ASSOCIATION OF OLD CROWS
Advancing Electromagnetic Warfare TOGETHER
crows.org

January 2023 Vol. 46, No.1

JED

Journal of Electromagnetic Dominance

Advancing HPM Technology

Also in this Issue:

SOLID STATE
RF POWER AMPLIFIERS
for Maximum Power Down Range
HF to X-Band
MULTI mission
EW
Radar
Satcom
Threat Simulation
Communications
Test
AIR COOLED
MULTI mode SSPAs
Mission Scenario Configurable
Pre-loaded Jamming Modes
Field Proven in Mobile Applications
High MTBF's
Best in Class SWaP
LIQUID COOLED
SCALABLE SSPAs
Hundreds of kW - Pulse and CW
No Single Point of RF Failure
"On Air" Hot Swapping
Long Pulse Widths and 500KHz PRF's
MODULES
Built in Protections
48V Models Available
Rugged and Highly Reliable
Custom Designs Available
Feature Rich with Digital or Analog Controls
EMPOWER'S AMPLIFIERS are tactically deployed and operating on multiple levels in support of DoD missions
EMPOWER
RF SYSTEMS, INC.
www.EmpowerRF.com
1(310)412-8100

JED
Journal of Electromagnetic Dominance

CONTENTS

January 2023 • Volume 46, Issue 1

US AIR FORCE

COVER PHOTO COURTESY OF EPIRUS, INC.

In November, Standing NATO Maritime Group 2 conducted its DYNAMIC GUARD 22 exercise, which was designed to build and maintain proficiency in maritime electronic warfare and anti-submarine warfare. Realistic electronic warfare capabilities were simulated by means of the Joint EW Core Staff (JEWCS) Transportable Radar and Communications Jamming and Simulator Vans (TRACSVAN), embarked on ITS Stromboli, plus special pods carried by G-FRAS DASSAULT FALCON 20 C aircraft (DRAKEN) (above).

NATO ALLIED MARITIME COMMAND PHOTO BY PETTY OFFICER 3RDCLASS EZEKIEL DURAN, USN

Departments

FEEDING THE SWARM

One of the biggest operational challenges the US has been addressing over the past decade is figuring out how it can take the fight to adversaries that employ anti-access, area-denial (A2/AD) strategies. Countries, such as China and Russia, have modernized their defensive battle networks (air defenses and naval defenses) to cover large swaths of the battlespace and put at risk enemy aircraft, ships and land forces well outside their sensor and weapons ranges.

In order to meet the A2/AD challenge, the US has been investing in a variety of interrelated technology areas, such as microelectronics, Artificial Intelligence (AI) and Machine Learning (ML), and small unmanned systems. The aim is to develop swarms of small autonomous weapons systems that can operate inside of an enemy's A2/AD bubble, coordinate with larger stand-off weapons systems at the edge of the battlespace and collectively degrade the air defenses and naval defenses in order to attack critical targets deeper in the battlespace, such as ballistic missile launchers and command and control centers.

The matrix of programs and efforts that feed into the DOD's swarming strategy is simply huge. It involves efforts such as DARPA's MOSAIC initiative (a program of programs), a variety of manned-unmanned teaming programs across the Services, and many, many more.

From an Electromagnetic Spectrum Operations (EMSO) perspective, these swarm nodes will be highly dependent on accessing the EMS, from sensing targets and accessing position, navigation and timing (PNT) information to transmitting and receiving information across data networks and attacking targets with jamming, cyber attacks, high-power microwave (HPM) systems and other weapons.

Two recent DOD solicitations released in late November illustrate how far the Department has progressed. DARPA's Autonomous Multi-Domain Adaptive Swarms-of-Swarms (AMASS) program is focusing on "the dynamic C2 of unmanned, autonomous swarms of various types (i.e., swarms-of-swarms) with a common C2 language for Theatre-level counter-anti-access(A2)/area denial (AD) capabilities," according to a DARPA program description in the solicitation. The idea is to enable different swarm weapons systems to communicate, form smaller groups, and compose those groups of different platforms best suited to accomplishing various tasks or missions – for example, as part of a suppression of enemy air defenses (SEAD) campaign.

The second solicitation calls for candidate EMSO technologies (at Technology Readiness Levels 2-5) to be demonstrated at the Silent Swarm 2023 exercise sponsored by Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)). Silent Swarm 2022 was a two-week event conducted in August that involved 150 personnel evaluating 17 different EMSO technologies on small, "multidomain unmanned systems." The Silent Swarm 2023 event will involve even more EW, including distributed electronic support and electronic attack (jamming, HPM and cyber attack) payloads, as well as deception payloads.

DOD labs and the defense electronics industry have been evolving swarm technologies to the point where programs, such as AMASS, and demonstrations like the Silent Swarm series are providing the warfighter with meaningful glimpses of what swarms can achieve against potential adversaries. This is allowing them to develop the tactics and concepts they will need to use swarms most effectively. Swarms are coming, and these capabilities cannot arrive too soon. *– J. Knowles*

JED
Journal of Electromagnetic Dominance

EDITORIAL STAFF
Editor: John Knowles
Account Manager: David Freeman
Senior Editor: John Haystead
Managing Editor: Aaron Brand
Technical Editor: Barry Manz
Contributing Writers:
Dave Adamy, Luca Peruzzi, Richard Scott, and Andrew White
Proofreaders: Ken Janssens, Shauna Keedian
Sales Manager: Kira Krewson
Sales Adminstrator: Amanda Glass

PRODUCTION STAFF
Layout & Design: Barry Senyk
Advertising Art: Elaine Connell
Contact the Editor: (978) 509-1450, JEDeditor@naylor.com
Contact the Sales Manager:
(800) 369-6220 or kkrewson@naylor.com
Subscription Information:
Please contact Glorianne O'Neilin at (703) 549-1600 or e-mail oneilin@crows.org.

Journal of Electromagnetic Dominance is published for the AOC by
NAYLOR
ASSOCIATION SOLUTIONS
550 SW 2nd Avenue
Gainesville, FL 32601
Tel (800) 369-6220
www.naylor.com

COVER PHOTO COURTESY OF EPIRUS, INC.
PUBLISHED JANUARY 2023/JED-M1222/7664

Calendar *Conferences & Trade Shows*

JANUARY

Surface Navy Association 35th Annual National Symposium
Jan. 10-12
Arlington, VA
www.navysna.org

FEBRUARY

Aero India 2023
Feb. 3-5
Bengaluru, India
www.aeroindia.gov.in

AFCEA West 2023
Feb. 14-16
San Diego, CA
www.westconference.org

IDEX
Feb. 20-24
Abu Dhabi, UAE
www.idexuae.ae

MARCH

AFA Air Warfare Symposium
March 6-8
Aurora, CO
www.afa.org

Satellite 2023
March 13-16
Washington, DC
www.satshow.com

Collaborative EW 2023
March 14-16
Point Mugu, CA
www.crows.org

DSEI Japan
March 15-17
Chiba, Japan
www.dsei-japan.com

Dixie Crow Symposium 46
March 20-23
Warner Robins, GA
www.dixiecrowsympsoium.com

APRIL

Annual Directed Energy S&T Symposium
Apr. 3-5
Mobile, AL
www.deps.org

Navy League Sea-Air-Space
Apr. 3-5
National Harbor, MD
www.seaairspace.org

Army Aviation Mission Solutions Summit
April 26-28
Nashville, TN
www.quad-a.org

MAY

Cyber Electromagnetic Activities (CEMA) Conference
May 2-4
Aberdeen Proving Ground, MD
www.crows.org

Special Operations Forces Week
May 7-9
Tampa, FL
www.sofic.org

AOC Europe
May 15-17
Bonn, Germany
www.aoceurope.com

EW Capability Gaps and Enabling Technologies Conference
May 16-18
Crane, IN
www.crows.org

*AOC conferences are noted in **red**. For more info or to register, visit crows.org. Items in **blue** denote AOC Chapter events.*

Calendar *Courses & Seminars*

JANUARY

AOC Virtual Series Webinar: Regaining the Spectrum Offensive
Jan. 5
2-3 p.m. EDT
www.crows.org

AOC Virtual Series Webinar: 2023 GPS Spoofing – History and Prevention
Jan. 19
2-3 p.m. EDT
www.crows.org

AOC Virtual Series Webinar: Alternate Approaches for Enhanced Survivability of Missiles
Jan. 26
2-3 p.m. EDT
www.crows.org

Radar EW
Jan. 30 - Feb. 3
Shrivenham, UK
www.cranfield.ac.uk

FEBRUARY

AOC Live Course: 21st Century Electronic Warfare – Systems, Technology and Techniques
Feb. 1 - March 1
8 Session, 3 hrs. each
www.crows.org

AOC Virtual Series Webinar: Importance of Signal Generator Phase Noise in RF/mm-Wave Subsystem Measurements
Feb. 2
2-3 p.m. EDT
www.crows.org

Communications EW
Feb. 13-17
Shrivenham, UK
www.cranfield.ac.uk

AOC Virtual Series Webinar: Joint All-Domain Command and Control (JADC2)
Feb. 23
2-3 p.m. EDT
www.crows.org

Advanced RF Electromagnetic Warfare Principles
Feb. 27 - March 3
Atlanta, GA
www.pe.gatech.edu

MARCH

AOC Virtual Series Webinar: Chinese Thinking on the Establishment of Information Dominance
March 2
2-3 p.m. EDT
www.crows.org

Advanced Radar
March 6
Shrivenham, UK
www.cranfield.ac.uk

AOC Virtual Series Webinar: Countering UAS Using EW and DEW Attack Vectors
March 9
2-3 p.m. EDT
www.crows.org

Aircraft Survivability
March 13-17
Shrivenham, UK
www.cranfield.ac.uk

IR/Visible Signature Suppression
March 21-24
Atlanta, GA
www.pe.gatech.edu

AOC Virtual Series Webinar: SDR for Strategic COMINT Applications
March 23
2-3 p.m. EDT
www.crows.org

Counter-IED Capability
March 27-31
Shrivenham, UK
www.cranfield.ac.uk

*AOC courses are noted in **red**. For more info or to register, visit crows.org. Items in blue denote AOC Chapter courses.*

EMSO ADVOCACY

Welcome to another new year for the AOC! One of the best gifts from 2022 remains the tremendously successful October AOC International Conference and Symposium chaired by Dr. Bill Conley in Washington, DC, which added the icing on the cake for an outstanding year! In fact, we broke all AOC Symposium records, with over 2,100 people touring the floor and attending the many riveting and insightful sessions on Electromagnetic Spectrum Operations (EMSO) around the world today. One particular highlight was our new AOC Future Five Program, where we recognized five incredibly talented EMSO professionals from across military and industry who are in the early stages of their careers. Overall, AOC 2022 was extremely successful in bringing the international EW community together and sharing new ideas. I know we all agree that helping our forces gain unfettered access to and decisively maneuver in increasingly challenging electromagnetic operating environments (EMOE) is more important than ever before. This points immediately to another exciting year for AOC.

As I mentioned in last month's message when discussing our Five-Year Strategy, "advocacy" continues to be our most important goal. What do I mean by advocacy, and why is it so important? In simplest terms, I mean for each Crow to be the assertive (and sometimes aggressive) representative armed with the knowledge to highlight the criticality of our weapon systems and platforms to help educate those influential leaders who want to understand more about EW. Every wise leader appreciates what they don't know, and they know when to listen to experts. Who is better positioned to help educate them about EMSO than our AOC members? Every one of our elected AOC Board members is focused on increasing advocacy for electromagnetic warfare capability and capacity to military, Government and industry leaders. In addition to engaging with the Symposium speakers, we have already briefed Congressman Larsen's staff, INDOPACOM and COMPACFLT leadership (during the INDOPACOM IO and EW Conference that was led brilliantly by Dr. Art Tulak of our Diamond Head Roost), and members of the Office of the Secretary of Defense. While this is a good start, we must bang the drum louder and longer. In the weeks and months ahead, we will be delving deeper into advocacy messaging to ensure: 1) all Crows have a consistent message to disseminate, 2) messages are tailored for specific audiences, and 3) we develop leading and lagging advocacy metrics to show progress made.

In closing, I just want to remind you all that AOC is a 501(c)6 organization – specifically designed as a (c)6 with the primary purpose of serving our members. This differs from a more standard 501(c)3, whose goal is to serve the public. Our members are and always will be priority number 1! We, the AOC board, staff, and regional directors are committed to serving you and excited to partner with you to network, to invigorate, to grow, to educate and to advocate. – *Brian "Hinks" Hinkley*

AFRL AWARDS CONTRACT FOR SOLID-STATE HPM TECHNOLOGY

The US Air Force Research Laboratory (AFRL) is advancing plans to transition novel high-power microwave (HPM) technology into frontline service, awarding Leidos a four-year contract on Dec. 13 to develop and mature solid-state HPM weapon concepts.

The High-Power Electromagnetic Division within AFRL's Directed Energy Directorate has been working for over a decade to determine the feasibility of novel concepts and technologies that enable smaller, lighter and more capable non-lethal HPM weapons able to address multiple types of targets. (See cover story on page 16.) Such weapons use electromagnetic effects to disrupt or disable vehicles, electronics or personnel, but their operational utility has hitherto been limited by operational range, size, weight and cost.

Under its new $8 million cost-plus-fixed-fee contract with AFRL, Leidos has been tasked to investigate, develop and ultimately transition nonlinear transmission line (NLTL) or other solid-state-based high-power electromagnetics weapon concepts. NLTL technologies are seen as a way of achieving low-cost, high-power pulse generation from a low-cost, all solid-state source.

Work will be performed at Kirtland Air Force Base, NM, and is expected to be completed by December 2026. Activity will include developing devices, including suitable user interfaces, embedded controls and diagnostics using an NLTL or alternative solid-state high-power microwave source.

The objective of AFRL's Electromagnetic Weapons Technologies Program is to investigate, develop, and ultimately transition new HPM Weapon concepts, HPM materials and components, and compact pulsed power topologies. The program is also evaluating advances in prime power technologies to optimize size, weight and power requirements for future weapon systems.

Leidos has a long history of undertaking HPM research with AFRL. The company was in 2017 awarded a five-year indefinite-delivery/indefinite-quantity to provide research and technology development to support the maturation of next generation HPM sources. – *R. Scott*

POLAND ORDERS NEW SIGINT SHIPS

Swedish defence group Saab is to deliver two new signals intelligence (SIGINT) vessels to Poland under the terms of a contract with the Polish State Treasury Armament Agency.

Valued at about €620 million ($646 million), the deal will see Saab serve as prime contractor for the program, including taking responsibility for the integration of an advanced SIGINT suite. The two ships, planned to be delivered during 2027, will be built by Polish subcontractor Remontowa Shipbuilding SA.

Saab is already completing a new SIGINT vessel, HMS *Artemis*, for Sweden under a contract awarded by the Defence Materiel Administration in 2017. Originally planned to enter service in 2020, completion of *Artemis* has been delayed because of financial difficulties impacting the Polish shipyard subcontracted to build the vessel.

Artemis began sea trials in early November 2022. Once delivered, *Artemis* will replace HMS *Orion*, which entered service in the mid-1980s. – *R. Scott*

ANG RECOMMENDS BRITECLOUD 218 DECOY FOR FIELDING

The US Air National Guard (ANG) has issued a fielding recommendation for the Leonardo BriteCloud 218 expendable active decoy (EAD) following extensive trials under the Office of the Secretary of Defense Foreign Comparative Testing (FCT) program. BriteCloud 218 will be designated AN/ALQ-260(V)1 in US service.

Developed by Leonardo's UK-based electronic warfare business, BriteCloud is a compact DRFM-based jammer designed to provide fast jet aircraft with effective end-game protection against advanced RF-guided missile threats and/or tracking radars. After ejection, the BriteCloud decoy searches and locks onto the highest priority threat; the DRFM's coherent response prevents the threat from detecting the deception as the decoy separates, so breaking the target lock and generating large miss distances.

Two fast-jet variants of the EAD have been developed: BriteCloud 55 is a cylindrical store designed for compatibility with standard 55-mm chaff and flare dispensers; while the BriteCloud 218 device adopts a form factor compatible with "square format" countermeasure dispensers such as the AN/ALE-40 and AN/ALE-47.

The FCT commenced in 2019, with the US Air Force and the ANG having previously identified a need for "last minute" expendable electronic decoy round to improve aircraft survivability against RF-guided missile threats. The three-year program, accomplished by the Air National Guard/Air Force Reserve Test Center in Tucson, AZ, has encompassed hardware in-the-loop trials, ground-based system evaluations and flight trials from ANG F-16 aircraft. Leonardo has been being contracted to provide a number of BriteCloud assets, comprising both operational decoy rounds and lab-based development units.

According to Leonardo, the fielding recommendation by the ANG is one of the final stages of the FCT program and gives the green light to BriteCloud 218 EAD as proven effective and fit for operations. – *R. Scott*

LEIDOS TAPPED BY AFRL FOR INTEGRATED THREAT WARNING RESEARCH

The US Air Force Research Laboratory (AFRL) has contracted Leidos to develop and demonstrate new advanced integrated threat warning systems designed to protect air platforms from multi-spectral guided weapons, hostile fire and directed energy weapon systems.

Under a $39 million Electro-Optic Sensing Defensive Electronic Warfare (EOS-DEW) contract awarded last month, Leidos will mature integrated multi-spectral threat warning solutions combining EO missile sensing, laser sensing, and hostile fire sensing, while also advancing test and developmental risk reduction methodologies. The latter include exploring new techniques for multi-spectrum simulation, multi-threat simulation, and sensing technology evaluation, together with enhanced testing and evaluation techniques to support research and development.

According to the statement of objectives laid out by the AFRL's Sensors Directorate, the EOS-DEW project will focus on five technical areas/objectives: multi-spectral threat sensor development, including component hardware, algorithm development/evaluation and evaluation of emerging technologies; multi-spectral threat simulation development to support evaluation of sensors/systems in hardware-in-the-loop (HITL) laboratory and field settings; modelling and simulation supporting sensor development/evaluation and multi-spectral threat simulation in HITL laboratory and field settings; experiments, characterizations and infrastructure operations to support risk reduction experiments of threat warning systems using HITL techniques; and test and demonstration events as part of multi-spectral threat sensor development and evaluation.

The four-year EOS-DEW contract, extending through to December 2026, will develop and demonstrate prototype advanced integrated threat warning systems. Flight test and field events may include operation of government-provided threat surrogate systems, government provided threat warning systems, instrumented threat sensors and seekers, search/track sensors, other countermeasures, and portable laser equipment. – *R. Scott*

SMART D2 ON CONTRACT FOR US NAVY AN/ALE-47 COMMON CARRIAGE PROGRAM

The US Navy has awarded BAE Systems (Austin, TX) a $13.5 million contract to incorporate its Smart D2 technology into existing AN/ALE-47 Airborne Countermeasures Dispenser Systems. The contract – an Other Transaction Agreement (OTA) through the Naval Aviation Systems Consortium (NASC) – represents the first purchase of Smart D2 technology by the US Department of Defense.

Forming part of the Navy's AN/ALE-47 Common Carriage program, Smart D2 technology supports the conversion from chaff and flare cartridges that use a round form factor to countermeasure stores with the same square form factor used by the US Air Force and the US Army. The Smart D2 sequencer and square style dispenser are a form and fit replacement to the current AN/ALE-47 sequencer and dispenser for the US Navy's effort under the NASC OTA.

Instead of replacing an aircraft's entire AN/ALE-47 system, Smart D2 technology allows for the replacement of key elements – the programmer, sequencer, dispenser, and expendables. The programmer contains a regularly-updated database of known threats and identifies the appropriate payload, quantity and dispensing intervals of each countermeasure. It also provides two-way communication of mission-critical information, such as monitoring how many rounds of each flare or chaff type are available during a mission.

Work on Smart D2 under the ALE-47 Common Carriage program is underway at BAE Systems' facility in Austin. Smart D2 will be deployed on both rotary- and fixed-wing aircraft, and is also designed to operate on future platforms. – *R. Scott*

IN BRIEF

The US Army's Program Executive Office for Intelligence, Electronic Warfare and Sensors (PEO IEW&S), **Project Manager for Intelligence Systems and Analytics (PM IS&A)** (Aberdeen Proving Ground, MD) has issued a Request for Information (RFI) for Project Linchpin to support the development of an Artificial Intelligence/Machine Learning (AI/ML) Operations (Ops) Environment to enable successful deployment of AI & ML capabilities to intelligence, cyber and electronic warfare sensor systems. According to the RFI, "The goal is to create a complete and efficient AI and ML development and delivery operational pipeline (AI/MLOPs) with supporting services for sensor programs within PEO IEW&S." Sensor types could include synthetic aperture radar (SAR),

News

RF spectrum, electronic intelligence (ELINT), full-motion video, and 3rd Generation Forward Looking Infrared (FLIR). PM IS&A is "seeking to meet with industry partners that are involved in end-to-end machine learning pipeline environments in addition to any company that has expertise and/or tools related to data holding, data labeling, model training, verification & validation, and deployment." The office is also seeking an AI integrator that can identify resources needed to support all of the functional areas and subcontract to meet the needs identified by the Project Linchpin team. The point of contact is Nick Mitrocsak, e-mail nicholas.m.mitrocsak.civ@army.mil.

Italy's **Elettronica** announced it has won a contract to supply two radar electronic countermeasures (RECM) systems for a pair of Offshore Patrol Vessels (OPVs) under construction for the Indonesian Navy. November saw a keel laying ceremony for the first OPV, a 90-meter hull under construction at PT Daya Radar Utama shipyard in Bandar Lampung, Indonesia. Interestingly, the OPVs are being configured for anti-surface and anti-submarine warfare. The RECM system will comprise two JASS (Jamming Antenna Sub System) units, and it will be integrated with other onboard EW sensors and RF decoy launchers, as well as the ships' Advent combat management systems, which are being supplied by Turkey's HAVELSAN. Elettronica's announcement hinted that additional OPVs are expected to be announced under the project. The contract marks the first sale for the company in Indonesia.

DARPA's **Tactical Technologies Office (TTO)** has issued a Broad Agency Announcement (HR001123S0009) for its Artificial Intelligence Reinforcements (AIR) program, which aims to "create a dominant Artificial Intelligence (AI) air combat capability compatible with existing sensors, electronic warfare, and weapons within dynamic and operationally representative environments." Program officials are seeking performer teams that have significant experience and expertise in aerial AI system design, as well as algorithmic design, aircraft sensors, electronic warfare and tactical combat operations. The four-year program is pursuing two technical areas (TAs). TA1 will focus on model development, while TA2 will concentrate on multi-agent AI training. DARPA could award up to six contract for the initial phase of the program. The BAA coordinator can be contacted via e-mail at HR001123S0009@darpa.mil. Proposals are due by March 3.

Marine Corps Systems Command's (MARCORSYSCOM'S) Program Executive Officer Land Systems (PEO LS), **Program Manager, Ground Based Air Defense (PM GBAD)** has issued an RFI to obtain industry feedback for its Installation Counter Small Unmanned Aircraft Systems (I-CsUAS) program. The requirement, according to the announcement, calls for a C-UAS system that can "provide the entire kill chain (detect, track, identify and defeat) against Group 1 and 2 sUAS threats. The defeat aspect of the kill chain, however, will be via non-kinetic means." The plan is to deploy the system to 33 Marine Corps installations – 20 in the continental US and 13 outside the continental US. Minimum system requirements include "24/7 detection in day/night, all-weather with multi-modal active and passive sensor payloads fusing all sensor data into a single operator view. It must have the ability to passively detect radio frequency (RF) signals associated with sUAS and defeat them." The system must be able to "autonomously detect, identify, classify, and track objects of interest (provide current and estimated minimum and maximum ranges)." Additionally, "the system should have the ability to apply sensor fusion, Machine Learning (ML), and Artificial Intelligence (AI). The system should facilitate end-to-end sensoring, including target handoff and track fusions. The Government differentiates and recognizes the definitional differences between sensor correlation and sensor fusion," it states. The solicitation number is M67854-23-I-0001. The point of contact is Autumn Dickinson, e-mail autumn.dickinson@usmc.mil. Responses to the RFI are due by January 13. PM GBAD intends to host an I-CsUAS Industry Day in the coming weeks in northern Virginia.

DARPA's **Microsystems Technology Office (MTO)** has issued a Broad Agency Announcement (BAA HR001123S0013) for its Technologies for Heat Removal in Electronics at the Device Scale (THREADS) program. The program aims to improve the output power density of gallium nitride (GaN) transistors by "achieving high power density through reduction in transistor thermal resistance, both within and outside the intrinsic device," according to the BAA. THREADS is part of a multipronged approach from DARPA that will benefit radar and communications, as well as EW systems, by improving the systems' RF output and operational range. THREADS complements other DARPA programs, such as Dynamic Range-enhanced Electronics and Materials (DREaM), which found ways to improve GaN power output density, and its Thermal Ground Plane (TGP) effort, which focused on novel transistor packaging to improve thermal management. Other MTO efforts, such as the Near Junction Thermal Transport (NJTT) and Intrachip/Interchip Enhanced Cooling (ICECool) programs yielded some thermal performance improvements for GaN transistors, but THREADS aims to provide greater benefits. The THREADS program focuses on two technical challenges (TCs). TC1 will concentrate on "reducing thermal resistance within the device while maintaining good channel current transport properties." TC2 will look at "moving heat away from high power transistors more efficiently without degrading RF performance." According to the BAA, THREADS will seek to demonstrate: "high efficiency, X-band (8-12 GHz) transistors and PA test vehicles whose output stage transistors have an output power density of 81 W/mm; 8X reduction in transistor thermal resistance; and reliable operation with a predicted mean-time-to-failure (MTTF) of 10^6 hours at 225°C channel temperature (comparable to today's production GaN operated at ~5 W/mm output power density)." Program officials anticipate awarding multiple contracts for the four-year program. The BAA coordinator is Dr. Thomas Kazior, Program Manager, e-mail HR001123S0013@darpa.mil. Proposals are due by Feb. 17.

The Air Force Research Lab's Sensors Directorate (Wright-Patterson AFB, OH) has awarded its first contract under Project Kaiju, its major Science and Technology (S&T) effort to develop next-generation EW technologies. **Booz Allen Hamilton** (McLean, VA) won a $14.7 million contract under Kaiju Call 01 (King Kong). (All efforts under Kaiju are named for classic monster movies.) The objective of King Kong is to perform "research and development (R&D) on the application of advanced data processing, artificial intelligence (AI), and machine learning (ML) to aid platform cognitive capability and next sortie reprogramming," according to the original solicitation issued in mid-2022.

The US State Department has formally approved the sale of 24 C-130J-30 aircraft for the **Royal Australian Air Force.** The Foreign Military Sale includes a significant EW self-protection package of 32 AN/ALQ-251 Radio Frequency Countermeasure (RFCM) systems; 27 Guardian Laser Transmitter Assemblies (GLTAs) for Large Aircraft Infrared Countermeasures (LAIRCM) systems; 16 AN/AAQ 24(V)N LAIRCM System Processor Replacements (LSPR); LAIRCM Infrared Missile Warning systems (MWS) or AAR-47 missile warning systems; AN/ALE-47 Countermeasures Dispensing Systems (CMDS); and AN/ALR-56M Radar Warning Receivers (RWRs). The estimated value of the deal is $6.35 billion.

LETTERS TO THE EDITOR

I particularly associated with your "Hard Problems" article in the December 2022 *JED*. For what it's worth, I would like to add to the C-130 flare gun protection of early C-130 A/C via my prior experience while at Texas Instruments.

In early 1966, the AC-130 Gunships used a more primitive technique involving an onboard "spotter." This SAM spotter's sole responsibility was to visually search for SAM launches from an open window platform and provide missile launch alerts and directional vectors with countdowns to the pilot with "jinking" directions to evade the inflight missile at the right moment. This technique was 100% effective for these early class of SAMs, and none of the early Gunships were lost.

I can tell you the AC-130 Gunship crew "pucker factor" was 10 out of 10, as some of the missile misses were much closer than others. Some spotters reported they could feel the missile engine heat as it passed. The debriefs were graphic, and the crew dedication always amazed me.

It's amazing the progress our industry has made to protect large aircraft. I only hope we continue to recognize the threats are continuing to advance, and so must our capability to stay head of the threat.

Robert Cockrell
Northrop Grumman Retired

I don't think you should think your former Vietnam-era C-130 crewmember talking about his counter-MANPAD flare gun was pulling your leg. That countermeasure system was not unusual, even much later, and I myself suffered with it personally as a USAF CSAR HH-3E pilot even as late as the late 1980s and early '90s.

In 1986, our IRCM solution was a single pistol-handled flare gun that mounted on the "broom closet," a panel adjacent to the sliding cargo door on the right side of the aircraft. Supposedly, the flight engineer or a PJ was supposed to observe a missile launch and then run across the cabin to the broom closet and pull the trigger (after making sure the cargo door was open) and hope that this single visible-spectrum shot would decoy the missile. One single flare out the right door – that was it! There were a few refills, if you could dig them out of storage.

Our ECM radar missile countermeasure was a hand-held cardboard box about a fifth as thin as a Kleenex box full of chaff that we were supposed to rip open and shake out the window or door or the aft ramp. This was our countermeasure suite for a combat aircraft even as late as the early 1990s, when I was deployed to SWA in HH-60Gs! All these countermeasures were completely incapable, ineffective and ignorant, but those were front-line technology even in the '80s and '90s on our USAF combat helicopters.

Randy Nelson

JED *welcomes your letters! To submit a letter to the editor, please email jededitor@naylor.com.*

High-Power Microwave (Much, Much) Closer t

By Barry Manz

Unmanned aerial systems (UAS) are a big topic these days, but not always in a good way. In October, Russia began an extensive campaign of attacks on the energy and electrical infrastructure across Ukraine using lethal drones and cruise missiles. Although many of Russia's missiles and loitering munitions (including Shahed-136s and -131s supplied by Iran) are rudimentary, it has launched hundreds of them – sometimes in waves of up to a dozen or more at a time – with the aim of overwhelming Ukraine's air defense systems. Ukraine claims to have shot down at least three-quarters of the drones and cruise missiles in these attacks, relying almost exclusively on its limited supply of RF- and IR-guided surface-to-air missiles. While a 75% kill rate is good for Ukraine, it's the 25% of successful Russian attacks against its energy infrastructure that poses a serious problem for Ukraine. Russia is unlikely to abandon its drone attacks against Ukrainian power plants any time soon. In the long-term, defeating $20,000 drones with $200,000 surface-to-air missiles also puts Ukraine on the wrong side of the cost equation. But you fight with what you have – until you can get something that's better.

Russia's drone and cruise missile attacks on Ukrainian infrastructure have captured the world's attention, but they not unique. In a future conflict, many countries could easily find themselves in a similar situation – facing an adversary's weaponized drones. As the war in Ukraine is demonstrating, surface-to-air missiles and radar-directed AAA are not a complete answer to this problem. While they offer longer range and precision against aerial targets, they are primarily designed to attack fighter and bomber aircraft, as well as cruise missiles, rather than large number of relatively inexpensive drones. What is needed are systems that can rapidly fire multiple times (deep magazine) at low cost (non-kinetic) and preferably operate at the speed of light. In other words, what air defense units need to counter these drone and cruise missile attacks are directed energy weapons (DEWs).

Over the past decade, the US, Israel and several European nations have made significant advances in their development of DEWs – mainly high-energy laser (HEL) systems and high-power microwave (HPM) systems. In this article, we're going to look at HPM technology, it's history and current programs.

HPM weapons offer several advantages over other types of kinetic and non-kinetic weapons. HPM systems can typically fire in less than a second, and the latest generation of systems provide deep magazines (i.e., the ability to fire multiple times in a short period). HPM weapons can generate a range of effects on a target, from destroying or damaging sensitive electronic components to degrading their performance or forcing reboots and restarts. An HPM system delivers RF and microwave energy into a target's processors and other logic components through the target's RF and microwave antennas or into unshielded wiring and circuits that essentially act as apertures. Also, because an HPM system transmits from an antenna, it's beam can be shaped to focus on a wide area or into a narrow beam. Depending on the type of aperture it uses wide antenna beam enables an HPM system to simultaneously attack several targets at one time and a narrow antenna beam can focus energy on a single target. Moreover, an HPM system equipped with an active electronically scanned array can change this beam shape very quickly as needed.

AFRL's THOR demonstrator system, developed by Leidos, BAE Systems and Verus Research, has been deployed to Africa as part of its operational evaluation. AFRL PHOTO

FROM SPARK GAP TRANSMITTERS TO PHASED ARRAYS

HPM weapons have a fascinating technological history, and it began when the US detonated a nuclear weapon 250 miles above the Pacific in 1962. As described by Stuart Moran in his 2012 article, "Historical Overview of Directed-Energy Work at Dahlgren,"[1] scientists noted, "The blast caused a large imbalance of electrons in the upper atmosphere that interacted with the Earth's magnetic field to create oscillating electric fields over a large area of

e Systems – Getting o Operational Status

the Pacific. These fields were strong enough to damage electronics in Hawaii, a thousand miles away, and clearly demonstrated the effects of an electromagnetic pulse (EMP)."

This discovery raised eyebrows at the Pentagon, because if it could somehow be harnessed, the result would be a very effective non-kinetic tool in DOD's arsenal. The question was how to realize such a weapon, which would require a means to generate field strengths of hundreds of thousands of volts (or more) per meter. Before exploring what came next, two facts are important to consider.

First, more than 60 years ago, DOD's intention was to annihilate targets rather than just to disable them. And second, virtually all components in a target were analog rather than digital, which were (and still are) far more resistant to damage from high levels of EM energy than a tiny semiconductor device. Consequently, the need for massive amounts of RF energy was considered essential. Although this remains true today in some cases, massive amounts of energy aren't always necessary or even desired when countering an adversary system using an HPM weapon.

As Air Power Australia think tank co-founder Dr. Carlo Kopp, who coined the term "E-bomb," has noted in a 2012 article: "Expose any monolithic semiconductor device to voltages, whether transient or radio frequency, of more than the specification limits of several volts, and bad things usually happen. With a mains or battery power supply attached to the device, very little energy is needed to initiate a catastrophic electrical failure because the power supply is what delivers the killing blow."[2]

Returning to the 1960s, Moran's article explains how researchers at the Special Applications Branch at the Naval Weapons Laboratory at the Dahlgren (what is today the Naval Surface Warfare Center Dahlgren Division (NSWCDD) in Dahlgren, VA) got to work after the blast in the Pacific, and their efforts focused on high-power versions of spark-gap transmitters like those in the early days of radio broadcast. The RF generators were Hertzian oscillators, in which "a capacitor is charged to a high voltage, a switch is closed, and current flows in the circuit, causing the stored energy to oscillate between the electric field of the capacitor and the magnetic field of an inductor" until the breakdown voltage of the air between the spark gap is reached. At breakdown, a spark completes the LC circuit, oscillating at its resonant frequency. It can then pass the electromagnetic waves as electric oscillations.

The Hertzian-type devices were typically connected to a simple antenna and oscillated at low frequencies at 100 MHz or below. Measuring the output field of these devices was difficult because of ground effects, so a 100-meter ground plane of welded wire was laid out in a field with semi-underground trailers at each end to house high-voltage generators and diagnostics, which formed a basic measurement system. The sources often produced over a gigawatt of peak power and field strengths of several kilovolts per meter at the target sites.

Moran describes many types of Hertzian devices that were designed, constructed and tested at Dahlgren throughout the 1970s. For example, the cavity oscillator "used a quarter-wavelength coaxial pipe that switched at one end to create an oscillating waveform." Another type, the so-called "frozen-wave" generator, used "quarter-wave sections of cable that were charged to create a two-cycle waveform 'frozen' in the cable" and produced multi-kilowatt RF pulses in the megahertz frequency range with repetition rates of tens of kilohertz. Almost all the solutions created at Dahlgren using Hertzian oscillators could create at least 500 kV and produce large electric fields hundreds of meters away from the antenna.

Other types of devices included "vector inversion generators that used spiral-wound capacitive plates to generate the voltage" but didn't require transformers, a significant improvement. A device called a Landecker ring mounted in the focal area of a parabolic dish antenna "used capacitors and inductors in a paddle-wheel arrangement charged in parallel and discharged in series." The circular arrangement allowed the system to radiate as a dipole, effectively creating an antenna.

Or consider the Flux Compression Generator (FCG) that produces low-frequency wideband effects. Primed with an initial electrical starting current, "a high-velocity explosive is used to mechanically compress the magnetic field, transferring energy from the explosive into the magnetic field," explains Kopp in an article about "E-Bombs."[2] "While the FCG disintegrates during operation, it produces a powerful pulse of electrical current." And when cascaded together, three FCGs can amplify power one hundredfold to deliver peak power outputs of many gigawatts.

Then there's the Virtual Cathode Oscillator (Vircator) that produces brief pulses at tunable narrowband frequencies at very high-power levels. As Kopp's "E-Bomb" article explains, the Vircator allows the power produced by the FCG to be precisely focused on a target area hundreds of meters away, although the

[1] *Moran, Stuart (2012), "Historical Overview of Directed-Energy Work at Dahlgren" (Report), downloaded from https://apps.dtic.mil/sti/pdfs/ADA560558.pdf.*

[2] *Kopp, Carlo (2012), "E-Bomb Frequently Asked Questions – For the EE Community," accessed at http://www.ausairpower.net/E-Bomb-FAQ.html.*

most severe damage occurs within tens of meters.

In 1973, Dahlgren began the Special Effects Warhead (SEW) program to explore the feasibility of "'burning out' enemy radar and missile systems using single-shot, very high peak-power EMPs." One of the goals was to determine if an electromagnetic warhead could be created that could disable electronics up to 1 mile away. The laboratory must have been both very interesting and very dangerous. As Moran's article explains, "The high-voltage fields and sparking caused the workers to make a sign for one of the buildings: 'Science Fiction Department'."

Little was known at the time about the vulnerability of foreign or US electronics and systems, and the transmitters used for testing could not produce fields high enough to test large targets, such as a Nike Hercules Radar System. To solve this problem, Moran explains, a trailer-based RF impulse system was constructed. It employed a "Marx generator-driven L-C oscillator charged charged at two million volts." Known as the Transportable Oscillating Pulser System (TOPS), "it was connected to a large bounded-wave structure that produced uniform fields over a region large enough to place an entire radar or missile." Moran goes on to write, "The electric field emitted from the system was so high that the air would arc unless a special bag of insulating gas (sulfur hexafluoride) was used until the radiating structure became large enough to transition to the normal atmosphere."

MORE POWER PLEASE

At Dahlgren, Moran explains, it had become apparent that "the size, weight and cost of these systems were driven by the pulsed DC technologies needed to drive the system, not by the RF source itself. Consequently, more effort began to be devoted to the power-delivery technologies needed for many of the weapon concepts." Pulsed-power components enabled energy to be stored over seconds – a long time in DE terms – and could be released in nanoseconds "to obtain a billion times increase in peak power." Dahlgren officials convinced Navy leaders to initiate a Pulsed Power Technology Program in 1978 "to develop the power sources, energy storage systems, high-power switches and power conditioning systems needed for future weapons."

Moran goes on to explain, "To provide large amounts of electrical prime power, new types of rotating machines were studied, including flywheels, conventional alternators, homopolar generators, rotary flux compressors and compensated pulsed alternators. These machines attempted to produce fast, high-power pulses using special materials to reduce losses, eddy currents and mechanical stresses."

Over the remainder of the 1970s and into the 1980s, prime and RF power technologies continued to improve, as universities and several other DOD departments (including the Air Force Research Lab) joined Dahlgren in its HPM these efforts. However, the end of the Cold War weakened interest in directed energy weapons. The Pulsed Power Technology Program and the Navy's Charged Particle Beam Program were canceled, although Dahlgren managed to cobble together funding to maintain a core technical competency that could be used later. Dahlgren is now one of two places in the US with a division specific to HPM technology development, the other being the Air Force Research Lab's Directed Energy Directorate at Kirtland AFB, NM.

HPM RETURNS

By the mid 2000s, the world had long since begun its transition from analog to digital technology, and products once almost completely analog had become almost entirely digital. Very few of these electronic systems had been tested for their vulnerability to an HPM attack. The creation of massive clouds of EMP had seemingly become less important after the Soviet Union collapsed, so protecting electronics from damaging levels of RF energy also became less important.

This complacency did not last, however. As digital electronics became more widely used in US military systems and for controlling civilian infrastructure, such as electrical power plants, communications systems, and emergency and industrial systems, the potential that an adversary could attack these systems with HPM weapons became an increasing concern. Today, more than a dozen countries, most of them US allies, but also Russia and China, are developing HPM weapons technology – some of them with decades of experience. Consequently, defending against HPM attacks, has captured more attention from Pentagon leaders in recent years. The Joint Program Office for Special Technology Countermeasures (JPO/STC) at Dahlgren has performed intensive work on the vulnerability of digital systems to RF attack. As Moran's article explains, the program also established a DoD-wide database of "vulnerability data, source designs and RF-effects information," combining it with the information that with considerable foresight had been stored over the years. "In the late 1990s and early 2000s, Dahlgren initiated programs regarding the potential for RF attack using non-kinetic disruption" and also "developed RF payloads for UAVs and demonstrated their effectiveness in field tests." It was DOD's first demonstration of this type of HPM technology. To test them, two multistory buildings were reconfigured to reflect different types of building construction and electromagnetic shielding. Within them were "large complexes of electronics, computer networks, server systems, telephone systems, security systems, and various types of digital industrial controls [that] could be assembled, instrumented and exposed to attack." This complex, called the Maginot Open Air Test Site (MOATS), was designed for testing the RF susceptibility of electronic equipment to potential HPM weapons and continues to be used to test target systems, as well as a variety of RF weapon technologies developed internally and by external and international organizations.

SO, WHERE ARE WE NOW?

Traditionally, HPM systems concentrated on destroying vulnerable electronic components in a weapons system. But in the case of drones, drone swarms, or other targets, what's required is only to either confuse the electronics or render them inoperable. Destroying them with high-power ultrawideband pulses is unnecessary, which means that an HPM system doesn't necessarily need to transmit gigawatts of power to destroy a single target, as it would against other assets, but only what's needed to render a sensor inoperable or affect the weapons systems navigation or flight controls. This capability has been demonstrated in one form or another for more than 15 years since Raytheon developed its Valiant Eagle system in 2006 and later BAE Systems Bofors HPM Blackout.

AFRL has been developing and evaluating at least four HPM demonstrator systems over the past few years. This includes Raytheon's Phaser system, which transmits high levels of RF energy to a reflector antenna and can destroy multiple targets simultaneously. The conical shape of the beam means that a single pulse can attack several drones in mid-air at once, making Phaser useful against drone swarms.

AFRL's Tactical High Power Operational Responder (THOR) HPM system, developed by Leidos, BAE Systems and Verus Research, has demonstrated the ability to disable more than 100 drones at a time. AFRL is also progressing on a more advanced version of THOR to disable drone swarms that threaten military bases. The next-generation platform is named Mjölnir as an homage to the mythical god Thor's hammer. AFRL has awarded Leidos a $26 million contract to develop the Mjölnir prototype and deliver it in early 2024.

Finally, AFRL is working with Raytheon to develop the Counter-Electronic High Power Microwave Extended Range Air Base Defense (CHIMERA) system. Unlike the Phaser and THOR systems, which operate against targets a close range, CHIMERA (as its name suggests) is designed to attack airborne targets at longer distances.

It's important to note that many of these systems, including THOR and Phaser, use vacuum tube technology to generate the required radiated power. Most of them are also relatively large and best suited to fixed site applications, such as defending military bases against drones and rocket attacks.

The Phaser is another counter-drone HPM system developed by Raytheon for AFRL. It is designed to take down drones either in single numbers or in swarms. AFRL PHOTO

AFRL and NRL have been developing another class of HPM weapons that is smaller and designed for use on missiles and UASs. The Counter-electronics High Power Microwave Advanced Missile Project (CHAMP), demonstrated in 2012 by Boeing and AFRL, uses the body of an AGM-86 Conventional Air Launched Cruise Missile (CALCM) to carry a Raytheon-developed HPM payload that can deliver multiple HPM "shots" per sortie. The High-Powered Joint Electromagnetic Non-Kinetic Strike Weapon, known as HiJENKS, also uses microwave technology to disable an adversary's electronic systems. HiJENKS is the successor to CHAMP and uses smaller and more rugged HPM technology that can be integrated into a wider range of carrier systems. Funded jointly by the Air Force Research Laboratory and the Office of Naval Research, the five-year HiJENKS program completed "capstone" tests at Naval Air Station China Lake (China Lake, CA) last summer.

POWERED BY GAN

The most recent development in HPM technology is the use of active phased arrays and solid-state (gallium nitride – GaN)-based RF power amplifiers rather than vacuum tubes to generate the required levels of RF power. One system, called Leonidas, was developed independently by a relatively new company named Epirus. Started in 2018, with facilities in Los Angeles and McLean, VA, Epirus is leveraging a select set of core technologies for both defense and commercial applications.

Leonidas is the company's scalable HPM offering. Initially developed in a trailer configuration, the company has also tested an airborne pod for UASs, and in October it disclosed a mobile version integrated onto a Stryker vehicle. Like an AESA system, Leonidas uses beam steering to focus its energy on a target or targets while defining no-fly zones to allow friendly forces to continue operating. Leonidas can be mounted on a comparatively small ground-based vehicle and can fire thousands of "rounds" per second. Leonidas has open systems architecture and relies on GaN-based line-replaceable amplifier modules and rapidly fires a barrage of unique waveforms to exploit the frequencies that make a UAS target susceptible.

The company stresses that rather than confusing the drone's digital electronics by interrupting their communication of satellite navigation signals, Leonidas is better described as an EMP generator that envelopes the target with electromagnetic energy that covers very low to very high frequencies, "DC to daylight" as EMP is often described. "We don't care what frequency a drone operates on", says Andrew Lowery, chief product officer at Epirus. "We are an EMP system, so frequencies do not matter. Trying to disable the data links or GPS is comparatively simple, and lots of companies can do that. Instead, we blanket the target from a long distance, way beyond kinetic ranges or even THOR."

Although the company defines the range of Leonidas only as a "tactically-relevant" distance, this typically means something like 10 km. "Our beam is actually not very narrow; its 3-dB beamwidth is about 6 deg.," he continues. "If I want to take

Epirus has developed a family of HPM systems based on its original Leonidas counter-drone system (below, left). It teamed with General Dynamics to introduce a Stryker-mounted system (top, left), and it has introduced a podded system for drones (above). EPIRUS

out a fleet of drones, we sweep the sky at a thousand times per second so any drone moving into that will encounter a wall of energy as we paint the beam across the sky.

"We just want to put a gigantic e-field there, and as cavities and other entry points are prone to vulnerability at some frequencies more than others, we create shields of energy rather than shooting a bullet of energy. Anything that flies into the shield gets disrupted. Even with little gaps and various other entry points, if you put 10 or 20 volts across a switch, it will mess up the electronics enough to shut it down. That's the power of EMP. It can affect a computer, a camera, engine control, or any other circuit."

Leonidas uses the company's proprietary SmartPower power management technology that optimizes RF performance for generating high-power pulses while ensuring the system does not overheat. The SmartPower technology platform, a proprietary combination of hardware, software and machine-intelligent algorithms, uses real-time artificial intelligence and machine learning, and can reduce power consumption by up to 70%, which lowers system power demands, the need for very high-power sources, and requires needs less cooling than vacuum-tube-based systems.

Digital technology oversees the conversion of energy, from AC to DC, for example. "Power is enhanced through a digital architecture, because all of those non-linear circuits in the target are surrounded by a passive network that places it in the right bias condition," says Lowery. "It optimizes the performance of the non-linear circuit, and we have a range of dynamic control, so we go beyond just what a passive static system can do. That is, we use machine learning to manage the circuit by modulating drain, gate and input signals to optimize every conversion metric.

"We also perform envelope tracking, predistortion and algorithms on the gate for pulsed applications, rise and fall times, etc.," Lowery explains. "This eliminates a vast amount of waste that traditionally occurs with nonlinear conversion, and it increases efficiency and reduces heat, so the cooling required is much less. We do everything we can to maximize EIRP on the target, as each of the channels doesn't have the EIRP required by a single-channel approach, such as THOR."

Because the system is software-defined, waveforms can be modified in bandwidth and other characteristics in real time to address a specific target in a crowded electromagnetic environment. This means Leonidas can deal with an enemy drone near a friendly asset while simultaneously mitigating large swarms of drones. Artificial Intelligence and Machine Learning also enable the Leonidas system to learn over time, as it is exposed to new target data. Software updates can be delivered over the air to optimize characteristics to achieve positive effects against new targets.

REAL-WORLD PROBLEMS

HPM technology is maturing rapidly and, just as it did in the 1970s and 1980s, the demand signal from the operational community is increasing – this time for air defense applications and for airborne weapons that can attack the many non-kinetic soft spots (i.e., unshielded wiring and unprotected digital components) in an adversary's sensor-to-shooter networks.

The Ukrainian Armed Forces could certainly benefit from many of these HPM systems right now, but that seems unlikely even though the Russian drones and cruise missiles would be an excellent field test for them. THOR and PHASER reportedly have been deployed outside the US as part of their evaluations, while Leonidas has not. Lowery at Epirus says the company has built four ruggedized prototypes of Leonidas that "could" become LRIP-ready and could be deployable and sent to Ukraine in 2023. As the drone and missile strikes against Ukraine are expected to increase over the next few months, however, Ukraine's need for HPM weapons to counter them will certainly increase, as well. They could form one part of a multi-layered air defense solution to an complex problem.

Electromagnetic Protection (Part 9)

Pulse Doppler Radars

By Dave Adamy

Pulse Doppler radars have a number of characteristics that enhance their ability to operate in the presence of jamming. As shown in Figure 1, they are coherent. That is the radar has a continuous wave (CW) signal that is passed as pulses by a modulator. This means that all pulses are different segments of the same signal, which makes it possible to measure the frequency of a signal over multiple pulses. By comparing the frequency of the received return pulse to that of the transmitted pulse, the Doppler shift caused by the rate of change of range to the target can be calculated. Thus, the true velocity of the target relative to the radar can be determined.

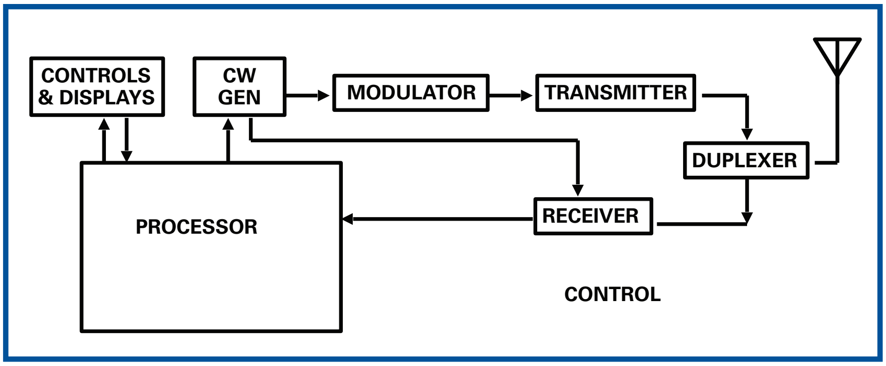


Fig. 1: *A pulse Doppler radar measures both the time of arrival of a returned pulse and its frequency.*

The pulses from a pulse Doppler radar are in general longer than would be the case in a non-coherent radar, so it may be necessary to include pulse compression measures to provide adequate range resolution. The processor also measures the time delay between the transmission of a pulse and the reception of a return pulse reflected from a target. Since the signal has travelled at the speed of light, the distance to the target is known.

The processor includes a bank of contiguous filters. In the past, this involved physical filters, but now this is usually performed in software. Fast Fourier transform (FFT) software produces a spectrum display that can be configured as a channelizer. The number of channels is half the number of digital samples input to the FFT. For example, if 100 samples are input, there will be 50 channels across the bandwidth of the radar receiver.

The processor has a frequency vs. range matrix as shown in Figure 2. Each column of this matrix represents the output of one of the frequency channels. Each row of the matrix represents the time delay of a pulse round trip (hence the range to the target). The red cell indicates that a pulse was received at that frequency and at that range from the radar. The width of each frequency column is typically the inverse of the coherent processing interval (CPI) and the depth of each range cell is typically half of the inverse of the effective receiver bandwidth (BW) multiplied by the speed of light.

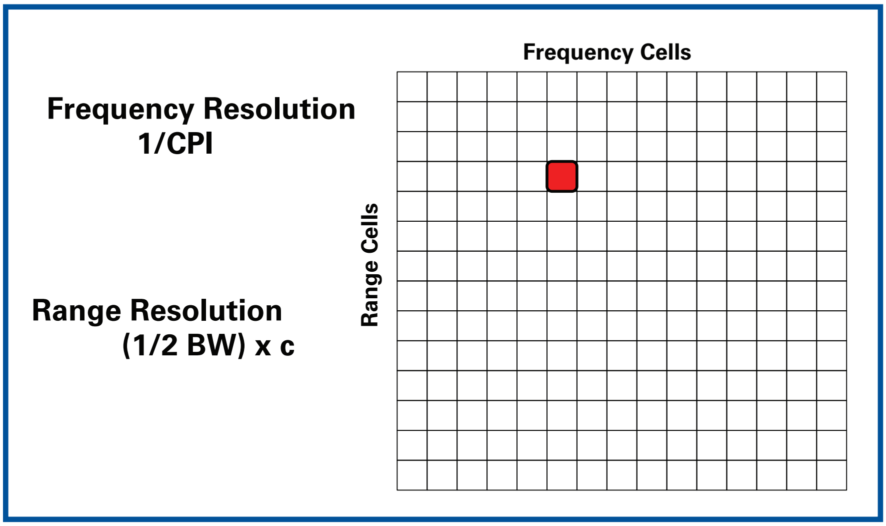


Fig. 2: *The processor of a pulse Doppler radar has a matrix of range vs. frequency on which the data from all returned pulses are collected. The range cells show the time of arrival of the received pulse and the frequency cells show the outputs of the bank of filters. The red cell represents a received return pulse at a specific frequency and a specific range.*

PRF RANGE PULSE DOPPLER RADARS

As shown in Figure 3, pulse Doppler radars are classified by pulse repetition frequency (PRF) – the rate that pulses repeat per second – which is equal to the inverse of the pulse repetition interval (PRI). A low-PRF radar has a long PRI. This means that targets can be at long ranges and the radar can still receive a return pulse before the next pulse is transmitted, so there is no range ambiguity over long radar-to-target ranges. However, the low PRF means that the Doppler shift measurement will be repeated at multiples of the PRF, causing frequency ambiguity. Low PRF pulse Doppler radars are ideally suited for acquisition radar roles.

High-PRF pulse Doppler radars have very short PRI and therefore are highly ambiguous in range, since many pulses will be transmitted before the first pulse is returned. This makes the range measurement highly ambiguous. However, the Doppler shift measurement is not normally ambiguous because of the short PRI. This type of radar is ideally suited to tracking airborne targets approaching a radar from the direction of its travel (i.e., traveling directly at the radar) because the high closing rate causes a very large Doppler shift. This creates a clean return, far from the frequency of the Doppler-shifted ground return.

In order to measure range to a target from a high-PRF radar, a frequency modulation (FM) must be added to the radar signal. Figures 4 and 5 show the way that a radar can determine the range by use of one particular FM waveform. This function can use many different waveforms; this waveform has been chosen here because the range determination process is easier to explain. The delay caused by the round trip between the radar and target at the speed of light means that the lower frequency at the beginning of the ramp will be received while the transmitter is broadcasting

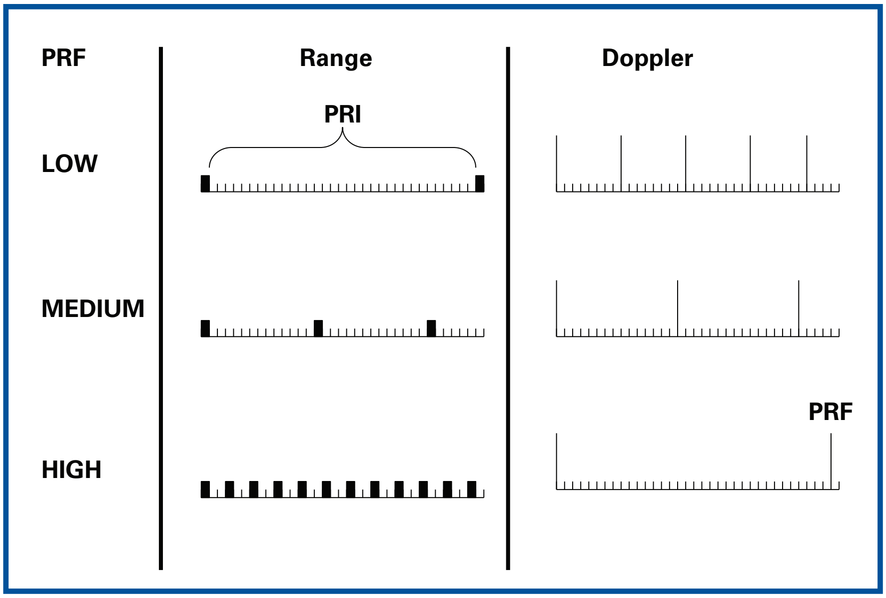


Fig. 3: *Low-PRF signals have very large pulse intervals and narrowly spaced frequency responses. High-PRF signals have small pulse intervals and widely spaced frequency responses.*

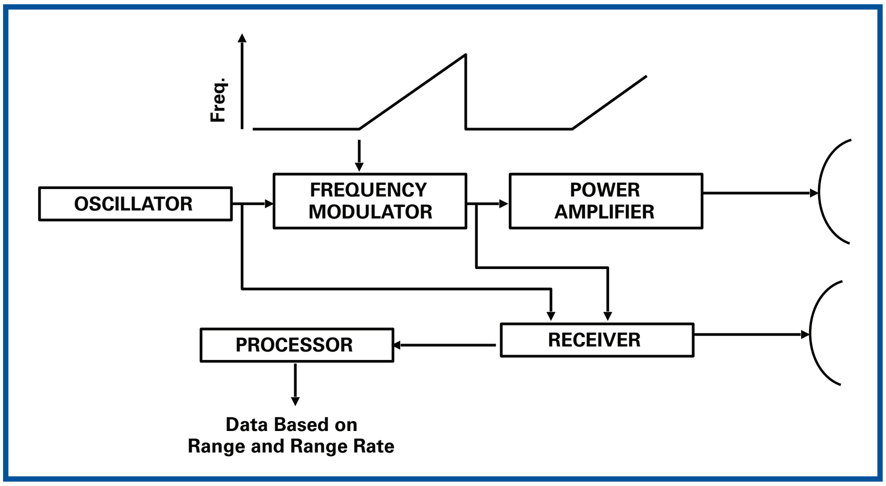


Fig. 4: *Many FM waveforms can be used for CW and high-PRF pulse Doppler radar ranging. In this waveform, the Doppler shift can be measured during the constant frequency part. The range to the target is determined during the ramped part of the waveform.*

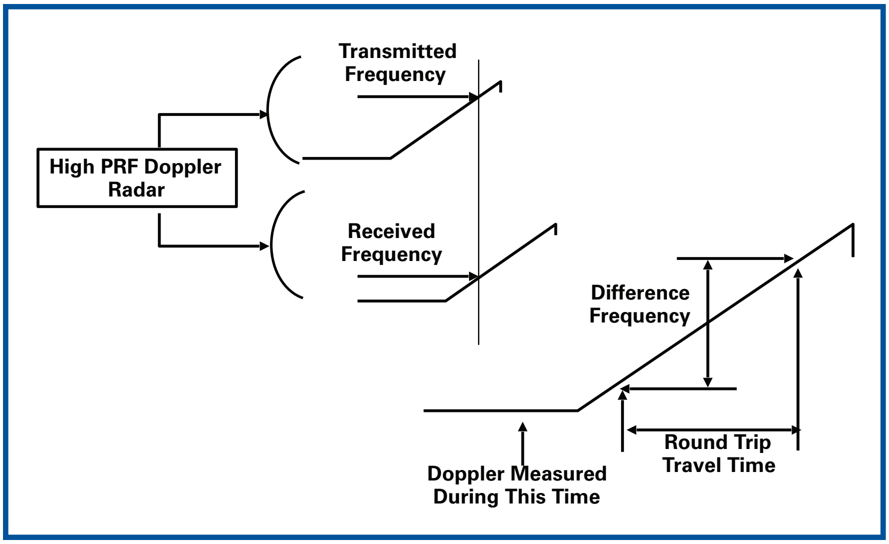


Fig. 5: *During the ramped part of this waveform, the frequency difference between the transmitted and return signals is proportional to the range to the target and also the Doppler shift. When the Doppler shift is removed, the remaining frequency difference is proportional to the radar to target range.*

the higher frequency later in the ramp. The instantaneous difference between the transmitted and return signals is proportional to the range. Note that this same range calculation technique is used for continuous wave (non-pulsed) radars.

Medium-PRF pulse Doppler radar modes are used for tail chase engagements. As the velocity of the radar and the target are very close, the Doppler shifts are small. This waveform causes ambiguity in both range and Doppler shift, but both the range and the Doppler shift can be determined by analysis of signals which have multiple PRFs. There are blind zones, as shown in Figure 6. By choosing some of the PRFs for analysis, the range and Doppler shift can be determined for a selected target located in a part of the matrix where there is no blind zone.

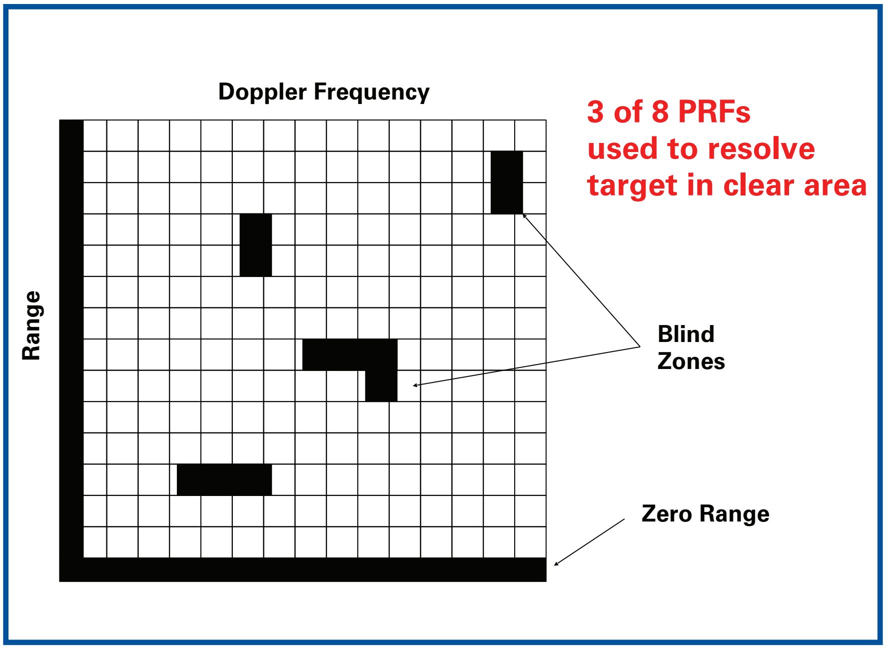


Fig. 6: *This shows the blind zones, in which medium PRF signals cannot be resolved. By using multiple PRFs, it is possible to analyze signals that are not in blind zones.*

WHAT'S NEXT

Next month, we will continue our discussion of the electronic protection advantages provided by Pulse Doppler radars. Dave Adamy can be reached at dave@lynxpub.com

UK CHAPTER CELEBRATES 50TH ANNIVERSARY

Members of the UK Chapter gathered at the International Bomber Command Centre (IBCC) Lincoln on Nov. 4 to mark the 50th anniversary of the formation of the AOC UK Chapter. A great evening was enjoyed by chapter members, family and friends in what was a truly fitting venue. Thank you to all those who turned out to support us, and in particular to BABCOCK for joining the dinner in healthy numbers.

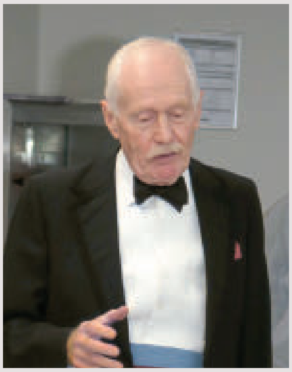
IMPORTANT DATES FOR AOC MEMBERS

2023 AOC AWARDS WILL OPEN MARCH 1 - APRIL 30

STEM STUDENT OF THE YEAR SCHOLARSHIP – FEB. 15 - APRIL 1

N&E – NOMINATIONS OPEN MAY 1 TO JUNE 30

FUTURE 5 – APPLICATIONS OPEN MAY 1 TO JUNE 30



AOC Members

SUSTAINING
AT&T Corp.
BAE Systems
Bharat Electronics Ltd.
CACI International Inc.
Chemring Group PLC
General Atomics Aeronautical
General Dynamics
Keysight Technologies
L-3 Harris
Leonardo
Perspecta
Raytheon Intelligence & Space
Rohde & Schwarz USA
Saab Sensor Systems Germany GmbH
SRC, Inc.
The Boeing Company

MILITARY UNITS
57 IS/DOD
293 EWS
Centro de Guerra Eletrónica – PTAF
Japan Air Self-Defense Force
Osan AB 25 FS
VMU-3

INSTITUTES/ UNIVERSITIES
Georgia Tech Research Institute
Mercer Engineering Research Center
Riverside Research Institute
RVJ Institute

GOVERNMENT GROUPS
Australia Department of Defence DIO
DE&S
Defence Science & Technology Agency
DOD
New Zealand Defence Technology Agency
NLR – Royal Netherlands Aerospace Centre

GROUPS
3dB Labs Inc.
Abaco Systems
Adaptive Dynamics Inc.
Aeronix, Inc.
Alaris Antennas
Algoptimal
Allen-Vanguard
Amentum
Analog Devices
Anritsu
ApisSys SAS
Apogee Engineering
Armtec Defense Technologies
ARS Products
AM LLC
Amentum
Annapolis Micro Systems Inc.
Aselsan A.S.
AssuredTek
Atkinson Aeronautics & Technology, Inc.
Atrenne, a Celestia Group Company
Avix
Azure Summit Technology, Inc.
Babcock International Group
Beca Applied Technologies Ltd.
Blue Ridge Envisioneering, Inc.
Booz Allen & Hamilton
Cablex PTY Ltd.
CEA Technologies, Inc.
Communications & Power Industries LLC
Comtech PST Corp.
Consunet Pty Ltd.
Crescend Technologies, LLC
CRFS Inc.
CRFS Ltd.
Cubic Defense
CyberOps
Daqscribe
Dayton Development Coalition
dB Control
DCS Corp.
Decodio AG
Defense Research Associates Inc.
Digital Receiver Technology (DRT)
Droneshield
Eagle Sales Corp.
Elbit Systems of America
Elbit Systems of EW & SIGINT
ELDES S.r.l.
Electro Rent
Elettronica GMBH
Elite RF
Elmtek Pty Ltd.
ELTA Systems Ltd
Empower RF Systems
Epiq Solutions
Epirus
ESG GmbH
ESROE Ltd.
Galleon Embedded Computing
GFD GmbH
Giga-Tronics, Inc.
Government Business Development
Hammer Defense Technologies LLC
Hasco
HawkEye360
Helsing GmbH
Hensoldt Australia
Hensoldt Sensors GmbH
HII
Hughes
IAI North America
Intelligent Fusion Technology Inc.
Intelligent RF Solutions
Interface Concept
IW Microwave Products Division
JT4, LLC
KBR
Kratos General Microwave Corp.
L3Harris Intelligence & Cyber International
L3Harris TRL Technology
LCR Embedded Systems
Leonardo DRS
Leonardo Electronics
Liteye Systems, Inc.
Lockheed Martin Co.
MarServices GmbH
Mass Consultants Ltd.
Maxar-Ypsi-EW
MBDA France
MC Countermeasures, Inc.
MDA
Meggitt Defense Systems
Menlo Microsystems
Microboard
Microwave Products Group
Milpower Source, Inc.
Milso AB
Mission Microwave Technologies
Mission Systems Babcock International
Motorola Solutions
MTSI
Nask, Inc.
Northrop Grumman Defense Systems Advanced Weapons
NSI-MI Technologies
Orolia Defense & Security
Parsons
PCTEL, Inc.
Peraton/Perspecta
Phasor Innovation
Photonis Defense Inc.
Predata
Procitec GmbH
Quantic Electronics
RADA Technologies LLC
RADX Technologies
ReleaseTeam
Research Associates of Syracuse, Inc.
Revolution Aerospace
Rincon Research Corp.
Rohde & Schwarz GmbH & Co. KG
Roschi Rohde & Schwarz AG
Ruag
S2 Corp.
Sciens Innovations
Scientific Research Corp.
SEA Corp.
Serpikom
Sierra Nevada Corp.
Signal Hound
Silver Palm Technologies
SimVentions
Skyworks
SMAG Mobile Antenna Masts GmbH
Smiths Interconnect – Tampa
SOIO
Spectranetix, Inc.
Spherea GmbH
Steatit
Stellant Systems
Stellar Industries Corporation
Swisscom Broadcast AG
Sypaq Systems
T2S
TCI International, Inc.
TCOM, L.P.
Tech Resources, Inc.
Tektronix Inc.
Teledyne Technologies, Inc.
Teleplan Globe Defence
Tevet LLC
Textron Systems
Textron Systems Electronic
The Mitre Corp.
ThinKom Solutions
Tinex AS
Transformational Security LLC
Transhield Inc.
Trideum
Ultra Electronics – EWST
Ultra Electronics Avalon Systems
Unival Group GmbH
Vadum Inc.
Valkyrie Enterprises LLC
Vectrus Systems Corp.
Viavi Solutions
Vic Myers Associates
Werlatone Inc.
work Microwave
X-COM Systems
Xolaris Civil Security

ASSOCIATION OF OLD CROWS

JED, Journal of Electromagnetic Dominance (ISSN 0192-429X), is published monthly by Naylor, LLC, for the Association of Old Crows, 1001 N. Fairfax St., Suite 300, Alexandria, VA 22314.

Periodicals postage paid at Alexandria, VA, and additional mailing offices. Subscriptions: *JED, Journal of Electromagnetic Dominance,* is sent to AOC members and subscribers only. Subscription rates for paid subscribers are $160 per year in the US, $240 per year elsewhere; single copies and back issues (if available) $12 each in the US; $25 elsewhere.

POSTMASTER:
Send address changes to
JED, Journal of Electromagnetic Dominance
c/o Association of Old Crows
1001 N. Fairfax St., Suite 300
Alexandria, VA 22314

Subscription Information:
Glorianne O'Neilin
(703) 549-1600
oneilin@crows.org

Index of Advertisers

JED Sales Offices

NAYLOR ASSOCIATION SOLUTIONS
550 SW 2nd Avenue
Gainesville, FL 32601
800-369-6220
Naylor.com

Project Manager:
Kira Krewson
Direct: +1 (770) 810-6982
kkrewson@naylor.com

Project Coordinator:
Alexandra Lewis
Direct: +1 (352) 333-3409
alewis@naylor.com

Advertising Sales Representatives:
Shaun Greyling
Direct: +1 (352) 333-3385
sgreyling@naylor.com

Robert Shafer
Direct: +1 (770) 810-6986
rshafer@naylor.com

Chris Zabel
Direct: +1 (352) 333-3420
czabel@naylor.com

NAYLOR (Canada) Inc.
200 - 1200 Portage Ave.
Winnipeg, MB R3G OT5
Canada
Toll Free (US): (800) 665-2456
Fax: +1 (204) 947-2047

JED QuickLook

RF Amplifiers and Sub-Assemblies for Every Application

Delivery from Stock to 2 Weeks ARO from the catalog or built to your specifications!

- Competitive Pricing & Fast Delivery
- Military Reliability & Qualification
- Various Options: Temperature Compensation, Input Limiter Protection, Detectors/TTL & More
- Unconditionally Stable (100% tested)

ISO 9001:2000 and AS9100B CERTIFIED

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

CIAO Wireless can easily modify any of its standard models to meet your "exact" requirements at the Catalog Pricing.

Visit our web site at www.ciaowireless.com for our complete product offering.

Ciao wireless

Ciao Wireless, Inc. 4000 Via Pescador, Camarillo, CA 93012
Tel (805) 389-3224 Fax (805) 389-3629 sales@ciaowireless.com