NOVEMBER 2019
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ASSOCIATION OF OLD CROWS

JED

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The Journal of Electronic Defense

The EW Story of the Gripen E

Also in this issue:

- Where is DRFM Technology Headed?
- Novel Antenna Technologies
- How Will Ground EW Evolve?
- Interview with Deb Norton, VP of F-35 Solutions, BAE Systems

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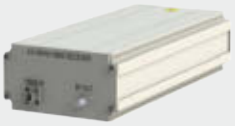

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US Marines from 2nd Radio Battalion, II Marine Expeditionary Force Information Group and Norwegian Army electronic warfare (EW) operators with the EW Task Unit, EW Company, Norwegian Military Intelligence Battalion, employ the Wolfhound Handheld Threat Warning System during Integrated Training Exercise (ITX) 5-19 at Marine Corps Air Ground Combat Center, Twentynine Palms, Calif., July 25, 2019. The Norwegians participated in ITX to enhance US Marine Corps' and Norwegian Army's abilities to use and integrate allied forces in a combat environment through EW support.

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GETTING TO "WHY"

There is an interesting thought exercise called "five whys" which is designed to help problem solvers get to the root of a particular problem. It allows you begin with an identified problem, and by asking a series of "why"-related questions it allows you to recognize the symptoms of a problem and to get past them to attack the heart of an issue. It's called the "five whys," because you usually have to dig down at least five layers to get to the root of the problem.

You may ask, "What does this have to do with electronic warfare (EW)?" Very often in EW, we think we are solving the root causes of a problem when we are really just scratching the surface and attacking the symptoms. Let look at the EW experience in the Iraq War using the "five whys" in a question-and-answer format to get at the heart of a larger EW issue facing the DOD.

In 2004, Iraqi insurgents began a campaign in which they would eventually trigger thousands of remote-controlled improvised explosive devices (RCIEDs) along Iraq's roads over the next several years. This campaign caused thousands of coalition casualties and constrained coalition operations throughout most of Iraq.

Q: Why did the Iraqi insurgents manage to achieve such a large operational effect against technologically superior and better trained coalition forces?
A: The insurgents were able to weaponize commercial electronics technology to make inexpensive RCIEDS. And in 2004-2005, most of the coalition forces in Iraq were not equipped to detect and defeat the RCIEDs.

Q: Why weren't the US forces equipped to detect and defeat the RCIEDs?
A: Because the Army and Marine Corps did not have requirements to defeat RCIEDs before 2004.

Q: Why didn't the Army and Marine Corps have any requirements to defeat RCIEDs before US forces entered Iraq?
A: US forces had not faced RCIEDs prior to the Iraq War. In addition, the Army had very few ground EW experts and no ground EW focus in 2004.

Q: Why weren't there enough ground EW experts and EW organizations in the Army prior to the Iraq War?
A: Because the Army had disbanded them in the 1990s.

Q: So, to extrapolate this lesson a bit, without people, organizations and leadership, EW requirements cannot be identified and EW technology cannot be developed and fielded ahead of a conflict?
A: Yes.

Q: Looking beyond the Army, how does the DOD ensure that it remains focused on maintaining EW personnel, organization and leadership?
A: The DOD needs an EMS enterprise approach to achieve these long-term goals.

Q: How do we establish an EMS enterprise approach and ensure that it can endure for the long-term?
A: We need to recognize the EM Domain as a strategic maneuver space, which will ensure a long-term focus on the EMS Enterprise.

Q: Is the DOD in the process of recognizing the EM Domain?
A: That's a good question. – *J. Knowles*

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www.milcom.org

Directed Energy Day
November 13
Alexandria, VA
www.directedenergy.dsigroup.org

Dubai Airshow 2019
November 17-21
Dubai, UAE
www.dubaiairshow.aero

AAAA Aircraft Survivability
Equipment Symposium
November 18-19
Huntsville, AL
www.quad-a.org

DSEI Japan
November 18-20
Tokyo, Japan
www.dsei-japan.com

Defence & Security 2019
November 18-21
Bangkok, Thailand
www.pandci.com

Directed Energy Systems Symposium
November 18-22
San Diego, CA
www.deps.org

DECEMBER

Expodefensa 2019
December 2-4
Bogota, Colombia
www.expodefensa.com.co

I/ITSEC
December 2-6
Orlando, FL
www.iitsec.org

JANUARY

Surface Navy Association 32nd Annual National Symposium
January 14-16
Arlington, VA
www.navysna.org

Directed Energy Test and Evaluation Conference
January 27-30
Albuquerque, NM
www.deps.org

FEBRUARY

AOC EW Asia
February 4-5
Singapore
www.crows.org

Defexpo 2018
February 5-8
Lucknow, Uttar Pradesh, India
defexpoindia.in

Singapore Airshow
February 6-11
Singapore
www.singaporeairshow.com

6th International Conference on EW – EWCI 2018
February 18-20
Bangalore, India
www.aoc-india.org

AFA Air Warfare Symposium
February 26-28
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JANUARY

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FEBRUARY

Radar Electronic Warfare
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Communications Electronic Warfare
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Swindon, UK
www.cranfield.ac.uk

Basic RF Electronic Warfare Concepts
February 11-13
Atlanta, GA
www.pe.gatech.edu

AOC Virtual Series Webinar: Electronic Warfare in the New Threat Environment
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MARCH

AOC Live Professional Development Web Course: EW Modeling and Simulation
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March 12
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AOC Virtual Series Webinar: How the West Is Losing the Navigation and Timing War – and Risking Everything
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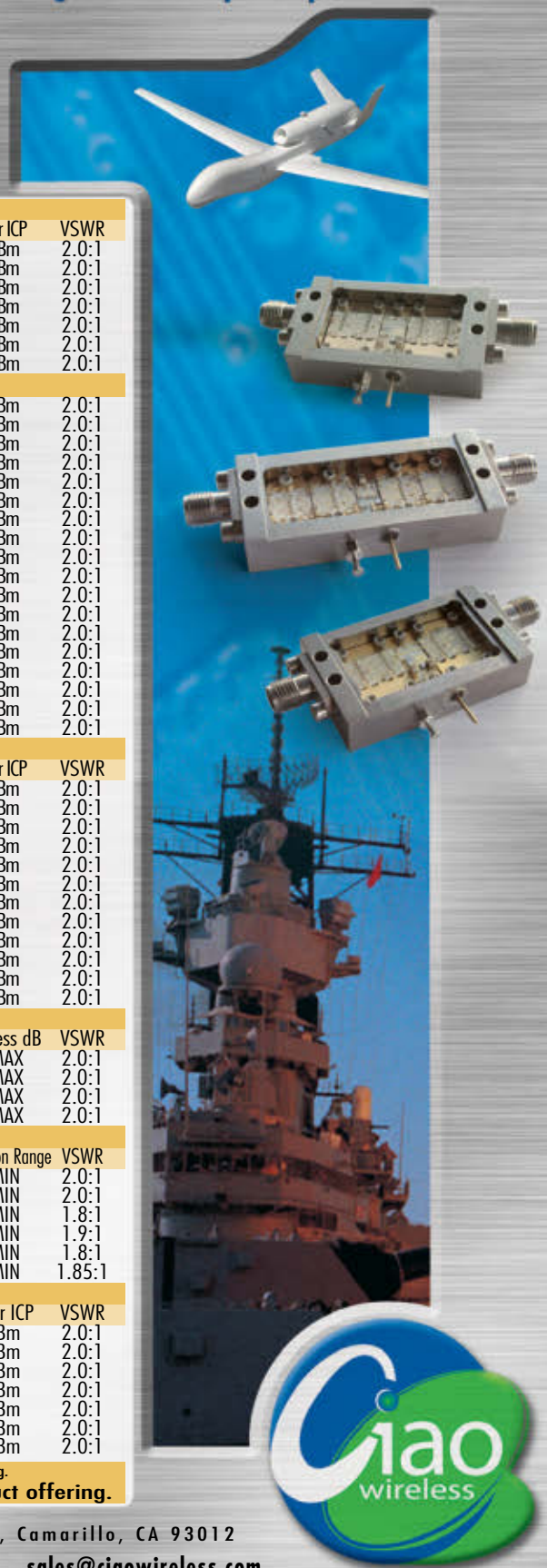

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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BUILDING THE EMS ENTERPRISE

As the AOC continues to champion the understanding of the Electro Magnetic Environment (EME) and the Electromagnetic Spectrum's (EMS's) value and criticality to our warfighting capabilities, I think back to the old Soviet mantra from their Maskirovka doctrine that states simply, "If you control the spectrum, you win the war." We are now viewing the EME as a maneuver space, but we face challenges that can only be addressed by developing requirements and building capabilities based on an "Enterprise approach." Traditionally, we have confronted maneuver in the EME from its tactical aspects upward (i.e., we focus on stovepipe solutions in areas of SIGINT, electronic protection, Airborne Electronic Attack, directed energy and EMBM, as examples). Our current approach impacts development, sustainability, coherence and delivering capabilities to our warfighters that will enable them to achieve EME superiority in current and more importantly future battles. This disruptive new *top-down* Enterprise approach includes the collection of governance, strategy, policies, organizations, workforce, processes, planning, technologies, support and operations relevant to an enduring shared interest. By developing and capitalizing on the Enterprise, we can create, deploy and sustain truly synergistic capabilities that will allow us to achieve *EME Superiority*.

To build the Enterprise will require capabilities that provide threat-based intelligence in the EMS, multi-functional EM capabilities, a professional EMS workforce, managing the EM battlespace, EMS force readiness and high-energy EM weapons. To drive the enterprise, we need the proper strategy, doctrine and policies that will enable us to dominate the great power competition in the EME. We must elevate EME superiority as a warfighting priority and establish stronger EME governance. This will empower senior EM warfare leaders who have the authority, the vision, and most importantly the ability to develop and execute a coherent investment strategy across the Services and in conjunction with national security partners to provide interoperability and capabilities that we need. You will see that we have built this year's 56th Annual AOC Symposium and Convention around the enterprise challenge, and this statement from our symposium chairman directly hits the target.

"A stable, deliberate, governed, and effective EMS Enterprise is now increasingly seen as an enduring requirement for *freedom of action across the EMS Domain*, the control of which underwrites all current and future military operations. As the EMS Domain's value increases, pursuit of an enduring Enterprise provides a clear framework and catalyst for those *necessary Defense reforms* unavailable via traditional means. This adaptation for strategic advantage will prove essential, as the fates of peaceful nations rely on global and regional stability, stability in turn relies on responsible use of power, and the ability of peaceful nations to project power rests on a solid foundation of EMS capability superiority."

To build the Enterprise will take all of our commitment, knowledge and effort and can be the culmination of all of the efforts we have championed in the electromagnetic environment for the last 20 years. – *Muddy Watters*

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the monitor news

US ARMY SEEKS "SIGINT APP"

The US Army's Combat Capabilities Development Center (CCDC) Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) Center (Aberdeen Proving Ground, MD) has issued a Request for Information for an "Intelligence SIGINT Application" that can provide tactical signals intelligence (SIGINT) analysis "…to meet the Commander's Critical Information Requirements."

According to the RFI, "The Intelligence Application will provide the capabilities to receive and process Tactical SIGINT reports at the appropriate security levels, and will provide to store, exploit and disseminate the SIGINT data, information, and intelligence products in support of the All Source analysis process and the Commander's decision-making process. The Intelligence Application shall have the capability to retrieve data from a national SIGINT database and from the Integrated Broadcast Service (IBS) to populate the local SIGINT repository at the proper security levels."

Additionally, "The Intelligence Application will provide to correlate and de-duplicate the SIGINT parametric data from multiple sources. The Intelligence Application will provide the emitter mapping capability for situation awareness and will provide the capability to refine the emitter geolocation information in order to provide an improved location approximation and probability of error information. The Intelligence Application will have the tools to assist the analysts to identify entities of interest include methods, motives, capabilities, and vulnerabilities; determines malicious behavior; recognizes emergent patterns and linkages."

In the RFI response, the Army wants companies to describe the software packages and hardware platform that will host the proposed solution, including CPU, RAM, and storage specifications. Interestingly, the RFI also asks respondents to describe how the proposed solution has the potential, through minor modifications, to meet the Federal Acquisition Regulation (FAR) 2.101 definition of a "commercial item."

Responses to the RFI are due by November 4. The contracting point of contact is Maurice P. Hinkson, e-mail maurice.p.hinkson.civ@mail.mil. – *JED Staff*

AFRL SEEKS DIRECTED ENERGY C-UAS CAPABILITY

The Air Force Research Lab's Information Directorate, acting through the System of Systems Consortium (SOSSEC), is requesting white papers on directed energy counter unmanned aerial system (C-UAS) solutions.

According to the Request for White Papers (RFWP), AFRL is seeking information about a "…fieldable, directed energy (DE) based counter unmanned aircraft system (C-UAS) for the purpose of area defense against group 1 and group 2 class unmanned aircraft systems (UAS) and other airborne threats. Both high energy laser (HEL) and high-powered microwave (HPM) based CUAS systems are considered potential solutions." The goal is identify a prototype C-UAS system that is "near production representative" and is "integratable with current military battle management systems." Functionally, the system must provide "detect, track, identify, and hard kill capability in a range of combat environments."

In terms of performance, AFRL is seeking a C-UAS system that is "capable of detection, identification, targeting, and/or tracking group 1 and group 2 UAS systems from a distance of 10 km threshold, engaging group 1 and group 2 UAS systems from a distance of 1 km threshold, and destroying group 1 and group 2 UAS systems from a distance of 500 m threshold." It must defeat Tier 1 and Tier 2 UAS platform at a minimum rate of five per minute. It must also be controlled by a single command and control system and be "…employed by an operator with limited engineering or directed energy experience."

Based on white paper responses, AFRL will invite selected companies to respond to a formal Request for Proposals (RFP). The point of contact is Linda Sasser, (603) 458-5529, e-mail lsasser@sossecinc.com. – *JED Staff*

IN BRIEF

The US Army's **Intelligence and Information Warfare Directorate (I2WD)** (Aberdeen Proving Ground, MD) has issued a Request for Information for high-altitude and Low-Earth-Orbit (LEO) sensing systems to support indications, warnings and targeting applications. Responses should address the following requirements: 1) SIGINT sensing capabilities that must operate on Low Earth Orbit satellites; 2) all sensing concepts must be at least a Technology Readiness Level (TRL) of 4; and 3) SIGINT sensing capabilities do not have to be common

across aircraft, stratospheric balloons, and LEO satellite platforms. The contracting point of contact is Chaz A. Slaughter, e-mail usarmy.apg.ccdc-c5isr.mbx.i2wd-Halo-rfi@mail.mil.

The **Electronic Warfare Air/Ground Survivability (EWAGS) Division** of the US Army's Combat Capabilities Development Command (CCDC) Command, Control, Communication, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) Center is requesting information in developing an anechoic chamber-based radar hardware-in-the-loop (HITL) simulator to assess performance of Active Protection System radar detection and multi-object tracking capabilities in a transmitted radio frequency (RF) scenario. The EWAGS Division would be leveraging a large anechoic chamber (76'L x 34'W x 32'H / 30MHz to 100GHz) to house the system. The requirement calls for a system that: 1) can interface to a radar system under test which will operate in two modes: an active search mode looking for targets of interest, and a cued-only mode accepting cues from an external source; 2) be capable of generating targets of interest through the use of repeaters, RF simulators, or some other method for collecting the radar signal and generating the targets of interested based on a simulation; 3) targets should have representative RCS and speeds at a minimum; and 4) be able to generate at least four simultaneous targets at different angles relative to the radar, and in particular should be able at least two targets by 90 degrees. Frequencies of interest include X through Ka band. RFI responses should be e-mailed to usarmy.apg.ccdc-c5isr.mbx.i2wd-gndsurvrfi@mail.mil are due by November 8. The contracting point of contact is Maurice P. Hinkson, e-mail maurice.p.hinkson.civ@mail.mil.

The US Air Force has released a final Request for Proposals (RFP) for an RF threat simulator to help maintain the EW systems on its A-10 and F-16 aircraft. The simulator will be used by the **36th EW Squadron** (part of Air Combat Command's 53rd EW Group) to maintain and update the operational mission data (MD) on the ALR-69A Radar Warning Receiver (RWR), ALR-69 RWR, ALR-56M RWR, and ALQ-213 EW Management System. The ALR-69A is currently undergoing operational test and evaluation (OT&E) pending a Force Development Evaluation (FDE) in 2020. The 36th EWS builds combat representative MD for these events and will inherit creation, updating, testing, and release of operational MD for the ALR-69A after Initial Operating Capability (IOC) in FY22. The solicitation number is FA2487-19-R-0002. Proposals are due by November 13. The contracting point of contact is Craig O'Neill, (850) 882-5070, e-mail craig.oneill.2@us.af.mil.

The Boeing Company (St Louis, MO) has received a $22.6 million contract option from the Air Force Life Cycle Center (Wright-Patterson AFB, OH) for the integration of the Suite 9.1/Eagle Passive Active Warning Survivability System (EPAWSS)

into F-15C and F-15E Mission Training Center (MTC). **BAE Systems** (Nashua, NH) is supplying the EPAWSS, which is based on its F-15 Digital EW System (DEWS).

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Naval Air Systems Command (NAVAIR) (Patuxent River, MD) has awarded **Mercury Defense Systems Inc.** (Cypress, CA) a $13.7 million fixed-cost contract for 27 Type II advanced digital radio frequency memory (DRFM) hardware and software for the Navy, Air Force, National Guard and Reserves. The contract was awarded against a previous basic ordering agreement. Work is expected to be completed June 2021.

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Crane Electronics Inc. (Fort Walton Beach, FL) has received an estimated $9 million contract for AN/ALR-56C radar warning receiver low voltage power supplies in support of the F-15 aircraft from the Defense Logistics Agency Aviation (Warner Robins, GA). The contract will run through September 2024.

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The Air Force Research Laboratory (Rome, NY) has tapped **Herrick Technology Laboratories Inc.** (Manchester, NH) for Spectrum-Agile, Location Aware, Enhanced Electromagnetic Kit (SLEEK) hardware and software under a $40 million contract that provides for R&D, integration, prototyping, demonstration, validation and verification of new software capabilities for a software-defined and reprogrammable transceiver. Work is expected to be completed in October 2022.

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Raytheon Missile Systems (Tucson, AZ) has been tapped by the Air Force Research Laboratory (Wright Patterson AFB, OH) for outside continental US (OCONUS) field assessment of one prototype Phaser high power microwave system under a $16 million contract. Experimentation will include 12 months of in-field testing by Air Force personnel against unmanned aerial systems (UAS) and other real-world or simulated threats; operator training; maintenance of systems in theater; and the collection of availability, reliability, maintainability and supportability data. All assessments are expected to be completed by December 2020. This contract follows a previous agreement for which Raytheon will supply the USAF with two prototype high-energy laser (HEL) systems for overseas deployment, which can be used independently or in conjunction with the HPM system.

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The Air Force Research Laboratory (Wright-Patterson AFB, OH) has awarded separate contracts to **Raytheon Co.** (El Segundo, CA) and **BAE Systems** (Nashua, NH) in support of the Technologies for the Mixed-mode Ultra Scaled Integrated Circuits (T-MUSIC) effort. T-MUSIC technology combines advanced silicon-germanium with advanced CMOS to enable ultra-wide bandwidth, high spurious free dynamic range and fine data converter resolution with high effective number of bits beyond current state-of-the-art. Raytheon has received a $10.9 million contract for the T-MUSIC

effort, and BAE Systems has received $8 million for the T-MUSIC effort as well as the Disruptive SiGe Circuits fabricated Onshore (DiSCO) effort, which will be used to assess advancements provided by T-MUSIC technology. Work is expected to be completed by both Raytheon and BAE in December 2023.

Communications & Power Industries (Palo Alto, CA) has been awarded an $8 million contract from the Air Force Sustainment Center (Hill Air Force Base, UT) for the Twystron Electron Tube Repair program. The contract includes teardown, test, evaluation and repair of Twystron electron tubes for the Unmanned Threat Emitter (UMTE) system used to simulate threat radars for air crew training and tactics development. Work will be completed by September 2025.

Defense Logistics Agency Land and Maritime, (Columbus, OH) has exercised a $495-million, five-year contract option for the addition of two national stock numbers for receiver/processors and high band receivers in support of the ALR-56C Digital Upgrade against a previous five-year contract. **BAE Systems** (Totawa, NJ) will complete all work by December 2025 for delivery to the US Air Force.

The Defense Logistics Agency Aviation (Philadelphia, PA) will exercise an $11 million contract option for electronic surveillance in support of the P-8 aircraft program for the US Navy and Royal Australian Air Force (RAAF), to be completed by **Northrop Grumman** (Linthicum Heights, MD). This is a two-year modification to the original five-year basic ordering agreement, with a December 2021 completion date.

Northrop Grumman Corporation (Falls Church, VA) has announced changes to the company's organizational structure in an effort to better align the company's portfolio of products and capabilities with customers' needs. Under the new structure, there will be four operating sectors: Aeronautics Systems, Defense Systems, Mission Systems and Space Systems, effective January 1, 2020. Northrop Grumman describes the four sectors as follows:

Aeronautics Systems, an innovative manned and unmanned air system provider, with a proven track-record of systems engineering, manufacturing excellence and reliability. This sector will be led by Janis Pamiljans, current corporate vice president and president of Aerospace Systems.

Defense Systems, a broad-spectrum provider of critical technology services, sustainment and modernization, including integrated battle command systems, directed energy, tactical weapons and information systems, focused on evolving threats and quick-turn requirements for a wide variety of national security, military and civilian customers. The sector will be led by Mary Petryszyn, current vice president and general manager, Land & Avionics C4ISR, Mission Systems.

Mission Systems, a technology leader in open, cyber-secure, software-defined systems for defense and intelligence applications across multiple domains. This sector will be led by Mark Caylor, current corporate vice president and president of Mission Systems.

Space Systems, a space and launch systems provider serving national security, civil and commercial customers. Blake Larson, current corporate vice president and president of Innovation Systems, will lead the Space Systems sector.

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Naval Air Systems Command has exercised a $10.6 million option with **Northrop Grumman Innovation Systems** for full rate production of Lot 8 Advanced Anti-Radiation Guided Missiles (AARGMs). The company will convert government-provided AGM-88B High Speed Anti-Radiation Missiles (HARMs) into 4 AGM-88E AARGM all up rounds (AURs) for the Navy; and 11 AGM-88E AARGM AURs for the government of Italy. Deliveries are scheduled through March 2022.

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Black River Systems Company (Utica, NY) has won a $1.8 million contract from the Air Force Research Lab Information Directorate (Rome, NY) for the Lab's Exploitation and Processing of Radar/ELINT Emitting Systems (EXPRESS) effort.

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Naval Sea Systems Command has exercised a $91 million contract option with **Northrop Grumman Mission Systems** (San Diego, CA) for technical and engineering support for repair and the integration of Technology Insertion Elements associated with Joint Counter Radio Controlled Improvised Explosive Device Electronic Warfare (JCREW) Increment One Block One.

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The **Defense Advanced Research Projects Agency (DARPA)** is planning to hold a Proposers Day on November 6 at the DARPA Conference Center (Arlington, VA) for its upcoming Providence program. According to a Providence program description, DARPA is soliciting "innovative proposals in the following technical areas: naval surface warfare, electronic warfare (EW), battlespace surveillance, machine learning, intelligent systems, and ultra-wideband receiving. The objective of the Providence program is to develop novel Radio Frequency (RF) sensing and signal processing. This program, Providence, is a vital part of the Mosaic Warfare end-state vision." Providence will be a 36-month, two-phase program consisting of an 18-month Phase 1 Base Period with a Phase 2, 18-month Option Period. The Providence Program Manager is David Tremper, e-mail HR001120S0005@darpa.mil.

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L-3Harris Integrated Systems (Greenville, TX) has won a $48.9 million contract from the Air Force Research Laboratory, Information Directorate (Rome, NY) for Advanced Exploita-

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tion of Electronic Signals software and hardware. This contract provides for improved detection, collection, characterization and reporting accuracy of emerging emitters, and improved reporting timeliness; improved classification of signal feature characteristics; and research, development and demonstration of technologies and algorithms for automatic detection, measurement, processing and exploitation of radio frequency emissions. Work expected to be completed by September 2024.

The **New Mexico Institute of Mining and Technology** (Socorro, NM) has won a $92.9 million contract from the Air Force Research Laboratory Sensors Directorate (Wright-Patterson AFB, OH) for the Playas Electronic Attack & Cyber Environment research and development. This contract will define, develop and deploy cyber electronic warfare (EW) capabilities for research and development, evaluation, test and training in support of employment of cyber EW effects. This effort will provide a unique and enduring environment to support Department of Defense assets for the employment of cyber and EW effects. The contract will run through October 2026.

The Air Force Research Laboratory, Information Directorate (Rome, NY) has awarded a $9.9 million contract to **Valley Tech Systems Inc.** (Folsom, CA) for the development and testing of open system signal intelligence framework. The company will enhance the body of knowledge in the cyber domain through the research and development of innovative concepts and advancement in the software defined radio state-of-the-art to support signal intelligence related capabilities including real-time collection, geolocation and signal exploitation. Work is expected to be completed by September 2022.

BAE Systems (Merrimack, NH), **Northrop Grumman** (Linthicum Heights, MD) and **Systems and Technology Research** (Woburn, MA) were each tapped by the Air Force Research Lab Sensors Directorate (Wright-Patterson AFB, OH) for the Mercury Program, a Top Secret/Special Compartmented Information Special Access Program. The overall objective of the program is to research electronic warfare. AFRL awarded contracts to each company – BAE Systems ($10.1 million), Northrop Grumman ($12.5 million) and Systems and Technology Research ($10.4 million). Under their respective contracts, all three companies will support the Mercury program through February 2021.

Raytheon Co. (Largo, FL) has been awarded a $52.8 million contract option for design agent and engineering services in support of the Naval Sea Systems Command's (Washington, D.C.) Cooperative Engagement Capability (CEC) program. The contract modification covers advanced studies and integration, as well as software sustainment and support. Work will be performed in Largo, Florida and completed by September 2020.

world report

GREEN LIGHT FOR SPEAR-EW TECHNOLOGY DEMONSTRATOR PROGRAM

MBDA (Stevenage, UK), partnered by Leonardo (Luton, UK), has been awarded a Technology Demonstrator Program (TDP) contract by the UK Ministry of Defence (MOD) to develop an electronic warfare (EW)/stand-in jammer variant of its SPEAR stand-off miniature precision-strike missile.

The 12-month, £10 million SPEAR-EW TDP contract will integrate a miniaturized Digital Radio Frequency Memory (DRFM) jamming payload developed by Leonardo into the MBDA-developed SPEAR powered air vehicle. SPEAR-EW is designed to take the EW payload inside the missile engagement zone to jam threat radars and provide screening for other strike platforms.

MBDA

Designed to meet the UK's Selective Precision Effects At Range Capability 3 (SPEAR Cap 3) requirement, the SPEAR weapon system is being developed by MBDA under a four-year, £411 million contract awarded by the MOD in March 2016. SPEAR Cap 3 calls for an intermediate range (>100 km) all-weather precision weapon to prosecute fixed, mobile and re-locatable targets in complex, hostile environments bound by restrictive Rules of Engagement.

The baseline SPEAR technical solution developed by MBDA is a sub-100-kg weapon featuring a Pratt & Whitney TJ-150-3 turbojet engine, flip-out wing surfaces, mid-course guidance via a combined GPS/inertial navigation subsystem (with a two-way datalink enabling mid-course updates, re-targeting and mission abort functions) and a multi-mode seeker. A "tunable" multi-effects warhead, combining precursor and penetrator charges, is fitted to provide a capability against a range of different target sets.

Development of the SPEAR-EW stand-in jammer variant was publicly acknowledged by MBDA for the first time in April 2019. While retaining the outer mold line and mass properties of the baseline missile, the SPEAR-EW variant dispenses with the seeker package and warhead in order to accommodate additional fuel (increasing range and loiter time) and the miniaturized DRFM payload (generating jamming techniques for the suppression of enemy air defenses [SEAD]).

The objective of the current TDP is to demonstrate the maturity of the SPEAR-EW design, which has emerged from privately funded work performed by MBDA and Leonardo over the last 18-24 months. Leonardo has already undertaken chamber tests to characterize jammer performance (including beam patterns, power levels and DRFM-based techniques).

Leonardo has been working on the development of stand-in jamming technologies and techniques with the MOD for over 10 years. One part of this effort was a Capability Concept Demonstrator program, delivered in conjunction with the UK Defence Science and Technology Laboratory, which demonstrated the maturity of this sovereign stand-in jammer payload, and proved its viability as a near-term option to meet any future SEAD requirement.

The UK subsequently conducted integration of a derivative sovereign jamming payload with a Raytheon Miniature Air-Launched Decoy (MALD) vehicle at Raytheon UK's Harlow facility. However, *JED* understands that the EW payload for SPEAR-EW is a new development specific to the form/factor requirements of the SPEAR air vehicle (which is somewhat smaller than MALD).

SPEAR is being integrated onto the F-35B as part of the F-35 Block 4 upgrade program. In March 2019, it was announced that BAE Systems had received initial funding from Lockheed Martin, as F-35 prime contractor, to begin integration efforts for both SPEAR and MBDA's Meteor beyond visual range air-to-air missile.

The compact size of the SPEAR family allows four weapons to be carried internally in each of the two internal weapons bays of the F-35, or three per weapon station on the Eurofighter Typhoon. SPEAR-EW will keep the same form and fit as the baseline SPEAR to enable a single integration pathway and launcher solution. – *R. Scott*

DAS SUITE FOR RAF SHADOW ISTAR AIRCRAFT

The UK Ministry of Defence (MOD) has contracted Leonardo and Thales to deliver an integrated defensive aids system (DAS) for the Royal Air Force's (RAF's) eight-strong fleet of Shadow R.1 intelligence, surveillance, target acquisition and reconnaissance (ISTAR) aircraft.

Designed to provide the aircraft with protection against the latest generation of infrared-red guided threats, the order marks the first sale for Leonardo's Modular Airborne Platform Protection System (MAPPS). Based around a Leonardo DAS controller, the MAPPS suite specified for the Shadow R.1 also includes the Thales

TRANSPORT PIXELS

Das Suite continued on page 24


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Continued from page 22

Elix-IR infrared threat warner system (IRTWS), the Thales Vicon XF countermeasures dispensing system, and a dual-head Leonardo Miysis directed infrared countermeasures (DIRCM) system.

Operated from RAF Waddington by No 14 Squadron, the Shadow R.1 is a special mission adaptation of the King Air 350 light twin aircraft. The ISTAR role, which requires the aircraft to potentially operate in hostile airspace, necessitates the provision of a robust DAS capability to counter the threat posed by IR-guided man-portable air defense systems.

The contract, initially covering the supply of five equipment sets and three Shadow R.1 aircraft embodiments, will be delivered by a combined MOD/Leonardo/Thales team under a Leonardo prime systems integration contract. Equipment integration onto the Shadow platform will be performed by Raytheon UK, with an initial operating capability targeted for early 2021. It is anticipated that all eight aircraft will receive the MAPPS DAS fit in due course.

Selection of the integrated Elix-IR/Miysis DIRCM combination follows on from a successful evaluation during the SALT III trials in Sweden last year. The contract marks the first sale of the Elix-IR IRTWS, and the first sale of the Miysis DIRCM into a UK customer. – *R. Scott*

THALES SECURES VIGILE D RESM CONTRACT

The Netherlands Defence Materiel Organisation has contracted Thales (Crawley, UK) to supply its Vigile D digital wideband radar electronic support measures (RESM) system for retrofit to Dutch and Portuguese warships.

Three systems will be installed as part of an equipment upgrade for three Royal Netherlands Navy vessels – the landing platform dock vessels, HNLMS Rotterdam and HNLMS Johan de Witt, and the joint support ship, HNLMS Karel Doorman. The remaining ship sets will be fitted to two Portuguese Navy M-frigates, NRP Bartolomeu Dias and NRP Don Francisco de Almeida, which are undergoing overhaul and upgrade in the Netherlands.

Vigile D is based on the Outfit UAT Mod 2.0 RESM already in service with UK Royal Navy warships. The wideband digital receiver system used in both systems has its roots in a UK research program known as Daphne, which was jointly delivered by Thales and the Defence Science and Technology Laboratory. – *R. Scott*

IN BRIEF

- The Royal Netherlands Army has selected BAE Systems Hägglunds to outfit its fleet of CV9035NL Infantry Fighting Vehicles with Elbit Systems' Iron Fist Active Protection System (APS). The APS is intended to detect, track and neutralize threats. Once added to the CV90s, the APS will allow for greater protection of the vehicles and their crews. BAE and the Dutch Army have been working since 2015 to test the feasibility and performance of the Iron Fist APS while integrated into the CV90. The first layer of soft-kill technology has been incorporated into the fleet of CV90s, and plans for the final APS installations are underway.
- Leonardo (Basildon, UK) has introduced two additions to its Guardian family of counter-improvised explosive device (C-IED) products. Guardian HFE is a responsive vehicle-borne C-IED jamming system based on a reprogrammable software-defined architecture. The system affords frequency coverage across the 20-MHz to 6-GHz frequency range, providing the ability to block the higher-frequency signals used by some cellular phone devices. Leonardo has also introduced Guardian HFE as a high-frequency extension for operators of existing vehicle-mounted C-IED systems such its own Guardian H3 system. Successfully trialed by the Italian Army in June this year, Guardian HFE can also be configured as an add-on to other third-party C-IED systems.
- South Korea's Defense Acquisition Program Administration (DAPA) is launching a $74 million-dollar (88 billion won) project to develop a laser weapons system to disable aerial threats. Named Block-I, the system will be designed to launch short-distance, precision strikes against unmanned aerial vehicles (UAVs) and other aerial targets. Completion and deployment of the Block-I system is slated for 2023.
- The UK Ministry of Defence (MOD) has chosen Leonardo to support a research and development (R&D) program that explores counter-drone technology through the evaluation of mature and developing technologies. The program will span three years, with the aim of understanding how current counter-drone capabilities meet the Royal Air Force's (RAF) needs to detect, track, identify and defeat UAVs. The program will consider how the RAF can combat current and evolving threats, and how counter-drone technology must be adapted for future needs. Leonardo's work on the program will begin in 2020 at the company's Basildon and Southampton, UK sites, with testing at MOD locations throughout the UK.
- Northrop Grumman Corporation (Rolling Meadows, IL) has been selected for continued support of the Royal Australian Air Force's (RAAF) Large Aircraft Infrared Countermeasures (LAIRCM) systems. Currently deployed on five aircraft types operated by the RAAF, the LAIRCM system detects missile launches, determines threats, and activates a high-intensity laser countermeasure system that tracks and defeats incoming missiles. The $96 million award to Northrop Grumman includes sustainment, repair, engineering, logistics and training support services for the LAIRCM system, as well as the AN/AAR-47 missile approach warning (MAW) system and the AN/APR-39 radar warning receiver (RWR). All work will be performed at Northrop Grumman's repair facility at the RAAF Edinburgh base, South Australia.

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Deb Norton, VP of F-35 Solutions, BAE Systems

This month, JED *talks with Deborah Norton, who is the Vice President of F-35 Solutions at BAE Systems Electronic Systems (Nashua, NH). After earning her master's degree in Mechanical Engineering from The Stevens Institute of Technology, she was selected for a program management position with the US Army. A few years later, she made the move to industry and in 1995, she joined BAE Systems where she began working on the company's EW programs. Today, her primary concern is managing the company's flagship program – the ASQ-239 EW system on the F-35.*

We sat down with Deb at her office in Nashua to discuss how she got her start as an engineer, her transition to BAE Systems and her career path in EW that led her to the F-35 program. We also talked about what the F-35 means to other programs at the company.

JED: Let's start at the beginning. How did you choose to become an engineer?

Norton: That answer is quite simple; my Dad inspired my career path. I am very proud of my dad; he worked for 40 years for the Air Force at Rome Labs and ended his career as the SES for that organization. In high school, I was strong in math and science, so he encouraged me to try engineering. In those days, we didn't have many resources to understand all the different career paths that are available. From my perspective, I enjoyed the engineering classes so I stayed with it!

JED: After earning your master's degree in Mechanical Engineering, what were some of your early roles in the field?

Norton: I started my career as a civilian with the Army working at Picatinny Arsenal in New Jersey. My first position was as a program manager working on the development and production of 30-millimeter ammunition for the Apache helicopter. Looking back, that role helped to influence my entire career. I really enjoyed the manufacturing side, especially the intricacies associated with producing high-rate ammunition.

My next move was with General Electric Aerospace primarily designing, developing, and producing electronic systems for many different military applications. At GE, I held a variety of different roles in producibility and process engineering along with factory management and operations leadership positions. GE Aerospace was sold to Martin Marietta and then Lockheed Martin, which led me to BAE Systems [then Lockheed Martin Sanders]. Since that first role at Picatinny, I have been able to combine my engineering background with roles focused on manufacturing, which I really enjoy. In my early career, I had several mentors who really helped encourage and guide me and helped to provide opportunities to grow – I truly appreciated their help and support.

JED: At BAE Systems, you began working on EW programs. How did these experiences help prepare you for your current role leading the company's F-35 program?

Norton: Two primary programs that I have worked on have really helped to provide the experience to ensure F-35 is successful today. First, F-22 [EW suite]. I worked on transitioning that program to production – going from development into production on highly complex hardware and ensuring the product is producible. From 2003-2008, I was working in program management on CMWS [AAR-57 Common Missile Warning System]. Early in that period, I was leading the completion of delivering the first 32 systems, and that was all the program was going to be because the Army was not interested in buying anymore. Extremely unfortunately, the Iraq War occurred, a CH-47 was shot down by a missile, and everything changed overnight. Instead of winding the program down, we were asked to ramp to 50 systems a month as quickly as possible, and that was a huge manufacturing challenge. The effect that the CMWS had on the warfighter is closely tied to our company motto: "We Protect Those Who Protect Us." Warfighters' lives were saved because our system worked flawlessly. I was so proud to be part of the team delivering the CMWS capability to the Army.

In 2008, I was asked if I wanted to work on F-35, which was extremely interesting to me, as it had both development and production challenges. Today, I've been on F-35 for 11 years; we are focused on affordability, aircraft availability and capability insertion. We were recently awarded Block 4, which will bring significant new capabilities to the aircraft. The excitement of F-35 is that it runs the full lifecycle; developing and inserting new technologies, ramping to rate and producing systems at production volumes that a fighter program hasn't seen in decades, and sustaining a global fleet to meet mission capability readiness requirements. The speed and pace of this program is second to none; I am truly blessed to be part of this program. I love my job!

JED: What does ASQ-239 program mean to BAE Systems?

Norton: BAE Systems is proud to be the electronic warfare (EW) leader providing a state-of-the-art EW System for the F-35 fifth-generation advanced fighter as it aligns with our mission: "We protect those, who protect us." It is a flagship program that allows us to develop and deploy cutting-edge technology. The footprint of 3,000 systems is huge from a manufacturing and sustainment perspective. BAE Systems has been able to invest over $100 million in state-of-the-art manufacturing capacity and facilities, and is the first supplier to be awarded a Performance Based Logistics (PBL) contract for sustainment of the F-35 fielded EW systems. The ASQ-239 is a system that will be in service for more than 30 years, and will provide a platform for continued EW capability development, not just for the F-35, but also for future EW platforms.

JED: Let's talk more about your career. As a woman entering an engineering field dominated by men, did you worry that your career path would be a struggle?

Norton: No, not really. As a kid, I spent my summers on a golf course playing mainly with boys, and in high school, I played on the men's golf team because there was no women's golf team. When I went to college for engineering over 35 years ago, my classmates were primarily men. I think the best way to put it is that I found a way to fit in. I believe that if you treat people the way you want to be treated, the majority of them do the same. I joined this industry during a very different time, and the majority of the people – both men and women – have been great to work with. Today, I enjoy being able to mentor the women on my team and share my experiences to make things I struggled with easier for them.

JED: Many people outside the engineering field think about it as "hands-on" design. But you seem to like the program management side of it more. What makes program management so attractive for you?

Norton: I love program management! You set the vision, you provide the leadership for the team, you help to develop the plan, you are responsible for cost, schedule and technical performance, and you work with the customers. It covers so many different aspects. The best part is proposing a program and then being able to execute and do what you set out to do in the proposal.

JED: What advice would you give to students who want to enter the engineering field?

Norton: I look at an engineering degree as the "liberal arts" degree for math and science. With the logical and creative problem solv-

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ing skills that an engineering degree provides, you can do so many different things – design, development, marketing, sales, production, and on and on. I encourage all aspiring and current engineers to step out of their comfort zones and get exposed to different opportunities to determine what they really love to do. We spend so much time at work, you should like who you work for, the people you work with, and you should love the work that you do. If you can find that, you will be very successful in your career.

I would also tell them that leadership, verbal and written communication, interpersonal skills and being able to work in a team environment are critical to your success. When I was in college, those kinds of skills were not even discussed. Today, they are required and integrated in everything I do.

JED: What would you do to encourage more young women to start STEM careers?

Norton: I would encourage them to learn about and experience the diverse ways that they can apply a STEM education. Working in science, technology, engineering or math in 2019 means using those skills as part of a team and in many different settings, and the opportunities continue to evolve. I think most people in high school do not understand that engineering careers are extremely versatile; most think they will be stuck behind a desk designing something. I think raising awareness on what engineers really do in "real life" would be eye-opening to many and draw more women into the field. As I mentioned earlier, engineering really is the liberal arts for math and science. Engineering trains you to be very logical and creative, and it can be applied to almost any profession. You can go the traditional route, or you can choose many other different career paths. I truly believe an engineering degree will give you a leg up on your competition.

Additionally, on day one of college in engineering, you're told to look to the right, then the left – two of you will be gone before graduation. Yes, engineering is hard, but I believe perseverance is a critical ingredient. Most people going into engineering do very well in high school; however, most people will not continue that level of excellence in a college engineering program. You will need to work hard for four years, and you will definitely learn humility. However, the doors an engineering degree open are worth the hard work. So, simply put: choose engineering – it leads to a great career with unlimited opportunities. Then persevere – it is worth the hard work and humility.

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More Than Mee

MFS-EW system provides the invisible

By Richard Scott

Now in advanced development for the air forces of Sweden and Brazil, Saab's next-generation Gripen E single-seat multirole fighter (Brazil will also receive a twin-seat Gripen F variant) represents a substantial evolution of the earlier Gripen C/D series. As well as the new and more powerful F414G engine, improved range performance and the ability to carry larger payloads, the Gripen E also introduces a new active electronically scanned antenna (AESA) radar, an infrared search and track (IRST) system, upgraded connectivity, and an advanced tactical system incorporating a high degree of sensor fusion.

Another critical part of Gripen E's genetic make-up is a new, fully integrated multifunction electronic warfare system, known as MFS-EW, which is being developed by Saab's EW business unit in Järfälla. Designed to provide both self-protection and situational awareness in complex electromagnetic environments, MFS-EW represents a substantial development in its own right (Sweden's investment in full scale engineering development being estimated at approximately $200 million). Accordingly, its design, engineering, integration, and test has required close working arrangements to be established between the MFS-EW team in Järfälla, Saab Aeronautics in Linköping and, as end customer, Sweden's Defence Materiel Administration (FMV).

To realize the high-end performance demanded of MFS-EW, Saab has engineered an integrated EW system architecture based around a number of leading-edge technologies, notably ultra-wideband digital receivers, digital radio frequency memory (DRFM) devices, gallium nitride (GaN) solid-state active electronically scanned array (AESA) transmitters, interferometric direction finding and very high speed signal processing. These same technology "building blocks" are now being applied by the company to a broader airborne EW portfolio known as AREXIS.

GENESIS

As so often occurs, the spur for a brand new development came from a prior failure. In the case of MFS-EW, it was Norway's decision in 2008 to select the Lockheed Martin F-35A Lightning II as its next fighter in preference to Gripen. "They [Norway] selected another fighter to meet their needs," Kristoffer Broqvist, Project Manager Survivability and EW for Gripen E in the Swedish Defence Materiel Administration (FMV), told the EW Europe conference in May. "We wanted to understand the reasons for their decision.

"While we disagreed, or didn't understand, in many areas, it was clear to us that they weren't happy with the EW solution offered with the Gripen as it looked in 2008," he continued. "We did our own thorough evaluation, and decided Norway was right – we didn't like it either."

Saab had in fact flown an advanced two-seat Gripen demonstrator in 2008. This was a Gripen D rebuilt in order to demonstrate and de-risk new technologies, notably the F414 engine and ES-05 Raven AESA radar, to be embodied in a nascent Gripen NG variant being promoted to potential export customers.

However, Swedish requirements for a next-generation fighter EW suite were at that stage undefined. As a result, a series of operational analysis studies were set in motion across the Swedish Air Force (Flygvapnet), FMV and the Defence Research Agency (FOI) to map out EW capability requirements from 2025 out to around 2040. Additional studies were placed with industry.

What became evident was that the changed strategic environment had raised the bar in terms of EW performance requirements. "The system on the Gripen C/D is very capable, but it was designed back in the late 1990s," said Petter Bedoire, Saab's Chief Technology Officer. "Back then, there was a big focus on Swedish participation in international operations. So the key drivers were interoperability with NATO, and a high degree of self-protection. Also, the RF threat-set at that time was primarily legacy systems."

Outputs from the analyses performed by the Flygvapnet, FMV and FOI gave an

ts the Eye

shield for Gripen E

insight into a very different, and much more demanding, future electromagnetic environment. For example, the threat set in the east was fast evolving in the shape of systems such as the S-400 Triumf air defense missile system (NATO reporting name SA-21 Growler) and the Sukhoi Su-57 PAK-FA fifth-generation fighter.

It became clear that a new fighter would require an advanced integrated EW suite that could handle increasingly complex signal environments, provide increased frequency coverage and waveform detection, much improved threat accuracy and geolocation, and generate advanced electronic attack (EA) responses. "What we recognized was that we were looking at a completely different operational scenario," said Bedoire. "We could see that our neighbor to the east was rebuilding. And, we could see a substantial increase in the [double-digit] RF threat."

In his address to EW Europe 2019, Broqvist used Defensive Counter Air as an exemplar for the capability demanded of the Gripen E EW suite. "We would initially seek to deny or degrade the situational awareness of the enemy by jamming surveillance radars," he said.

The MFS-EW system will equip Saab's new-generation Gripen E multirole fighter. SAAB

"We would also seek to do the same to their target-acquisition radars.

"We would aim to destroy the distributed picture. That forces low-observable platforms to go active so we can find them. If the enemy manages to shoot, then we shall counter that too. And, we must do that against multiple simultaneous threats."

Broqvist continued: "We want to be able to coordinate jamming within a group [and] use cooperative EA techniques against the same threat radar. But we must do this while maintaining our own situational awareness and minimizing pilot workload."

PROPOSALS

Industry was asked to come up with proposals for a new EW suite. In the early stages, Saab's EW business unit worked together with Italy's Elettronica. "At that time, there was a Swedish/Italian research and development cooperation on AESA technology known as M-AESA [Multi-role Active Electronically Scanned Antenna]," explained Bedoire. "So, Elettronica was invited to participate in those MFS-EW pre-study activities."

Working in partnership, Saab and Elettronica came up with a proposal that sought to evolve from the two companies' respective experience on Gripen C/D and Eurofighter. "We designed what we considered to be a very capable system based on existing technology," Bedoire explained. "For example, we took a modified AESA jammer antenna, adapted from the system previously developed by Elettronica for Typhoon, and beefed this up with DRFM technology from Gripen C/D."

However, these initial proposals were not well received by FMV or FOI. "We were quite taken aback," admitted Bedoire. "Our feeling had been that the technology in the existing Gripen EW system was pretty good, and that it offered the basis for evolution.

"But FMV and FOI wanted a more advanced and high-performance approach in terms of both technology and architecture. It meant moving away from a largely centralized system, and moving instead to a more distributed but still highly-integrated architecture."

This elevated level of ambition saw Saab's take a more radical approach to what became MFS-EW. At the same time, it required Saab Aeronautics to give much greater consideration as to how the various EW subsystems would be engineered into the internal and external design of the next-generation Gripen airframe, and to the integration of the EW suite into the new mission system architecture.

"From a technology standpoint, we were looking at a range of new technologies that were now coming to maturity," Bedoire said. "So, that meant a wide-open, fully-digital receiver architecture, direct sampling of incoming signals, broadband antenna elements and high-precision parameter measurement. It also meant that Saab would part company with Elettronica, and that the active jamming component of the system would become Saab's responsibility.

The move to a distributed architecture meant that much of the processing would occur as close to the antenna units as possible. "You still have an EW central unit [EWCU] in the main equipment bay," said Bedoire, "but that is purely for coordinating those functions that require inputs from all of the wingtip quadrant receive and transmit antennas.

"Of course, integrating this new architecture into the Gripen airframe also became a priority for our colleagues in Saab Aero," he added. "The new elongated wingtips challenged the aerodynamicists, we needed sufficient isolation between the various antennas, and there was also the need to get cooling fluid and services to the wingtip antenna stations."

By 2011, according to FMV's Broqvist, the way ahead was becoming clearer. "We worked with industry to study lots of different internal and external configurations [to understand] for example, the best siting for receivers and techniques generators. Each was evaluated on the basis of performance, feasibility, cost and risk," he said. "A configuration was recommended fairly close to what was finally embodied."

However, all the while that the nascent MFS-EW suite architecture was taking shape, Saab Aeronautics was pursuing a major opportunity for Gripen NG in Switzerland in competition with Dassault's Rafale and the Eurofighter Typhoon. At the end of November 2011, the Swiss government selected Gripen NG to meet its requirement. (Contract terms were agreed by the Swedish and Swiss governments in August 2012, and in August 2013, the Swiss parliament gave its approval for the Gripen E deal. However, in May 2014, the 22 aircraft program was voted down in a national referendum.)

Saab's success in Switzerland (although short-lived) was a huge spur to the Gripen program (subsequently re-cast as Gripen E/F), and prompted the Swedish government to advance its plans to procure Gripen E for the Swedish Air Force. Yet, it was also a fact that the full definition of the Gripen NG had at that stage not been completed.

"By the middle of 2012, we had a recommended configuration and a loose set of requirements, but no official assignment," Broqvist recalled. "And then, the decision came [from government]

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to take the program forward. We were asked to agree and sign a contract [with Saab] in just three months. Actually, it was more like two months because the government needed a month to take the program through its approval process."

He continued that, "It would be impossible to agree to a full and detailed requirements-based specification in that time. But, we knew from previous experience that simply defining a few high-level requirements was not going to be sufficient.

"So, we went for a middle way. We pinned down the detailed requirements only where it really mattered, and left open those aspects where the potential performance remained unknown during the negotiations, deciding that it would be possible to further detail and specify the requirement in a post-contract definition period."

"For that to work meant we had to have trust in our industry partner," said Broqvist.

Bedoire agreed. "We simply didn't have time to agree to a detailed specification before committing to the contract. So, it was a question of signing up to some key contract elements, and accepting there was a lot of detailed deliverables still to be defined. It relied on the trust between FMV and Saab post-contract."

MFS-EW hardware for MS 21 has been qualified, and the system is now flying on Gripen E development aircraft 39-9. SAAB

PERFORMANCE DRIVERS

One of the big drivers for the MFS-EW performance specification was the requirement to not only contribute to Gripen E's situational awareness, but to also act as a target-acquisition sensor. "The Swedish Air Force wanted to use this platform in a silent or passive mode," said Broqvist. "One part of that was the decision to introduce an IRST, and there are also passive radar modes available. But, there was additionally an increased requirement on the EW suite for [measurement] accuracy and geolocation."

This drove a very advanced radar warning receiver (RWR)/electronic support measures (ESM) solution based on a wide-open, fully-digital receiver architecture offering a very high probability of intercept and direct sampling of

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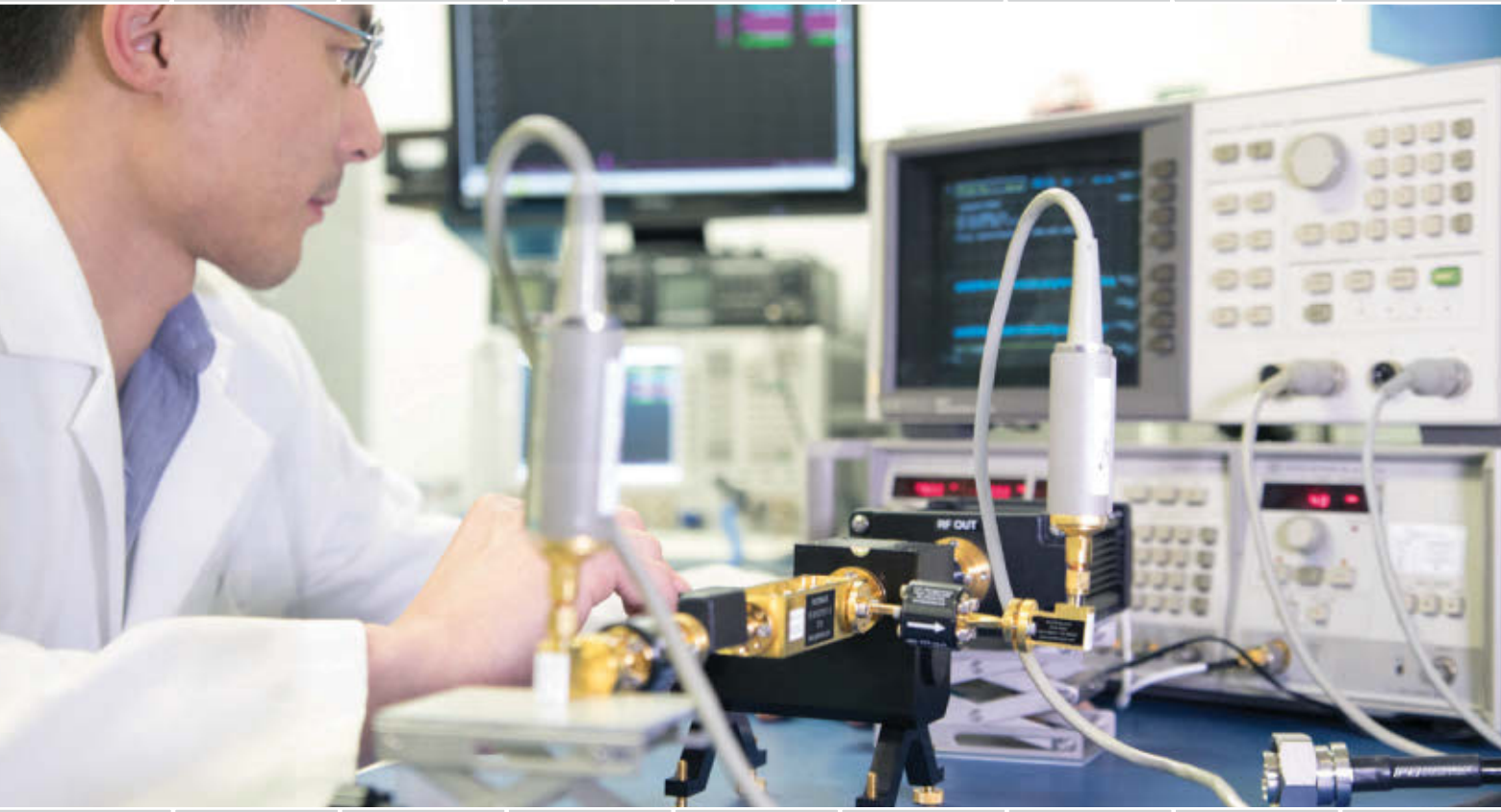

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incoming signals. "On Gripen C/D, the RWR system is based on amplitude monopulse direction finding techniques," said Bedoire. "But on Gripen E we have gone for an interferometric approach in order to achieve fully-spherical precision DF even when performing high-g maneuvers.

"The system functions as a warner to cue countermeasures and jammers, but it also incorporates full ESM functionality. So, with increased dwell time, it can perform precise targeting with much more detailed parameter measurement.

"Also, the system is constantly sampling the electromagnetic environment. This means a vast amount of data is recorded for post-mission analysis and emitter-database support."

The Gripen E requirement also specified the need for a missile approach warner (MAW). In this case, explained Bedoire, the demanding nature of the performance requirement resulted in the decision to procure a third-party solution. "We had actually performed some demonstrations of ultraviolet [MAW] in the Gripen NG demonstrator program, but it turned out that UV technology did not meet the requirements for post-burnout missile detection. As a result, the decision was made to go for an infrared [MAW] solution."

Following a comprehensive in-depth evaluation, testing in various scenarios, and a comparative live-fire test, the decision was made in favor of the PAWS-2 system from Elbit System in Israel. The embodiment into the Gripen E comprises six MAW sensor units, plus a central MAW processor.

In terms of self-protection, the single biggest innovation in MFS-EW is the adoption of GaN-based AESA transmitters for the jamming subsystem. Mid-band transmitters are located in the wing tip "quadrant" stations, while the low-band transmitters are positioned atop the fin to cover the fore and aft sectors.

"The wideband DRFMs for jamming are built on the same technology as the digital receiver," said Bedoire, adding: "Saab's radar business in Gothenburg was already developing GaN AESA technology. What we had to do was take this narrow-band antenna technology and adapt it to the wideband [frequency coverage] required of the MFS-EW system.

"While it is outside the direct scope of MFS-EW, we also consider the nose aperture [the ES-05 Raven radar] to be a very good AESA for a jammer. The aircraft's mission system architecture takes account of that."

The potential integration of a towed radar decoy was dropped early on, but new expendable countermeasures dispensers are being introduced. The Gripen E will feature four BOP-G pyrotechnic dispensers (three upward firing in the right wing root, one downward firing from the rear fuselage) plus four BOL-700 dispensers integrated into underwing pylons.

The latest iteration of the BOL line, the -700 series system has been designed to retain full commonality with existing RF and IR BOL payloads, but the package-dispensing equipment is internal so as to have no impact on the radar cross section (RCS) or aerodynamic performance of the host aircraft.

BOL dispensers use an electromechanical drive mechanism that feeds the RF and IR payload packs (adopting

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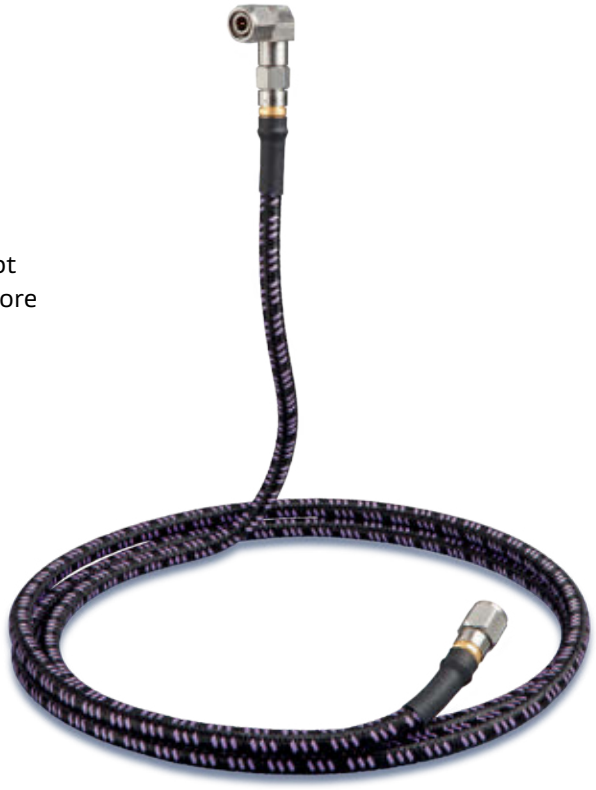

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a 2 x 3 x 0.25-inch "flat-pack" form factor) towards the back of the dispenser where, one pack at a time, they are separated from the stack and released into the airstream. Chemring Countermeasures manufactures BOL Mk 2 Type 1 chaff packs, while US-based Chemring subsidiary Alloy Surfaces produces the MJU-52/B and L5A2 BOL-IR pyrophoric or "activated-metal" decoys.

BOL-700 adopts a revised ejector mechanism that dispenses countermeasures sideways (rather than aft) through the boundary layer and into the airstream.

According to Christer Zätterqvist, Saab's Head of Product Management CMDS, the eject port is covered by a 3-inch hatch, which opens only when countermeasures are being dispensed. "The hatch is designed such that it will keep drag and RCS to a minimum without affecting the performance of the BOL countermeasures," he said. "The sideways dispense mechanism itself has been patented by Saab."

Saab began full scale engineering development of BOL-700 in early 2014 after selection for the Gripen E program. The BOL-739 variant – "39" as the identifier for the JAS-39 Gripen – will be fitted into pylon extensions (two under each wing).

"We began test flights of the -739 on a JAS 39D two-seat testbed in the third quarter of 2018," Zätterqvist said. "Both IR and chaff payloads have been deployed and dispensed.

"We are continuing flight testing in different flight regimes [such as speed and g-loads]. Because there are no air scoops [acting as vortex generators], dispensing sideways presents some different challenges in terms of airflow, but our plan is to qualify BOL-700 by the end of this year."

Bedoire added, "The BOP-G dispensers will dispense standard '218' format expendables. As well as chaff and flares, expendable active decoys, such as 'BriteCloud,' could be included."

DEVELOPMENT PATH

A major challenge for the MFS-EW program has been to keep close watch on the changes in the threat, and advances in technology, which have occurred during the course of the fixed-price development program. "This is a long project," said Broqvist, "with approximately 10 years from contract to delivery on the front-line.

"The system was designed with hardware two generations in the future in mind. But, there was inevitably some 'guesswork' as to where the peer competition would be. So, we have been continuously assessing if the requirements are correct, given that we negotiated the contract some years ago.

"We have been continuously evaluating the design, for example, by testing noise jamming and false-target generation in the EMC chamber," he explained. "As a result, we have done two large 'balancing-of-requirements' events to reflect change. But, on a fixed budget, we had to take something out to put something in. And, of course, the 'window' to change is decreasing all the time as we approach the end of development."

Broqvist added, "You can't put requirements for everything into such a complex system, and there is more to getting an operationally relevant system than just formal requirements. So, we are working very closely with industry to clarify the actual operational needs behind the [system] requirements."

For Saab, the rapid contracting process meant that there was no time to build technology demonstrators to de-risk key subsystem technologies. "We had done some internal work on direct sampling receivers, but the way this program came together in a hurry meant there was simply not time," said Bedoire. "It has added some cost to the program, but, at the same time, it has forced us to work at pace from day one."

TEST AND TRIALS

Initial deliveries of Gripen E to the Swedish Armed Forces are planned to take place in 2021. When the aircraft enters service, it will be with the mission system at MS21 standard. In this initial configuration, only the passive [RWR/ESM] functionality of MFS-EW is enabled; the full configuration, with AESA jamming functionality, will follow in MS22.

Pre-production systems are currently being tested in ground rigs in Järfälla and Linköping, and in flight test on two

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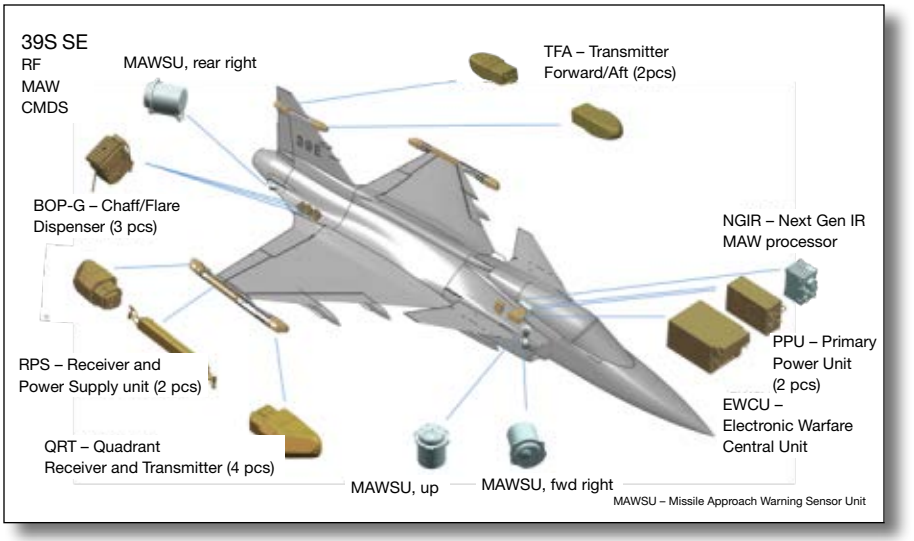
Gripen E development aircraft. "Hardware for MS21 has been qualified, and the system is now flying on 39-9 and 39-10," said Broqvist. Added Bedoire, "The performance of the system at this stage looks amazingly good – we have been very impressed by what we have measured. We are reading through lots of data to see if the installed performance matches the requirement. Right now, we are exceeding it."

As regards MS22, the AESA hardware central to the MFS-EW block upgrade is entering qualification. In-service Gripen E aircraft will be modified by means of an upgrade kit; later new-builds will come off the line with MS22 embodied.

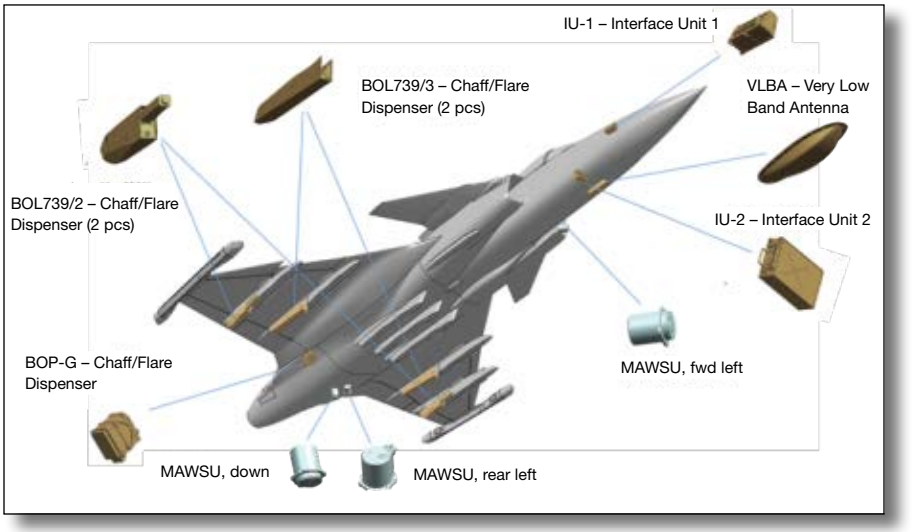
Cooperative jamming – in which a group of aircraft employ coordinated techniques against a specific threat – is one important capability that will be realized in due course. "FOI has performed a lot of simulations and studies," Bedoire noted. "The ability for multiple Gripen E aircraft to employ coordinated electronic attack techniques will be extremely useful to counter the jamming resistance built into opposition threat radars. The [MFS-EW] system is fully prepared for this capability, which will be enabled through the aircraft tactical system and data links."

While early testing has demonstrated promise, it is recognized that integrating MFS-EW with the complete tactical system presents a more difficult task. "Perfecting that integration will be challenging," said Broqvist. "That work is still to be finalized."

According to Bedoire, integration efforts are already starting using a development environment integrated to Linköping. "This means that any flaws in the interface can be corrected overnight," he explained. "What is important to remember is that the Gripen E systems architecture partitions the tactical system from the flight control software. That's a real game-changer because it means that new or updated functionality can be introduced without the need for expensive and time-consuming re-qualification of safety-critical flight avionics. So, we will continue to evolve the MFS-EW system after delivery of MS22."



MFS-EW has adopted an integrated system architecture based around a number of technology building blocks, notably ultra-wideband digital receivers, DFRMs, GaN solid-state AESA transmitters, interferometric direction finding, and very high speed signal processing. SAAB



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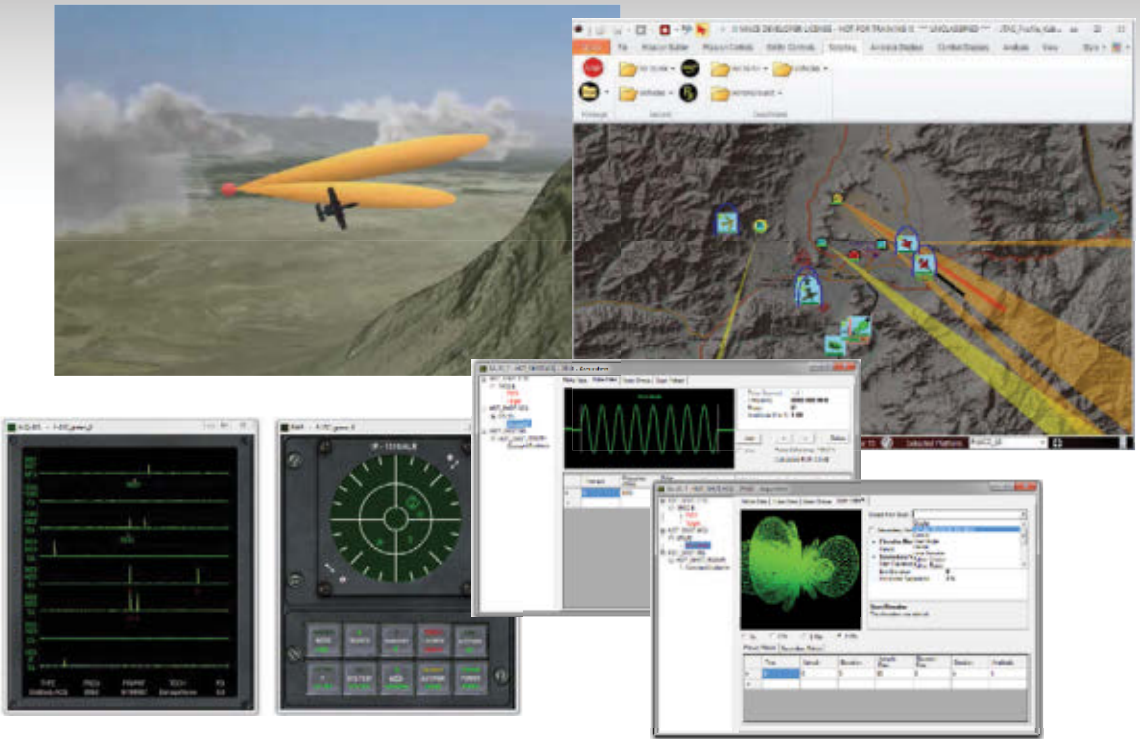

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AREXIS DEVELOPMENT

Saab's EW business unit has sought to leverage Sweden's investment in MFS-EW by developing a wider portfolio of airborne EW under the family name AREXIS. "Through this program, we have been able to mature a series of 'building blocks' based on the latest available technology," said Peter Bedoire, Saab Vice President, Head of Marketing and Sales. "So, as well as producing the MFS-EW systems for Sweden and Brazil, we are now also proposing scaled solutions for platforms other than Gripen."

Another key component of the AREXIS family is a new escort-jamming pod that is intended to provide strike packages with an airborne electronic attack capability to defeat early warning radars. "You need high-powered electronic attack to deny shared situational awareness and targeting data, and to negate data networks," said Jonas Grönberg, Saab's Head of Marketing and Sales for Emerging Products for Fighter EW. "The AREXIS escort jammer pod has the capability to screen, and so protect, the approach and departure of entire strike formations against lower frequency radars by the smart utilization of DRFM-based jamming techniques, such as smart noise, coherent false targets and various saturation techniques."

Saab took the decision in 2017 to self-invest in the build of a prototype system, with the assembly and integration of the demonstrator pod completed at Järfälla at the start of 2019. "This is a pre-production model, covering the L- and S-bands, designed for a limited number of flight hours, and a limited flight envelope," said Grönberg. "But, it will allow us to prove the product engineering with regard to issues such as packaging, cooling, power supply, radome performance, and power levels.

Mock-up of the AREXIS escort jammer pod. A prototype system will begin trials at the end of 2019. SAAB

"We had the system in [anechoic] chamber testing less than 18 months after starting development. That was only possible because of our previous development of higher frequency AESAs for the Gripen program."

Ground trials of the escort jammer pod prototype began in April. According to Grönberg, flight testing is planned to follow at the end of 2019 on a Gripen D aircraft.

As well as the Gripen family, Saab is pitching the AREXIS escort jammer pod at other fast jet platforms, with Typhoon already identified as a key target platform. – *R. Scott*

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P2T-0R5G8G-45-R-SFF-50W-SM https://www.pmi-rf.com/product-details/p2t-0r5g8g-45-r-sff-50w-sm	0.5 - 8	3.0	30 Min	100 ns	50 W CW	+5 VDC @ 32 mA	1.20" x1.0" x 0.5" SP2T Reflective SMA Female
P2T-500M10G-60-R-515-SFF-10WCW https://www.pmi-rf.com/product-details/p2t-500m10g-60-r-515-sff-10wcw	0.5 - 10	2.5	60 Min	100 ns	10 W CW Max	+ 5 VDC @ 38 mA -15 VDC @ 43 mA	1.20" x 1.00" x 0.5" SP2T Reflective SMA Female
P2T-1G1R1G-25-R-SFF-100W-SM https://www.pmi-rf.com/product-details/p2t-1g1r1g-25-r-sff-100w-sm	1 - 1.1	0.8	25 Min	250 ns	100 W CW, 5 kW Peak	+50 VDC @ 10 mA +5 VDC @ 128 mA	3.25" x 2.75" x 0.7" SP2T Reflective TNC Female
P2T-1G18G-10-R-528-SFF-HIP10W https://www.pmi-rf.com/product-details/p2t-1g18g-10-r-528-sff-hip10w	1 - 18	4.0	10 Min	100 ns	10 W CW	+5 VDC @ 2.19 mA, -28 VDC @ 2.5 mA	1.2" x 1.0" x 0.5" SP2T Reflective SMA Female
P2T-1R2G1R4G-25-R-SFF-250W https://www.pmi-rf.com/product-details/p2t-1r2g1r4g-25-r-sff-250w	1.2 -1.4	0.8	25 Min	250 ns	250 W Peak	+30 V @ 50 mA, +5 V @ 200 mA	4.22" x 2.98" x 0.7" SP2T Reflective SMA Female
P2T-6G18G-40-R-570-TFF-1D6KW https://www.pmi-rf.com/product-details/p2t-6g18g-40-r-570-tff-1d6kw	6 - 18	2.2	40	1.1 µs	1.6 kW Peak - Tested to 125.89 W CW	+ 5 VDC @ 300 mA -70 VDC @ 60 mA	2.0" x 2.0" x 0.75" SP2T Reflective TNC Female
PDT-8G12G-40-515-SFF https://www.pmi-rf.com/product-details/pdt-8g12g-40-515-sff	8 - 12	2.0	40 Min	200 ns Max	40 dBm CW, 57 dBm, 1 µs, 1% DC	+5 VDC @ 100 mA -15 VDC @ 60 mA	1.25" x 1.25" x 0.3" SP2T Reflective SMA Female
P2T-8G18G-50-R-SFFF https://www.pmi-rf.com/product-details/p2t-8g18g-50-r-sfff	8 - 18	3.0	50 Min	200 ns	40 W Max, 300 W Peak	+5 VDC @ 150 mA, -28 VDC @ 80 mA	1.55" x 2.3" x 0.5" SP2T Reflective SMA Female


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Cognitive/Adaptive Learn Continuous Advancemen

By John Haystead

In what has been a continuous cat-and-mouse game between radar and EW system developers, the competition between countermeasure and counter-countermeasure advancement has never been fiercer. Digital RF Memories (DRFMs) have become essential elements of both modern radars and EW systems, often dueling it out in terms of which application can more rapidly field ever more sophisticated capabilities. Today, driven by the realization and implementation of artificial intelligence and cognitive/adaptive learning capabilities in both sectors, DRFM technology is being continuously challenged to provide greater and greater performance and processing power.

As described by Chris Rappa, Technical Director at BAE Systems' FAST Labs (Nashua, NH), DRFMs are not new, and have been a part of EW self-protect and electronic attack (EA) for decades. "The capability to digitally capture radar signals, modify them and transmit them back has been around since the 1980s, but what made this so challenging in the past was the requirement for very expensive RF microwave components, as well as the need for very large frequency coverage and rapid signal tailoring, to ensure that the radar was not able to recognize your return signal as a countermeasure." Today's radar systems are looking at even more spectrum, which means that EW system DRFMs must also cover larger bandwidths but, says Rappa, digital signal processing capabilities have also at the same time evolved exponentially, "allowing us to capture much wider bandwidths, longer waveforms, and much more."

Rappa points out, however, that the threat systems have also gained the same advantages from digital processing improvements. "The technology on both sides has been accelerated by commercial investment and advancements in digital technology." In addition, he observes that "the cost and size of microwave components has also gone down significantly, making it much cheaper for both radar and EW makers to build many more channels and add capabilities to their systems."

Brian Hood, Director and Manager for the Gryphon EW System product line at Mercury Systems (Andover, MA), agrees, pointing out that the radar world's counter to the countermeasure of DRFMs, or electronic protection (EP), has been to evolve both the variance and frequency agility of their output pulses. "That variance can be pulse-width, pulse shape, frequency, modulation, etc., and we expect to see even more pulse variance over greater frequency bandwidth in future."

To continue to function against such EP approaches, Hood says DRFMs must also continually improve to the point where they can operate at this next level. "Just as they have capabilities on the EP side, we have to be able to match and replicate their signals with extremely low latency. There are different things we can do on a DRFM return, such as modulating their pulse in frequency or power, or if they're getting data out of the pulse itself, by doing additional wavelet modification and modulation. But, although we have, in fact, modified the signal, we must also return it in a way that it will be received undetected." Hood emphasizes that radars are continuously modifying their transmitted pulses, and that every pulse is unique, changing in fre-

"We're now really starting to see a much more rapid counter-to-counter loop in the radar/EW cat-and-mouse game that we have to sustain. This is where things like extreme learning, cognitive/adaptive and artificial intelligence (AI) come into the picture."

BACKGROUND IMAGE: ISTOCK.COM/MISTERSUNDAY

ing Requirements Drive t of DRFM Technology

quency, shape, width, power, etc. "Still, the modified DRFM return must be seen as their original pulse, which means we have to do this with extremely low latency and precision."

DRFM HARDWARE TECHNOLOGY

To deal with threat radars' increasingly complex pulse variance and frequency agility, EW DRFMs require extremely fast and precise wideband digital synthesizers. But, as Hood points out, "It's not a specific component that provides the solution, it's a complete system. It's not just the speed and accuracy of A/D or D/A digital conversion, it's also keeping up with the radar's movement in frequency." As he says, the difference between the military's requirement for extremely low latency in order to make undetected modifications in real time – as opposed to that of a cell phone or Wi-Fi spread spectrum network, where data is just being moved in an out – explains why most available commercial hardware is not designed for the environment.

According to Nick Koranda, Director and Product Line Manager for Mercury Systems' Gray Hawk Line, "In terms of the tuning speed within a DRFM, it really comes back again to getting ahead of the technology of any potential adversary. We're trying to look at a broader and broader spectrum, while radars are doing the same, so the faster

Advanced DRFMs are essential in any modern EW system. The US Air Force is expected to upgrade most of its F-15s with the Eagle Passive Active Warning Survivability System (EPAWSS), which is based on the ALQ-239 Digital EW System (DEWS) from BAE Systems. US AIR FORCE

SWaP-C is an essential consideration driving DRFM technology. On the left is a mid-1990s MU-679C DRFM unit for an SLQ-32 system. On the right is an example of current DRFM technology, the RFM3101 3U Wideband Microwave Transceiver from Mercury Systems. GOVPLANET AND MERCURY SYSTEMS

that we can move the RF the better. We've reached a point where, if we miss the first pulse that we're tuning, the radar will see that we missed it, and our return will become suspect."

Koranda says Mercury Systems is focusing heavily on direct digitization to address this challenge. "By moving directly to digital, you no longer have to take the time to identify where signals are in an environment, and then move your RF converters or transceivers to it. Direct capture allows you to immediately begin digital signal processing, and to address low latency by removing any kind of delay occurring while passing through the RF converters."

In addition to low latency, another discriminator between the requirements of commercial applications and military DRFMs is size – an increasingly important factor with the desire to achieve digitization closer to the antenna. In regard to this, Hood references what Mercury Systems refers to as its Integrated Microwave Assemblies (IMAs). "These are extremely small packages that can be placed either on a standard open-architecture card size, or can be built specifically as an assembly for size-limited applications, such as a missile guidance system or at the back of an antenna. They can provide not only an RF tuning or EP capability, but can also be applied to provide digitization and/or other storage capabilities based on some of the latest technology that can be put in these rugged packages."

Adds Koranda, "One of the things that directly relates IMAs to DRFMs is that, in the technology race that we're in, minimizing size, weight, power and cost (SWaP-C) is critical. So, if you can put more technology in the same form factor, then that is a technological advantage in and of itself, providing more capability than a potential adversary can achieve. Smaller and smaller packaging, along with direct digitization, all add capability and provide advantage." Hood sums up the current requirement saying, "Smaller packages, faster responses and vast volumes of low-latency compute power define modern DRFM evolution."

Gryphon and Gray Hawk are the internal names used by Mercury Systems for the two developmental EW product lines managed by Hood and Koranda respectively. The Gryphon line is directed at training and testing applications where, as described by Hood, the

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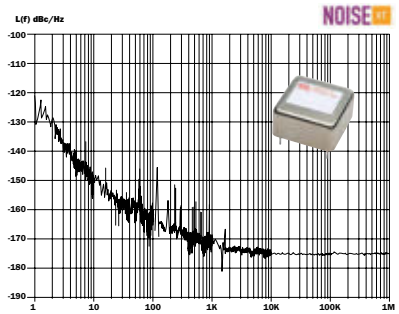

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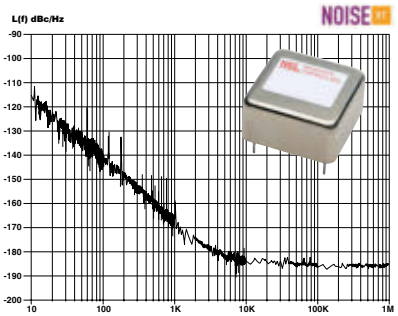

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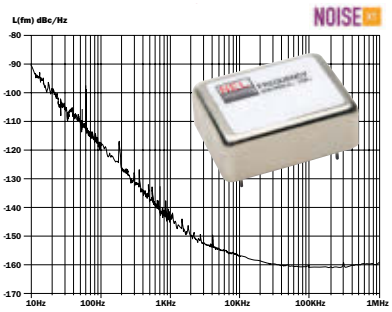

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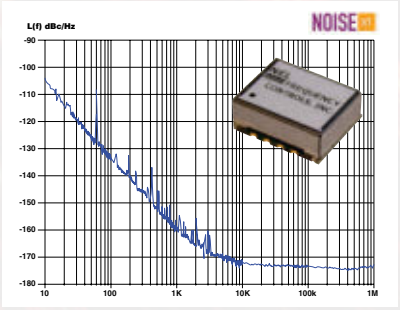

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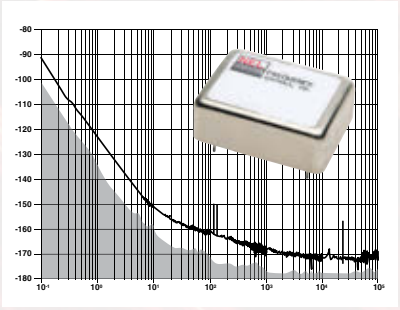

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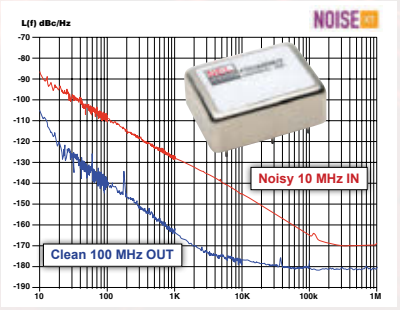

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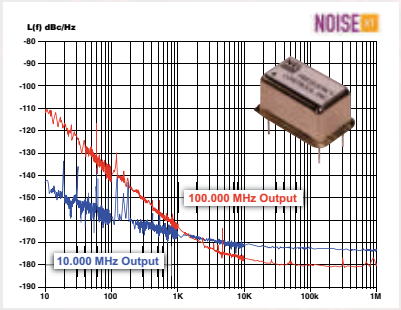

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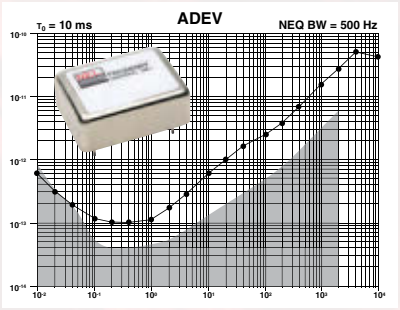

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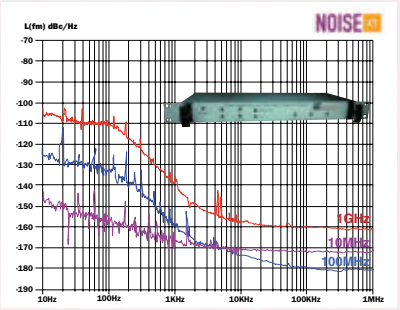

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technology is being used by the military in its combat environment simulations. Says Hood, "For the Gryphon EW line, we're actually the trainers and testers for our own military forces' radars (aircraft and ground), emulating an adversary and where we think that adversary is going. The pilots that are flying the aircraft are not only testing their equipment, they're testing their tactics as well."

Gryphon grew out of Mercury Systems' Modular Digital Receiver Exciter (MoDREx) technology, described in the company's literature as a "suite of flight-qualified subassemblies with capabilities researched and demonstrated under Navy SBIR N06-036 Advanced Techniques for DRFMs. MoDREx emitter filtering separates multiple emitter signals and adaptive technique generation responds to emitter changes, while providing specific responses to specific emitter signals. It's a scalable solution for applications ranging from simple single-threat/single-response environments, to complex and sophisticated multi-threat/multi-response environments."

The MALD-J from Raytheon use DRFMs to create false targets and disrupt enemy integrated air defense systems. RAYTHEON

Says Hood, "We've been building DRFMS for testing and training for Navy and Air Force aviation for decades, and MoDREx was an initial step in moving forward with Gryphon. It was basically a multi-channel system offering that allowed us to be fairly wideband, but not as wideband as we are now, or where we're going."

The Gray Hawk product line is also a developmental effort, but is targeted for tactical response applications and protection of ships, vehicles, and aircraft. According to Koranda, "The plan for the

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Gray Hawk line is to be our own integrated EW system, as well as a capability that could be integrated into a larger system by a prime. The vision is that it be an open system that can be used across a lot of different applications, including as an internal system. We have a framework that is somewhat hardware agnostic, so we can use multiple vendors hardware if needed, and we have an abstraction layer that allows for the rapid development of applications."

BAE Systems' Rappa emphasizes that his company doesn't provide DRFMs per se, but rather integrated, digital EW systems. "We don't look at the challenge as just having a better DRFM, but rather as providing holistic survivability approaches to RF countermeasures that include improved ESM and improved situational awareness in a tight coupling with additional EW countermeasure capabilities." In conjunction with its partners and suppliers, BAE builds most of its system componentry end-to-end. "We don't purchase DRFM technology directly, but rather we purchase component technology that we integrate into our EW systems to include DRFM technologies."

Going forward, Rappa sees RF hardware increasingly becoming a commodity item. Still, he adds, that when and where they have extreme performance requirements in SWaP-C, they are indeed building custom chips. "In most cases, it's a question of using those custom chips where you need them and commercial parts where you can get away with them."

In the context of DRFM requirements, one hardware technology area that BAE is focusing on is high-performance RF signal conditioning and filtering and moving this functionality to ICs. In collaboration with the Defense Advanced Research Projects Agency (DARPA), the company's FAST Labs developed its Microwave Array Technology for Reconfigurable Integrated Circuits ("MATRICs") RF-FPGA transceiver. As Rappa describes it, "It's really a library of mixed-signal IC technologies taking a lot of the traditional RF componentry and putting it inside ICs that significantly improves performance where performance is measured as both key performance parameters as well as (SWaP-C)."

BAE is also investing in compound, wide-bandgap semiconductor technologies like gallium nitride (GaN), particularly GaN on silicon carbide (SiC) technologies. In October, BAE Systems announced that it had completed a Phase 1 effort to transition short-gate GaN semiconductor technology developed by the Air Force Research Laboratory (AFRL) (Wright-Patterson, AFB) to its Advanced Microwave Products (AMP) Center. The company's FAST Labs and the AMP Center were also selected for Phase 2 of the program, which according to the announcement, will collaborate to further develop and advance the readiness of the technology. "Specifically, the project will scale the 140-nanometer GaN monolithic microwave integrated circuit (MMIC) technology to 6-inch wafers and increase its manufacturing level of maturity as part of the validation process, which will include optimizing performance, ensuring process stability, and maximizing wafer-to-wafer uniformity and wafer yields." At the end of Phase 2, the technology will transition to a foundry service product, available through BAE's open foundry service.

ADAPTIVE/COGNITIVE TECHNOLOGY FOR DRFMS

Even as DRFM technology advances to keep pace with the capabilities of the threat on both sides of the radar/countermeasure equation, a new, even greater, technology demand is looming – one that promises to challenge solution providers at an entirely new level, and one that can be expected to remain an increasingly difficult challenge *ad infinitum*.

Says Mercury Systems' Koranda, "We're now really starting to see a much more rapid counter-to-counter loop in the radar/EW cat-and-mouse game that we have to sustain. This is where things like extreme learning, cognitive/adaptive and artificial intelligence (AI) come into the picture. Some of the radar systems out there are changing so rapidly that the existing counter-to-counter loop just doesn't support the requirement anymore from a timeframe standpoint. Now, we're asking, 'How do we incorporate these AI technologies

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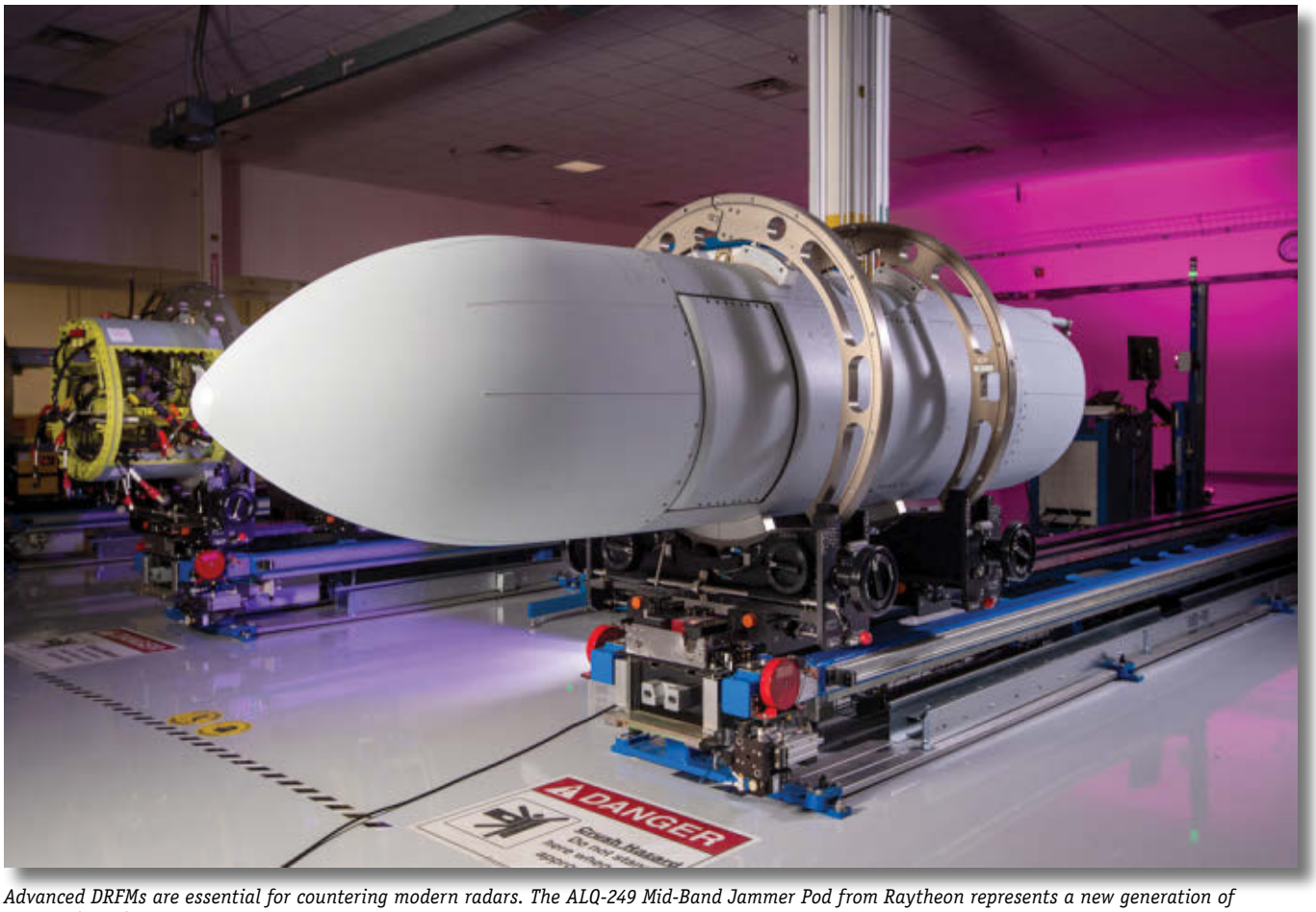

Advanced DRFMs are essential for countering modern radars. The ALQ-249 Mid-Band Jammer Pod from Raytheon represents a new generation of support jamming systems. RAYTHEON

so that the counter-to-counter loop is actually within the system itself?'–systems that can look at the variations in waveforms and spectrum and make decisions on their own on how to best counter a particular threat, as well as evaluate their level of success, and learn from that. DRFMs play a critical role in this."

BAE's Rappa says the solution ultimately resides in the software and firmware of a system. "The reality is that when you look at what makes a DRFM a DRFM, there's really very little difference from a software defined radio (SDR). Modern systems are all software- and firmware-based because the hardware costs have gone down, and that's

true for most threat systems, as well. So, in order to counter a software/firmware based threat, you have to have a software/firmware-based DRFM. Otherwise you'll always be behind the development curve."

Software-based solutions are also the only practical way to keep pace with the ever-more-rapidly changing software-based threats. Says Rappa, "With all of these advancements in software, threats can be modified on a faster timeline, so from a technology perspective, you have to be able to develop, release, test, verify and validate all in a span of time that is measured in the same span of time as the adversary is doing the same thing." Software-based systems also allow for much greater agility and sophistication within capabilities. "It's really only determined by imagination what can be done to a waveform on the threat side, so we need to be even more creative and agile. Our software has to be adaptive and cognitive – able to autonomously respond to threats that we've never seen before. Ultimately, these are software and firmware challenges."

One of the biggest challenges to be faced with the move into cognitive assessment of the spectrum, according to Mercury Systems' Hood is that, "In the modern world, with technologies like 5G LTE, WIFI, Bluetooth, etc., there is a lot of spectrum being generated in the 'background' and, if you can cognitively assess that background and see that there is something moving around within it, then you don't really need a radar anymore, you can track based on this alone. It's the 'holy grail' of passive radar."

Making the challenge even more complex, Hood says to expect systems that incorporate IR, UV, and visible light, along with the RF spectrum, to provide a multi-spectrum cognitive background assessment of the entire picture at once. "With machine-learning over time, systems will be able to pick out and track anomalies and learn on their own how to best do that from all the available data. So, as we move forward, we need to build systems that can both rapidly adapt, as well as provide spectrum modification through the DRFM that can be continuously improved in the software, firmware and hardware. They must evolve at the machine pace as they learn."

In particular, Hood says a critical point moving forward will be the production turn time of technology-advancement. "Turn times will need to get shorter because of the variants that can be programmed in software by adversaries. With a software-defined threat, and radars also employing software-programmable DRFMs, we need to be able to have hardware that is wider bandwidth, more precise, and to be able to field new software even quicker. To do that, we need to stay at the latest core of processing technology where we have faster processors than they can field in their radars, and that means faster, lower latency DRFM technology, and the ability to put in newer firmware and software packages that we can immediately field across the entire fleets of aircraft, ships, and ground vehicles."

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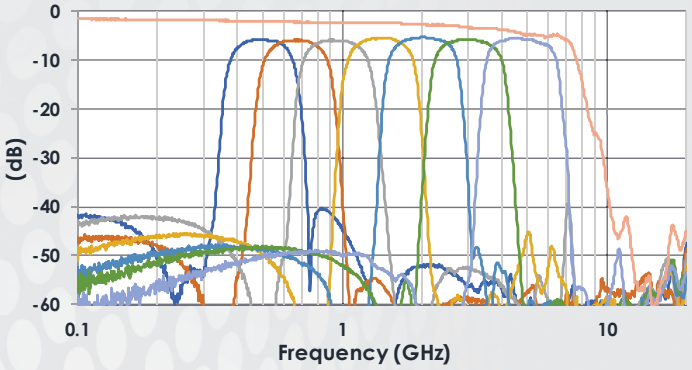

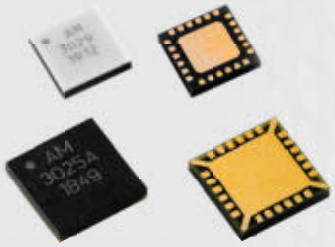

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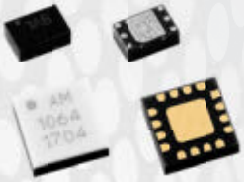

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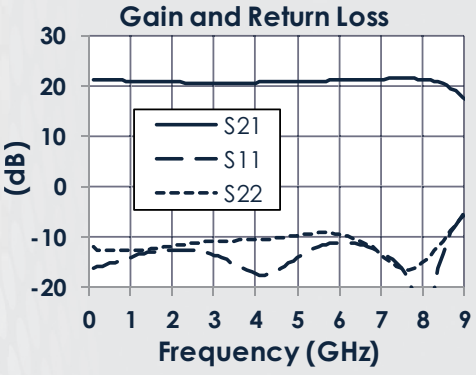

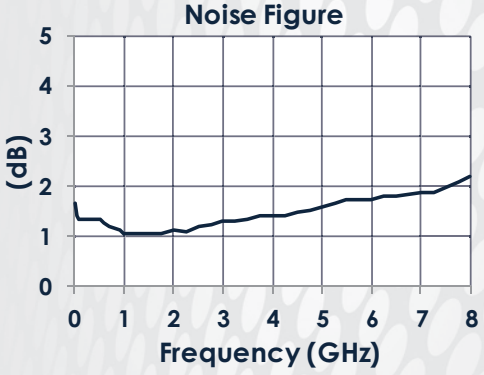

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Novel Antenna Technologies Will Drive EW In the Future

By Barry Manz

Hundreds of different types of antennas have been used for electronic warfare (EW), signals intelligence (SIGINT), radar, and communications applications over the years, so it might seem improbable that there are major breakthroughs waiting to be developed in this area. But, that's not the case, as researchers are exploring antenna concepts that have long been studied, but only recently made possible. That's good news for the DOD, as its systems move to higher frequencies, are embracing "multifunctionality," and platforms are getting both smaller and more crowded with antennas. All of these factors and others make it more difficult than ever to produce antenna systems that can work together to cover the huge swaths of electromagnetic performance from HF through at least 90 GHz.

While DOD has historically relied exclusively on defense electronics companies to develop new technologies, it has increasingly leveraged technologies from the commercial market, especially as companies frantically work to deliver on the promises of commercial 5G. Manufacturers, universities, and government agencies throughout the world are attempting to reduce latency to near the vanishing point, achieve downstream data rates of more than 1 Gb/sec, and serve a bewildering number of devices under the Internet of Things (IoT) umbrella, everywhere they're required, all the time.

As the first 5G rollouts are demonstrating, this is the most formidable challenge ever faced by the wireless industry. And, even though the media focuses on the roles played by AI, edge computing and massive processing power, RF technology remains the core element of any system in which electromagnetic energy is the medium, and antennas remain the "point-of-entry" for RF signals.

So, it's not surprising that enormous resources are being devoted to these deceptively simple devices, from which DOD should reap significant benefits – from materials through complete systems. What's interesting is that while defense systems have been using active phased array antennas for years, they're now appearing in commercial systems as well, and not just for 26 GHz and below, but at frequencies up to 60 GHz in 64 x 64 element arrays with a roadmap to double this number in the future.

This work is driving down the cost of the GaN devices powering the latest AESA radars and EW systems, increasing their performance, and moving the technology forward far faster than if the defense industry was the only developer. It's also, of necessity, rapidly accelerating the millimeter-wave antenna state-of-the-art, as the White House administration demands that the US, not China, win the "Race to 5G."

Millimeter-wave radar for defense systems will also benefit from the more advanced radars being developed for vehicles that are incorporating higher angular resolution in azimuth and elevation, which provides a far better view of the environment. They may eventually employ phased-array antennas, along with digital (rather than analog) beamforming, and reduce the number of RF components. Costs of these sensors have dropped dramatically from about $8,000 to about $1,000, and will likely continue falling in the coming years.

The RC-135V/W Rivet Joint uses a variety of antennas on its cheeks and belly (left) to collect ELINT and SIGINT, as well as a series of communications antennas on its spine (right) to send and receive information. USAF PHOTOS

In short, DOD will be able to exploit more advanced antennas (and other technologies) developed for commercial markets sooner, and at far less development cost. This was former defense secretary Ash Carter's goal when he rebooted DOD's Defense Innovation Unit – Experimental (DIU-x) initiative in 2016 and traveled the country as the evangelist for defense/commercial synergy. While the accomplishments of DIU have been mixed, its results have been substantial enough for DOD to remove "experimental" from its name, as it's now become permanent.

EMERGING FROM ESOTERICA

That said, the antennas being developed for 5G are mundane compared with emerging technologies that are either still in development or just now being commercialized and, in this group, plasma antennas top the list.

Forming an antenna from a plasma obviously seems futuristic, considering that most obvious commercial applications are along the lines of the "neon sign", fluorescent tubes and flat-screen televisions. But plasma antennas are not only feasible, they are being commercialized, although it's no surprise that the initial target market is wireless applications. Nevertheless, DOD has been interested in plasma antennas for years, as they could have huge benefits for EW systems and others as well. To understand what makes such an antenna possible, it's necessary to delve into the physics of plasmas.

A plasma is one of four states of matter (the others being solids, liquids, and gases), and was first identified as the fourth state by Sir William Crookes in 1879 and further described by chemist Irving Langmuir in the 1920s. A patent entitled "Aerial Conductor for Wireless Signaling and Other Purposes" was even awarded to J. Hettinger in 1919. It suggested that a long beam ionized medium could be used to both radiate and receive signals. Since then, there has been a steady stream of developments from scientists throughout the world to realize the potential of this unique technology.

Gases are generally insulators rather than conductors, but when they are exposed to heat or electromagnetic energy, a plasma state is created in a phenomenon called ionization – converting atoms to ions and electrons. Unlike a neutral gas, a plasma is conductive and produces radiation in the electromagnetic spectrum as well as at some frequencies of light. The most common way of generating a low-temperature plasma is by applying an electric field to a neutral gas. For antenna applications, however, other sources are used, such as microwave energy and lasers.

The advantages of plasmas for antennas are numerous because they can perform the same functions as conventional array antennas with fewer components and at lower cost. They are electronically steered, perform beamforming and, depending on the design, they can reach frequencies well into the millimeter-wave region and handle substantial power levels.

In addition, as the length of an ionized "filament" can be changed rapidly, a plasma antenna can be retuned to a new frequency, and can be turned off making it almost invisible, dramatically reducing its scattering signature. Stated another way, as soon as the energy source is removed, the plasma returns to its former state as a neutral gas and becomes nonconductive, essentially disappearing as the plasma cools down, with only its container, which can be glass, remaining visible. It takes only milliseconds for these antennas to be energized and deenergized.

And, even when a plasma element is energized, it's still difficult to detect by radar because it's transparent to the transmission at the plasma frequency, which conveniently falls in the microwave region. Consequently, plasma antennas can generate radiation patterns that provide low probability of intercept and detection at some frequencies. They can also be resistant to jamming, because if the plasma frequency is low enough, the signal simply passes through the antenna without disrupting its transmission and reception characteristics. Plasma antennas can also present low sidelobes, which also increases their jamming resistance. At frequencies below the plasma frequency, the plasma becomes a very good reflector, so a plasma can be used instead of metal for this purpose.

Dr. Theodore Anderson, a physicist and antenna engineer, and CEO of Haleakala Research and Development, Inc. in Brookfield, MA has, along with Igor Alexeff, been working on plasma antennas since 1996, and has multiple patents on the technology for use in transmitting, receiving, filtering and reflecting electromagnetic radiation. His efforts have resulted in some of the most useful information about plasma antennas

including a book by that name, as well as patents covering specific applications and novel antenna designs. His work spans commercial as well as defense applications.

There are two basic types of plasma antennas: semiconductor and gaseous, the former being the first type to be developed, and can be fabricated using materials and manufacturing techniques like those used to manufacture fluorescent and neon lighting. The latter, and most recent, are fabricated using common silicon fabrication processes to create plasma silicon antennas (PSiANs).

A PSiAN consists of thousands of diodes on a silicon chip. When activated, each diode generates a cloud of electrons, forming a plasma. Then, when electron density is high enough, each cloud reflects RF energy like a mirror. By selectively activating the diodes, the shape of the reflecting area can be changed to focus and steer a beam. One company, Plasma Antennas in the UK, has been offering PSiANs, targeted initially for wireless applications, but there is also interest from defense agencies.

A metalized silicon die acts as a waveguide and as a thin circular lens to RF energy injected at the focus point to form an antenna beam. An electronically-generated plasma "mirror" re-directs RF energy to the focal point and feed, and the mirror is electronically rotated to steer the beam. A plasma reflector is created by forward-biasing a set of PIN diodes within a two-dimensional array whose surface is typically elliptical. The shape of the reflector can be adjusted for different beamwidths. A typical 28-GHz PSiAN is 10 mm in diameter and 4 mm at 60 GHz, and if lower amounts of gain are acceptable, RF can be radiated directly from the chip via printed structures.

Both types of plasma antennas can be electronically controlled to steer beams at millimeter wavelengths, and have beam shaping and electronic beam steering at speeds less than 300 nsec. Current RF power-handling ability of the devices is at least 40 W CW with 100 W or more likely in the future. Anderson has also stated that much higher power levels can be achieved.

A PSiAN developed by Plasma Antennas for 5G applications. PLASMA ANTENNAS

Based on the increasing amount of research being conducted on plasma antennas throughout the world, it's likely that they will move more into the mainstream of antenna technology for both commercial and defense applications.

METAMATERIALS

Another promising technology for antenna construction involves the use of metamaterials which, like plasma antennas, trace their origin to the early 1900s, but are only recently beginning to realize their potential. Extensive research on metamaterials has been conducted by industry, DOD and academia for many years. Those of interest for antenna systems have a negative index of refraction called, appropriately, negative-index metamaterial (NIMs), as they have a negative refractive index (i.e., smaller size) than the wavelength of the frequency applied to them.

Negative index materials were predicted to exist in 1968 by Russian physicist Victor Veselago, but they had not been demonstrated using conventional materials. In 2000, however, the first artificially-structured NIM – sometimes called a Veselago material – was demonstrated. What is now called the David R. Smith Research Group (or Meta Group), demonstrated the first NIM operating at microwave frequencies at the University of California Davis. Smith is currently a James B. Duke Distinguished Professor at the Electrical and Computer Engineering Department of Duke University and Director of the Center for Metamaterial and Integrated Plasmonics.

NIMs are artificial rather than natural, and they don't have characteristics commonly found in nature. They're made from composites, such as metal or plastic, that contain elements (unit cells) arranged in repeating patterns to form an array. Each unit cell is tuned to respond in a specific way based on the desired characteristics of the system they support. The geometry, size and orientation of cells in the array allows them to block, absorb, enhance or bend electromagnetic waves.

This allows control over material parameters known as permittivity and magnetic permeability that together determine the propagation of electromagnetic waves, whether radio waves or their optical near-neighbors. The result is a structure that can achieve remarkable capabilities that are beyond the means of conventional materials and, when arranged in an array on an electrically-thin surface, they can achieve performance like that which can be achieved with conventional three-dimensional antennas. Their small size reduces loss over an array, and their fabrication cost is low because they can be printed using standard lithographic processes.

A discussion of metamaterials in an antenna context requires ignoring conventional antenna theory because they are counterintuitive. That is, they are inherently "electrically shortened," which in traditional antenna theory translates into reduced efficiency – the shorter the antenna compared to the operating frequency of the system, the more inefficient it will be. However, while a metamaterial-based antenna is very electrically short at a given frequency (about a tenth of a wavelength or less), its properties are not the same as conventional types, so comparisons are difficult.

In natural materials, magnetic permeability and electric permittivity are determined by the response of the material's atoms and molecules to the electromagnetic wave passing through it. In metamaterials, these properties are determined by the arrangement of the unit cells, and these small structures can be designed to interact with electromagnetic waves to create finely-tuned resonances and other unconventional properties.

One of the leaders in making these antennas commercially available is Kymeta

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Corp. (Redmond, WA), which uses a diffractive, rather than a refractive, surface to define an antenna beam holographically. This method of forming an electromagnetic beam is known as holographic diffraction, and Kymeta's commercial approach to fabrication is called metamaterial-surface antenna technology (MSAT).

The holographic approach to beamforming uses the resonant frequency of each unit cell to form a dynamically-reconfigurable diffraction grating. To create an antenna with hundreds or thousands of elements, it is placed next to a broad wall of a rectangular waveguide feed structure that couples all the elements to an electromagnetic wave generated by a single RF power source.

The elements are spaced so their radiated waves are in phase (i.e., coherent) at the desired scan angle of the beam to scatter strongly, while elements out of phase are detuned and do not radiate. The scan angle is defined as the angle between the beam and an axis that is perpendicular to the plane of the antenna surface.

At the 2018 Special Operations Forces Industry Conference, Kymeta teamed with Microsoft to demonstrate their mobile SATCOM solution.
MICROSFOT/KYMETA PHOTO

The Kymeta metasurface uses the controllable permittivity of liquid crystals to tune each radiating element, and the design is compatible with liquid crystal display (LCD) fabrication processes, so it is suitable for high-volume production using manufacturing processes used in the LCD industry. Dynamically adjustable polarization from linear to circular (right-hand circular polarization and left-hand circular polarization) allows the antenna to work with different types of satellite polarization schemes without the need to modify or replace equipment.

The metasurface antenna is a passive device, as active phase shifters and amplifiers are not required to achieve the desired element tuning. So, for many applications there is minimal power dissipation, in contrast to typical phased array or electronically scanned antenna systems. Through the control over the phase or amplitude of each radiating element, holographic patterns can be created on the metasurface that mimic the functionality of Fresnel lenses or other diffractive optical elements. The metasurface aperture can function as a low-cost, dynamically-reconfigurable lens that consumes minimal power.

Other companies, such as Alcan Systems (Darmstadt, Germany), are also beginning to commercialize antennas based on metamaterials, although Alcan Systems' approach differs from that of Kymeta beyond the fact that both use liquid crystals to form the array. In addition, both companies are focusing on the satellite and aerospace industries that have used either mechanically-steered antennas to cap-

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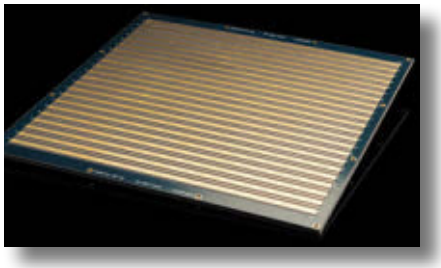

Pivotal Commware's holographic beamforming technology "has the potential to target and follow individual or small clusters of devices and provide them with their own high-fidelity beams of radiofrequency (RF) energy," according to the company. PIVOTAL COMMWARE PHOTO

ture the signal or phased arrays that provide beamforming.

Yet another company, Pivotal Commware (Kirkland, WA), which created holographic beamforming, is also developing metamaterial arrays, and like Kymeta, has received significant funding from Intellectual Ventures, founded by Dr. Nathan Myhrvold, formerly chief strategist and chief technology officer at Microsoft. He and Bill Gates oversee the group's Global Good unit that invents technologies for global health and development, along with the group's metamaterials commercialization center.

MIGRATING FROM COMMERCIAL TO DEFENSE

Needless to say, there is massive interest in new antenna technologies for both commercial and defense applications and, with backing from DOD and powerhouses like Intellectual Ventures, developers have the wherewithal to move technologies like plasma and metamaterial antennas forward at a rapid pace. Together they represent the forefront of next-generation antenna development that will change how the systems are built, and what they can achieve. But, these breakthroughs are only two of many research endeavors that are under way.

For example, passive millimeter-wave cameras (PMMWs) are being developed, along with LIDAR and EO sensors, to provide enhanced vision systems (EVS) that enhance situational awareness for pilots by showing everything present in the scan, including terrain, buildings, highways, or obstacles. Their predecessor, the synthetic vision system (SVS), is a standard component in the cockpits of commercial airliners, and increasingly in military aircraft and UASs.

PMMW cameras, being passive, do not emit any radiation, but rather collect radiation naturally emitted by objects or those emanating from other sources. A PMMW camera obtains a bidimensional map from radiation of the scene, reflected or emitted by various objects. Four types of PMMW imaging systems exist – mechanical scanning, phased-array, synthetic aperture, and focal-plane array (FPA) – among which, the single-channel mechanical scanning imaging system is currently more favorable due to its simplicity and low cost.

In addition, there are frequency-selective surfaces (FSS) that have been focused on creating components such as filtering, but are now being developed for antenna applications, as well as a long list of antenna types that have been studied for years, but are now being rejuvenated as the technologies required to realize them are now available.

So, are there new antenna types still yet to be discovered? The answer is a resounding "yes!"

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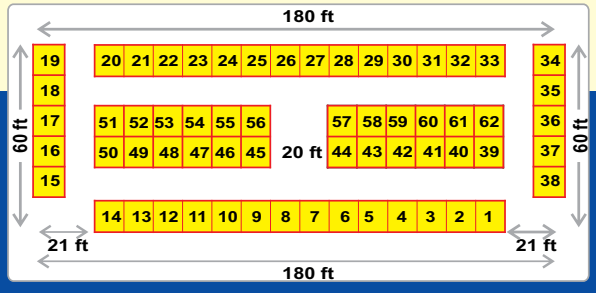

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01 August 2019	Start date to receive Abstracts/Summary of Technical Papers (1000 Words)
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15 October 2019	Last date to submit Full Technical Paper
30 October 2019	Intimation of Final Acceptance of the Technical Paper
31 December 2019	End date for Submission of Final Paper, Delegates & Authors Registration
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EXPLORING THE FUT

By Andrew White

Editor's note: In the October 2019 JED*, we looked at US Army EW developments. This month, we're addressing ground EW from an industry perspective in order to provide additional insight into the trends and concepts driving this area forward.*

As defense departments around the World consider how best to counter near-peer adversaries across contemporary and future operating environments, ground forces remain in the early stages of identifying suitable technologies, tactics, techniques and procedures (T3P) to optimize their electronic warfare (EW) capabilities.

Such consideration currently dominates the attention of NATO members and eastern European partners, including Ukraine, all of whom continue to monitor the information warfare activities of Russian intelligence units across the region.

As a result, state actors including Australia, the United Kingdom and the United States, lie at the forefront of strategic thinking in EW to support ground force commanders attempting to operate across congested and contested Electromagnetic Environments (EMEs).

Dating back as far as 2010, defense departments from the three countries continue to publish ground-breaking reports, many of which highlight "great changes in cyber electromagnetic activities" (CEMA) as exemplified by the fourth edition of the UK Ministry of Defence Development, Doctrine and Concepts Centre's (DCDC's) Global Strategic Trends paper. Other works include the US Army Training and Doctrine Command's (TRADOC's) "Win In A Complex World" and Defense Science Board's "21st Century Military Operations in a Complex Electromagnetic Environment", published in 2014 and 2015 respectively; as well as Australia's "Future Land Warfare Report" of 2013.

Seeking optimal solutions to operate across these EMEs, ground forces are increasing tempo in training serials, specifically designed to better enable ground combat units to operate across Command and Control Degraded or Denied Environments (C2D2Es). Examples include the US Army's *Exercise Dragoon Ready*, last conducted over the course of October 2018 at the Grafenwoehr Training Area, Germany, which is designed to allow force elements to shape EW doctrine in the ground environment through the employment of technologies and tactics, techniques and procedures (TTPs) development.

With the aim to mimic the contemporary EME, as witnessed in Ukraine as well as the Baltic States and Poland, the exercise allowed the US Army's 2nd Cavalry Regiment the opportunity to implement their own organic levels in EW protection, as well as the detection and disruption of enemy forces.

As an exercise official described to *JED, Exercise Dragoon Ready* allowed the army to shape current and future training strategies; update task organizations and the synchronization of EW teams and their equipment. Specifically, this included developments in TTPs to support EW operators maneuvering across the battlespace.

New or revisited skill sets explored by the US Army during the exercise (previously lost following more than 15 years focused on asymmetric warfare in Iraq and Afghanistan) included concealment and displacement techniques reconnaissance of primary and secondary sites and antenna propagation, exercise officials explained. Specifically, this included line of sight analysis, spectrum surveys, on-the-move operations, streamlined reporting, and tipping/cueing of additional assets. "Defining the future of the EW soldier is complex in nature," the exercise official explained. "The amount of fieldcraft involved demands attention. None of this happens without being in a real world environment. [The exercises] are the first steps. Then we can start concentrating on the equipment."

EW equipment utilized during the exercise included Versatile Radio Observation and Direction (VROD) and VROD Modular Adaptive Transmit (VMAX) manpack solutions, Sabre Fury EW system integrated on board three Stryker

The 2nd Cavalry Regiment establishes the tactical action center and tactical operations center in preparation for the live fire exercise as part of Dragoon Ready at Rose Barracks, Germany in October 2018. US ARMY

URE OF GROUND EW

infantry fighting vehicles, as well as the Raven Claw Electronic Warfare Planning and Management Tool. (For more on these programs, see "Aberdeen Proving Ground Home to Army EMBM Development and Acquisition" on page 24 of the October *JED*.)

"The need for EW continues to grow, as capabilities develop and are fielded to the force. Low echelons will be more effective if new equipment is provided and integrated," exercise officials described before confirming how soldier feedback remains critical to the overall success and implementation of future EW equipment. Similarly, the army has continued to run regular iterations of *Exercise Cyber Quest* since 2016, aimed at supporting the Cyber Battle Laboratory's (CBL's) assessment of technologies suitable for the TRADOC Capability Manager-EW (TCMEW). Technology is assessed against Multi-Function EW requirements, with lessons learned from exercises fed back into the development of future roadmap feature releases, exercise officials confirmed.

Future exercises will be supported by the US Army's first EW Tactical Vehicle (EWTV), which was delivered in September 2018 with the intention to assist commanders in the identification of TTPs, CONOPS and doctrine over a two year assessment program.

Based on a MaxxPro-Dash mine resistant ambush protected vehicle, the EWTV is equipped with a series of undisclosed EW systems, which will be evaluated by the 1st Cavalry Divisions' 3rd Armored Brigade Combat Team at Yuma Proving Ground, AZ.

The US Army explained at the time of the evaluation how the EWTV will be tested to "sense and jam enemy communications and networks from an operationally relevant range at the brigade combat team level." "This effort will allow the ability for EW Soldiers to influence future vehicle improvements and grow their knowledge, This is an advanced EW technology that can provide the army new offensive and defensive capabilities," explained LTC Scott Schumacher, chief of the Rapid Equipping Force solutions team.

"[EWTV] has never been used at the brigade-level," said CW2 Alexander Torres, the brigade's electronic warfare technician at the end of the two-week EWTV evaluation, "so we have to really put it through its paces and see what its capabilities and limitations are. We have to develop best-practices and TTPs that will help future units as well as continue the development of a dedicated EW platform."

L3HARRIS

Industry gained valuable experience during the Iraq War, and it is leveraging that knowledge to provide a new, more capable set of EW solutions for ground forces. According to L3Harris Electronic Systems' Director, Ground EW Enterprise, Bill Lambalot, both contemporary and future operating environments represent some of the most challenging arenas ground forces have ever faced.

"Our customers have made it abundantly clear that they are short on every conceivable resource on every platform and that any deployed kit can no longer be special purpose," he explained. "Deployed EW systems must address the wide range of threats found in peer and near-peer environments. Industry's challenge is to bring distrib-

uted capabilities that offer flexibility in detecting and defeating legacy and emerging threats."

Lambalot outlined the role of ground-based EW solutions in the wider context of a three-dimensional battlespace, warning how such a concept could be fraught with challenges, including ground coupling, ground clutter, multi-path errors and other natural phenomena capable of disrupting and confounding a mission. "So long as RF-initiated devices pose a threat to ground maneuvering, localized EW capabilities are a must. These threats are requirements drivers. The key to effective sensing and defeating will lie in distributed action in which interaction with aerial assets (including tethered and untethered drones) are enabled by low probability of detect (LPD) and anti-jam (AJ) communications waveforms."

According to Lambalot, capability gaps in existing ground-based EW inventories remain prevalent across the battlespace: "Of course, high-efficiency defeat waveforms and highly sensitive detect capabilities will be required to find and counter rapidly evolving threat signatures, but so too is a cohesive distributed workflow capability that both empowers services to operate with their own distributed assets and to cooperate with partner services. At Harris, we're leveraging internal investment and working with our customers to develop new capabilities and to fuse and to expand our incumbent technologies into true multifunction EW offerings, such as secure communications, defensive electronic attack, offensive electronic attack and electronic support. With the shifting focus on OTA-based procurement, industry is challenged to become more agile in its ability to deliver capability. It is incumbent upon industry to recognize that working together to drive to open standards is both vital for business, as well as necessary to bring disparate capabilities to the end user," Lambalot concluded.

A US Army soldier raises the antenna on the EWTV which provides Army Electronic Warfare Teams with the ability to sense and jam enemy communications and networks from an operationally relevant range at the brigade combat team level. US ARMY

CHEMRING TECHNOLOGY SOLUTIONS

According to Chemring Technology Solutions' (CTS') EW Product Manager Mike McCombie, a great deal of work has been completed over recent years to better understand and outline potential challenges associated with EW across future operating environments (FOE). "The predicted effects across the sector can already be seen in active theaters and grey conflict [zones], and there is no reason to think these trends will do anything but continue to stay on course," McCombie explained.

As a subsidiary of the Chemring Group working alongside its sister unit, Roke Manor Research, CTS has developed what it terms an "enhanced understanding" of operating in the EME through a process of wargaming and red-teaming. "These explore a collection of scenarios that capture the breadth of conflict scenarios and take into account established and developing doctrine," he said. "Red-teaming has defined a reference against which to test concepts and enabled an honest assessment of the problem, avoiding being constrained by what we think is possible. Only by this approach can new vision be gained, providing a point of reference that can continue to be refined over time. This all defines a warfighting operational environment that is very challenging for EW," McCombie continued while highlighted a series of critical concerns for ground forces.

These include operating in congested and high-signal density EM Operating Environments with a mix of civil and military communications networks; the proliferation of complex signals; high multi-path environments; requirement for long-range and short-range detection over very wide frequency ranges; information sharing among multivendor platforms; as well as the employment of multi-use, task-equipped, agile and flexible platforms.

"The threat scenarios expose extreme technical challenges, from the asymmetric use of high-power jamming and kinetic strike; distinctive communications modes targeted at the tactical edge; and co-channel interferers which present a unique challenge," McCombie said. "The proliferation of communications modes and devices, including a rapidly changing and expanding availability and use of communications and a growing number of communicating devices that could be subverted in the FOE, further complicates the operational environment. While this represents a view on the technical challenges, this is magnified in the ultimate conflict zone predicted to be dense, urban and/or littoral mega-cities. Aspects of this environment are already present in contemporary conflict. It is clear that a technical solution alone will not be sufficient, but equally, that the technical solution will need to be of a different nature than what has been the accepted norm to date," he warned.

Referring to ground-based EW capabilities, McCombie discussed how force elements require an ability to be creative and agile during an operation, with additional flexibility of freedom of action to maximize effect while also minimizing their own detection and remaining sufficiently synchronized across the domain to achieve cross-domain mission objectives. "As part of a multidomain deployment, ground forces must be equipped for their environment in order to deliver their part in the creation of multiple dilemmas for the enemy," he said. "The contemporary operating environment is already challenging, and has the potential to escalate rapidly, presenting scenarios in which traditional air power can be denied through direct and indirect means. The future operating environment has potential to bring greater uncertainty with each new mission.

CTS's Resolve EW suite can be mounted on a tactical ground vehicle or in manpack configuration. CHEMRING

In these contexts, it will be the ground forces who are in first, and throughout, delivering persistent actionable intelligence, providing clarity and enabling the mission."

According to CTS, a number of militaries have taken significant strides towards the development of capabilities to ensure they remain at the forefront of deployed ground forces EW technology. However, emphasis continues to be paid towards multi-function capabilities including T3P to assist in preparing the battlespace for CEMA effects while moving away from more rigid and stove-piped capabilities.

Specifically, McCombie asserted, this includes movements towards the better understanding and employment of Big Data as well as integrated and automated machine learning. "Based on our own analysis of the contemporary and future operating environments, there is a collection of discriminating capabilities that an EW system must offer," he said. "The capabilities of the EW system will need to be extensible through adjacent systems, to provide for functional and machine-intelligence-directed extension to support evolution. This will become part of the EW system architecture, enabling open extensibility of the sensor-based capability. The sensor system will also integrate closely with adjacent capabilities to deliver combined CEMA effects."

Additionally, McCombie illustrated more "active and prevalent" scales in the deployment of jamming and deception technology and TTPs, calling for sensors to be capable of rapidly discriminating attacks from innocent emissions, particularly in the context of specific fast-paced incidents in an otherwise slow-paced conflict. Supporting communications through identification and localization of deception will also ultimately need to be automatic and immediate, CTS officials explained, before calling for ground forces to be able to "sense-through" jamming, to prevent denial of capability at the same time as identifying and localizing jammers and jamming behaviors.

Finally, CTS highlighted how ground EW solutions must be capable of not only acting independently but also as part of a more complex infrastructure delivering operational interoperability, full-spectrum CEMA capability and strategic SIGINT reach-back to deliver confirmed coordinated tactical effects across a contested environment.

CTS solutions, which has participated in legacy US Army Cyber Quest exercises dating back to 2016, include the Resolve 3 Manpack and Locate-T systems.

SRC INC.

According to SRC Inc's Assistant Vice President, Business Development, Jim Periard, ground forces operating throughout the contemporary operating environment remain largely restricted to stove-piped technology, particularly in relation to counter-IED (CIED) and counter-UAS (CUAS) missions.

Periard criticized the lack of ability to network together individual EW systems for distributed and collaborative EW operations, as well as for the dissemination of emitter information collected by each individual EW system.

Furthermore, he called for enhanced on-board processing capacity in order to "rapidly characterize the signal environment for effective and efficient EW operations" in the ground environment. "SRC has been working on these technology gaps for several years," he said, "including the incorporation of embedded machine-to-machine networking of EW systems, and the implementation of advanced signal processors and AI/ML-based cognitive EW techniques into EW systems." Examples include SRC's AN/VLQ-12 Counter RCIED Electronic Warfare (CREW) Duke systems, which continues to be deployed by US armed forces to protect soldiers against roadside bombs.

"The CREW systems that have been widely deployed to ground forces provide a significant capability to operate in the EMS," Periard said. "Today's CREW systems feature sophisticated receiver and transmitter subsystems that can execute a wide range of RF functions and missions in support of overall operations," he continued before turning his attention to the fusion of CIED and CUAS missions into a single technology solution. "Both [CIED and CUAS] are separate missions, each of which are executed by separate systems that run the same baseline hardware. In SRC's opinion, these missions should be combined to the greatest extent possible. The future ground-based EW system should be a spatially distributed collection of EW subsystems over which the EW mission is partitioned and executed and for the dissemination of the EMS data that is routinely sensed by the individual EW systems for enhanced EMS situational understanding," he added.

"SRC continually upgrades our family of ground-based EW systems. We are developing and demonstrating advanced ground-based EW capabilities through sponsored programs and internal investments. Advanced EW/cyber capabilities, machine-to-machine networking, simultaneous multi-mission EW and other capabilities have been implemented and demonstrated to inform requirements and show what can be done with advanced ground-based EW systems," Periard said. Echoing the thoughts of Lambalot, Periard also warned that procurement processes must be shortened in order to meet tight EW development timelines to match the evolution of adversary communications systems that exploit commercially-sourced technologies. "Many of the threats faced by CIED and CUAS systems are weaponized COTS systems that utilize rapidly evolving, robust and commercial communications technologies that are specifically designed for operation in the congested, heavy-interference environments of the ISM bands. Countering these threats requires robust software programmable EW hardware platforms with continual countermeasures development and implementation," he concluded.

LEONARDO

Also demanding a "convergence" between CIED and EW capabilities, Leonardo Electronics' vice president for sales, Paul Burt, described how the growing threat of proxy warfare by "sophisticated, ruthless and well-trained" irregular forces would result in requirement for greater protection of ground forces, particularly in terms of CEMA. He described how counter-RCIED had begun as a somewhat rarified electromagnetic countermeasure (ECM) force protection (FP) capability, developed and deployed by only a select handful of nations. "The United Kingdom and Israel were notable users of this skillset, with well-established industrial bases to develop, supply and support a vital FP capability. Operations in Iraq and then Afghanistan saw a widespread adversarial use of increasingly sophisticated RCIEDs resulting in spiraling casualties that challenged the ability of coalition forces to dominate ground, despite their massive conventional superiority. Given the increasing prevalence of asymmetric warfare, these lessons will not have been lost on potential adversaries. The threat posed by RCIED seems certain to remain a substantial danger to our service personnel," Burt warned.

"ECM/FP is a key enabler in allowing the deployed force to achieve its military aims and objectives, while enhancing military freedom of maneuver and of movement for civilian populations alike," he said. "In an ever-changing

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threat environment, future ECM/FP systems must be effective, highly flexible, scalable and easily upgradable. These aspects will be likely key user requirements, set against a background of future expeditionary operations and the ever-increasing availability and exploitation of cheap COTS technologies by our adversaries," he explained before considering how technology advances must also enable industry to develop more capable and flexible countermeasures by using example software-definition technology.

"The use of such techniques provides the flexibility to counter emerging threats quickly by simple, soft- and firm-ware upgrade and insertion, without the need for costly physical system upgrades. The application of AI and augmented reality is also likely to have an increasingly important role to play in future system-of-systems design. Such technologies also enable ECM/FP systems to increasingly converge and become closely integrated with the wider group of EW systems, thus enabling multi-role capabilities to form part of a wider sensor-decider-effector network."

Leonardo's Guardian family of systems is designed to protect ground forces from RCIED attack.
LEONARDO

Leonardo solutions include its Guardian ECM/FP family of products, designed to support ground forces with the suppression of RCIED threats.

THE FUTURE

As CTS's McCombie summarized: "The ground mission will in future need greater resilience to attack, greater ability for independence during attack, and rapid recovery of synchronization with command, following neutralization of an attack. This means that future capabilities will be required to provide intelligence development for independent ground command in the forward tactical space."

As defense departments continue to consider the rapidly evolving character of conflict in view of both the contemporary and future operating environments, it appears ground components will continue to require upgrades in terms of both offensive and defensive EW capabilities. In order to ensure a smooth transition to this more optimal set of EW solutions, ground commanders will be forced to pay similar attention to the development of suitable doctrine, CONOPS and TTPs to support frontline force elements.

Report from the 8th Annual AOC Pacific Conference – Honolulu, Hawaii

By COL (Ret.) Arthur N. Tulak, Ed.D.
Vice President, Hawaii AOC Diamond Head Chapter

The theme for this year's AOC Pacific IO Symposium, "Countering Coercion: The Role of Information Operations," focused on understanding the threat of the comprehensive coercion carried out by adversaries across the globe, with special attention on the People's Republic of China and its campaign of coercion in the Indo-Pacific. The first two days of the conference held at the Hale Koa Hotel in Waikiki examined the Information Environment (IE) through the prism of adversary coercion, and discussed various concepts and capabilities to counter coercion via information operations.

Gen Charles Q. Brown, Commander of Pacific Air Forces, started off the unclassified portion of the symposium as the keynote speaker with a focus on campaign-level planning. LT Gen Stephen Fogarty, Commanding General of Army Cyber, was the keynote for the second day and addressed how the Army is organizing for this campaigning effort in the IE.

Over the two days of the unclassified portion of the symposium, participants heard from two keynote speakers, twenty-two presenters, and one panel discussion comprised of six Army Colonels from the US and UK who are currently serving in service and Joint IO billets. The agenda included special emphasis on electronic warfare (EW), Cyber and other technical IRC contributions to countering coercion. Examples include Ms. Whitney McNamara's presentation focused on the roles of EW and cyber in countering PRC political and hybrid warfare, and Dr. David Stoudt's presentation of the contributions of directed energy to countering PRC coercion. Mr. Doug Jordan from the Joint Special Operations University delivered his presentation from Kiev Ukraine as he addressed examples of Russian coercion in the European Theater.

The co-sponsored symposium then moved to HQ, USINDOPACOM at Camp H. M. Smith, for two additional days of classified discussions, where participants heard from an additional thirteen presenters, with Dr. George Ka'iliwai, Director of Resources and Assessment, and COL Sean Berg, Deputy Commander of Special Operations Command Pacific, providing keynote and senior leader remarks, respectively. As part of the Allied engagement effort, the INDOPACOM J39 conducted bilateral engagements with Chile, Korea, Philippines, Singapore and Taiwan regarding efforts to build part-

Hawaii AOC Chapter member LTC (Ret.) Curtis "Manny" Manchester presents a case study on US efforts countering coercion during the U.S. Support Group East Timor (USGET) 2000-2002, alongside the United Nations Transitional Administration East Timor (UNTAET) Peacekeeping Operations (PKO), 2000-2002.
PHOTO BY COL (RET.) ARTHUR TULAK

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Dr. George Ka'iliwai III, Director of INDOPACOM J8, delivers keynote remarks at the classified plenary at HQ, U.S. Indo-Pacific Command.
PHOTO BY LCPL DANNY NATERAS, MARINE FORCES PACIFIC, COMMUNICATIONS STRATEGY AND OPERATIONS, COMBAT PHOTOGRAPHER.

ner capacity for information operations (IO) and EW, and to improve procedural inter-operability. The final day of the symposium was a FVEY workshop with an additional three presentations focused on procedural interoperability in IO, and the US INDOPACOM strategic messaging process.

The symposium enjoyed great support from AOC leadership, marking the third year in a row that the serving AOC President has participated. AOC President Muddy Watters both gave a presentation "Multi-Function Impact to EMBM" and officiated the presentation of AOC scholarships and National AOC awards. The National Service Award, Navy, went to LT Nguyen who serves aboard the USS Preble, and the scholarship was awarded to Hawaii University Electrical Engineering Senior Nicholas Yama. In addition to National AOC representation, both the Australian and Capitol Club AOC Chapters supported this year's symposium. Allied participation in this event continues to grow, with 40 Allied personnel attending in delegations from Australia, Canada, Chile, Japan, Korea, New Zealand, Philippines, Singapore, Taiwan and the United Kingdom.

The 8th Annual AOC Pacific was run as a Chapter level event, with the Federal Business Council providing management and support services. The registration response for the 8th Annual AOC Pacific was the strongest yet, setting a new attendance record. Next year's AOC Pacific Conference is scheduled for 20-23 October 2020, so mark your calendars now!

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The Impact of Pulse Compression on Self-Protection Jamming (contd.)

By Dave Adamy

BARKER CODE

The nominal purpose of pulse compression is to improve the range resolution of a radar. The range resolution diagram **(Figure 1)** shows the volume in which the radar cannot determine whether there is a single target or multiple targets. This volume is limited in cross-range by the 3-dB beam-width of the antenna and, in range by half of the pulse duration multiplied by the speed of light. Last month, this diagram was shown in two dimensions for a radar with chirped pulses, and now (in Figure 1), it is shown in three dimensions without compression.

A second way to compress the pulse (vs. chirp) is to place a binary-phase-

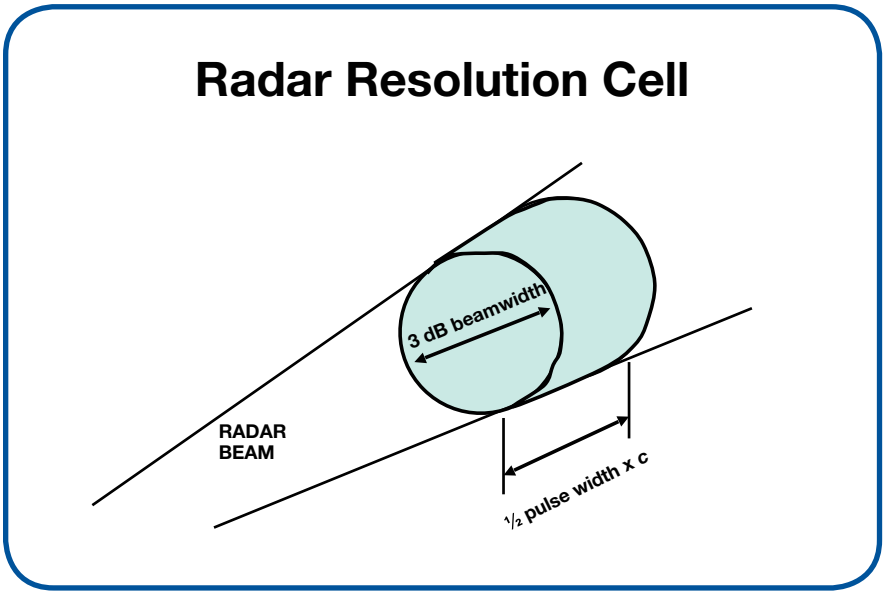

Figure 1. The resolution cell for a radar is a slice of the cone made by the 3-dB beamwidth. Its range dimension is half of the pulse width multiplied by the speed of light, "c."

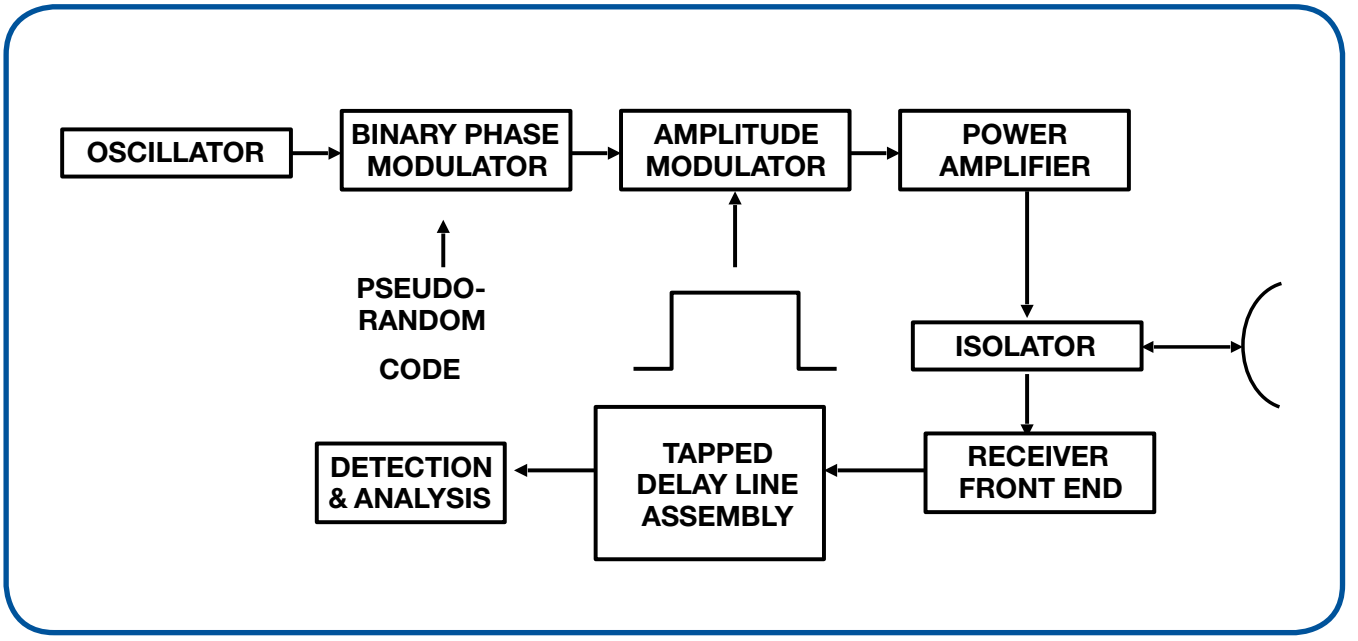

Figure 2. A binary frequency shift keyed code is modulated onto each pulse; a tapped delay line in the receiver reduces the effective pulse width, improving range resolution.

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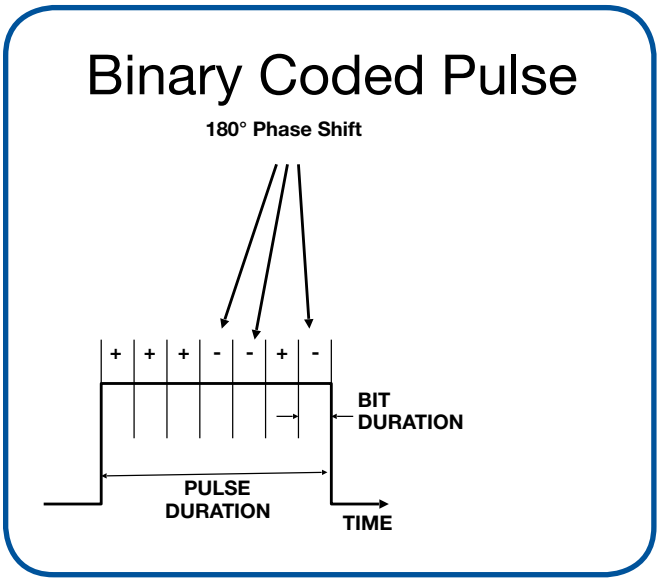

Figure 3. This is a seven-bit Barker code.

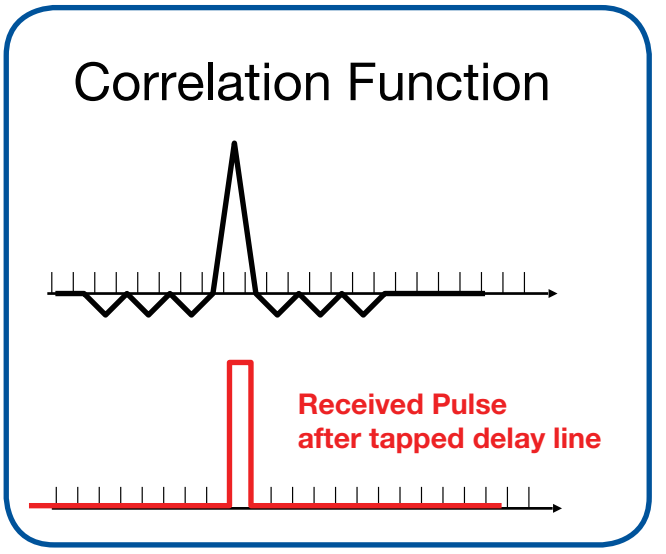

Figure 4. When a pulse arrives at the radar receiver, the correlation is either zero or minus one, unless the pulse is exactly fitted to the tapped delay line. Then, for one bit, the correlation jumps up to seven.

shift keyed digital modulation (called Barker code) on its pulses. The transmitted pulse has all of its energy for performance of the radar's primary function. However, in processing the skin return pulses, the effective pulse width is reduced.

As shown in **Figure 2,** the skin-return pulses are passed to a tapped delay line in the radar receiver. The delay line assembly is designed for the specific code on the pulses. The output of this circuit is a pulse that is only as wide as one bit period of the Barker code. This shorter pulse enables a significant improvement in the range resolution. It is now half of the code bit period times the speed of light.

Figure 3 shows a 7-bit Barker code (1110010). The Barker code is ideal because of its correlation function. **Figure 4** shows the correlation function of this specific code. As the skin return pulse progresses through the tapped delay line, the output level remains at zero or minus one until the code is exactly aligned to the delay line. Then, it pops up to the value of the number of bits in the code. Thus, the pulse has all of its energy, but it is concentrated in the period of one bit of the code.

Figure 5 shows a detailed block diagram of the tapped delay line assembly. There is a 180° phase shifter at the 4th, 5th and 7th bit taps. The lower part of this figure shows the 7-bit code progressing through the shift register. You can see that the summing output is zero or -1, except when the pulse is exactly fitted to the shift register; then it pops up to 7.

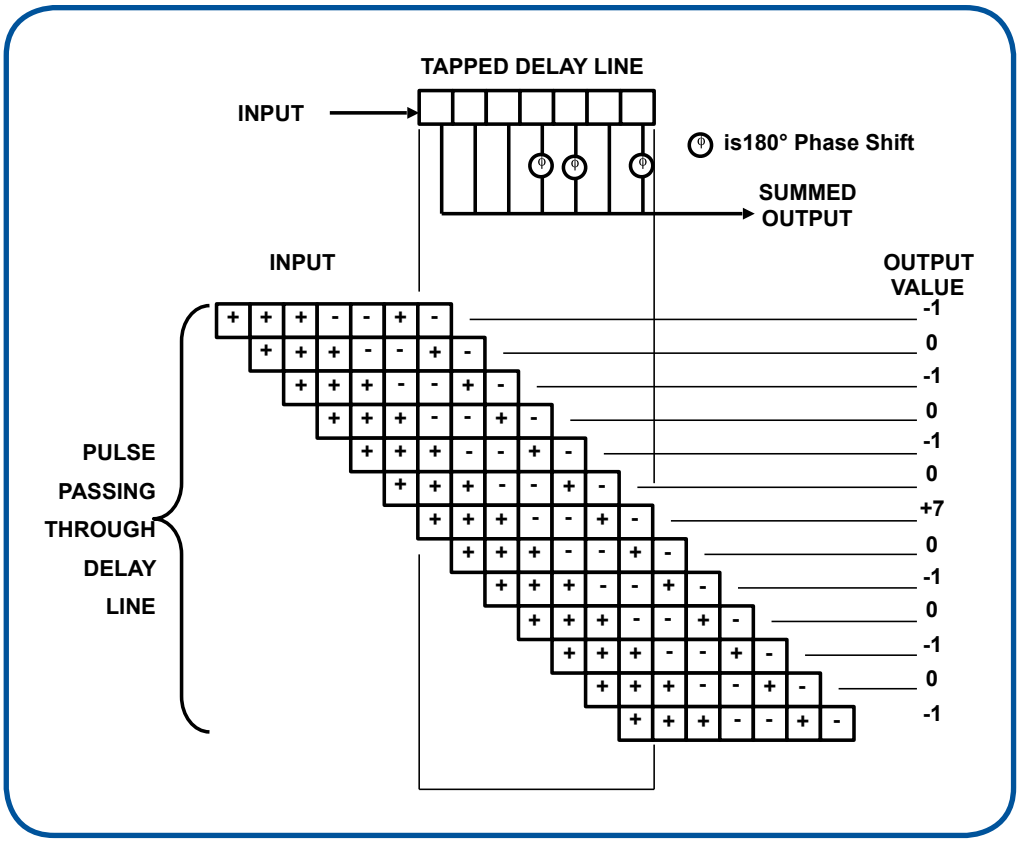

Figure 5. As the skin-return pulse passes through the tapped delay line assembly, the summed output value stays very low until the pulse exactly fills the delay line. Then, the output increases to the full value of the number of bits in the code.

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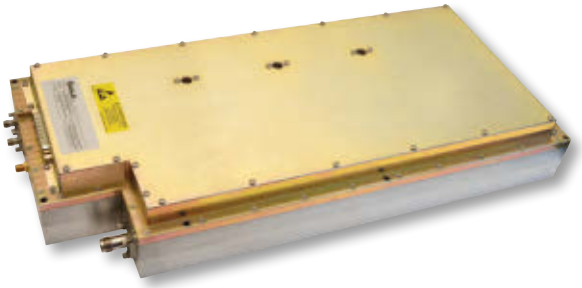

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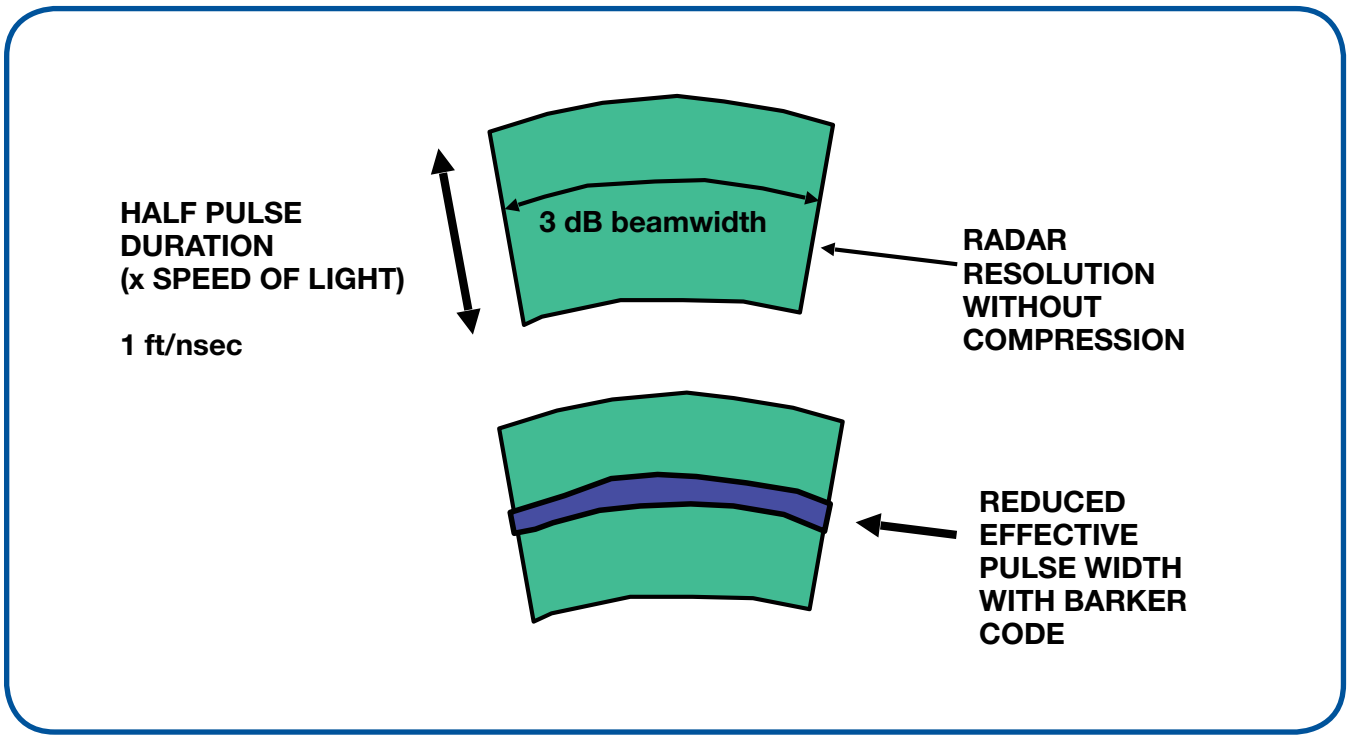

Figure 6. The coded pulse produces a large output from the delay line when all of its bits align to the taps. This shortens the pulse to one-bit duration and effectively reduces the depth of the resolution cell.

The longer the code, the greater the pulse compression. A Barker code can only have 13 bits, so longer codes cannot be true Barker codes; their correlation functions have false peaks. However, codes are chosen to have false correlation peaks that are significantly lower than the true correlation peak. This allows a threshold to be set to isolate the maximum correlation output. Therefore, the summed output has the full energy of the pulse concentrated into this one-bit period. The Barker code compression technique is said in literature to allow up to 1000 bits in the code.

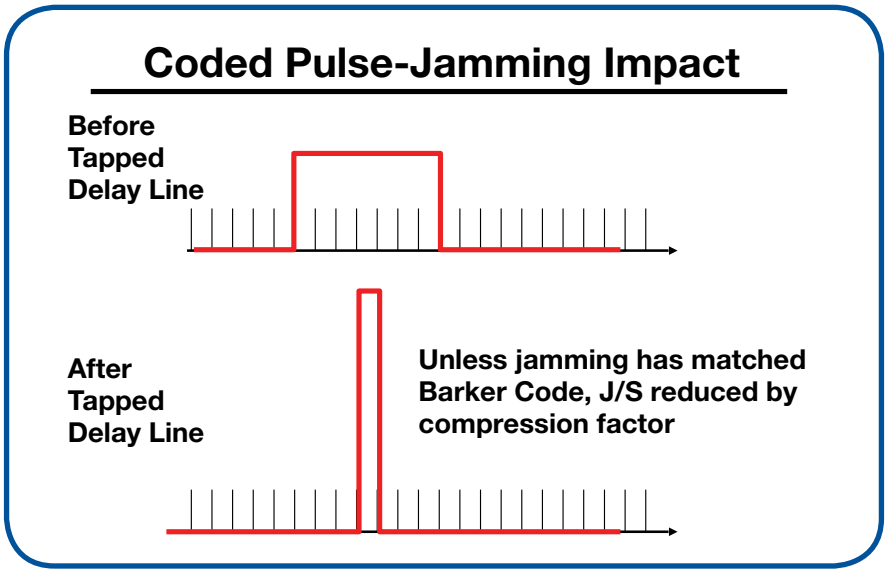

Figure 7. If a jamming pulse does not have the correct Barker code on it, the jamming energy is reduced by the ratio of one-bit duration to the full pulse width. If there are 1000 bits, this means that the J/S ratio is reduced by 30 dB.

IMPACT ON JAMMING EFFICIENCY

The narrowing of the post-processing pulse makes it more difficult for a towed decoy to be used, for the same reasons explained last month for the chirped radar. **(See Figure 6.)** Also, like the chirped radar, the effective jamming-to-signal (J/S) ratio created by a jammer is reduced unless the compression waveform is present in the jamming signal. Otherwise, the skin-return pulse is compressed (and optimally processed), while the jammer pulse is not compressed as shown in **Figure 7**. With the Barker code shown in Figure 3 above, this J/S reduction is only 8.45 dB [10 log (7)], but a longer code has a greater impact. If the code is 1000 bits long, the J/S reduction is 30 dB.

To be effective in eliminating the J/S reduction, the code placed on a jamming signal must accurately reproduce the bit rate and the random pattern of ones and zeros present in the target radar signal. Unless the code is known ahead of time, this requires the jammer to be able to determine the code in the received radar signal very rapidly and to place it on the jamming signal within a very few pulses.

WHAT'S NEXT

Next month, we will continue our coverage of the impact of electronic protection techniques by discussing the effects of leading-edge tracking. For your comments and suggestions, Dave Adamy can be reached at dave@lynxpub.com.

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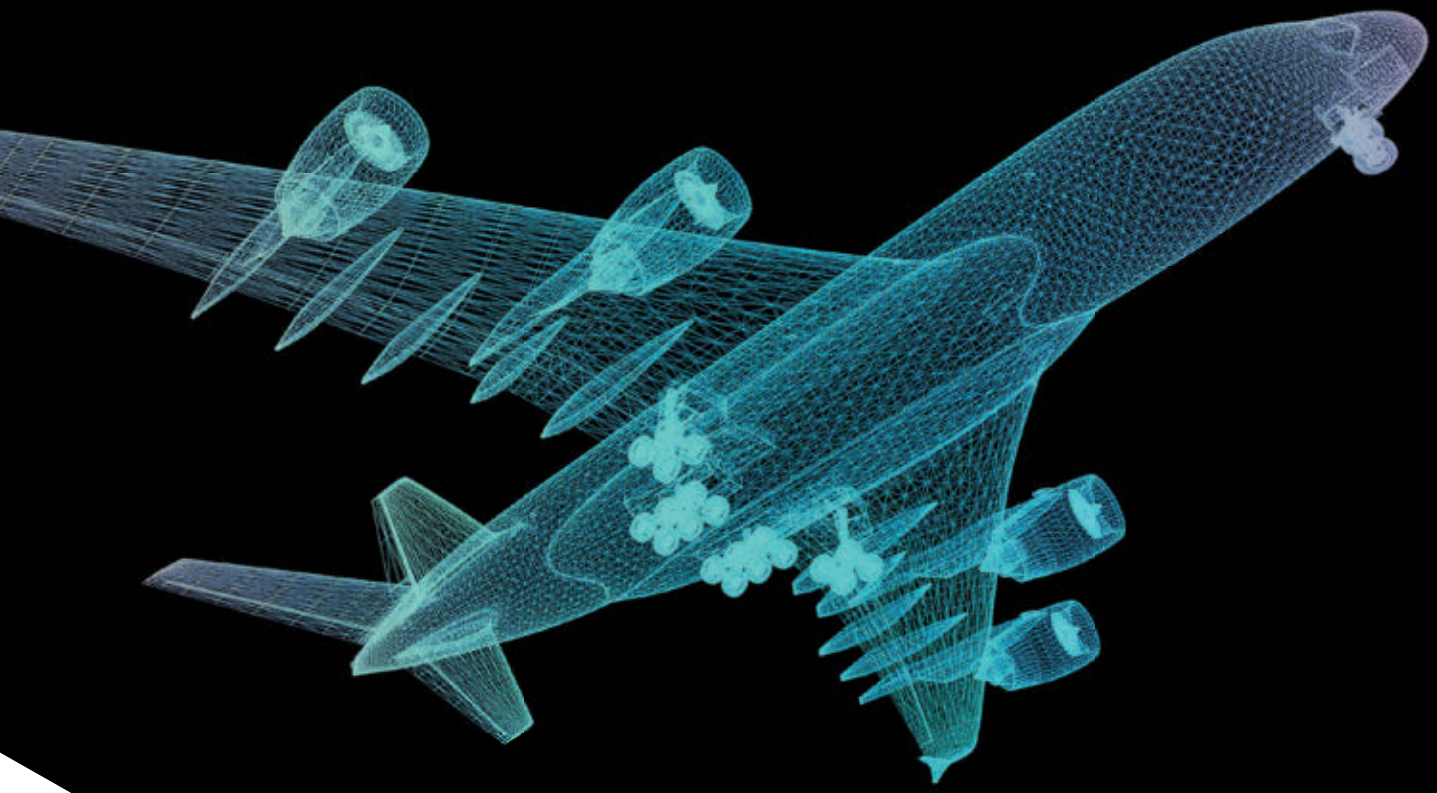

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FEATURED LIVE COURSES

21st Century Electronic Warfare, Systems, Technology, and Techniques

Dr. Clayton Stewart

Mondays, Wednesdays, & Fridays
13:00 – 17:00 EST | February 3 – 21, 2020
This course offers a comprehensive overview of modern electronic (EW) warfare systems, technology, and techniques.

EW Against a New Generation of Threats

Dave Adamy

Mondays, Wednesdays & Fridays
13:00 – 16:00 EDT | April 13 – 29, 2020
This is a practical, hands-on course which covers Spectrum Warfare and current EW approaches, and moves on to discuss the new equipment capabilities and Tactics that are required to meet the new threat challenges.

Intermediate Electronic Warfare
EW EUROPE 2020

Dr. Clayton Stewart

Friday & Saturday | **08:00 – 17:00 BST**
June 19 – 20, 2020 | Liverpool, UK
We will begin with a historical perspective and introduce use of radar, integrated air defense system, early EA functions and conclude with an overview of modern EA, ES, and EP.

Electronic Warfare Signal Processing

Kyle Davidson

Mondays, Wednesdays, & Fridays
13:00 – 16:00 EDT | September 14 – 30, 2020
This course introduces students to Electronic Warfare (EW) signal processing systems and their implementation, providing a foundation in learning to solve modern EW problems.

EW Modeling and Simulation

Dave Adamy

Mondays & Wednesdays
13:00 – 16:00 EST | March 2 – 25, 2020
This is a practical course in which the basic concepts and techniques of Electronic Warfare modeling and simulation are presented and applied to practical problems.

RF Theory for ES Operations

Dr. Patrick Ford

Mondays & Wednesdays
13:00 – 16:00 EDT | June 1 – 17, 2020
This course will include a thorough overview of key electromagnetic spectrum (EMS) concepts, with an emphasis on the RF spectrum and commensurate propagation mechanisms and environmental impacts.

Missile Design, Development, and System Engineering

Eugene Fleeman

Mondays, Wednesdays, & Fridays
13:00 – 16:00 EDT | July 13 – 31, 2020
Missiles provide the essential accuracy and standoff range capabilities that are required in modern warfare. Technologies for missiles are rapidly emerging, resulting in the frequent introduction of new missile systems.

Electro-Optical/Infrared Sensor Engineering

Dr. Phillip Pace

Mondays & Wednesdays
13:00 – 16:00 EDT | October 5 – 28, 2020
This course presents the fundamentals of electro-optical (EO) & infrared (IR) sensor technology, its analysis and its application to military search, track and imaging systems. Electronic warfare (electronic attack and electronic protection) are emphasized.

= Web Course, no travel required!

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Association of Old Crows

Award Recipients 2019

The AOC will recognize the premier leaders in EW, IO and EMS Operations fields throughout our 56th Annual Symposium and Convention. Please join us in celebrating these award winners for their exemplary service to our community. The Gold Medal Award is the highest award given by the AOC for outstanding advances and contributions in all fields of EW and IO. The Gold Medal Award as well as the Technology Hall of Fame Awards will be presented during the Opening Session on Monday, October 28th. The Hal Gershanoff Silver Medal Award is presented to an AOC member to recognize outstanding service in furthering the goals of the Association or its Chapter Organization(s). It is the highest award given to a member for service to the AOC. The Hal Gershanoff Silver Medal, the Colonel Anton D. Brees Lifetime Service Awards, and the Joseph W. Kearney Award will be presented at the Annual Banquet on Tuesday, October 29th. All other Individual awards will be presented at separate venues.

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We understand how important it is to be prepared for the worst, and are pleased to announce that we now offer LegalShield and IDShield to Members of the Association of Old Crows at a discounted rate.

For the last 43 years LegalShield has been providing families affordable access to legal assistance, no matter how big or small the issue. Today, they also offer the IDShield which goes beyond basic credit monitoring to include coverage of all types of fraud and impersonation – as well as full identity restoration services.

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Go to: www.legalshield.com/info/oldcrows.

Customer Care starts with Louise Yale, our LegalShield representative.

Call her at 703.622.7972, anytime. Or email LSYale@legalshieldassociate.com.

MILITARY BENEFIT ASSOCIATION

Military Benefit Association can help retired military, federal civilian employees, spouses, National Guard and Reservists, honorably discharged veterans and adult former dependents of MBA members get the coverage needed to protect your family. Obtain life insurance as well as health care coverage and a variety of non-insurance benefits from MBA.

LONG TERM CARE RESOURCES

The Association of Old Crows is proud to announce a new benefit for our Members – Individual Long Term Care Insurance. Our new partner, Long Term Care Resources (LTCR), is ready to deliver the protection that meets your individual and family's needs to assure that your assets are not at risk to pay for the daily care needed should you or your loved ones require it later in life. And what's more, because of your Crow's membership you can get this protection at a discount as an added benefit.

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continued on page 94

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PENTAGON FEDERAL CREDIT UNION

The Association of Old Crows is also pleased to announce to its members and their families that they are now eligible to join Pentagon Federal Credit Union (U.S. Citizenship required), one of the largest and strongest credit unions in the nation.

If you are already an AOC member, you can join PFCU online anytime. Call toll free 1-800-247-5626 or 703-683-7787 in the Washington, D.C. area 24 hours a day. To get your complimentary membership when applying online, select "fund my account by check" and indicate "AOC member Code 815" in the comments box.

If you are not an AOC member, you can join more than 15,000 others who already are by submitting our individual membership registration. By becoming a member of the association, you are not only given the opportunity to join PFCU, but also provided with national representation, professional education, the monthly *Journal of Electronic Defense*, and many other AOC benefits.

NEW AOC MERCHANDISE AVAILABLE

There are two great new AOC products available – an AOC mug and shot glass! Take a look at the AOC merchandise available in the online store at www.crows.org/store to see more items for sale. Items will also be on sale at the AOC Membership booth at the 56th Annual International Symposium and Convention in Washington, D.C.!

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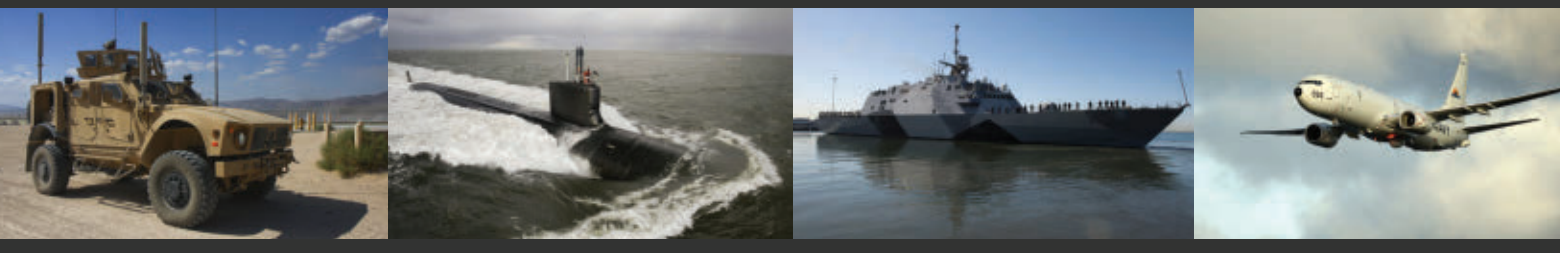

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