FEBRUARY 2019
Vol. 42, No. 2

ASSOCIATION OF OLD CROWS

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JED

The Journal of Electronic Defense

The RAF Tornado's EW Evolution

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Soldiers of the newly activated Intelligence, Information, Cyber, Electronic Warfare and Space (I2CEWS) Detachment stand in formation during a ceremony Jan. 11, 2019, at Joint Base Lewis McChord, Washington. The ceremony marked the launch of the Army's first-ever I2CEWS Detachment.

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the view
from here

TIME'S ARROW

In the next few months, the US and the UK will retire two venerable aircraft, the EA-6B Prowler and GR.4 Tornado, respectively. One is a dedicated EW platform that achieved initial operational capability with the US Navy in 1971, and the other is a multirole combat aircraft that entered service with the RAF in 1982.

What is remarkable about these two aircraft is how useful they were in many types of conflict. The US Navy's first EA-6Bs were deployed onboard the USS America and flew missions to protect Navy strike aircraft and B-52s during the Vietnam War. Prowlers took part in several operations, including the 1983 invasion of Grenada, air strikes against Libya in 1986, the Gulf War (1991) and NATO operations against Serbia in the 1990s. The operational flexibility of the Prowler was demonstrated in the Iraq War beginning in 2003-2005, when its missions shifted from suppressing Iraqi air defenses to protecting coalition ground vehicles from remote controlled IEDs along the roads of Iraq. Part of what made the Prowler so adaptable was its use of ALQ-99 jamming pods, which were more easily upgraded than internal aircraft installations.

The EW history of the RAF's Tornado aircraft is perhaps a bit more conventional. The RAF bought several variants of the Tornado, including an Interdictor Strike (IDS) variant that performed lethal suppression of enemy air defense (SEAD) missions. While the Tornado's EW upgrades were primarily limited by the restricted space available for internally mounted EW systems, the RAF made extensive use of pods and missile rails to add new EW capabilities (including RF jammers, fiber-optic towed decoys, an IR countermeasures suite and a long-duration IR decoy dispenser) to the aircraft over its lifetime.

Although we may look at the Prowler and the Tornado as "old" aircraft today, they were both tremendously successful designs. Their success is reflected partly by how much they influenced their respective successors. Although the EA-18G Growler may not look much like the EA-6B and the FGR4 Typhoon may not appear to share much in common with the swept-wing design of the Tornado, from an EW perspective the basic approach, such as the extensive use of pods, has remained very consistent. Pods existed before each aircraft, of course. But pods were central to each aircraft's ability to adapt to different missions and conflicts. On the Growler, pods are essential to the Navy's modernization strategy to shift from the ALQ-99 to the ALQ-249 Next Gen Jammer. And many of the same podded EW systems that will be carried by GR.4 during its final missions over Syria are fitted to the FGR4.

When a long-serving aircraft type is retired, it tends to generate a lot of nostalgia, especially by the aircrews that flew it. On the other hand, understanding an aircraft's history and what made it so special and useful can be carried forward through time. These aircraft certainly reflect EW's trajectory, and they should be honored for this role. – *J. Knowles*

ASSOCIATION OF OLD CROWS
JED
www.crows.org
The Journal of Electronic Defense

FEBRUARY 2019 • VOL. 42, NO. 2

Subscription Information: Please contact Glorianne O'Neilin at (703) 549-1600 or e-mail oneilin@crows.org.

The Journal of Electronic Defense is published for the AOC by
NAYLOR
ASSOCIATION SOLUTIONS
5950 NW 1st Place
Gainesville, FL 32607
Phone: (800) 369-6220 • Fax: (352) 331-3525
www.naylor.com

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PUBLISHED JANUARY 2019/JED-M0219/8105

FEBRUARY

Modern Threats: Surface-to-Air Missile Systems Conference
February 5-7
Huntsville, AL
www.crows.org

IDEX 2019
February 17-21
Abu Dhabi, UAE
www.idexuae.ae

Aero India 2019
February 20-24
Bengaluru, India
www.aeroindia.gov

Avalon 2019
February 26 - March 3
Geelong, Victoria, Australia
www.airshow.com.au

MARCH

12th Annual Military Radar Summit
March 12-14
Washington, DC
www.idga.org

Counter UAS Summit
March 12-14
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www.idga.org

2019 Directed Energy Summit
March 20-21
Washington, DC
www.boozallen.com

Dixie Crow Symposium 44
March 24-27
Warner Robins, GA
www.dixiecrowsymposium.com

AUSA Global Force Symposium and Exposition
March 26-28
Huntsville, MD
www.ausa.org

APRIL

48th Annual Collaborative Electronic Warfare Symposium
April 2-4
Point Mugu, CA
www.crows.org

Annual Directed Energy Science and Technology Symposium
April 8-12
Destin, FL
www.deps.org

2019 Army Aviation Mission Solutions Summit
April 14-16
Nashville, TN
www.quad-a.org

Directed Energy to DC (DE2DC)
April 29 - May 2
Washington, DC
www.deps.org

Security Cooperation Symposium: Interoperability, EW & FMS 2019
April 30 - May 2
Atlanta, GA
www.crows.org

MAY

Sea-Air-Space
May 6-8
National Harbor, MD
www.seaairspace.org

Electronic Warfare Europe 2019
May 13-15
Stockholm, Sweden
www.eweurope.com

11th Annual Electronic Warfare Capability Gaps and Enabling Technologies Conference
May 14-16
Crane, IN
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calendar courses & seminars

FEBRUARY

Radar Electronic Warfare
February 4-8
Swindon, Wiltshire, UK
www.cranfield.ac.uk

AOC Virtual Series Webinar: Practical DRFM Technology and EMS Design Considerations
February 7
1400-1500 ET
www.crows.org

Communications Electronic Warfare
February 11-15
Swindon, Wiltshire, UK
www.cranfield.ac.uk

NATO Joint Electronic Warfare Course
February 11-15
Oberammergau, Germany
www.natoschool.nato.int

Modeling and Simulation of Phased Array Antennas
February 12-14
Atlanta, GA
www.pe.gatech.edu

NATO Electronic Warfare Operational Planning Course
February 18-22
Oberammergau, Germany
www.natoschool.nato.int

Introduction to Pyrotechnics
February 25-27
Swindon, Wiltshire, UK
www.cranfield.ac.uk

Advanced Electronic Warfare Principles
February 25 - March 1
Atlanta, GA
www.pe.gatech.edu

Networked and Distributed Simulation
February 25 - March 1
Swindon, Wiltshire, UK
www.cranfield.ac.uk

Radar – Advanced
February 25 - March 1
Swindon, Wiltshire, UK
www.cranfield.ac.uk

Advanced Pyrotechnics
February 27 - March 1
Swindon, Wiltshire, UK
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MARCH

Aircraft Survivability
March 4-8
Swindon, Wiltshire, UK
www.cranfield.ac.uk

Sensor Data Processing – Advanced
March 11-15
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www.cranfield.ac.uk

Electromagnetic Materials and Measurements: RAM, Radome, and RAS
March 12-14
Atlanta, GA
www.pe.gatech.edu

Basic Electronic Warfare Modeling
March 12-15
Atlanta, GA
www.pe.gatech.edu

Counter Improvised Explosive Device Capability
March 18-22
Swindon, Wiltshire, UK
www.cranfield.ac.uk

Introduction to Open Systems Architecting Solutions for Decision Makers
March 20
Atlanta, GA
www.pe.gatech.edu

Infrared/Visible Signature Suppression
March 25-28
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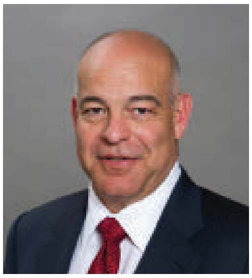

ENABLING MDO

The relatively new concept of Multi-Domain Operations (MDO) has been generating lots of discussion in the Services, OSD and in the international community. We are all aware of the current US-defined domains of sea, land, air, space and cyber. (The Electromagnetic Environment has been recognized as a maneuver space by some in the DOD, but it is not officially designated as a warfighting domain.) What does MDO bring to the fight? Let's start with some terminology.

Cross Domain Maneuver has been characterized as the employment of mutually supporting lethal and non-lethal fires of multiple domains to create conditions which present a complex decision tree to the enemy. This impacts an adversary's ability to rapidly observe, orient, decide and act, which in turn enables our freedom of movement.

Cross Domain Fires has been characterized as the integration and delivery of lethal fires across all of the five domains previously listed and the Electromagnetic and Information environments.

To maneuver and bring fires to bear requires *Cross Domain Command and Control*. We must be able to sense the environments (including RF and cyber), fuse the data into intelligence, deconflict the effects, and then direct and authorize the optimum platform, weapon or capability. So this sensing and C2 is what all the yellow lightning bolts on most of the briefings I've seen or built represent. I got it – great concept. But what is the major enabler of MDO? It's our ability to use the Electromagnetic Spectrum. This great and imposing multi-domain operations concept can't happen unless we can control the EMS and protect our ability to use it whenever and wherever we need.

To some, this may sound easy, but it's not because we lack the ability at the tactical and operational levels to sense the spectrum in real time beyond more than a localized area. If you aren't sensing, if you can't fuse data from multiple sources (think coalition operations), then how do you maneuver, how do you deconflict, how are we protecting our systems from enemy attack? As we build systems, are the requirements clearly stated, and is funding allocated to make our platforms and weapons cyber-survivable and RF-resilient? (Based on what we have seen in the Ukraine, for example, if we aren't prioritizing Electronic Protection to include HPM hardening, we will lose.) Oh, and remember the offensive side – if we can deny, delay and degrade an adversary's ability to use the EMS, then we significantly impact his ability to observe, orient, decide and act.

The bottom line is this. If we are talking about MDO in any form, the critical enabler both offensively and defensively is the Electromagnetic Spectrum. This means the US and its allies need to have a robust Electromagnetic Spectrum (EMS) Domain concept. In other words, treating the EMS as a "utility" is not going to cut it anymore. Are we prepared to make the investment in capability, to include platforms, weapons and people? This is not a sermon, but it is something we need to think about and solve. – *Muddy Watters*

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the monitor

news

US AIR FORCE PURSUING RAPID DEVELOPMENT/DEPLOYMENT OF NEW F-16 EW SUITE

The US Air Force last looked at upgrading the EW suite of its F-16 fleet in 2012 as part of the planned upgrade of 300 F-16s under the Combat Avionics Programmed Extension Suite (CAPES) program. CAPES was to include an improved Terma ALQ-213 EW system, but that program was cancelled in 2014 over budget constraints.

Now, however, SOSSEC, Inc. (The System of Systems Consortium) (Atkinson, NH) together with the F-16 System Program Office (Wright-Patterson AFB, OH) and the Air Force Research Laboratory Information Directorate, Information Handling Branch (AFRL/RIEB), Rome Research Site (RRS), are soliciting whitepapers for a new F-16 EW Suite Program Prototype.

As stated in the white-paper-request announcement, The F-16 EW Suite Prototype program will design, develop, and test internal EW suite prototypes to include a Digital Radar Warning Receiver (DRWR), with detection, identification and jamming capabilities for F-16 Blocks 30/32/40/42/50/52, C&D model aircraft. And, according to a briefing by the F-16 System Program Office given in December during an F-16 EW Suite Upgrade industry day, the program's objective is to design, develop, and field an EW suite system that will meet both current threat capabilities and remain relevant through at least 2046.

The Air Force intends to award rapid-prototyping agreements to multiple project level performers (PLPs) for competitive demonstration and testing. Both Government and non-Government employees will be involved in the evaluation and selection process, including personnel from AFRL and the F-16 Program Office.

The entire prototype program will consist of up to four phases, referred to as ALPHA, BETA, GAMMA, and DELTA. The initial ALPHA phase will consist of the "rapid development, demonstration, and testing of multiple prototypes in a competitive environment." Release of an Other Transaction Agreement (OTA) RFP for the ALPHA phase was planned for January 19 as this issue of JED went to press. If successful, a separate limited sources competitive solicitation will be issued on July 19 to two of the awardees of the prototype agreement, followed by a single production contract to begin the follow-on rapid procurement and fielding, or BETA phase. It is expected that the production contract will be the result of a FAR-based competition for production of up to 899+ units. According to the planned schedule, the BETA phase will consist of fielding a digital radar warning receiver (DRWR)-only solution, with very limited modifications to the aircraft, beginning in approximately 4QCY21.

The subsequent GAMMA phase adds the fielding/upgrading of an internal jamming capability to the integrated EW Suite solution, beginning approximately 1QCY24, however the request for papers notes that the ideal prototype solution would actually allow for "fielding of the entire EW suite in approximately 4QCY21 (i.e., GAMMA Phase only), if possible." The final DELTA phase covers operation and sustainment of the suite, and will begin after all fielding is complete. PLPs will be required to deliver a prototype for testing at multiple Government facilities, including Wright-Patterson, Eglin, and Warner Robins Air Force Bases, as well as to provide sufficient on-site support during testing operations

A number of milestones are set for the program. Milestone 1: PLP Facility Demonstration/Preliminary Design Review (PDR), set for approximately 3QCY19, will involve the demonstration of hardware, software and mission data maturity in the F-16 installation configuration at the facility laboratories of the competing PLPs. This will be followed by Milestone 2: Preliminary Integrated Defense Avionics Laboratory (IDAL) trial, in approximately 4QCY19, where each PLP will have one week in the IDAL facility to run through the Government's pre-defined test scenarios.

At Milestone 3: Government IDAL in 4QCY19, the Government will conduct follow-on, week-long IDAL testing with the measures of performance and capability of interest evaluated and scored. The results will be included in the evaluation criteria for the follow-on production solicitation. Milestone 4: Electronic Warfare Avionics Integration Support Facility (EWAISF), in 1QCY20, will involve Government-conducted testing in the EWAISF to validate early jamming capabilities of the EW Suite system. These results will also be included in the evaluation criteria for the follow-on production solicitation.

At the final Milestone 5: Chamber/Open Air Testing, approximately 4QCY20, the Government will conduct testing in Government chambers and/or open-air testing against threat systems at EW ranges. According to the Air Force, the extent and number of tests will be determined by available resources, schedule and system maturity. The tests will be designed to validate DRWR/aircraft system compatibility, Electromagnetic Interference (EMI), Electromagnetic Control (EMC), as well as test the maturity of DRWR software and mission data against threat systems in a controlled environment

Each PLP will be required to establish a Memorandum of Understanding (MOU) or Memorandum of Agreement (MOA) with Lockheed Martin Aeronautics (LMA) Corporation and agree to work directly with LMA to assist with an integration plan. This will include providing sufficient hardware and software documentation to support the integration of the EW Suite on the F-16. Additionally, an MOU or MOA may be required with Northrop Grumman to support integration and compatibility testing with the APG-83 radar.

The point of contact is Mark Southcott. Phone: 315-330-4590. Email: Mark.Southcott.1@us.af.mil. – *J. Haystead*

HARRIS SUPPORT FOR NULKA ADAP PROGRAM

Harris (Clifton, NJ) has been awarded a $2.1 million contract by the US Naval Sea Systems Command (NAVSEA) to continue support for an updated RF payload developed for the Mk 234 Nulka electronic decoy cartridge.

Known as the Advanced Decoy Architecture Program (ADAP), the payload upgrade effort is intended to field an improved Nulka-X decoy in the US Navy (USN) as a Rapid Deployment Capability to address the advanced anti-ship missile threat. The ADAP payload will also be deployed on Australian Nulka decoys.

The original Nulka decoy combines a hovering rocket payload carrier vehicle (produced by BAE Systems Australia) atop which is mounted a broadband RF repeater payload (produced by Lockheed Martin's Sippican business) that radiates a large ship-like radar cross section designed to seduce RF homing anti-ship missiles away from their intended targets. In USN service, the Nulka decoy round is fired from the Mk 53 Decoy Launching System.

Plans to introduce an improved electronic payload have been led by the US Naval Research Laboratory (NRL) under an upgrade initiative originally known as Enhanced Nulka (E-Nulka). Believed to be based on solid-state Gallium Nitride technology, the E-Nulka upgrade was intended to expand frequency coverage "to counter an emerging class of anti-ship missiles" and covered the engineering development of a new payload receiver, signal processor and transmitter, together with the build of complete payloads, and integration of the completed payload with the Nulka flight vehicle.

NRL's ADAP program is an outgrowth of E-Nulka. Harris was awarded a three-year $54 million ceiling indefinite delivery/indefinite quantity contract in September 2015 to develop and deliver EW payloads under the ADAP effort.

In a justification and approval (J&A) document signed off in November 2017 for other than full and open competition, NAVSEA – through the Naval Surface Warfare Center's Crane Division – said that the ADAP payload program is the result of a NRL-led development effort stretching back to 2010. Under an initial contract, Harris fully tested a captive-carry prototype of the initial ADAP payload, and based on the success of the test, manufactured additional ADAP payloads to be integrated by the Navy with the existing Nulka decoy. "The positive results of this effort gave birth to a second contract with Harris, funded by NRL, to rapidly transition the ADAP payloads and provide rapid deployment capability to the fleet," said NAVSEA.

The J&A document suggests that the ADAP program has in fact spawned two payload variants. Initial payloads were delivered in the first quarter of FY2018, with the next variant of the ADAP payload to be delivered in FY2019. – *R. Scott*

IN BRIEF

BAE Systems (Nashua, NH); **The Boeing Co., Defense, Space & Security** (St. Louis, MO); **General Atomics Aeronautical Systems Inc.** (Poway, CA); **Goodrich Corp., UTC Aerospace Systems, ISR Systems** (Westford, MA); **Harris Corp., Electronic Systems, Integrated Electronic Warfare Systems** (Clifton, NJ); **Lockheed Martin Aeronautics Co.,** (Fort Worth, TX); **Northrop Grumman Aerospace Systems** (Melbourne, FL); and **Raytheon Co.,** (El Segundo, CA), have each been awarded $22,500,000 ceiling indefinite-delivery/indefinite-quantity contracts for the formation of a collaborative working group of various industry partners to develop, evolve, and update the Open Mission Systems and Universal Command and Control Interface standards, collectively referred to as the Open Architecture standards. These contracts, awarded by the Air Force Life Cycle Management Center (Wight-Patterson AFB, OH) provide for the development, updating and management of the above standards with the following business goals: promote adaptability, flexibility, and expandability; support a variety of missions and domains; simplify integration; reduce technical risk and overall cost of ownership of weapon system programs; enable affordable technology refresh and capability evolution; enable reuse; enable independent development and deployment of system elements; and accommodate a range of cybersecurity approaches. The contracts will run through December 2022.

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Raytheon Space and Airborne Systems (El Segundo, CA) received a $16.7 million contract from the Air Force Research Labs, Sensors Directorate (Wight-Patterson AFB, OH) for the Precision Real-Time Engagement Combat Identification Sensor Exploitation (PRECISE) program. The program will primarily develop technologies that continue to advance combat ID for warfighters. PRECISE will leverage current efforts supporting the Air-to-Air Hydravision program, and is principally focused on radar-based identification of air and ground targets for airborne platforms, both tactical and reconnaissance. The effort may investigate other sensors to include electro-optical, infrared, and multi-and hyperspectral. Work will be completed in March 2024. Northrop Grumman won a similar contract in October 2018.

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The **Naval Surface Warfare Center, Crane Division** (NSWC Crane) (Crane, IN) is seeking Cooperative Research and Development Agreement (CRADA) partners for joint research and development in the characterization, test, and evaluation of Counter-UAS threat libraries on multiple host platform sensors. Specifically, program officials are seeking partners with expertise in: 1) evaluation of video processor algorithm's ability to detect, identify, and track small commercial UAS; 2) ability to fuse sensor data from radar and electro-optic sensors to detect, identify, and track small commercial UAS; and 3) validation of a modular open systems architecture (MOSA) for integration into a Government Command and Control software suite according to evaluation criteria. The point of contact is Mrs. Jenna Dix, e-mail jenna.dix@navy.mil.

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The US Army's **Product Manager Vehicle Protection Systems** (PdM VPS) is planning to conduct a "Rodeo" or series of demonstration events to validate the maturity of laser warning receivers (LWRs) and to evaluate their potential for integration onto the Ground Combat Systems (GCS) Combat Vehicle Fleet. This effort would tentatively consist of four phases to ensure maximum competition and potentially result in procurement of systems for the GCS Army ground vehicle fleet. The LWR will be expected to demonstrate platform compatibility and an increase in ground combat vehicle survivability, at a minimum, detect military laser aided threats such as laser range finders (LRFs) and laser target designators (LTDs), and laser beam riding missiles (LBRs). The LWR shall be required to provide rapid warning of threat type and signal direction to the Modular Active Protection System (MAPS) Controller (MAC) via the Modular APS Framework (MAF), as well as signals to enable deployment of obscurants and other electronic warfare countermeasures. The PdM VPS has issued an Ad-Hoc Request for Enhanced White Papers for prototype Modular Active Protection System Framework (MAF) Compliant LWRs under the Ground Vehicle Systems Other Transaction Agreement (GVS OTA) with the National Advanced Mobility Consortium (NAMC). The contracting point of contact is David Patti, (586) 282-8724, e-mail david.m.patti4.civ@mail.mil.

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In a recent announcement, the US Air Force's **Headquarters Air Combat Command** (ACC) said it wants to step up its Technology Interchange Events (TIEs), which are discussions for senior military leaders, industry, academia and other government organizations to "explore emerging technologies with potential applications to combat airpower." Among the potential topics are: 1) Enhanced Air Domain Awareness in Highly Contested Environment (HCE): "Enhanced cross domain data fusion to find, fix and track air targets in a HCE to maximize air domain awareness across multiple platforms and BMC2 nodes." Battlespace Awareness; Battlespace Characterization; Data Fusion; Visualization; 2) Non-Kinetic Effects (NKE) in munitions: complimentary effects and impacts of NKE across the kill chain (F2T2EA) including spectrum management, Directed Energy (DE), high power jamming, network and hardware disruption, A2AD, multi-domain, cyber effects; and 3) Rapid Intelligence source data and identification data-mining and distribution of signals and systems used by adversaries during conflict to facilitate rapid identification and system reprogramming including data-mining, real-time, multi-spectral, Artificial Intelligence (AI), quantum computing, predictive, identification, countermeasures, mission data reprogramming. The point of contact is Andrew Nault, (757) 764-9084, e-mail andrew.nault.1@us.af.mil.

✪ ✪ ✪

The Air Force Research Lab's Directed Energy Directorate, Laser Division (Kirtland AFB, NM) has issued a Closed Broad Agency Announcement (BAA FA9451-19-S-0001) for its new Compact High Energy Laser Subsystem Engineering Assessment (CHELSEA) effort. AFRL, which is developing high energy laser technology for tactical aircraft under the Self-protect High Energy Laser Demonstrator (SHiELD) Advanced Technology Demonstration (ATD), will pursue the CHELSEA effort to help "identify, quantitatively analyze and assess candidate technologies for significant increases in power over the SHiELD design. CHELSEA is intended to identify the most promising technology options to scale laser power by calendar year 2024 as a possible drop-in replacement for the SHiELD laser subsystem (Laser Advancements for Next Generation Compact Environments (LANCE)) or as part of a new, prototype laser system for airborne applications," according to the BAA. The Air Force plans to "use the data and results produced from CHELSEA to help the Government in designing, building and demonstrating a TRL 5 [component and/or breadboard validation in a relevant environment] laser subsystem for subsonic and transonic airborne applications by 2024." AFRL plans to award at least one firm-fixed price contract valued at up to $750,000. The technical point of contact is Dr. Kevin Hewlett, (505) 853-2684, e-mail kevin.hewett@us.af.mil. Proposals are due by February 26.

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The US Army's **Program Manager Unmanned Aircraft Systems** (PM UAS) has issued a Request for Information (RFI) for "Air Launched Effects," (ALE) which is envisioned to be "a family of small, air launched systems that operate as members of a team with other manned and unmanned platforms to penetrate defense-in-depth anti-access and area denial (A2AD) environments and dis-integrate Integrated Air Defense Systems (IADS)." The operational concept calls for these systems to be launched from UAVs, manned helicopters, artillery systems and ground vehicles. The RFI further states, "The ALE family will support interchangeable payloads including capabilities to: 1) detect, identify, locate, report and share information on enemy threats, 2) act as a decoy, 3) disrupt through Electronic Warfare, Cyber effects or other methods and 4) preemptively destroy enemy systems via a kinetic engagement capability. Payloads may be both recoverable and non-recoverable with one or more payloads per ALE to maximize the combination of effects needed for mission success." The contracting point of contact is Carolyn J. Gates, (256) 313-4509, e-mail carolyn.j.gates2.civ@mail.mil.

✪ ✪ ✪

The US Army Tank-Automotive Research, Development, and Engineering Center (TARDEC) has announced plans to award a sole-source R&D services contract to **Michigan Technical University** (Houghton, MI) for Ground Vehicle Survivability and Protection (GVSP). The contract, which includes combat vehicle threat detection and neutralization, as well as countermeasures, among other survivability-related areas, will run through December 2023.

✪ ✪ ✪

Sierra Nevada Corp. (Centennial, CO), won a $23.9 million indefinite-delivery/indefinite-quantity, firm-fixed-price contract from the US Air Force for development and sustainment of the Tactical Systems Emulator (TSE). This contract provides for continued development of the TSE for tactical systems operator airborne signals intelligence terminal guidance training. It also funds new development for direct support operator training, upgrades delivered TSE classrooms, adds a mobile TSE capability, and provides sustainment to delivered systems and software. The contract period extends through December 2022.

✪ ✪ ✪

Harris Corp., Space and Intelligence Systems (Colorado Springs, CO), has won a $72.3 million contract from the Air Force Space and Missile Systems Center) Los Angeles AFB, CO) for the Combat Mission Systems Support (CMSS) program. The company will sustain the Space and Missile Systems Center portfolio of ground-based electronic warfare systems and develop the Counter Communications System (CCS) Block 10.3. The CCS is a deployable jamming system designed to counter adversary satellite communications (including C2, early warning and propaganda) in theater. The contract runs through February 2024.

✪ ✪ ✪

Naval Air Systems Command (Patuxent River, MD) has awarded a $68.9 million contract option to **Lockheed Martin** (Fort Worth, TX) to develop upgrades for the F-35 program's US Reprogramming Laboratory "to execute the Mission Data (MD) programming and reprogramming mission for the F-35 Digital Channelized Receiver/Technique Generator and Tuner Insertion Program (DTIP) and non-DTIP configurations." The contract is scheduled to be completed in May 2021.

✪ ✪ ✪

SRC Inc. (North Syracuse, NY) has received a $13.5 million contract option for the Sensor Beam program managed by the Air Force's 57th Intelligence Squadron at Joint Base San Antonio (Lackland, TX). Under the contract, the company will continue to provide analysis and support for four electronic warfare databases that are used across the DOD and US security partners. The option extends the Sensor Beam contract to January 2020.

world report

BRITECLOUD DECOY SET FOR RAF TYPHOONS

The Royal Air Force (RAF) is introducing the Leonardo BriteCloud expendable active decoy (EAD) into service on its Eurofighter Typhoon FGR.4 fleet, a UK Ministry of Defence (MOD) contract notice has revealed.

This follows the introduction to service last year of the 55-mm diameter BriteCloud radio frequency (RF) countermeasures device on the Tornado GR.4 to meet an Urgent Capability Requirement (UCR).

Integration on Typhoon has resulted from "unforeseen changes in the threat state in theatre", said the MoD. While the specific theater is not identified by the MoD, RAF Typhoons are currently flying operations over Iraq/Syria from Akrotiri, Cyprus, as part of Operation "Shader."

Developed by the EW business of Leonardo (Luton, UK), BriteCloud is a second-generation expendable DRFM jammer designed to provide fast-jet aircraft with effective "end-game" protection against advanced RF-guided missile threats and/or tracking radars. After ejection, the BriteCloud decoy searches and locks onto the highest priority threat; deception techniques include Doppler and false targets in range.

Leonardo, in April 2017, signed a £7 million, three-year contract agreement with the RAF's Rapid Capabilities Office for EAD joint development under the umbrella of Project Arma. Release to service of BriteCloud for the Tornado GR.4 was approved following evaluation of tests carried out by the RAF in the United States in June 2017.

The introduction of BriteCloud to the RAF's Typhoon fleet was publicly disclosed in late 2018 when the MoD's Fast Air Support Team issued a transparency notice for independent safety advice. This advised its intention to single-source System Design Evaluation Ltd for the production of a safety and environmental case report and assurance statement, together with specialist engineering and safety advice "for the introduction of the 55 mm Brightcloud [sic] No 2 Mk 3 Type 2/3 EADs onto the Typhoon Weapon System using the proposed Smart Dispenser System [SDS] as part of [a UCR]".

Saab in July 2018 revealed that it had been contracted by BAE Systems for development of the SDS for the Typhoon aircraft. A company statement said that the development and integration of the SDS, which is the latest generation of Saab's BOP family of pyrotechnic countermeasure dispensers, is being performed at the company's Järfälla (Sweden) site and will complete in the 2020 timeframe. – *R. Scott*

IN BRIEF

- The Deutsche Marine (German Navy) has ordered a second batch of UL 5000K shipboard EW systems (providing radar ESM and radar ECM) from **Indra** for its five new K130 *Braunschweig*-class corvettes currently being built by a consortium led by Lürssen Defence in Bremen. The Deutsche Marine already operates the UL 5000K (marketed by Indra as the Rigel system), on five *Braunschweig*-class corvettes currently in service. The ships are also fitted with the MASS decoy launching system from **Rheinmetall.**
- **The Norwegian Defence Materiel Agency Landkap** (FMA Landkap) has announced plans to issue a Request for Information (RFI) for electronic warfare analysis tools. The agency is particularly interested in an overview of potential suppliers, technical solutions and performance as well as the "on"-period of the delivery. The received information will be used to prepare a Request for Tenders (RFT) which is planned for March 1. The point of contact is Jørgen Hagen Bjørnå, +47 90509459, e-mail: jbjorna@mil.no.
- **Russia's Ministry of Defence** (MOD) said it has deployed new EW equipment with Army units in its Eastern Military District. The Borisoglebsk-2 electronic warfare complex, which "is made up of several machine stations on the basis of a multipuspose armored all-terrain vehicle," was deployed with a motorized rifle unit in the Jewish Autonomous District which is situated along China's northerneastern border. According to the Russian MOD, the complex features "an extended frequency range of radio intelligence and electronic jamming," as well as more powerful jamming against UAVs and RCIEDs.
- **RUAG** and armasuisse (Switzerland's Federal Office for Defense Procurement) have inked a deal to upgrade eight Cougar transport helicopters in service with the Swiss Air Force. According to the company, the upgrade program calls for "new flight management computers, a precision navigation system for instrument flights, a collision avoidance system, which alerts pilots to aircraft in critical proximity, and a system developed by RUAG which emits an audible signal when the rotorcraft leaves a defined flight level." The company will also supply Saab's IDAS-3 self-protection system, which includes the RWS-300 radar warning receiver, the LWS-310 laser warner, the MAW-300 missile warning system and the BOP-L countermeasures dispenser, as well as the EWC300 suite controller. The package is essentially a mid-life upgrade for the Cougars, which were procured in 1998. The work will be performed at RUAG's facility in Emmen and should be completed by mid-2022.

Protection for the

The Evolution of RAF Tornado EW 1982 –

By Richard Scott

The Royal Air Force (RAF) will retire the Tornado GR.4 ground attack aircraft from service at the end of March 2019, bringing the curtain down on an operational career going back to the introduction of the original GR.1 variant some 37 years before. Conceived during the Cold War as an all-weather, low-level strike and reconnaissance platform for missions in the NATO theatre, the RAF's Tornado force went on to win its spurs in operations over Iraq, the Balkans, Afghanistan, Libya and Syria.

During the course of its service, the aircraft has been substantially evolved to reflect new threat environments, different target sets, and changing operational doctrines. That metamorphosis is perhaps best reflected in the transformation of the Tornado weapons fit.

When the GR.1 variant entered service in 1984, it was configured as a low-level delivery platform for 1,000-lb HE bombs, BL755 cluster bombs, the JP233 runway denial dispenser and the WE177 freefall nuclear bomb. In its latter years, the GR.4, flying at medium altitude, has been equipped with an arsenal of precision-guided weapons, specifically the Dual-Mode Brimstone precision missile and the Paveway IV precision-guided bomb (typically used in combination with the Litening III targeting pod) and, in the deep strike role, the Storm Shadow conventionally armed standoff missile.

The evolution of the electronic warfare (EW) and self-protection systems carried by the Tornado in RAF service is also illustrative of the varied nature of the aircraft's roles and missions over time, and the attendant threat change during the same period. Accordingly, the defensive aids suite fitted to the Tornado GR.1/GR.4 has been subject to numerous upgrades during its career – some long-planned, others expedited at speed to meet emergent operational needs – to enhance survivability in the face of both RF and IR threats.

ORIGINS

The Tornado was the product of a trinational development program for a Multi Role Combat Aircraft (MRCA) to meet the needs of Italy, Germany and the United Kingdom (UK). The core program for the three partner nations was the development of the Tornado Interdictor Strike (IDS) variant, which was designed to excel as an all-weather, terrain-following precision bomber. The UK alone developed a modified Air Defence Variant (ADV) to meet its needs for a long-range interceptor to defend UK airspace against the threat of Soviet bombers inbound over the North Sea.

A new tri-national consortium, given the name Panavia, was established in 1969 to manage the design and development of the MRCA and weapon system. Physical production and development of the prototypes was carried out at the principle sites of the aerospace companies which were partners in Panavia, more specifically FIAT Aviazione (subsequently Aeritalia, Alenia Aermacchi, Finmeccanica, and now Leonardo), British Aircraft Corporation (later British Aerospace, now BAE Systems) and MBB (later Deutsche Aerospace then EADS, now Airbus Defence and Space). Final production activities were also split, according to national requirements, between the three principal facilities of the Panavia partners, specifically Warton in the UK, Manching/Augsburg in Germany, and Turin/Caselle in Italy.

For the RAF, the IDS variant – entering service with No. IX (Bomber) Squadron in 1982 as the Tornado GR.1 – provided the service with a long awaited replacement for Strike Command's Vulcans, Buccaneers and reconnaissance Canberras, and RAF Germany's Buccaneers. A total of 228 IDS variant aircraft were delivered to the UK.

The only significant difference between the IDS aircraft constructed for the three nations was that the Tornado GR.1 incorporated an extra fuel tank in the tail fin. The RAF subsequently de-

A Tornado GR.1 from No. 15 Squadron, pictured in its original grey/green camouflage, parked on the flightline at Wright-Patterson AFB in 1987. No. 15 Squadron was the first Tornado unit stationed in Germany. USAF veloped two further specific variants: the GR.1A, optimized for reconnaissance; and the GR.1B, equipped with the Sea Eagle missile for anti-shipping strike missions.

The supply of a radar warner subsystem for the Tornado IDS was inside the bounds of the original tri-national MRCA program. To meet this requirement, Marconi Space and Defence Systems and its Italian counterpart, Elettronica, came together to develop what was known as the Radar Warning Equipment (RWE). This was an E- to J-band radar warning receiver (RWR) system that married Marconi's existing analog crystal video receiver (essentially identical to that in ARI 18223/ARI 18228 RWRs already in RAF service) with a hard-wired logic controller developed by Elettronica. Alerts took the form of audio tones and a simple quadrant indicator.

However, the provision of self-protection electronic countermeasures (ECM) to protect the Tornado from hostile radar-controlled weapon systems was pursued on a national basis. In the UK, the assumption was that Air Staff Requirement 853 (ASR 853) would deliver RAF strike/attack/reconnaissance aircraft with a podded responsive noise jamming capability.

This would in time lead to the development of the ARI 23246/1 Skyshadow self-protection jammer. Borne out of a technology research and development effort established by the UK MoD in the late 1960s to address the requirements of ASR 853, the overall responsibility for delivering a "productionized" pod – originally known as Ajax, and later BG 725 – was in 1972 given to Marconi Space and Defence Systems.

ASR 853 was conceived to provide RAF strike aircraft with an advanced software-controlled, self-screening jammer to counter the tracking radars associated with the Soviet SA-2, SA-3 and SA-6 surface to-air missile (SAM) systems, and the S60 and ZSU 23-4 anti-aircraft artillery (AAA) systems. The requirement called for a self-contained system, housed in an underwing pod, able to detect and identify hostile pulse emitters, pick out the technique required to counter the threat from a number of stored programs, and then automatically set-on "smart" phase noise jamming techniques to "blind" pulse radars across the H-J band.

A Tornado GR.4 takes off from Nellis Air Force Base in Nevada during Exercise Red Flag in 2014.
RAF/CROWN COPYRIGHT

Ajax/BG 725 design activity was well advanced by the time that the Yom Kippur war in October 1973 had revealed the SA-6 "Gainful" SAM system to use continuous wave (CW) semi-active radar homing guidance, and not command guidance as originally postulated. As a result, Marconi Space and Defence Systems completed the study to examine the feasibility of adding a CW capability into BG 725.

The outcome was favorable, concluding that "a performance similar to that provided against pulse radars could be incorporated." The decision was subsequently made to add a CW capability into the BG 725 system, although given the lack of volume remaining within the existing pod shell, it was necessary to graft on additional panniers on either side of the pod. These contained new receiver channels, and a techniques generator for range/velocity deception jamming modulations (the signal output from the latter then being routed through to the TWT transmitters in the main pod).

Airborne trials of what was designated ARI 23246 began in 1976, initially flying on a Buccaneer. The name Skyshadow was formally announced in 1978.

In September 1979, Skyshadow was taken to the United States for a series of trials at the Air Force Electronic Warfare Evaluation Simulator (AFEWES) facility in Fort Worth, TX, over an eight-week period. The success of these trials paved the way for a follow-on program of Skyshadow flight trials, both within the UK and back on instrumented US test ranges. First deliveries of Skyshadow began in late 1980.

ARI 23246/1 Skyshadow was fitted as standard under the Tornado's outer port wing. The other part of the aircraft's self-protection shield was the sleek-looking Phillips Elektronikindustrier BOZ-107 countermeasures pod. Carried on the starboard outer pylon, the BOZ pod (ARI 23336) housed a dispenser system for both chaff and IR flares.

The job of the Skyshadow and BOZ pods was to delay radar acquisition or break lock, those few extra seconds buying time for the Tornado to escape the weapon engagement zone or find terrain cover. Tactics were developed to counter various different types of threat, combining high-speed, low level flight profiles with evasive maneuvering, jamming and the dispensing of countermeasures.

RHWR UPGRADE

While the RWE system was developed to meet the tri-national radar warning requirement for the Tornado IDS, the long-range interceptor role envisaged for the Tornado ADV drove the UK-specific development of a higher performance Radar Homing and Warning Receiver (RHWR) afforded the designation ARI 18241/1.

Feasibility study work was commenced by Marconi Space and Defence Systems in 1977, with a full development and production contract placed the following year. To meet the RHWR requirement, Marconi opted for a scanning dual-superheterodyne receiver. This offered much improved sensitivity over crystal video types, and also provided for the accurate measurement of signal parameters, such as angle of arrival, frequency and pulse width. So instead of just providing threat alert, the RHWR made a far more useful contribution to EW situational awareness.

The antenna configuration adopted on the Tornado F.2, and later F.3 aircraft, reflected this. Large high-band and low-band interferometer arrays, hidden behind dielectric panels, were fitted in the wing roots to provide high-accuracy angle-of-arrival over the frontal aspect; a standard amplitude comparison RF head was sited at the rear of the fin to provide coverage over the rear hemisphere.

ARI 18241/1 also exploited modern signal processing techniques. This provided for improved handling of multiple threats, accurate threat classification and a highly adaptable display system.

Although the RHWR had been conceived to meet the needs of the Tornado ADV, it was not long before its merits were also recognized in relation to the Tornado GR.1. While the original RWE system met its stated performance requirement, it was quickly accepted that the bar had not been set high enough.

Accordingly, it was decided to introduce a lighter weight adaptation of the RHWR into the Tornado GR.1 fleet as a matter of urgency, with priority given to RAF Germany squadrons. Designated ARI 18241/2, this "cut-down" system used the same swept superheterodyne receiver, but with fin-mounted forward- and aft-facing RF antennas only. The RHWR was well received by the Tornado GR.1 community – its improved sensitivity and measurement accuracy providing crews with far more comprehensive threat appreciation than the original RWE.

THOR UPGRADE

Accelerating technological change, as well as the rapid pace of threat development, meant that the RAF was by the mid-1980s looking at a further upgrade to the Tornado GR.1's self-protection suite. Staff Requirement (Air) 907 (SR[A] 907) was driven by two considerations. First, developments in computer processing and capacity would allow significant software-based performance improvements to be embodied in both the RHWR and the Skyshadow pod, which would in turn enhance the aircraft's ability to detect, recognize and counter radar threats. Second, there was a desire to more tightly integrate the RWHR and

Skyshadow systems, which had very much been developed in isolation, with the aim of reducing crew workload and minimizing response time.

Following several years of requirements definition, technology scoping, and commercial negotiation, the MOD in late 1988 awarded the SR(A) 907 contract – given the project name Thor – to what was by then Marconi Defence Systems. Delivering Thor would entail many hundreds of man-years work for the company's Stanmore site; software development would require over 100,000 lines of new Ada code.

The upgrade of the RHWR to what became known as RHWR-2 saw the introduction of a new digital processing unit, a larger memory store (holding an expanded emitter library), and a fast program loader. New de-interleaving algorithms were written that offered the ability to analyze increasingly complex pulse trains, and provide more accurate identification and matching of emitters.

Skyshadow was improved to a new Skyshadow-2 standard. Borrowing RF techniques and digital technologies from Zeus, Skyshadow-2 was given higher fidelity and an expanded repertoire of modulations.

Thor also called for closer integration of the EW assets on the Tornado GR Mk 1, this being predicated on the exploitation of RHWR-2 measurements to cue Skyshadow-2. While Skyshadow-2 retained its integral receiver subsystem, the enhanced sensitivity offered by RHWR-2 would, it was assumed, allow it to detect threats earlier.

Two Tornado GR.4 aircraft prepare to launch from Gioia Dell Colle, Italy, as part of Operation Ellamy in 2011. The BOZ-107 pods have remained a standard fit throughout the aircraft's career.
RAF/CROWN COPYRIGHT

A Tornado GR.4 at Kandahar airfield in Afghanistan. The BOL-300 dispenser rails (fitted to the inboard weapon pylons) are clearly visible in this photograph. RAF/CROWN COPYRIGHT

The Thor EW suite achieved its in-service date in May 1994. However, the aspirations contained within SR(A)907 for the retrospective integration of RHWR-2 and Skyshadow-2 into a federated suite was never fully realized. Fundamentally, it proved too difficult to reconcile the competing logics within two essentially standalone systems and, in the end, a fully holistic integration was not achieved.

Consideration was also given to fitting the Tornado GR.1 with the Plessey PVS2000 pulse-Doppler radar missile approach warner. A fin-mounted antenna installation was developed and flight tested (using a Canberra trials aircraft) but the program was abandoned in 1991 on cost grounds.

POST-COLD WAR

The early 1990s were a time of profound and far-reaching change for the RAF. The fall of the Berlin Wall, the subsequent break-up of the Soviet Union, and the lessons of the air campaign over Iraq in 1991 – during which two Tornado GR.1 aircraft were brought down by SAMs and two more likely lost to AAA in the initial low-level phase of the campaign – forced the fundamental reappraisal of air power doctrines and operational tactics that had been developed for a Cold War confrontation in central Europe. Having for three decades been equipped and trained to fly fast and low, the RAF would now find itself adapting its posture and moving to a new way of air warfare that emphasized the precision delivery of smart munitions from medium altitude. This required new thinking on platform survivability and self-protection.

The 1991 Gulf War had, of course, demonstrated that things could be done differently. Indeed, the US Air Force had been championing the shift to operations at medium level for some time before, believing that the balance of risk now militated against ultra-low level ingress. This view was based on an analysis of many factors, including very high pilot workload, the ever-present danger of controlled flight into terrain or other ground obstacles, reduced situational awareness, the difficulty inherent in acquiring the right target, the risk of hitting the wrong target or missing altogether, and exposure to concealed very low-level air defenses in the shape of concentrated AAA and man-portable air-defense systems (MANPADS).

In contrast, operations at medium altitude were perceived to afford advantages with regard to reduced workload, greater target acquisition time, improved weapons delivery, and a reduced training burden in peacetime. Aircraft would also be outside of the AAA and MANPADS threat envelope. And, perhaps most significantly, aircrew could fully exploit the capability of the new generation of stand-off targeting and precision-guided weapons then coming into service.

But while the move to medium level took offensive air assets out of the AAA hornet's nest, it at the same time meant that aircraft were increasingly obliged to operate in the middle of the SAM missile engagement zone (MEZ). Moreover, while exposure to the threat tended to be fleeting while flying fast and low, operations at medium altitude left platforms vulnerable to many more threat systems, and for far longer periods of time. This reality had been brought home by the loss of a Tornado GR.1 to a SAM during a medium-level laser-guided bomb sortie in the latter stages of the Gulf War air campaign.

In response, tactical development work was undertaken by the RAF to hone clever combinations of chaff, High-G maneuvers and jamming to defeat the SAM threat. Trials performed over fully instrumented US ranges against Soviet-origin equipment provided the evidence that these new variations on the classic ploy of "chaff, jink, jam" remained absolutely relevant to aircraft "locked up" in the heart of the MEZ.

GR.4 UPGRADE

The upgraded Tornado GR.4, developed to meet Staff Requirement (Air) 417, entered operational service in 2001. Embodying improved capabilities in the medium-altitude role – in part based on lessons learned from the GR.1's performance in the 1991 Gulf War – the GR.4 standard introduced a new forward-looking infrared sensor, cockpit improvements, night-vision goggle compatibility, targeting pod integration and an integrated Global Positioning/Inertial Navigation System. The GR.4A reconnaissance sub-variant received the RAPTOR pod.

No specific changes were made to the GR.4 self-protection suite as part of the upgrade. However, under an Urgent Operational Requirement (UOR) for Operation 'Telic' (the 2003 Iraq War), new defensive aids hand-controllers were installed in the rear cockpit, and BOL-300 dispenser rails introduced as part of the pylon-mounted rail launcher fit associated with the AIM-9 Sidewinder missile.

Informed by operational experience in the Balkans in the 1990s, where UK air assets had run the gauntlet of medium-range SAM systems operated by well-trained and highly-skilled Serb air defense crews, the RAF had in the late 1990s begun to develop plans for a new fast-jet countermeasures capability under the title Integrated Platform Countermeasures (IMPC). At its outset, the IMPC program was looking at RF and IR defensive aids capabilities across the RAF's offensive air fleet.

By 2002, IMPC had morphed into the Modular Defensive Aids System (MoDAS), and was focused solely on providing the Tornado GR.4 with an upgraded self-protection suite "to provide modern RF and IR countermeasures against a variety of threats, primarily guided missiles, to enable aircraft survivability and mission success in the present and future operating environments."

The MoDAS requirement called for a modular solution to allow for incremental acquisition, and a podded installation to enable a mission-specific role fit across the Tornado fleet. In its initial instantiation, the system was expected to focus on RF threats, with additional equipment to be added modularly through incremental upgrades to meet the full system requirement.

Owing to the short timescale – an in-service date of 2006 was postulated – and limited available budget, it was anticipated that the requirement would be met by military off-the-shelf equipment procured through competition. Interested parties were invited to register their interest in mid-2002 in expectation of an Invitation To Tender (ITT) the following year. The MoD notified industry that it planned to hold full system assessment trials as part of the procurement process.

The MoDAS ITT was released in January 2003 to BAE Systems Avionics (which had taken over the EW activities of Marconi following its acquisition of GEC's Marconi Electronics Systems business in 1999), EADS Systems and Defence Electronics, Saab, Elta Systems, Thales, ITT and Northrop Grumman. Out of these, ITT, Northrop Grumman, and Saab were downselected to loan systems for MoD trials ahead of a follow-on tender for equipment supply.

In the event, other equipment priorities ultimately saw the MoDAS program cancelled in 2004. Yet, with the Tornado GR.4 at that stage still expected to remain in service until 2025, there was a recognition within BAE Systems Avionics' EW Division that up-front investment was needed to develop an enhanced Skyshadow pod. So was born an internally-funded technology demonstration project, named Loki, which saw the build of a demonstrator pod incorporating a proprietary Compact TG digital techniques generator, and integrating a Towed Radar Decoy (TRD). The Loki test-bed was successfully flown and tested by the RAF, although no production contract was forthcoming.

INTO AFGHANISTAN

In 2009, with commitments in Iraq at an end, the RAF deployed the Tornado GR.4 into Kandahar as part of Operation "Herrick" (the UK contribution to the

The Terma AIRCM pod (visible under the starboard outer wing pylon) was introduced as a UOR for operations in the Afghanistan theatre. RAF/CROWN COPYRIGHT

International Security Assistance Force in Afghanistan). Replacing the Harrier in-theater, the aircraft found itself roled for close air support missions.

Given the perceived MANPADS threat, an Urgent Operational Requirement (UOR) was raised to provide the Tornado GR.4 with a podded Advanced Infrared Countermeasures (AIRCM) system. The absence of RF threats in theater meant the AIRCM pod could replace the Skyshadow-2 pod on the port outer pylon.

The implementation of the improved self-protection capability was led by BAE Systems as aircraft Design Authority. Terma developed the AIRCM pod itself, adapting its Modular Countermeasures Pod (featuring six radial-dispensing countermeasures magazines as standard) with the addition of two forward firing flare dispensers and six sensor heads for the AN/AAR-57 Common Missile Warning System. The AIRCM fit was completed by the integration of a Terma AN/ALQ-213(V) EW Management System and a tactical data unit in the cockpit.

Flight test and integration activities began in the first quarter of 2009 from BAE Systems' Warton airfield; the AIRCM capability was deployed into theatre with No.12 Squadron from June 2009. While procured as a UOR for "Herrick," the AIRCM fit was subsequently retained as a core fit.

RETURN TO RF SELF-PROTECTION

Tornado GR.4 operations over Libya in 2011 as part of Operation "Ellamy" provided a wake-up call that the radar threat was again a top EW priority. In 2012, what was then Selex ES – now Leonardo Airborne & Space Systems – was awarded a Skyshadow sustainment feasibility study, the outputs of which provided the basis to satisfy an Urgent Capability Requirement for a new Common Jamming Pod (CJP) to restore and sustain the RF self-protection capability of the GR.4 to end-of-life.

The CJP program was based on the recapitalization and re-architecture of existing Skyshadow-2 pods to meet current and anticipated radar threats. In particular, the CJP design was optimized to reflect the fact that the Tornado GR.4 was now largely operated at medium altitude.

While retaining the outline of the legacy Skyshadow pod, the CJP was essentially new inside the shell. Work involved the replacement of the entire receiver chain, the introduction of a new digital control unit to replace the old PEC, a new Core TG digital techniques generator, an update of the existing TWT transmitters, and the installation of new waveguides and switching units. In addition, two Towed Radar Decoys (TRDs) – identical to those in service with the Typhoon aircraft – were incorporated in the aft part of the pod together with their associated power supply.

Initial funding was approved in 2013 to mature the program, with a contract for CJP demonstration and manufacture following in early 2014. The first "B" model pod was released for ground testing in January 2015, with instrumented flight testing performed during mid-2015. Operational evaluation testing of two "B" model pods in the United States followed in December 2015.

The original intention was to deliver an Initial Operating Capability by the end of 2015. In the event, the scale of the software task, and the need to validate structural/aerodynamic clearances, injected delays into the program, and the CJP pod eventually achieved an in-service date in July 2017. Due to the lack of utility for operational employment, the pods were subsequently placed in storage.

However, that was not the end of efforts to improve the survivability of the Tornado GR.4 in hostile RF environments. In April 2018 the Leonardo Airborne & Space Systems BriteCloud expendable active decoy (EAD) entered operational service with the Tornado force following qualification performed in conjunction with the RAF's Rapid Capabilities Office (RCO).

Dispensed from the Saab BOZ 107 countermeasures pod, the 55-mm diameter BriteCloud device is a new-generation DRFM-based EAD designed to provide effective "end-game" protection against advanced radar-guided missile threats and/or tracking radars (such as those associated with the Russian S-300/S-400 series systems). The DRFM's coherent response prevents the threat from detecting the deception as the decoy separates, so generating large miss distances and breaking the target lock.

Leonardo and the RCO have worked to introduce BriteCloud into RAF service under a £7 million contract agreement, known as Przoject Arma, signed in April 2017. Release to service followed a series of tests carried out by the RAF in the United States in June 2017 during which several dozens of BriteCloud decoys were dispensed from Tornado GR.4 aircraft against a range of threat radar systems.

The RAF will retire the GR.4 from service next month. In its last missions, the Tornado has supported Operation "Shader," the UK's contribution to coalition air operations over Syria and Iraq. Within the RAF, the GR.4's role will be assumed by Typhoon aircraft and the F-35B.

ALARM Call: Defense Suppression from the RAF Tornado

UK Ministry of Defence studies undertaken in the 1970s, informed by US suppression of enemy air defenses (SEAD) experience over Vietnam and growing concern over the proliferation of Soviet mobile air defense systems, highlighted the need for investment in a more robust defense suppression capability, and shaped requirements for a new anti-radiation missile. These were captured in Air Staff Requirement 1228 (ASR 1228), issued in 1978.

ASR 1228 stipulated a guided weapon solution that was sufficiently autonomous to allow for launch from a combat aircraft without a dedicated emitter location system; able to be launched from aircraft flying at high speed and very low altitude from outside the range of hostile air defense systems; and sufficiently small and lightweight to maximize the number of rounds carried by the Tornado GR.1. This defense suppression capability was judged essential to reduce aircraft attrition.

The ALARM missile provided the Tornado with a highly effective lethal SEAD capability.

RAF/CROWN COPYRIGHT

British Aerospace (BAe) Dynamics and Marconi Space and Defence Systems completed a feasibility study, only for the requirement to be shelved in 1979. ASR 1228 was resurrected in 1982, with the choice coming down to the US AGM-88 High Speed Anti-Radiation Missile (HARM) being bid essentially off-the-shelf by Texas Instruments with UK partner Lucas Aerospace, and the rival Air-Launched Anti-Radiation Missile (ALARM) proposed by BAe and Marconi.

Although carrying a somewhat higher level of developmental risk, ALARM was touted as more flexible and effective than HARM. Most notably, the weapon offered a loiter mode, being able to climb after launch to around 40,000 ft, deploying a parachute while it searched for threat emitters, then diving directly onto the selected target.

Following an intense industrial and political battle, ALARM was selected in July 1983, with BAe Dynamics (later subsumed into MBDA) receiving a £400 million full development and production contract. Marconi Space and Defence Systems took its place as principal subcontractor and Design Authority for the passive broadband seeker.

State-of-the-art for its time, the two-stage, four-channel superheterodyne receiver employed novel RF signal processing techniques allowing it to analyze the millions of pulses being received to select a target radar according to pre-programmed emitter types and priorities. This borrowed from software sorting algorithms already embodied in Marconi's RHWR systems.

In loiter mode, with the missile descending slowly beneath a small parachute, the ALARM seeker would "listen" for radar emissions pre-programmed into the threat library. Once a hostile emission had been detected, the missile would jettison its parachute, reactivate the motor and dash towards the source of the emission before detonating its high explosive fragmentation warhead and destroying the radar.

Furthermore, ALARM had a clever trick up its sleeve to overcome the radar operators' traditional "switch-off" ploy: if an emitter was detected, but then deactivated, the missile seeker could "remember" its position and execute its attack regardless.

ALARM development was protracted, largely as a result of the need to replace the original Nuthatch rocket motor with an alternative design, with the missile only completing trials in October 1990. By this time, the Cold War was thawing fast.

Notwithstanding, the ALARM missile found an early opportunity to demonstrate its worth during the 1991 Gulf War, with over 120 missiles fired as part of Operation "Granby" (the UK's contribution to the liberation of Kuwait). ALARM was subsequently used in support of NATO's Operation "Allied Force" over Serbia and Kosovo in 1999.

The increasing sophistication of threat radars and anti-radiation countermeasures saw an ALARM seeker mid-life update program instigated in the mid-1990s under Staff Requirement (Air) 1247. This improved seeker entered service in the early 2000s and was employed by Tornado GR.4 aircraft in 2003 during Operation "Telic" (the UK's contribution to the US-led assault on the regime of Saddam Hussein). Around 45 ALARM missiles were fired in support of Telic.

ALARM was retired from RAF service at the end of 2013. – *R. Scott*

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DIXIE CROW SYMPOSIUM XLIV

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MARCH 24-27, 2019 // MUSEUM OF AVIATION, ROBINS AFB, GA

KEYNOTE SPEAKER
Brig Gen Hersey, Commandant Cyber School – Fort Gordon

BANQUET SPEAKER
Lt Gen Bradley Heithold, USAF (ret)

SCHEDULE OF EVENTS

SUNDAY, MARCH 24

Registration	Marriott Courtyard, Warner Robins, Georgia	5:00 PM-8:00 PM
Hospitality Suite	Marriott Courtyard, Warner Robins, Georgia	5:00 PM-8:00 PM

MONDAY, MARCH 25

Registration	Landings Golf Club	10:00 AM-2:00 PM
Spring Golf Tourney	Landings Golf Club	12:00 PM-5:00 PM
Registration	Century of Flight Hangar, Museum of Aviation	2:30 PM-5:00 PM
Sports Banquet and BBQ Dinner	Landings Golf Club	5:00 PM-7:00 PM

TUESDAY, MARCH 26

Registration	Century of Flight Hangar, Museum of Aviation	7:00 AM-6:00 PM
Plenary Session	Scott Theater, Eagle Building, Museum of Aviation	8:00 AM-11:00 AM
Exhibits Open	Century of Flight Hangar, Museum of Aviation	11:00 AM-7:00 PM
Chapter President's Mtg	Century of Flight Hangar, Museum of Aviation	11:30 AM-1:00 PM
Exhibitor Reception	Century of Flight Hangar, Museum of Aviation	5:00 PM-7:00 PM

WEDNESDAY, MARCH 27

Registration	Century of Flight Hangar, Museum of Aviation	7:00 AM-2:00 PM
Exhibits Open	Century of Flight Hangar, Museum of Aviation	10:00 AM-3:00 PM
Crows N.E.S.T.	Century of Flight Hangar, Museum of Aviation	10:00 AM-2:00 PM
Banquet	Nugteren Exhibit Hangar One	Cocktails – 5:30 PM-6:30 PM Dinner – 6:30 PM-8:30 PM

6TH ANNUAL THE CROW'S

N.E.S.T.

(Novel Experiments with Science & Technology)

WEDNESDAY, MARCH 27 // 10:00 A.M. - 2:00 P.M.
// MUSEUM OF AVIATION CENTURY OF FLIGHT HANGAR

The Dixie Crow Chapter of the Association of Old Crows Science, Technology, Engineering, and Mathematics (STEM) Robotics displays and technology demonstrations, are an interactive experience that will capture the minds and hearts of students, parents and teachers. The displays are a collaborative effort between local military, government civil service, academia, defense industry and volunteers designed to inspire students to pursue STEM careers. Interacting with the robotics displays and technology demonstrations will demonstrate to students that STEM can be both fun and engaging. Enthusiastic workers in STEM fields will also be on hand to answer questions and help students learn how they can prepare to enter the exciting world of STEM. Make time to visit and participate in our Crows N.E.S.T. displays and technology demonstrations.

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If you have any questions and/or would like to participate, please feel free to contact:
Robert Usher at Robert.Usher@us.af.mil (478) 222-0022
Event open to Students age 8 and up.

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Our Symposium Committee, Dixie Crow Chapter President, Matthew Bryant, and the Chapter Directors cordially invite you to join us for all the exciting events described here. Thank you in advance for your support of this important electronic warfare/information operations trade show.

Sincerely, Karen Brigance, *Co-Chair* | kkbrigance@gmail.com
Lisa Frugè-Cirilli, *Co-Chair* | lisa.fruge@baesystems.com

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TECHNOLOGY SURVEY
A SAMPLING OF ADCS AND DIGITIZER BOARDS

By Barry Manz

Analog-to-digital converters (ADCs) are arguably some of the most critical components in any EW, radar, communications system and RF and microwave instruments as well. They are the first devices after analog signal capture, so their sampling rate, bandwidth, spurious-free dynamic range, and other characteristics set the benchmark for what the subsystems following them can achieve. So, it's not surprising that ADCs and the digitizer boards that employ them are subjects of intensive development efforts, and it's resulted in device performance that only a few years ago would have been unimaginable.

Digitizer boards today pack vast amounts of real-time processing capability, gigabytes of data acquisition memory for each channel, massive I/O options from high-speed serial to parallel LVDS, GPIO, and Gigabit Ethernet, and other features that collectively form comprehensive subsystems that provide multiple phase-coherent channels in a single slot.

FPGAs are now mandatory components in these subsystems as they provide unmatched flexibility and the ability to process radar and electronic warfare applications such as target generation, jamming, advanced processing algorithms including multichannel algorithms found direction-finding, Space Time Adaptive Processing (STAP) radar, ELINT, and Synthetic Aperture Radar (SAR) image formation.

Test and measurement systems are among the primary drivers of ADC development, as instrument makers must have the seeming clairvoyance to determine future customer needs and provide test solutions for them before the systems they test are even available. As a result, test equipment, such as real-time spectrum analyzers, oscilloscopes, and other instruments require the best ADCs available, with resolution up to 14 bits, spurious-free dynamic range above 75 dB, and sampling rates of 12 Gsps (and higher) with bandwidths up to 6 GHz. However, ADCs with higher performance have been developed but are typically proprietary to their creators (such instrument companies) or whose performance is classified as they are designed for extremely high-performance digital RF memories or other defense systems.

All these applications have one thing in common: the need to meet the requirements of systems that are operating at higher and higher frequencies in which direct sampling is used to directly convert analog signals to the digital domain after passing through only a low-noise amplifier and bandpass filter. In contrast, a traditional heterodyne receiver performs this conversion process after a bandpass filter, low-noise amplifier, mixer, and local oscillator, requiring downconversion to a lower intermediate frequency (IF).

Another technique called interleaving, which has been available for decades, is now increasingly used to dramatically increase sampling rates through multiple, identical, ADCs with a precisely-controlled time relationship. That is, if an ADC has 1 Gsps sampling rate, four could theoretically achieve 4 Gsps. The big benefit is increasing bandwidth by broadening the Nyquist zone of the interleaved ADCs. It also makes frequency planning easier and reduces the design complexity (and thus cost) of the anti-aliasing filter required at the input of the ADCs.

Of course, there being no ideal solution; interleaving is not only complicated but has disadvantages that must be overcome by the greatest possible amount, which is not simple either. The main issue is dealing with the spurious responses (spurs) that appear in the ADCs' output that are caused by mismatches in gain, timing, bandwidth and offset between the devices. Fortunately, advances in the calibration of channel mismatch and suppression of the spurious signal content allows very-high-speed 12-, 14-, and 16-bit interleaved ADCs to be realized.

THE SURVEY

This survey includes ADCs (as standalone components) and digitizer boards (with ADCs mounted on them). In the table, the first column lists the model number – whether it is an ADC or a digitizer board. The second column lists the ADC (if it is mounted on a digitizer board). The next column indicates the number of channels, followed by the number of bits of resolution. Note that the number of bits of resolution and the effective number of bits (ENOB) are not the same figure. The ENOB defines the number of bits that actually contain useful information. The reason the ENOB figure does not equal the actual number of bits is because analog-to-digital performance is degraded by noise distortion. ENOB can be approximated using the theoretical Signal-to-Noise (SNR) of the ADC and the following equation; $ENOB = (SNR-1.76dB)/6.02$. The sample speed defines the maximum rate at which the ADC can be operated without distortion in the measurements. Further along, in the "Features" column, you will see that many digitizer boards also provide digital to analog converters (DACs), as part of a transceiver architecture.

Next month, we will look at benchtop and rack-mount spectrum analyzers.

ANALOG TO DIGITAL CONVERTERS

Product Name or Model Number	ADC Model Number	Channels	BITS	EFF BITS	SAMPLE SPEED
Analog Devices; Norwood, MA, USA; +1 781-329-4700; www.analog.com					
AD9208	AD9208	2	14	9.6 @ 2.1 GHz	3 Gsps
AD9684	AD9684	2	14	11.8	500 Msps
AD9689	AD9689	2	14	9.6 @ 2.1 GHz	2.6 Gsps
Teledyne e2v; Chelmsford, Essex, UK; +44 (0) 1245 493493; www.teledyne-e2v.com					
EV12AS350A	EV12AS350A	1	12	8.9	5.4 Gsps
Texas Instruments; Dallas, TX, USA; +1 512-434-1560; www.ti.com/dataconverters					
ADC12DJ3200QML-SP	ADC12DJ3200QML-SP	1 or 2	12	9	6.4 Gsps
ADC12DL3200	ADC12DL3200	1 or 2	12	9	6.4 Gsps
ADC32RF45	ADC32RF45	2	14	10	3 Gsps

DIGITIZER (ADC) CARDS AND BOARDS

Product Name or Model Number	ADC Model Number	Channels	BITS	EFF BITS	SAMPLE SPEED
Abaco Systems; Huntsville, AL, USA; +1 866-652-2226; www.abaco.com					
FMC163	ADC12D2000RF	2	12	9.3	4 Gsps
FMC134	ADC12DJ3200	4	12	9.3	6.4 Gsps
FMC172	ADC12DL3200	2	10	*	6.4 Gsps
Annapolis Micro Systems; Annapolis, MD, USA; +1 410-841-2514; www.annapmicro.com					
WILDSTAR 6XBU Ultra-Wide-Bandwidth Digitizer & Processor	*	2/4	10	7	32/16 Gsps
WILD FMC+ GM60 ADC & DAC	Xilinx Zynq UltraScale+ RFSoC: ZU25DR, ZU27DR, or ZU28DR	4	12	*	4 Gsps
WILD FMC+ 8A30 ADC	ADI AD9689-2000, AD9689-2600, or AD9208-3000	2/4/8	14	*	3/2.6/2 Gsps
ApisSys SAS; Archamps, France; +33 450360758; www.apissys.com					
AV122	AD9208	8	14	9.6 @3.2GHz, -10dBFS	3 Gsps
AV125	EV12AS350	1	12	9 @2.1GHz, -10dBFS	5.4 Gsps
AV129	AD9208	4	14	9.6 @3.2GHz, -10dBFS	3 Gsps

INPUT BAND	SPUR	FORMAT	ENVIRONMENT	FEATURES
5 GHz	70 dBFS	196-Ball BGA	–40°C to +85°C	Four integrated, wideband decimation filter and NCO blocks supporting multiband receivers.
2 GHz	85 dBFS	196-Ball BGA	–40°C to +85°C	Designed for communications, SDR, ultrawidebandwidth satellite receiver, radar and instrumentation.
5 GHz	73 dBFS	196-Ball BGA	–40°C to +85°C	Wide, input –3 dB bandwidth of 9 GHz supports direct radio frequency (RF) sampling of signals up to about 5 GHz.
4.8 GHz	68 dBFS	EBGA380	-40°C to +125°C	Combines signal digitization at 5.4GSps, input bandwidth in excess of 4.8GHz.
10 GHz	67 dB	196-pin CLGA	-40°C to +85°C	Dual channel mode, up to 3.2 Gsps; sngle-channel up to 6.4 Gsps.
8 GHz	70 dBFS	256-pin GCBGA	-40°C to +85°C	Applications include COMINT, ELINT and test instrumentation.
3.2 GHz	66 dBc HD2, HD3	72-pin VQFN	-40°C to +85°C	The ADC32RF45 device is a 14-bit, 3.0-Gsps dual-channe ADC that supports RF sampling with input frequencies up to 4 GHz and beyond.

INPUT BAND	SPUR	FORMAT	ENVIRONMENT	FEATURES
4.5MHz-3GHz	*	FMC	0°C to +70°C (commercial) -40°C to +85°C (industrial)	Provides one 12-bit A/D channel at 4 Gsps and one 14-bit A/D channel at 5.7 Gsps; low latency LVDS interface
5MHz-4GHz 1.7GHz-6.7GHz	*	FMC+	0°C to +50°C (commercial) -40°C to +71°C (industrial)	Provides four 12-bit A/D channels at 3.2 Gsps or two channels at 6.4 Gsps; JESD204B interface
>6GHz	*	FMC	*	Provides two 10-bit A/D channel at 3.2 Gsps or one channel at 6.4 Gsps, and one 10-bit D/A channel at 6 Gsps.
13.0GHz	60 dBc	6U OpenVPX	-40°C to +85°C (air or conduction cooled)	Digital outputs at least 24 I/O @ 28Gbps each = 672Gbps
	*	FMC or xVPX	-40°C to +85°C (air or conduction cooled)	Operates as a standalone “brick” that is 1/3 smaller & lighter than 3U VPX, or pair with 3U or 6U Baseboard for additional processing.
6.0GHz	*	FMC	-40°C to +85°C (air, conduction or air-flow-through cooled)	Pair with WILDSTAR 3XB0 Baseboard for a complete 3U solution. WFMC+ interface supports 100 LVDS, 32 HSS, and I/O Card stacking.
6 GHz	67dBc @3.2GHz, -10dBFS	3U OpenVPX	0°C to 55°C (air cooled), -40°C to 85°C (conduction cooled)	Octal 14-bit 3 Gsps ADC with Kintex UltraScale FPGA KU115
5.4 GHz	55dBc @2.1GHz, -10dBFS	3U OpenVPX	0°C to 55°C (air cooled), -40°C to 85°C (conduction cooled)	Ultra low latencty ADC/DAC (EV12DS460) DRFM with Kintex UltraScale FPGA KU115
6 GHz	67dBc @3.2GHz, -10dBFS	3U OpenVPX	0°C to 55°C (air cooled), -40°C to 85°C (conduction cooled)	Quad 14-bit 3 Gsps ADC, quad 16-bit 12 Gsps DAC (AD9162) with Kintex UltraScale FPGA KU115

DIGITIZER (ADC) CARDS AND BOARDS

Product Name or Model Number	ADC Model Number	Channels	BITS	EFF BITS	SAMPLE SPEED
Curtiss-Wright Defense Solutions; Ashburn, VA, USA; +1 613-254-5112; www.cwcdefense.com					
VPX3-530	ADC12D2000RF	4 or 2	12	8.6 @ 498MHz (2 GSPS)	4 or 2 Gsps
VPX3-534	ADC12DJ3200	4 or 2	12	8.4 @ 498MHz	6 or 3 Gsps
CHAMP-WB-A25G	HFD204	1	8	5.9 @ 4GHz	25 Gsps
Delphi Engineering Group; Irvine, CA, USA; +1 949-537-7701; www.delphieng.com					
ADF-D3030	AD9208	Dual	14	*	3.0 Gsps
ADF-Q3114	AD9208	Quad	14	*	3.1 Gsps
DAC-Q30	AD9172	Quad	16	*	12.6 Gsps
DynamicSignals LLC; Lockport, IL, USA; +1 800-567-4243; www.gage-applied.com					
EON Express	*	1 or 2	12	8.7	6 Gsps
RazorMax Express	*	2 or 4	16	12	1 Gsps
Razor Express	*	2 or 4	16	11.7	200 Msps
Innovative Integration; Camarillo, CA, USA; +1 805-383-8994; www.innovative-dsp.com					
FMC-500M	AD9684	2	14	10.9	500 Msps
FMC-1000	AD9680BCPZ-1250	2	14	10.8	1.25 Gsps
X6-1000M	ADS5400	2	12	8.9	1 Gsps
Mercury Systems; Andover, MA, USA; +1 978-256-1300; www.mrcy.com					
DCM6212	ADC12DL3200	2	12	7.5	6.4 Gsps
DCM6112	ADC12DL3200	4	12	8.4	3.2 Gsps
DCM3110	ADC12D2000	4	12	8.9	2.0 Gsps
Pentek; Upper Saddle River, NJ, USA; +1 201-818-5900; www.pentek.com					
Model 5950	*	8	12	*	4 Gsps
Model 71141	TI ADC12DJ3200	2	12	*	6.4 Gsps
Model 71141	TI ADS42LB69	8	16	*	250 Msps

INPUT BAND	SPUR	FORMAT	ENVIRONMENT	FEATURES
1.5 GHz	62 dBc @ 498 MHz (2 GSPS)	3U VPX	0°C to 50°C or -40°C to 71°C (air cooled) -40°C to +85°C (conduction cooled)	Dual or quad ADC channels, dual DAC channels, user programmable Virtex-7 VX690T FPGA.
8 GHz (preliminary)	62 dBc @ 1.013 GHz (3 GSPS, preliminary)	3U VPX	-55°C to +71°C (conduction cooled)	Dual or quad ADC channels, dual DAC channels, user programmable Kintex UltraScale KU115 FPGA.
15 GHz	44 dBc @ 8 GHz	6U VPX	0°C to 50°C (air cooled)	User programmable Virtex-7 VX690 FPGA. VxWorks and Linux support.
*	*	FMC	Convection and Conduction	Dual ADC/Dual DAC 3.0 GS/s
*	*	FMC+	Convection and Conduction	Quad 3.1 GS/s Channels w/DDC
*	*	FMC+	Convection and Conduction	12.6 GS/s w/Interpolation
1.75 GHz	70 dBFS	PCIe	0°C to 50°C (air cooled)	4+ GB/sec continuous data streaming rate; eXpert FPGA processing signal averaging; 8 GB onboard RAM
700 MHz	75 dB	PCIe	0°C to 50°C	4+ GB/sec continuous data streaming rate; eXpert FPGA processing signal averaging; 8 GB onboard RAM
125 MHz	86.6 dB	PCIe	0°C to 50°C	2 GB/sec continuous data streaming rate; eXpert FPGA processing signal averaging; 16 GB onboard RAM
500 MHz	81.7 dB	FMC	-40°C to +85°C	Features a dual-channel, 14-bit 500Msps A/D device plus a dual 1200 MSPS update rate DAC device.
1.3 GHz	84.1 dB	FMC	-40°C to +85°C	Features two 1000 or 1250-Msps A/D channels and two 1230-Msps D/A channels supported by sample clock and triggering features.
2 GHz	68 dB	PCI Express XMC	-40°C to +85°C	Features two, 12-bit 1 GSPS A/Ds and four 500 MSPS 16-bit DACs.
*	*	6U OpenVPX	0°C to 40°C (air cooled)	EnsembleSeries DCM6212 - 2Rx, 2Tx Open VPX w/ Front I/Oand V67 RIO options.
*	*	6U OpenVPX	0°C to 40°C (air cooled)	EnsembleSeries DCM6112 - 4Rx, 4Tx Open VPX w/ Front I/O and V67 RIO options.
*	*	3U OpenVPX	0°C to 40°C (air cooled) -40C to 85C (conduction cooled)	EnsembleSeries DCM3110 oVPX w/ Front I/O. 2 12-Bit, 3GSPS ADCs (or 4 12-Bit, 2GSPS ADCs), 2 12-Bit, 3GSPS DACs, 1 KU115 FPGA + 4GB DDR4 SDRAM
4 GHz	<-70 dBFS @ 900 MHz	3U VPX	-20°C to 65°C (L2) -40°C to 70°C (L3)	Also features 8-channel, 14-bit D/A offering 6.4 Gsps; includes dual 100 GigE optical interface.
8 GHz	-67 (-1 dBFS) @ 347 MHz	XMC	-20°C to 65°C (L2) -40°C to 70°C (L3)	Also features 2-channel 14-bit D/A offering 6.4 Gsps.
700 MHz	-87 (-1 dBFS) @ 170 MHz	XMC	-20°C to 65°C (L2) -40°C to 70°C (L3)	Dual channel A/D & D/A with Kintex UltraScale FPGA.

DIGITIZER (ADC) CARDS AND BOARDS

Product Name or Model Number	ADC Model Number	Channels	BITS	EFF BITS	SAMPLE SPEED
Red Rapids; Richardson, TX, USA; +1 972-671-9570; www.redrapids.com					
Model 273	AD9652	2	16	12.1	310 Msps
Model 277	ADS42LB69	4	16	11.9	250 Msps
Model 278	AD9653	8	16	12.5	125 Msps
Sundance DSP; Reno, NV, USA; +1 775-827-3103 (West), +1 514-684-8315 (East); www.sundancedsp.com					
FMC-ADC500-5	ADC31JB68	5	16	11.3	500 Msps
FMC-DAQ2p5	ADC12J2700	1	12	8.8	2.7 Gsps
FMC-SDR400	AD9361	2	12	8.8	2700 Msps
VadaTech, Inc.; Henderson, NV, USA; +1 702-896-3337; www.vadatech.com					
VPX570	EV12AS350A	1	12	8.9	5.4 Gsps
AMC598	AD9208	4	14	9.6	3 Gsps
AMC587	TI ADC12DJ3200	2 or 4	12	9	6.4 or 3.2 Gsps

KEY: ANALOG-TO-DIGITAL CONVERTERS AND ADC CARDS

MODEL

Product name or model number

ADC MODEL

Specific analog-to-digital model number; if on a circuit card, indicates the A/D part number.

CHANNELS

Number of analog-to-digital channels

BITS

Number of analog-to-digital bits

ENOB

Effective number of bits

SAMP SPEED

Sample speed in MHz or GHz

Msps = mega samples per second

Gsps = giga samples per second

INPUT BAND

The input bandwidth in kHz, MHz or GHz

SPUR

Spur free dynamic range (SFDR) in dB, dBC or dBFS

FORMAT

If circuit card, 6U, 3U, PMC, XMC or component package type

AMC = Advanced Mezzanine Card

BGA = Ball Grid Array

FMC = FPGA Mezzanine Card

LFCP = Lead-Free Control Plan

QFN = Quad Flat No-lead

VQFN EP = Very thin Quad Flat No-lead Exposed Pad

XMC = Switched Mezzanine Card

ENVIRONMENT

Operating temperature and cooling method

INPUT BAND	SPUR	FORMAT	ENVIRONMENT	FEATURES
0.1 - 400 MHz (AC coupled); 0 - 450 MHz (DC coupled)	95 dBc (AC coupled); 93 dBc (DC coupled)	PCIe, XMC, CCXMC, VPX	-30°C to +85°C (air cooled)	Continuous, snapshot, or periodic capture modes; programmable digital down converter; ANSI/VITA 49 compliant data format.
0.1 - 500 MHz	90 dBc	PCIe, XMC, CCXMC, VPX	-30°C to +85°C (air cooled)	Continuous, snapshot, or periodic capture modes; programmable digital down converter..
0.1 - 180 MHz (AC coupled); 0 - 140 MHz (DC coupled)	86.5 dBc (AC coupled); 85.2 dBc (DC coupled)	PCIe, XMC, CCXMC, VPX	-30°C to +85°C (air cooled)	Continuous, snapshot, or periodic capture modes; programmable digital down converter..
4.5 - 250 MHz 400-4000 MHz	80 dBFS	FMC (HPC)	*	External Clock up to 4 GHz; 100 MHz onboard VCXO and 10MHz TCXO for reference clock.
30 - 1800 MHz	71.6 dBFS	FMC (HPC)	*	1 x ADC 12 bit @ 2.7 GSPS; 2 x DAC 16 bit @ 2.8 GSPS; external clock up to 4 GHz.
70 MHz-6 GHz	*	FMC (HPC)	-40°C to +85°C	2 RF Channels, DC to 6 GHz acquisition; software tunable channel bandwidth 200 kHz-56 MHz; 2 x multiple synchronized input and output.
5.7 GHz	*	VPX	-40°C to +85°C	Also features 6 Gsps 12-bit DAC and Xilinx UltraScale+ XCVU13P FPGA with 8 GB DDR4
5 GHz	*	AMC	-40°C to +85°C	Features four DAC channels providing 16-bit resolution at 12 Gsps.
8 GHz	67 dB	AMC	-40°C to +85°C	Also features 2-channel DAC w/ update rate of 12 Gsps.

FEATURES

Other functionality for circuit cards

OTHER ABBREVIATIONS USED

- DNL = Differential Nonlinearity
- INL = Integral Nonlinearity
- LVDS = low-voltage differential signaling
- SNR = Signal-to-Noise Ratio

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

MARCH 2018 PRODUCT SURVEY: SPECTRUM ANALYZERS

This survey will cover benchtop and rack-mount spectrum analyzers for military applications. Please e-mail JEDeditor@naylor.com to request a survey questionnaire.

New Electronic Attack Techniques – Part 1

By Dave Adamy

For the past 15 months, we have been discussing new Russian radars. All of them present challenges to our normal ways of performing electronic attack (EA) against them. In this series, we will first review the approaches to countermeasures and the formulas applicable to conventional EA. Then, we will discuss the new approaches that are required to counter the new threat systems.

In order to support some of the later material in this series, we will include discussion and formulas for both simple and complex configurations in this introductory material. Later material on new types of radars will deal with the ways in which the new radars and the ways they are employed impact the success of legacy and new countermeasures techniques.

GEOMETRIC JAMMING CONSIDERATIONS

We can divide EA into self-protection jamming and support jamming. Self-protection jamming involves transmitting countermeasures signals from the vehicle that is targeted by the radar, as shown in **Figure 1.** The radar can be an acquisition radar, a tracking radar, or a radar designed to detonate a missile's warhead. It can be located at or near a missile launcher or anti-aircraft gun or on a missile.

The effective range of the radar is generally taken as the range at which the energy received in the radar's receiver is a factor of 20 greater than the noise in the receiver. This is 13 dB. The radar in Figure 1 has its transmitter colocated with its receiver, and uses a single antenna for both transmitting and receiving. This means that the modulation of the radar signal must be pulse. Since the transmitted signal is typically strong enough to damage the colocated receiver, the system must allow for the isolation of the receiver from the transmitter during the pulse. Thus the transmission and reception are separated in time.

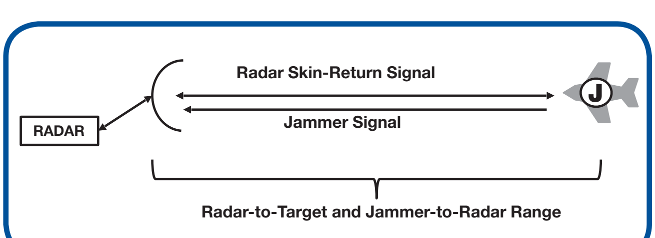


Figure 1: Self protection jamming uses a jammer on the target and transmits directly into the main beam of the jammed radar.

SELF-PROTECTION JAMMING

A self-protection jammer can employ either cover or deception jamming. Cover jamming generally broadcasts frequency-modulated noise waveforms. Its purpose is to deny the jammed radar the ability to receive the skin-return signal with adequate signal-to-jamming ratio to perform the desired function. (Thus "blinding" the radar.) Deceptive jamming generates signals that appear to the jammed radar to be valid skin returns, but the analysis circuits in the radar are forced to conclude that the target is at an incorrect angle or pulse return time or frequency.

An advantage of self-protection jamming is that the boresight of the radar's receiving antenna is aimed directly at the jammer so the jamming signal experiences the full gain of the receiving antenna.

To effectively jam this type of radar, the received jamming signal in the radar receiver must be strong enough to prevent the radar receiver from properly acquiring, or tracking the target with adequate fidelity. This so called jamming-to-signal ratio (J/S) can be a low as 0 dB or as high as 40 dB depending on the jamming technique employed. The formula for the J/S ratio is:

$$J/S = ERP_J - ERP_S + 71 + 20 \log R - 10 \log RCS$$

Where: *J/S* is the jamming to signal noise in dB,
ERP_J is the effective radiated power of the jammer (the dB sum of the jammer transmitter power and the gain of the jamming antenna in the direction of the target) in dBm, and
ERP_S is the effective radiated power of the jammed radar in dBm.
R is the range from the radar to the target (and jammer) in km
RCS is the radar cross section of the target in m^2

Since some radars use continuous wave (CW) signals, they must have separate transmit and receive antennas as shown in **Figure 2** to allow simultaneous transmission and reception. Since the receiving antenna provides the same gain to the received skin return signal and the jamming signal, the above formula applies to both pulsed and CW radars. This assumes that the transmit and receive antennas are close together and are antennas with similar patterns, both focused on the same target. If the transmit and receive antennas of the radar are at significantly different locations or with different antenna

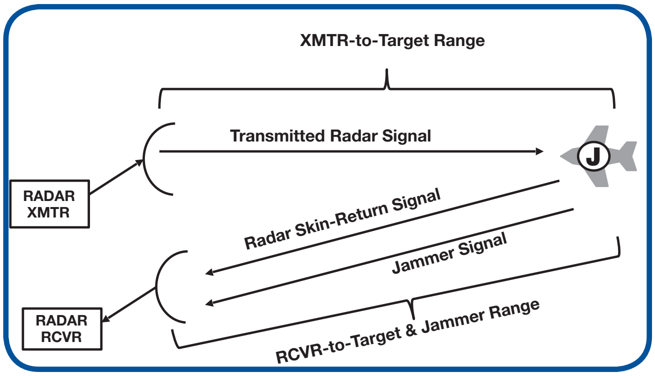


Figure 2: A radar that transmits a CW signal must have separate transmit and receive antennas to allow simultaneous transmission and reception.

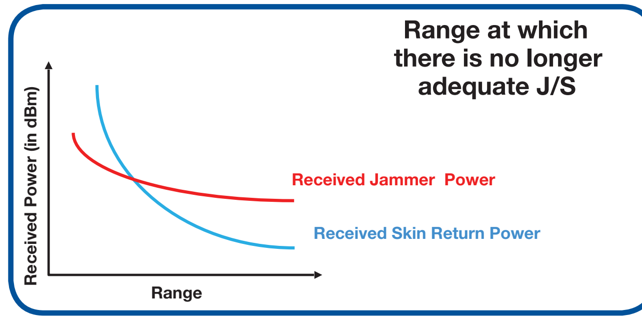


Figure 3: This compares a radar's received signal strength from a skin return and a jamming signal for a self-protection jammer as a function of range. From the radar's perspective, the skin return reduces as 4th power of the range to the target and the jammer power reduces as the square of the range to the jammer.

orientations or gain patterns the J/S equation becomes more complex. Remember that the jammer is located at the target.

$$J/S = P_J - P_X + G_{JR} - 20 \log R_{TR} + G_{RT} - G_{XT} + 20 \log R_{XT} - 10 \log RCS + 20 \log R_{TR} - G_{RT}$$

Where *J/S* is the jamming to signal ratio in dB,
P_J is the transmitter power of the jammer in dBm,
P_X is the transmitter power of the radar in dBm,
G_{JR} is the gain of the jamming antenna in the direction of the receiver in dB,
R_{TR} is the range from the target to the receiver in km,
G_{RT} is the gain of the receiving antenna in the direction of the target in dB,
G_{XT} is the gain of the radar transmit antenna toward the target,
R_{XT} is the range from the transmitter to the target in km,
RCS is the radar cross section of the target as effecting a signal from the transmitter to the receiver in square meters,
R_{TR} is the range from the target to the receiver in km, and
G_{RT} is the gain of the receiving antenna in the direction of the target.

Both of these J/S equations show that jamming effectiveness increases with the ERP of the jammer and as the range between the radar and the target (carrying the jammer) increases. Jamming effectiveness decreases with the ERP of the radar and as the target's RCS increases.

BURN-THROUGH RANGE

This discussion focuses on the case in which the radar's transmit and receiving antennas are colocated (or the same antenna). The J/S varies directly with the range from the radar to the target. **Figure 3** compares the received power from the skin return and the jamming inside the radar's receiving antenna. The received jamming reduces as the square of the range because it is a one-way transmission, while the received skin return power varies with the fourth power of the range because it is a two-way transmission.

SELF-PROTECTION BURN-THROUGH

The range from the radar at which the radar can reacquire its target in the presence of jamming is defined as the "burn-through range." In self-protection jamming, the jammer and the target move together. Thus, the jamming-to-signal ratio is a function of the square of the range. **Figure 4** shows the concept of burn-through range. For mission planning, burn-through range is normally defined in terms of a jamming-to-signal ratio that is operationally deemed to no longer provide adequate protection. The equation for burn-through range is presented here in two parts: first the range term in the J/S formula at the burn-through range, then the actual burn-through range.

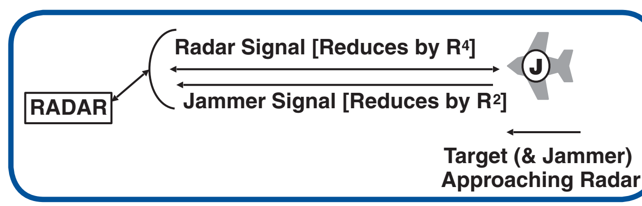


Figure 4: The jamming-to-signal ratio reduces as the target and the jammer approach the radar. "Burn through" occurs when the radar can re-acquire the target in the presence of jamming.

The formula for the range term (at burn-through) is:

$$20 \log R_{BT} = ERP_S - ERP_J - 71 + 10 \log RCS + J/S\ Req$$

Where: R_{BT} is the range from the radar to the target at burn-through in km, and
J/S Req is the J/S value at which the jammer can no longer effectively jam the radar.

The required J/S for burn-through varies with the type of jamming employed. Sometimes, 0 dB J/S is adequate to protect the target, but it can be as much as 20 to 40 dB. Now, we determine the burn-through range from the range term with the formula:

$$R_{BT} = \text{Anti-log } \{(20 \log R_{BT}) / 20\}$$

This equation looks strange, but note that we are taking the anti-log of the *value* of 20 log R_{BT}.

WHAT'S NEXT

Next month, we will continue our discussion of jamming techniques and the associated formulas for legacy radars. For your comments and suggestions, Dave Adamy can be reached at dave@lynxpub.com.

7th Annual AOC Pacific Conference

9-11 OCTOBER 2018

ASSOCIATION OF OLD CROWS

Honolulu, HI

Report from the 7th Annual AOC Pacific Conference – Honolulu Hawaii

By Col (Ret.) Arthur N. Tulak, Vice President, Hawaii Diamond Head Chapter

PHOTOS: CPL PATRICK MAHONEY, MARINE FORCES PACIFIC

The theme for the 2018 AOC Pacific Conference, co-sponsored by HQs, U.S. Indo-Pacific Command (USINDOPACOM), "Deterrence in a Complex World: The Role of Information Operations" permitted a comprehensive examination of the role of information operations in support of peacetime deterrence in the Indo-Pacific theater. Effective deterrence against peer-competitors is becoming increasingly challenging due to today's complex operations and information environments – both of which are impacted significantly by hybrid warfare and Anti-Access/Aerial Denial (A2/AD) strategies.

Admiral Phil Davidson, Commander of U.S. Indo-Pacific Command, was the keynote speaker, making this the third year in a row that conference attendees heard from a 4-Star Commander from the Indo-Pacific Region. Brigadier General Dagvin Anderson, the INDOPACOM Deputy J3, and Air Commodore Phillip Champion, INDOPACOM DJ5, were the keynote speakers for the second and third days of the conference. Once again, the

conference venues were the Army's Hale Koa Hotel on Waikiki Beach for two days of UNCLASSIFIED discussions, followed by classified discussions at Marine Corps Base Hawaii Camp H.M. Smith, in the Headquarters of U.S. Indo-Pacific Command.

Over the two days of unclassified discussion, AOC Pacific Conference participants also heard from 24 presenters drawn from U.S. and Allied militaries, academia and industry. The participation from Academia this year proved critical to providing context to the current challenges in effective deterrence, as professors, course directors and research faculty from the U.S. Army War College, University of North Carolina, Joint Special Operations University and RAND provided a framework for understanding the problem. The conference saw strong support from the U.S. Army, with senior officers representing HQs, Army Cyber G39, 1st Information Operations Command, U.S. Army Information Proponent Office, Asymmetric Warfare Group, 8th Army and U.S. Army Pacific, along with many other regionally aligned Army units. The Marines were represented by the Marine Corps Information Operations Center (MCIOC) and Marine Forces Pacific. The Air Force was represented by HQs Air Force, Air Combat Command, the 28th Bomber Wing and Pacific Air Forces. Joint participation included the Joint Information Operations and Warfare Center (JIOWC), located at Lackland AFB.

Allied military participation grew to 11 nations, with Australia, Canada, Japan, Korea, New Zealand, Philippines, Singapore, Taiwan and the United Kingdom returning, and Chile and France officially represented for the first time in the symposia series. Altogether, twenty-eight active duty Allied Officers or government civilians participated, with Australia, Taiwan and the United Kingdom representatives presenting. Allied participation and presentations in both the unclassified and classified sessions significantly enhanced the networking opportunities and built a nuanced appreciation of the information environment of the Indo-Pacific Theater.

Industry participation broke previous records, as the conference saw thirteen sponsors – two more than in 2017, and five more than in 2015 and 2016. Industry also produced many of the highly qualified speakers at both the unclassified and classified venues. Industry sponsors filled the exhibition hall at the Hale Koa Hotel and reported many productive engagements with U.S. and Allied government and military personnel

over the two days of the unclassified sessions. In addition, the top-level sponsors hosted two evening socials held at the Hale Koa hotel, further expanding networking opportunities.

The conference also provided the perfect opportunity to recognize professionalism in the EW and IO communities of the Indo-Pacific Theater. AOC recent Past President Lisa Frugé-Cirilli presented the Association of Old Crows Outstanding Unit Navy (Surface) Award to the USS Hopper (DDG 70) electronic warfare module in recognition of having achieved the highest level of mission success and tactical performance throughout two deployments in the Indo-Pacific and Arabian Gulf. Major Jason Taylor, USAF, was sworn-in as the new Hawaii AOC Chapter President, along with Chapter Vice President and Secretary.

Chapter President Taylor recognized corporate sponsor Chesapeake Technology International for their support of STEM Scholarships awarded by the Chapter to University of Hawaii Students. AOC Chapters in the Pacific Region, and International Region II from Australia and Singapore provided presentations outlining their chapters' activities in their countries. In particular, Dr. Lee Kar Heng, President of the Singapore Chapter, provided an update on the extensive STEM program. The Singapore STEM program and the Hawaii scholarship program both demonstrate how AOC Chapters are involved in the community.

"We're No Longer Pushing:" Army Prepares for Next Steps with CEMA 2018 Conference

By Edric Thompson, RDECOM Communications-Electronics Center

The U.S. Army and the Association of Old Crows hosted the fourth annual Cyber Electromagnetic Activity (CEMA) conference at Aberdeen Proving Ground, Maryland from Oct 23-25.

More than 750 stakeholders from across the DOD's technical, acquisition, doctrinal and operational communities joined representatives from industry to discuss acquisition, doctrine, threat, and research and development information and initiatives.

The event was hosted by the Program Executive Office for Intelligence, Electronic Warfare and Sensors (PEO IEW&S); the U.S. Army Research, Development and Engineering Command's Communications-Electronics Center (CERDEC); and the Association of Old Crows (AOC).

"I get energized every time I come to APG because this is where it's all happening, thanks to a lot of good work by everyone in the labs here and their industry partners," said Lt. Gen. Stephen Fogarty, commander of U.S. Army Cyber Command.

The CEMA Conference provides the broader CEMA community of Cyber, Electronic Warfare (EW), Signals Intelligence (SIGINT) and Spectrum Management an opportunity to annually share ideas, discuss accomplishments and identify technical challenges, said Giorgio Bertoli, acting director for CERDEC's Intelligence and Information Warfare Directorate and senior scientific technology manager for cyberspace operations.

"CEMA development needs to keep pace with how that domain changes, which is rapidly. So collaboration with industry, our sister services, government agencies and coalition partners is very important. We want to link the different organizations together so everyone can understand each other's perspective," Bertoli said.

The theme of this year's event was "CEMA as a Critical Enabler of The Army's Modernization Priorities" and was designed to highlight how CEMA capabilities are essential to the success of the Army's "Big-6" priority areas: Long Range precision Fire, Next Generation Combat vehicle, Future Vertical Lift, Network/C3I modernization, Advanced Missile Defense and Soldier Lethality.

"If you look at the Army's six modernization priorities, they're very kinetic focused; it's hard to see where CEMA fits in because non-kinetic stuff is a little bit more amorphous. But CEMA capabilities can help improve the effectiveness and lethality of the kinetic fight maintaining communications, ensuring that you have freedom of maneuver within the spectrum or ensuring that our networks are secure from an adversary's cyber attack. The whole concept of multi-domain battle is the merger of the kinetic and non-kinetic to provide more than each on its own," Bertoli said.

From building CEMA capabilities at the brigade Combat Team echelon to institutionalizing CEMA at the Division and Corps level for maneuver, leadership from the Army's CEMA community provided their personal and command perspective of how CEMA is supporting the Army now and in the foreseeable future as well as their challenges and their proposed solutions to those challenges.

Building capacity, integrating CEMA capabilities and training in realistic situations will be key, as the Cyber/EW force structure is expected to double over the next four years.

"We're in a good spot. If you're not excited to be part of the community now, I can't help you," said Maj. Gen. Jon Morrison, Jr., commander of the U.S. Army Cyber Center of Excellence. "I think we have the requirements figured out, but there are different capabilities coming down the pipeline that we need to start playing with to figure out what 'right' looks like. We need to establish force structure and then equip it, not the other way around. So it will be key for us, as a community, to get after experimentation and demonstration."

The training environment will also be key as "getting kit into the hands of operators" will accelerate CEMA growth across all echelons, noted Brig. Gen. Jennifer Buckner, Director of Cyber G-3/5/7.

"In 2014, we were asking, 'how do we push this to the greater Army?' The environment has changed. We're no longer pushing; the Army understands the importance of CEMA and is now pulling," Buckner said.

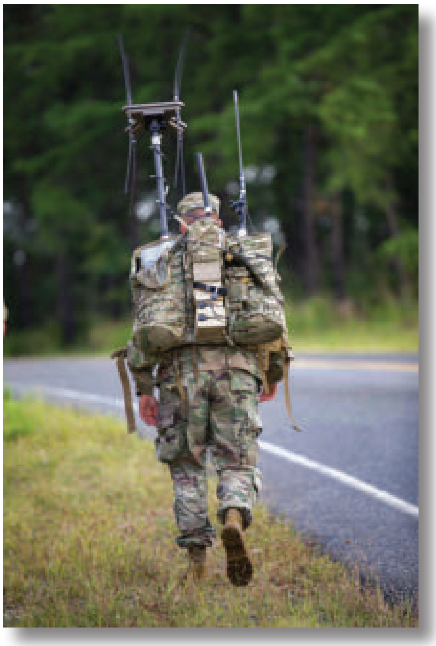
With both a Cyber and EW Strategy in place, the Army is hoping to have a SIGINT strategy in place within the next year. However, there is still a ways to go, said Fogarty, who noted that the integration of cyber, electronic warfare information operations is on the right path.

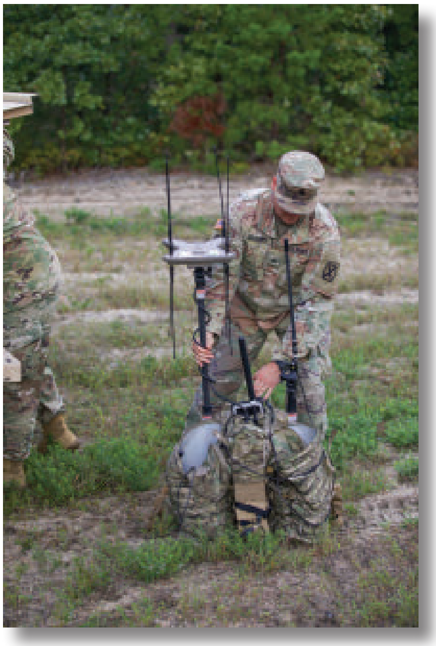
"We have made significant gains, but the environment is quickly changing. The requirement to collaborate, however, will not change. Being good at your piece of the puzzle is no longer good enough – we must have the ability to integrate and operate as a cross-arms team. It's all got to come together," Fogarty said.

This year's event also broadened collaboration amongst the community by establishing a partnership with the Army Cyber Institute (ACI) at West Point who conducted a special workshop, available to conference participants only, as an adjunct to the event. The workshop focused on identifying basic and applied research topics within the CEMA technology space that are important to the community.

Next year's CEMA conference is in the early planning stages and will be held Oct 8-10 at the same venue.

"We have so much technology at our fingertips these days with our phones, tablets and laptops that we've forgotten how to sit down and talk face to face," said AOC President Lisa Frugé-Cirilli. "The CEMA Conference offers the community of interest an opportunity to listen to our leadership, ask questions and talk about what is going on in the world today. Communication and collaboration are essential to success."





GREEN JACKET ROOST HOSTS QUARTERLY MEETING

The Green Jacket Roost (Ft. Gordon, GA) hosted their quarterly meeting, led by Chapter President Dennis Leanhart, on December 6, 2018. In attendance were 21 chapter members along with two special guests: Southern Regional Director Karen Brigance and the recent Past President Lisa Frugé-Cirilli. The Green Jacket Roost has shown significant growth over the past 6 months, resulting in an overall 378 percent increase in membership. The quarterly meeting focused on outlining the AOC Awards program and how to best support both the AOC and the local chapter. Additionally, as a method to facilitate communications for the AOC about chapter events, special interest areas and more, the Green Jacket Roost established several social media venues to support information sharing with other members and the AOC, as a whole.

2019 AOC SCHOLARSHIPS

The Association of Old Crows Educational Foundation provides two scholarships annually, each in the amount of $12,500, to students studying in the fields of Science, Technology, Engineering, and Math. As an organization, the AOC is committed to supporting the students of today, as they will become the support for, and the warfighters of, tomorrow. Submissions must be made by March 31, 2019 and all students are encouraged to apply!

Learn more about eligibility and selection criteria, and apply at www.crows.org/page/scholarshipprogram.

2019 AOC AWARD NOMINATIONS

As the premier organization for individuals and groups in the Electromagnetic Warfare community, the AOC has the pleasure of recognizing members of our community for their achievements. In 2019, there are over 20 awards available to honor members and non-members alike for their contributions. Nominations for 2019 AOC awards are due by May 1, 2019.

Learn more about 2019 awards at www.crows.org/page/awards.

2019 BOARD OF DIRECTORS NOMINATIONS

Each year, the membership of the AOC determines the future of this organization by electing representatives to the Board of Directors. Nominations will be accepted between January 2 and March 15, and elections will be from June 1-30. Current AOC members are able to be nominated for the following positions:

President-Elect
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Learn more about 2019 nominations at www.crows.org/page/elections.


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JED, The Journal of Electronic Defense (ISSN 0192-429X), is published monthly by Naylor, LLC, for the Association of Old Crows, 1555 King St., Suite 500, Alexandria, VA 22314.

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

POSTMASTER:
Send address changes to
JED, The Journal of Electronic Defense,
c/o Association of Old Crows,
1555 King St., Suite 500
Alexandria, VA 22314-1652

Subscription Information:
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