ET system. Lastly, accurate, stable timing alignment between the RF and envelope signals is necessary to achieve low PA distortion and this function is also typically implemented in the digital baseband.

MODULATOR ARCHITECTURES

Examples of basic ET modulator architectures are shown in ***Figure 3***. The

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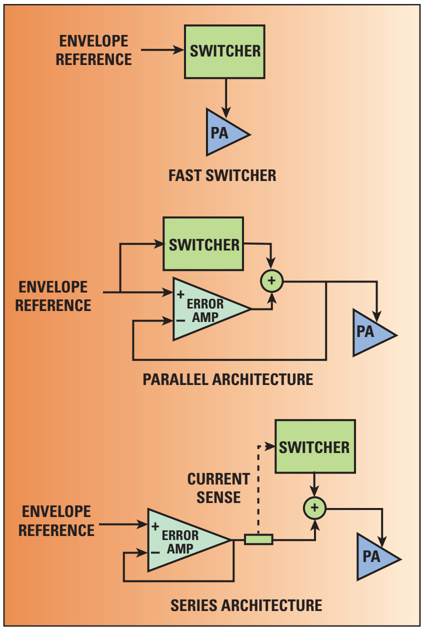


Fig. 3 *Modulator architectures.*

first is a fast switcher-only architecture. This simple scheme can achieve ~90 percent efficiency with low power and low bandwidth signals but is difficult to scale up in bandwidth and power. To achieve good TX linearity, the bandwidth of the envelope path has to be 2 to 3 times the RF bandwidth. Furthermore, to achieve good stability margin and switching noise suppression, the ratio between switching rate and modulation bandwidth for a single phase buck converter is typically 10×, resulting in a switching frequency to RF bandwidth ratio of 20 to 30:1. This means that to achieve an RF modulation bandwidth of only 2 MHz, a switching frequency of ~50 MHz is required. Increased switching frequency results in excessive semiconductor switch and inductor losses. Multi-phase/multi-level switch mode techniques can be used to reduce the ratio between switching rate and modulation bandwidth, at the expense of increased complexity.

The second architecture is the hybrid parallel switcher-error amplifier architecture. The switcher 'leads' by creating a crude approximation of the desired waveform, and a linear amplifier 'follows' by cleaning up the output of the switcher. An efficient but relatively low bandwidth switch-mode power supply provides 80 to 90 percent of the power at DC and low frequencies, and the less-efficient but high-bandwidth linear error correction amplifier provides the remaining

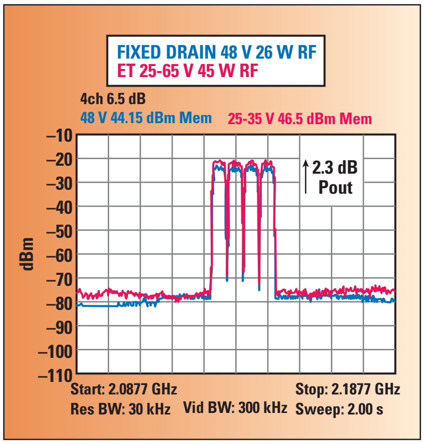


Fig. 4 *Increased O/P power capability using ET.*

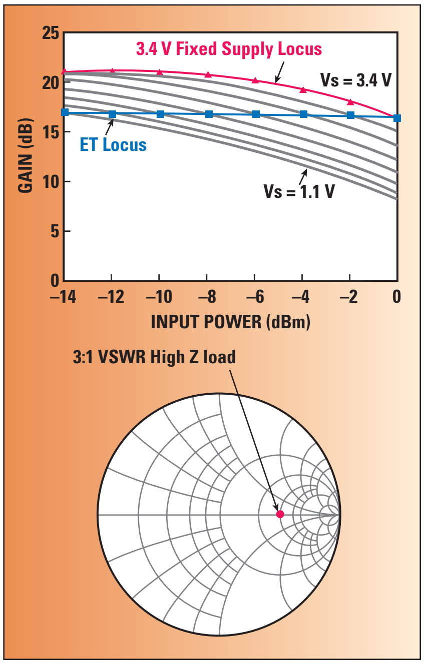


Fig. 5 *ET and fixed supply operation into mismatched load.*

HF power. In addition to providing the modulator's HF signal content, the error amplifier also suppresses high frequency switcher noise by comparing the switcher output with the desired reference. Feedback loops around the error amplifier and switcher ensure that the modulator exhibits low output impedance across a wide frequency range – a feature critical to achieving high tracking accuracy and good transmitter linearity. The overall efficiency of the modulator architecture is typically >80 percent and is almost flat with increasing bandwidth – a highly desirable characteristic.

The third is the hybrid series switcher-error amplifier architecture. This comprises a 'leading' error amplifier driving the PA supply and a 'following' switcher. Current sensing detects when the current drawn from the error amp exceeds a pre-determined threshold and a hysteretic switcher is used to efficiently supply additional current to the PA. At low bandwidths, the overall efficiency of this architecture is similar to the parallel architecture, but the efficiency tends to fall with increasing signal bandwidth as delays in the switcher loop result in the switcher working against the linear amplifier. In addition, the switcher ripple current has to flow into the low impedance output of the linear amplifier, resulting in increased linear amplifier dissipation.

More complex derivatives of both the parallel and series hybrid architectures are possible. These generally use multi-phase and/or multi-level switchers to increase modulator efficiency, provide voltage boost capability or increase bandwidth. Low power (~750 mW average RF) handset modulator ASICs providing high efficiency and voltage boost capability are becoming available. One such ET IC uses a single phase buck converter to provide the DC and LF power, and a multiphase, multilevel converter to provide the bulk of the remaining power. A linear error amplifier is used to clean up the switching noise of the switch-mode converters. Such ASICs operate with standard 2.5 to 5.25 V Li-ion batteries and generate a 4.5 V peak/1.2 A peak PA supply capable of supporting RF bandwidths up to 20 MHz.

High-density IC components incorporating all necessary ET functions for medium-power mobile applications (~5 to 25 W average RF) are also emerging. For instance, all signal processing and DAC functions may be integrated on one IC whilst a second IC may integrate several switcher controllers. At this power level, external O/P stages may be used to allow the power and voltage range of the modulator to be optimized to suit the PA voltage and power. Compact scalable ET modulators fit into satcoms and higher-power handset applications, in addition to low-power vehicle-mounted terminals. At this power level, a typical modulator may operate from 10 to 30 V supplies to generate a 10 to 30 V peak/1 A peak PA supply capable of supporting RF bandwidths up to 20 MHz.

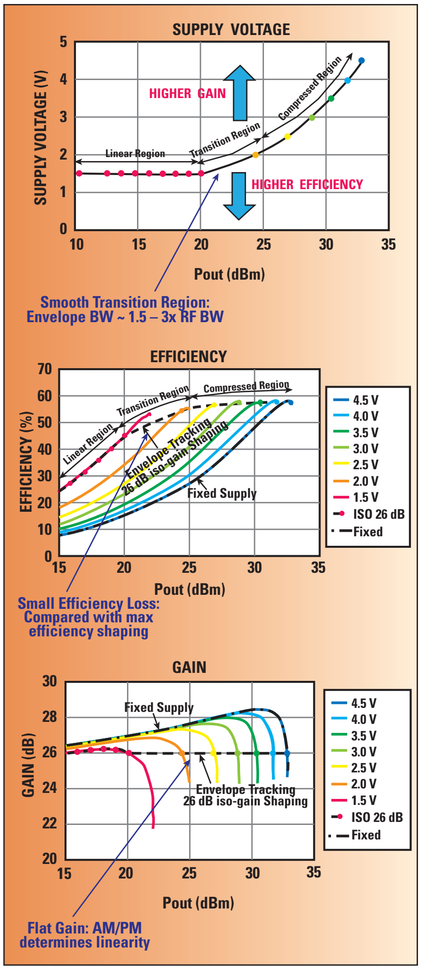
BENEFITS OF ET-ENABLED PAs

A fixed-supply PA only operates in compression during infrequent waveform peaks, whereas an ET PA operates in compression most of the time. This results in ET PAs operating more efficiently and with lower die powers, enabling smaller PA devices and smaller, lighter batteries to be used for a given system capability.

The PA die size is primarily determined by the system peak power requirements and is in principle the same for both fixed supply and ET having the same peak voltage. However, the use of ET greatly reduces die power dissipation and temperature which often results in further increased peak power capability. In addition, for GaN devices the peak power capability may be significantly increased by operating in ET mode, allowing a higher peak supply voltage than could be sustained in fixed supply operation. This is possible because the output power in fixed supply mode is often limited by thermal issues rather than voltage considerations. In the example shown in ***Figure 4***, the peak output power of a fixed drain 48 V GaN PA increased by 2.3 dB when operated in ET mode with 25 to 65 V swing range. Despite the increased RF output power, the die power dissipation actually decreased from 45 to 32 W.

The reduction in PA die power dissipation reduces heat sinking requirements, simplifying the thermal design. This can eliminate the need for fans, heat pipes, heat sink fins, etc., reducing product size, weight and cost.

A perhaps unexpected benefit of ET is increased VSWR tolerance compared with fixed supply PAs. The increasing use of wideband PAs and wideband antennas means that the antenna match is often not ideal and may vary dynamically in use. In these situations, a fixed-supply PA would need to operate with significant power back-off to maintain linearity. But it is



▲ *Fig. 6 ISOgain shaping.*

found that ET PAs can work into high VSWR loads with significantly less ACPR degradation. The explanation for this initially surprising finding may be found in the fact that an ET PA operates in compression over much of the envelope cycle by design, using a shaping table chosen to achieve flat AM-AM characteristics. If exposed to a VSWR phase angle that results in a significantly higher load impedance, it operates in even heavier compression, but the shaping table still results in approximately flat AM-AM characteristics – i.e., the PA linearity does not alter dramatically. In contrast, the AM-AM characteristics of a fixed supply PA will be considerably altered when working into load impedances higher than intended (see ***Figure 5***).

The provision of a fall-back Average Power Tracking (APT) mode means that ET PAs can also offer high efficiency when operating with legacy low bandwidth, constant envelope or low PAPR waveforms, or when operating at low power with backed-off high PAPR waveforms. This APT mode is generally accomplished by disabling the linear amplifier of a hybrid modulator and running only the switcher. This then generates a variable voltage fixed DC output with an efficiency of 90 to 95 percent so that the PA runs with the minimum fixed-supply necessary to reproduce the legacy waveform with adequate linearity.

ET PA CHARACTERISTICS

As previously noted, the shaping function plays an important role in determining many key metrics of an ET PA system. To understand why, it is necessary to appreciate some of the fundamental efficiency and linearity characteristics of the PA itself.

A traditional fixed supply is usually considered to be a two port device whose fundamental output characteristics (efficiency, gain, phase, etc.) are a function of only a single input variable, the instantaneous input RF voltage. An ET PA may be considered to be a three port device whose output characteristics are determined by both instantaneous input power and supply voltage. Surface plots are therefore required to properly understand its

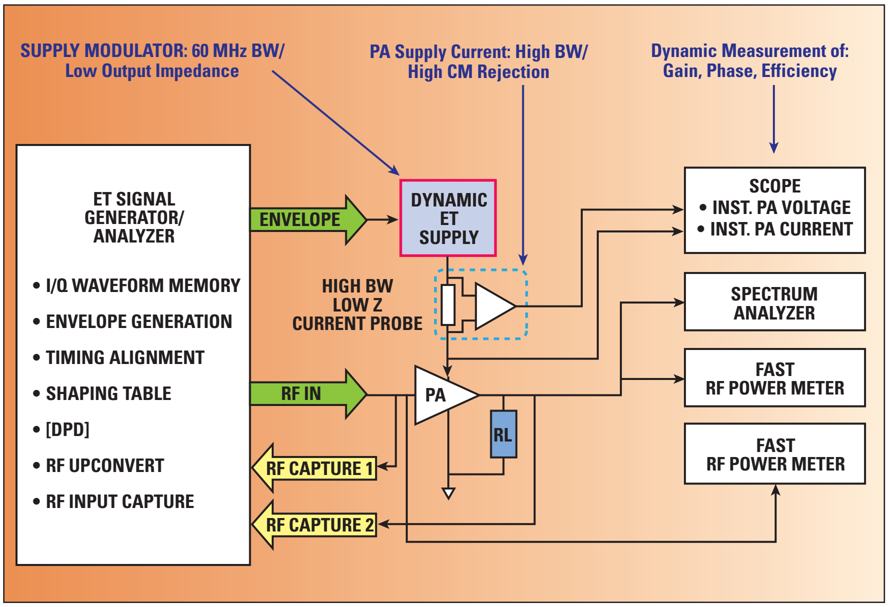


Fig. 7 PA characterization.

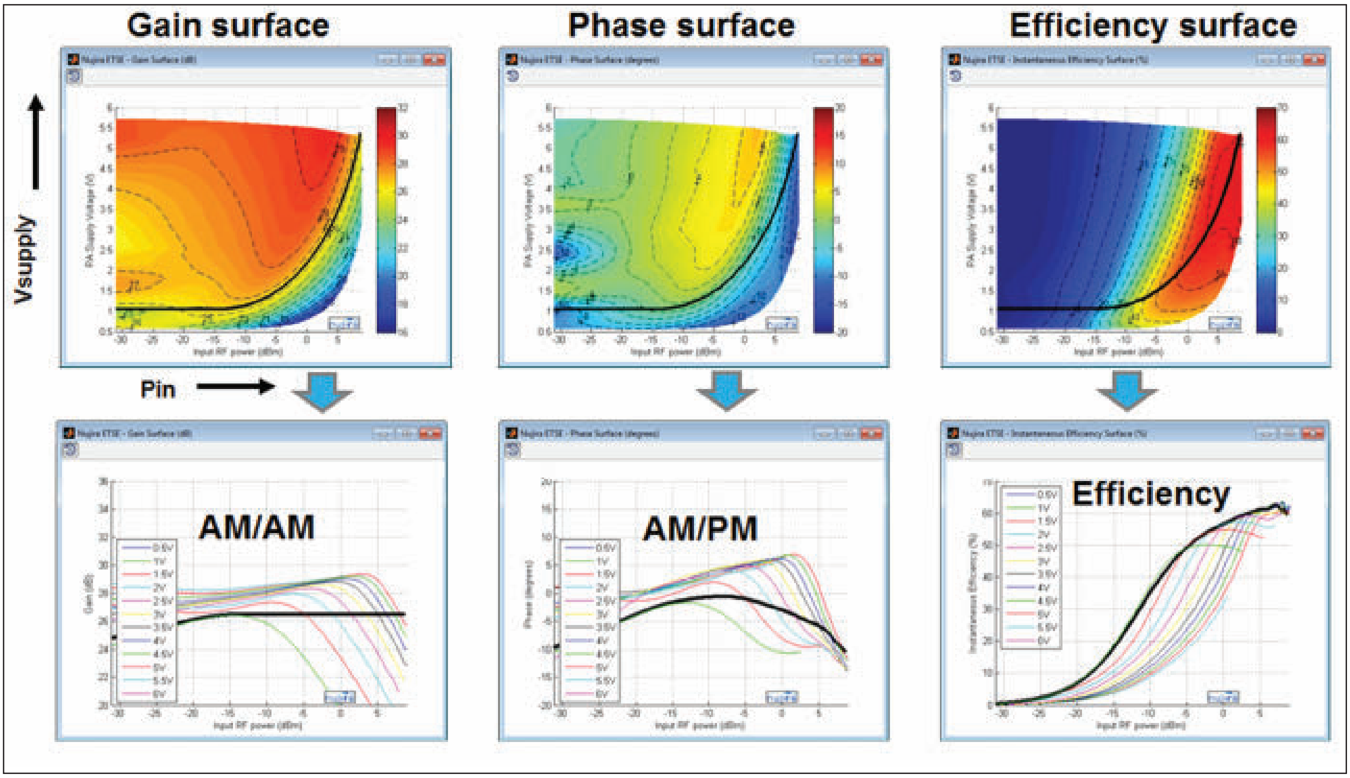


Fig. 8 ET PA characterization and shaping function derivation.

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ET mode behavior. The operating trajectory across the output surfaces is determined by the shaping function, which determines the nonlinear mapping between instantaneous input RF voltage and supply voltage.

Three operating regions may be identified for a typical ET PA as shown in ***Figure 6***. At high instantaneous power, in the compressed region, the PA's output characteristics are determined by the supply voltage. At low instantaneous power, in the linear region, the PA operates as a conventional fixed supply PA and its output characteristics are determined by RF input voltage. In between these, in the transition region, the PA's characteristics depend on both supply voltage and RF input voltage. The choice of shaping function determines the trade-off between the efficiency and compression characteristics of the PA and determines the transition points between operating regions.

Figure 6 illustrates that it is possible to select a shaping function that results in a flat PA gain characteristic (ISOgain), with only a slight impact on its efficiency. Hence ET offers the possibility of a simple method for linearizing the AM characteristics of a PA whilst simultaneously raising its efficiency. The AM-PM characteristics are not directly controllable by the shaping function in the same way, so to fully exploit this linearization benefit, the PA should be designed to show low intrinsic AM-PM.

To determine the ET shaping function, the PA must first be characterized under representative operating conditions. So how can the PA be measured? It might initially be thought that a VNA power sweep to capturing AM-AM and AM-PM data across a range of supply voltages would be adequate. Unfortunately, data captured in this way results in poor ET performance prediction on account of die heating effects due to the slow CW sweep. A better characterization can be achieved using a setup like that shown in ***Figure 7***. The key elements of this setup are an ET signal source which generates time synchronized RF and envelope waveforms, and a dynamic power supply which generates the PA supply voltage. Simultaneous captures of the instantaneous input and output RF power, together with instantaneous supply voltage and supply current, enable the key PA characteristics to be captured under representative operating conditions.

Once this raw data has been captured, it may be post-processed in

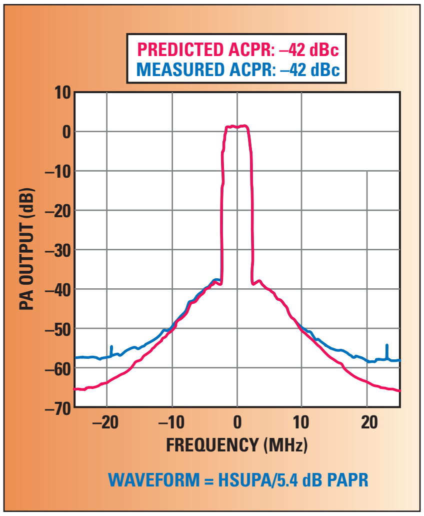
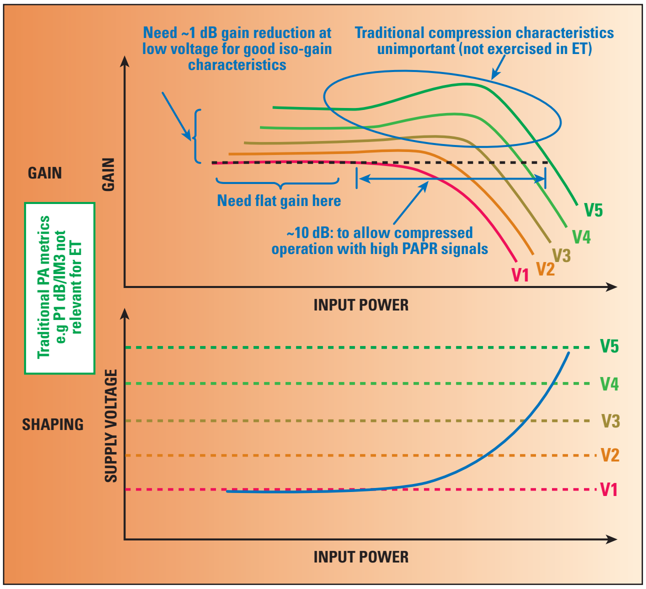


Fig. 9 ET performance prediction from ET PA characteristics.

many ways to examine different aspects of ET PA performance. Three particularly useful surfaces (gain, phase and efficiency) are shown in ***Figure 8***. In these plots, color-mapped contours of constant gain, phase and efficiency are represented by the z direction. The shaping function – the mapping between instantaneous input power and supply voltage – is overlaid as a black line on all three plots. Once this is determined, more familiar 2D plots of the PA's AM-AM, AM-PM and instantaneous efficiency may be derived, as shown in Figure 8.



▲ *Fig. 10 ET PA – ideal characteristics.*

These metrics are useful as they give considerable insight into mechanisms that may be limiting linearity or efficiency performance. Typically, however, PA specifications are defined by system level parameters such as ACPR, EVM and average efficiency. Further post-processing of the instantaneous AM-AM, AM-PM and efficiency data together with knowledge of the target waveform may be used to predict these parameters also. This is shown in ***Figure 9*** which shows a comparison of predicted ACPR based on PA characterization and waveform data, and measured results using the actual waveform.

This begs the question of how a PA should be designed to achieve good ET performance, particularly where the target application cannot support the complexity and power overhead of sophisticated closed loop DPD linearity correction. ***Figure 10*** shows the AM-AM or gain characteristics of an ET optimized PA. To achieve flat gain as shown by the dotted black line, the PA operates in moderate compression at high instantaneous power and gradually comes out of compression as the instantaneous power reduces. It is important that the gain at very low powers and low supply voltage is flat, and that the low supply voltage small signal gain is less than the high supply voltage small signal gain. If this is not the case, the ET PA will exhibit gain recovery at low instantaneous power, resulting in wideband TX distortion due to the high rate of change of signal at low power. It is interesting to note that the PA compression characteristics of a traditional fixed supply PA are of little relevance to an ET PA, as the PA never operates in this region.

ET SYSTEM PERFORMANCE OPTIMIZATION

Murphy's Law for PAs dictates that there is always some trade-off between system efficiency and linearity, hence it usually makes sense to trade linearity for efficiency to just meet the TX linearity target with adequate margin. In high power systems, this can be achieved through use of baseband crest factor reduction (CFR). However, this is computationally intensive, and ET allows a crude form of CFR to be implemented simply by modifying the contents of the shaping table as shown in ***Figure 11***. The level and 'sharpness' of the soft clipping may be used to provide a degree of control over how far from carrier the inevitable distortion products lie. By reducing the PAPR of the PA output signal, this technique enables the PA to operate at high average power, increasing system efficiency.

It has been shown that ET may be used to linearize a PA in addition to improving its efficiency; however, this may necessitate use of a wider supply voltage swing range than is needed to achieve best efficiency from the PA/

supply modulator combination, particularly if the PA has not been well optimized for ET operation. Where this is the case, it can make sense in low and medium power systems to include simple RF pre-correction – a cut-down version of traditional DPD – allowing the minimum supply voltage to be optimized for best efficiency. In this architecture, shown in ***Figure 12***, envelope shaping is used to control AM at high instantaneous powers and RF path pre-correction is used to provide AM correction at low instantaneous powers and PM correction across the entire power range.

CONCLUSION

With the move to networked combat data services driving the demand for higher data rates, envelope tracking satisfies the diverse requirements of next generation military radio transmitters. ET-enabled PAs allow for the use of smaller power sources or longer battery life, together with lower cooling requirements resulting in lighter, smaller radios. They can handle the range of waveform types from legacy voice to high-capacity data, offer broadband RF capability, and have improved linearity and antenna mismatch tolerance. ■

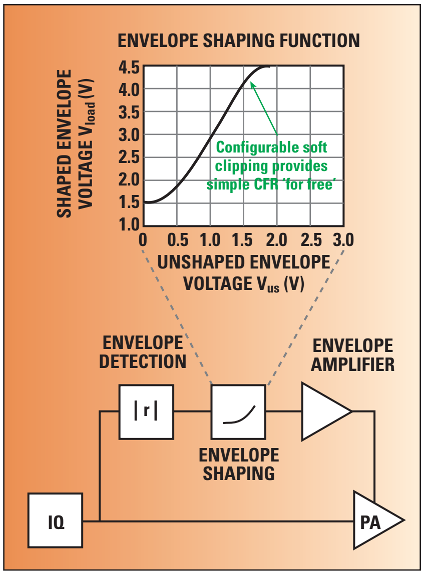


Fig. 11 Shaping table based crest factor reduction.

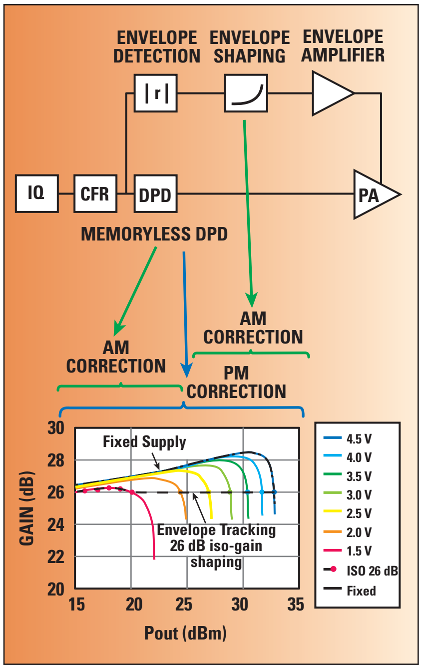


Fig. 12 Combined RF pre-correction + shaping function linearization.

Reference

1. JTNC Newsletter Vol. 1, Issue 1, March 2013.

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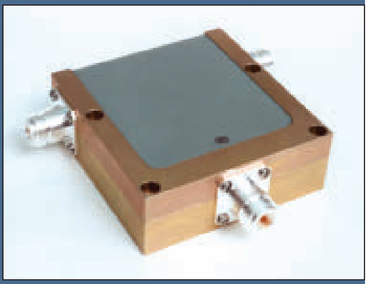

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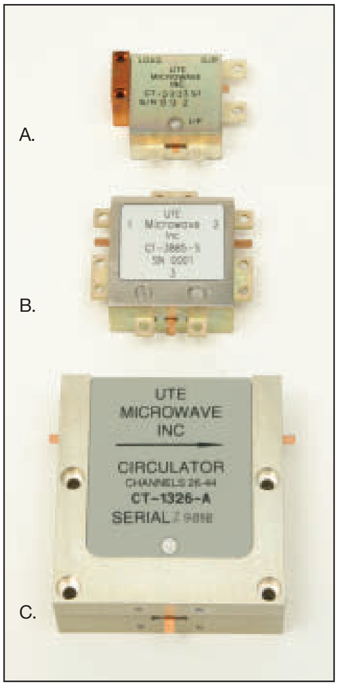

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Receiver Protection in S-Band Radars for Mitigation of 4G Signal Interference

Spectral proximity of 4G communication signals to S-Band radar frequencies can result in the introduction of false target signals into a radar sensor system. Furthermore, the magnitude of 4G communication signal levels (when radiated in the vicinity of a radar) can cause the radar receiver to begin to limit then fully activate the receiver protector, and so cause any synchronous target signal to be lost.

An updated pre-TR limiter receiver protector (RxP) has been designed to tolerate high levels of 4G signal interference, and enables the use of a low-power filter at the RxP output to minimize 4G signals before they enter the radar receiver. This approach has preserved the operational performance characteristics of the legacy pre-TR limiter design, and presents a robust alternative to high-power filtering at the radar antenna.

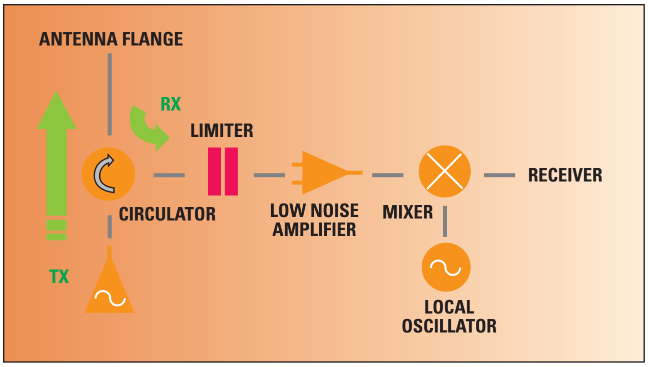

Fig. 1 Surveillance radar transceiver functional schematic.

Allocation of communication frequency bands close to existing radar frequencies[1-3] has seen study of potential interference and disruption effects in surveillance radar systems.[4-7] As the margins between allocated frequency bands narrow, there is a growing demand for precision in the requirements for band-edge filtering of transmitted signals and out-of-band rejection of any extraneous received signal frequencies[1-7] which otherwise threaten the mission reliability of the radar system.

4G interference signals can reach and activate the limiter causing it to compress and attenuate all in-band incoming signals (including target echo returns), as illustrated in the radar system schematic shown in ***Figure 1***. These 4G signals can also pass through the RxP and generate false signal returns or saturate the receiver.

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Amplitude Variation, Narrow Band	±0.5dB across any 50MHz (100MHz to 500MHz) ±0.5dB across any 100MHz (500MHz to 18GHz)		
Phase Variation, Narrow Band	±2° over any 50MHz (100MHz to 500MHz) ±2° over any 100MHz (500MHz to 18GHz)		
Phase Resolution	0.8° max.		
Return Loss (Input / Output)	10dB min.		
Input Power, Operating Max.	+7dBm		
RF Input Power (CW) Damage Threshold	+30dBm CW max.		
Control Type - Frequency Control Setting (Optional) - Phase Shift Setting - Attenuator Setting	 8-Bit TTL for 100MHz Bands & More Accuracy 9-Bit TTL 8-Bit TTL		
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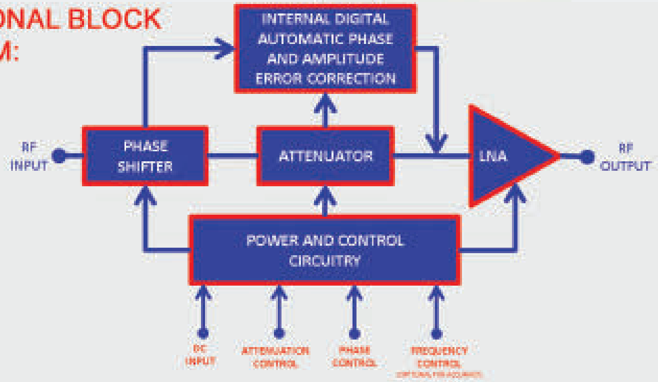

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IF FILTERING OF 4G SIGNALS

Radar receivers generally incorporate filtering within the IF stages; however, it may not be practical to reduce the impact of 4G interference by introducing narrowband filtering at this point because the desired signal and all interfering signals must pass through the receiver protector into the low-noise microwave amplifier (LNA) and frequency converting mixer before reaching the IF amplifier. Consequently this "downstream" IF filtering approach can lead to:

- Limiter compression and impeded target signal reception due to the attenuation from the receiver protector
- Harmonic generation from the 4G signal; saturation and potential damage of the LNA
- In- (radar) band products of the mixing process; third-order intermodulation can generate products at frequencies up to 2.81 GHz from base station signals in the 2.6 GHz 4G communications band
- Saturation of the IF amplifier leading to missed and erroneous target returns.

RF INPUT FILTERING OF 4G SIGNALS

The solution of filtering the received signal before the receiver protector and gain stages[8,9] relies on a filter capable of handling the high-level antenna reflection signals and potential high-power fault conditions and having a sufficient number of high-Q elements to attenuate the 4G signals.

With this "up-stream" approach, incoming RF power levels could exceed the filter's electric field rating and cause internal arcing, leading to long-term filter degradation – this is especially a problem when the system is specified to operate at high altitude without waveguide pressurization.

Alternatively, a power-compliant filter design can prove excessively large in size, leading to accommodation issues with a retro-fit filter installation.

MODIFICATION OF THE RECEIVER PROTECTOR

Receiver LNAs have been optimized to operate in radar receivers close to 4G communication signal bands.[10] It is also feasible to enhance the behavior and operation of the duplexer and receiver protector to mitigate any signal interference, and avoid further modification of the receiver LNA.

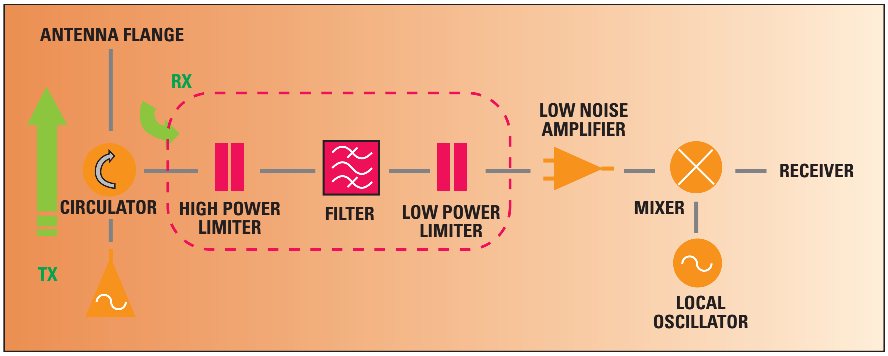

Fig. 2 Functional concept for a 4G-resilient surveillance radar transceiver.

An updated receiver protector design is presented for S-Band (2.8 GHz) applications, which accommodates a higher input compression level to mitigate attenuation in the radar receive chain from the ingress of 4G signals. This updated RxP was designed for use with a low-power filter and secondary low-power limiter (included in front of the receiver LNA) to allow reliable filtering of 4G interference signals and maintain robust protection of the LNA as shown in ***Figure 2***.

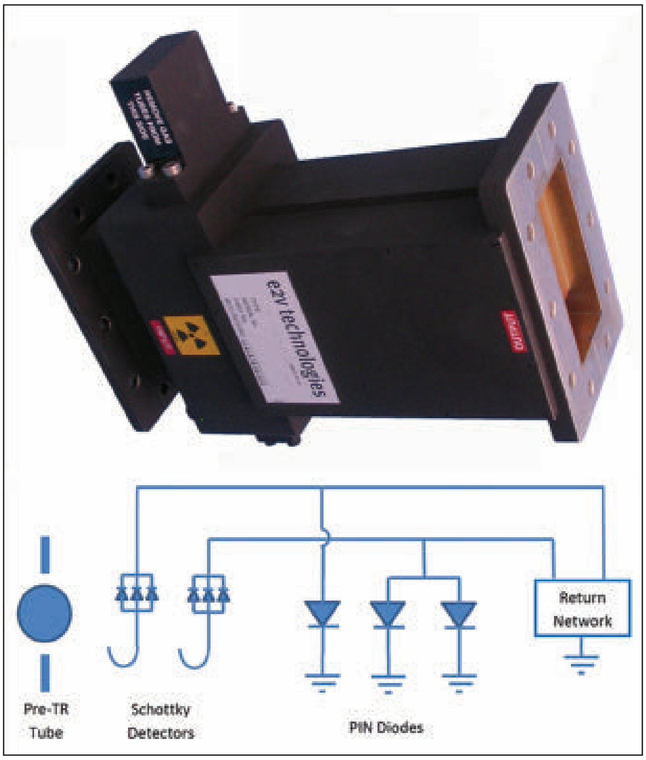

Fig. 3 General arrangement of a legacy S-Band pre-TR limiter receiver protector.

4G signals within the frequency bands 2.5 to 2.69 and 3.4 to 3.6 GHz, at +23 dBm peak power, can be incident on an S-Band radar limiter receiver protector.[12] The existing pre-TR limiter design (see ***Figure 3***) did not meet this interference specification owing to too low a compression point: the limiter was therefore redesigned to increase its compression threshold, and to replace the pre-TR gas cell filling with a non-radioactive fill.[11] The limiter redesign approach was to conserve the fit, form and function of the original unit, whilst optimizing the PIN diode arrangement for higher compression operation.

UPDATED RECEIVER PROTECTOR DESIGN

Modifications were made in the waveguide structure and PIN diode configuration of the limiter design:

- PIN diodes with a thicker I-region and reduced sensitivity that therefore require a higher level of incident RF before limiting starts
- Modification of the return DC current path, to impede the flow of the self-generated current sufficiently to raise the limiting power value
- Modification of the tuning structure to reduce the level of coupling, reducing the power present at the PIN diode for a given power level, and improving operational reliability under high-power conditions.

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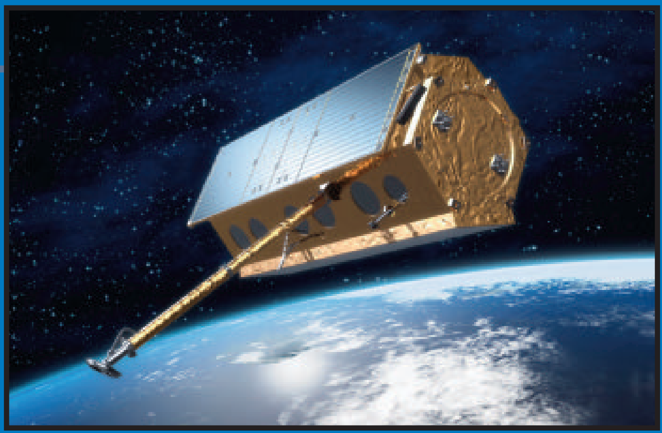

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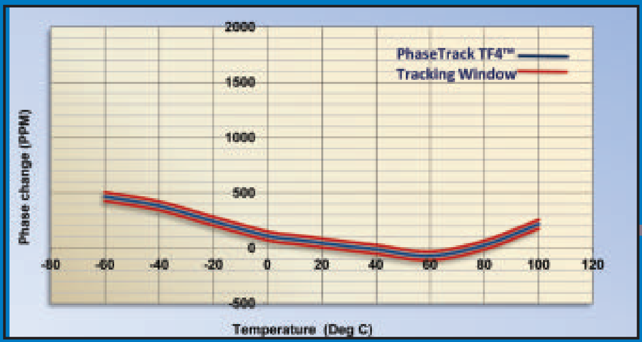

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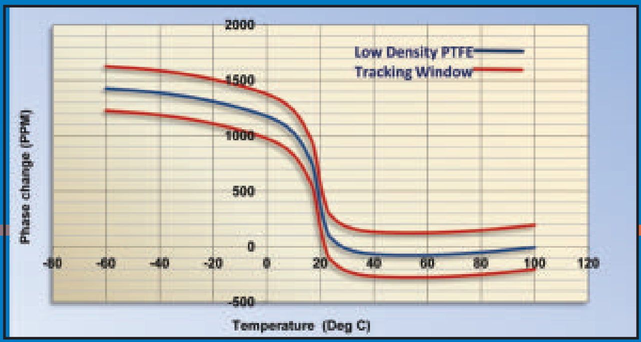

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The present unit (in Figure 3) had a pre-TR mount located at the input to protect the limiter section diode from higher, potentially damaging levels of incident RF power (typically > few hundred watts). Routinely a non-radioactive device solution is preferred in new and upgraded radar installations.

The use of the radioactive gas (tritium, H_3) within the pre-TR tube improved the pre-TR performance by enhancing the avalanche breakdown process with the onset of a high-power RF input level, assisting the formation of a plasma discharge in the gas tube. With the tritium removed, the statistical time period to activate the pre-TR tube therefore increases, and can expose the solid-state limiter section to higher incident power levels for longer periods.

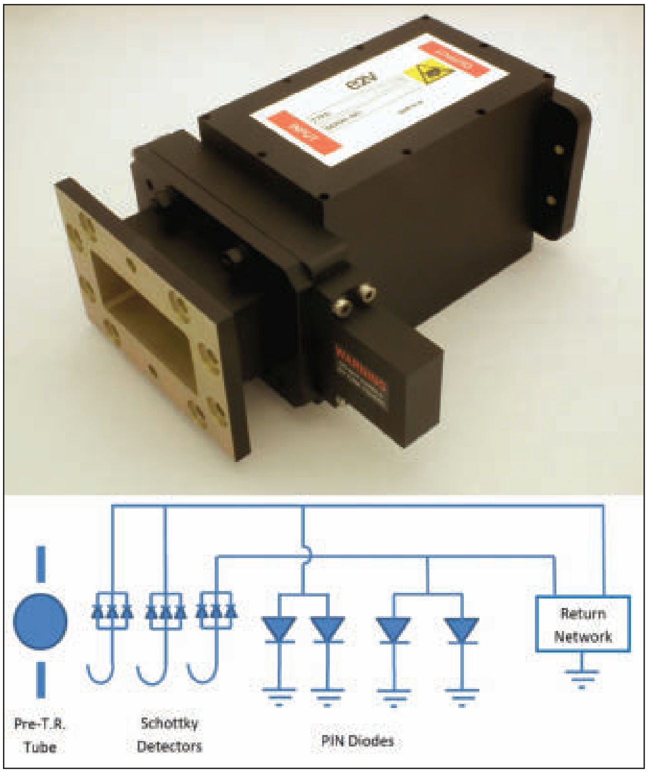

Fig. 4 General arrangement of an updated S-Band pre-TR limiter receiver protector.

The updated limiter design therefore had a dual PIN diode stage incorporated into the input: this arrangement offered increased power handling capability (with minimal insertion loss increase) for robust limiter operation in conjunction with a non-radioactive pre-TR input stage. Increased power handling of the input diode stage was augmented with a more robust detector (a Schottky diode assembly lightly coupled into the input waveguide that outputs a DC bias current to the PIN diodes). This updated pre-TR limiter design is shown in ***Figure 4***.

RECEIVER PROTECTOR PERFORMANCE

The specification for the updated limiter was identical to that of its legacy predecessor with the following modifications:

- Addition of the requirement for the limiter to function unimpeded by the presence of the close proximity of the new 4G signal bands
- Change to the flat and spike leakage power levels (1 and 6 W increased to 10 and 100 W, respectively).

The small-signal test results are very similar to the existing device, achieving an insertion loss better than 0.4 dB and return loss of 20 dB (VSWR approximately 1.25:1) over 2.75 to 3.05 GHz at 20°C. Similarly, the biased attenuation performance of the limiter was retained at > 60 dB over the operating frequency band.

Flat and spike leakage were measured up to a peak input power of 5 kW; the pulse rise-time of the test equipment was typically 20 ns, in line with typical transmitter system specification requirements. The flat leakage maximum was just over 1 W, and the curves shown in ***Figure 5*** have no indication that the flat leakage level would rise rapidly at power levels beyond a 5 kW peak incident power level. At this 5 kW incident power level, the pre-TR gas tubes had fired and the level of leakage will typically remain

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SKY12210-478LF	SPDT Switch	900-4000 MHz; 100 W; 0.4 dB IL; 44 dB Isolation
SKY13286-359LF	SPDT Switch	100-6000 MHz; 1 W; 0.8 dB IL; 62 dB Isolation
SKY73134-11	PLL Frequency Synthesizer	350–6000 MHz; Integer-N; Divide by 1, 2, 3, 4, 8
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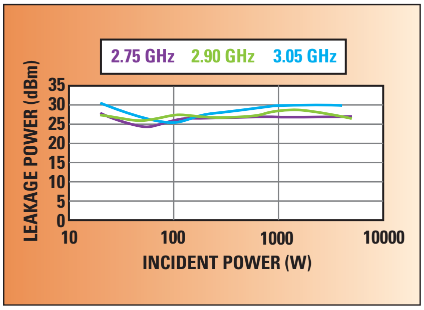
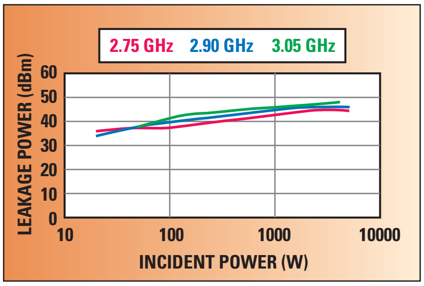


▲ *Fig. 5 Flat leakage performance – updated S-Band pre-TR limiter.*

constant for a wide range of increasing incident power levels. The spike leakage maximum measured was 48 dBm (> 60 W) and the curves shown in ***Figure 6*** indicate that the increase in the spike leakage to be leveling-off at the 5 kW incident power level. The spike leakage pulse was typically 10 ns wide at the –3 dB point: for a 48 dBm peak leakage level this equated to a maximum spike leakage energy of ~600 nJ per pulse.

The minimum power level at which the device compressed by 0.2 dB was 16.5 dBm, a 21 dB improvement over the legacy device design. Typical 4G input signal levels into a surveillance radar are dependent on a number of factors, not least being local proximity of a 4G antenna. For a close-in base station, a nominal value for 4G peak power levels incident on the receiver protector could be +13 dBm mean power, with a ~10 percent probability of peak power spikes at +10 dB above this within a 7 µs period.[12]



▲ *Fig. 6 Spike leakage performance – updated S-Band pre-TR limiter.*

These spikes of peak power can be sufficient to cause cone breakdown in legacy TR Cell equipment, leading to high-attenuation states with significant recovery periods. The full effect of charge generation in the high-power diodes of the proposed high power limiter is under further investigation, specifically the 'pre-energizing' and 're-energizing' effect on the solid-state limiter PIN diode stages owing to 'pumping' from close-range 4G interference signals where this may slow the rate of RxP recovery.

The updated, non-radioactive pre-TR gas tube breakdown level demonstrated no change in the breakdown threshold with the legacy (radioactive content) pre-TR tubes. Gas tube breakdown (with the maximum RF pulse width) was between 200 and 400 W: the variation with frequency was due to the position of RF standing wave maxima in relation to the pre-TR tube mount iris. Monitoring the leakage pulse behind the receiver protector unit showed no signs of instability pulse-to-pulse: constant recovery time values and steady leakage pulse amplitudes were consistently measured with no detectable jitter. Comparison between breakdown activations with a 40 and 1 µs pulsewidth gave the expected approximate doubling of the peak power level required to initiate breakdown; nominally the breakdown power at 1 µs being twice the value at 40 µs.

FILTERING AND LIMITING AT LNA INPUT

Existing receiver filter and input protection on the LNA can be used in conjunction with the updated receiver protector. The updated RxP clearly has an elevated compression threshold, requiring the LNA input protection to work harder, and in general this may require an additional low-power limiter at the LNA input.

Previous sections describe the vulnerability (due to RF breakdown under fault conditions) of a bandpass (BP) filter to reflected RF energy. The solution presented here is the integration of a receiver protector at the input to the receiver, a key requirement of the updated receiver protector being that it must not be driven into compression by an incident 4G communications signal.

Unattenuated by the receiver protector, predicted levels of 4G signal power are expected to exceed the dynamic ranges of the receiver LNA typically used in S-Band radars.[12] It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is therefore essential that a BP filter is integrated within the receiver protector assembly. With the threat from damaging levels of reflected RF energy now mitigated by the receiver protector, it becomes possible to design a BP filter which attenuates the 4G signal without needing to consider the contra design requirement of minimizing peaks in field strength; a less-challenging BP filter requirement specification also realizes a cost benefit for the radar system.

A PIN diode receiver protector requires a finite time to react to damaging levels of RF energy. Typically, PIN diodes designed to handle higher levels of RF power tend to be slower to switch from 'through state' to 'limiting state.' During the transition from 'through state' to 'limiting state,' a spike of RF energy will leak through a receiver protector: the energy contained in the spike may be sufficient to damage the LNA input stage. A second, fast reacting, low-power limiter to attenuate residual levels of spike leakage energy may therefore be included at the input to the LNA, as shown in Figure 2.

SYSTEM DESIGN CONSIDERATIONS

High power testing was performed over an incident peak power range up to 5 kW, covering the range of typical incident power levels the device will experience under normal operating conditions. Spike leakage was closer to the specification limit in the updated unit, however, the spike leakage energy remains comparatively low and the spike level measurement is heavily dependent on the incident RF pulse conditions.

More information on the failure mode of downstream modules and components in the radar receiver chain would be needed in order to determine if the leakage should be specified (a) as a peak power level or (b) the energy content per pulse.

An operational assessment of the updated receiver protector in an S-Band surveillance radar system will provide extremely useful information and guidance on the effects of the receiver protector to incoming 4G signals, when tested in the actual operating environment. Assessment of the updated RxP has already demonstrated no loss of performance characteristics when compared with the legacy unit.

The ultimate performance of the receiver protector/filter combination is achieved by integration of the limiter stages with the filter: this leads to providing the full level of fault protection afforded by the high level gas switch, operating at a level well above the received 4G signals, but capable of limiting incoming signals to a level compatible with a high-Q filter design.

Following this limiter-filter arrangement comes the lower-level limiter, providing low leakage levels into the LNA and (due to the preceding filter) only attenuating in the presence of in-band antenna reflections (and unaffected by the filtered-out 4G signals), described in the limiter-filter arrangement shown earlier in Figure 2. Integration of the

filter with the final low-power limiter further reduces the likelihood of any internal breakdown within the filter, since the standing wave position within the waveguide assembly is now well-defined. This alternative arrangement, together with modern LNA offerings with lower noise figures, leads to a receiver solution with a positive effect on the overall noise figure of the receive chain, enabling a measurable improvement in minimum detectable signal levels.

CONCLUSION

The small-signal performance of a legacy radar receiver protector has been reproduced in an updated high power pre-TR limiter design, to be used in conjunction with (i) an output filter and (ii) low-power limiter at the LNA input. This arrangement provides a retrofit solution into S-Band radar systems to mitigate interference effects from 4G communications signals, and avoids the need for a high-power filter at the antenna. ■

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Simplifying Signal Analysis in Modern Radar Tests

The evaluation of direct digital synthesis (DDS)-based radar systems is challenging for traditional signal analysis test techniques. This is especially true when it comes to pulse compression analysis, pulse trend analysis over time and frequency agility verification. The test tools used to simplify the testing of modern radar systems are evolving, like the systems they must test. This article focuses on the evolution of spectrum analyzers from relatively basic instruments used for measuring traditional pulsed signals to the advanced test system architectures required for signal analysis of leading-edge radars.

Sophisticated, next-generation radar systems benefit from advances in digital technology and computational power. The trend is toward the use of DDS to enable powerful wideband waveform generation capabilities and digital signal processing in radar baseband electronics in order to create software-defined radar. When used along with active electronically scanned antenna (AESA) technology, this offers the following potential radar system benefits:

- Frequency agility – the ability to operate over a wide frequency band to account for atmospheric effects, jamming, interference and detection avoidance.
- Waveform agility – the ability to operate pulse compression (PC) techniques such as frequency and phase modulation on pulse (FMOP and PMOP) to improve target resolution.
- Mode agility – the ability to change waveforms and sequences on a pulse-to-pulse basis, including turning PC on and off, changing the pulse repetition interval (PRI) and staggering PRI to avoid range ambiguities.
- Multifunctionality – the ability to operate as a radar, a communications system (radio) and an electronic warfare (EW) asset.
- Rapid technology insertion – the ability to change the function and performance of the radar through software.

The same DDS technology is also appearing in the EW assets used to deceptively jam these radar systems. In addition to evaluating radar performance in a benign environment, the anticipation of DDS-generated radar countermeasures warrants enhanced receiver testing to assess radar system vulnerabilities.

Spectrum analyzers have long been used for analyzing radar signals. To perform even

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basic pulse measurements, however, users must have a thorough knowledge and understanding of the signal parameters and the operation of the spectrum analyzer in order to obtain valid results. With advancements in DDS technology, the pulse characteristics and pulse sequences produced by radar waveform generators and radar test signals are becoming more complex. For the measurement of these waveforms, conventional swept-tuned spectrum analyzers may not be adequate.

BASIC PULSE MEASUREMENTS

The main advantage of a traditional spectrum analyzer is that it can be used to test frequency-dependent power components over a wide dynamic range. Simple measurements, such as checking the symmetry of the pulse spectrum, are useful in verifying radar transmitter operation. An asymmetrical spectrum, for example, can waste power, generate unwanted spurious emissions and degrade overall radar system performance.

When making measurements using a spectrum analyzer, especially on signals with low duty cycles, one must be familiar with the waveform parameters. The proper resolution bandwidth (RBW), span and sweep time must be set to correctly measure the signal under test in order to yield informative results.

Figure 1 shows the swept-tuned architecture of a traditional spectrum analyzer. A signal is filtered and downconverted to an IF frequency by applying various resolution bandwidth (RBW) and video bandwidth (VBW) filters to the signal while the local oscillator is swept across a frequency span. Energy versus frequency is plotted on the display.

Since a pulsed signal is not on at all times, its energy will not completely 'fill' the spectrum on a single sweep. ***Figure 2*** shows the spectral characteristics of a simple pulsed RF radar waveform with a pulse width τ and the pulse repetition interval T; the amplitudes of the spectral lines are determined by the envelope about the center frequency, f_0.

When measuring the frequency spectrum using a spectrum analyzer, it is possible to display the individual spectral lines or the envelope of the pulse spectrum, depending on the instrument settings. To display the spectral lines, the RBW should be set to a value significantly less than the pulse repetition frequency (1/T). The line spacing is equal to the inverse of the pulse period (pulse repetition interval) and is independent of the setting for the sweep time on the analyzer. The amplitude of the spectral lines is also independent of the RBW.

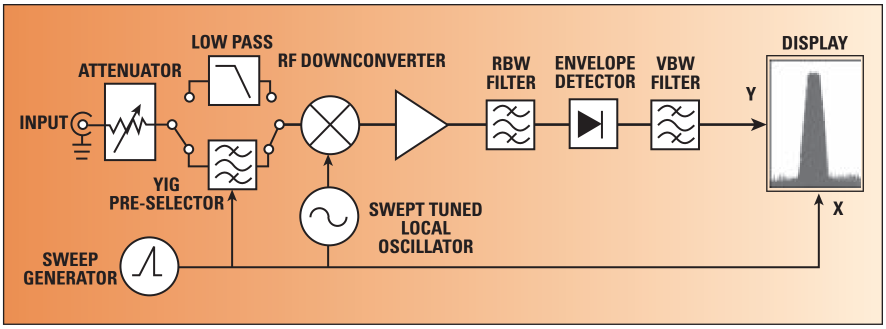

Fig. 1 Traditional swept-tuned spectrum analyzer architecture.

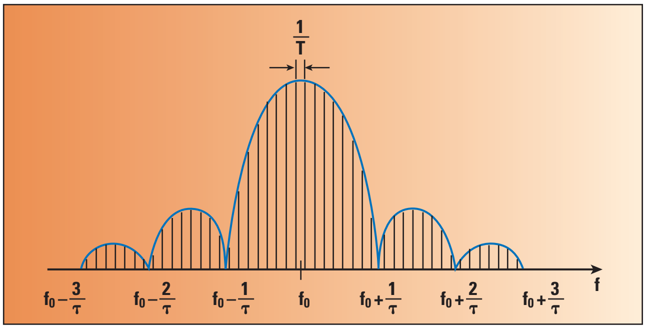

Fig. 2 Typical display of a pulse signal showing pulse width τ and pulse interval T.

While this technique can help characterize a relatively stable, and repetitive pulse signal that does not contain other forms of complex modulation, there are additional challenges for the assessment of DDS-based radar systems that employ more complex and dynamic modes such as frequency agility, variable PRI, pulse compression (modulation inside the pulse), and dynamically variable pulse trains.

In addition, a swept-tuned analyzer typically provides a zero span function or a video output such that an oscilloscope can capture the time-domain signals. The bandwidth of the time-domain signal is constrained, however, by the maximum RBW of the spectrum analyzer. This could be a limitation if the frequency content of the pulse waveform being analyzed exceeds the RBW.

SPECTRUM ANALYZER ARCHITECTURES FOR TESTING RADARS

Analysis of modern radar signals requires a spectrum analyzer architecture that exceeds the limited capabilities the traditional swept-tuned spectrum analyzer. State-of-the-art spectrum analyzers now incorporate fast Fourier transform (FFT) acquisition and vector signal analysis operating modes. This class of spectrum analyzer is also called a signal analyzer. When signal analyzers incorporate run-time sequential processing of FFTs for functions such as persistency display and triggering, they are also known as real-time spectrum analyzers.

A real-time spectrum analyzer includes a dedicated processing function between the analog-to-digital converter (ADC) and the memory to provide sequential processing of incoming sampled data. One of the benefits of sequential processing and real-

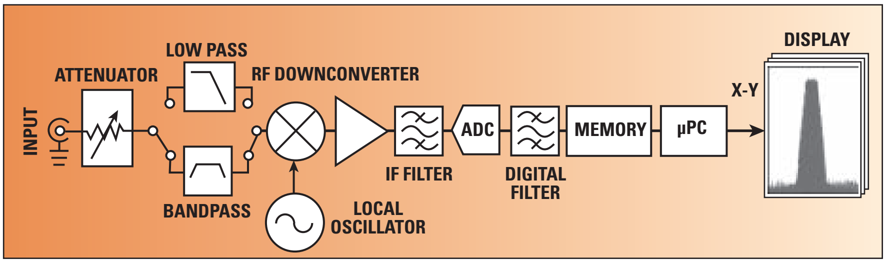

Fig. 3 Vector signal analyzer architecture.

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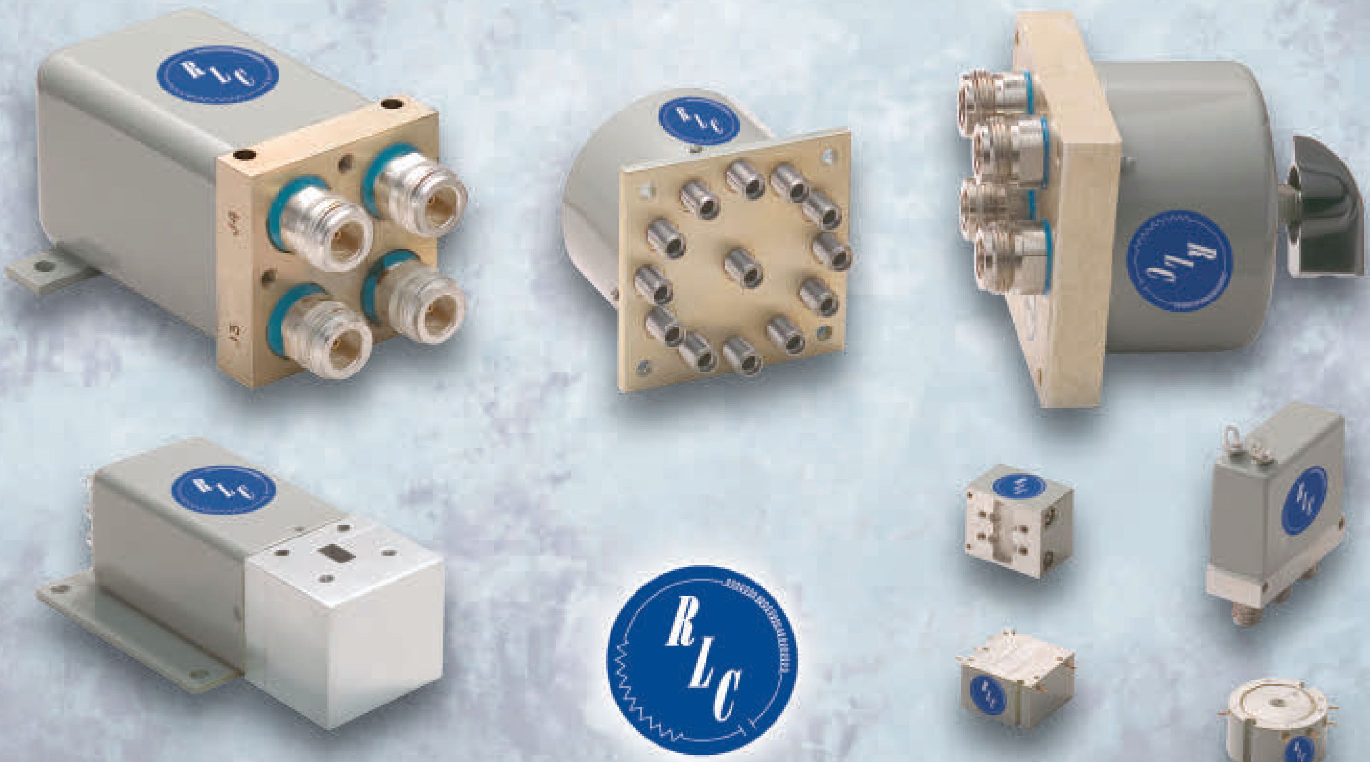

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time display technology is the ability to see very fast events with 100 percent probability of intercept (POI). A figure of merit for a real-time spectrum analyzer is the minimum event duration for 100 percent POI. As the radar pulse compression technique tends to reduce pulse widths below 4 µs, high-performance real-time technology can improve test confidence.

As shown in ***Figure 3***, a vector signal analyzer has a front end similar to that of a traditional swept-tuned spectrum analyzer with filtering and downconversion. Once the signal is downconverted to an intermediate frequency (IF), however, the entire spectrum is digitized by an ADC and placed into memory. The time-sampled data can then be converted through FFT and waveform processing, where the spectrum, time and phase information is extracted and stored for analysis.

Unlike the swept-tuned analyzer, the bandwidth of a vector signal analyzer is not limited by resolution bandwidth, but by its IF bandwidth defined by the ADC, the sampling rate and associated IF filtering. Typical vector signal analyzers have bandwidths ranging from tens to hundreds of MHz. Acquisitions are seamlessly captured into memory, and subsequent FFT processing and analysis can be performed on the acquired signals. The wider IF bandwidth enables analysis of much faster rise/fall times (and narrower pulse widths), wider bandwidth signals (e.g. chirps), and the analysis of frequency-agile radar waveforms across a much wider band.

Figure 4 shows the spectrum of a frequency hopping sequence over a 160 MHz span. There are two displays shown for comparison. The lower display (Frequency Sweep) is what is measured using a traditional swept-tuned spectrum analyzer, with the trace set at Max Hold while the parameters of the sweep are set to 50 kHz RBW and 6.4 ms sweep time. The five hopping frequencies are displayed and there appears to be some level of spurious emission across the band of interest. The upper display (Persistence Spectrum) in Figure 4 is what can be seen using the features of a vector signal analyzer. It shows a color gradient scale based on the accumulated occurrence of the pulse signals. Since the real-time display is based on vector analysis techniques, the entire sequence of the pulse events is captured instantaneously. Observing the difference between the two acquisition techniques, there appears to be a distinctly different spectral shape appearing infrequently in this operating mode on the lowest of the five hopping frequencies.

Because the spectrum of this event is different from that of the other pulses, a frequency mask trigger (FMT) function can be used to isolate the signal (see ***Figure 5***). Once isolated, a spectrogram display shows that this event appears to be faster than the other frequency hops. Shown in the bottom of the spectrogram display in Figure 5 the adjacent event also appears to be ON for a longer period of time than the triggered spectrum event.

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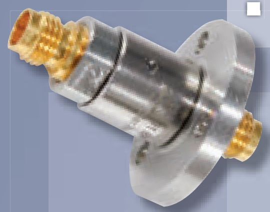

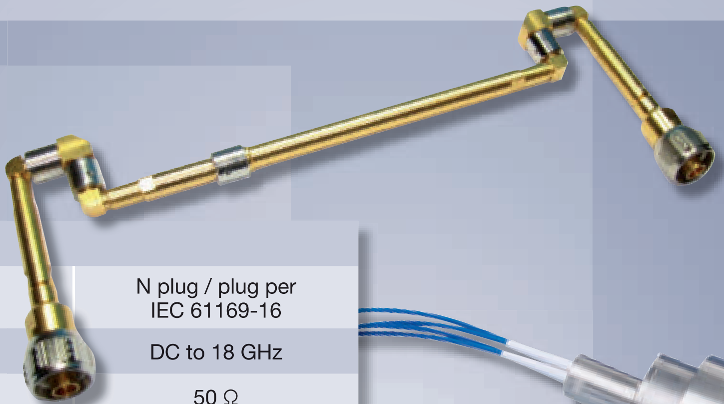

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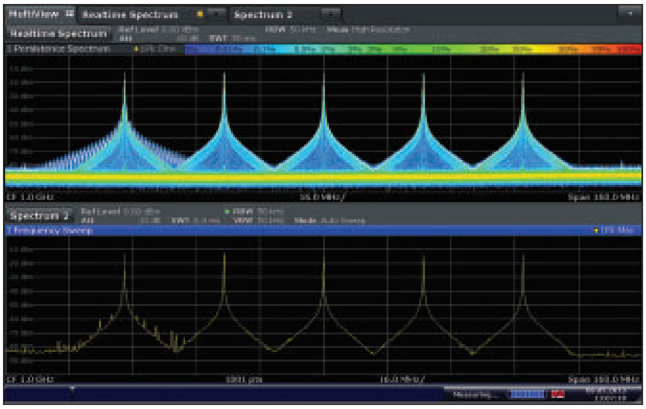

Fig. 4 *The Real-time Spectrum display (top) shows a different spectrum on the lower frequency event, while on the Frequency Sweep display with Max Hold (bottom) it is not as visible.*

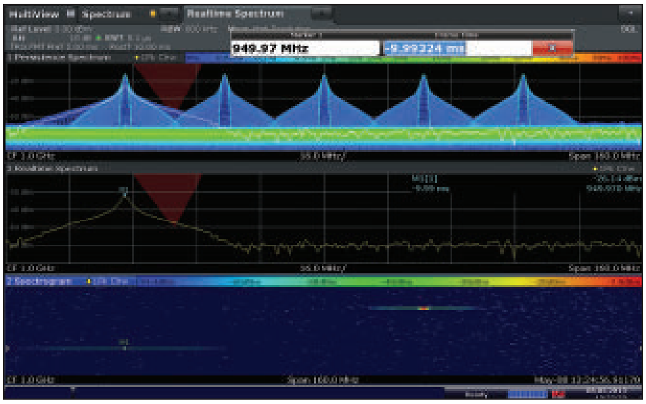

Fig. 5 *Triggering on the spectrum enables event isolation and spectrum vs. time viewing in the spectrogram.*

Fig. 6 *The unique pulse signal can be isolated and analyzed completely using the R&S FSW-K6 pulse measurements option.*

ory, state-of-the-art vector signal analyzers can now provide pulse measurement options to completely analyze the pulses and pulse trend sequences of modern DDS radar signals. For example, the R&S FSW signal and spectrum analyzer with the R&S FSW-K6 pulse measurements software option can be used to analyze over 100,000 pulses with time-correlated views of the spectrum, timing, modulation and statistical properties of the signal. These are useful functions not readily available on traditional swept-tuned spectrum analyzers.

Furthermore, based on the performance of the analyzer and independent time synchronization, important

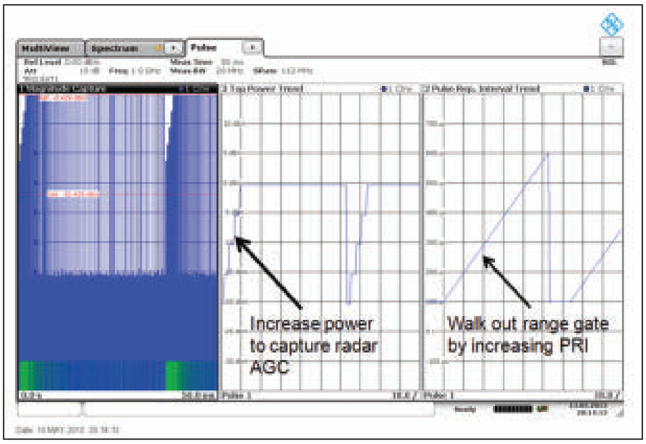

Fig. 7 *RGPO test signal including power trend and PRI trend.*

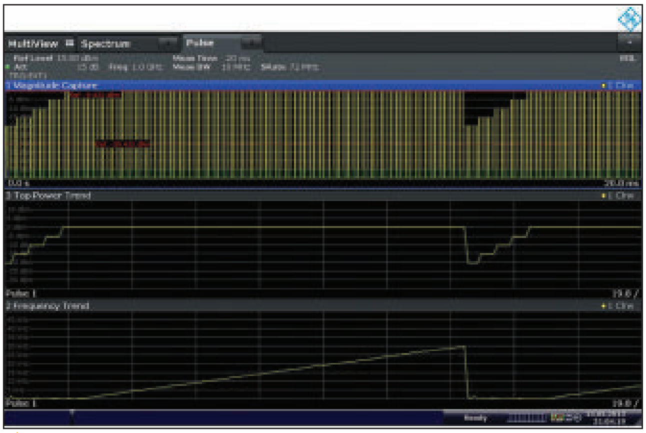

Fig. 8 *VGPO test signal including power trend and frequency trend.*

pulse-to-pulse parameters can be measured. The accuracy of the analysis depends on several of the signal and performance features of the spectrum analyzer: the signal-to-noise ratio of the signal, the signal bandwidth and measurement filters applied, the reference clock jitter, and the phase noise accumulated during the measurement pulse period.

An example of automatic pulse measurement analysis is shown in ***Figure 6***. For this analysis, the pulse width trend, the results table and the pulse information are displayed for several hundred pulses captured over a 250 ms period. The ratio of the signal is 128:1, meaning there are 128 events with a 20 µs pulse width to a single event with a 1.0 µs pulse width as shown in the upper right pulse width trend display. The selected pulse from the results table (the upper right display in Figure 6), selects the pulse waveform of interest to be displayed for the two trace display windows at the bottom of the figure (Pulse Phase and Pulse Frequency). It can now be seen that the demodulated pulse waveform has changed from a pulsed continuous wave signal to a polyphase pulse compressed Barker 13 waveform for the 1 µs pulse period. This dramatically changes the radar's resolution on a repetitive basis, but only for a very short period of time. By utilizing a combination of real-time technology to isolate the signal of interest and pulse measurement analysis of a single pulse, a complex pulse signal is easily characterized.

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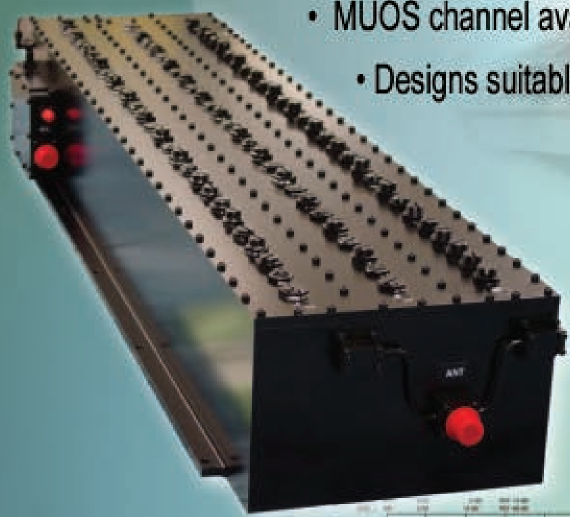

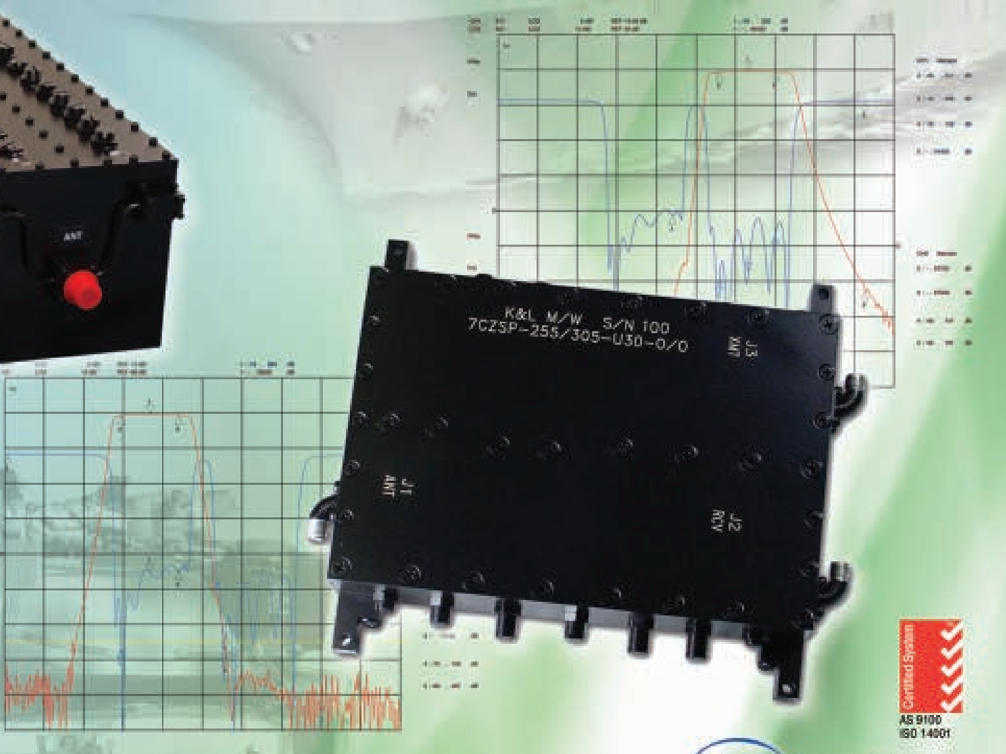

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VALIDATING ELECTRONIC PROTECTION (EP) WAVEFORMS

Traditionally, radars that needed EP required a substantial amount of testing to evaluate their effectiveness against likely deceptive jamming techniques. As new threats evolve, the test profiles for DDS radars must also evolve. It is also important to validate the test signals used to evaluate radar receiver vulnerabilities. Range gate pull-off (RGPO) is a classic deceptive jamming technique where a jammer tries to confuse the radar's range tracking system. As shown in ***Figure 7***, during RGPO the power of a jammer will increase in an attempt to capture the automatic gain control (AGC) of the target radar. Once captured, the jammer will then attempt to push or pull the range gate in time by varying the PRI, forcing the radar to break track with the target.

Pulse compression techniques can be used to reduce the effectiveness of RGPO, since the radar can sense the type of signal being processed in the receiver as a foreign (bogus) return and respond either by ignoring the jammer temporarily or by switching modes and/or frequencies.

One of the more advanced DDS jammer techniques, and potentially much more troublesome for the radar, is digital RF memory (DRFM). DRFM directly captures, modifies and retransmits a response that is much more difficult to detect as a foreign return. DRFM typically modifies the delay or Doppler of the return to attempt to deceive the velocity gate of the target radar system.

Figure 8 shows an example of the velocity gate pull-off (VGPO) deceptive jamming technique, which is similar to the range gate technique. VGPO employs a similar increase in power to capture the radar AGC, and then gradually shifts the frequency of the return such that the velocity tracker system breaks with the target.

As DDS-based radars encounter new EW capabilities and tactics, radar receiver testing will continue to evolve in order to keep pace. Many of these threats are based on a thorough understanding of the radar signals in order to provide realistic target speeds (Doppler walk), for example, to deceive the radar processor. Having the tools to perform trending and timing analysis of various parameters can provide confidence in the test process.

CONCLUSION

Modern radars have evolved and capitalized on the improvements in DSP processing and wideband digital converters. This evolution has dramatically improved the functionality and utility of DDS radars. At the same time, the test methods and tools have had to evolve in order to keep up with the requirements for testing these radars. State-of-the-art spectrum analyzers based on vector signal analysis architectures can provide the building blocks for simplifying the testing of DDS radars. By combining real-time functions and automatic pulse software, the sophisticated new spectrum analyzers are up to the task of simplifying testing and analysis. ■


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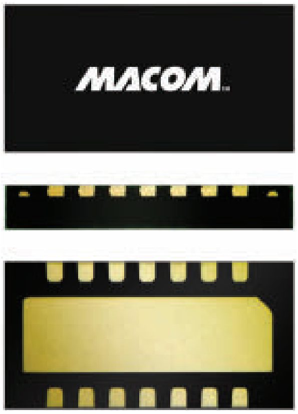

High Power GaN in Plastic Transistors

Radar and communications designers are continuously challenged to strike the optimal balance of size, weight and power profiles for their unique radar system designs, from military applications spanning ground/air surveillance and target tracking, to civilian radar systems including air traffic control and weather observation. The ever exacting performance, reliability and ruggedization requirements associated with this new generation of mobile radar systems are straining the limits of conventional Si- and GaAs-based power transistor components. The challenge facing radar system designers – accommodating higher power with smaller components – is accelerating the pace of innovation in power transistor packaging technology. But with each incremental gain in component power density, the resulting thermal management issues grow increasingly problematic.

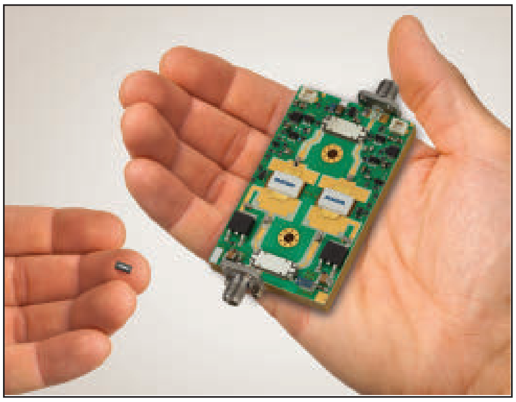

Fig. 1 *Size comparison of plastic vs. ceramic packaging.*

Indentifying these system requirements early, M/A-COM Technology Solutions Inc. (MACOM), introduced its GaN in plastic packaged power transistors for high-performance civilian and military radar and communications systems. The first entries in MACOM's GaN in plastic power transistor product portfolio include 90 W (MAGX-000035-0900P), 50 W (MAGX-000035-05000P) and 15 W (MAGX-000035-01500P) transistors, all of which are available in standard 3 × 6 mm dual-flat no leads (DFN) packaging. The devices can be mounted on PCBs via ground/thermal arrays. Internal stress buffers allow the devices to be reliably operated at up to 200°C channel temperature. The GaN in plastic series also includes a 5 W device in an even smaller SOT-89 package, measuring 2.5 × 4.5 mm. All of these transistors are capable of operating at frequencies up to at least 3.5 GHz. ***Table 1*** shows a

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TABLE I

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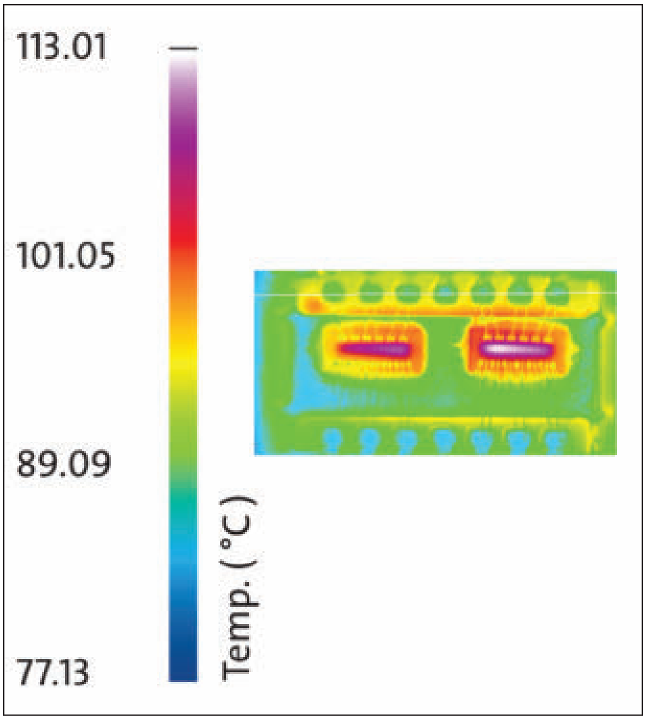
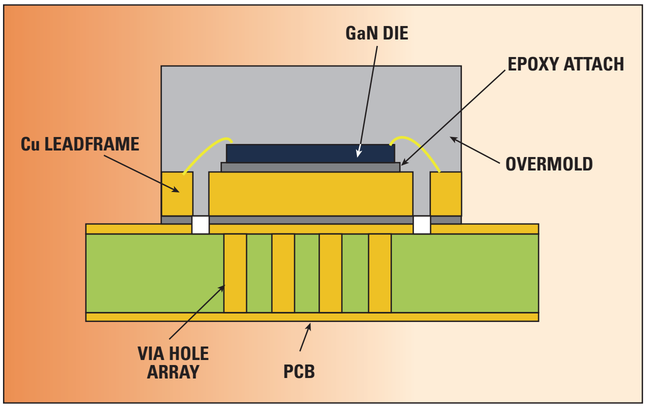
Parameters	Units	MAGX-000035-0900P	MAGX-000035-05000P	MAGX-000035-01500P	MAGX-000040-00500P
Frequency	GHz	DC-3.5	DC-3.5	DC-3.5	DC-4.0
Pout	W	95	50	17	5.3
PAE @ 1 GHz	%	65	65	68	65
Duty	%	10	10	10	10
Gain	dB	17.5	18	19.5	14
Size	mm	3 × 6	3 × 6	3 × 6	SOT-89



▲ *Fig. 2 93 W output power shows 113°C junction temperature.*



▲ *Fig. 3 MACOM's plastic packaging construction.*

summary of the GaN in plastic devices and key performance data.

Scaling to peak pulse power levels of 100 W, MACOM's GaN in plastic transistors exceed the power, size and weight limitations of competing ceramic-packaged offerings to enable a new generation of high performance, ultra compact military and civilian radar systems (see ***Figure 1***). As a result, customers can use these products to provide new capabilities and take advantage of the total system cost reductions associated with size, weight and cooling requirements. MACOM's GaN in plastic builds on the company's 60+ years of packaging innovation, and rich heritage of expert engineer-to-engineer customer support, ensuring that radar system designers are best equipped to harness the highest power in the smallest possible size.

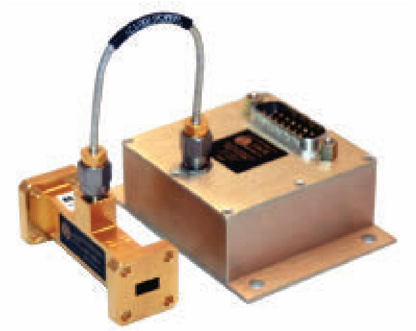
Packaged in miniature 3 × 6 mm DFN and standard small outline transistor (SOT-89) packages, MACOM's GaN in plastic transistors operate at 50 V drain bias resulting in outstanding power density and performance, higher efficiency, and smaller impedance matching circuits due to improved device parasitics. The high voltage operation also benefits overall system design with smaller energy storage capacitors and lower current draw.

To achieve this new standard, MACOM leverages over six decades of radar design experience to pioneer sophisticated, proprietary thermal dissipation techniques to ensure that its GaN in plastic power amplifiers offer comparable reliability to conventional ceramic-packaged GaN-based offerings. MACOM's approach optimizes the transistor die layout and uses advanced heat sinking and die attachment methods. Utilizing some of the most stringent thermal imaging testing methodologies in the industry, the 90 W transistor demonstrates less than 115°C junction temperature (80°C baseplate) for a pulsed power output of 93 W, using a 100 µS pulse, 10 percent duty cycle on standard Rogers board material (see ***Figure 2***).

MACOM's GaN in plastic-based power transistors are also lightweight compared to the existing ceramic-packaged GaN-based offerings. Measured in aggregate across the hundreds of power amplifiers within a typical modern radar system, this can reduce overall system weight considerably. The resulting weight reduction ensures greater ease of movement for mobile radar systems.

MACOM's high performing GaN in space saving plastic enables radar system designers to take full advantage of GaN technology and achieve new levels of power density while reducing system size and weight significantly. Utilizing sophisticated packaging (see ***Figure 3***) and thermal management techniques to maximize design efficiency and component reliability, MACOM is working hand-in-hand with designers to overcome challenging development hurdles and pioneer a new generation of high-performance, rugged radar systems that transcend the capabilities of systems based on conventional GaN in ceramic packages. GaN in plastic test fixtures are available and datasheet are available online.

MACOM,
Chelmsford, MA,
www.macomtech.com/gan.



Ka-Band Digital Attenuator

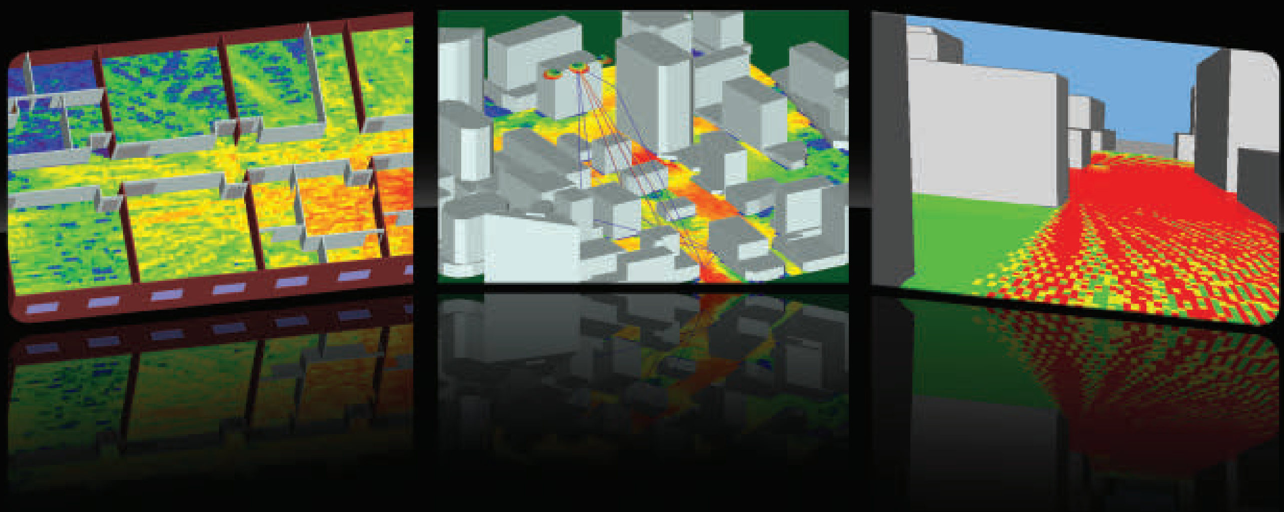
Digitally controlled attenuators are the key components in communication, radar, instrumentation and automatic test systems. Broad bandwidth, high dynamic attenuation range, low insertion loss, high control resolution and fast control speed are key considerations in nearly all applications. SAGE Millimeter has introduced a new line of digitally controlled attenuators offering the best of these parameters in Ka- through W-Band waveguide bands. These attenuators are configured with an analog PIN diode attenuator and a programmable digital driver that provide up to 8 bits of input control.

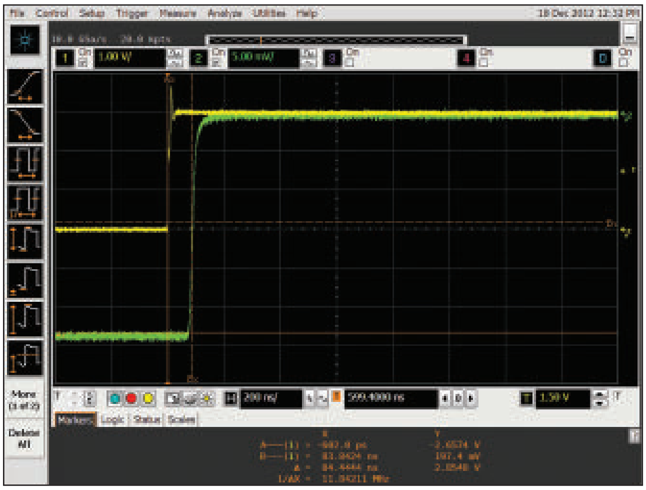
▲ *Fig. 1 Programming board for programming attenuator driver.*

Over the entire Ka-Band frequency range from 26.5 to 40 GHz, the SAGE Millimeter model SKA-2734033040-2828-D1 digitally controlled attenuator offers 3.0 dB insertion loss and 40 dB dynamic range. The attenuation flatness is ±2.0 dB across the band with a CW power handling capability of +23 dBm. The attenuation level is controlled by a digitizing driver which features TTL control with up to 8 bits of resolution. The bias voltage required is ±10 VDC/90 mA. The RF interfaces of the attenuator are with standard WR-28 waveguide with UG599/U flanges. Without the digital driver, the attenuator can be used as an analog attenuator with control voltage from 0 to 5 V DC and current up to 25 mA.

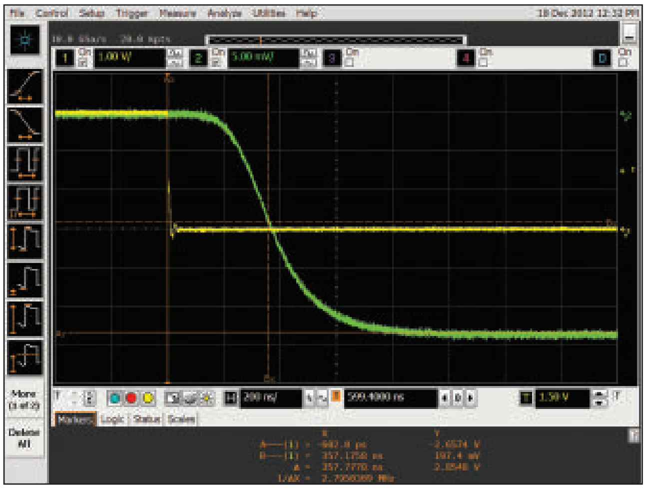
The digital attenuator driver is fully programmable and can be configured to operate with 1 to 8 bits of digital input data for the standard version, and up to 12 bits for custom versions. This allows the driver to be easily configured for different attenuation ranges and resolutions. Switching speed for the driver is under 80 nsec from the digital input to the analog voltage output from the driver. Overall digital-to-RF switching time is dependent upon the specific bias circuit design within the attenuator, but overall switching times under 100 nsec are achievable. The programmable digital driver consists of a digital input buffer that drives a static, non-volatile memory with 12 bit output that drives a high-speed DAC. Internally, the digital input word is sampled every 10 nsec to provide very fast update rates for the driver. A differential current-to-voltage converter transforms the DAC output and provides a single-ended drive to the PIN attenuator. A current-limiting resistor within the

SAGE Millimeter Inc.
Torrance, CA





▲ *Fig. 2 Attenuator switching time to 30 dB attenuation.*



▲ *Fig. 3 Attenuator switching time to low insertion loss state.*

attenuator limits the overall current to the PIN diodes, but the 80 mA output capability of the driver will easily handle wide dynamic range attenuator designs with multiple PIN diodes.

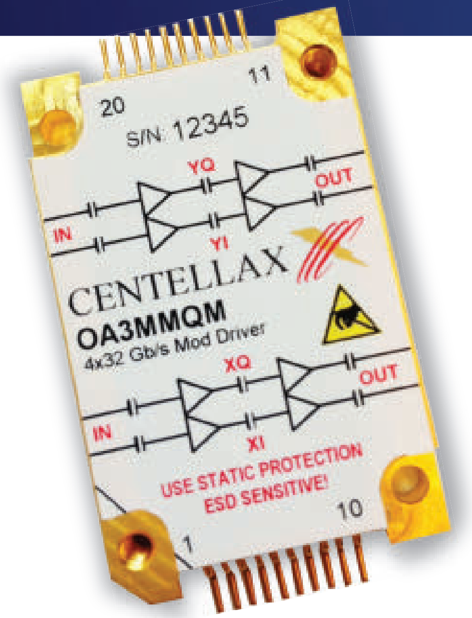
Figure 1 shows the custom developed model SKA-WC-E01-P programming board for programming the attenuator driver. The programming board is a standalone product designed for connecting directly to a programming header inside the driver enclosure, along with a ribbon cable to the driver sub-D connector. Programing the attenuator is a simple procedure that involves measuring the insertion loss of the attenuator on a network analyzer or power meter while dialing the setting knobs for a specific data address and output voltage. The programmer can set the 8 bit digital input word to the driver and then allow the attenuator drive voltage to be set to any desired value with 12 bit resolution. Values are saved in the non-volatile driver memory by simply pressing a STORE button on the programmer. Once the programming is completed, the programmer is removed and the attenuator is ready for remote control or system use.

The featured digitally controlled attenuator was designed to provide over 40 dB of dynamic range with 1 dB attenuation resolution. Only a 6 bit digital input word was required for this resolution; however, due to the 12 bit DAC resolution within the driver, the accuracy of the attenuation could be set to within 0.25 dB of any desired attenuation value. The attenuator exhibits ±0.25 dB attenuation accuracy and a switching time from the low insertion loss state to 30 dB attenuation in 84 nsec, as shown in ***Figure 2***. Conversely, the switching time from 30 dB attenuation to the low insertion loss state was 357 nsec, as shown is ***Figure 3***.

While the featured Ka-Band digitally controlled attenuator is packaged with a separate driver enclosure, an integrated version is available as a custom design. The attenuators are available in frequency bands from Ka- to W-Band under various model numbers.

VENDORVIEW

SAGE Millimeter Inc.,
Torrance, CA
(424) 757-0168,
info@sagemillimeter.com,
www.sagemillimeter.com.



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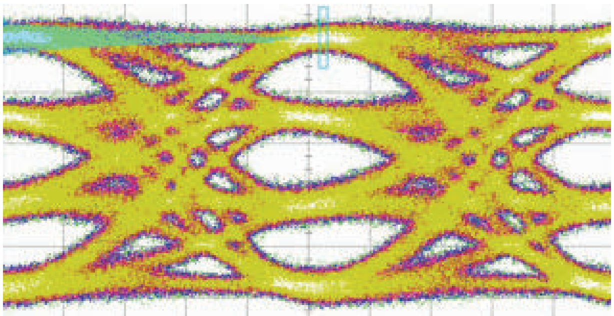

PAM-4 eye

RF Simulators for Next Gen Phased Array Radar

The next generation of phased array radar systems currently being developed by military research laboratories and major defense contractors is expected to eliminate shortcomings in older systems for faster target detection, higher detection sensitivity and clutter mitigation. As a result, this research and development is concurrently driving demand for commercial testing and quality assurance products designed to simulate RF signals as they would appear in the field at varying distances and in more crowded urban environments.

With more sophisticated receivers comes the need to test them during the research and development phase. Although custom one-off testing units are a possibility, the market is beginning to respond with commercial testing devices that simulate an RF signal as it travels and bounces off objects. Renaissance Electronics Corp., a manufacturer of RF and microwave subsystems and components, is now offering a 6 × 6 (REC part number 18A6NAD) and 12 × 12 (REC part number 18A6NAC) matrix with programmable delay lines (PDL) and attenuators designed to simulate RF signals for next generation systems.

The units synthesize both amplitude and phase to replicate a variety of phase array RF signals at different distances. Each of the available inputs can be programmed to synthesize a 30 to 2500 MHz RF signal that is electronically attenuated up to 91 dB in 1 dB steps and to simulate signal propagation and absorption loss, along with delays up to 5 ns to simulate the natural effects of distance. Armed with such RF signal simulators, military research laboratories and defense contractors will be able to move past the "proof of concept" phase and verify the sensitivity and accuracy of the next generation of receivers.

VENDORVIEW

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

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Teledyne Microwave Solutions delivers the most comprehensive Ka-Band Microwave RF solutions.

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Ka-band MIL-BUC & MIL-LNB

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500 Watt Ka-band TWTA

- *Integral BUC*
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Ka-band Compact Outdoor SSPA

- *30-31 GHz*
- *Integral BUC*
- *Passes WGS certification*
- *Exported as EAR-99*

10 Watt Ka-band vBUC

- *8 watts Linear Power*
- *10 lbs*
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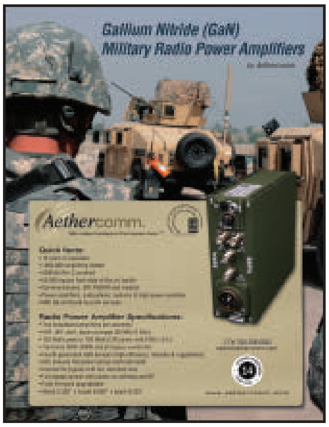


GaN Military Radio PAs Flyer

Aethercomm designs and manufactures sophisticated RF and microwave hardware for the military and commercial electronics marketplace. Aethercomm hardware falls into five product categories: systems, subsystems, RF modules, medical and high power switches. Aethercomm is housed in a new 50,000 square foot facility and are also AS9100 Rev C certified. The company's manufacturing and test capabilities is top in the industry. Aethercomm manufactures typically 30,000 RF products per year with outstanding results.

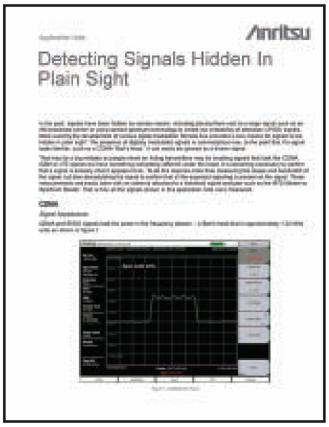
Aethercomm,
www.aethercomm.com.

EW Measurement Application Notes

VENDORVIEW

Agilent's new radar and EW measurement application notes help you keep pace with the latest technology. Get an overview of both the transmitter and receiver sides of the radar block diagram with "Agilent Radar Measurements" and "Agilent Radar, EW & ELINT Testing: Identifying Common Test Challenges." Learn how to build flexible test environments inexpensively in "Creating Realistic Multi-Emitter Signal Scenarios." Order the "Radar Fundamentals" poster for great reference information and the latest products from Agilent.

Agilent Technologies Inc.,
www.agilent.com.

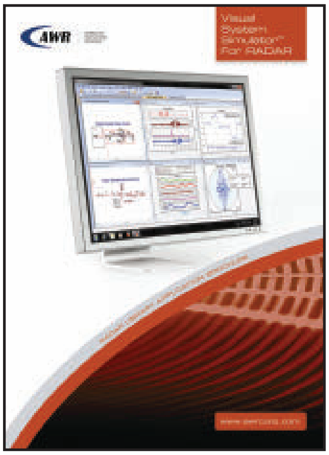


Signals Application Note

VENDORVIEW

In the past, signals have been hidden by various means. Recently signals have been hidden by making them look like an CDMA, GSM, or LTE signal, while they could be something completely different. It is becoming necessary to confirm that a signal is actually what it appears to be. This application note will discuss and provide examples of the importance of not only measuring the shape and bandwidth, but demodulating to confirm the signal type.

Anritsu,
www.anritsu.com.

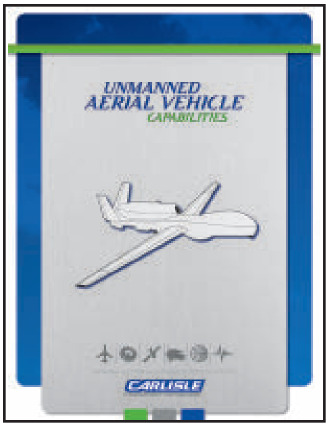


VSS for Radar

VENDORVIEW

The new AWR Visual System Simulator Advanced Radar System Design Brochure details the capabilities of the software for behavioral modeling of radar RF and signal processing systems and 3D antenna patterns derived from synthesis or measurement. VSS Radar offers a wide variety of waveform options, as well as RF modeling, antenna and phased array models, DSP modeling, third-party connected verification solutions and a complete radar design library. Read more about VSS Radar online and download the brochure at www.awrcorp.com/VSS.

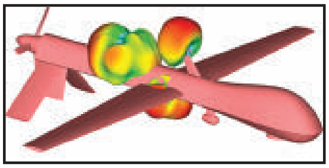
AWR Corp.,
www.awrcorp.com.



Unmanned Aerial Vehicle Capabilities Brochure

When performance matters, Carlisle Interconnect Technologies (CarlisleIT) is a global leader in interconnect solutions for unmanned aerial vehicle (UAV) and unmanned combat air vehicle (UCAV) systems featuring aerospace grade wire; high-speed digital cable, fiber optic cable; high density interconnect solutions; integrated racks and structures; lightweight trays; antenna doublers; RF/microwave cables and connectors; contacts and a complete offering of custom interconnect solutions perfect for limited space and harsh environments to ensure mission success.

Carlisle Interconnect Technologies,
www.carlisleit.com.



EMIT Brochure

VENDORVIEW

Aircraft, ships, land vehicles and satellites have demanding and complex electromagnetic (EM) environments. EMIT, a product of Delcross Technologies distributed worldwide by CST, is a simulation tool that provides rapid identification and root-cause analysis of EMI issues in complex environments. This brochure details the advantages of cosite interference simulation and outlines the features, analysis methods and results views available in EMIT, showcasing how specific causes of interference can be identified. Download the brochure at: www.cst.com/EMIT.

CST-Computer Simulation Technology AG,
www.cst.com.

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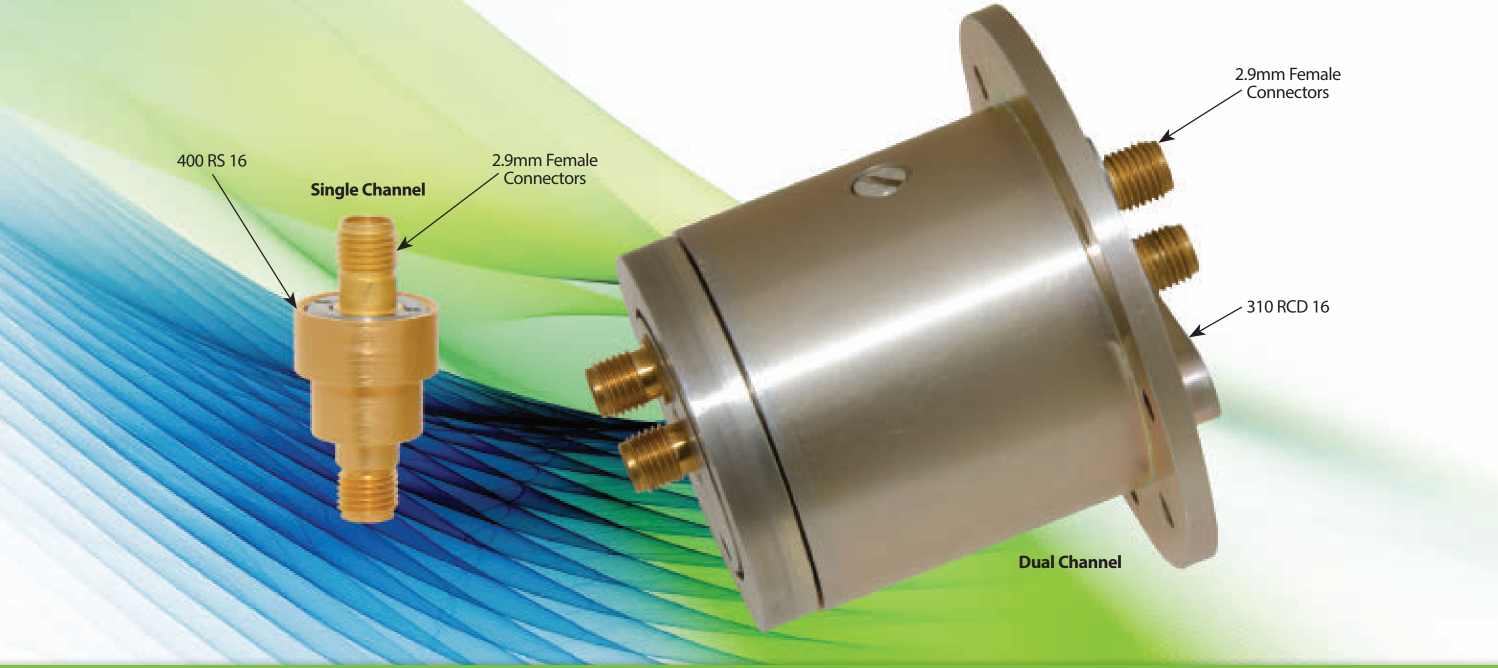

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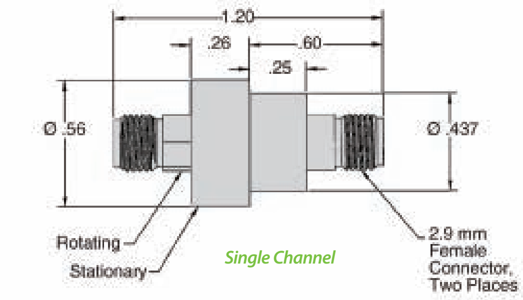
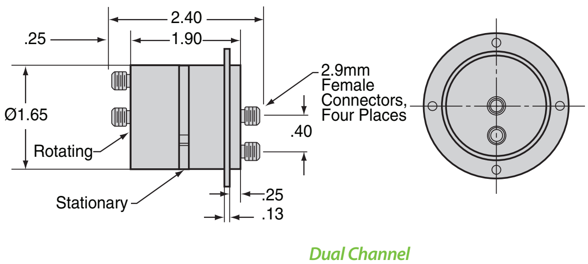


Single Channel



Dual Channel

400 RS 16
SINGLE CHANNEL SPECIFICATIONS:

ELECTRICAL		
FREQUENCY	DC - 18 GHz	
VSWR	DC - 10 GHz	1.20 : 1 MAX.
	10 - 26 GHz	1.35 : 1 MAX.
	26 - 40 GHz	1.75 : 1 MAX.
WOW	1.05 MAX.	
INSERTION LOSS	DC - 10 GHz	0.2 dB MAX.
	10 - 26 GHz	0.4 dB MAX.
	26 - 40 GHz	0.6 dB MAX.
PEAK POWER	Equal to connector rating	

310 RCD 16
DUAL CHANNEL SPECIFICATIONS:

ELECTRICAL	Channel 1	Channel 2
FREQUENCY	7.0 - 22.0 GHz	29.0 - 31.0 GHz
VSWR	1.50:1 MAX.	1.70:1 MAX.
WOW	0.15	0.25
INSERTION LOSS	0.5 dB MAX.	1.0 dB MAX.
ISOLATION	Channel to Channel	50.0 dB MIN.

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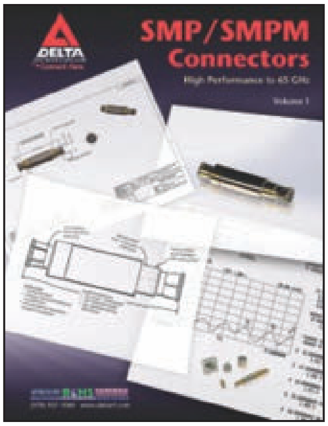
LITERATURE SHOWCASE

Power Amplifiers Catalog

CTT announces a new four-page power amplifiers short form catalog that was introduced at IMS 2013 is Seattle, WA. The catalog features more than 75 models developed for radar, EW and multifunction systems design. The amplifiers feature Narrowband CW, Narrowband Pulsed, Wideband (CW) and Ultra-Wideband (CW) coverage. Frequency coverage is from 0.1 to 18 GHz. CTT's family of solid-state amplifiers are finding applications in many of the next generation of high-performance communications, instrumentation and medical systems where high power is required.

CTT Inc.,
www.cttinc.com.



SMP/SMPM Catalog

Delta Electronics Manufacturing Corp.'s new 24 page SMP/SMPM series catalog details 167 part numbers that span 37 different connector configurations in these two series that operate from: SMP: DC to 40 GHz/SMPM: DC to 65 GHz. These connector interfaces are developed for applications in phased array radar systems, airborne radar, ground radar, shipboard radar and active antennas. The SMP/SMPM series address the High Density Modular packaging requirements of the aerospace, defense, telecom and instrumentation markets.

Delta Electronics Manufacturing Corp.,
www.deltarf.com.

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.,
www.ewtfilters.com.

Cable Assemblies Catalog

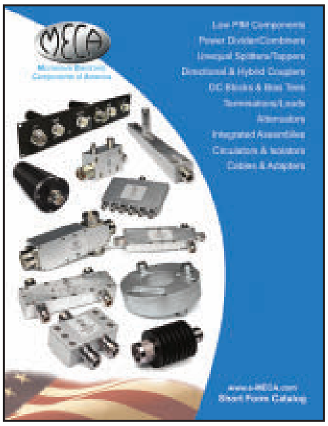
Emerson Network Power Connectivity Solutions has a wide range of cable assemblies suited for RF and microwave signal transmission. Emerson Connectivity Solutions is a vertically integrated supplier of custom, fixed length and semi rigid cable assemblies from DC to 50 GHz. The company can create custom cable assemblies to satisfy your specific application requirements, also with manufacturing in the United States, United Kingdom and China; it has a cable assembly to meet any price requirement.

Emerson Network Power Connectivity Solutions,
www.emersonnetworkpower.com.

RF Portfolio

This 36-page brochure by HUBER+SUHNER offers a clear-cut overview of the company's versatile range of RF cable and connector families. The brochure supplements its comprehensive catalogues, *RF Cables* and *RF Connectors*, which are continuously updated as online versions. The brochures *RF Portfolio*, *RF Connectors* and *RF Cables*, along with another hundred brochures, can be downloaded as e-papers or PDFs from the download section of the website.

HUBER+SUHNER AG,
www.hubersuhner.com.

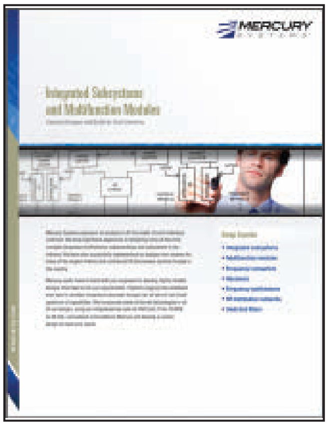


Components Catalog

VENDORVIEW

Celebrating its 52nd anniversary, MECA (Microwave Electronic Components of America) designs and manufactures an array of RF/microwave components with industry leading performance, most recently low PIM products. MECA is recognized worldwide as a primary source of supply for rugged and reliable components to commercial and military OEMs, service providers and installers by only providing products made in the USA. Download the company's components catalog at www.e-meca.com/pdfs/MECA_Short_Catalog2013.pdf.

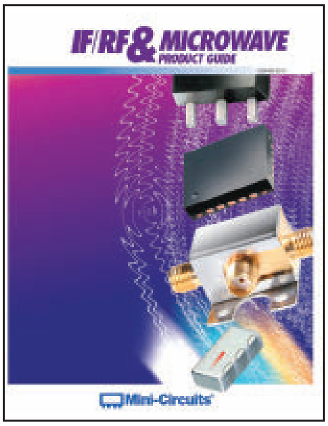
MECA Electronics Inc.,
www.e-MECA.com.



Integrated Subsystems Flyer

Mercury offers a broad spectrum of design, manufacturing and testing services for complex integrated multifunction assemblies and subsystems. Working hand-in-hand with your engineers, the company helps develop highly reliable designs from 10 MHz to 40 GHz for narrowband or broadband. Manufacturing capabilities include vacuum lamination of substrates, surface mount solder assembly, chip and wire assembly, and hermetic sealing. Test capabilities include static and dynamic phase noise measurements and detailed automated test routines to ensure compliance to all of your requirements.

Mercury Systems,
mrcy.com/engineering.



IF/RF & Microwave Product Guide

VENDORVIEW

Mini-Circuits' 24-page IF/RF & Microwave Product Guide provides details on 18 hot new products plus established and custom offerings. Innovative new products include the 10 MHz to 6 GHz CMA high-IP3 MMIC amps, 100 W SYBD 400 MHz to 6 GHz bi-directional couplers with directivity up to 35 dB, and 15 more exciting new products including cables, switches, limiters, transformers and mixers. The guide also features custom products that meet unique application requirements. Custom designs range from 300 W rack-mount base station combiners to three-way active GPS splitters.

Mini-Circuits,
www.minicircuits.com.

RF and Microwave Filters and Assemblies

NIC celebrates 27 years of uninterrupted service to the military and space markets. This catalog features NIC's design and manufacturing capabilities from DC to 40 GHz and showcases a broad range of filter technologies including: LC, crystal, ceramic, cavity, delay equalized and phase matched filters, as well as NIC's integrated assemblies such as: switch filter banks, filter/amplifiers, and phase shifters. NIC is ISO 9001:2008 certified and AS-9100C certified for aerospace applications.

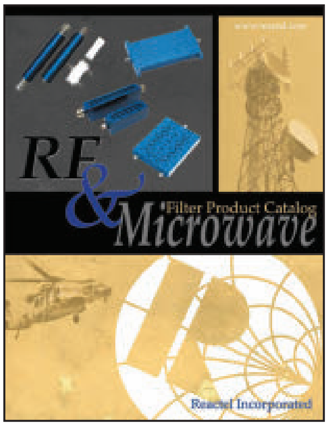
Networks International Corp.,
www.nickc.com.

Overview and Capabilities Brochure

VENDORVIEW

Planar Monolithics Industries (PMI) has released its latest product Overview and Capabilities Brochure. The brochure contains a listing of various RF components and RF module product types up to 40 GHz, including amplifiers, attenuators, phase shifters, detectors, DLVA/SDLVAs, filters, limiters, switches and switch matrices.

Planar Monolithics Industries,
www.pmi-rf.com.

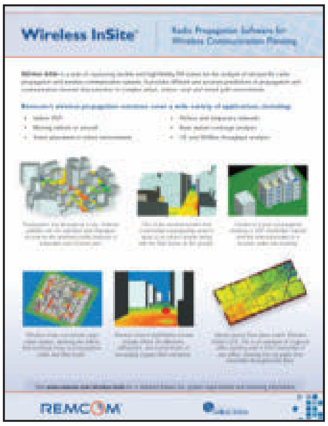


Filters, Multiplexers and Multi-function Assemblies

VENDORVIEW

When being first to react makes all the difference in the world, choose Reactel for your mission-critical filter requirements. This catalog features RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request your copy, please email reactel@reactel.com, or visit www.reactel.com.

Reactel Inc.,
www.reactel.com.



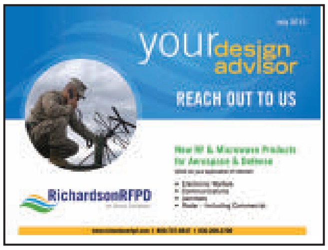
Radio Propagation Software Flyer

VENDORVIEW

Wireless InSite is a suite of ray-tracing models and high-fidelity EM solvers for the analysis of site-specific radio propagation and wireless communication systems. This new wireless propagation application flyer gives a brief tour of some of Wireless InSite's key features and provides a comparison of the models that are included in the standard, real time and professional versions.

Remcom,
www.remcom.com.

LITERATURE SHOWCASE



A&D Selector Guide

VENDORVIEW

Richardson RFPD's July 2013 A&D Selector Guide includes the latest RF and microwave products for electronic warfare, communications, jammers and radar (including commercial) applications. Featuring more than 70 new products from the world's leading suppliers, the Selector Guide is organized by application and frequency bands. It is updated monthly and features links for data sheets and online shopping. You can find it on the Richardson RFPD website, in the new and improved Design Resource Center. Download it at: www.richardson-rfpd.com/AD-SelectorGuide.

Richardson RFPD Inc.,
www.richardsonrfpd.com.

Precision Microwave Components Catalog

RLC Electronics is a leader in the design and manufacture of RF and microwave components. In this catalog, you will find standard RLC products, including coaxial switches and filters up to 65 GHz, as well as power dividers, couplers, attenuators and detectors up to and beyond 40 GHz. As you will see, many of these components are available in surface mount or connectorized packages. RLC can also provide customized designs to meet specific customer requirements not shown in the catalog.

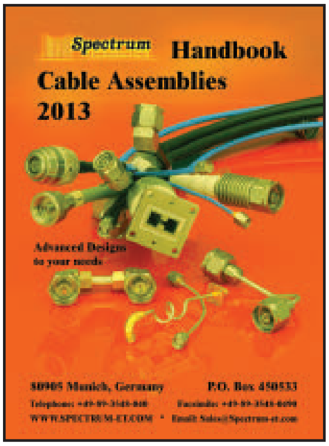
RLC Electronics,
www.rlcelectronics.com.

Value Instruments Catalog

VENDORVIEW

Whatever your job is, you are not always performing complex measurements and do not always need the ultimate high-end T&M equipment. What you need are precise, reliable, universal measuring instruments. That is exactly what you get with value instruments from Rohde & Schwarz: they combine practical features with excellent measurement characteristics; they are easy to use and easy on the budget. Find out more in the Value Instruments Catalog 2013 from Rohde & Schwarz.

Rohde & Schwarz GmbH & Co. KG,
www.rohde-schwarz.com.



Cable Assembly Handbook

Spectrum Elektrotechnik GmbH is issuing a new comprehensive handbook, covering the following products: high performance cable assemblies, operating to 71 GHz; phase matched cable assemblies, showing also phase adjustable connectors to 40 GHz; multipin/multiport cable assemblies; phase king assemblies with limited phase shift over temperature; phase stable assemblies to 26 GHz; push on and quick connection assemblies; assemblies with interchangeable connectors; SpectrumFlex assemblies; commercial cable assemblies; semi rigid cable assemblies; handy form cable assemblies; delay lines; and details on connector outlines.

Spectrum Elektrotechnik GmbH,
www.spectrum-et.com.

ATC Catalog

SPINNER is a reliable supplier of advanced components for radar systems – especially rotary joints. These include the broad field of air traffic control (ATC) radar systems like surface movement radar (SMR), precision approach radar (PAR), air surveillance radar (ASR), en-route radar or Doppler weather radars (DWR). When it comes to application in ATC, all major customers in Europe already trust in SPINNER rotary joints. With this new catalog, the company wants to put a special focus on this market.

SPINNER GmbH,
www.spinner-group.com.

Millimeter Wave Connector Series Catalog

SV Microwave has released a new catalog for its millimeter wave connector series. SV's line has the precision, quality and performance needed for the millimeter wave spectrum through 67 GHz. Products include 2.92 mm, 2.4 mm and 1.85 mm and are available as connectors, terminations, attenuators, cable assemblies and customized solutions. To obtain the new catalog, please visit www.svmicrowave.com/ProductLiterature or email marketing@svmicro.com.

SV Microwave,
www.svmicrowave.com.

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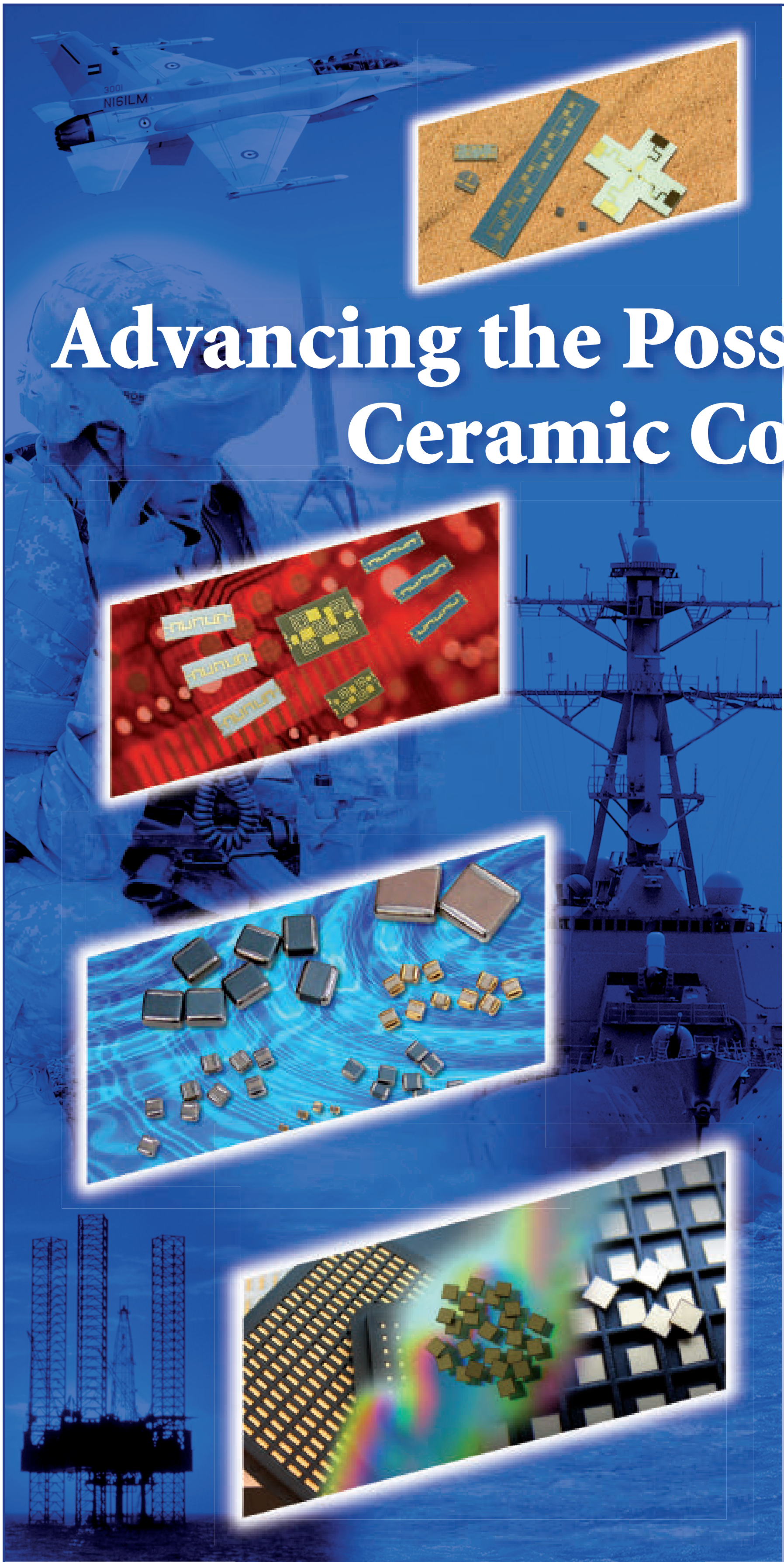

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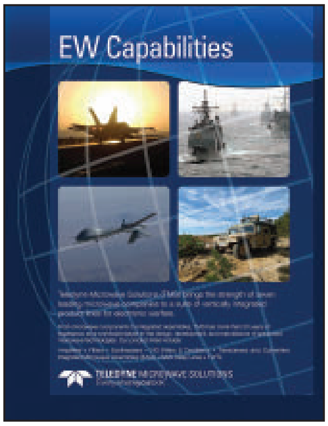

Teledyne Microwave Solutions EW Capabilities Brochure

For more than 50 years, Teledyne Microwave Solutions (TMS) has provided advanced microwave technologies for the demanding requirements of electronic warfare. From components to sub-systems, the company's vertically integrated product lines include the design, development, and manufacture of amplifiers, filters, synthesizers, YIG filters & oscillators, transceivers and converters, integrated microwave assemblies (IMA), BAW delay lines and TWTs. These products are detailed in this brochure, which can be downloaded from the company's website.

Teledyne Microwave Solutions,
www.teledynemicrowave.com.

Harness Capabilities Brochure

The Teledyne Storm Microwave Multi-Channel Microwave Solutions brochure details the company's capabilities in the design and manufacture of both standard and custom multi-channel microwave harness assemblies. The harnesses, found in a wide range of airborne, ground and sea-based military and commercial applications, are backed by Teledyne Storm's more than 30 years of microwave cable design and manufacturing expertise. The brochure includes a case study.

Teledyne Storm Microwave,
www.teledynestorm.com.

Crystal Oscillators Flyer

Ultra low phase noise and excellent spectral purity are the main characteristics provided in Wenzel Associates' Multiplied Crystal Oscillator (MXO) Series of products at fixed frequencies between 200 MHz and 12 GHz, detailed in this flyer. This versatile product line allows the customer to specify the exact frequency needed and select specific options such as phase locking with an external or internal reference, high output level, base oscillator output and multiple outputs along the multiplier string.

Wenzel Associates Inc.,
www.wenzel.com.

2013 Catalog

VENDORVIEW

Werlatone is a leading supplier of high power, broadband RF coaxial components to include (uni, dual, bi) directional couplers, 90° hybrid couplers, RF combiners/dividers and 180° hybrid RF combiners/dividers. The company's Mismatch Tolerant® directional couplers and combiners/dividers are designed to operate continuously, at rated power, into high load VSWR conditions without damage. This new catalog highlights some of its new products as well as several of its most popular designs. Please note that 65 percent of Werlatone's business revolves around custom designs.

Werlatone Inc.,
www.werlatone.com.

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- **Excellent Port-to-Port Isolation**
- **Lowest Loss**
- **Conservative Power Ratings**
- **Small Package Sizes**

In-Phase Combiners/Dividers

Model	Type	Frequency (MHz)	Power (W CW)	Size (Inches)	Insertion Loss (dB)	VSWR	Isolation (dB)
D6233	2-Way	10-1000	25	3.25 x 2 x 1.1	0.75	1.35:1	20
D8632	2-Way	20-1000	50	2.2 x 2.02 x 1.5	0.7	1.40:1	20
D8300	2-Way	20-1000	100	2.45 x 2 x 0.91	0.5	1.35:1	20
D8544W*	2-Way	20-1000	100	2.85 x 2.5 x 1	0.5	1.35:1	18
D8682	2-Way	20-1000	500	5.2 x 2.65 x 1.8	0.6	1.35:1	15
NEW DESIGN!! D9264	2-Way	20-1000	1000	6.5 x 6.25 x 2.25	0.8	1.40:1	18
D7365	4-Way	20-1000	100	5 x 2 x 1	0.75	1.35:1	20
D7439	4-Way	20-1000	250	5 x 5 x 1.5	0.75	1.35:1	18
D8746	4-Way	20-1000	500	7.2 x 3.5 x 1.4	0.7	1.35:1	15
D9048	4-Way	20-1000	500	5 x 4.7 x 1.4	0.6	1.35:1	17
NEW DESIGN!! D9075	4-Way	20-1000	1000	5.7 x 4.7 x 1.75	0.65	1.35:1	15

* "W" references a Watertight Design

Dual Directional Couplers

Model	Coupling (dB)	Frequency (MHz)	Power (W CW)	Size (Inches)	Insertion Loss (dB)	VSWR (ML)	Directivity (dB)
C8858	40	10-1000	250	2.09 x 1.16 x 0.57	0.4	1.30:1	20
C9191	30	20-1000	100	1.76 x 1.16 x 0.565	0.7	1.25:1	20
C8631*	40	20-1000	150	1.5 x 0.95 x 0.5	0.35	1.25:1	20
C8696	40	20-1000	150	1.76 x 1.16 x 0.57	0.35	1.25:1	20
C8686	40	20-1000	500	5.2 x 2.7 x 1.7	0.35	1.25:1	20
NEW DESIGN!! C9107	53	20-1000	1000	4.45 x 2.4 x 1.59	0.4	1.30:1	20

* Non-Connectorized / Tabs

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90° Hybrid Couplers

180° Hybrid Combiners

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