ASSOCIATION OF OLD CROWS
Advancing Electromagnetic Warfare TOGETHER
crows.org

June 2022
Vol. 45, No. 6

JED

Journal of Electromagnetic Dominance

Enabling Technologies for Next-Gen SIGINT

Technology Survey: Power Amplifiers for Jamming Applications

News: AFRL Solicits AI/ML Solutions Under Project Kaiju

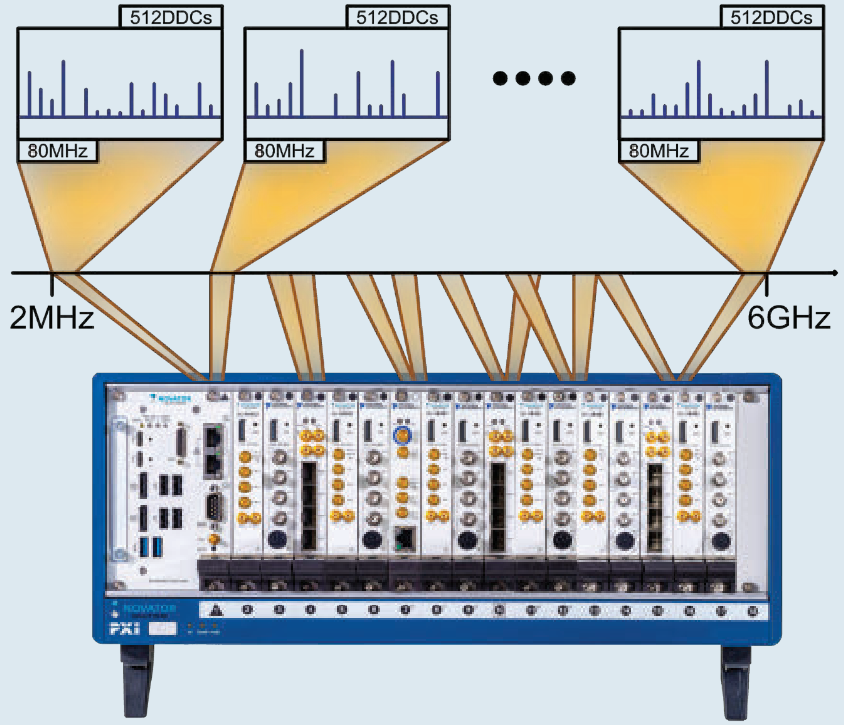
HUGIN 4000 SERIES

Next Generation COMINT Receiver Platform

HUGIN 4000 is the state-of-the-art receiver platform for a wide range of strategic COMINT applications like monitoring, scanning and direction finding. Built on a modular platform, HUGIN 4000 series is the flagship range of receivers from Novator Solutions that are based on the latest SDR technology.

Highlights

- High sensitivity and dynamic range that enables operators to intercept any signals
- A cost-efficient receiver design with a very low cost per channel ratio
- Parallel interception of up to 6144 signals
- Individually configurable DDCs that are reconfigurable in real-time
- Independent and phase-coherent tuning enabled

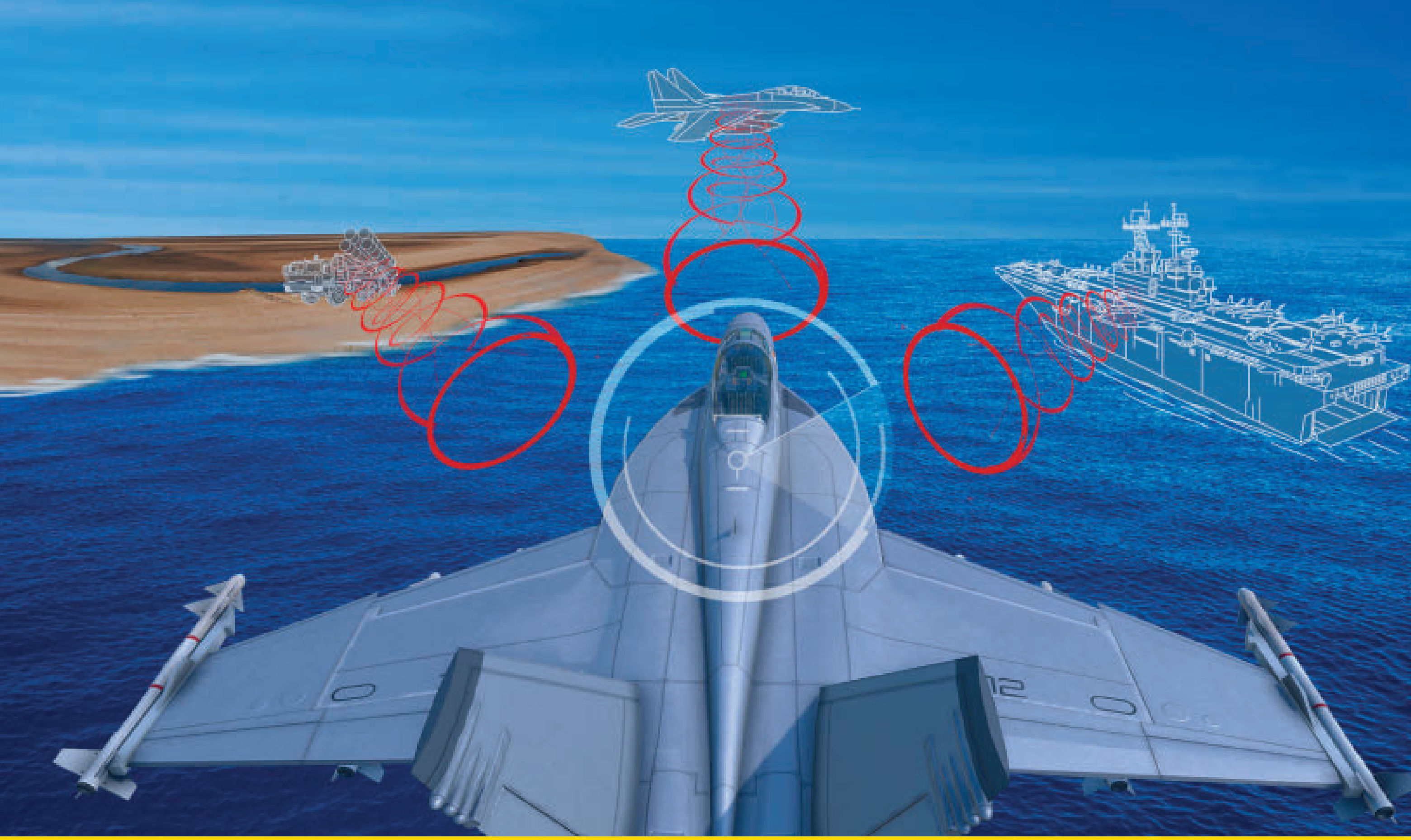


Monitoring Receiver | Scanning Receiver | Direction Finder

Key Technical Specifications:

- Up to 12 RF receiver channels (Rx)
- Frequency range 2MHz-6GHz
- Up to 960MHz aggregated bandwidth
- Up to 6144 narrowband DDCs

Learn more



JED
Journal of Electromagnetic Dominance

CONTENTS

June 2022 • Volume 45, Issue 6

Last month, soldiers and marines from 7th Signal Regiment, Australian Army; Y Squadron, 3 Commando Brigade, 30 Commando, Royal Marines; and 2nd Radio Battalion, II Marine Expeditionary Force Information Group, US Marine Corps, participated in the Radio Reconnaissance Operators Course (RROC) at Camp Lejeune, NC. RROC combines skills across SIGINT, EW and other reconnaissance disciplines and tests them in an intense training environment. Part of last month's RROC involved an air insertion from a CH-53. This was the first time the annual event has been held at Camp Lejeune.

USMC PHOTO BY SGT JOSHUA DAVIS

Departments

COVER PHOTO COURTESY OF US NAVY

ON UKRAINE

Over the past few months, I have resisted the urge about Russia expanding its 2014 invasion of Ukraine, mainly because events on the ground were developing so quickly in the early weeks of the conflict. Also, as in any conflict, there has been a limited amount of reliable information (understandably) about electromagnetic spectrum operations (EMSO) in the conflict. But now, nearly three months into the current phase of the conflict (at the time I am writing this), I think there is more to discuss, or rather, there are more questions to ask.

Let me begin by saying that I have long assumed that EMSO would play a critical role in any conflict between two modern forces of this size. The Russian Army has certainly deployed many of its EW and SIGINT systems, some of which have been captured by Ukrainian forces. Yet the reports coming out of Ukraine – from both Russian and Ukrainian forces, as well as independent reporting – indicates that the electromagnetic contest between the two is much less robust than I anticipated.

My expectations about the role that EMSO would play in the conflict were based in part on the EW and SIGINT capabilities that the Russians have been fielding for the past decade and the systems they had revealed at exercises such as Zapad 2021 in Belarus and Kavkaz 2020 near Volvograd. Beginning with the initial Russian invasion in 2014 and the subsequent fighting in the Donbas region, however, Ukrainian forces have gained familiarity with Russian EW and SIGINT capabilities and they have learned how to protect their sensors, radios and weapons systems well enough to continue using them. The Ukrainian Army also learned to employ counter-drone technology quite effectively during the years of Donbas operations.

Whatever the reasons, Russian EW does not seem to be as prominent over the past three months as I would have expected. This has led me to ask some fundamental questions. First, is the EMS a strategic maneuver space in this conflict? I think the answer to this question is still a definite "yes." Both forces are employing long-range artillery, which requires forward-positioned sensors (such as UASs or humans), as well as effective communications links to relay target information and to correct fire. For Ukrainian forces, those sensors and links do not seem to be widely disabled by Russian jamming.

Another question is, why does Russian EW seem to be so ineffective? The Russian Army has clearly modernized its EW capabilities, and it has deployed EW systems with its forces in Ukraine. It has also trained with those systems and developed doctrine and tactics for this equipment. Could this be a case of developing new capabilities but then failing to integrate them into the larger force? Or is it a matter of Russian military commanders failing to understand how to use these EW capabilities effectively? It's still too early to say, for sure. And the apparent underperformance of Russian EW is being overshadowed by larger logistics failings and certain manpower shortfalls. Still, these are the types of questions we need to keep asking ourselves. – *J. Knowles*

JED
Journal of Electromagnetic Dominance

EDITORIAL STAFF
Editor: John Knowles
Account Manager: John Bacon
Senior Editor: John Haystead
Managing Editor: Aaron Brand
Technical Editor: Barry Manz
Contributing Writers:
Dave Adamy, Luca Peruzzi, Richard Scott, Dr. David Stoudt, 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 US NAVY
PUBLISHED MAY 2022/JED-M0622/9785

Calendar *Conferences & Trade Shows*

JUNE

Eurosatory
June 13-17
Paris, France
www.eurosatory.com

AOC Kittyhawk Week
June 14-16
Dayton, OH
https://kittyhawkaoc.org

AOC Space-Cyber Resiliency Summit
June 14-16
Bedford, MA
www.patriotsroostaoc.org

Electronic Warfare Technical Conference
June 14-16
Shrivenham, Swindon, UK
www.cranfield.ac.uk

International Microwave Symposium
June 19-24
Denver, CO
https://ims-ieee.org

JULY

Farnborough International Air Show
July 18-22
Farnborough, Hampshire, UK
www.farnboroughairshow.com

AUGUST

TechNet Augusta
Aug. 15-18
Augusta, GA
www.afcea.org

Defence & Security 2022
Aug. 29 - Sept. 1
Bangkok, Thailand
www.asiandefense.com

SEPTEMBER

29th International Defence Industry Exhibition MSPO
Sept. 6-9
Kielce, Poland
www.targikielce.pl

AFA Air, Space and Cyber Conference
Sept. 19-21
National Harbor, MD
www.afa.org

Africa Aerospace and Defense (AAD2020)
Sept. 21-25
Air Force Base Waterkloof
Gauteng, South Africa
www.aadexpo.co.za

OCTOBER

AUSA Annual Meeting
Oct. 10-12
Washington, DC
www.ausa.org

EURONAVAL
Oct. 18-21
Paris, France
www.euronaval.fr

59th Annual AOC International Symposium and Convention
Oct. 25-27
Washington, DC
www.crows.org

NOVEMBER

Indo Defence Expo and Forum
Nov. 2-5
Jakarta, Indonesia
www.indodefence.com

Bahrain International Airshow 2022
Nov. 9-11
Sakhir Air Base, Bahrain
www.bahraininternationalairshow.com

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


GET EW & RF
CAPABILITIES
FAST
LEARN MORE
COGNITIVE TEST CAPABILITY
VALIDATE OPERATIONAL STATUS OF YOUR SYSTEM
INTUITIVE, TAILORED DESIGN
MULTI-SPECTRAL & MULTI-DOMAIN
BUY NOW
FOR QUICK
DELIVERY
TextronSystems.com
(800) 655-2616 | electronicsystems@textronsystems.com
TEXTRON Systems
PUSHING PAST POSSIBLE
© 2022 Textron Systems Corporation.

Calendar *Courses & Seminars*

JUNE

AOC Virtual Series Webinar: Millimeter-Wave (mmW) Propagation
June 6
2-3 p.m. EDT
www.crows.org

Radar Cross-Section Reduction
June 6-8
Atlanta, GA
www.pe.gatech.edu

AOC Virtual Series Webinar: Development of Cognitive EW Datasets
June 16
2-3 p.m. EDT
www.crows.org

Basic RF Electromagnetic Warfare Concepts
June 28-30
Las Vegas, NV
www.pe.gatech.edu

Cyber Warfare/Electronic Warfare Convergence
June 28-30
Las Vegas, NV
www.pe.gatech.edu

AOC Virtual Series Webinar: Electromagnetic Battle Management
June 30
2-3 p.m. EDT
www.crows.org

JULY

AOC Virtual Series Webinar: Low SWAP Multifunctional Electronic Warfare System Development
July 14
2-3 p.m. EDT
www.crows.org

AOC Virtual Series Webinar: Cognitive EW, an Artificial Intelligence Approach
July 28
2-3 p.m. EDT
www.crows.org

AUGUST

Directed Infrared Countermeasures: Technology, Modeling and Testing
Aug. 16-18
Atlanta, GA
www.pe.gatech.edu

SEPTEMBER

AOC Virtual Series Webinar: Cognitive EW and Reinforcement Learning
Sept. 8
2-3 p.m. EDT
www.crows.org

AOC Virtual Series Webinar: Across the Spectrum Pond: How the US Military Can Procure Tested Solutions from Europe
Sept. 22
2-3 p.m. EDT
www.crows.org

OCTOBER

AOC Virtual Series Webinar: The World of Small Unmanned Aerial Systems (sUAS) – 2022 Update
Oct. 20
2-3 p.m. EDT
www.crows.org

NOVEMBER

AOC Virtual Series Webinar: Electromagnetic Maneuver: Towards a Theoretical Underpinning
Nov. 10
2-3 p.m. EST
www.crows.org

Cyber Warfare/Electronic Warfare Convergence
Nov. 15-17
Atlanta, GA
www.pe.gatech.edu

Infrared Countermeasures
Nov. 15-18
Atlanta, GA
www.pe.gatech.edu

AOC courses and webinars are noted in red. For more info or to register, visit crows.org.

WERLATONE®

DIGITAL RF POWER METERS

40 dB Dynamic Range ✦ **Optimal Accuracy** ✦ **No Calibration Required**

Simultaneously Monitor: Forward Power, Reverse Power, Load VSWR, & Temperature

ACCURACY

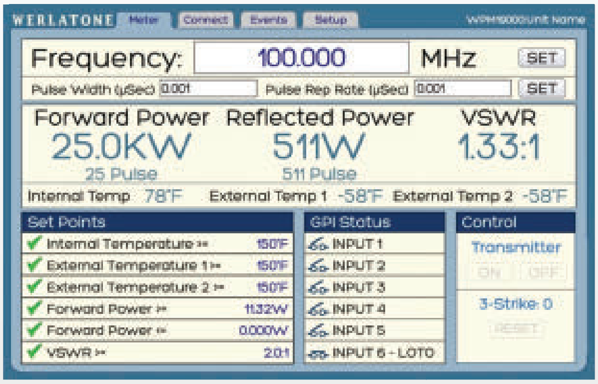
- Multi-Octave Solutions provide accuracy within ± 5% of a Customer Lab Standard (± 2% Typical).

CALIBRATION

- No On-Site Calibration Required.
- Calibration Routine completed internally to each Power Sensor.
- Traceable to National Institute of Standards & Technology (NIST).

ALARMS & RELAYS

- Alarm Thresholds of Forward & Reverse Power.
- Full VSWR Monitoring/Alarm Capability.
- Full Temperature Monitoring/Alarm Capability.
- Six General Purpose Inputs & 2 Form-C Relays to External Devices



FIRMWARE

- Windows Application includes an ergonomic tab-based access system for easy setup and operation of the Power Meter.
- Multi-Window Display for access to up to five Meters on screen.
- VSWR Indication & Reflected Power on main Power Sensor display.
- MIB File available for use with SNMP software.
- LabVIEW Driver Available.

Werlatone, Inc. 17 Jon Barrett Road Patterson, NY 12563 845-278-2220 sales@werlatone.com www.werlatone.com

President's Message

EMSO IS NOT EASY!

Carl von Clausewitz wrote, "In war, while everything is simple, even the simplest thing is difficult." I think this is true for Electromagnetic Spectrum Operations (EMSO). Maneuver in the EMS can be pretty straightforward: we sense the Electromagnetic Operational Environment (EMOE), we can attack in the EMOE and we can protect from the EMOE. I receive a signal and radiate back at the same frequency. Simple, correct? I wish it was that simple, but there is a lot more to it than that.

For today's EMOE, we need to know much more than frequency, PRF, pulse lengths, etc. Today, these parameters are just the beginning. We need those answers, as well as many more, like waveform descriptions, algorithms, agility of the signal, power, just to mention a few. How fast does my response need to be? Is the signal pulse-to-pulse agile? What is the correct technique and power needed to have an effect? Additionally, for electromagnetic support, we now want to geolocate emitters, instead of just detecting signals and determining a rough angle of arrival. Electromagnetic protection is also not simple. What am I protecting against: detection, electromagnetic attack, electromagnetic pulse or directed energy?

Another variable in the dynamic EMOE is "what is that signal?" Is it friendly or an adversary's, military or commercial? There are signals that could be either, so how do we make sure we know whether to counter that signal or not? What are the rules of engagement within the EMS?

The war in Ukraine has shown that the EMOE is critical and complex. EMSO and EW are being used by both countries, and this activity includes traditional platforms and assets across all domains. The use of unmanned and uncrewed vehicles has added to the dynamic and complex EMOE. These systems range from small civilian/commercial drones to military strike weapons.

Communication systems have also evolved from operator set single-frequency radios with omni directional antennas, to encrypted frequency-hopping radios with directional and low-probability-of-intercept antennas. Datalinks are another capability that provide communications to platforms, weapons and personnel, and they are used to move information across the EMS.

As I have mentioned in a previous message, the Kill Chain is now a Kill Web. What used to take multiple systems (early warning, height finders, acquisition, engagement/tracking radars and many communication nodes/links) can now be accomplished with a wide variety of sensors and shooters connected on a robust battle network. In addition, this process took minutes from the start of an engagement to putting a weapon on target. Today's digital and highly networked threats can engage and fire within seconds, and some systems can operate independently and still be quite effective. Many of these systems have many agility features and complex waveforms.

So, what in theory was perhaps "simple" once upon a time (or at least straightforward), has definitely become dynamic, complex and "difficult."

As always, AOC continues to be active and engaged in the EMSO community, and we need your involvement and engagement to continue to grow the organization, especially our Young Crows! – *Glenn "Powder" Carlson*

High Power, Broadband
Solid State Power Amplifiers
on EW / EA MISSIONS
SSPA 0.020-6.000-70
• 20 - 6000 MHz
• 70-120 Watt SSPA
• Ground or Airborne
SSPA 0.25-2.00-100
• 250-2000 MHz
• 100 Watt Transmitter
• 2.0"x3.0"x0.5
• Airborne
SSPA 6.0-12.0-100
• 6.0-12.0 GHz
• 100 Watt min Transmitter
• Ground or Airborne
SSPA 2.0-6.0-250
• 2.0-6.0 GHz
• 250 Watt Transmitter
• Airborne
SSPA 0.020-1.000-1000
• 20-1000 Mhz
• 1000 Watt Transmitter
• Airborne
Aethercomm supports both ground & airborne EW missions. Whether you are looking to upgrade an existing RF system or designing for a new platform, our team of technical RF experts are here to support.
23 YEARS IN BUSINESS
23
1999-2022
nqa.
ISO 9001
AS9100
INTEGRATED MANAGEMENT
59
Booth 232
L3Harris
Small Business Supplier of the Year Award
Aethercomm
DEFENSE
www.aethercomm.com | 760.208.6002 | sales@aethercomm.com

AFRL SOLICITS AI/ML SOLUTIONS UNDER PROJECT KAIJU

The Air Force Research Lab, Sensors Directorate (AFRL/RY) (Wright-Patterson AFB, OH) has issued its long-awaited Broad Agency Announcement (BAA) for Project Kaiju, which represents one of its largest and most ambitious electronic warfare research and development programs.

According to the BAA, Project Kaiju aims to "… research, develop and transition advanced electronic warfare (EW) technologies to ensure future dominance of the US and its allied nations within the electro-magnetic spectrum (EMS) across all domains. These advanced EW technologies will encompass the following technical areas: data collection, artificial intelligence (AI) and machine learning (ML), modeling and simulation, algorithm design and development, hardware development, testing (in the lab and in the field), and analysis."

Project Kaiju's total budget is estimated $300 million over five years, and the work will be solicited under eight separate "calls" for proposals, each valued at between $1 million and $95 million. (Kaiju and its respective calls are named after classic monster films.) Project Kaiju is being managed by the Sensors Directorate's Spectrum Warfare Division, RF Electronic Warfare Branch (AFRL/RYWE).

AFRL issued its first call concurrently with the Kaiju BAA release. Call 01, titled "Cognitive Electronic Warfare (EW) Software Development for In-Flight, In-Field, and In-Squadron Applications (King Kong)," will focus on conducting "… 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."

The solicitation further states, "Of primary interest are the application of multi-sourced AI/ML to: 1) process synthetic and tactically recorded data to include in-phase and quadrature (I/Q), pulse descriptor word (PDW), emitter descriptor word or waveform descriptor word (EDW and WDW, respectively), and emitter identification (EID); 2) identify and develop algorithmic solution space to learn emitter ID, intent, and behavior to enable emitter and IADS tracking and prediction; 3) interpret and compare IMD and platform mission data; 4) determine and analyze data traceability to perform root-cause analysis; 5) provide analysis and visualization into MD quality; and 6) perform multi-tiered M&S to analyze solution space effectiveness and extensibility across the battlefield. Additionally, the next sortie reprogramming capabilities developed under this effort will produce analysis to aid in prioritizing operational flight programming (OFP) tuning and updates as well as identifying new AI/ML capabilities to be utilized and integrated into OFP upgrade cycles." This 39-month effort is valued at $16 million, and program officials intend to award one contract. Companies must submit an "intent to propose" notice by June 1 and then submit their proposal by June 14.

The Project Kaiju solicitation number is BAA FA8650-22-S-1004. The technical point of contact for Project Kaiju is Gary Kaufman, Project Engineer, AFRL/RYWE, (937) 713-4007, gary.kaufman.1@us.af.mil. The contracting point of contact is Jennifer M. Skalski, Contracting Officer, (937) 713-9837, jennifer.skalski@us.af.mil. – *J. Knowles*

UK MOD TO DEVELOP INNOVATIVE COUNTER-IED TECHNOLOGIES

The UK MOD's Defence and Security Accelerator (DASA) has launched a new Innovation Focus Area (IFA) titled, "Countering IEDs by Novel Technology and Techniques," which will "develop innovations that use either the Radio Frequency (RF) spectrum or provide an understanding of the RF spectrum in order to detect and disrupt the functionality of IEDs," according to the solicitation.

The program description further states, "The aim of the IFA is to provide a range of successful solutions that can be developed for front line use. Electronic Counter Measures (ECM) and Electronic Support Measures (ESM) systems need to counter an evolving range of electromagnetic technologies operating across the RF Spectrum, using an ever growing and diverse range of signaling schemes. As possible threat technology types in this area are constantly changing, front line operators need to have a wide variety of options at their disposal to mitigate emerging problems quickly and effectively."

The IFA outlines three "challenge areas." Challenge 1 will focus on capturing and analyzing RF signals using novel spectrum survey techniques, which may include:

- Signal analysis techniques and classification algorithms, which identify and distinguish between multiple technology standards and protocols, while being able to operate across a wide spectrum in real time.
- Generating methods or data analysis techniques to provide an understanding of the RF environment, which can be used to inform tactical decisions; for instance, the ability to identify abnormal changes in the environment.

Challenge 2 addresses "approaches to permanently or temporarily disable commercial communications links and/or the electronics within a Remote Controlled Explosive Device." Examples include techniques that:

- Disable communications links to prevent a trigger signal being received. Examples of communication links of interest include push-to-talk radios, wireless doorbells, cellular devices, Wi-

Fi and any other readily available communication devices. This may include approaches against the RF signal or the wireless transceivers themselves.

- Disable multiple communication types simultaneously across a wide spectrum, preventing devices from switching to alternative RF bearers that they may have access to.
- Disable the electronics within a Remote Controlled Explosive Device, preventing its detonation. Examples include RF techniques to affect the operation of microcontrollers or cause permanent damage.

Finally, Challenge 3 aims to develop novel hardware and system components, which may include:

- Novel antenna concepts to improve performance and lower the RF and visual signature of the service person or vehicle with respect to the ECM system and its ancillaries.
- Advancements in hardware design, such as tunable filters and efficient ultra-wide band amplifier designs.
- Improving size, weight, or power, or efficiency in wideband RF signal generation technologies (in the order of several GHz).
- Novel signal and data processing hardware technologies and techniques that offer advances in efficiency, parallelism or dynamic configurability.

The program is seeking technologies that are at Technology Readiness Level 5/6 or higher and are "short- to medium-term, nominally between 6 to 18 months, with a funding amount between circa £150k and £400k per project."

The program's unique identifier is IFA034. – *JED Staff*

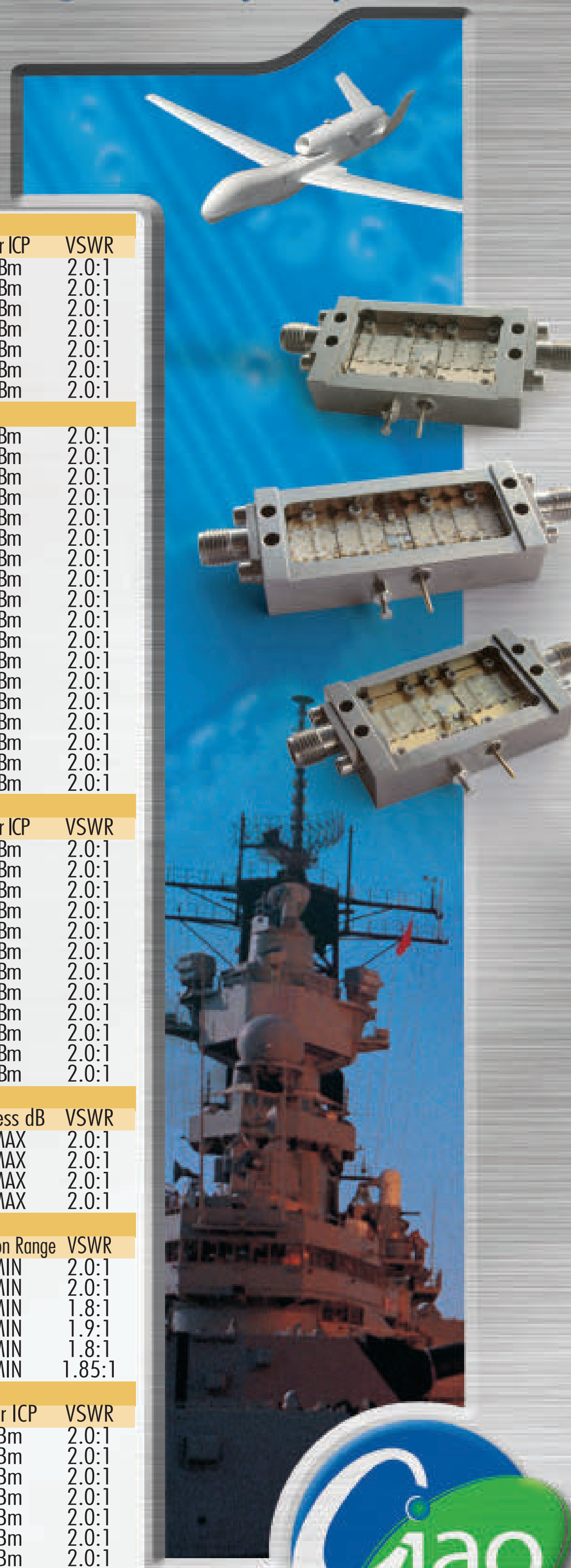
TRAINABLE DECOY LAUNCHER IN FRAME FOR CANADIAN FRIGATE PROGRAM

Safran's Next-Generation Dagaie System (NGDS) trainable decoy launcher has been selected to equip Canada's next-generation surface combatant.

Public Services and Procurement Canada (PSPC) disclosed the selection of the "NGDS/MSDS" for the 15-ship Canadian Surface Combatant (CSC) program in a separate request for information (RFI) for suitable offboard countermeasures. Acquisition of decoy rounds is to be pursued independent of the launcher procurement.

The NGDS will be fitted aboard the Global Combat Ship design being procured under the Canadian Surface Combatant (CSC) program. LOCKHEED MARTIN CANADA PHOTO

Lockheed Martin Canada Rotary and Mission Systems – proposing a BAE Systems' Global Combat Ship design derived from the UK Royal Navy's Type 26 frigate – was in October 2018 selected as CSC ship design and combat system partner.



All 15 ships are to be built by Irving Shipbuilding Inc. at its yard in Halifax, Nova Scotia; construction of the first-of-class is expected to start in the mid-2020s.

In its RFI for offboard electronic countermeasures (OB ECM) munitions for CSC, published on April 14, PSPC confirmed that the CSC will be equipped with the Safran NGDS/MSDS launcher as a core defensive capability. It added that the system was selected by Lockheed Martin Canada through the competitive bid process approved by both Irving Shipbuilding and the Canadian government.

NGDS uses a two-axis launcher able to train in both azimuth and elevation so as to achieve optimum placement of the decoy payload. The original 12-round launcher developed for the French Navy is compatible with Lacroix Defense 150-mm caliber SEALEM and SEALIR decoy rockets respectively deploying RF and IR payloads. Safran has subsequently introduced alternative barrel module configurations to meet specific customer needs.

In a statement, Safran Electronics and Defense confirmed its selection for CSC. "NGDS is a versatile and highly capable platform suitable to fire a wide variety of anti-air warfare/anti-submarine warfare, both of the mortar and rocket types, whether chaff, flares, obscurants, corner reflectors, anti-torpedo, passive or active, of various calibres up to 150 mm," said the company, adding: "Safran is not contracted to supply the ammunition for CSC and will comply with the ammunition selected by Canada."

According to PSPC, the RFI for OB ECM munitions is intended to inform a subsequent request for proposals. Canada is seeking to work with industry towards licensing approved NGDS/MSDS launcher munitions for final in-country assembly through Canada's Munition Supply Program. – *R. Scott*

DARPA TO DEVELOP VLEO SENSOR NETWORK TO MONITOR IONOSPHERE

The Defense Advanced Research Project Agency (DARPA) (Arlington, VA) has issued the first solicitation for its Ouija Program, which aims to "… use sensors on low-orbiting satellites to provide new insights into HF radio wave propagation in the ionosphere." With these sensors, DARPA program officials hope to "… quantify the space HF noise environment and improve characterization of the ionosphere to support warfighter capabilities." Understanding this information in real-time would benefit HF communications, radar and SIGINT activities.

The aim is to launch Very Low Earth Orbit (VLEO) satellites (i.e., 200-300 km above Earth), each of which will be equipped with a mission payload comprising a space-deployable HF antenna and a 2- to 30-MHz receiver that will help to map the constantly changing "terrain" of the ionosphere in real-time.

According to the solicitation, "The goal of the Ouija program is to quantify the High Frequency (HF) noise environment in space and improve the characterization of the ionosphere in support of warfighter capabilities. Ionospheric measurement campaigns typically rely on ground-based instrumentation to characterize the ionosphere. Ouija will aug-

ment these ground-based measurements with in-situ measurements from space to develop and validate accurate near real-time HF propagation predictions."

Under Ouija Technical Area-1 (TA-1) DARPA will "develop, qualify, launch and operate multiple small satellites carrying scientific and mission instrumentation," according to the solicitation. It further stated, "The Ouija scientific payload will measure electron density by both direct sampling and indirectly via radio occultation using navigation satellites. It is anticipated that the scientific payload will use or adapt Commercial-Off-the-Shelf (COTS) components, but innovative instrumentation proposals that enhance the functionality of the scientific payload over a COTS baseline are welcome."

According to the solicitation, "The key technology enabler is real-time in-situ measurements of the ionosphere at VLEO. The space-based measurement density will be increased from that achievable with a single satellite, the Ouija Pathfinder, to the greater density achieved with multiple satellites operated as a Flight in near proximity. The Ouija Flight will measure gradients of the electron density, which have a profound impact on HF propagation, at resolutions between 50 km – 100 km. The VLEO altitude regime ... is of particular interest due to its information rich environment where ionospheric electron density is at a maximum. Fine-grained knowledge of the spatial-temporal characteristics of electron density at these altitudes is required for accurate HF propagation prediction."

In terms of the Ouija sensor payload, the solicitation states, "The HF mission payload will require a high sensitivity, high dynamic range, low noise HF measurement subsystem. The antenna for this subsystem is a particular challenge, as efficient HF antennas that operate at the lower end of the band are long, presenting deployment and space vehicle drag challenges. The impedance matching network for the antenna will also be a challenge, as the antenna is coupled to the ionospheric plasma, significantly altering its impedance characteristics."

Proposals for TA-1 were due on May 25. DARPA plans to issue a follow-on Broad Agency Announcement (BAA) for TA-2, which will address "Ionosphere Modeling and Compensation." The ionosphere measurement data provided by TA-1 will be used in the analytical work performed under TA-2 to improve ionosphere assimilative models. The Ouija solicitation number is DARPA-PS-22-06.

Ultimately, DARPA plans to develop a complete solution: "a fully integrated Ouija Pathfinder satellite with integrated scientific and mission payloads built, launched and operated for its lifetime, followed by the build, launch and operation of the Ouija Flight of six satellites. The space-based data collection will be for Government test events and demonstrations that will also utilize ground-based instrumentation. The first test event using the Ouija Pathfinder satellite is planned for the April/May 2024 timeframe, approximately two years from award. A second test event using the Ouija Flight of six satellites is planned for approximately November 2025." – *J. Knowles*

SYMPOSIUM AGENDA

The EMSO Playbook: Maneuvering to Win in a New Era

Global security is changing rapidly from Russia's invasion into Ukraine to growing tensions in the Pacific. The EMSO fight will be complex in all future conflicts, yet it is one of the last ways we invest to improve our ability to maneuver in the next 5 years.

The symposium will explore the playbook required for successful EMSO for US and coalition partners.

Symposium Sessions

Below is a sample of some symposium sessions that are on the agenda this year. You can learn more about themes, session chairs, and agenda descriptions at **59.crows.org**

- Operations, Readiness, and Training
- Joint & Coalition EMSO Integration
- JADC2
- Unmanned/Uncrewed Systems
- 5G/NextG
- Space EMSO: C-C5ISRT
- Standards & MOSA
- Supply Chain

**As of May 11, 2022 – Subject to Change*

REGISTRATION INFORMATION

Registration and housing will be opening in June.

Master Pass

The 'Master Pass' includes access to keynote sessions, access to all symposium sessions Tuesday–Thursday, Program Manager Briefing Series sessions, access to the Welcome Reception; access to the exhibit hall, lunches and happy hours, First-Time Attendee Orientation, and access to all recorded keynote sessions and briefings as released by the speakers. *Registration does not include access to post-convention courses.*

	By 7/22	7/23-9/30	10/1-On-Site
Industry (Member)	$795	$895	$995
Industry (Non-Member)	$995	$1095	$1195
Academia*	$545	$645	$745
Young Crows (35 and younger)*	$545	$645	$745
Government Civilian*	FREE	FREE	FREE
Military in Uniform**	FREE	FREE	FREE

*Must present proper ID for discounted price:
- Academia - faculty/staff/student ID.
- Young Crows (35 and younger) - photo ID with DOB.
- Government Civilian - government ID or civilian CAC card.

**Duty uniform must be worn each day. If not, a fee of $100 will be assessed.

Discounted pricing ends 7/22!

Exhibition Only Pass

This complimentary registration type provides access to the Welcome Reception, keynote sessions and the exhibit hall. *It does not allow access to all other symposium sessions, Program Manager Briefing Series or post-convention courses. It is not intended to be used for booth staff registration. Booth personnel registration will open in August. For more information on how to register your booth staff, contact Sara Capistrant at sara@blueskyz.com.*

	By 7/22	7/23-9/30	10/1-On-Site
Exhibition Only	FREE	FREE	FREE

POST-CONVENTION COURSES

Post-convention courses offer unique educational opportunities for focused professional development immediately following convention. These courses are eligible for credit and taught by our subject-matter experts.

EDUCATIONAL COURSES

More information coming soon.

Enroll in a course from our on-demand collection of courses at crows.org/PDC_OnDemand_Catalog

PROGRAM MANAGER BRIEFING SERIES

AOC's highly anticipated Program Manager (PM) Briefing Series returns to AOC 2022. This program focuses on bridging requirements to programs and informing industry on the acquisition milestone chart for contracting opportunities.

PROGRAM MANAGER BRIEFING SERIES
WHERE GOVERNMENT & INDUSTRY MEET

This program is only open to booth personnel and master pass attendees (master pass new for 2022) – closed to media.

OPTIMIZE YOUR EXPOSURE

The best of the best in the world of Electromagnetic Warfare attend the Annual AOC Symposium & Convention. Have your organization stand out and make an impact. Custom sponsoring opportunities are available, no matter what the size and budget of your organization. Learn more about sponsoring and exhibiting at the show: go to 59.crows.org or contact **Sean Fitzgerald** at **fitzgerald@crows.org**.

Booth space is selling quickly! Book now! *Special opportunities for Small Businesses are available.*

#CROWS2022

LIVE ONLINE COURSE
Cognitive Electronic Warfare: An Artificial Intelligence Approach

September 12-28, 2022
Mondays & Wednesdays

1:00-4:00
PM EDT

Meet the Instructor

Dr. Karen **Haigh**
is an expert and consultant in Cognitive EW and embedded AI. Her focus is on physical systems with limited communications and limited computation resources that must perform under fast hard-real-time requirements. She received her PhD in from Carnegie Mellon University in Computer Science with a focus on AI and Robotics.

Register today!

www.crows.org/CognitiveEW-AICourse

Details

This course will cover how artificial intelligence (AI) can be used in electronic warfare (EW). The course is based on the book “Cognitive Electronic Warfare: An Artificial Intelligence Approach” by Karen Haigh.

Learn and discuss:

- How AI enables EW systems to respond more quickly and effectively
- AI-based situation assessment techniques for electronic support (ES)
- Decision-making techniques for electronic protect (EP), electronic attack (EA), and electronic battle management (EBM)
- How to handle real-time in-mission learning, motivate why this capability is crucial, and discuss how to evaluate a system that learns during a mission
- Data management approaches and system architecture

EDUCATIONAL COURSES

To the Boundaries of t Edges of the Battlefiel Pursues Exponential S

By John Haystead

In the not-too-distant past, and in some cases even into the present day, the performance of advanced signals intelligence (SIGINT) was considered to be, in many ways, an artform, with the level of success largely dependent on the experience and skill-level of operators, rather than a straightforward exploitation of purely science-based collection and analysis techniques. This is no longer the case, at least in terms of the leading-edge work currently being done to dramatically improve SIGINT technology and system capabilities at all levels. For example, over the years, debate has raged as to what type of processors are best for the rapid and comprehensive identification and sorting of signals, whether FPGAs, ASICs, DSPs, or General-Purpose Graphics Processing Units (GPGPUs) – each offering advantages and disadvantages but, in any case, only providing incremental improvement in specific types of applications, specific areas of the Electromagnetic Spectrum and specific signal types. That being said, although it may seem self-evident to anyone involved in SIGINT, it's still critically important for designers and builders of SIGINT collection capabilities to maintain a focus on the ultimate big-picture goal of signals collection and distribution – collecting all signals, identifying each, doing it in real-time, extracting information content, recognizing who needs to receive that information, and providing it to them in a battlefield-relevant timeframe. Accomplishing this goal requires not merely incremental improvements, but rather exponential advancements in core technologies. The Defense Advanced Research Agency's (DARPA's) Microsystems Technology Office (MTO) is one organization leading the pursuit of these advancements.

Tom Kazior, DARPA MTO Program Manager (PM), says "In terms of the big-picture, I look at the overall SIGINT challenge from the perspective of eventually, or ideally, being able to detect and identify signals from DC-to-light or beyond. Of course, that's a very wide aperture, particularly when you also want to be able to focus on specific parts of the spectrum where there may be known threats that we want to keep an eye on. We will need to have systems flexible and adaptive enough that they can be reconfigured to look into new parts of the spectrum as they begin to be exploited."

IT'S STILL BOTH AN ANALOG AND A DIGITAL PROCESS

Kazior says his work is focused on two aspects of the SIGINT mission challenge. "How can we make the analog receiver more sensitive – to operate efficiently and collect a broad set of analog information – and how can we best provide actionable information, in real or near-real time, to the warfighter or whatever other organization has an interest in it."

Kazior points out that although we live in an analog world with signals-of-interest all around us, in our desire to find and identify these signals as efficiently and flexibly as possible, the common approach today is to as quickly as possible convert these analog signals into digital information prior to processing. This, however, creates its own challenges. "So this becomes, 'How do we collect all of this digital information, while at the same time minimizing power consumption, particularly when we're looking over a very wide range of spectrum and we want to manipulate and reduce the data to get actual actionable information.'"

This leads to the processor choices discussed earlier. As Kazior observes, "Some people say, 'ok we do things with FPGAs,' because you can program them, but remember there's also a price to pay for that programmability and flexibility, because FPGAs can be very power hungry."

In that regard, Kazior recalls that, "Historically, the power amplifiers in a radar or other active system were what dominated the energy consumption, but over time, this has shifted to the point where the digital processing is actually dominating the power consumption, which is why we're so focused on reducing this in a way that we can also achieve the flexibility to be able to do real-time, or run-time reconfiguration and be able to operate in these multi-function, or put in a better way, to be able to operate in a more congested and contested signal environment."

On the flip side, however, Kazior also points out that while you can make ASICs much more energy efficient, the downside is that they're customized or limited to a single application (or set of applications), the ASIC is programmed to perform. "Ultimately, the solution, as we move into the future, is to find a way to get the best attributes of both ASICs and FPGAs – something that taps into the efficiency of an ASIC but also the reconfigurability of an FPGA.

DSSOC AND SOFTWARE PROGRAMMING TOOLS

DARPA's Domain-Specific System on Chip (DSSoC) program seeks to prove that there need not be a continued tradeoff between the efficiency of ASICs and the flexibility of FPGAs and GPUs. The goal is to develop a heterogeneous System-on-Chip (SoC) comprised of many cores that mix GPUs, special purpose processors, hardware accelerators, memory, and input/output (I/O) de-

he Spectrum and the d – DARPA's MTO IGINT Advances

US AIR FORCE

vices to significantly improve performance of applications within a domain. As noted in MTO's program description, a domain is larger than any one application, where one processor can effectively address problems more efficiently than a general-purpose processor but without the challenge, time, and cost of building a special-purpose system like an ASIC. DSSoC is exploring architectures that improve the efficiency of computing through specialized processing while maintaining programmability.

As described by Kazior, the DSSoc program is looking at "how we can create a multi-processor fabric, an SoC where you can get the best of both worlds – the energy-efficiency of an ASIC and the programmability and flexibility of an FPGA. How can I get these two different processor blocks working together, how do I best allocate the processing resources, what functions should I perform in the ASIC and what should I do in the FPGA, and maybe there are other processing elements that I want to include."

Put simply, says Kazior, "All of this is really just doing mathematical operations, so the question is really what mathematical operations do I have to do on this giant set of data to get the information I need, and how do I best do that and best partition it, but more importantly, how do I get it to reconfigure rapidly or reconfigure on the fly so I don't essentially have to build a whole new system whenever a new signal of interest arises that my sensor wasn't necessarily looking for. So, how can I rapidly reconfigure these compute resources and do it as efficiently as possible to reduce the amount of power consumption?"

Kazior says, "Some of the most promising approaches with DSSoC are in new methodologies for creating an SoC based on essentially integrating different IP blocks known as accelerators for specialized functions, along with programmable functions, in the same chip and having them communicate with each other via a 'network-on-a-chip.' A key aspect of this comes into play via the software programming tools, and the program performers have developed something called an 'intelligent scheduler' in order to look at how do you best schedule or use the compute resources available on the SoC so that you can process the data as efficiently as possible, but also do it with low latency."

Kazior describes that, in processing the data, it's going through a series of mathematical functions, from function 1 to function 2 and so on to function *n,* with the goal of doing this as quickly as possible with no delay. "Now, as I begin sharing computation resources, the question is how do I best manage them so that I minimize the time that the data takes to go through these processes and be manipulated by the processors. This is where the level of intelligence comes in, by determining which particular accelerator or programmable fabric block is the best at this point of time to perform that function as quickly as possible."

In addition, Kazior says the DSSoC program is also trying to process as many different types of signals simultaneously and deal with multiple signals and multiple applications within specific "domains." In this context, domain refers to things like an advanced communication system, autonomous vehicle, or a multifunction radar. He explains, "What we're doing is using these SoCs to simultaneously share and run multiple applications, but sharing the resources, and getting the best and most efficient use out of those resources, instead of having a separate compute engine or compute fabric and processors for each function. We will do it all in one SoC and be able to switch back and forth. So, I may be doing SIGINT and looking at a broad range of spectrum, and then tune down to a certain area of frequency that I want to narrow down to and tell the system to adapt and focus on extracting information from that specific part of the spectrum." He adds that the objective is to do this in real-time as opposed to traditional SIGINT systems where, when something interesting pops up, almost having to go in and reprogram the entire system.

"One of the big accomplishments that came out of this work conducted by several of the program's performers," says Kazior, "was the demonstration of a 50x-plus improvement in productivity, meaning the time or speed to reconfigure or reprogram one of these SoCs compared to a traditional FPGA for example."

DREAM AND NEW TRANSISTOR MATERIALS

Looking further down the RF-electronics technology-development ladder, we come to another challenge facing the exponential advancement of SIGINT capabilities. In addition to contending with an ever more congested and contested electromagnetic environment and a spectrum that hosts everything from smart phones to RF jammers, there is also an ongoing push to operate at higher and higher frequencies, such as moving up to millimeter wave (mmW) bands. To address this, DARPA MTO started the Dynamic Range-enhanced Electronics and Materials (DREaM) program in 2018. According to its program description, DREaM "is exploiting new materials and novel device structures to create RF/mmW transistors that will enable asymmetric operations in a complex electromagnetic spectrum." The objective is to create "high dynamic range RF transistors for a diverse set of amplifier applications by developing non-traditional materials, integrating new device structures, and innovating transistor layouts to attain a 2x higher output power density and 10x better amplifier linearity than current state-of-the-art devices."

Says Kazior, "DREaM was focused on the RF front-end or the transmit/receive portion of the system. The goal was to make the transmit/receive electronics more efficient, more linear, and to improve their dynamic range, which would translate to improved sensitivity of the receiver and allow us to extend operation to higher frequencies so that we could be ready to anticipate emerging opportunities and threats. Traditionally, what has been done to increase the operating frequency of an RF amplifier is 'scaling,' similar to what was done in silicon technology to make processors faster and go to these finer and finer nodes. The same thing is analogous in the RF domain, where we scale the transistors. The problem is that if you just continue to do this with conventional scaling, you're giving up other important features, like the power density of the transistor, or you compromise the linearity or dynamic range."

To break this paradigm and avoid the tradeoff dilemma, DREaM is exploring new material and device structures, looking at ways to manipulate the actual material that composes the transistor so that it's possible to still maintain a high dynamic range while scaling to higher frequency operation. One approach involved introducing new materials that could support higher operating voltages in the devices. Says Kazior, "The DREaM program has been primarily focused on a class of wide bandgap semiconductor materials, such as Gallium Nitride (GaN). These wide bandgaps allow you to operate the devices at higher voltages and higher dynamic range. Coupled in with this is looking at whether there are other wide bandgap or wider high-bandgap materials that you could integrate with them to begin manipulating the properties. In essence it's pushing GaN-based technology to its extreme limits."

Another approach being studied is the use of multi-channel devices (essentially a lot of transistors in parallel) that will produce very high current from the devices. This higher current translates into the higher gain needed to operate at the

higher frequencies, but is done in a way that maintains a high dynamic range or high operating voltage.

Still another approach was looking at different device topologies that would allow for simultaneous support of both high current and high voltages. Says Kazior, "Ultimately, this is needed to support high-gain or high-frequency operation with high dynamic range while also simultaneously achieving an optimal noise figure, which is how much noise or distortion it adds to a signal. Since, in some sense, these are all competing factors, different performers have looked at how you can manipulate the material structure and the device topology to get the best of all of these worlds."

To date, performers have been able to push the performance up to the W frequency band, which is approaching 100 GHz, and they have set record efficiency and dynamic range numbers for the transistors, just by doing these manipulations – essentially advancing the state-of-the-art by 10x."

AI AND NEURAL NETWORKS DRAMATICALLY IMPROVE SIGINT CAPABILITIES

In addition to advancements in hardware performance, DARPA MTO has also been aggressively pursuing parallel SIGINT advancements in software-driven capabilities (i.e., Artificial Intelligence (AI) and Neural Networks (NN)). One of these programs was the Hyper-Dimensional Data Enabled Neural Networks (HyDDENN) program. Begun in 2019, the objective of HyDDENN was to "seek new data-enabled NN architectures to break the reliance on large Multiply-Accumulate (MAC)-based Deep Neural Networks (DNNs). HyDDENN will explore and develop innovative data representations with shallow NN architectures based on efficient, non-MAC, digital compute primitives to enable highly-accurate and energy efficient AI for DOD edge systems."

What this essentially means is using a feedback loop to update the front-end of a collection system with information from the back-end. HyDDENN basically looked at whether you could make a more efficient electronic AI system using an encoding technique called hyper-dimensional representation. The technique involves taking AI information and coding it into extremely long binary effectors (like 10k bits long), the main benefit of which is that when performing relatively simple computations on these vectors, it's possible to easily see similarities or differences. By comparing two pieces of information that on their face seem relatively the same, but in fact now reveal maybe 100 different bit flips, it becomes clear that they would be easily recognizable as quite different from each other.

Another important benefit of representing things in hyper-dimensional form is that it allows for an X-OR evaluation between all the bits, thus the computation to check for similarities is much more efficient. Using hyper-dimensional representation together with a feedback loop, it's possible to achieve a much more accurate or, at least, a highly-accurate classification, from a neural network with 10x less parameters than traditional neural networks, as well as gain the associated power and latency savings from their much smaller size. The process is particularly valuable for SIGINT applications in terms of doing in-band interference separation in signals.

SPINN – USING AI TO IMPROVE PROCESSING SPEED PERFORMANCE

One development spawned out of the work on HYDENN is the Signal Processing in Neural Networks (SPiNN) program. As outlined in the program announcement (January 2020), "the SPiNN program will develop a new set of advanced NN computing kernels, which embed established physics-based mathematical digital signal processing (DSP) models." As James Wilson, DARPA MTO Program Manager, points out, ensuring own communications is also a part of their SIGINT work, so on the communications side, the physics-based kernels are the modem, the channel equalizer, de-noising filters and error correction. On the radar-processing side, they are the adaptive waveform generator and space/time adaptive processing, spectrum management, down-conversion filtering, waveform filtering, and Doppler and clutter processing and range and Doppler dating.

Wilson says, "SPiNN was based on the idea that when you're trying to train an RF neural network model, you face the problem that generating real-world RF data and storing it is much more difficult than, for example, video which comes out digitally. RF is RF, so ideally you'd like super-high resolutions, or high bit rate or high dynamic range A/D [analog-to-digital] converters sampling at very high frequencies so you can get all of the sideband information from the signal. Then, the question becomes, how to store all that data for later replay when you're talking about terabits/second of information per collection. It's a much harder problem than trying to do image recognition or even video processing, just because of the amount of the data, and because you don't know where it is or what to look for."

To address this, SPiNN asked the question, "What if you start with physics-based models for digital signal processing modules instead of what is conventionally used for things like auto-encoders and the other parts that go into both comms and radar?"

Says Wilson, "You can start with these physics-based models and train-up the neural network against it, but if you want more data and more accuracy, you need to provide it with more training data. This is where SPINN came in again as we asked, 'What if we start with those physics-based models and then build Generated Adversarial Networks (GAN) on top of them to generate the data that we will then train the neural networks against?' So you have a neural network that is generating information, and then it is sent to an adversarial network, which compares it to existing models and tries to guess if is real or fake. The generator model and the adversarial model are trained together at the same time. So, you're training the generator, which is getting better and better at generating correct data, while on the other end you have your GAN discriminator, which is at the same time getting better and better at telling the difference between real and fake."

Wilson continued, "One of the performer teams showed that by using these GAN models, they were able to train an auto-encoder for a communication environment, which required training on both sides – the transmitter encoder and the decoder – both using neural networks and with GAN generating the signals and the interferers that exist in the training environment. What they found was that they could get a better than 30 dB improvement in signal-to-jam ratio compared to a conventional digital signal processing approach. And, that same 30-dB number was something we saw in the work of a number of performers, whether filtering or classification, etc., there was a large gain by using AI to do different parts of building blocks that we hadn't done before."

Tom Kazior, points to another example of how DARPA MTO's work in AI and NN technology is advancing SIGINT technology development. "With DSSoC, what we've been looking into is how to use these AI and NN technologies to speed up the design process for new hardware and to make designers more productive. For example, AI or NN techniques can help designers more rapidly explore a larger design space and come to an optimal design for an SOC. Of course, that has to ultimately couple with the tools and the software. You can't separate a call for hardware, from the firmware, from the software."

ANALOG PROCESSING

As pointed out by MTO's Tom Kazior, "In radar, SIGINT, EW and other defense systems, there's long been a debate as to how to best process or manipulate information. Do you do it all digitally or do you do it in a hybrid analog/digital fashion?" As he observes, much of what is currently emerging today is hybrid signal processing, where some manipulation of the signals is first done in the analog domain before converting to digital. "The question becomes how to best partition this functioning and what ultimately gets you the most efficient solution in extracting the specific data that you want," he explains. "With 'smart partitioning,' you can begin looking at it as dividing the problem up into smaller bites or chunks, how to best manipulate it, and then ultimately cohering it all together in the digital domain, but you have already done different manipulations in the analog domain."

On the other hand, Kazior notes that there's also a lot of research being done on immediately and directly converting the analog signals to digital data and performing the entire process in the digital domain. "Of course, that means that you've just created an incredibly large data-manipulation problem, and we're looking at ways to solve this problem. For example, if I wanted to end up doing direct-digital conversion, I'd want to be doing some of the digital manipulation right up at the sensor and then shipping data, or reduced data, back to a central processor or 'brain.' If you think of it in terms analogous to the human body, the human body is made up of multiple sensors (eyes, ears, tactile, etc.), and there's actually some bit of processing done in these sensors before that information gets piped back to your brain to be cohered. This approach of distributed processing, where some of the data is processed right at the sensor before sending it back to a central processor, is one area of definite interest."

PROCESSING "AT THE EDGE"

Wilson's MTO group is also looking at the tradeoffs between analog and digital signal processing. "Here we're taking a little bit different direction from that of our conventional digital processing work, recognizing that analog signal processing has an intrinsic place where it can achieve higher power efficiency than digital," he says. "And, if you can get higher power efficiency, you can push more capability into SWaP-constrained places, such as operations 'at the edge' [of the battlespace] that you couldn't do from a digital approach."

One program that developed out of a workshop at DARPA's 2021 Electronic Resurgent Initiative (ERI) and subsequent Proposers Day in February of this year, was the Massive Cross Correlation (MAX) program which is one example of doing analog signal processing in place of digital. In signal processing, cross-correlation is a measure of the similarity of two waveforms as a function of a time-lag applied to one of them. As noted in the Proposers Day presentation, "MAX will increase today's analog efficiency advantage to 100 TOPs/W [tera-operationsper second per watt] at 120 dB dynamic range and minimize wasted energy by improving the analog efficiency by >100x." DARPA received proposals for the program in early May and the program is currently in source selection.

Wilson also points to their earlier work in HyDDENN as part of what they're doing aimed at providing smaller, lighter neural networks where you can use a platform with the same Size Weight and Power (SWaP) that you have today, but provide it with a higher compute capability and higher performance using the same size battery. "Alternatively, you can keep the application and the performance the same but shrink it down to where something that used to require a rack of computers is now a backpack or a handheld. That's really where so much of MTO's work is aimed – where can we scale-up in performance or scale-down in SWaP, or some combination of both – to bring all that data center style High Performance Computing (HPC) AI up into a much more low-latency-response situation to the warfighter."

In addition, Wilson says his earlier work at the Army Research Laboratory (ARL) highlighted for him a major problem for the Army in that "they glow in the dark electromagnetically, seeming to radiate all the time, so everybody knows where they are. So, one of my focus areas is really how much more can we do passively that we haven't been able to do before – the ability to move from active-and-observable to passive-and-hidden is a major thrust and where we put a lot of our effort."

For his part, Tom Kazior says an underlying theme for everything his group is pursuing within MTO is finding ways to push system efficiency. "This becomes more and more important for untethered applications or untethered stuff. For example, your cellphone, sensors at the edge, the Internet Battlefield of Things (IoBT) – how do we make them as sensitive as possible but also as efficient as possible so we can collect and use all that data and at the end of the day create more actionable information for the warfighter."

TECHNOLOGY SURVEY

A SAMPLING OF POWER AMPLIFIERS FOR ELECTROMAGNETIC ATTACK APPLICATIONS

By John Knowles and Ollie Holt

This month, we're looking at power amplifiers for electromagnetic attack (EA) applications. Jammers need to cover a wide range of frequencies in order to attack multiple types of target receivers that collectively operate across many bands and employ differing types of electromagnetic protection. Stand-off jammers also need sufficient ERP to be effective against targets that may be located hundreds of kilometers away. These requirements, as well as several others, flow down to the jammer's power amplifiers.

Defense electronics technology is constantly evolving. Over the next decade, for example, some types of radar threats (i.e., missile seekers) and communications systems (i.e., 5G) will move even further into the millimeter wave region. On the jamming side, this push into millimeter wave performance is initially being met by traveling wave tube (TWT) technology. But GaN technology, which only started meeting jamming requirements about 15 years ago, is also achieving better performance at higher frequencies very quickly. This gives EA systems developers critical options in their designs.

Another trend that will affect amplifier requirements is the push toward multifunction RF systems. As the US and others pursue AESA-based multifunction systems that can perform radar, EW, IFF and communications, these systems (large and small) will need reliable wideband amplifiers that can support all of these nuanced functions – sometimes simultaneously. This demands smarter amplifiers that can perform some degree of RF signal processing and monitor and manage its performance while supporting a variety of tasks for the system. Moreover, the space constraints on some smaller platforms that offer less prime power will place an emphasis on amplifier performance in terms of power density and cooling.

THE SURVEY

This month's survey includes nearly 75 products from 26 companies. There have been a few acquisitions since our last power amplifier survey in June 2020, and our survey table reflects changes where two previous suppliers are now operating under a single company.

In the survey table, the first column lists the amplifier model name or number. The second column describes the unit's operational frequency range. As mentioned above, most EW power amplifiers cover a wide frequency range (several hundred megahertz to several gigahertz) with consistent performance over that span.

The third column shows which technology (or technologies) the power amplifier features, such as LDMOS (typically used for lower frequency ranges), GaN, TWTs or MPMs. The next column lists the output type(s): pulsed or continuous wave (CW). Many EW requirements call for CW performance (and an associated higher duty cycle) in addition to pulsed output for some radar jamming techniques.

The fifth column indicates the unit's output power and/or gain. Gain defines the increase in power that can be achieved from input to output. Multiplying the input power by the gain equals the output power, as long as the amplifier operates in the linear region. Typically, a power amplifier is in the linear operating mode if the maximum input power limit is not exceeded.

Harmonic and spur levels are listed in the next column. Decibels relative to the carrier (dBc) is a measure of how much higher the carrier signal is with respect to harmonics or spurious signals created within the device. For most applications, the larger this value, the better the amplifier's performance. When the input power exceeds the maximum, the amplifier will start operating in non-linear mode. In this mode, the harmonics and spurious signals will continue to increase in output power, but the signal will not, until the signal's output power and the spurious output power are equivalent.

In the next column of the table, dBc relative to the carrier is a measure of how much higher the carrier signal is with respect to harmonics or spurious signals created within the device. For most applications, the larger this value, the better the solid-state power amplifier's (SSPA's) performance. Also, note that when the input power exceeds the maximum, the amplifier will start operating in non-linear mode. In this mode, the harmonics and spurious signals will continue to increase in output power, but the signal will not, until the signal's output power and the spurious output power are equivalent.

Efficiency is defined as the amplifier's power added efficiency (PAE). This is the output power (RF) minus the input power (RF) divided by the DC power. In high-gain systems, the results are almost the same as efficiency (output power divided by input power), but in low-gain systems, the efficiency can be very different. In this survey, the input power (DC power) is the average input power. For a pulsed system, the PAE is calculated using input power (DC) when the pulse is created as opposed to the average.

The next column indicates the amplifier's reliability. Reliability is a probabilistic value of how many hours the product may operate before failure. In this case, the reliability value is the manufacturer's derived length of time the typical SSPA will operate under stated conditions.

NEXT MONTH

In our July *JED* technology survey, we will look at airborne radar warning receivers (RWRs) and radar electronic support measures (ESM) systems.

EW POWER AMPLIFIERS

MODEL	OPERATING FREQ	TECHNOLOGIES	OUTPUT TYPE	OUTPUT PWR/GAIN	HARMONIC AND SPUR LEVELS	SUPPLY VOLTAGE
Aethercomm Inc.; Carlsbad, CA, USA; +1 (706) 208-6002; www.aethercomm.com						
SSPA 0.020-1.000- 350	20 MHz - 1 GHz	GaN	CW	350W	*	50 VDC
SSPA 0.020-6.000-70	20 MHz - 6 GHz	GaN	CW	70 W	*	28 VDC
SSPA 2.0-6.0-250	2-6 GHz	GaN	CW	250W	*	28 VDC
Analog Devices Inc; Norwood, MA, USA; +1 (781) 329-4700; www.analog.com						
HMC8113	2-6 GHz	*	*	500W / 57dBm / 85dB	-12 dBc harm.; -60 dBc spur. (@ Pin = 0 dBm)	220 VAC
HMC8114	5.8-18 GHz	*	*	100W / 49.5dBm / 68dB	-16 dBc harm.; -60 dBc spur. (@ Pin = 0 dBm)	48 VDC
Applied Systems Engineering; Fort Worth, TX, USA; +1 (817) 249-4180						
Model 200	1-18 GHz	TWT	CW	200W/250W, 35 dB	-50 dBc spur.	208 VAC 3 phase
Model 270	1-18 GHz	TWT	CW	250W	-20 dBc harm., -50 dBc spur.	208 VAC 3 phase
Model 367	1-18 GHz	TWT	CW/pulsed	200-300W	-50 dBc spur.	208 VAC 3 phase
ASELSAN; Ankara, Turkey; +90-312-592-10-00; www.aselsan.com.tr						
AD-0000-0123	20-500 MHz	LDMOS, GaN	CW	46 dBm / 48 dB	< -12 dBc harm. / < -50 dBc spur.	28V
MW-0000-1341	500MHz - 3 GHz	GaN	CW	52 dBm / 52 dB	< -6 dBc harm./ < -40 dBc spur.	36V
MW-0000-1998	2-6 GHz	GaN	CW/pulsed	46 dBm / 50 dB	< -8 dBc harm. / < -50 dBc spur.	28V
Comtech PST Corp.; Melville, NY, USA; +1 (631) 777-8900; www.comtechpst.com						
BME2969-300	2-6 GHz	GaN	CW/pulsed	300W	<-12 dBc harm./ -60dBc spur.	18-32VDC
BME49189-50	4-18 GHz	GaN	CW/pulsed	50W	<-19 dBc harm. / -60dBc spur.	28VDC
BME69189-100	6-18 GHz	GaN	CW/pulsed	100W	<-19 dBc harm. / -60dBc spur.	18-32VDC
CPI; Palo Alto, CA, USA; +1 (650) 846-3900; www.cpii.com						
VTF-6130C1	2-8 GHz	TWT	CW	80W	*	800 W
VTA-6193A4	26.5-40 GHz	TWT	CW/pulsed	40W / 37 dB	*	675 W
PTX8808	26.5-40GHz	MPM	CW/pulsed	60-115W	-40 dBc spur.	270V
CTT INC a KRATOS Company – KRATOS Microwave Electronics Division; San Jose, CA, USA; +1 (408) 541-0596; www.cttinc.com						
AGM/060-5056	2-6 GHz	GaN	CW	100W (+50 dBm)	-60 dBc	30V / 17.2A (Typ) @ Psat, 30V / 2.4A (Typ) @ SSG
AGX/0218-3946	2-18 GHz	GaN	CW	8W (+39 dBm)	-60 dBc	32V / 3.1A (Typ) @ Psat, 33V / 1.4A (Typ) @ SSG
AGX/0318-4656	3-18 GHz	GaN	CW	40W (+46 dBm)	-60 dBc	32V / 16.8A (Typ)
dB Control; Fremont, CA, USA; +1 (510) 656-2325; www.dBControl.com						
dB-3201	26.5-40 GHz	MPM	CW/pulsed	125W CW min./51 dB min.	-10 dBc max. harm. / -50 dBc max. spur. 270 VDC	11 (L) x 9.38 (W) x
dB-3202	27.5-31 GHz	MPM	CW	200W CW min./53 dB min.	-10 dBc max. harm. / -50 dBc max. spur.	270 VDC
dB-3205	43.5-45.5 GHz	MPM	CW	80 W CW min./49 dB min.	-10 dBc max. harm. / -50 dBc max. spur.	270 VDC

EFFICIENCY	RELIABILITY	SIZE (HxWxL inches/mm)	WEIGHT (lb/kg)	FEATURES
40%-50%	*	6.3 x 12.8 x 1.8 in.	10 lb	Can be blanked on and off in 10µsec maximum; designed and tested to withstand MIL-STD-810 shock and vibration requirements.
11%-39%	*	5.5 x 6.5 x 2 in.	5 lb	Includes an external DC blanking command that enables and disables the module in 25 µsec maximum
36%	*	8.0 x 13.5 x 2.37 in.	15 lb	DC and logic connections are accessible via Combo-D connectors; RF input connector is an SMA female; RF output connector is a type N female.
20%	*	8.7 x 19 x 21 in. (rack mount)	100 lb	DC blocked RFin/out, 1,2,4,8,16,32 dB attenuation stepping, current, Temp, VSWR and supply monitoring with alarm.
10%	*	2.65 x 10.5 x 17.6 in.	32.2 lb	DC blocked RFin/out, 1,2,4,8,16,32 dB attenuation stepping, current, Temp, VSWR and supply monitoring with alarm.
*	*	12.25 x 19 x 28.5 in.	140 lb	Internal power supplies are solid state DC-DC converter designs with fast loop response times so that output level variations are minimal.
*	*	68 x 29 x 36	750 lb	Consists of three amplifiers: 1-2.5 GHz, 2-6.5 GHz, and 6.5-18 GHz.
*	*	12.25 x 19 x 28.5 in.	130 lb	Dual-mode pulse/CW TWT; RF output pulse is generated by the grid pulse without the use of RF switches
> 35 %	MTBF>20000 hrs.	95 x 90 x 22 mm	0.25 kg	Forward and reverse power monitoring, enable control.
> 35 %	MTBF>20000 hrs.	300 x 156 x 28 mm	2.2 kg	Forward and reverse power monitoring, temperature monitoring, enable control.
> 35 %	MTBF>20000 hrs.	160 x 94 x 20 mm	0.7 kg	Includes isolator, forward and reverse power monitoring, enable control with fast switching.
18-20%	100k hrs.	15.25 x 7 x 2.67 in.	17	Composite Fault Indication (Over Temperature, Over Voltage, Over Current)
18-20%	100k hrs.	6.56 x 3.50 x 0.84 in.	1.5	Composite Fault Indication (Over Temperature, Over Voltage, Over Current)
18-20%	100k hrs.	8.0 x 6.0 x 2.5 in.	5.5	Composite Fault Indication (Over Temperature, Over Voltage, Over Current)
*	*	13.4 x 1.75 x 2.28 in.	3 lb	*
*	*	16.0 x 2.75 x 3.35 in.	7 lb	*
*	*	450 x 224 x 59.5 mm	8.5 kg	
19.4% (typ.)	*	6.32 (L) x 4.50 (W) x 0.84 (H) in.	<2.0 lb	TTL On/Off Option, Rack-Mount Configuration Available.
17% (typ.)	*	4.25 (L) x 3.25 (W) x 0.88 (H) in.	<1.0 lb	TTL On/Off Option, Rack-Mount Configuration Available.
7.4% (typ.)	*	5.16 (L) x 4.90 (W) x 0.82 (H) in.	<1.0 lb	TTL On/Off & Heatsink Options, Rack-Mount Configuration Available.
*	*	2.38 (H)	12 lb	Millimeter wave, pulsed or CW operation; high PRF pulse modulation
*	*	11 (L) x 9.38 (W) x 2.38 (H)	12 lb	Millimeter wave, CW operation
*	*	11 (L) x 9.38 (W) x 2.38 (H)	12 lb	Millimeter wave, CW operation

EW POWER AMPLIFIERS

MODEL	OPERATING FREQ	TECHNOLOGIES	OUTPUT TYPE	OUTPUT PWR/GAIN	HARMONIC AND SPUR LEVELS	SUPPLY VOLTAGE
Diamond Microwave; Shipley, UK; +44 (0)113 278 9793; www.diamondmic.com						
DM-SC100-02	2-6 GHz	GaN	CW/pulsed	100W / 55 dB	-70dbC@6GHz harm.	28 VDC
Elbit Systems; Bene Beraq, Israel; +972-3-6175411; www.elbitsystems.com						
4500A40000	30-520 MHz	GaN	*	1000W	60 dBc	48V
4600A40000	1-3 GHz	GaN	*	100-200W	60 dB (with filter bank) in-band harm.	48V
4900A40000	3-6 GHz	GaN	*	100W	*	28 V
Elite RF LLC; Hoffman Estates, IL, USA; +1 (847) 592-6350; www.eliterfllc.com						
AB.026.0G4340AC	20 MHz - 6 GHz	GaN on SiC	CW	20W	-20 dBc/ -60 dBc	200W/240 VAC
MB2.06.0G504828	20 MHz - 6 GHz	GaN on SiC	CW	100W	-20 dBc/ -60 dBc	28 VDC
Empower RF Systems; Los Angeles, CA, USA; +1 (310) 412-8100; www.EmpowerRF.com						
System 2236	2.8-3.5 GHz	GaN on SiC	CW/pulsed	120 kW pulse @ 20% duty cycle; 12 kW CW	-40 dBc (2H) -50 dBc (3H)	208 V 3 phase
System 2176	1750-2120 MHz	GaN on SiC	CW	4 kW / 73dB	-72 dBc w/LPF	208 V 3 phase
Module 1222	9-10 GHz	GaN on SiC	Pulsed	250 kW @ 20% duty cycle	-20 dBc / -60 dBc	48 VDC
ERZIA; Santander, Spain; +34 942 29 13 42; www.erzia.com						
ERZ-HPA-0600-1800-40-E	6-18 GHz	GaN	CW	40 dBm / 46 dB	-20 dBc	28 V
ERZ-HPA-0200-2000-44	2-20 GHz	GaN	CW	44 dBm / 51 dB	*	28 V
ERZ-HPA-0175-0625-43	1.75-6.25 GHz	GaN	CW	43 dBm / 43 dB	*	28 V
ETM Electromatic Inc.; Newark, CA, USA; +1 (510) 797-1100; www.etm-inc.com						
S300L-ODU	0.5-2.0 GHz	Solid State	CW	300W min / 55dB gain	-12 dBc max (-18 dBc typ) harm.; -60 dBc max spur.	190-260 VAC
S200SC-M	2.0-6.0 GHz	Solid State	CW	200W min. (2.0-5.7 GHz); 180W min. (5.7-6.0 GHz); 53dB gain	-10 dBc max harm; -60 dBc max spur.	190-260 VAC
300IJ-XM2	6.0-18.0 GHz	TWT	CW	300W typ.; 55 dB gain	-5 dBc max harm.; -50 dBc max spur.	190-260 VAC
Exodus Advanced Communications; Las Vegas, NV, USA; +1 (702) 534-6564; www.exoduscomm.com						
AMP1146A	2-8 GHz	GaN	CW	70W	-20 dBc max harm.; -60 dBc max spur.	32 VDC
AMP2033LC	6-18 GHz	GaN	CW	100W / 50 dB	-20 dBc max harm.; -60 dBc max spur.	240 VAC
General Microwave Corporation; Syosset, NY, USA; +1 (516) 802-0900; www.kratosmed.com						
SGN-6-12-30	6 to 12 GHz	Class AB GaN	CW/pulsed	30W (44.8 dBm) / 50 dB	-12 dBc harm.; -60 dBc spur.	23V/±12V
SGN-X3-400	X band, 10% bandwidth	Class AB GaN	Pulsed	400W (56 dBm) / 40dB	-40 dBc harm.; -70 dBc spur.	28V per MIL-STD-704 or 48V DC, 600W
SGN-Ku-250	Ku band (upper), 1GHz band width	Class AB GaN	Pulsed	250W (54 dBm) / 50dB	-50 dBc harm.; -60 dBc spur.	48V DC, 450W
Leonardo; Palermo, Italy; +39 0916482945; www.leonardo.com						
ET3407	4-8 GHz	TWT	CW/pulsed	280W	*	*
MPM3580	4.5-18 GHz	MPM	CW/pulsed	150W	*	270 VDC

EFFICIENCY	RELIABILITY	SIZE (HxWxL inches/mm)	WEIGHT (lb/kg)	FEATURES
20-40%	*	24 x 120 x 137 mm	1.65lb/0.75kg	Ultra-compact wideband GaN SSPA; currently part of a manportable electronic attack system.
23% (typ.)	10k hrs.	7U x 19 x 28 in.	71 kg	*
23% (typ.)	10k hrs.	5U x 19 x 28 in.	42 kg	*
*	*	19 in. x 3U	45 lb	Phased array; CW and pulse transmitter; air cooled; low SWaP; applicable to airborne , ground and naval platforms.
*	*	19 x 15 x 5.25 in.	25 lb	Class AB, high-power 19-in. rack mount RF amplifier; built-in self-protection against reverse polarity and overheating.
*	*	8.5 x 10.0 x 1.25 in.	3 lb	Wideband amplifier module.
24%	Redundant architecture	70 x 46 x 40 in.	2100 lb	Scalable design with 32 fully integrated 2U amplifiers - fast field replaceable boosters - 15 minute MTTR at the transmitter level without taking the system offline.
24%	27,500 hr	30 x 23 x 48 in.	400 lb	Air cooled design and standing 30 inches tall, it's less than half the size of the typical legacy uplink HPA's that it replaces.
25%	200,000 hr	1 x 4 x 7 in.	1.5 lb	New product introduction - pulsed amplifier module guaranteed to deliver 250W minimum peak output power at 20% duty cycle.
26.70%	>100k hrs. MTBF	80 x 100 x 21 mm	0,66 lb/0,3 kg	ON/OFF, Temp & current sensors
16%	>100k hrs. MTBF	96 x 100 x 23 mm	0,92 lb/0,42 kg	ON/OFF, Temp & current sensors
20%	>100k hrs. MTBF	125 x 95 x 22 mm	0,99 lb/0,45 kg	ON/OFF, Temp & current sensors
*	*	15.25 x 10.25 x 22 in.	74 lb	Outdoor unit; MIL-STD-810E, 810F
*	*	19 x 5.25 x 24 in.	60 lb	Mobile unit; MIL-STD-461E, 810E, 810F
*	*	19 x 5.25 x 24 in.	72 lb	Mobile unit; MIL-STD-461E, 810E, 810F
*	*	250 x 110 x 25 mm	1.4 kg	High power covering the full S and C bands; suitable for all single channel modulation standards
*	*	430 x 133.3 x 560 mm	35 kg	Class A/AB linear design; suitable for broadband EMI/RFI, lab, comms and EW applications; CW, pulse and all single channel modulation standards.
15% typ.	>40,000 hrs.	130 x 110 x 25 mm	1.1 lb/0.5 kg	Internal voltage regulation and sequencing (protection), external enable and over-temperature protection.
25% typ.	>17,000 hrs.	140 x 280 x 73 mm	8.8 lb/4 kg	Internal voltage regulation and sequencing (protection), external enable and over-temperature protection.
25% typ.	>21,500 hrs.	160 x 214 x 83 mm	6.6 lb/3 kg	Internal voltage regulation and sequencing (protection), external enable and over-temperature protection.
*	*	*	*	ECM applications
*	*	250 x 220 x 40 mm	3.6 kg	ECM applications

EW POWER AMPLIFIERS

MODEL	OPERATING FREQ	TECHNOLOGIES	OUTPUT TYPE	OUTPUT PWR/GAIN	HARMONIC AND SPUR LEVELS	SUPPLY VOLTAGE
Mercury Systems; Andover MA, USA; +1 (866) 627-6951; www.mrcy.com						
DM-HPSC-150-101	2-6 GHz	GaN	CW	140W	-15dBc max harm.	28V
DM-HPMB-10-101	2-18 GHz	GaN	CW	10W	-15dBc max harm.	32V
DM-HPKA-20-102	29-31 GHz	GaN	CW	15W	-15dBc max harm.	20V
Microwave Amplifiers Ltd.; Bristol, UK; +44-01275-853196; www.microwaveamps.co.uk						
AM8-20-520-50-50	20-520 MHz	GaN	*	100W	-13 dBc typ (20-200 MHz); -20 dBc typ (200-520 MHz) harm.; -80 dBc min spur.	28 VDC
AM6-0.5-3-50-50	0.5-3 GHz	GaN	*	125W	-15 dBc max harm.; -80 dBc min spur.	28 VDC
AM9-2-6-50-50	Reverse power protection; reverse polarity protection +L76+A78	GaN	*	100W	-15 dBc typ @ 90 W harm.; -90 dBc min spur.	28 VDC
Microwave Dynamics; Irvine, CA, USA; +1 (949) 679-7788; microwave-dynamics.com						
MPA00518-30	0.5-18 GHz	GaN	*	30 dBm/ 30 dB	*	28V @ 0.9A; 12V @ 0.25A
MPA0612-40	6-12 GHz	GaN	*	40 dBm/ 33 dB	*	24V@2.4A
MPA0618-40	6-18 GHz	GaN	*	40 dBm/ 35 dB	*	20V @ 6A
NuWaves Engineering; Middletown, OH, USA; +1 (513) 360-0800; www.NuWaves.com						
NuPower 13G05A	0.8-2.5 GHz	GaN	CW	50W (Psat)	-17 dBc (2nd harm.)	27-30 VDC
Ophir RF; Los Angeles, CA, USA; +1 (310) 306-5556; www.ophirrf.com						
5304043-020	2-6 GHz	GaN	Type SMA	50W	-20 dBc	28 VDC
6565	6.5-18 GHz	TWT	Pulsed	3000W	Spur: -55 dBc (0-250 MHz); -60 dBc (>250 MHz)	2.6 kVa max.
4135	2-30 MHz	LDMOS	CW/AM/FM/PM	20,000W	-80 dBc	208 VAC
Photonis Defense, Inc.; Lancaster, PA, USA; +1 (717) 295-6000; www.photonisdefense.com						
2441	6-18 GHz	Mini-TWT	*	70W / 60 dB	*	*
2258	26.5-40GHz	TWT	*	40 W / 50 dB	*	*
9106B	6-18 GHz	MPM	CW	100W / 50 dB	*	28 VDC
RF-Lambda USA LLC; Carrollton, TX, USA; (888) 976-8880; rflambda.com						
RFLUPA02G06G	2-6 GHz	GaN	CW	30W / 48-52 dB	*	30 VDC
RFLUPA18G40GM	18-40 GHz	GaN	*	51 dBm	*	48 VDC
Stellant Systems; Torrance, CA, USA; +1 (310) 517-6000; www.stellantsystems.com						
M1201	2-6 GHz	MPM	CW/pulsed	70W min (2.0-2.5 GHz); 80W min (2.5- 6.0 GHz); 50 dB	-40 dBc spur.	28 VDC
M1225	6-18 GHz	MPM	*	52 dBm	-4 dBc harm. / -45 dBc spur.	28 VDC
M1231	6-18 GHz	MPM	*	*	-50 dBc spur.	28 VDC
Teledyne Defense Electronics; Rancho Cordova, CA, USA; +1 (916) 638-3344; www.teledynedefenseelectronics.com						
TSA-220005-201	2-18 GHz	GaN	*	20W/43 dBm	-10 dBc harm.	22 V
MEC-5508	6-18 GHz	TWT	CW	200W / 26-27.5 dB	-3 dBc harm. separation @ 6 GHz	840 W typ.
MEC-5493	18-26.5 GHz	TWT	CW	50W / 26-28 dB	-8 dBc	450 W
Triad RF Systems, Inc; East Brunswick, NJ, USA; +1 (855) 558-1001; www.triadrf.com						
TA1216	300 MHz - 6 GHz	GaN	CW	32W / 45 dB	2nd harmonic: -35 dBc at Psat	12-28 VDC
TA1264	300 MHz - 6 GHz	GaN	CW	32W / 45 dB	*	28 VDC

EFFICIENCY	RELIABILITY	SIZE (HxWxL inches/mm)	WEIGHT (lb/kg)	FEATURES
25%	*	7.85 x 6.00 x 1.00 in.	*	TTL control
15%	*	2.50 x 2.75 x 0.45 in.	*	TTL control
15%	*	3.50 x 4.50 x 0.78 in.	*	TTL control
40% @ 100 W	*	220 x 100 x 34 mm	*	Reverse power protection; reverse polarity protection; TTL Control for remote operation; RF output status monitor
30% @ 125 W	*	220 x 100 x 28 mm	1.1 kg	Reverse power protection; reverse polarity protection.
22% @ 90 W	*	300 x 127 x 51 mm (module)	*	Reverse power protection; reverse polarity protection.
*	*	3 x 2.125 x 0.812 in.	2 lb	Benchtop (MDPA) model with fan & heatsink (120/220VAC), size: 6.7 x 6.1 x 2.1 in.
*	*	3 x 2.125 x .812 in.	2 lb	Benchtop (MDPA) model with fan & heatsink (120/220VAC), size: 6.7 x 6.1 x 2.1 in.
*	*	3 x 2.125 x .812 in.	2 lb	Opt. pulse modulation, heatsink and input limiter.
40%	*	0.61 x 3.50 x 4.50 in.	9 oz	GaN, low SWaP, ruggedized chassis.
30%	*	1.0 x 6.0 x 3.0 in.	1.2 lb	Amplifier module for airborne/ground based applications.
*	*	19 x 21 x 28 in. (12RU)	150 lb	Primary power options: 208 V 3 phase, 400 Hz,; European or Asian primary power.
25%	*	Three 6-ft.-tall cabinets	1800 lb	Switched filter bank
*	*	*	*	
*	*	*	1.7 lb	
30%	*	2.6 x 7 x 6.1 in.	5.8 lb	Conduction Cooled; -40°C to +85°C Baseplate; Altitude 50,000 ft.
*	*	49 x 110 x 15 mm	*	
5%	*	6.1 x 8.1 x 1.2 in.	*	
19%	*	10.75 x 7 x 1.25 in.	< 6 lb	Low-noise, compact, wideband MPM for airborne, shipboard and ground military EW applications; contains a TWT, an SSA and a power supply within a single conduction-cooled package.
30%	*	1.4 in. x 7.75 in. x 8 in.	< 6.5 lb	Multiple packaging/power options available including active cooling heat exchanger system.
27%	*	2.5 x 6.1 x 7 in.	6 lb	Broadband MPM w/ integrated forced air cooling; suitable for airborne platforms up to 40,000 ft.
*	*	2.8 x 1.9 x 0.41 in.	*	EW, radar and datalink applications.
28%	*	2.8 x 1.47 x 11.08 in.	*	*
11%	*	3.4 x 2.76 x 16.1 in.	*	*
25% at Psat	>50k hrs.	3.75 x 2.30 x 0.95 in.	< 1 lb	Wideband, high power
*	*	3.75 x 4 x 0.95 in.	1 lb	For C-UAS jammer applications.

SURVEY KEY – EW POWER AMPLIFIERS

MODEL
Product name or model number

OP. FREQ. RANGE
Operating frequency range in MHz or GHz

TECHNOLOGIES
Types of technologies used in the amplifier

OUTPUT TYPE
Types of output the amplifier provides

OUTPUT POWER/GAIN
P1 dB or gain in dB

LEVELS
Harmonic and spurious levels in dBc

SUPPLY VOLTAGE/INPUT POWER
In Watts, VAC or VDC

EFFICIENCY
Power Added Efficiency (PAE) in percent
- Psat = saturated power
- typ = typical

RELIABILITY
In thousands (k) of hours
- MTBF = mean time between failures

SIZE
H x W x L in inches or millimeters

WEIGHT
Weight in lb/kg

FEATURES
Additional features

OTHER ABBREVIATIONS USED
- < = greater than
- > = less than
- config = configuration
- CW = continuous wave
- dep = dependent
- freq = frequency
- max. = maximum
- min. = minimum
- opt. = option/optional
- typ. = typical

** Indicates answer is classified, not releasable or no answer was given.*

UPCOMING TECHNOLOGY SURVEYS:

JULY 2022: AIRBORNE RADAR WARNING RECEIVERS AND RADAR ESM SYSTEMS

AUGUST 2022: ANALOG-TO-DIGITAL CONVERTER (ADC) AND DIGITAL-TO-ANALOG CONVERTER (DAC) BOARDS

WHATEVER YOUR NEEDS, CPI TMD HAS GOT YOU COVERED
TWT AND SOLID STATE TECHNOLOGY

Electromagnetic Protection – Part 2

Protection of Radars

By Dave Adamy

ABOUT RADARS

Figure 1 shows a radar, a target and a jammer. The radar is either trying to acquire the target or is tracking the target. In order to do either, it must achieve an adequate jamming-to-signal ratio (J/S). The purpose of radar electromagnetic attack (EA) is to prevent the radar from achieving that adequate J/S. To begin this part of the discussion, we will be considering the way that the radar goes about its task.

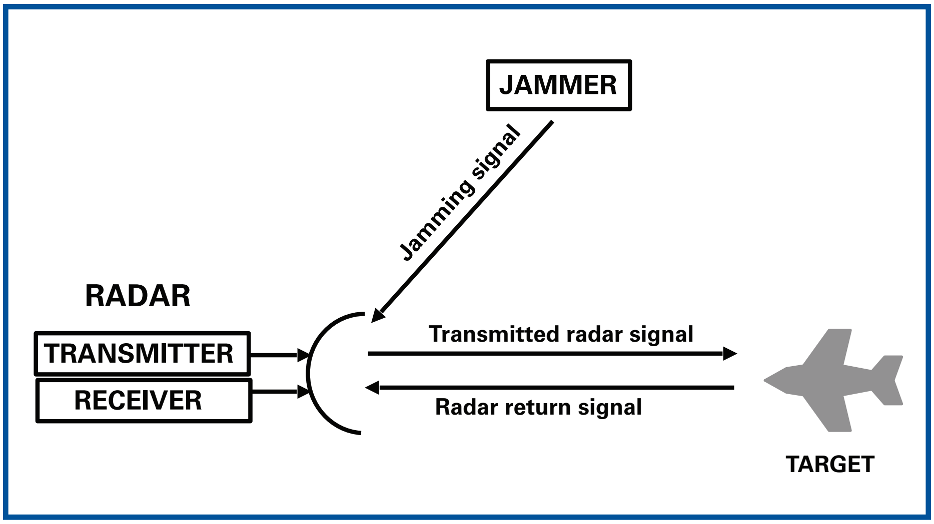


Fig. 1: *A radar must acquire or track a target using the return signal that is reflected from the target. The jamming signal is received in the radar's antenna and processed in the radar's receiver along with the return signal. The ratio of received power of the jamming signal to that of the received return signal is the jamming-to-signal ratio.*

The required J/S depends on the type of radar being jammed and the type of jamming being employed. If non-coherent noise jamming is used against a simple pulsed radar, less than 3 dB J/S may be adequate. On the other hand, 30- or 40-dB J/S may be required to deceptively jam a sophisticated radar.

Figure 2 shows a self-protection jammer that is located on the target. The radar gets returns from the target only when the boresight of its antenna is pointed at the target. Thus, the jammer has the advantage of jamming directly into the maximum radar receiving antenna gain. This allows a jammer to achieve very effective jamming performance.

Figure 3 shows a remote jammer that is located away from the target. The radar's main beam boresight is pointed at the target when the radar receives target returns, and it has a significantly lower side-lobe gain in the direction of the jammer.

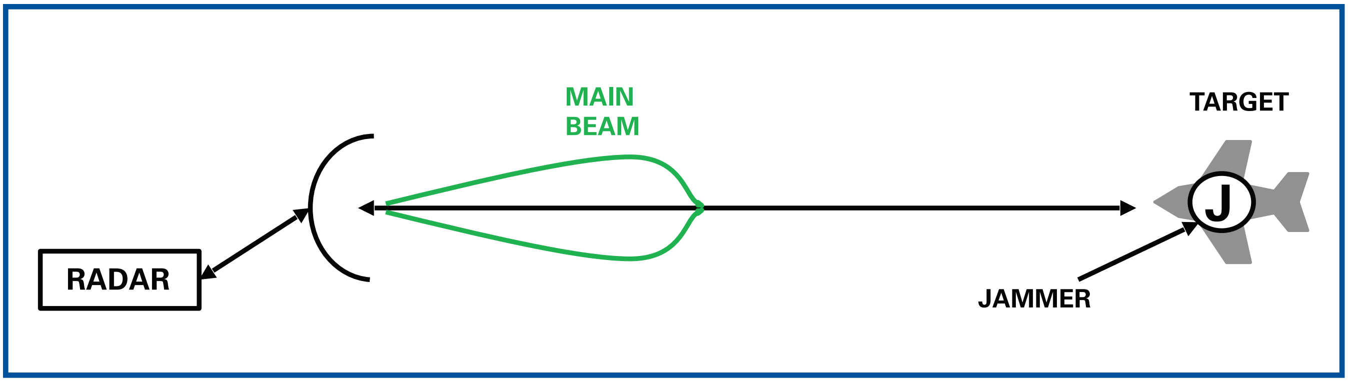
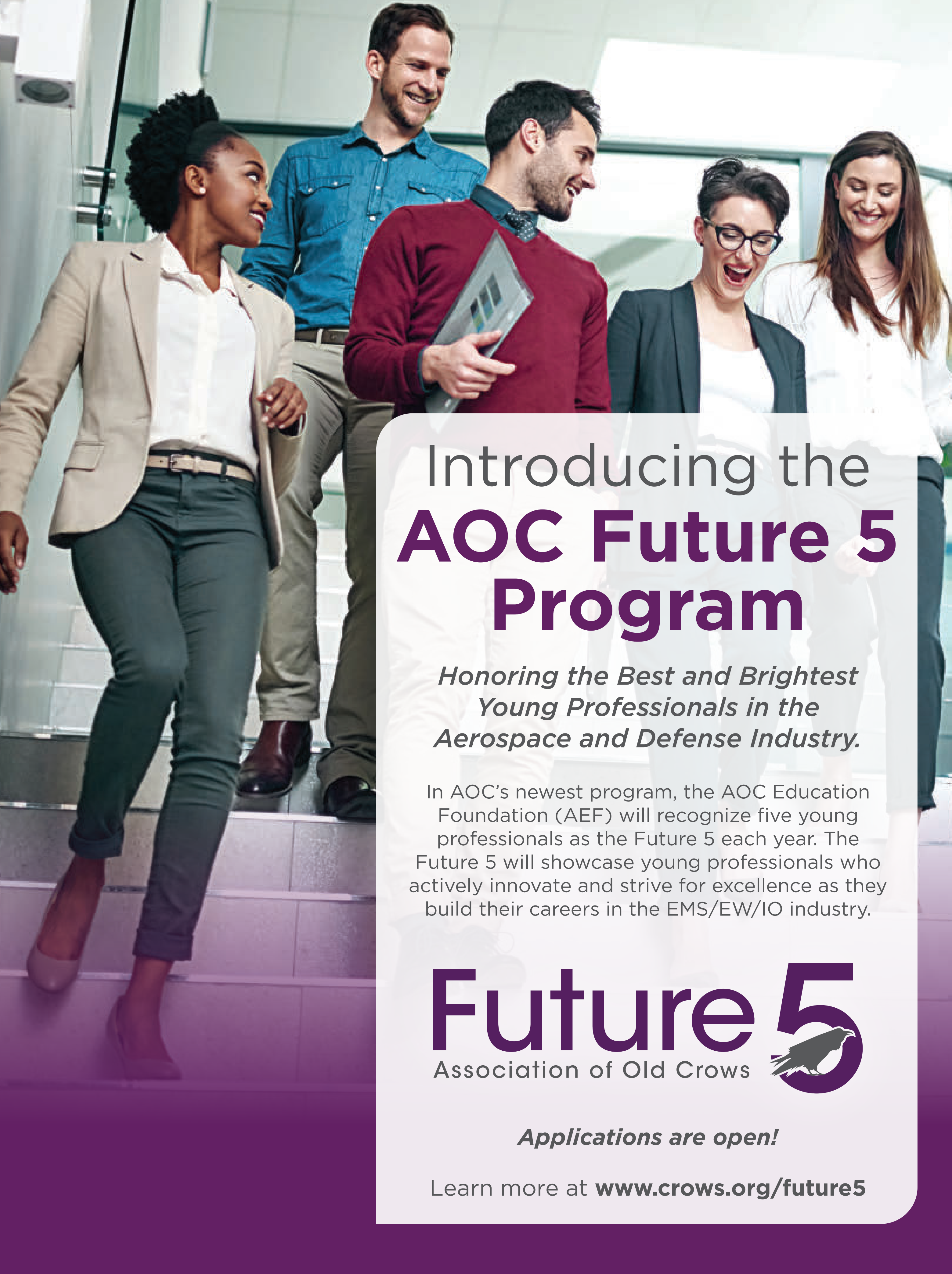


Fig. 2: *Self-protection jamming has the jammer located on the radar's target. It has the advantage of broadcasting its jamming signal directly into the boresight of the radar tracking the target, since the radar will have its antenna pointed directly at the target when it is receiving a return signal from the target.*


Introducing the
AOC Future 5 Program
Honoring the Best and Brightest Young Professionals in the Aerospace and Defense Industry.
In AOC's newest program, the AOC Education Foundation (AEF) will recognize five young professionals as the Future 5 each year. The Future 5 will showcase young professionals who actively innovate and strive for excellence as they build their careers in the EMS/EW/IO industry.
Future 5
Association of Old Crows
Applications are open!
Learn more at www.crows.org/future5

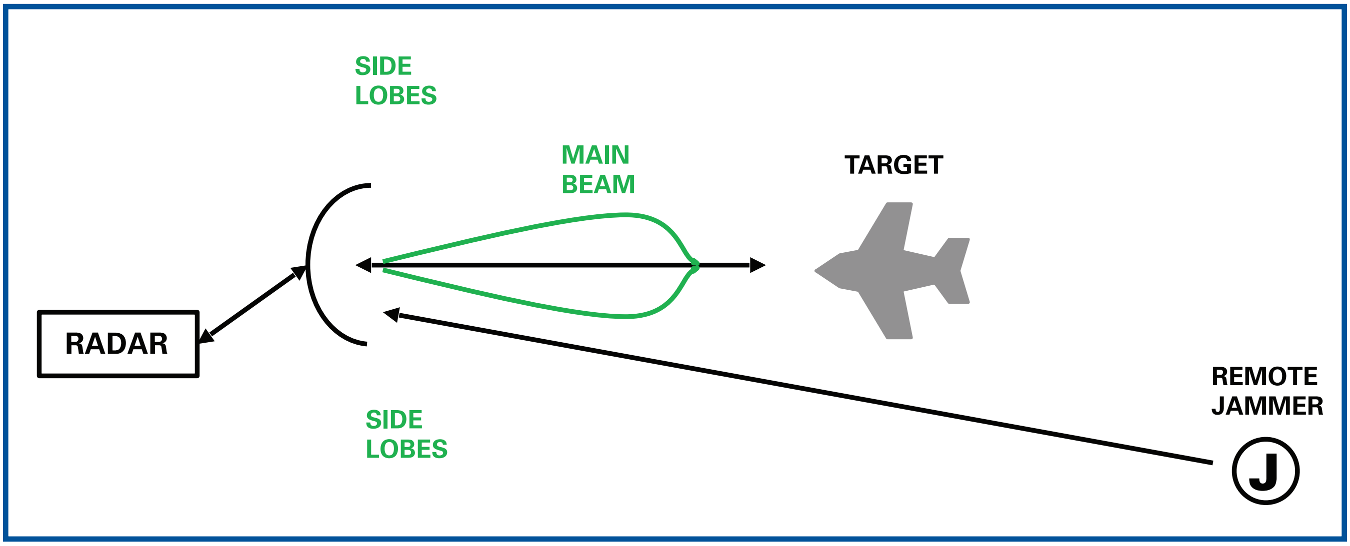


Fig. 3: *A remote jammer is located away from the target. It may be farther from the radar than the target, which makes it a "stand-off jammer," or closer, which makes it a "stand-in jammer." In either case, it is assumed that the radar antenna is pointed at the target (rather than the jammer), so the jammer will broadcast to a side lobe of the radar antenna.*

Since the jammer is in a side-lobe, the goal of EP is to cause that side-lobe gain to be low or to counter it in some way.

Radar EP involves radar features that are designed to reduce the effectiveness of jamming. **Table 1** lists EP techniques that are used against radar jammers, the jamming techniques they are intended to counter and some characteristics of the radars protected. In this part of the EP series, we will consider each of these techniques.

SIDE-LOBE RELATED EP

The first three entries in Table 1 are used to counter remote jammers, which broadcast into side lobes of the radar's antenna. Since jamming signals are received in side-lobes, anything the radar does to reduce the received side-lobe signal will reduce the J/S.

Very Low Side-Lobes

The first, and most obvious approach is to design the radar's antenna with low side-lobes. Phased array radars can be designed with reduced gain in the antenna elements at the edges of the antenna array. This sharpens the beam and reduces the side-lobes. In a simple phased array, the peak of the first side-lobe (nearest the main beam) might be 10-13 dB weaker than the main-beam boresight gain. Intelligence databases show specially designed antennas to have multiple orders of magnitude less peak gain in their side-lobes. If a radar antenna has (for example) 40 dB side-lobe isolation relative to the main beam boresight gain, and the power of the return signal arriving at the radar location is 10 dB lower than the jamming signal arriving at the radar antenna from the side lobe direction, the resulting J/S will be -30 dB.

Side-Lobe Cancellation

The other way to reduce the power of a signal received from a direction away from the target is via side-lobe cancellation. The key is to provide an additional antenna that has more gain in the direction of the side-lobe than provided by the side-lobe of the main radar antenna. **Figure 4a** shows (in black) the gain pattern of the primary antenna. Note that there is a large main beam and smaller side lobes, which diminish with angular distance from the antenna bore-sight. In the same diagram, the main-beam gain pattern of the auxiliary antenna is shown in red. The auxiliary antenna has a smaller diameter, which causes it to have lower gain than the main antenna but a significantly wider beam. The auxiliary antenna is designed so that its main beam has more gain in any direction than the peak gain of the side-lobes of the main antenna. This means that the auxiliary antenna output will be higher than that of the main antenna if a signal is received away from the angular coverage of the main beam of the main antenna.

Jamming signals from a remote jammer can be either FM noise or pulses. If the jamming is FM noise, it is relatively narrow band. An oscillator is phase locked to the jamming signal and shifted by 180^0 in phase. This phase-shifted signal is added to the output of the main antenna and has the effect of reducing the amplitude of that signal by many dB. The amount of the reduction depends on the accuracy of the phase-lock, but could reasonably be 30 dB or more. As shown in **Figure 4b**, there can be multiple auxiliary antennas. One off-axis jamming signal can be cancelled by each of the auxiliary antennas. This is called coherent side-lobe cancellation (CSLC), and it is very effective against a remote jammer.

If the remote jamming signal is pulsed, the auxiliary antenna works the same. The remote jammer signal will be stronger in the auxiliary antenna output than it is from the side-lobe of the main antenna. When this is detected, a very fast microwave switch cuts off the main antenna output during that pulse as shown in **Figure 4c**.

It should be noted that a sophisticated jammer can counter either of these EP techniques. If the jammer transmits high-duty-cycle pulses along with FM noise, the spectrum of the pulse signal will have a large number of continuous-wave components. The radar will only have a limited number of auxiliary antennas. Each will lock up on and cancel a single spectral line of the pulse signal. Once all of the auxiliary antennas are locked onto spectral lines, the FM noise jamming will pass through to the radar and allow effective jamming.

Share your expertise and knowledge with the AOC and EMSO community. AOC is seeking presenters and instructors for sessions on the following topics:

WEBINAR TOPICS

- Electromagnetic Battle Management (EMBM)
- Joint Electromagnetic Spectrum Information, Analysis, and Fusion (JEMISIAF)
- Test & Evaluation of Electronic Warfare/ EMSO
- Standdown of the Land-Based EA-18G Growler Squadrons; what that means for the Joint Force
- Status of the new EC-37B Compass Call Aircraft for the USAF
- SpaceX, Starlink, and Quick Defeat of Russian Electronic Attack in Ukraine and Other Quick Takeaways
- Joint All-Domain Command and Control (JADC2)
- No HARM, no foul. An update on the AGM-88 HARM and AARGM
- What's After 5G? 6G of Course!
- U.S. Spectrum Auctions and the Future of EMSO/EW Training in the U.S.
- What's Next After GPS? Time for a new Precision, Navigation and Timing (PNT) Solution
- Clean Energy and EMSO/EW: Do Wind Turbine Farms Really Impact EW Testing?
- Moving EMSO Education "Left of Bang"—The state of civilian undergraduate education in EMSO principles

COURSE TOPICS

- Space EW
- AI/MLL
- Cyber
- ELINT and Modern Signals
- Fundamental EW
- Advanced EW
- EW Project Management
- Radars and EW
- ELINT and EW
- Introduction to Radar
- Introduction to EW
- Modeling and Simulation
- EMBM Concepts
- LPI
- Satellite Communications

Interested? Contact Raleigh Leavitt, AOC Education Coordinator, at **leavitt@crows.org**

ASSOCIATION OF OLD CROWS

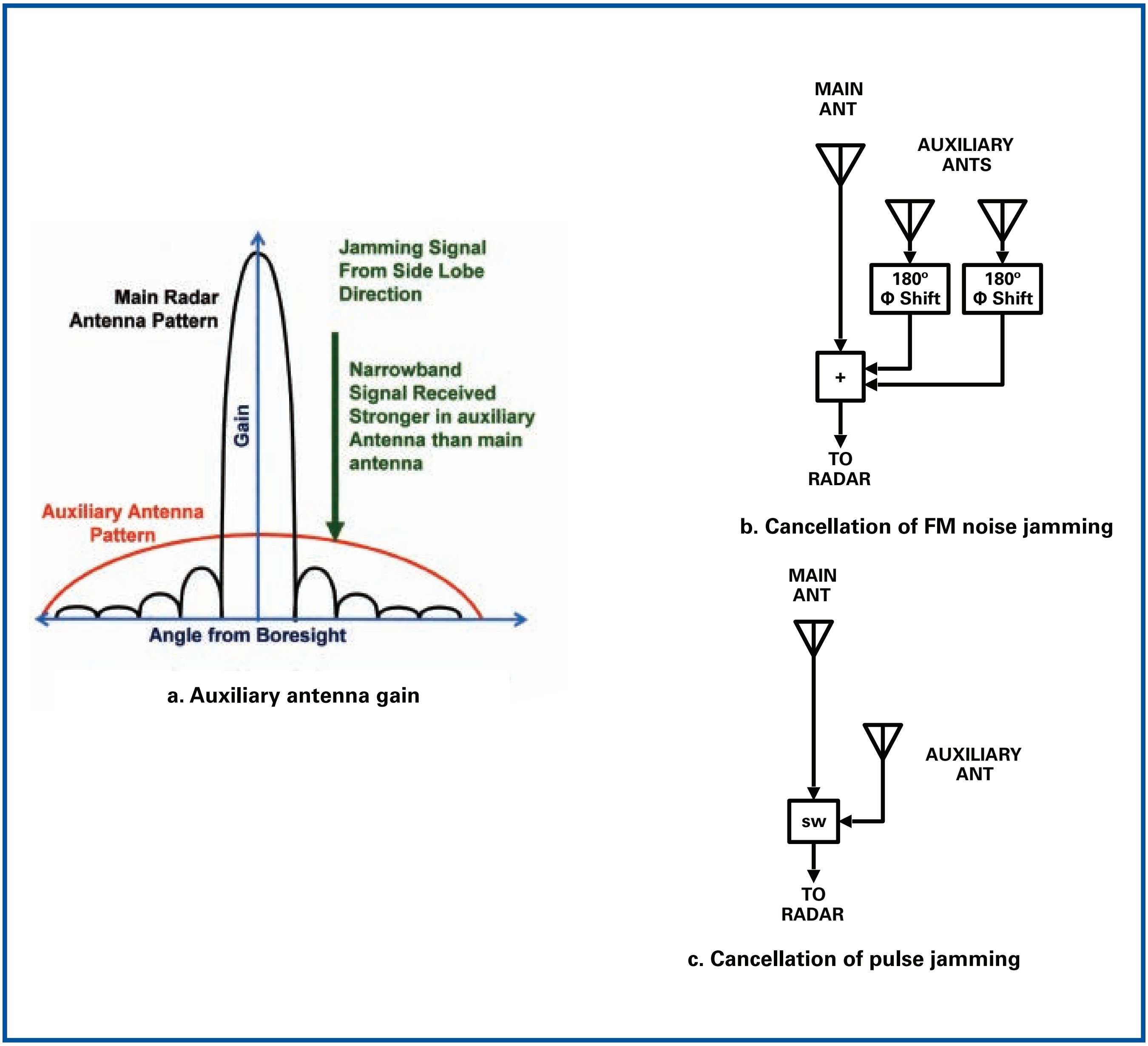


Fig. 4: *Auxiliary antennas allow the cancellation of jamming signals from side-lobe directions*

If the pulsed jamming signal is received by the radar's receiver during the received return pulse, the canceller will cancel the radar's own signal – very effective jamming! However, since a radio signal travels at about a foot per nanosecond, there can be a significant delay between the time the radar gets its return and the time that the jammer causes the switch to open. There is a very complex relationship as a function of the radar-to-target and radar-to-jammer distances. Remember that the jammer is remote from the target and may maneuver independently.

Table 1: Radar Electromagnetic Protection Techniques

- Ultra-low Side Lobe (Against detection & Side Lobe Jamming)
- Side lobe canceller (Against side lobe noise jamming)
- Side Lobe Blanker (Against side lobe pulse jamming)
- Anti Cross Pol (Against cross pol jamming)
- Mono-pulse (Against chaff & non-coherent jamming)
- Pulse Compression (Against decoys & non-coherent jamming)
- Mono-pulse Radar (Against many kinds of deceptive jamming)
- Pulse Doppler (Against chaff & non-coherent jamming)
  - Anti Doppler pull-off
  - Frequency, range rate correlation
  - Anti Chaff
- Leading Edge Tracking (Against range gate pull-off)
- Dyke-fix (Against automatic gain control jamming)
- Burn-through modes (All types of jamming)
- Frequency Agility (All types of jamming)
- PRF Jitter (Range gate pull-off and cover pulses)
- Home-on-Jam Modes (All types of jamming)

WHAT'S NEXT

Next month, we will continue our discussion with a look at additional radar EP techniques. Dave Adamy can be reached at dave@lynxpub.

APPLICATIONS OPEN – US ARMY CYBER CORPS WARRANT OFFICER SCHOLARSHIP

The US Army Cyber Corps Warrant Officer Scholarship, established by the Laurie Buckhout Foundation, was created to provide support to US Army Cyber Corps warrant officers by allowing them to apply for financial assistance in gaining various levels of formal higher education.

To qualify, applicants must meet the following criteria:

- Be a CW3 or under, demonstrate excellent promotion potential, be in the Cyber Warfare or EW workforce (i.e., 170A, 170B, and 170D)
- Minimum of two years left on active duty
- Be eligible and accepted to attend a Masters or PhD program

Learn more and apply today: crows.org/USA_WO_Scholarship

WINNERS ANNOUNCED – 2021 AOC MUDDY WATTERS' STEM PROGRAM

The AOC Muddy Watters STEM Program encourages and supports student STEM groups to consider the electromagnetic spectrum (EMS) in their studies and grants participants the opportunity to work closely with an AOC Mentor, learn more about EMS application in everyday life, and the chance to win a financial award for their school or STEM group.

2021 WINNERS

FIRST PLACE

- Oakton High School

SECOND PLACE

- Civil Air Patrol Hertz Power
- Civil Air Patrol NJ102

THIRD PLACE

- Montgomery Blair

View the full list of winners at crows.org/stem

PROVEN POWER

Model BME49189-50 & BME69189-100

4-18 GHz, 50 Watts & 6-18 GHz, 100 Watts
Solid State Power Amplifier Module

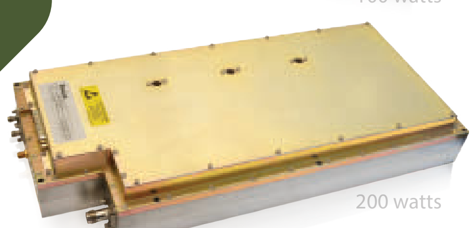
- Full Power Across the Entire Bandwith
- Maintains Output Power, Gain, and Efficiency with Real World Load Conditions
- Superior Harmonics *AND* Input /Output VSWR
- Compact, Lightweight, and Usable in the Harshest Environments
- 28 VDC GaN Technology
- High Speed Blanking
- Operating Temperature: -40º C to 55º C

SOLID STATE PERFORMANCE

Model BME2969-100 & BME2969-200

2–6GHz, 100 & 200 Watts
Solid State Power Amplifier Module

- High Efficiency Over the Entire Bandwidth
- RF Input/Output Sample Ports
- Internal DC to DC Converters
- External T/R Switch Available
- Maintains Output Power with Real-World Load Conditions
- Operating Temperature: -40º C to 55º C
- Also Available in 300 Watts



COMTECH POWER SYSTEMS TECHNOLOGY™

Subsidiary of Comtech Telecommunications Corporation
www.comtechpst.com

Contact our sales & marketing department today to discuss your exact project needs.
Comtech...*meeting needs, exceeding expectations.*

105 Baylis Road, Melville, NY 11747
Tel: (631) 777-8900 • Fax: (631) 777-8877

417 Boston Street, Topsfield, MA 01983
Tel: (978) 887-5754 • Fax: (978) 887-7244

AOC Members

SUSTAINING

BAE Systems
Bharat Electronics Ltd.
CACI International Inc.
Chemring Group PLC
Electronic Warfare Associates, Inc.
General Atomics Aeronautical
Systems, Inc.
General Dynamics
Keysight Technologies
L-3 Harris
Leonardo
Perspecta
Raytheon Intelligence & Space
Rohde & Schwarz USA
Saab Sensor Systems Germany GmbH
SRC, Inc.

MILITARY UNITS

30 Cdo IX Gp RM
547 IS
57 IS/DOD
Air Command Denmark
Detachment-A 743d
Helicopter Wing 53
IWTG Norfolk
Japan Air Self-Defense Force
NASIC/AC
NIWTG SD
Zentrum Elektronischer Kampf
Fliegende Waffensysteme

INSTITUTES/ UNIVERSITIES

Georgia Tech Research Institute (GTRI)
Mercer Engineering Research Center (MERC)
Riverside Research Institute
RVJ Institute

GOVERNMENT GROUPS

ACEASPO
Australia Department of Defence DIO
DE&S
Defence Science & Technology Agency
DOD
Los Alamos National Lab
New Zealand Defence
Technology Agency
NGA – National Geospatial Intelligence Agency
NLR – Royal Netherlands
Aerospace Centre
Swedish Defence Materiel
Administration T&E Directorate

GROUPS

3dB Labs Inc.
Abaco Systems
ACE Consulting Group
Ad Hoc Research Associatates, LLC
Aeronix, Inc.
Aethercomm, Inc.
ALARIS Antennas
Allen-Vanguard
Analog Devices
Anritsu
API Technologies
ApisSys SAS
Apogee Engineering
Applied Systems Engineering, Inc.
Armtec Defense Technologies
ARS Products
Aselsan A.S.
Atkinson Aeronautics & Technology, Inc.
Atlanta Micro, Inc.
Atrenne, a Celestia Group Company
Avix
Azure Summit Technology, Inc.
Babcock International Group
Beca Applied Technologies Ltd.
Black Horse Solutions, Inc.
Blue Ridge Envisioneering, Inc.
Booz Allen Hamilton, Inc.
Boyd Corporation
Cablex PTY Ltd.
CEA Technologies, Incorporated
Centauri
Centro de Guerra EletrÃ³nica – PTAF
Clearbox Systems
Cobham Advanced Electronic Solutions
Colorado Engineering, Inc.
Communication Power Corporation
Communications & Power Industries LLC
Comsec LLC
Comtech PST Corporation
Crescend Technologies, LLC
Defense Solutions
CRFS Inc.
CRFS Limited
CSIR DPSS
Cubic Defense
D-TA Systems, Inc.
Daqscribe
Darkblade Systems
Dayton Development Coalition
dB Control
DCS Corp.
Decodio AG
Defense Research Associates Inc.
DEFTEC Corporation
DEWC Group
Dreamlab Technologies AG
Eagle Sales Corp.
ELBIT Systems of America
Elbit Systems of EW & SIGINT Elisra
Electro-Metrics, Corp.
ELDES S.r.l.
Elettronica S.p.A.
Elite RF
Elmtek Pty Ltd.
Empower RF Systems
Epiq Solutions
ESROE Limited
Evans Capacitor Company
Galleon Embedded Computing
GFD GmbH
Government Business Development
Hammer Defense Technologies LLC
HASCO
HawkEye360
Hegarty Research LLC
Hensoldt Sensors GmbH
Hermetic Solutions
Herrick Technology Laboratories, Inc.
IAI North America
IDS International Government Services
Indra
Intelligent RF Solutions
Interface Concept
ISPIN AG
ITA International, LLC
IW Microwave Products Division
JT4, LLC
KBR
Key Bridge Wireless
Kihomac, Inc.
Kranze Technology Solutions, Inc. (KTS)
Kratos General Microwave Corporation
L3Harris TRL Technology
LCR Embedded Systems
Leonardo DRS
Leonardo Electronics – US
Liteye Systems, Inc.
Lockheed Martin Co.
MarServices GmbH
Mass Consultants Ltd.
Maxar-Ypsi-EW
MBDA France
MC Countermeasures, Inc.
MDA
MDSI
MegaPhase LLC
Meggitt Baltimore
Meggitt Defense Systems
Meta Mission Data Ltd.
Microwave Products Group
Milpower Source, Inc.
Milso AB
Mission Microwave Technologies
The MITRE Corporation
Molex
Motorola Solutions
MTSI
My-Konsult
MyDefence System Integration
N-Ask Incorporated
Nagravision S.A.
NEL Frequency Controls, Inc.
Northeast Information Discovery Inc.
Northrop Grumman Defense Systems – Advanced Weapons
Novator Solutions AB
OCS America, Inc.
Parsons
Pentek
Penten
Peraton/Perspecta
Persistent Systems, LLC
Perspecta
Phasor Innovation
Photonis Defense Inc.
Physical Optics Corporation
Plath GmbH
PredaSAR
PROCITEC GmbH
QuantiTech
RADA Technologies LLC
RAFAEL Advanced Defense
RFHIC US Corporation
Systems Ltd.
Research Associates of Syracuse, Inc.
Rincon Research Corporation
Rohde & Schwarz GmbH & Co. KG
Rohde & Schwarz Norge AS
Roschi Rohde & Schwarz AG
Rotating Precision Mechanisms
Rowden Technologies
S2 Corporation
School of Information Operations
SciEngines GmbH
Scientific Research Corp.
SEA Corp.
Serpikom
Sierra Nevada Corporation
Signal Hound
Silver Palm Technologies
SimVentions
SMAG Mobile Antenna Masts GmbH
Smiths Interconnect
SOIO
Spectranetix, Inc.
Spherea GmbH
Spirent Communications
SR Technologies
STEATITE
Stellant Systems
Swisscom Broadcast AG
SYPAQ
Systems & Processes
Engineering Corp. (SPEC)
Tabor Electronics
TCI International, Inc.
Tech Resources, Inc.
Teledyne Technologies, Inc.
Telemus Inc.
Teleplan Globe Defence
TERMA
Tevet LLC
Textron Systems
Textron Systems Electronic
Systems UK Ltd.
ThinkRF
Tinex AS
TMC Design
TMD Technologies Ltd.
Transformational Security LLC
Transhield Inc.
Trenton Systems
Trideum
TUALCOM, Inc.
Ultra Electronics – EWST
Ultra Electronics Avalon Systems
Unival Group GmbH
Vadum Inc.
Valiant Integrated Services
Valkyrie Enterprises LLC
Verus Research
VIAVI Solutions
Vigilant Drone Defense Inc.
VITEC
W.L. Gore and Associates
Warrior Support Solutions LLC
WGS Systems, Inc.
X-COM Systems
ZARGES, Inc.
Zentrum Elektronischer Kampf
Fliegende Waffensysteme

LEARN ANYTIME, ANYWHERE
EDUCATIONAL COURSES
On-Demand Professional Development Courses from Leading Experts in the EW Field
Achieve your professional development goals and learn at your own pace with AOC's growing library of 20+ on-demand online courses.
Enroll in a course today!
crows.org/PDC_OnDemand_Catalog

ASSOCIATION OF OLD CROWS

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

JED Sales Offices

NAYLOR
ASSOCIATION SOLUTIONS
550 SW 2nd Avenue
Gainesville, FL 32601
Tel (800) 369-6220
www.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

Index of Advertisers