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AESA RADAR

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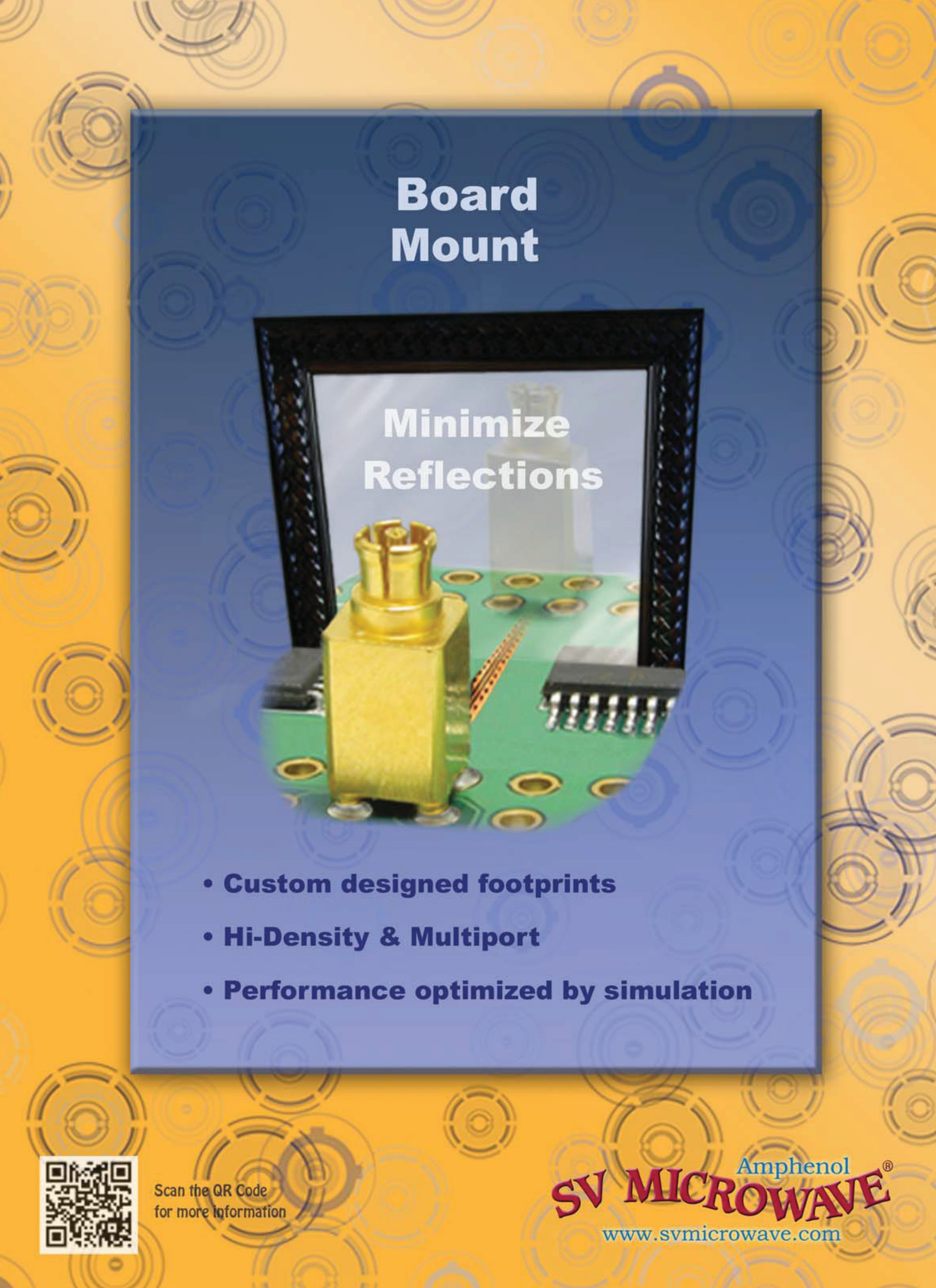
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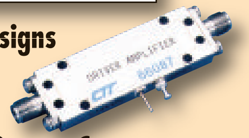

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Evolution of AESA Radar Technology

Active Electronically Steered Array (AESA) X-Band radars are now the baseline in state of the art combat aircraft, progressively displacing legacy Mechanically Steered Arrays (MSA) and Passive Electronically Steered Arrays (PESA) in most new designs and some block upgrades of existing designs. The technology is now penetrating into other areas historically dominated by MSA and PESA technology, including Airborne Early Warning radars, Surface to Air Missile engagement radars, and volume search radars. This trend will continue for a number of very compelling reasons, which will be further explored.

The AESA is not a panacea for all radar applications and imposes a number of unique requirements on supporting hardware, which are lesser or indeed absent, in many legacy radar technologies. These requirements amount to costs in systems integration, which matter to varying degrees across applications. What is abundantly clear is that AESAs will become the dominant technology in many high volume radar applications over the coming years, as the technology matures and manufacturing costs progressively decline. To best appreciate why the AESA has been so successful, it is worth first exploring the evolution of ESAs or "phased arrays."

EVOLUTION OF ELECTRONICALLY STEERED ARRAY RADAR TECHNOLOGY

The first "modern" operational production phased array radars were the German VHF-Band GEMA FuGM41 Mammut or "Hoarding" series of air and sea surveillance radars, deployed during the latter part of the Second World War.[1] These revolutionary radars introduced the idea of electronic or "agile" beam steering, whereby the direction of the antenna main lobe was controlled not by physically pointing the antenna boresight, but by altering the relative phase or delay of the signals passing through elements in an antenna array. Earlier British "Chain Home" radars, decisive during the Battle of Britain, exploited phase relationships between pairs of antenna elements for direction finding, but the Mammuts were the first volume production designs to employ the idea of transmitting and receiving through an array of individual phase or delay controlled elements.[2]

This presented a major advantage, in that the physically large and heavy antenna, necessary for high gain at such long wavelengths, did not have to be mechanically pointed to sweep across a volume of space. Agile beam steering via electronic control of beam direction remains the principal advantage of ESAs over MSAs, as it permits flexible control of beams for tracking individual targets or groups of targets, as well as scan rates over volumes of space. The penalties for designers and maintainers were complexity, volume and weight, compared to MSAs. Until recently, complexity, volume and weight have remained the principal obstacles to wider use of ESA technology. The need for complex feed networks, individual phase or delay control components, and supporting control hardware, is reflected accordingly.

The 1970s saw important advances in ESA technology, with the development of a number of important systems in the United States and the Soviet Union. In all instances, the motivation was the ability to track large numbers of fast targets concurrently, to support missile guidance applications, whether defending against tactical or strategic ballistic missiles, or cruise missiles at low or high altitudes.

In the critical strategic ballistic missile acquisition and tracking role, the 450 MHz Raytheon FPS-115 Pave PAWS[3] and Soviet 150 MHz NIRI 5N15 series Dnestr/Hen House ESA radars were developed and deployed.[4]

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The later Pave PAWS variants delivered an average power of 145.6 kW, and peak power of 582.4 kW, using no less than 1,792 array elements, each rated at 325 W.

The U.S. Army/Raytheon C-Band MPQ-53 Patriot engagement radar and the Soviet X-Band 5N63/30N6 Flap Lid S-300PT/SA-10 Grumble and 9S32 Grill Pan S-300V/SA-12 Giant/Gladiator engagement radars were also PESAs, all developed to engage aircraft, cruise missiles, standoff missiles and tactical ballistic missiles. All three also shared the same design approach, using a passive optical space feed and transmissive primary antenna array of phase shift elements. The Soviet designs used an elaborate monopulse feed horn arrangement, placed behind a lens assembly.[5]

A similar space feed arrangement was adopted in the Soviet X-Band 9S19 Imbir/High Screen ABM acquisition radar, developed for the S-300 V/SA-12 Giant/Gladiator system, and the Janus-faced S-Band NIIIP 5N64/64N6 Big Bird battle management radar developed for the later S-300PM/SA-20A Gargoyle.[6]

Similar operational requirements drove the development of the U.S. Navy's S-Band RCA SPY-1 Aegis PESA radar, with each antenna face comprising 4096 elements, divided into 140 modules, each with 32 elements, and complex feed network of waveguides to distribute transmit and receive signals. The SPY-1A qualified as a hybrid array, with 4352 solid state receivers embedded in each antenna face, and employed eight transmitters for a total of 132 kW peak power per face.[7]

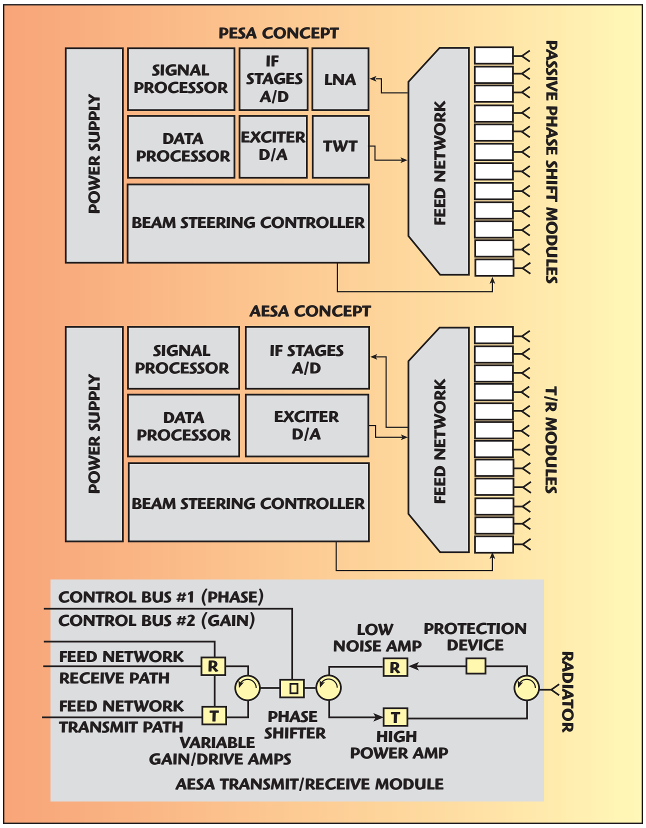
Features shared by this generation of ESA radars were the use of passive transmissive ferrite technology phase shift elements and Travelling Wave Tube (TWT) transmitter stages, often ganged to increase total peak power. Optical space feeds were preferred in weight sensitive applications such as land based missile batteries, unlike the Aegis system and lower band BMD radars, which used feed networks. Variants or derivatives of all these radars remain in operational use and production today.

The 1980s saw a second generation of ESA radars emerge, for airborne applications, leveraging experience gained by designers during the early 1970s. In the United States, Westinghouse developed the X-Band APQ-164 radar for the B-1B Lancer bomber, a PESA design derived from the EAR demonstrator, which shared a single 1,526 element aperture for ground mapping, weapon targeting and automatic terrain following waveforms, with some Low Probability of Intercept (LPI) capabilities. The APQ-64 employed a redundant pair of TWTs, and redundant receiver chains, to match the reliability of the ESA antenna.[8]

It was soon followed in development by the Hughes Ku-Band APQ-181 LPI PESA "covert strike radar," developed for the B-2A Spirit stealth bomber. While the APQ-181 used similar antenna technology to the APQ-164 and provided similar navigation, targeting and automatic terrain following capabilities, an additional and challenging requirement was that the structural mode Radar Cross Section of the antenna face had to be compatible with the "small bird sized" signature of the host aircraft.[9] The APQ-181 demonstrated a critical advantage of ESAs over MSAs, which was compatibility with low observable applications, a key long term driver of demand for AESAs, especially in airborne applications.

While early U.S. effort in airborne ESA radar focused on bomber radars, the first Soviet airborne X-Band PESA was the 1,700 element Tikhomirov NIIP BRLS-8B Zaslon or Flash Dance pulse Doppler air intercept radar, developed for the large MiG-31 Foxhound interceptor. This aircraft had the challenging role of intercepting low flying Boeing AGM-86B cruise missiles, GD BGM-109G Gryphon ground launched and RGM-109 naval cruise missiles. The Zaslon was built to concurrently guide four long range R-33 Amos missiles against low signature targets in ground clutter, and was the first volume production ESA fitted to a fighter aircraft. An interesting feature was that an L-Band IFF interrogator PESA was embedded in the X-Band array.[10]

Like the first generation of surface-based ESAs, features shared by this generation of ESA radars were

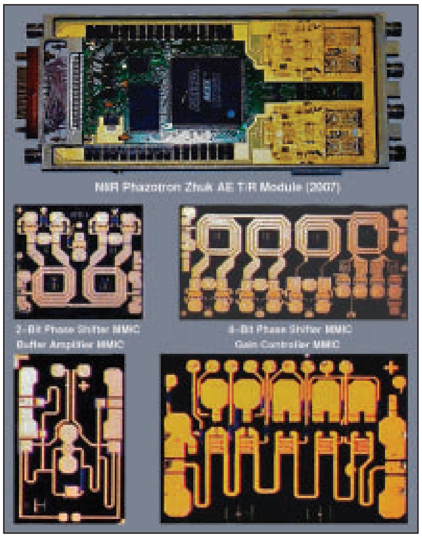


▲ *Fig. 1 Comparison of PESA and AESA designs.*

the use of passive transmissive ferrite technology phase shift elements, and Travelling Wave Tube transmitter stages, but antenna feed networks were employed, typically in stacked row structures. Many ideas first employed in these radars have since been employed in AESAs.

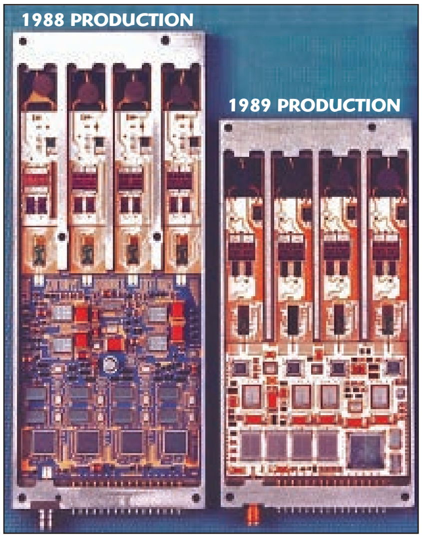
PESA technology continues to be used in a number of new production Russian designs, including the hybrid ESA Tikhomirov NIIP N011M BARS radar in the Su-30MKI/MKM Flanker H fighter, the derivative N035 Irbis E radar in the Su-35S Flanker fighter, the Phazotron Zhuk-MFS/MFSE PESA for the Su-33 Flanker D naval fighter, the Leninets B004 multimode attack radar for the Su-34 Fullback bomber, modelled on the APQ-164, and the NIIP Ryazan GRPZ Pero PESA upgrade package for the N001VE Flanker radars. The Pero is curious insofar as it is a reflective space feed design, with an X-Band horn on a boom placed in front of the array. The technology is also used in the X-Band 9S36 engagement radar developed for the new 9K317 Buk M2/SA-17 Grizzly battlefield air defence missile system.[11]

The 1990s saw a progressive transition in the United States and EU to AESA designs in key applications, with Russia and China now following. While the new AESAs exploited much of the technology previously developed for PESA radars, they introduced fundamentally different transmitter technology. The critical enabler was the maturation of GaAs planar monolithic processes, which permitted the production of power transistors and monolithic phase shifters. GaAs MESFETs with low noise figures (NF) for low power receiver applications were widely available 25 years ago, but AESAs did not become feasible until MMIC technology became mature enough to package the necessary volume of circuitry into Transmit-Receive Module (T/R module) volumes of sizes compatible with critical applications. That point was reached 15 years ago for L-Band and S-Band applications, and a decade ago for more challenging X-Band applications. ***Figure 1*** shows a comparison of PESA and AESA designs, based on typical X-Band airborne radars. Whereas the PESA employs passive phase shift elements, the AESA T/R modules combine multiple MMICs to produce independently controlled receivers, transmitters and beamsteering controls, usually by phase. ***Figure 2*** shows a Phazotron Zhuk AE X-Band Quad Module and MMIC dies, developed in 2006-2007. The Russian industry lags the United States in T/R module design, but can be expected to close the gap rapidly. ***Figure 3*** shows an early United States quad module technology versus current single channel T/R module technology. Single channel modules permit better production yields in comparison with quad modules or multichannel "stick" designs.



▲ *Fig. 2 Phazotron Zhuk AE X-Band quad module and MMIC chips.*

At this time, AESA technology has penetrated into a number of key application areas, encompassing X-Band airborne and fire control radars, early warning and search radars between the VHF-Band and S-Band, and specialised S-Band and X-Band BMD radars. AESAs are appearing both as technology insertion upgrades into established

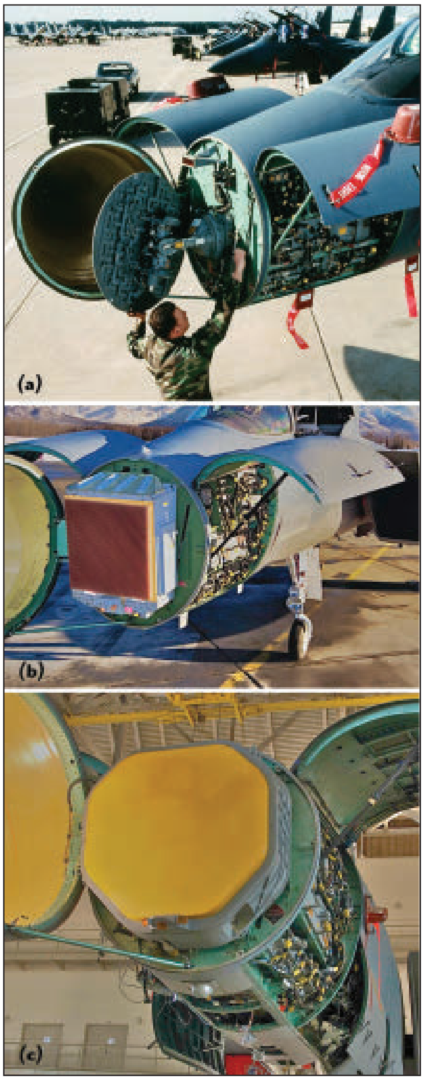


▲ *Fig. 3 Early U.S. developed quad T/R module technology.*

operational radars, but also as entirely new designs displacing legacy radars.

In airborne applications for fighter and bomber aircraft, dominated by X-Band designs, the first volume production AESA was the 1,500 element Westinghouse, now Northrop-Grumman, APG-77 for F-22A Raptor. This radar was the trend setter in technology and is now in its second configuration, the APG-77(V)1 which uses common modules to the smaller 1,200 element APG-81 developed for the F-35.[12]

A parallel development was the 1,100 element Raytheon APG-79, developed initially as a block upgrade to the extant APG-73 in F/A-18E/F Super Hornet, but eventually evolving into a unique design. The T/R module technology developed for the APG-79 was exploited for the subsequent APG-63(V)3 AESA upgrade to the F-15C and APG-82(V)1 AESA radar upgrade for the F-15E. ***Figure 4*** shows the evolution of F-15 X-Band AESA radars. Early F-15 radars employed TWT driven MSA technology, exemplified by the APG (a). Some F-15Cs were later retrofitted with the early APG-63(V)2 AESA, which employed "stick" technology T/R modules (b). The most recent upgrade involves the APG-63(V)3/APG-82 configuration using single element T/R modules, based on the APG-79 design (c). The T/R module technology also migrated into a deep upgrade of the APQ-181 which, in its AESA incarnation, uses a pair of 2,000 X-Band element arrays. Northrop-Grumman concurrently developed the 1,000



▲ *Fig. 4 Evolution of the F-15 X-Band AESA radars.*

element APG-80 as a block upgrade or new build design for the competing F-16 fighter, the APG-80 evolving into the Scalable Agile Beam Radar (SABR) design.[13]

While combat aircraft dominate the U.S. airborne X-Band AESA effort, the AN/ZPY-2 Multi-Platform Radar Technology Insertion Program (MP-RTIP) was launched, specifically to provide a dedicated surveillance imaging and Ground Moving Target Indicator capability, intended for the E-8 JSTARS, E-10 MC2A and RQ/MQ-4 Global Hawk. The MP-RTIP X-Band radar was intended for ISR. ***Figure 5***[14] shows a production RQ-4B Block 40 Global Hawk Remotely Piloted Vehicle, which will carry the MP-RTIP AESA under a ventral radome (a), and a prototype carried by the Scaled Composites Proteus demonstrator (b). AESA technol-

ogy will also be central in the design of the Next Generation Jammer (NGJ) support jamming podset for the EA-18G Growler, intended to use GaN components.[15]

European manufacturers lagged behind the U.S., but now offer several X-Band AESA products, including the Thales AESA RBE2 for the Dassault Rafale fighter, replacing the initial PESA design, the Euroradar Captor-E (ECR-90) for the Typhoon fighter, and the smaller Selex Vixen 500E and 1000E AESA radars, the latter intended for Gripen NG. All designs leveraged experience gain in the collaborative Airborne Multirole Solid State Active Array Radar (AMSAR) program.[16]

Phazotron was the first Russian manufacturer to offer an X-Band AESA with the Zhuk AE for the MiG-35 Fulcrum fighter in 2007, soon followed by the competing Tikhomirov NIIP with a larger AESA for the SU-27/30 Flanker fighter, and the low observable Sukhoi T-50 PAK-FA.[17]

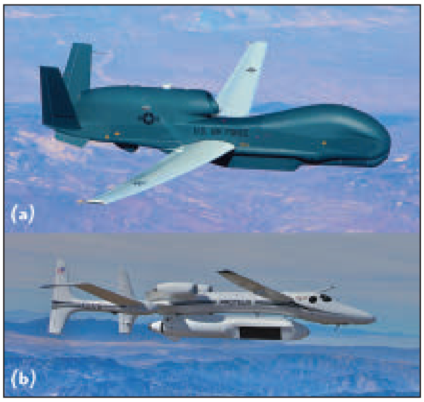


Fig. 5 The MP-RTIP X-Band radar is a scalable design intended for ISR applications.

An interesting parallel development is a Tikhomirov-NIIP L-Band AESA intended for embedding in the leading edges of fighter wings and strakes, providing a dual role IFF and Counter Low Observable capability.[18]

There have been no disclosures of substance on China's X-Band AESA technology, but it is known that the J-10B fighter has a radar bay shape and is sized for an APG-82 class AESA. While fighter applications are predominantly in the X-Band, the Northrop-Grumman AN/ASQ-236 AESA Radar Pod is a Ku-Band design developed specifically for precision ground mapping.[19] While X-Band AESAs for combat aircraft remain numerically dominant, AESAs penetrated into the Airborne Early Warning radar market during the 1990s. Israel's IAI/Elta developed the L-Band EL/M-2075 Phalcon on a Boeing 707-320, later selling the demonstrator to Chile. The technology evolved into the EL/W-2085 radar carried by the G550 airframe and is currently flown by Israel and Singapore.[20]

The same technology was offered unsuccessfully to Australia in 1998 for the Wedgetail requirement, then sold to China, the order later cancelled under pressure from the Clinton Administration. Eventually India procured the system, with a three sided EL/W-2090 L-Band AESA installed inside a fixed radome, carried on a Beriev modified Ilyushin Candid airframe designated the A-50EI.[21] Sweden has been highly successful in exporting its S-Band Erieye family of AEW&C radars, supplied to Swe-

▲ *Fig. 6 Northrop-Grumman MESA radar.*

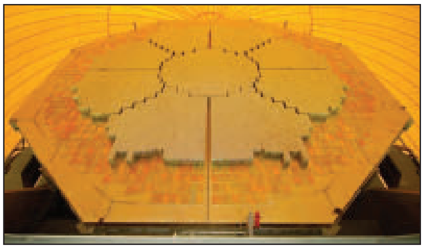
▲ *Fig. 7 AN/TPY-2 THAAD-GBR/FBX-T radar.*

den, Brazil, Greece, Mexico, Pakistan, Thailand and the United Arab Emirates and carried on commuter sized airframes, jet or turboprop.

The only new U.S. AEW&C AESA design is the Northrop-Grumman L-Band Multi-Role Electronically Scanned Array (MESA) system, developed commercially and sold to Australia, Turkey and South Korea on the Boeing 737-600 airframe. ***Figure 6*** shows the Northrop-Grumman MESA radar. Operating in the L-Band, the design combines a pair of side looking arrays, with a cavity endfire array to provide coverage over the nose and tail, in a surfboard shaped "tophat" radome.[22]

The cancellation of the Israeli order led China to initiate the development of the KJ-2000 system, which is modelled on the three sided EL/W-2090 L-Band AESA, and has been supplied to the PLA Air Force, on the Ilyushin Il-76 Candid airframe. The PLA Navy has been procuring the KJ-200, itself modelled on the Swedish Erieye design.[23]

While airborne applications have been the primary target for AESA developers, niche surface based applications are seeing increasing use. One of these is acquisition and fire control radars for missile defense applications. The first of these was the Israeli L-Band Elta EL/M-2080 Green Pine, developed to support the Arrow ABM. It was soon followed by



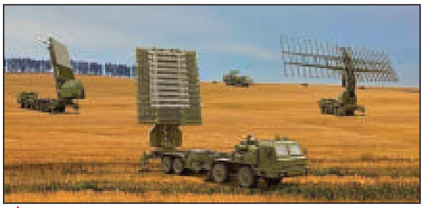
▲ *Fig. 8 The 22-meter diameter, 45,056 element SBX radar.*

▲ *Fig. 9 A 3,000 element four-sided THALES APAR.*

the 25,344 element X-Band Raytheon AN/TPY-2 Theater High-Altitude Air Defense Ground-Based Radar/Forward-Based X-Band - Transportable (THAAD-GBR/FBX-T) wideband AESA, (see ***Figure 7***) developed as an acquisition and engagement radar for the THAAD anti-ballistic missile system. The largest and most powerful AESA in this domain is the 45,056 element Sea Based X-Band (SBX) radar, developed for the Ground-Based Interceptor (GBI) three stage exo-atmospheric ABM – the AESA antenna face is 22 meters in diameter (see ***Figure 8***).[24]

X-Band acquisition and fire control radars for defending warships against sea skimming cruise missiles are another domain where AESAs have become prominent and will be central to the intended Air and Missile Defense Radar (AMDR) competition. Known examples include the Raytheon AN/SPY-3 Multi-Function Radar (MFR) developed for the Zumwalt class destroyer and Ford class carriers, the

▲ *Fig. 10 Australian CEA technologies 1,024 element CEAFAR/CEAMOUNT system developed for the ANZAC (Meko) class FFGs.*



▲ *Fig. 11 Russian Almaz-Antey/NNIIRT 55Zh6ME RLM-M Nebo M VHF-Band three-dimensional counter low observable search and acquisition radar.*

3,000 element four-sided Thales Active Phased Array multifunction Radar (APAR) deployed on the Dutch De Zeven Provinciën class FFG and German Sachsen class FFGs, (see ***Figure 9***), and the Australian CEA Technologies 1,024 element CEAFAR/CEAMOUNT system developed for the ANZAC (Meko) class FFGs, (see ***Figure 10***) – all are intended to guide the RIM-162 Evolved Sea Sparrow Missile.[25]

Search and acquisition radars are also seeing increasing use of AESA technology. The Thales/Raytheon Groundmaster series S-Band GM200 and GM400 are good examples, as was the developmental S-Band component of the Zumwalt's Dual Band Radar (DBR) system. The Chinese S-Band Type 305A/K/LLQ305A appears to be fundamentally influenced by the Thales designs.[26] No less interesting are the Russian Almaz-Antey/NNIIRT 1L119 Nebo SVU and 55Zh6ME RLM-M Nebo M VHF-Band three-dimensional Counter Low Observable search and acquisition radars, (see ***Figure 11***). The former employs 84 elements, each with 1.4 to 1.7 KW power ratings, the latter employs 168 elements, possibly of higher rating.[27] At this time, it is abundantly clear that AESA technology has invaded all traditional mainstream niches in military radar.

THE ADVANTAGES AND LIMITATIONS OF ACTIVE ELECTRONICALLY STEERED ARRAYS

There are some compelling reasons why AESAs are displacing PESA and MSA designs and will eventually relegate the latter to specialised niches.[28] The first and foremost is beam forming and beam steering agility which, in contemporary designs, permits changing beam parameters at rates of up to kilohertz. This was the initial imperative in early ESA applications, as the antenna could track multiple targets with very high update rates, critical when intercepting fast targets like supersonic cruise missiles and aircraft, or re-entering warheads.

A byproduct of this agility is the ability to "timeshare," "multiplex" or "interleave" the antenna between different tasks. In fire control applications, this permits concurrent tracking of widely separated targets, or concurrent search and missile midcourse guidance or terminal guidance. In search applications, it permits the ability to concurrently perform volume searches while tracking and, in surveillance applications, the ability to interleave surface mapping and moving target detection. In combat aircraft, it offers the ability to interleave mapping, terrain following or avoidance, air target and surface target searches and data linking. A single AESA equipped multimode radar can thus replace two or more legacy single function radars.

The second critical driver is that AESAs are much more reliable than traditional radars, primarily due to the use of hundreds to thousands of independent T/R modules – the failure of even large numbers of T/R modules only degrades antenna performance. Catastrophic AESA failure only arises when a shared subsystem like a power supply or beam steering controller (BSC) fails. MSAs on the other hand are exposed to mechanical component wear out failures, and single point failures in highly electrically stressed components like TWTs, waveguides, feeds and high voltage supplies.

An important advantage of AESAs over PESAs is the ability to independently control per-element gain as well as phase. This has important impacts in several areas:

The first is that beam forming can be more precise and different taper functions can be applied for different beams. This is most commonly used in side lobe suppression, which is a long running issue in clutter and jammer rejection, but more recently in achieving stealth, as very low side lobes reduce the probability of detection by hostile intercept or surveillance receivers. Other byproducts of this capability include the ability to make design trades between wavefront planarity in the main lobe, versus side lobe magnitude, or generate nulls within the main lobe to reject jammers.

AESAs can potentially be built with much greater bandwidth than PESAs or MSAs, facilitating Low Probability of Intercept (LPI) modes and enabling functions such as Electronic Attack (jamming) against in-band emitters. This capability is also exploited in some designs to permit the use of a radar AESA as an additional high gain antenna for a threat warning subsystem, or a data link with bandwidth potential of Gigabits/second, or LPI/covert capabilities, or both.

AESA receivers typically enjoy a 6 dB or better noise figure advantage over PESA/MSA receivers, as the loss between the antenna radiating element and first receiver stage contributes to the net noise figure or system level noise temperature. Higher power aperture AESAs also have significant potential as Directed Energy Weapons, to produce disruptive or electrical damage effects in electronically dense target systems.[29] Fixed AESAs are inherently better than gimballed MSAs in terms of structural radar cross section, which makes them inherently compatible with stealth vehicles, airborne or other.

These advantages do not come for free. Complexity and development costs are higher for AESAs versus MSAs. Weight and volume can be significantly higher than MSAs. Power consumption and cooling are major issues for AESAs and have often presented "brick wall" barriers to integration in smaller platforms. Power density limitations in the semiconductor devices and T/R module level cooling architectures can set hard limits on AESA performance growth in many designs. AESAs are software intensive with rigid real-time processing demands, presenting many unique engineering challenges well outside the RF domain, with much potential for software gremlins and outright functional failures.

From a raw gain performance perspective, AESAs must confront the problem of aperture foreshortening for targets well off the antenna boresight, and hard limits on beam steering angles between 45° and 70°. Phase steered AESAs also suffer intrinsic bandwidth limitations arising from aperture fill and side lobe steering effects, which impact all high bandwidth demand applications, with varying severity.[30] In many applications, the only solution compatible with low structural RCS is the use of multiple AESA installations, incurring concomitant penalties in cost, complexity, weight, volume and cooling. Examples include the planned for but never fitted F-22A cheek arrays, or planned T-50 PAK-FA cheek arrays. AESAs are not a panacea for all microwave antenna applications, but present significant advantages in most applications, advantages which justify additional penalties incurred in using the technology.

ACTIVE ELECTRONICALLY STEERED ARRAY TECHNOLOGY TRENDS

The technology driving advances in AESA design is without doubt monolithic device technology, which determines bounds on power-aperture performance of AESAs, directly via power transistor performance and indirectly via cooling performance. The latter is also heavily impacted by packaging technology, which imposes limits on density and cooling systems.

The GaAs MMIC was the enabling technology for AESAs in the S-Band and above, and also the reason why L-Band AESAs were early entries in airborne applications as these were the least dependent on transistor f_T performance. The poor thermal performance of GaAs substrates, despite the excellent carrier mobility in the material, has been a persistent problem through much of the history of the AESA, and has been a strong imperative for the use of materials with better thermal properties, such as SiGe, or especially GaN.[31] Packaging techniques have also evolved dramatically since the first X-Band AESA demonstrators were built. Array design theory dictates element spacing of a half wavelength or less, which presents increasing density challenges with increasing frequency. The contemporary power density benchmark is exceeding 4 W/cm^2 at the array face.

Early U.S. X-Band AESA designs and current Russian designs used a "stick" or "quad element" packaging design for T/R modules, with a single module containing a row or column of elements or channel in a "stick" or four in a quad. This approach presented persistent problems in

production repeatability, as a defect in any channel required a rework of the whole stick or quad module, if that was feasible. Contemporary U.S. and EU AESAs employ a "single channel" approach where each element employs a stack of components (tile approach) normal to the antenna face. Backplane feed networks also present design challenges, especially in loss performance and bandwidth, despite the advantage versus the PESA in not having to handle high power levels. In X-Band designs, the feed network may incur further complexity due to the need to segment the array to create multiple phase centers to accommodate dual plane monopulse tracking or GMTI displaced phase centres (DPCA).

A single channel or element in an AESA must contain an LNA for the receive path, a power amplifier, a phase shifter, impedance matched low insertion loss interconnections, gain control blocks, RF buffer amplifiers if required, as well as the digital circuits and control logic required to latch downloaded gain and phase parameters into the T/R module phase shifter and gain control components. Modern AESA T/R modules will also include circuits for health monitoring and Built-In-Test (BIT), and calibration.

Heat from semiconductor components in the T/R module must be conducted out of the module and carried out of the antenna using a cooling system. X-Band AESAs typically employ a Poly-Alpha-Olefin coolant, dumping heat into aircraft fuel, or via a heat exchanger into surrounding air.

In assessing futures for AESA technology, advanced RF device materials and processes will comprise one part of the equation and exponentially growing density in photolithographically fabricated digital components is the other part. Brookner has recently identified the following benchmarks and trends in device and materials technology:[32]

- Arrays using micro-electromechanical systems (MEMS) phase shifters
- Low cost 24 GHz phased-array car radars driving down T/R module costs through volume
- Extreme MMIC circuitry for 8 to 32 element arrays on single SiGe/BiCMOS chips
- GaN technology offering tenfold higher power and higher efficiency, permitting >1000 W peak power with single transistor packages
- Low cost Silicon based SiGe single chip
- Purdue University low-cost S-Band two panel GaN Digital Array Radar having 700 MHz bandwidth, 25 W per element peak; gets wide angle scan through use of electromagnetic band gap (EBG) material for increased isolation between antenna elements (lower mutual coupling); has potential of eliminating circulator
- Arrays with instantaneous bandwidths of 10:1 up to 33:1
- 20 dB increased receiver dynamic range through improved A/D linearity and reduced intermodulation
- Exploitation of meta-materials in passive antenna components
- 3D micromachining technology for interconnections

Exponential density growth is a well documented feature of the digital landscape, but is less prominent in RF components, due to the encumbrances of impedance matching and need for analogue components.[33] Growth, especially in parallel processing computer hardware, will impact radar across all categories, by providing abundant capability to perform floating point arithmetic. Current General Purpose Graphics Processing Unit (GPGPU) chips have internal memory bandwidths in excess of 100 Gigabytes/sec and often in excess of 500 pipelined floating point optimized processing cores in a single chip. Density growth in this technology will yield larger numbers of cores and higher memory bandwidths, enabling signal and data processing algorithms which are currently computationally infeasible in realtime applications.

In conclusion, continuing advances in MMIC materials and fabrication technologies, advancing packaging technology and exponential growth in digital circuits open many possibilities for future AESA designs. ■

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SPECIFICATIONS

Freq Range (Min) (MHz)	*Freq Range (Max) (MHz)*	*Gain (dB)*	*OP3dB (dBm)*	*Power Added Efficiency (%)*	*V_D (V)*	*I_D (mA)*	*Package*	*Part Number*
30	2500	11.0	39.0	40.0	28	55	AIN SOIC-8	RF3826
30	2000	13.0	43.0	45.0	48	88	RF270-10	RF3833
50	1000	16.0	41.3	53.0	28	88	AIN SOIC-8	RFHA1000
30	512	18.5	39.5	70.0	28	55	AIN SOIC-8	RFHA1003
225	1215	16.6	39.4	62.5	28	88	AIN SOIC-8	RFHA1006

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- High power added efficiency
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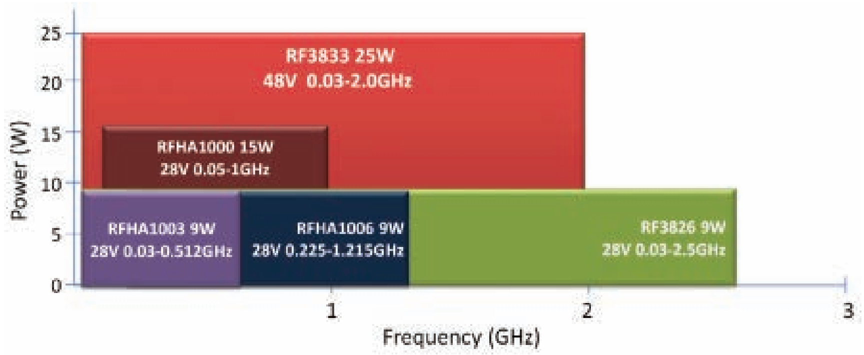

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SSHPS 2.9-3.1-1000	2.9-3.1 GHz	100 Watts	1000 Watts	0.8 dB	40 dB	1.8:1	4 µsec	3.5 x 3.5 x 1.0 inches
SSHPS 2.7-3.5-1000	2.7-3.5 Ghz	50 Watts	1000 Watts	0.9 dB	40 dB	2.0:1	4 µsec	3.5 x 3.5 x 1.0 inches
SSHPS 0.020-1.000-200	20-1000 MHz	200 Watts	1500 Watts	0.7 dB	25 dB	2.0:1	5 µsec	3.0 x 3.0 x 1.0 inches
SSHPS 0.225-0.450-400	225-450 MHz	400 Watts	2000 Watts	0.7 dB	40 dB	2.0:1	5 µsec	3.0 x 3.0 x 1.0 inches
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Reducing the Cost of SIGINT ISR Test

The development and upgrade of SIGINT ISR platforms is a time consuming and costly endeavor that must balance two somewhat conflicting requirements. On one end, the mission critical nature of a deployed system maximizes the importance of fielding a proven system, often creating a preference for existing systems that have been successful in the past. On the other end, the need to address rapidly evolving threats, many of which are based on quickly changing commercial technology, requires that a SIGINT ISR system must incorporate enough state-of-the-art functionality to adjust to new requirements. Exacerbating this challenge is the difficulty of testing ISR systems during development and integration. The final success of a SIGINT ISR solution is completely dependent on how it performs when deployed under real world conditions where the RF spectrum is increasingly crowded. As a result, the developer and/or buyer are often forced to rely on fully testing systems only once they are installed on the target platform.

While Field Tests have the benefit of replicating in-service conditions, complete control of the RF spectrum during flight is not possible. SIGINT ISR systems are tasked to operate against many environments including terrestrial point-to-point communication, SATCOM, wireless networks and a wide variety of commercial and military systems. Frequency reuse results in a densely overlapped spectrum when viewed from an ISR platform. Spectrum efficiency and interference mitigation have led to complexity of waveforms that are difficult to collect and decipher even when they are clearly received by ISR systems. The variety of transmitters and power levels as well as density leads to very high dynamic range requirements. A further complication is that most ISR platforms operate transmitters that are in-band with desired collection. With the variety of possible end-use environments and the expense and time required for testing on the target platform, Field Testing is best reserved for systems that have already been thoroughly tested against realistic collection environments representing multiple potential scenarios.

A-T Solutions, in collaboration with National Instruments (NI), has demonstrated the ability of a modular commercial-off-the-shelf (COTS) platform to generate realistic, complex test scenarios with signals that reflect relative motion, spectral overlap, frequency and time offset. This system can be used in a laboratory environment, in-lieu of field test installed on a platform. This article will briefly discuss the forces in the commercial sector that are driving applicable capability in COTS test equipment, the architecture of the COTS instrumentation selected and the results of the collaboration to produce a realistic SIGINT ISR collection environment codenamed LoBSTER (Low-Band System Test and Evaluation in Real-time).

Dave Giles
A-T Solutions, Larkspur, CO
Sean Thompson
National Instruments, Austin, TX

A TEST ENVIRONMENT THAT BENEFITS FROM ADVANCES IN COMMERCIAL TECHNOLOGY

At the end of 2011, the number of wireless mobile subscriptions in the world had exceeded 5.9 billion. Approximately 1.2 billion of these connections are capable of accessing third generation (3G) networks and the increased data rates and functionality they provide.[1] The constant evolution of the use of wireless spectrum as methods of communication, whether it be voice, video, data, emergency information or command and control, is driving tremendous investment by commercial industry to create an infrastructure capable of supporting development of new wireless devices.

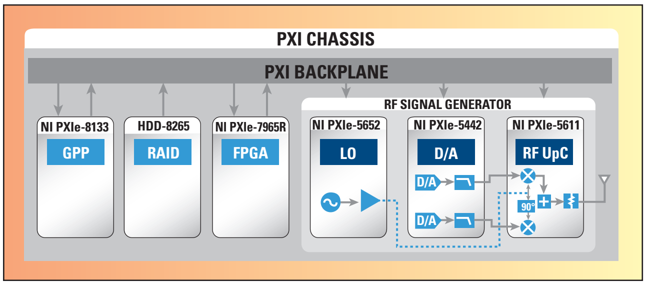
In test, this has translated to the need to provide new test methodologies and system architectures that enable faster product development cycles from concept to reliable product – meeting the requirements that are driven by current wireless standards but with the capability to quickly adapt to new technology. Over the last few years, this has resulted in various trends driving modern wireless test systems. Two of the most relevant trends in reducing the cost of testing SIGINT ISR systems are the development of modular instrumentation platforms based on COTS technology and software-defined instrumentation.

Modular Instrumentation Based on COTS Technology

By modularizing the key functional blocks of traditional instrumentation, modular instrumentation platforms are built to take advantage of the rapid advancement of COTS technology in various functional areas.

- Processing elements – integration of different computational elements (heterogeneous computing) allows for the tasks comprising wireless test applications to be executed on the element offering best performance. General Purpose Processors (GPP), field-programmable gate arrays (FPGA), Graphical Processing Units (GPU) and digital signal processors (DSP) continue to be driven by Moore's law, offering increasing computational horsepower.
- Bus technologies – high speed point-to-point interconnects offering guaranteed bandwidth and deterministic latency. Modern instrumentation buses, such as PXI Express, enable individual modules to transfer data at rates of GBs/sec.
- Baseband elements – A/D and D/A components continue to evolve, enabling wider bandwidths and increasing dynamic range.
- RF front ends – multiple implementations from super-heterodyne to wideband homodyne architectures provide options for maximizing RF performance in different areas. Separate local oscillators (LO) ease frequency/tuning constraints and enable phase synchronous, multi-channel systems.

One such modular instrumentation standard is PXI. ***Figure 1*** shows an example of a high level block diagram of a modular RF vector signal generator in a PXI chassis with an embedded host computer, programmable FPGA module and external RAID storage interface. The RF signal generator itself is broken into three separate modules: an IQ modulator that translates an RF signal from baseband to RF, an arbitrary waveform generator that drives the IQ modulator with a user-defined waveform and an LO module. The other modules in the system provide shared resources for the RF generator to use, such as the display connected to the embedded controller or the massive storage available in the external RAID system, or additional resources to expand the functionality of the generator, such as the FPGA module adding real-time processing to create waveforms on the fly. The modular nature of the platform allows for test systems to be easily reconfigured for additional channels of RF generation, greater computational power for embedded processing and larger data storage while maintaining the original investment.



▲ *Fig. 1 Example of a modular RF instrumentation system.*

Software-Defined Instrumentation

Test environments are moving from closed, fixed capability to open, software-defined functionality. This has been driven by the need to test increasingly complex devices that are themselves defined more and more by software. Software-defined instrumentation allows a test environment to become a dynamic system that adopts functionality defined by the user.

In the context of wireless test, the ability to embed user-created software into the instrumentation platform provides the capability to reuse work done in the design stage of a wireless product or standard. During the development phase of new wireless standards, comprehensive simulation is done to determine how a receiver will perform under deployed conditions. Models are created for the protocol, the physical layer and the actual environment. Software-defined instrumentation provides a methodology to move these models from the simulation domain to hardware to generate and receive physical signals. Final functionality could include custom measurements, generation of RF signals previously recorded or generated from off-line modeling, and/or implementation of a full software defined radio or complex channel model to simulate a deployment environment in real time.

An important consideration with software-defined instrumentation is the potential complexity of programming the different elements within the system. A software environment/tool chain that simplifies the integration of hardware with abstraction, supports heterogeneous computing with a common programming paradigm for the different computational elements and is compatible with models generated from other languages and tools, is critical.

An ideal way to address this challenge is by using the graphical system design approach, which provides an integrated software and hardware platform that scales across design, simulation, deployment and test, from desktop to embedded systems. An example is NI LabVIEW system design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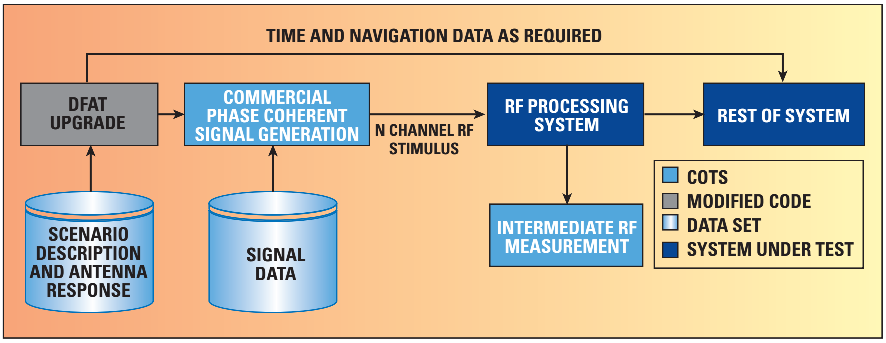
software, which is the heart of the graphical system design approach, as it uses a graphical dataflow language to abstract hardware control functions. This unified abstraction combines user interfaces, models of computation, math and analysis, input/output signals, technology abstractions, and various deployment targets to greatly simplify any system.

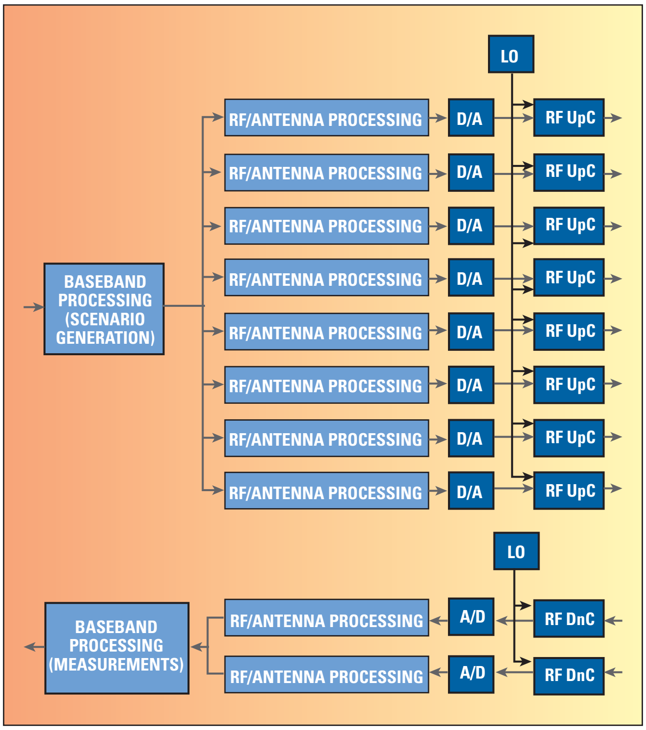


▲ *Fig. 2 LoBSTER system architecture.*

ARCHITECTURE OF SIGINT ISR TEST PLATFORM (LoBSTER)

A-T Solutions' LoBSTER is designed for test and integration of complex ISR systems, providing multiple channels of RF stimulus conditioned to replicate the signal normally received at the antennas of the system(s) under test (SUT). Input to more than one collection platform can also be provided. The RF stimulus to the SUT is based on a scenario that describes the movement of collection platforms and the location and activity of emitters. Scenario time and navigation data are provided to the SUT as well as the ability to monitor and record their RF processing. Emitter signals can be defined strictly from simulation or can incorporate previously recorded signals. Output signals are individually adjusted for collection platform motion, propagation conditions, collection antenna patterns, angle of arrival at collection platform, and collection platform separation. LoBSTER provides up to eight coherent channels of RF stimulus with precise control of scenario signals. The overall architecture is given in ***Figure 2***.

In order to generate an accurate representation of a realistic SIGINT ISR collection environment, multiple channels of phase-synchronous RF generation with tight specifications on relative channel-to-channel phase, amplitude and frequency accuracy are required. Using the modular nature of the RF signal generator in Figure 1, LoBSTER consists of up to eight channels of RF upconverters and ARBs driven by a shared LO. Each channel provides up to 100 MHz of generated bandwidth. The RF/antenna signal processing and hardware control necessary to align the channels and maintain precise phase, amplitude and frequency levels is done in on-board FPGAs in the instrument modules. With a shared LO driving all upconverter stages and the PXI backplane driving the sample clocks for the digital-to-analog converters, normal contributors to inaccuracy, such as phase noise from the reference clock, affect each channel equally and therefore cancel out when examining relative channel-to-channel values. Along with the RF signal generation, LoBSTER adds two channels of coherent RF signal acquisition to monitor and record the RF processing done by the SUT. ***Figure 3*** illustrates the high-level diagram of the RF generation and signal processing elements.



▲ *Fig. 3 COTS RF subsystem.*

Performance values are derived from analysis of the phenomena to be modeled. The fundamental goal is to create a stimulus environment that will be good enough so that simulated signals will evaluate the performance of the SUT without simulation artifacts becoming a controlling factor in SUT performance assessment. ***Table 1***

TABLE I

SUT PLATFORM EXAMPLES

Collection Platform Example	*Nominal V (Km/second)*	*Nominal Target Range (Km)*	*Maximum Observation Angle Rate (degrees/second)*	*Δτ (second)*	*Δφ (degrees)*	*Δω (Hz) @ 50 MHz (Hz)*
Low Altitude UAV @ 100 NM/hour	0.051	10	0.29	1.7×10^{-12}	0.011	1.30×10^{-6}
Med Altitude Turbo Prop at 150 NM/hour	0.077	12	0.37	2.56×10^{-12}	0.015	1.66×10^{-6}
Business Jet at 300 NM/hour	0.154	25	0.35	5.13×10^{-12}	0.014	1.57×10^{-6}

TABLE II

COTS TEST SYSTEM REQUIREMENTS

Parameter	*Adjustment Range*	*Precision*	*Accuracy*
Channel to Channel Phase Offset	0 to 360 Degrees	0.01 degree	0.1 RMS
Received Signal Waveform Strength Channel to Channel	Noise floor to +5 dBM	0.1 dB	0.5 dB RMS
Collector to Collector Time Delay (Narrowband)	0 to 100's of μseconds	2 ps	5 ps RMS
Collector Frequency Offset (Narrow Band)	Determined by Radial Velocity Difference	Interpolation Limit ~.001 PPM	0.1 PPM RMS of Settling Frequency

TABLE III

TARGET EMITTER DESCRIPTIONS

Emitter 1	Lat=34.639 deg Lon=118.088 deg Alt = 2401 ft. Signal amplitude = 0.35 Baseband RF = -383000 kHz Stepped frequency modulated signal Az = 153.3 deg and El = 93.4 deg during time of interest
Emitter 2	Lat=37.266 deg Lon=117.010 deg Alt = 1200 ft. Signal amplitude = 0.25 Baseband RF = -225000 kHz Stepped frequency modulated signal Az = 175.6 deg and El = 93.2 deg during time of interest
Emitter 3	Lat=34.736 deg Lon=114.390 deg Alt = 500 ft. Signal amplitude = 0.3 Baseband RF = -800000 kHz Stepped frequency modulated signal Az = 221.7 deg and El = 93.05 deg during time of interest

shows incremental changes for selected conditions that are comparable to peak value of real collection scenarios, with the delta change assessed at 10 millisecond intervals.

This assessment is made at the point of maximum rate of change for the indicated range and velocity. Using simple stimulus signals, the ability of the COTS RF signal generation hardware to meet the listed accuracies was validated. Derived COTS test system requirements for simulating these real world effects are shown in ***Table 2***.

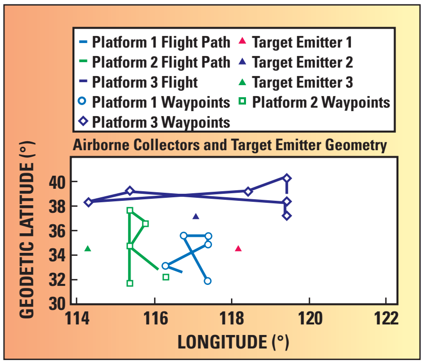
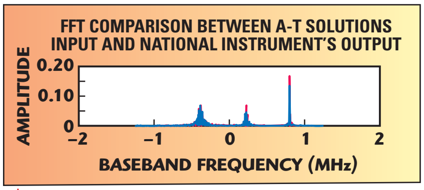


Fig. 4 Test scenario geometry.

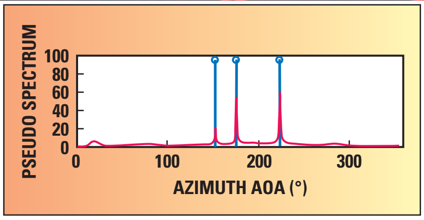
RECREATING THE ENVIRONMENT

To validate the ability of the final test system to accurately reproduce flight scenarios, a scenario with three airborne ISR systems collecting multiple emitters is created. The scenario is illustrated in ***Figure 4,*** with the target emitter characteristics defined in ***Table 3***.

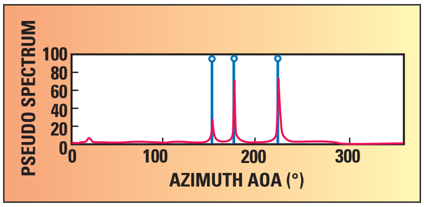
The COTS test system, shown in Figure 3, was used to generate the RF signals from the defined scenario and the output was recorded with a multi-channel, phase-aligned RF measurement system. The results were compared with the original models. ***Figure 5*** displays the spectrum of the simulated data versus the baseband recovered from the actual RF generated from the test system. The blue signals are the original baseband spectra, and the red spectra are the recovered baseband. As will be noted, the spectra are essentially indistinguishable.



▲ *Fig. 5 Spectrum comparison: simulated versus generated RF.*



▲ *Fig. 6 Angle of arrival simulated data.*



▲ *Fig. 7 Angle of arrival generated RF.*

To validate that the phase relationships remained consistent between the original models and the generated RF, the MUSIC algorithm[2] was applied to the four input channels for platform 1 defined in the scenario shown. ***Figure 6*** depicts the pseudo spectrum which results from covariance and eigenvector analysis of the four channels of baseband data collected by platform 1. This shows three peaks of amplitude when plotted against the 360° range of angles of arrival around the collection platform. In Figure 6, the vertical blues represent the azimuth angle of arrival at platform 1 with pseudo spectrum plotted in red.

Figure 7 depicts the results of applying the same analysis to the recovered spectrum after RF conversion. As can be observed, the recovered angle of arrival and pseudo spectrum are essentially identical to that derived from the original simulated baseband. Further analyses included placing a beam former on the signal at 176° and recovering the spectrum. The desired spectrum was isolated and validated to be as simulated.

The key functionality of LoBSTER is based on the software Direction Finding Analysis Toolset (DFAT) which provides the key software components to compute incident angles and antenna responses to received signals, so that the SUT receives RF stimulus as though it were from system antennas. LoBSTER also uses the extensive library of geo location modeling codes and scenario simulation to address time offset, frequency shift and channel-to-channel phase offset. ***Table 4*** gives some examples of these.

The signal generator is aligned to the first channel of the suite. This uses the embedded firmware to control the output waveforms, which achieves the necessary adjustment range accuracy and precision as shown. Because the scenario explicitly controls the waveforms, LoBSTER can provide signal environments that are difficult if not impossible to replicate during flight test. These signal environments can be merged with RF signals recorded off air or modeled on platform transmitter output, as desired, to provide a representative RF environment to SUT.

CONCLUSION

This ability to recreate a realistic SIGINT ISR collection environment

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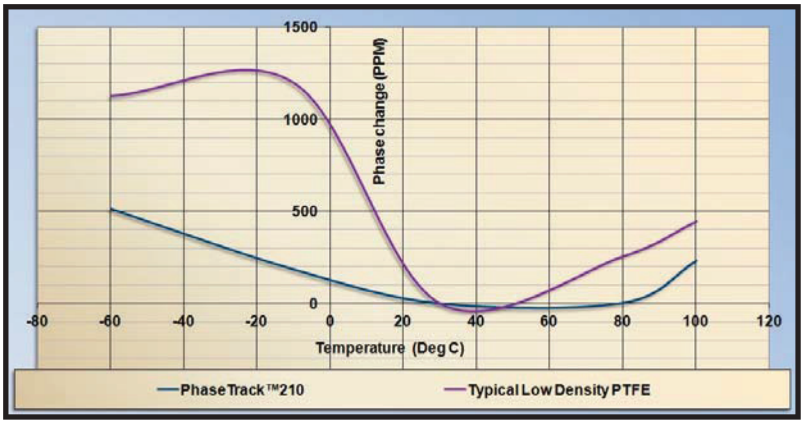

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TABLE IV

EXAMPLE LoBSTER MODELING EFFECTS

Emission Effects	For Each Emitter	Method
Doppler Frequency Shift	Based on each SUT velocity and direction relative to each emitter	$f_0*(1- {}^{v}{}_{emitter}/ C)$
Time of Arrival	Based on SUT position relative to each emitter	$\tau = \tau_0 + (Emitter_{location} - SUT\ Antenna_{location})/C$
Signal Amplitude	Controlled by scenario, adjusted for propagation loss and receive antenna pattern	$A = A_0 - 10\log(4\pi D/\lambda)^2$ + Antenna Pattern at (az, el, and frequency)[3]
Signal Phase for each Coherent Channel	Determined by distance from scenario emitter to each SUT antenna, azimuth and elevation of incident wave front modified by receive antenna response	Reflects pitch, roll, yaw of SUT platform, and offset from SUT location to each receive antenna location
Signal On/Off Time Duration and Content	Specified in scenario	
Channel Effects – Fading, etc.	Available models	

in the laboratory can be used throughout system development, integration and verification. With more complete test coverage of real world conditions before Field Test, ISR development schedules are not tied to deployment platform availability and, when ready, the SUT can be installed on the target platform and proceed to operational verification with high confidence against real world environments. The ability of a COTS test environment to evolve efficiently with new technology driven by the commercial sector enables testing future requirements and provides support for ISR system updates, problem resolution, and similar activities over its lifecycle. ■

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Dave Giles *holds a bachelor's degree from Stanford University, advanced studies and a Juris Doctorate from Santa Clara University. Giles has lead the development of several systems and provided engineering to multiple system developments during his career of more than 40 years in ISR, including software, system design, analysis, and field support. As the lead SIGINT System Engineer for A-T Solutions Colorado office, he leads the development of ISR tools for A-T Solutions.*

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Emulation Provides a Cost-Effective Strategy for Replacing Obsolete Instruments in ATEs

Typically, test systems used in aerospace and defense applications have a lifespan of 25 years or more – far longer than the lifespans of the individual measurement instruments that comprise the system. Replacing obsolete instruments can have major negative consequences for the deployed test program set (TPS) and for the maintenance, calibration and repair costs of Automated Test Equipment (ATE). However, by employing instrumentation with a sophisticated emulation strategy, the new test instruments can be successfully integrated, using a less expensive, more efficient migration path. For example, modern T&M instruments can be controlled by commands other than the built-in native SCPI commands. As shown in ***Figure 1***, users can replace legacy signal generators in a test system without having to change the remote control code.

Fig. 1 Instruments such as the R&S SMA100A can be controlled by commands other than the built-in SCPI commands.

BILLIONS AT STAKE

Between 1980 and 1992, the U.S. Department of Defense spent over $50 billion on ATS procurement. During this period, the standard practice was to develop a unique ATS or ATE to support a single military system, which resulted in a proliferation of hard-to-maintain test systems.[1] Solving the problem of test equipment obsolescence is both difficult and necessary, because the cost of system ownership is greatly influenced by ATE calibration and repair costs and by the current maintenance procedure for TPSs. There is also an increasing risk of replacement parts becoming unavailable and of calibration and repair capabilities eroding during the system's lifetime once the instrument is no longer supported by the vendor.

Jochen Wolle and Rainer Lenz
Rohde & Schwarz, Munich, Germany

EMULATING OBSOLETE DEVICES

Test program sets used in ATE systems are generally certified, which makes it very time-consuming and costly to modify and reapprove them when an obsolete instrument is replaced. Replacement also triggers software modifications – and the cost of a TPS rewrite almost always exceeds the cost of instrument replacement. It is therefore very cost effective to manage instrument replacements without changing the existing TPSs. An attractive migration strategy is to deploy new measuring instruments that emulate the discontinued instruments. This approach saves time and is cost-effective but not trivial. The requirements for the new instruments are determined by the test programs themselves and by the electrical and functional features of the instruments to be emulated.

DIFFERENT STRATEGIES

There are three basic approaches to solving the obsolescence problem: ATEs can be maintained, modernized, or upgraded. The appropriate choice depends on remaining ATE system life and on cost. Maintaining an existing ATE by repairing its instrumentation has lower costs and is relatively simple, but is limited to the number of years the legacy instruments are available. Benefits are zero or few changes to hardware and software and minimal capital expense. Problems are the limited time span, higher downtime and the increased risk when the product is no longer supported.

Modernizing or replacing the entire ATE solves the code compatibility issue, but also has much higher costs and usually can be done only during major program updates or extensions. Advantages include greater reliability, faster tests and extended life. On the other hand, this approach requires major changes to hardware and TPS, which lead to higher complexity, compatibility issues, higher risk and high costs.

Upgrading the ATE with modern instruments is a middle way that has the potential to create modern systems at a reasonable cost. However, it requires that the line replaceable units (LRU), or units under test (UUT), give the same response when stimulated with the replacement instrument as they did with the legacy instrument. In other words, the replacement has to be done with code-compatible instruments.

ACHIEVING CODE COMPATIBILITY

Usually, replacing legacy instruments with new instruments that emulate them exactly requires the same hardware interface (GPIB) used by the existing test system. It also requires adopting the existing command language (such as for frequency and measurement range setting, dynamic range setting and noise level setting for the replacement instruments). Fortunately, the Standard Commands for Programmable Instruments Standard (SCPI) has significantly reduced the problem of interchangeability. Footprint in most cases is not a problem because modern instruments tend to be smaller in size and have lower power consumption.

Faster testing (increased throughput, higher yield) may also be possible because the replacement instruments deliver higher accuracy and speed and this can lead to higher margins for the DUTs. Other benefits include minimal hardware and software changes, greater reliability and reduced cost of ownership.

Since the late 1990s, remote control of instrumentation has been based on the common SCPI standard. Before that, legacy instruments used vendor-specific command sets that had their own syntax and semantics. To make these instruments compatible with earlier generations at a minimum requires switching from the SCPI parser to a parser for the legacy commands that understands the old syntax. But just translating the legacy commands into SCPI is not enough. The right emulation mode has to be activated first, as well as the selection of the emulated instrument model. (Although most of the legacy instruments share a common set of remote commands, each model may respond to the commands quite differently.)

GETTING INTO EMULATION MODE

Activating emulation mode includes selecting the particular model of in-

HIGH POWER

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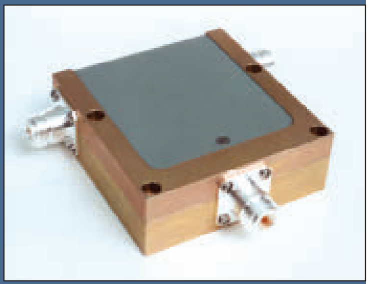

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A.

B.

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CT-3838-N	5 Kw Pk 500 W Av	N Conn.	2.7–3.1 GHz
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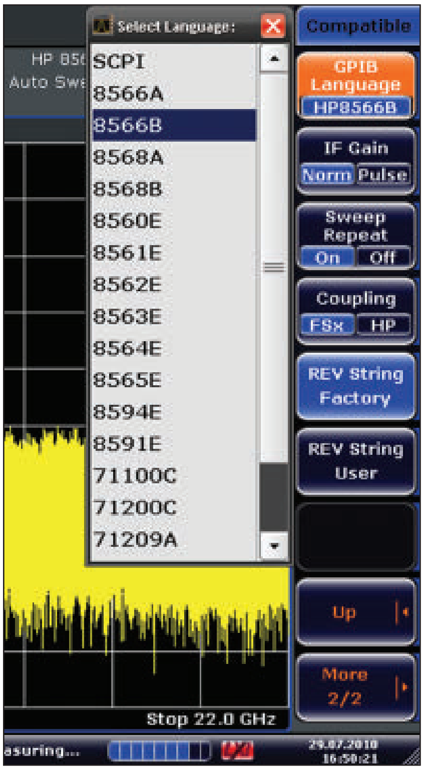

Fig. 2 Emulation mode: Selection of legacy signal analyzers to be emulated by the R&S FSV.

strument to be emulated. Instruments from an earlier family might have a common set of legacy commands but they can show considerable differences in many areas. Activating emulation mode includes selecting the particular model of instrument to be emulated. ***Figure 2*** shows the selection of legacy signal analyzers to be emulated by the R&S FSV as an example. ***Figure 3*** shows the sample selection of a legacy signal generator to be emulated by the R&S SMA100A and ***Figure 4*** shows that power meters like the R&S NRP2 are often used in automated test applications. The remote emulation feature allows the user to control the R&S NPR2 by using the exact same commands that were implemented in the original instrument.

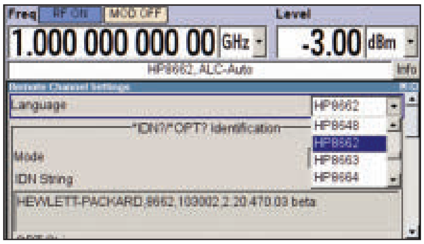

Fig. 3 Emulation mode: Sample selection of a legacy signal generator to be emulated – example shown here is the R&S SMA100A.

It is also very important for the emulation to function in both directions. Besides being able to understand and be capable of processing incoming commands, the new instruments must also deliver responses such as measurement or query results to the control program that are compatible with the emulated instrument.

In addition, activation of the emulation mode enables proper adaptation to the different preset settings of the instruments to be emulated (That is, for a spectrum analyzer: span, start and stop frequency, number of trace points, reference level and bandwidth coupling).

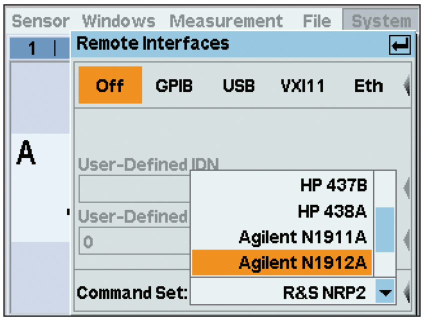

Fig. 4 Power meters like the R&S NRP2 are often used in automated test applications.

Activation of emulation mode (or native mode) can also be handled automatically by means of a control command. This makes it possible for new control programs to take advantage of the features provided by state-of-the-art instruments, in addition to their emulation capabilities.

ID STRING EMULATION AND RESPONSE FORMATS

To address different members of the same instrument family, simply editing the ID string is often sufficient. For a valid ID string emulation, the response to a query for an instrument ID must match the original. ID strings should also be editable manually. In addition, preset settings need to be adjusted to match the legacy instrument.

Properly formatted instrument responses to queries by the control program are essential for proper emu-

lation of previous instruments, along with identical formatting of all parameters (integer, float, ASCII strings) and an identical number of characters. When querying trace data from a spectrum analyzer, it is particularly important for the different query formats of previous instruments to be implemented to result in correct emulation. For example, legacy analyzers provide different formats for reading out trace data.

SERVICE REQUESTS AND STATUS REPORTING

Service requests are messages the instrument sends to the controller when specific conditions or events occur that require a response by the controller. An example would be a message indicating that the analyzer has completed a sweep. The controller analyzes the different events and status messages using status byte queries.

Service requests and status reporting present a tricky emulation problem. Although they are defined in the IEEE488.2 standard, legacy instruments implemented this functionality only partially and with different behaviors. Since the requirement is an identical response to service request, not only the status bits of the legacy instrument must be emulated, the behavior of the status bit combinations generated by the legacy instrument has to be emulated also. The responses of the status reporting (service requests) must be simulated as precisely as possible, including the response times and the related assignment of the status registers.

MODIFICATIONS MAY BE NEEDED

Sometimes a problem arises due to the different functional feature sets of the legacy instrument and the new instrument. The challenge is to replace a legacy instrument such as HP8340B by a new instrument, when the feature set of the legacy instrument is not a true subset of the new instrument. Normally, an emulation would implement the overlapping functions, but not those functions available in the newer instrument. This can lead to faults. The reason is that very often, during the initialization of the application, the legacy instrument calls for a function, which is not available in the new instrument and which is never needed during the rest of the application.

The following example illustrates this problem: The HP8340B, for instance, sends the command “PD0” to disable the pulse modulation in an application where no pulse modulation is needed. If the legacy instrument is replaced by an R&S SMB100A, for example, without a pulse modulation option, this command leads to an error message and possibly to a malfunction of the application. One solution is to implement the unavailable functions as “dummies” for the emulation. This means that set-up commands will be absorbed and polling commands will be answered with default values.

HARDWARE AND TIMING ISSUES

In today’s instruments, signal processing is fully digital. This means that

the analog design of legacy instruments must be carefully taken into account, particularly with respect to timing, filters and level aspect. For example, reference level differences between modern and legacy spectrum analyzers can be adjusted with internal mixer levels. Emulation with digital filters must fit the shape factor of the analog filters in legacy instruments.

Modern instruments, such as analyzers, signal generators or power meters, are much faster than legacy instruments. In most cases, this is not an issue and even leads to better throughput. On the other hand, calibration and self-alignment may take much longer in modern instruments because it takes a larger number of correction steps to achieve higher accuracy. In this case, the solution is to reduce alignment to only a part of the procedure in emulation mode. Another problem on command execution may occur if test programs are not properly synchronized.

CONCLUSION

Many ATEs in use today are facing obsolescence problems in the short or mid-range term. Since modern instruments can now emulate legacy instruments and achieve code compatibility in many cases without modifications to the TPSs, migrating to the new generation of instrumentation makes it a strategy worth considering to keep system readiness at the highest level.

Backward compatibility requires both command compatibility and true functional/behavioral compatibility. The advanced spectrum analyzers, network analyzers, signal generators, power meters and audio analyzers from test and measurement companies like Rohde & Schwarz and others offer built-in emulation to ensure the highest possible code compatibility. For example, the R&S Legacy Pro concept makes it feasible to use the migration approach in test systems, if desired, and replace obsolete measuring instruments. In many applications, it is possible to continue using existing control programs without any modifications. ■

Reference

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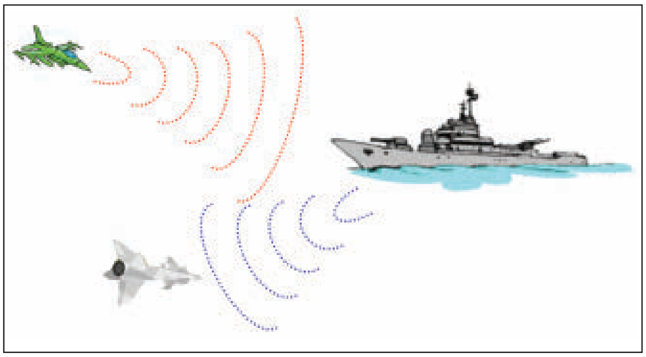
Rainer Lenz *studied electrical engineering at the University of Karlsruhe (TH) where he received his Dipl.-Ing. degree and PhD. After his studies, he worked for several years in RF engineering and in system engineering. In 2012, he joined Rohde & Schwarz GmbH & Co. KG in Munich as product manager for signal generators and power meters.*

The Ins and Outs of Microwave Signal Capture and Playback

The capture and playback of microwave signals has a multitude of applications in the evaluation of communications, radar and electronic warfare systems. The stimulus and analysis requirements of system level testing differs from the functional testing of the various sub-systems, boards and components that make up the system for a number of reasons. For instance, these types of systems are becoming increasingly multi-role and multi-mode in nature, perhaps even performing multiple functions at the same time. The systems will need to automatically reconfigure themselves depending on the stimulus at one or more of their sensor ports. So, a benign or static test stimulus that may be sufficient to verify a lower level subsystem will not be sufficient to fully exercise the dynamic operation of the full system under all or even a few of its operating conditions.



▲ *Fig. 1 The reflected waveform is unique and changing at the receiver antenna during the entire flight.*

To provide an environment adequate for functional evaluation of the system, the test stimulus must be long and unique – in other words, a complete, non-repetitive scenario. The issue is that these systems may internally operate in the realm of microwave frequencies and nanoseconds of time, but the environment in which the system lives is governed by real world events that can take seconds, minutes or even hours to unfold. In order to analyze or generate the scenario, the signal must be captured and/or played back at a sample rate that can recreate the highest frequency element

John Hansen
Agilent Technologies, Santa Clara, CA

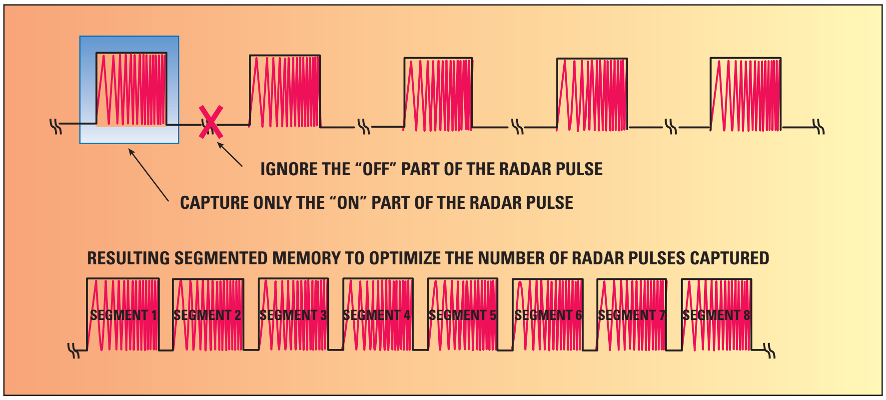


Fig. 2 *Segmented capture of a long pulse train.*

(usually the carrier) and the slowest changing or rarest event the system encounters.

For example, consider the flight of a radar guided missile as illustrated in ***Figure 1***. The signal at the receiver of the missile will be constantly changing from the time it is launched to the time it reaches its target. It may begin in a bi-static mode, where the radar signal is transmitted at a certain frequency from the launching platform, like a fighter jet. During the flight, the missile and target will be accelerating or decelerating, putting a Doppler frequency shift on the carrier at a relatively low rate of change. The Radar Cross Section (RCS) changes constantly as the relative position of the missile and target changes. As the missile approaches the target, the pulses become more closely spaced. The mode of the radar may change to maintain optimal tracking of the target through changes in the pulse repetition frequency (PRF) and pattern. There will probably be an attempt to jam the signal. Finally, the radar seeker in the missile may take over at a different carrier frequency and PRF.

This requires a very deep memory in order to store all the samples needed to capture or playback this type of scenario. For instance, if the radar operates in X-Band at 10 GHz, a sample rate of approximately 25 GS/s (GigaSamples per second) will be required (Nyquist frequency plus some margin) to accurately capture the signal. For the discussion here, a sample consists of a 32-bit I and Q sample pair. So a memory depth of 2 GS will only hold 80 ms of data at this rate. Fortunately, there are methods for optimizing the use of memory during capture and playback.

SEGMENTING AND SEQUENCING FOR CAPTURE AND PLAYBACK

When performing measurements on pulsed radar signals, capture and analysis of a large number of pulses is often required. For example, the Agilent 90000X oscilloscope has a deep capture depth of 2 GS. This is the same depth that was used in the example above. The amount of data in terms of time, of course, depends on the sample rate selected.

Segmented memory can further optimize the number of radar pulses that can be captured and analyzed with the available oscilloscope memory. Essentially, it enables the user to zoom in on a pulse and capture only the “ON” portion of the pulse, while ignoring the “OFF” portion of the pulse as illustrated in ***Figure 2***. This helps to optimize memory usage and maximizes the number of pulses that can be captured with the 2 GS of physical memory.

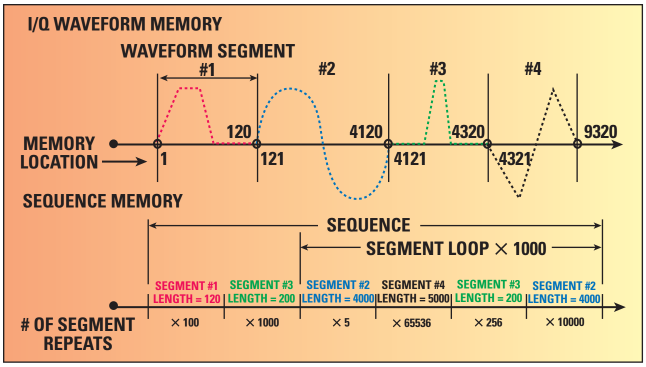


Fig. 3 *Example arrangement of segments in a loop and sequence.*

Many arbitrary waveform generators (AWG) feature a similar sample memory optimization capability. This is termed segmenting and sequencing. Playback of stored waveforms can be defined in a way which effectively “multiplies” the use of existing memory. This multiplication effect is especially apparent for waveforms with significant “OFF” time and repetitions. For example, pulse waveforms with low duty factors need only to define the unique “ON” time plus some small portion of the “OFF” time as separate segments in memory. The single “OFF” segment is looped and replayed as needed.

Many different waveform segments can be stored in the AWG waveform memory. Sequences are formed, using a contiguous series of segments. Because each segment has a specified start and stop address, sequence play is continuous and without gaps, when played from one segment to the next. Multiple segments can be grouped and looped for even greater memory compression. This waveform scenario construction is illustrated in ***Figure 3***.

APPLICATIONS FOR CAPTURE AND PLAYBACK

In addition to the radar guided missile example, there are broad requirements in the aerospace and defense community for capture and playback of long, unique, non-repeating signals. One application example is interference testing. Interference is an undesired emitter, which could reduce or block the sensitivity of a receiver. Interfering emitters are often unpredictable: one does not know when they will occur, where in the spectrum they will appear or how long they will last. In order to fully understand the true nature of these interfering signals, many seconds, minutes or even hours of capture time may be required to guarantee that an event is captured.

What may be the most challenging application of signal capture and playback is radar target simulation. Here, the target return is coherent with the transmit pulse radar because the transmit pulse is captured and “immediately” played back to the radar receiver, with some fixed and perhaps added latency while maintaining a constant phase. Systems dedicated to

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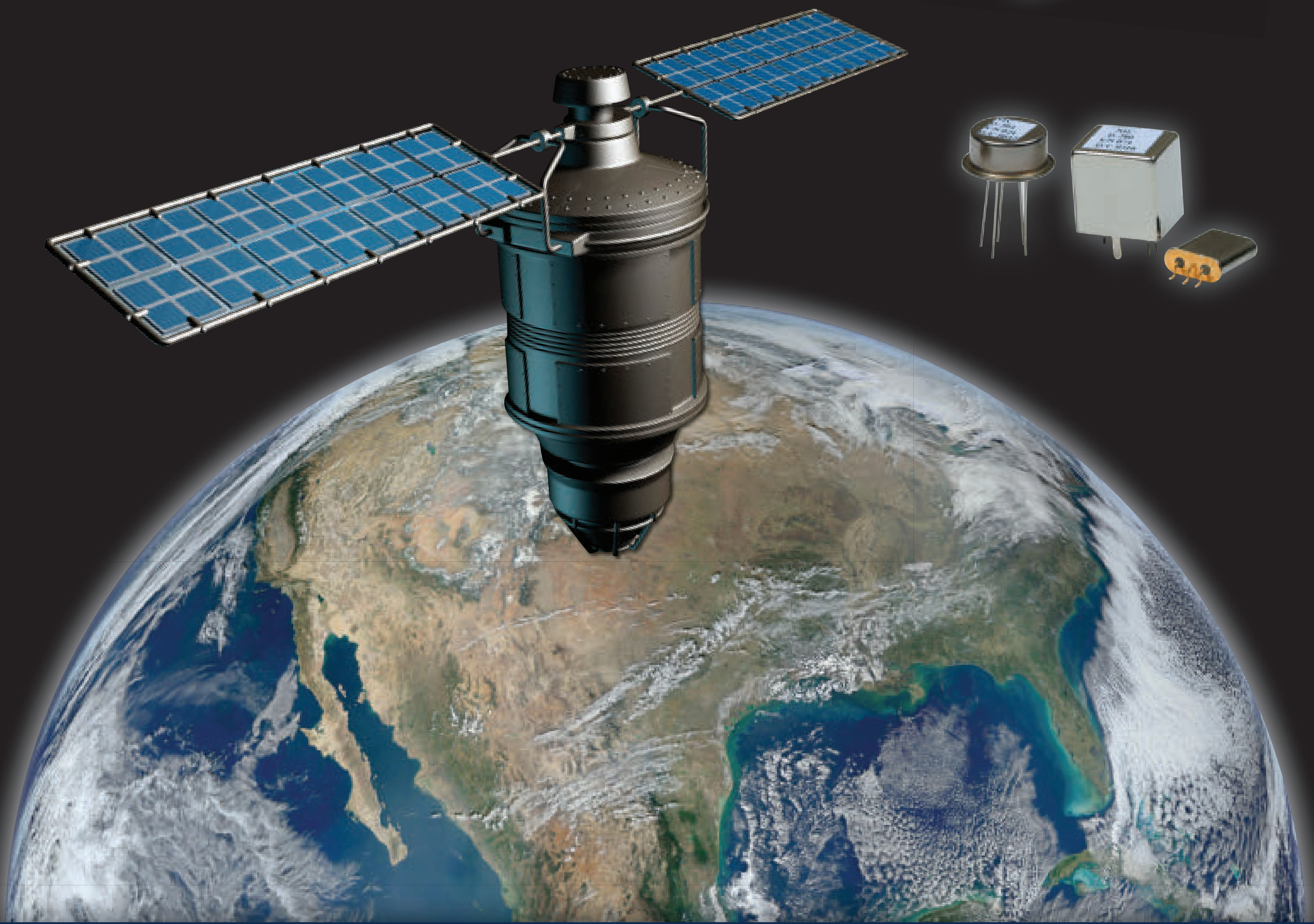


this function are termed Digital RF Memories (DRFM). Due to the relatively narrow use cases (radar target simulation and deceptive radar jamming) and custom nature of these DRFM systems, they are generally quite expensive. No solution using general purpose, off the shelf instruments currently exists. The requirements for such a capability include: a known, fixed signal latency through the system and the ability to act on the signal as it passes through the system (e.g., adding simulated Doppler).

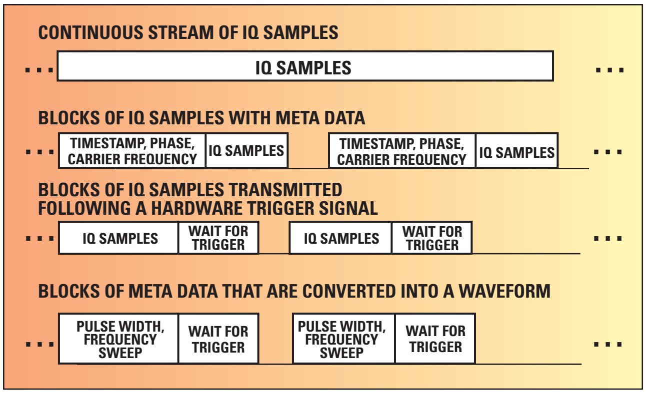
For applications such as these, an extremely large amount of memory is needed. The ability to capture and perhaps playback without gaps at a very high data rate is also needed. So let's now discuss the concept of waveform streaming.

WAVEFORM STREAMING

Streaming is a flow of data that can be I and Q sample data, symbols, bits, waveform description, etc. The stream can last for an indeterminate, although generally finite, period of time, so there is not necessarily information about when the stream will end. The average data rate at the destination of the data is the same as at the source.

There are three basic use cases for streaming capture and playback of RF and microwave signals:

- Capture or playback of long waveforms to or from an extremely deep memory, which could be disk array of many Terabytes set up in a RAID configuration for faster write speeds.



▲ *Fig. 4 Possible transmission over the streaming interface.*

- Waveform to be defined dynamically during playback, based on the system's reaction to the current waveform. The next waveform segment to play is selected just prior to the current segment completing or it is created mathematically at run-time.
- Streaming allows a digitizer to capture a signal, optionally process it in a DSP and re-transmit it from an AWG in real time, as described in the DRFM application example above.

There are many different ways and types of data that can be utilized to stream a waveform in addition to just a continuous stream of I and Q samples. ***Figure 4*** shows the

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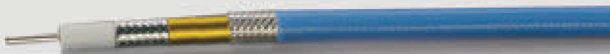

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possible data transmissions over the streaming interface, which define a waveform. Meta data can be employed with waveform description data. Triggering enables control over the timing of the waveform.

THE STREAMING INTERFACE

The link or interface between the source of the data and its destination in a streaming configuration is, of course, critical for the rate that samples can be captured and the bandwidth of the signal that can be streamed. There are a few possibilities here, but one most promising is PCI Express (PCIe).

PCIe is a serial high speed interconnect, which replaced legacy bus-based PCI and PCI-X technologies, and is now migrating from desktop to embedded applications. PCI-Express operates more like a network than a bus. It utilizes a point-to-point topology, with separate serial links connecting peripherals to the processor. Data rates for PCIe 1.x ranges from 250 MB/s per lane to 4 GB/s using up to 16 lanes in each direction. The latest release version of the standard (3.0) can support 1 GB/s per lane to 16 GB/s for 16 lanes.

What kind of signal bandwidths can be accommodated in streaming over PCIe? With a data rate of 1 GB/s, this equates to 250 MS/s (32 bit I and Q pairs) and a capture/playback modulation bandwidth of 200 MHz. As can be seen from the evolution of PCIe, much wider bandwidths are possible. One difficulty might lie in the development of an interface driver to unlock the potential of the PCIe architecture and handle the flood of data over multiple lanes.

CONCLUSION

Streaming capture and playback of microwave signals is necessary for the development of advanced systems that operate in multiple modes, in a constantly changing environment. Solutions using off-the-shelf equipment have been lagging for this need, making it necessary for some to develop expensive custom solutions. It appears now that general purpose instrument manufacturers are beginning to implement the needed architectural features to stream waveforms at a high enough sample rate to address today's wide bandwidth applications. This is good news for our equipment budgets. ■

John Hansen *is currently a senior application engineer for Agilent Technologies' Electronic Measurements Group. He has more than 20 years of experience in system engineering and new product development within the wireless, microelectronics and defense industries. At Agilent, he has been responsible for the launch of new high frequency microwave signal generator products and is currently involved in market analysis and generation of technical content for the aerospace & defense markets. Prior to joining Agilent, Hansen worked at Hughes Network Systems, where he participated in the development of terrestrial cellular and satellite communication products as an engineering test manager.*

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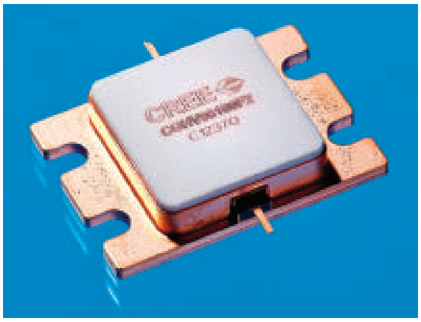

50 and 100 W, X-Band Fully Matched Transistors

GaAs MESFET and Traveling Wave Tube (TWT) amplifiers have long addressed high power X-Band applications from 10 W to multi-kW. GaAs MESFET solid state amplifiers deployed range from 10 to 100 W while TWT deployment range extends power to multi-kW; these amplifiers have served applications such as satellite communications, marine radar, medical imaging and military.

0.4 micron GaN HEMT transistors were first released into the market during the 2005 to 2006 time frame. The initial GaN HEMT offering focused on UHF through C-Band, primarily on CW broadband power and L- and S-Band pulsed power applications. Since the initial release, GaN HEMT suppliers have successfully fielded several million transistors. At Cree, the reported field FIT rates are less than 10 parts per billion hours of device operation. This FIT value rivals or is superior to any GaAs or Si power FET technology demonstrating GaN HEMT has established itself as a reliable and accepted technology.

Recently, a 0.25 micron GaN HEMT process technology has been released and to date includes product in die form, foundry service and X-Band fully matched packaged transistors. The X-Band matched device product family consists of four products:

- CGHV96050F1: 50 W, 50 Ω matched transistor tested under OQPSK at 25 W Pave from 7.9 to 8.4 GHz
- CGHV96100F1: 100 W, 50 Ω matched transistor tested under OQPSK at 50 W Pave from 7.9 to 8.4 GHz
- CGHV96050F2: 50 W, 50 Ω matched transistor tested from 7.9 to 9.6 GHz under 100 μsec, 10 percent duty cycle
- CGHV96100F2: 100 W, 50 Ω matched transistors tested from 7.9 to 9.6 GHz under 100 μsec, 10 percent duty cycle

The CGHV96050F1 and CGHV96100F1 are characterized for satellite communication linear power requirements under OQPSK. ***Figures 1*** and **2** show the linear features over frequency based on -30 dBc offset mask. Both the 50 and 100 W, X-Band GaN HEMT transistors show excellent linearity in the 30 percent power added efficiency (PAE) range while providing linear gain exceeding 12 dB. The spectral compliance is achieved while operating at 3 dB backed-off from Psat.

The CGHV96050F1 and CGHV96100F1 can be deployed in 25 to 100 W linear power solid state amplifiers (SSPA) which have ear-

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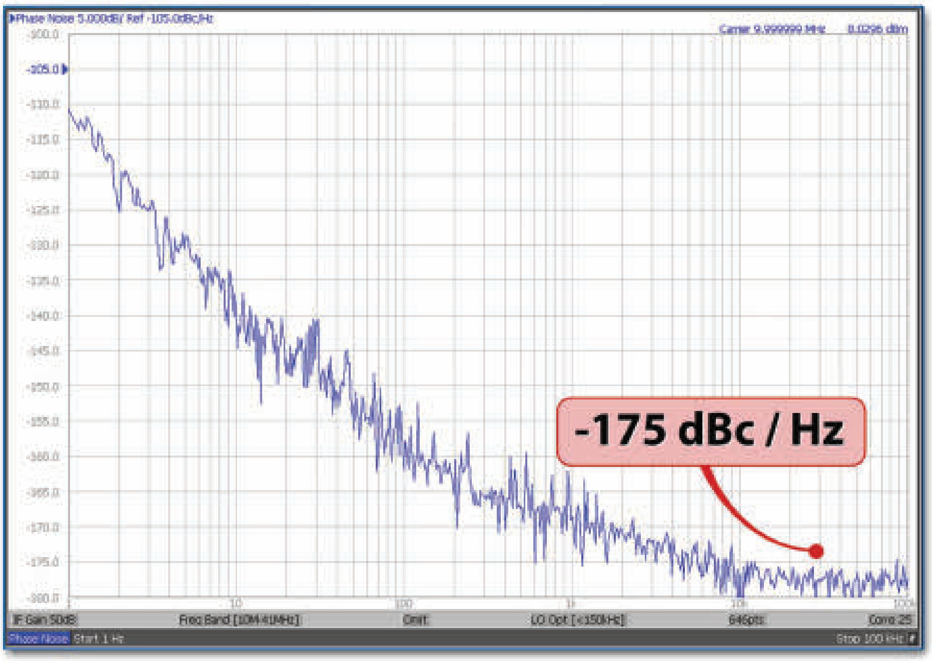
Phase Noise Performance



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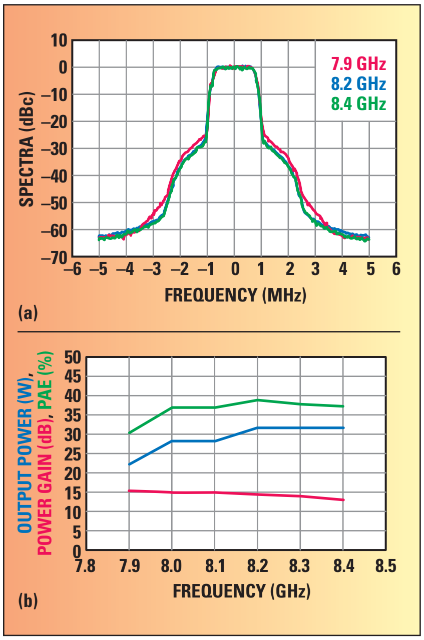
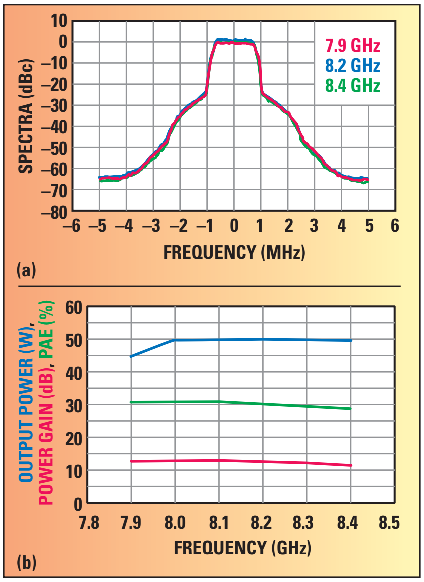


▲ *Fig. 1 CGHV96050F1 typical performance spectral mask under OQPSK modulation, 1.6 Msps V_{DD} = 40 V, output power = 44 dBm/25 W (a) and linear output power, gain and PAE, V_{DD} = 40 V, I_{DQ} = 500 mA, 1.6 Msps, OQPSK modulation at –30 dBc (b).*

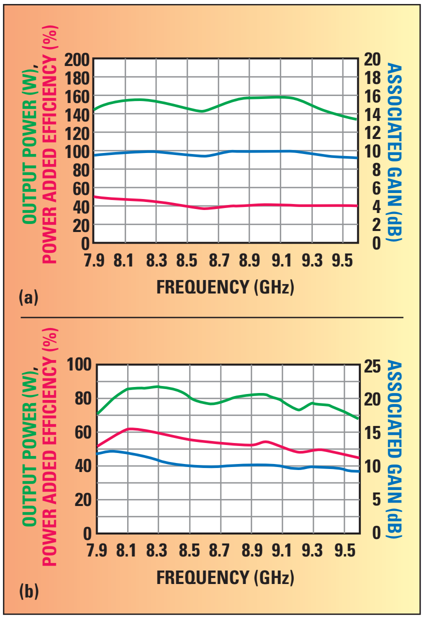
lier typically utilized GaAs MESFET technology. Devices are easily combined. For example, a high power SSPA could be developed with multiple combined 100 W transistors. Typical performance for a four-way combined 100 W transistor could realize a 200 W average power linear amplifier. TWTs typically operate at 6 dB backoff from their saturated power and in many cases require external linearization to be able to meet the linearity requirements for satellite communications. A 200 W GaN HEMT linear performance (400 W peak power) would be equivalent to a corresponding 800 W TWTA in terms of linear power performance capability.

The CGHV96050F1 and CGHV96100F1 offer the wide video bandwidth capabilities important for multi-carrier satellite communication applications. ***Figure 3*** shows tone spacing through 80 MHz separation while maintaining spectral stability in terms of IM3, IM5 and IM7.

The CGHV96050F2 and CGHV96100F2 GaN HEMT transistors have also been characterized for saturated power, pulsed applications such as weather and marine radar as shown in ***Figure 4***. The transistors offer a minimum power gain of 10 dB while offering 80 or 140 W output power over the 7.9 to 9.6 GHz frequency band and PAE offered is 45 to 50 percent. These features correspond to an average of two times improvement over comparable GaAs MESFET transistors at this frequency and power level.

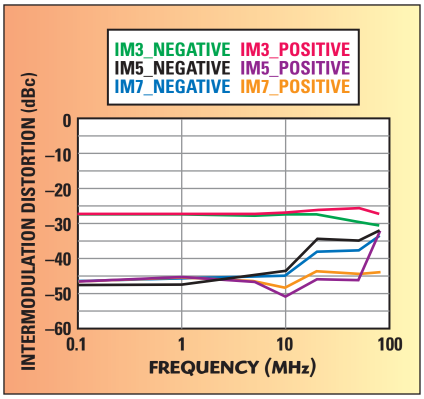


▲ *Fig. 2 CGHV96100F1 typical performance spectral mask under OQPSK modulation, 1.6 Msps V_{DD} = 40 V, output power = 47 dBm/50 W (a) and linear output power, gain and PAE, V_{DD} = 40 V, I_{DQ} = 1000 mA, 1.6 Msps, OQPSK modulation at –30 dBc (b).*

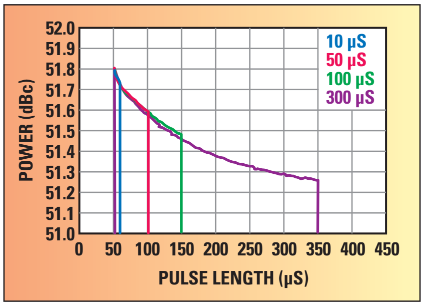


▲ *Fig. 4 CGHV96100F2: 100 W X-Band internally matched transistor (a) and CGHV96050F2: 50 W X-Band internally matched transistor (b) performance.*

The pulse droop demonstrated by the 50 and 100 W GaN HEMT transistors is excellent as shown in ***Figure*** **5**. Short pulse width droop is extremely low and even a relatively long (for this application) 300 µsec pulse droop is a very good 0.5 dB as shown in the figure. The minimal pulse droop is due to the superior thermal properties of the Silicon Carbide (SiC) substrate used as a substrate material for the GaN-on-SiC HEMT structure.



▲ *Fig. 3 Intermodulation distortion performance vs. tone spacing, V_{DD} = 40 V, frequency = 8.2 GHz, output power = 43 dBm/20 W.*



▲ *Fig. 5 Output power vs. time, V_{DD} = 40 V, P_{IN} = 41 dBm, duty cycle = 10%.*

These high power X-Band transistors offer excellent features for 50 thru 100 W requirements and can be combined into high power SSPAs exceeding 1 kW by deploying 100 W transistors into a multiple device combination scheme. The advantages of GaN HEMT transistors for X-Band will offer significant systems benefits in terms of power management, thermal management, power supply load, package size shrink of the SSPA unit size or offering significant reliability and cost advantages when compared with TWTA. GaN HEMT SSPA system advantages are overwhelming when compared with GaAs MESFET-based SSPA and TWTA.

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Tri-Band VSAT Single Case Antenna

Military missions and natural disaster response share the need for rapid deployment of SATCOM infrastructure under very challenging conditions. Speed, performance and agility are critical, and until now, those capabilities largely have been viewed as incompatible. Greater bandwidth was available, but not in a form factor that could be fielded quickly or easily. Newer VSAT terminals offered more complex capabilities, but required lengthy set-up and adjustments.

Harris Corp.'s 1.3-meter Seeker™ terminal provides support for X-, Ku-, and Ka-Bands in a single transit case that can be checked as airline baggage. Supporting throughput of 8 Mbps, Seeker offers the highest gain possible in a single-case (see ***Figure 1***) antenna that is as small as many 0.9-meter systems.

Fig. 1 Transit case for 1.3-meter Seeker terminal.

What makes this possible? Seeker was designed to operate without an antenna controller unit or fans, drastically reducing weight, bulk and noise – as well as cost and power consumption. One battery can provide 80 minutes of airtime in the event of a power interruption.

An integrated RF receiver/transmitter is slice mounted directly to the back of Seeker's reflector hub, significantly reducing the number of cables required to just five: one input power, one output power, one input GPS, and two transmit/receive cables.

Seeker is self-contained, with a GPS receiver, inclinometer, flux gate compass and simpli-

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Melbourne, FL

fied keyboard with a built-in display. Its large aperture size reduces the need for ESD spreading, thereby conserving up to 50 percent of satellite transponder bandwidth power compared with 0.6-meter solutions.

Ease of deployment and use are paramount in Seeker's design. The system can be set up by one person and operating in just 10 minutes. This is due not just to its innovative packaging and agility, but also to its user-friendly Acquisition Wizard. This embedded tool "coaches" the user through three simple steps to signal acquisition using elevation, azimuth and skew angle adjustments.

Even the novice user can acquire and join the satellite network in less than five minutes – something not possible with other VSAT systems, which still require the operator to pre-plan the mission, peak the terminal after acquiring, and fine-adjust the polarization skew angle to align to the target satellite.

Seeker excels in outdoor tactical environments. Its ruggedized electronics can withstand challenging thermal, wind and water conditions with minimal degradation in throughput capability.

▲ *Fig. 2 Seeker 1.3-meter terminal with transit case.*

Seeker was designed in conjunction with other Harris terminals ranging in size from 0.45 to 3.8 meters. This "family" approach ensures efficient use of common, swappable components such as the modem, power supply, cabling and hardware. Each reflector panel also is interchangeable, simplifying field repairs and lowering sparing costs compared with traditional, matched-set reflector panel configurations. Use of common elements has the added benefit of reduced training time. The product can be bundled with Harris CapRock satellite bandwidth and services to provide a complete end-to-end SATCOM solution anywhere in the world.

Seeker has been demonstrated to several government organizations and companies that have recognized its unique benefits. During a recent demonstration, military attendees commented, "A 1.3-meter terminal in one case (see ***Figure 2***). Seeker's terminal throughput is impressive for its class. It is so easy to use and the common receive/transmit unit across apertures ranging from 0.45 meters to 1.3 meters allows me to tailor my equipment for my specific mission needs."

Onsite demos are available.

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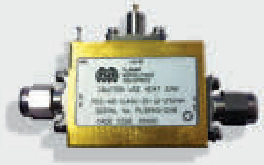

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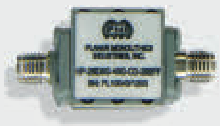

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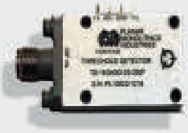

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High Performance Airborne Router for Critical Defense ISR

iDirect Government Technologies' (iGT) new satellite airborne router, the e8000 AR, is for government customers who want high speed communications on a variety of transport and intelligence, surveillance and reconnaissance (ISR) aircraft platforms. The new router is designed for easy roll-on, roll-off integration into both low-speed and high-speed military airframes, supporting multiple missions from a single satellite router or modem that can be connected into an existing iGT regional or global satellite internet protocol (IP) network.

The e8000 AR is a software-defined satellite modem that comes in a one RU rack-mount enclosure, 21 inches deep, and fits into the smallest portable flyaway cases. Weighing less than 16 pounds, the new router will not bust the operator's margin for weight. Also included are locking Ethernet, RF and 38-999 connectors that provide military-grade interfaces for high performance and secure connections that will not loosen during operations where high vibration is present. With both AC (100 to 240 V, 50 to 400 Hz) and DC (28 V) inputs (see ***Figure 1***), the router can be easily powered from an airplane's native power bus eliminating power converters that may produce dirty power. The entire unit is designed and tested to meet MIL-STD 810G airborne environmental standards and MIL-STD 461F standards for EMI and radiated emissions.

Fig. 1 e8000 AR back side inputs and connections.

iGT routers have flown on multiple military airframes, from the low-speed King Air C12 surveillance aircraft to the high-speed C17 transport aircraft, supporting multiple military-specific applications. The e8000 AR router's high-speed communications-on-the-move (COTM) features along with the iDirect IP network, delivers voice, video and data applications to and from personnel on board the aircraft. The e8000 AR can be optimized for downstream or upstream data rates using either Deterministic Time Division Multiple Access (D-TDMA) or Single Channel Per Carrier (SCPC) operational modes. The router can be operated in either mode and switched by the operator depending upon the mission. For bandwidth intensive ISR applications, the e8000 AR can be operated in SCPC mode where up to 19 Mbps can

iDirect Government Technologies
Herndon, VA

be transmitted off the aircraft in the upstream path. These data rates can support multiple high-definition cameras for surveillance and sensor data from on-board video and sensor gathering equipment. The e8000 AR can also be operated in D-TDMA mode for improved bandwidth efficiency and achieve transmit data rates as high as 11 Mbps upstream from the aircraft, depending upon satellite link budget limitations.

Router data rate performance on aircraft platforms are antenna and satellite frequency band dependent. The e8000 AR is designed to operate in any combination of antennas and satellite frequency bands, including wideband global satellite (WGS) constellation, to provide optimum performance to the operator. The e8000 AR has a built-in open antenna modem interface protocol (OpenAMIP) to interface with airborne antenna's antenna control unit (ACU), which provides real-time location and pointing information during flight. For antennas without OpenAMIP, the e8000 AR includes an on-board CPU with an applications interface (API) for custom antenna interface development. The CPU comes with a thin-Linux operating environment that can be accessed through keyboard, video and mouse (KVM) interface, front-panel USB, or Ethernet port.

Some frequency bands, such as Ku-Band, have adjacent satellite interference (ASI) requirements due to decreased satellite spacing that can limit the power spectral density (PSD) transmitted from an airborne antenna system. The e8000 AR router has inherent COTM features that allow the operator to continue to optimize data rate performance, select operational modes and comply with ASI requirements. The router does this with spread spectrum technology that allows waveform spreading to meet PSD requirements, while maintaining the same data rate. The e8000 AR supports spreading factors 2, 4, 8 and 16.

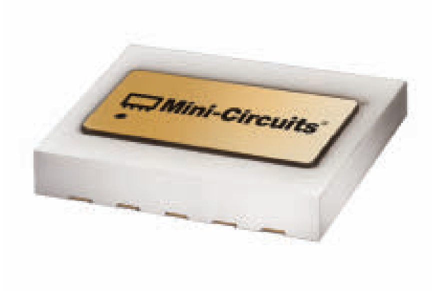
On other satellite frequency bands such as X-Band and Ka-Band, ASI is less of an issue due to increased satellite spacing and allows much higher transmit power in the airborne antenna system. The e8000 AR takes advantage of this higher power operating environment and can be operated without waveform spreading, and uses SCPC mode where iDirect routers have achieved data rates upstream from the aircraft as much as 14 Mbps from a 17-inch airborne antenna.

The e8000 AR also supports COTM features such as automatic satellite beam switching (ABS) and global roaming. Airborne networks can be regional, multi-regional or global as airplanes typically travel great distances and it can require more than one satellite or satellite beam to cover the traversed area. In order to maintain constant communications when the antenna needs to re-point or the modem needs to select a new beam, the e8000 AR and iDirect's Global Network Management System (GNMS) work together to make this physical transition nearly seamless. Along with on-board satellite beam maps, GPS input and an awareness of a multi-node network, the e8000 AR provides the intelligence to transmit when it is safe, or legal to do so, and switch between satellites as the airplane moves from one satellite beam or coverage area to another satellite beam, reestablishes the connection and provides the optimum data rates that can be achieved for that link.

In addition to delivering high performance, the e8000 AR is certified to federal information processing standard (FIPS) Level 2 and can be operated in transmission security (TRANSEC) mode while operating in an airborne network. The iDirect system uses AES 256-bit key encryption and exchanges X.509 digital certificate authentication with automatic key management. The e8000 AR can be operated with TRANSEC in a regional or global network with the use of iDirect's unique global key distribution management system that allows roaming between secure networks.

The e8000 AR operates in a star topology and uses standards-based DVB-S2 with ACM waveform and can operate in networks with downstream rates up to 45 Msps and upstream rates up to 15 Msps in SCPC mode. Input frequency range is 950 to 2000 MHz and supports WGS frequencies. Modulation formats on the downstream are QPSK, 8 PSK and 16 APSK, and BPSK, QPSK and 8 PSK on the upstream.

iDirect Government Technologies, Herndon, VA (703) 648-8118, www.idirectgt.com.



High Gain, 1 to 4.2 GHz Mixer

The MRA-42MH+ combines a double balance mixer with a highly linear, low noise IF amplifier to provide a high gain active mixer for efficient operation from 1000 to 4200 MHz. The LO power is +13 dBm, conversion gain is 11.5 dB typical, L-R isolation of 33 dB is typical and output IP3 of dBm is typical with an IF frequency range of 10 to 800 MHz. It is packaged in a small LTCC substrate that is 0.300" × 0.250" × 0.060". Maximum operation temperature range is from -55° to 125°C. Typical applications include cellular, PCN, WCDMA, fixed satellite, defense radar and communications.

The MRA series, due to its ultra compact size, offers the additional flexibility to enable the user to install design specific components (i.e., filters, attenuators, switches, etc.) based upon the design needs. The Schottky diode and MMIC amplifier are bonded to a multilayer integrated LTCC substrate, and then sealed under a controlled nitrogen atmosphere with gold plated covers and eutectic Au-Sn solder. These very compact active mixers have been tested to MIL requirements for gross leak, fine leak, thermal shock, vibration, acceleration, mechanical shock and HTOL.

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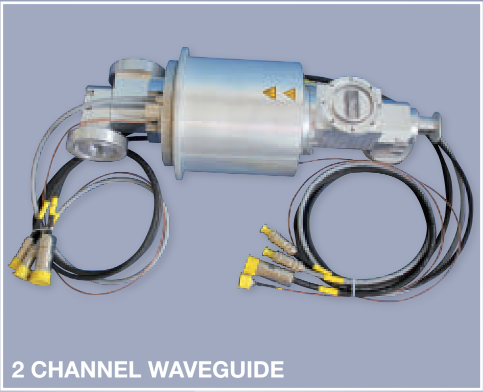
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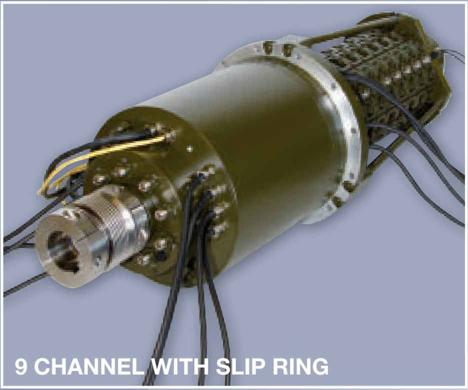

9 CHANNEL WITH SLIP RING

SPINNER is a global supplier for rotary joints and slip ring assemblies. With more than 50 years of experience in RF Design and Engineering, SPINNER is your ideal partner for customised solutions. Our product range includes **coaxial, waveguide and fibre optic, single or multi channel rotary joints, slip ring and media joint assemblies. Systems are available for all frequency bands.**

SPINNER offers superior rotary joints and slip rings for:

- **Air traffic control radars**
- **Civil applications**
  automotive, satellite tracking
- **Defence applications**
  air, sea, land
- **SatCom**
- **Space applications**
- **Fibre optic**
  single channel, multi channel
  (up to 21 channels)


AIR TRAFFIC CONTROL RADAR SYSTEM

SPINNER is a global leader in developing and manufacturing state-of-the-art RF components. Since 1946, the industries leading companies have trusted SPINNER to provide them with innovative products and outstanding customised solutions.

Headquartered in Munich, and with production facilities in Germany, Hungary, USA, China and Brazil the SPINNER Group now has over 1,300 employees worldwide.

Our subsidiaries and representatives are present in over 40 countries and provide our customers with an international network of support.

SPINNER GmbH || Germany
ads@spinner-group.com
www.spinner-group.com

SPINNER

High Frequency Performance Worldwide

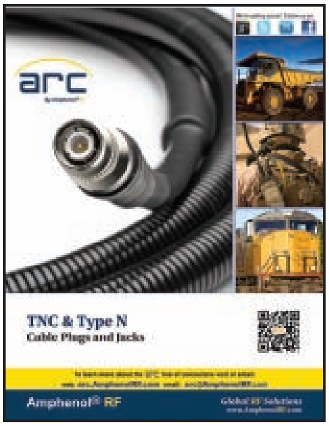
MILITARY MICROWAVES
LITERATURE SHOWCASE

A/D Symposium DVD

VENDORVIEW

Get a complimentary copy of Agilent's 2012 A/D Symposium DVD that includes 20 technical papers on design tools and robust test solutions to help you build greater assurance in test system readiness. Areas covered include radar/EW, satellite, SDR/MilCom, general RF and microwave test. Also included are product and solution videos, application notes and additional resources. Get a copy at www.agilent.com/find/ad2012dvd.

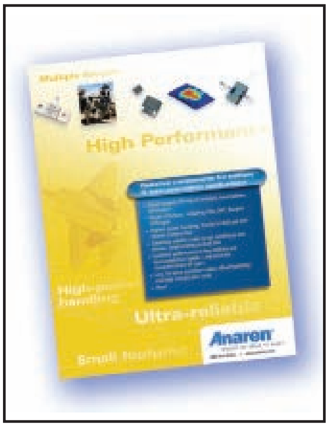
Agilent Technologies Inc.,
Santa Clara, CA (800) 829-4444, www.agilent.com.



Ruggedized Connectors

Amphenol® RF's ARC line of ruggedized connectors literature and video training are now ready for download at arc.amphenolrf.com under the resource section. Download the cutsheet and watch the video training to learn more about how these connectors are fully submersible and are designed to handle the harshest of elements. The ARC line comes in Type N and TNC, as well as with or without cables.

Amphenol RF,
Danbury, CT (800) 627-7100, www.amphenolrf.com.

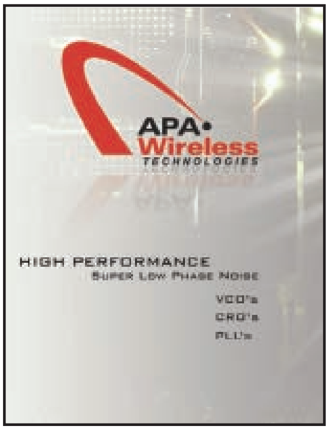


Resistive Components

VENDORVIEW

Precision-engineered and proven again and again in the toughest applications – Anaren's family of terminations, resistors, and attenuators addresses your needs. They are designed for high-power applications, from 4 to 800 W and are suitable for 'mission critical' applications from DC to 6 GHz, including beamforming networks, military radios, combiners/dividers, T/R modules, high voltage power supplies and high-power detectors. They have a range of packages (SMD, chip, flanged, and flangeless), accurate characterization of performance and are available in low, 50-piece minimum order quantities.

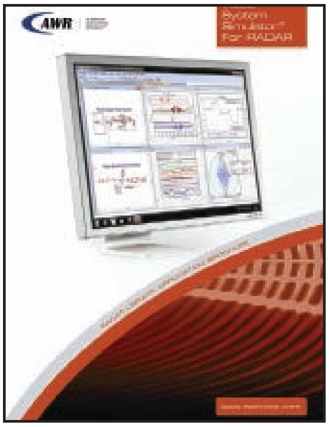
Anaren Ceramics,
Salem, NH (603) 898-2883, www.anaren.com.



VCO/CRO Solutions

Looking for high frequency, low phase noise, wideband VCO/CRO solutions to integrate successfully into your RF design? APA Wireless offers total engineering support and assistance that far exceeds competitors in helping you attain your system performance goals. Custom designs are the company's specialty. Its INSTA-SOURCE and ACCUSOURCE online ordering system allows you to tailor a product to your unique specifications while maintaining reasonable lead-time.

APA Wireless,
Oakland Park, FL (954) 563-8833, www.apawireless.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.,
El Segundo, CA (310) 726-3000, www.awrcorp.com.

Connectors

CarlisleIT has added two new connector lines to its push-on family – the TMP® and WMP® series. The TMP family was designed to provide higher power handling capacity for radar applications, while the WMP line provides the smallest form factor for space restricted applications. Both connector series provide the benefits of a push-on interface (simple connection and ease of use in dense package configurations) and include PCB mount, field replaceable, microwave cable, and custom connectors.

Carlisle Interconnect Technologies,
St. Augustine, FL (800) 458-9960, www.carlisleit.com.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www.polezero.com

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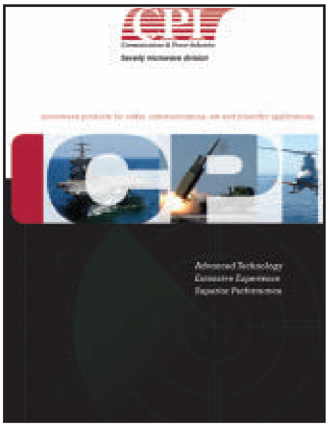
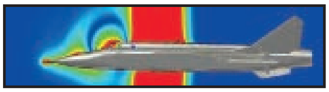


Product Catalog

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

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



Electromagnetic Fields Simulation Software

VENDORVIEW

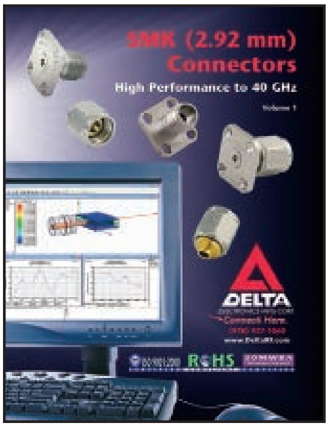
CST develops and markets software for the simulation of electromagnetic fields. Its products allow you to characterize, design and optimize electromagnetic devices all before going into the lab or measurement chamber. The extensive range of tools integrated in CST STUDIO SUITE® enables numerous applications to be analyzed without leaving the user-friendly CST design environment and can offer additional security through cross verification. CST's customers operate in industries as diverse as defense, telecommunications, automotive, electronics, and medical equipment.

Computer Simulation Technology AG (CST), Darmstadt, Germany +49 6151 7303 0, www.cst.com.

SSPA Family

CTT Inc. announces a new family of compact, GaN-based solid-state power amplifiers (SSPA) operating in the 6.4 to 11 GHz frequency range for a wide variety of RF and microwave applications including commercial, industrial and military radar applications. CTT's latest SSPA designs offer as much as 160 W of output power in a compact package. The SSPAs include models for narrowband (in both continuous wave and pulsed mode), wideband and ultra-wideband applications.

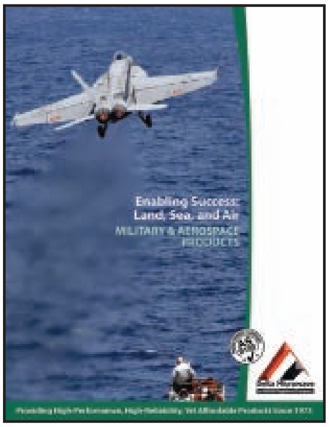
CTT Inc., Sunnyvale, CA (408) 541-0596, www.cttinc.com.



SMK Series Catalog

Delta Electronics Manufacturing's new 15 page SMK (2.92 mm) series catalog details over 65 part numbers that span 31 different configurations in this range of products that operate mode-free to 40 GHz. These products include: Cable plugs and jacks, field replaceable flange mount receptacles (jacks and plugs), thread-in "spark plug" receptacles, adapters within series, hermetic seals and accessory pins. In addition, the catalog features thorough information on materials and finishes, typical electrical performance, assembly procedures, detailed mounting information and a competitive cross reference.

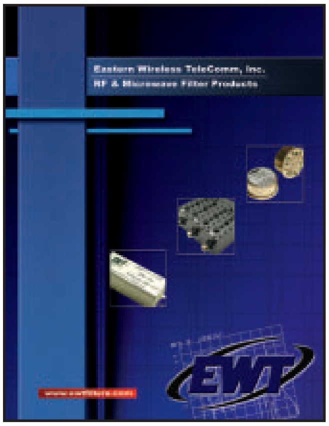
Delta Electronics Manufacturing Corp., Beverly, MA (978) 927-1060, www.deltarf.com.



Components and Assemblies

Delta Microwave has been designing, manufacturing, and testing microwave components and assemblies for military, space, and commercial applications since 1973. Delta Microwave uses advanced technologies to provide custom solutions for challenging customer microwave requirements. The result is a broad product offering that includes low noise and power amplifiers, filters, filter-amplifiers, couplers, combiners and dividers, limiters, multiplexers, and integrated assemblies covering frequencies from 1 MHz to 40 GHz with power handling up to 25 kW.

Delta Microwave, Oxnard, CA (805) 751-1100, www.deltamicrowave.com.



Filter Catalog

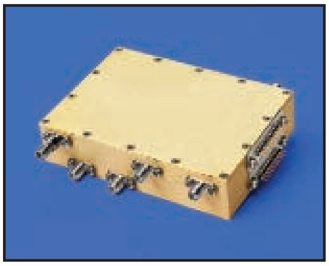
This new short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial and wireless applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities.

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

Midwest Microwave Catalog

The new Midwest Microwave catalog highlights passive microwave components for military, space and testing applications. The catalog features current product offerings along with an updated Qualified Parts Listing of attenuators, terminations and SMA connectors manufactured to meet or exceed the performance specifications set forth in the MIL Specification. Also contained within this release is an updated list of approved Defense Logistics Agency (DLA – Formerly DESC) specification products. This list includes SMA, SSMA and BMA connectors and precision adapters.

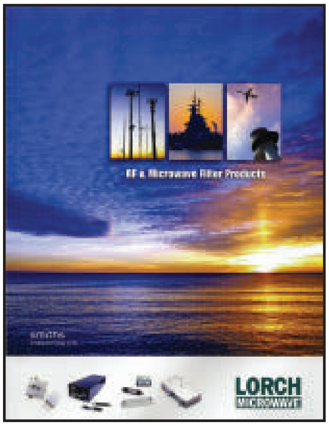
**Emerson Network Power Connectivity Solutions Inc.,
Bannockburn, IL (847) 739-0300,
www.emersonnetworkpower.com.**



RF Synthesizers and Generators

The ITT Exelis Microwave Systems business has been designing and manufacturing high performance DDS-based RF synthesizers and RF waveform generators for more than twenty years. If your radar, IFF, EW or SIGINT system requires fast switching and clean signals, please review ITT Exelis' technical brief for a sampling of capabilities in low spurious, wideband solutions, tuning in less than 200 nanoseconds from DC to 26 GHz.

**ITT Exelis,
McLean, VA (703) 790-6300, www.exelisinc.com.**



Short Form Product Guide

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

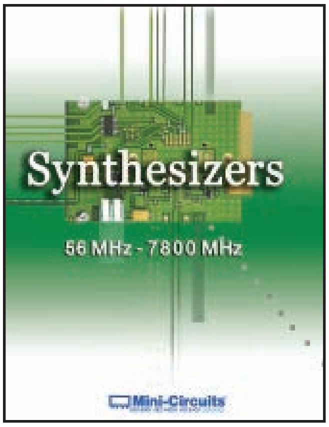
**Lorch Microwave,
Salisbury, MD (410) 860-5100, www.lorch.com.**

Components Catalog

VENDORVIEW

Celebrating its 51st anniversary, MECA (Microwave Electronic Components of America) designs and manufactures an array of RF/microwave components with industry leading performance. 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.

**MECA Electronics Inc.,
Denville, NJ (866) 444-6322, www.e-meca.com.**



Synthesizers Brochure

VENDORVIEW

The Mini-Circuits design team can create a custom frequency synthesizer tailored to your requirements. They review your requirements and, following technical discussions between your engineers and Mini-Circuits designers, work closely with you to create final specifications that meet or exceed your requirements. To ensure high yields, they factor in component tolerances and even variations in manufacturing processes. You will have full access to performance data from sample units, and can even evaluate sample units in your system to ensure that final production units fulfill your performance requirements.

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

RF and Microwave Filters and Assemblies

VENDORVIEW

NIC celebrates 25 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. To request a copy, email sales@nickc.com or visit www.nickc.com.

**Networks International Corp.,
Overland Park, KS (913) 685-3400, http://nickc.com.**

PERFECTION

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Single Channel & Dual Channel Rotary Joints — Frequency DC to 40.0 GHZ
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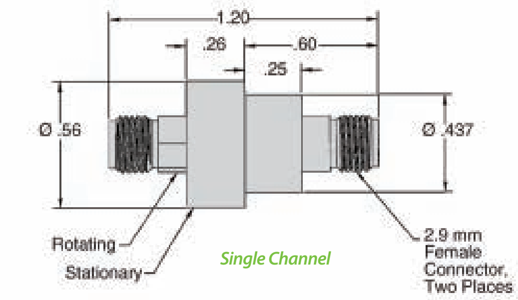
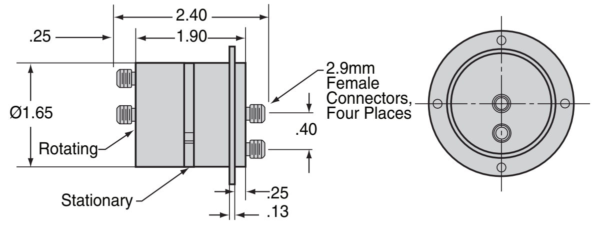
You'll find that we specialize in perfection.



Single Channel



Dual Channel

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	

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.

MDL

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MILITARY MICROWAVES
LITERATURE SHOWCASE

Overview and Capabilities Brochure

VENDORVIEW

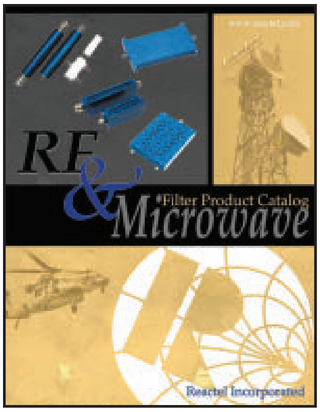
Planar Monolithics Industries (PMI) has released its latest product Overview and Capabilities Brochure. The brochure contains a listing of various RF components and RF module product types up to 40 GHz, including amplifiers, attenuators, phase shifters, detectors, DLVA/SDLVA's, filters, limiters, switches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

Planar Monolithics Industries, Frederick, MD (301) 662-5019, www.pmi-rf.com.

Product Catalog

RF Communications become more difficult in the presence of multiple interferers, as is common in today's Military ConOps where many radios are operating in close proximity. Pole/Zero's new product catalog provides a broad range of solutions to purify transmitters and protect receivers so you can achieve the clarity and range you need for your mission. Fast tuning, agile products are available in the tuning range of 1.5 MHz to 2 GHz. Contact Pole/Zero to resolve your interference issues.

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



Filters, Multiplexers and Multi-function Assemblies

VENDORVIEW

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

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

MILITARY MICROWAVES

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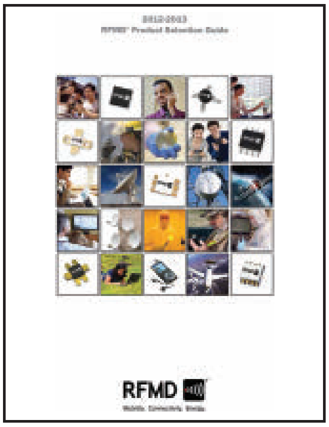
Analyzing Antenna Performance

VENDORVIEW

Successful integration of an antenna onto a vehicle platform poses many challenges, from vehicle features and motion impacting antenna performance to environmental factors, and radiation hazards. This paper provides a variety of examples on how modeling and simulation can be used to analyze antenna performance, identify problems and evaluate potential solutions. Download at www.remcom.com/antenna-platform-integration/.

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



Product Selection Guide

VENDORVIEW

RFMD's 2012-2013 Product Selection Guide provides specifications for more than 750 products including more than 90 recently released products targeting multiple end-market applications. The 64-page guide allows customers to cross-reference and search products using end-market application diagrams. RFMD's Product Selection Guide lists products servicing more than 15 end-market segments including cellular, point-to-point microwave radio, WiFi, WiMAX, LTE, CPE, smart energy AMI, Zigbee®, wireless infrastructure, military and space, broadband transmission, consumer, and others.

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

A&D Selector Guide

VENDORVIEW

The June 2012 A&D Selector Guide includes the latest RF and microwave products for electronic warfare, communications, jammers, and radar (including commercial) applications. Featuring more than 30 new products, the Selector Guide is organized by application and frequency bands. The Richardson RFPD A&D New Product Selector Guide is available on Richardson RFPD's website, updated monthly, and features direct hyperlinks for purchasing the latest products from the world's leading suppliers, along with links to the data sheet for each product.

Richardson RFPD Inc.,
LaFox, IL (800) 737-6937, www.richardsonrfpd.com.

Power Divider Short-Form Catalog

RLC Electronics introduces the release of its newest short-form catalog featuring power dividers. This catalog provides a comprehensive listing of DC to 40 GHz standard designs as well as the company's capabilities to customize in accordance with your specifications. RLC has designed and manufactured a wide variety of power dividers for both commercial and military applications. Please contact them to request a copy of this catalog, or to obtain information regarding any of RLC's products.

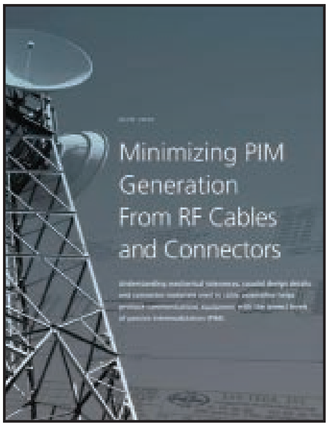
RLC Electronics Inc.,
Mt. Kisco, NY (914) 241-1334, www.rlcelectronics.com.

Test & Measurement Catalog

VENDORVIEW

This catalog will give you an overview of all Rohde & Schwarz's T&M products. It contains almost 200 pages full of information about the company's T&M instruments and systems as well as their software. Each product has a short description, photos, the most important specifications and ordering information. On the Rohde & Schwarz website, you can find this catalog as a PDF file for download. Order number: PD 5213.7590.42.

Rohde & Schwarz GmbH & Co. KG,
Munich, Germany +49 89 4129-12345,
www.rohde-schwarz.com.



PIM White Paper

VENDORVIEW

San-tron's latest white paper, "Minimizing PIM Generation From RF Cables and Connectors," explores passive intermodulation (PIM), its effects on modern communication systems, and how it can be minimized in high-frequency cables, connectors, and cable assemblies. In addition to exploring the different causes of PIM, this white paper also reviews San-tron's efforts to create connector interfaces with low-PIM mechanical structures and to minimize the use of paramagnetic materials in its connectors.

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

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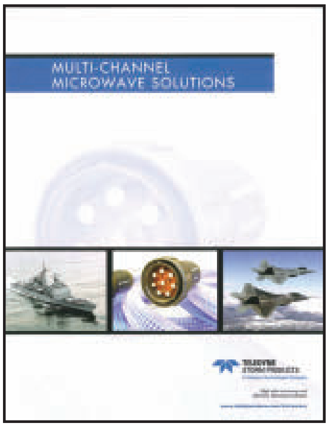
FleXtra Application Note

SV Microwave is proud to introduce the FleXtra™ line of cable assemblies – a new family of high performance flexible 0.047 style cable assemblies. Available in multiple variations, the new FleXtra cables will surely fit your needs. Choose from a wide variety of industry standard connector styles or custom designs to meet your performance requirements.

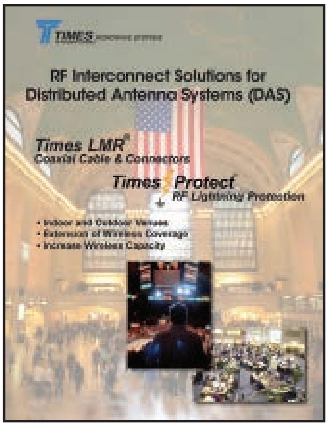
SV Microwave,
West Palm Beach, FL (561) 840-1800, www.svmicrowave.com.



Harness Capabilities Brochure

Teledyne Storm Products' new 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. It includes a case study.

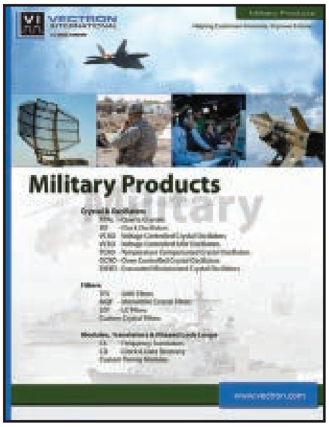
Teledyne Storm Products,
Woodridge, IL (630) 754-3300, www.teledynestorm.com.



RF Interconnect Solutions for DAS

Times Microwave Systems announces the availability of its RF Interconnect Solutions for Distributed Antenna Systems (DAS) brochure. Typical applications of DAS technology include large buildings, stadium venues and shopping malls where signals are either attenuated because of the surrounding building structure or large groups of people congregate to overload the otherwise limited capacity of carrier networks. Included in the brochure are the popular LMR® low loss, flexible coaxial cables, connectors and cable assemblies, low PIM plenum and non-plenum rated cables and jumpers and surge protection devices.

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



Military Products Catalog

Vectron International is both a product manufacturer and a solutions provider, leading with its unique technology but always prepared to design and engineer custom solutions where required. Vectron's core competency combines its classic crystal and SAW technology with sophisticated integrated circuits and advanced packaging. Aside from these capabilities, Vectron strives to be extremely flexible and focused on service, responding quickly and professionally helping customers innovate, improve and grow their business.

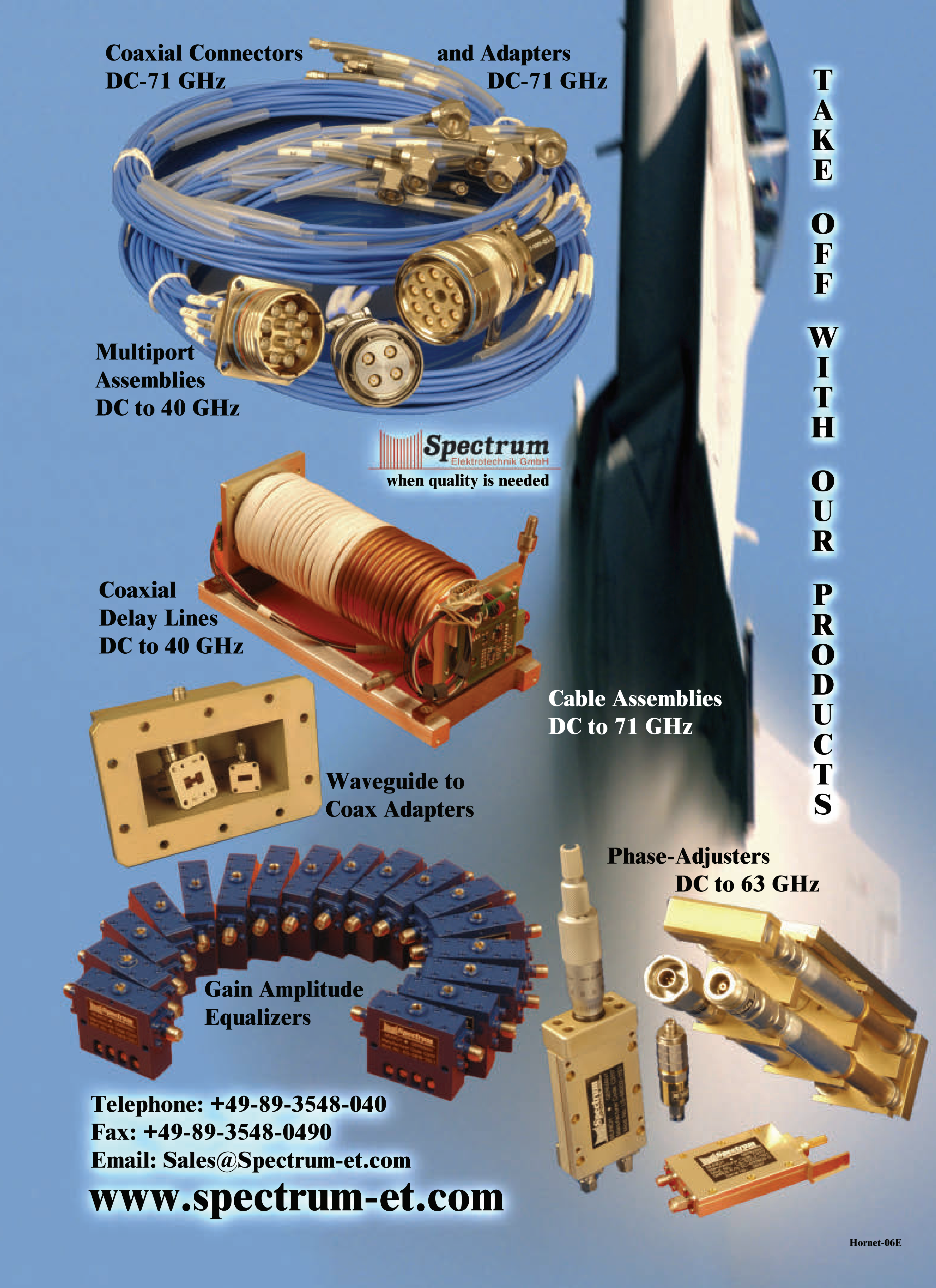
Vectron International,
Hudson, NH (888) 328-7661, www.vectron.com.

Werlatone 2012 Catalog

VENDORVIEW

Werlatone, in business since 1965, supplies a full range of high power combiners, dividers, 90° hybrid couplers, and directional couplers. The company's new catalog highlights some of its new products as well as several of its most popular designs. Werlatone's full library contains over 2000 models. Please note that 65 percent of the company's business revolves around custom designs.

Werlatone Inc.,
Patterson, NY (845) 278-2220, www.werlatone.com.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and Adapters
DC-71 GHz
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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
D8851W*	2-Way	20-1000	500	5.6 x 3.05 x 1.8	0.6	1.35:1	15
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

* "W" references a Watertight Design

Dual Directional Couplers

Model	Coupling (dB)	Frequency (MHz)	Power (W CW)	Size (Inches)	Insertion Loss (dB)	VSWR	Directivity (dB)
C8858	40	10-1000	250	2.09 x 1.16 x 0.57	0.4	1.30:1	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

* Non-Connectorized / Tabs

Our Patented, Low Loss designs tolerate high unbalanced input powers, while operating into severe Load Mismatch conditions.

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