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June 2020 Vol. 43, No. 6

JED

Journal of Electromagnetic Dominance

After the Tornado – Europe's Next-Gen AEA

- Early Success for US Army's Air-Launched Effects
- DE101: Building Operational Understanding of DE Weapons
- News: US Army Awards TLS-L Contracts

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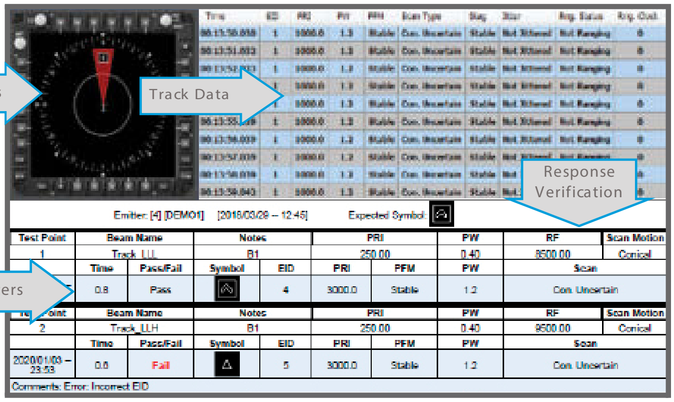

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The DOD's first high energy laser programs concentrated mainly on one parameter – power. As the DE community learned more, it's thinking evolved, too. Today, we realize our need to understand a variety of DEW aspects before operational users will embrace them. PHOTO: DOD

COVER PHOTO COURTESY OF SHAUN SCHOFIELD

US Marines formed as an Electronic Warfare Support Team (EWST) with 2nd Radio Battalion, II Marine Expeditionary Force Information Group, emplace specially modified bandvagns outfitted with EW equipment alongside Norwegian Army soldiers with Electronic Warfare Company, Military Intelligence Battalion, near Setermoen, Norway, March 14, 2020. EWSTs are working with Electronic Warfare Company soldiers to enhance interoperable electronic warfare capabilities and create an allied team capable of operating in austere conditions and environments.
US MARINE CORPS PHOTO BY 2ND LT. BEN COLYER

Departments

LOSING A DEAR FRIEND

The global EW community lost one of its most committed supporters when John Clifford OBE passed away on May 5. John was a great EW leader throughout his career. He was a Wing Commander who served 37 years in the RAF; he helped to grow the AOC's UK Chapter, which he led for 11 years as chapter president; and he also was director of the Electronic Warfare Europe conference for many years. (For more on John's career, see our remembrance on page 52.) For most of us who had the honor to know him personally, John was a great friend and a supportive mentor. He was also one of our community's most innovative thinkers.

I first met John in 2008. At the time, he was approaching the end of his military career and was wrapping up his fifth tour on the MOD staff. More specifically, John was leading the MOD's EW staff, which was in the final stages of developing new joint EW doctrine. He explained to me that from the beginning of his time in the MOD, one of his biggest challenges was helping senior military leaders (many of whom were not familiar with EW) understand EW's importance to the warfighter. Some senior leaders understood the value of EW, he said. But for many of them, he explained, as soon as you start describing EW in terms of megahertz or gigahertz, you could see their eyes start to glaze over, and you knew they had lost interest. This was not a new problem in the UK or in any other country. It was probably as old as EW itself, but it was a major constraint in terms of getting senior leaders to buy into an EW strategy.

John thought about this problem not from an EW perspective but from the perspective of his audience. He needed to help non-experts understand what EW could do in the battlespace, and he needed to communicate this idea in a non-technical way. Eventually, he came up with a solution: by recognizing that every military officer is schooled in "maneuver," he hit on the idea of explaining EW as a form of maneuver in the Electromagnetic Environment (EME). He introduced it in a few briefings in the 2004-2005 timeframe and observed that he had captured the interest of his skeptical audience as soon as he mentioned "maneuver." EW suddenly made sense to them, and the EME looked similar the other warfighting domains.

John continued to develop this concept of maneuver in the EME, and by 2008, it was evolving into the basis of joint EW doctrine for the UK. Eventually, the EME concept was adopted by other EW thought leaders, and it spread (often with John's help) into more European nations, NATO and eventually the US, where the EW community discusses EMS Operations (EMSO) in the EMS Warfighting Domain.

John would not have accepted credit for any of this this because he knew the EME maneuver concept was built by and belonged to the whole EW community. But John definitely lit the fire that became the big idea we are pursuing today. Without his contribution, who knows where the EW community would be in our strategic thinking. As I mentioned, John was one of our most innovative thinkers.

We will miss you, John. But we will never forget what you did for EW. *– J. Knowles*

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Calendar *Conferences & Trade Shows*

JUNE

5th Annual Directed Energy Summit Online
June 25-26
Online
www.idga.org

AUGUST

TechNet Augusta
August 17-21
Augusta, GA
www.afcea.org

Defense officials have announced extended restrictions on domestic travel for service members, Department of Defense (DOD) employees and family members in response to the novel coronavirus, COVID-19. All travel will be halted through June 30, per the DOD's memorandum. For conferences taking place after June 30, please contact the conference organizer.

SEPTEMBER

AFA 2020 Air, Space and Cyberspace Conference
September 14-16
National Harbor, MD
www.afa.org

Modern Threats: Surface-to-Air Missile Conference
September 15-17
Redstone Arsenal, AL
www.crows.org

Directed Energy to DC (DE2DC)
September 22-24
Washington, D.C.
www.deps.org

2020 DE Systems Symposium
September 28 – October 2
Washington, D.C.
www.deps.org

OCTOBER

AUSA Annual Meeting
October 12-14
Washington, DC
www.ausa.org

EW Gulf Cooperation Council 2020
October 20-21
Abu Dhabi, UAE
www.electronic-warfare-gcc.com

9th Annual AOC Pacific Conference
October 20-22
Honolulu, HI
www.crows.org

EURONAVAL
October 20-23
Paris, France
www.euronaval.fr

6th Annual Cyber Electromagnetic Activities (CEMA) Conference
October 27-29
Aberdeen Proving Ground, MD
www.crows.org

NOVEMBER

EW Europe
November 16-18
Liverpool, UK
www.crows.org

DECEMBER

57th Annual AOC International Symposium and Convention
December 8-10
Washington, DC
www.crows.org

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

Calendar *Courses & Seminars*

JUNE

AOC Live Professional Development Web Course: EW Modeling and Simulation
June 1-17
8 sessions, 1300-1600 EST
www.crows.org

AOC Virtual Series Webinar: Deep Learning and Waveform Classification
June 4
1400-1500 EST
www.crows.org

AOC Virtual Series Webinar: The Fundamentals of Electro-Optical/ Infrared Sensor Engineering
June 18
1400-1500 EST
www.crows.org

AOC Virtual Series Webinar: Introduction to Space EW
June 25
1400-1500 EST
www.crows.org

Defense officials have announced extended restrictions on domestic travel for service members, Department of Defense (DOD) employees and family members in response to the novel coronavirus, COVID-19. All travel will be halted through June 30, per the DOD's memorandum. For all in-person courses, please contact the course provider.

JULY

AOC Virtual Series Webinar: Denial & Deception: Getting Back to SIGINT's Roots
July 9
1400-1500 EST
www.crows.org

AOC Live Professional Development Web Course: Missile Design, Development, and System Engineering
July 13-31
9 sessions, 1300-1600 EST
www.crows.org

Cyber Warfare/Electronic Warfare Convergence
July 21-23
Atlanta, GA
www.pe.gatech.edu

Infrared Countermeasures
July 21-24
Shalimar, FL
www.pe.gatech.edu

AOC Virtual Series Webinar: EW System Development: Critical Thinking in Design Tradeoffs
July 23
1400-1500 EST
www.crows.org

AUGUST

AOC Virtual Series Webinar: The Lost Art of HF: The Rebirth of Shortwave in a Digital World
August 6
1400-1500 EST
www.crows.org

Radar Cross Section Reduction
August 10-12
Atlanta, GA
www.pe.gatech.edu

Directed Infrared Countermeasures: Technology, Modeling, and Testing
August 18-20
Atlanta, GA
www.pe.gatech.edu

AOC Virtual Series Webinar: High Resolution Direction Finding
August 20
1400-1500 EST
www.crows.org

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

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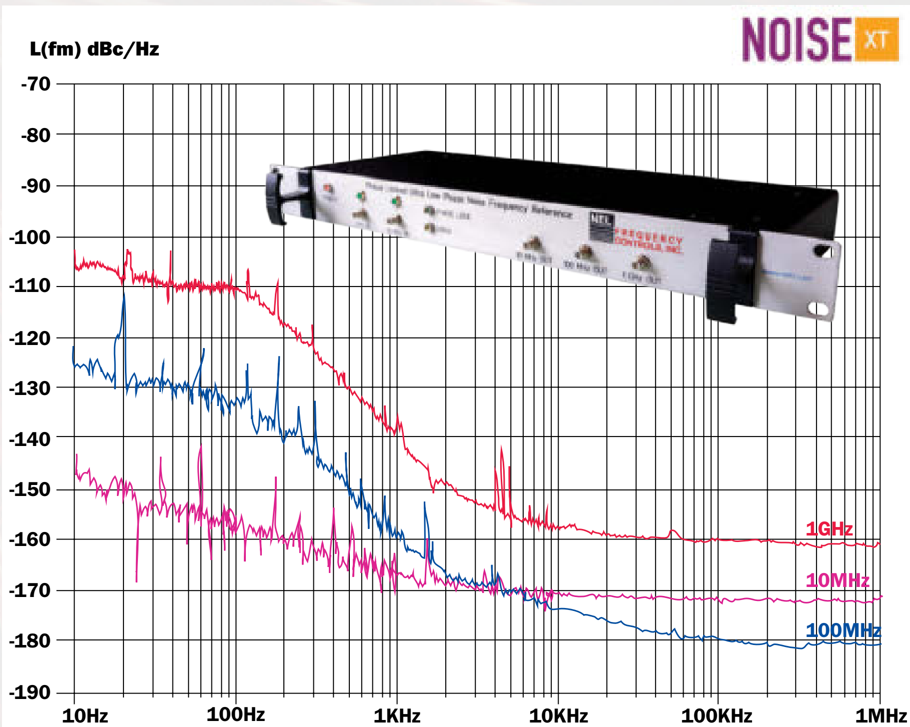

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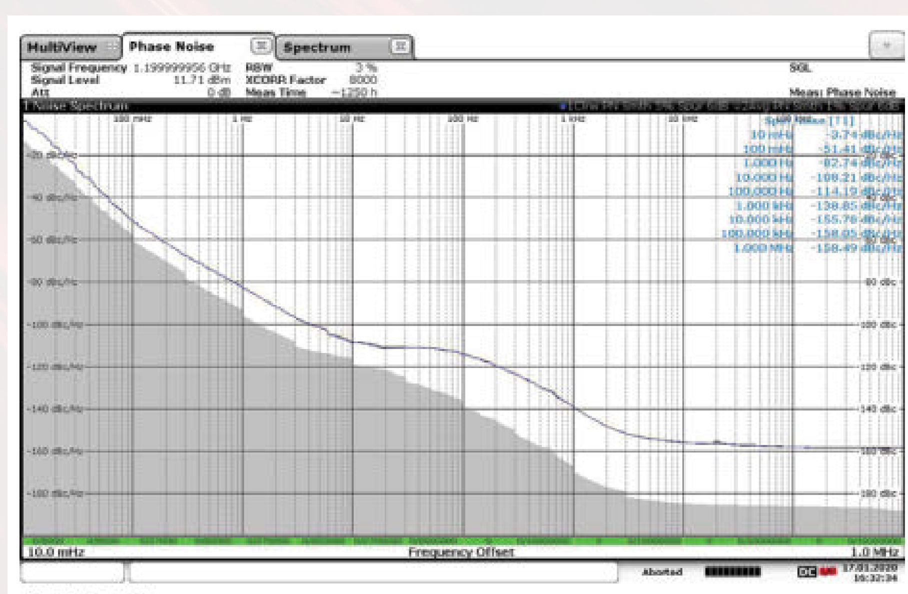

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VIRTUAL EMS SUMMIT RECAP

My heart is heavy with the news that last month, on 5 May, we lost one of our champions with the passing of John Clifford OBE, a former RAF Wing Commander, President of the UK Chapter, and former Director of AOC Global Operations and Conferences. A friend and true professional, John dedicated over 40 years of his life to the EW community. He will be missed. Our hearts go out to his family and friends.

Last month, the AOC held the first virtual two-day EMS summit, with 1,853 registered attendees and 35 countries represented. I want to recap, for those AOC members who couldn't attend, the major salient points from our session chairs and speakers. Our summit began with discussions of Collaborative Electronic Warfare (EW) and Multi-Domain Operations (MDO) in the Electromagnetic Spectrum (EMS). Presentations focused on the need to create adaptable systems with distributed, cooperative decision-making capability in response to complex and dynamic threats. We covered solutions to several EMS challenges, including training and Testing & Evaluation (T&E). More specifically, we addressed the need for synergy across intelligence, operations and resourcing organizations, and sensitivity in sharing, testing, and fusing data across distributed and complex operating environments to create a common EW operating picture. We learned that we must adopt a persistent modernization campaign to recapitalize and upgrade current systems and create an expedited path for insertion of new technology and sensors. Central to this effort is our ability to conduct technology demonstrations and rapid prototyping, and adopt modular open system architectures. We also must keep pace with the threat, both in terms of capability and capacity to maintain kill chain wholeness across all warfighting domains.

On the second day of the Summit, we addressed EW Capability Gaps and Enabling Technologies. We reviewed the current initiatives of the EMS Operations Cross Functional Team (EMSO CFT), including the forthcoming EMS Superiority Strategy and Implementation Plan. It was noted that every warfighting domain is contested and we face an ever-more-lethal battlefield. A necessary reform the CFT is advancing is budget certification analysis to enable a capability portfolio management approach. There was a discussion on the evolution and present challenges of EMS operations, especially as they relate to Great Power Competition and Gray Zone Operations.

In the future, EW must be seen as a more offensive asset that is distributed throughout the force structure. We discussed Mosaic Warfare, a single-continuum vision where technology is engineered for interoperability and creates an adaptable, resilient, and distributed system. We also need rigorous modeling and analysis throughout the process of turning technology from a concept to fielded system. We talked about the progress of the Sensor Open Systems Architecture (SOSA) initiative to develop a unified technical OSA standard for radar, EO/IR, SIGINT, EW and Communications.

The EMS Summit concluded with updates on the development of Space Force and the need for Space Control through EW, as well as an update from the Hawkeye AEW community. I hope this summary was useful to you. I am proud of the AOC staff and all those who participated in the Summit. It showed how resilient our community can be in the face of obstacles. Please stay healthy. – *Muddy Watters*

JED 2020 Writing Contest

The *Journal of Electromagnetic Dominance* (*JED*) is pleased to announce a new writing contest open to all active duty military personnel from the armed forces of any nation.

The subject area of the writing contest is operations and/or operational support (training, testing, spectrum management, etc.) in the Electromagnetic Environment (EME).

TOPICS INCLUDE (BY DOMAIN):

- Multi-Domain Operations in the EME
- Maritime Operations in the EME
- Air Operations in the EME
- Land Operations in the EME
- Space Operations in the EME
- Cyberspace Operations in the EME

SUBMISSION GUIDELINES:

- Articles must be 3,200 words or less and sent in Microsoft Word format.
- All articles must be unclassified, original and unpublished material.
- Academic theses edited to meet the word count requirement (3,200 words) and written less than one year prior to the submission due date are welcome.
- Supporting photos must be high-resolution (1 MB or larger), print-quality JPEG or TIFF files. Figures must be sent in Microsoft PowerPoint format.
- Authors, please identify your title, military unit and commanding officer.
- Authors who wish to submit separate articles for more than one topic are welcome.

Submissions are due Tuesday, June 30.

Please send all questions and submission materials to JEDEditor@naylor.com.

By submitting your article, you are granting the editors of *JED* permission to publish your article in The *Journal of Electromagnetic Dominance* at such a time as we are able. If we do not intend to publish your submission in *JED* within one year of submission, you will be notified within 30 days of the submission due date.

US ARMY AWARDS TERRESTRIAL LAYER SYSTEM-LARGE CONTRACTS

The US Army, acting through the Consortium for Command, Control and Communications in Cyberspace (C5), has selected Digital Receiver Technology Inc. (DRT, a Boeing subsidiary, based in Germantown, MD) and Lockheed Martin MS2 (Annapolis Junction, MD) to begin developing Terrestrial Layer System-Large (TLS-L) prototypes. TLS-L vehicles will perform electronic warfare (EW), cyber attack and signals intelligence (SIGINT) for Brigade Combat Team (BCT) commanders in support of the Army's Multi-Domain Operations (MDO) concept.

The two awards – Lockheed Martin received a $6 million contract, and DRT received $7.6 million – begin the first phase of TLS-L development. The companies will perform component engineering and prototyping to mature critical technologies and subsystems, such as antennas, radios and software architectures. They also will participate in developmental testing of their respective components and subsystems through the end of 2021.

The TLS-L program is expected to transition to System Development and Demonstration (SDD) in 2QFY2021. This phase of the program will initially focus on integrating and evaluating a TLS-L system on a ground vehicle, with developmental testing scheduled in2Q-3QFY2021. A TLS-L production decision could follow in 1QFY2022. Further SDD work calls for the TLS-L system to be integrated onto a second ground vehicle type in FY2022. In terms of its funding profile, the program budget is estimated at $122 million for the SDD phase through FY2024 and $489 million for production of 68 TLS-L systems through FY2025.

TLS is envisioned to complement another Army program, Multi-Function EW (MFEW), a family of airborne systems that will also feed information to the BCT commander, help to build an operational picture of the electromagnetic operating environment and perform electronic attack and cyber attack missions. In January, C5 awarded Lockheed Martin a $74.9 million follow-on contract for MFEW-Air Large (MFEW-AL) to begin the program's Engineering and Manufacturing Development (EMD) phase, which will run through Q4FY2022. During this phase, the company will build four MFEW-AL systems, and the system will undergo integration onto an MQ-1C Gray Eagle UAS. Following a User Assessment in Q2FY2021, the program will make a "Tailored Milestone C" decision that could begin MFEW-AL production shortly afterward. – *J. Knowles*

AUSTRALIA FUNDS NEXT PHASE OF MOESS PROJECT

The Australian Department of Defence has awarded DEWC Systems Pty Ltd (Adelaide, South Australia) an A$3.1 million Defence Innovation Hub contract to advance Phase 2 of its Miniaturised Orbital Electronic Warfare Sensor System (MOESS) project.

MOESS is a dynamically reprogrammable, multi-purpose EW sensor system for integration and deployment on micro satellites. The program objective is to develop a sovereign, space-based tactical sensor system based on a constellation of about 20 CubeSats. If successful, this technology will enhance the Australian Defence Force's surveillance capability in the space domain.

Phase 1 of MOESS project was seeded by a $150,000 Collaborative Research Fund award, funded in 2018 through South Australia's Defence Innovation Partnership. This phase saw DEWC Systems collaborate with Defence Science and Technology, Finders University, The University of Adelaide and University of South Australia. Work undertaken in Phase 1 was designed to prove the MOESS concept and demonstrate the feasibility of using small CubeSats.

Phase 2 has funded the development of a MOESS concept demonstrator that will be representative of the final system's size, weight and power. The final deliverable will include at least one complete system plus software simulations.

Technology being developed under Phase 2 includes new identification and classification techniques, including the application of artificial intelligence algorithms. Work is expected to run through to mid-2021, and a follow-on Phase 3 would develop the program's first orbital prototype for launch in 2022. – *R. Scott*

US NAVY LAUNCHING MAJOR "RF SPECTRUM DOMINANCE" PROJECT

Working via the Strategic & Spectrum Missions Advanced Resilient Trusted Systems (S2MARTS) Other Transaction Authority (OTA) contracting vehicle, the Naval Surface Warfare Center (NSWC) Crane Division has issued a Request for Solutions (RFS) for the Radio Frequency Spectrum Dominance (RFSD) Prototype Project.

The RFSD Prototype Project is intended to address the growing problem that "military personnel supporting deployed missions have little to no control of the frequency spectrum," according to a program description. As such, the Navy is seeking a capability to detect and counter emerging threats which utilize the Internet, telecommunications and the electromagnetic spectrum (EMS).

As observed in the RFS document, "Improved RF spectrum analysis will allow warfighters greater ability to counter threats posed in the RF spectrum, namely enemy fighters' use of remote IEDs and UAVs, and the RFSD project aims to collect RF signals between 40 MHz and 6 GHz, analyze the signals, compare against a baseline environment, and automatically alert warfighters to anomalous signals." Ultimately, the intent of the project is to pursue the development and evaluation of an autonomous system-of-systems to mitigate the growing threat.

The multiphase project's duration is expected to be from 24 to 36 months,

culminating in a final demonstration of each performers' prototype system on DOD range facilities, successfully proving its capabilities. The Technology Experimentation Center (TEC) at Muscatatuck Urban Training Center (MUTC), IN, will provide operationally focused assessment and demonstration planning, coordination, execution, analysis and report writing.

As described in the announcement, "As the project requires the development of multiple systems (RF/anomalous signal analyzing, data scraping to include all signals of interest to including 4G/5G/Wi-Fi internet signals, database creation), there will be multiple sets of deliverables required." The final deliverable specifications for the project will be dependent on the selected solution, but at a minimum, will include: an RF Spectrum analysis tool or system that is capable of collecting and analyzing RF and other spectrum communications; a software tool capable of "scraping" the internet to detect threats to DOD interests abroad; and a virtual database to store and organize information pertinent to DOD contractors, manufactures and suppliers operating in complex geopolitical environments.

The current budget for the project is $30 million.

The Navy will award the project, via S2MARTS (Agreement No. N00164-19-9-0001), and may issue either a single award or multiple awards as fixed-price agreements comprised of payable milestones. All respondents must be members of the National Security Technology Accelerator (NSTXL) Consortium (Alexandria, VA).

Proposals submitted in response to the RFS are due by June 15. To submit a proposal, go to www.nstxl.org/opportunities. Acceptable responses not selected for the immediate award will be retained by NSTXL & the Government for possible future execution and funding. – *J. Haystead*

TAIWAN'S KANG DING FRIGATES TO RECEIVE UPGRADED DAGAIE DECOY LAUNCHER

Taiwan's Ministry of Defense has confirmed that the Dagaie Mk 2 soft-kill decoy systems fitted to the Republic of China Navy's (RoCN's) six *Kang Ding*-Class frigates are to be modernized.

French defense advisory and facilitation group DCI-DESCO will act as prime contractor for the NT$835 million (US$27.8 million) program. The upgrade kits themselves and new decoy ammunition will be provided by Lacroix Defense, the original equipment manufacturer for Dagaie Mk 2.

Each *Kang Ding*-Class ship is equipped with two Dagaie Mk 2 launchers (fitted amidships port and starboard). The upgrade of the Mk 2 launchers to Dagaie NG standard introduces the capability to launch the SEALEM RF seduction corner reflector decoys and the SEALIR IR seduction decoys developed by Lacroix for its SYLENA LW decoy launcher system. At the same time, the modernized Dagaie launcher retains the ability to fire REM RF distraction rockets.

Lacroix has previously supplied Dagaie NG to the Republic of Korea Navy. – *R. Scott*

UK ACCELERATOR FOCUSED ON COUNTER-IED TECHNOLOGIES

The development and demonstration of novel counter-improvised explosive device (IED) technologies and techniques is being pursued by the UK Ministry of Defence (MoD) under a new Defence and Security Accelerator (DASA) call.

Run on behalf of the MOD's Defence Science and Technology Laboratory (Dstl), the DASA competition is seeking proposals that can rapidly accelerate and enhance counter-IED electronic countermeasures (ECM) which either use the RF spectrum, or provide an understanding of the RF spectrum in order to detect and disrupt IED functionality.

According to a competition notice issued in late April, the challenge is to develop ECM systems that can counter "an ever-growing range of electromagnetic technologies operating across the RF spectrum, using an ever growing and diverse range of signaling schemes". At the same time, such solutions should be "adaptable to evolving technologies and able to operate in an increasingly congested electromagnetic spectrum."

Three key challenge areas have been identified for proposers: to capture and analyze RF signals using novel spectrum survey techniques: to neutralize targets in a timely and effective manner; and to demonstrate new or novel hardware and ancillaries.

Total funding of at least £3 million has been earmarked, split across a number of phases. Phase 1, expected to last a maximum of nine months, will fund up to 10 projects to explore technologies and techniques that have not been exploited in the counter-IED context before.

Any future phases will seek to further develop selected ECM concepts to a higher level of maturity (up to Technology Readiness Level 5 or 6). – *R. Scott*

US ARMY TO ISSUE RFI FOR HELO RF COUNTERMEASURE CAPABILITIES

The US Army's Project Manager Aircraft Survivability Equipment (PM-ASE) is seeking unclassified industry comments on a draft request for information (RFI) for an RF electronic countermeasure (RF-ECM) capability for rotary and fixed-wing aircraft, and to participate in an RF-ECM capability demonstration. A final RFI for industry response is expected to be released this month and will incorporate relevant industry comments.

As described in the draft RFI, the RF-ECM capability must be "able to operate anywhere in the world and in any environment suitable for Army fixed and rotary wing aircraft." The Army expects to conduct independent demonstrations of suitable RF-ECM prototypes in late FY21, with a planned First Unit Equipped (FUE) date of FY2028. Systems must support both the Army's Future Vertical Lift (FVL) and enduring aviation platforms. As such, PM ASE is looking for common technologies and/or component technology that can be scaled to application on various aviation platforms, as well as to Air Launched Effects (ALE).

The demonstration will be conducted through an "Other Transaction Agreement (OTA)" by the Aviation & Missile Technology Consortium (AMTC). As part of the process, in early FY21, AMTC will publish a request for members to submit enhanced white papers. Only consortium members will be eligible to submit a white paper.

The desired RF-ECM capabilities include: the ability to either interface with on-board RWRs or alternative approaches for providing RWR functionality; description of the system's Digital System Model (DSM) and its capabilities to incorporate threat models; description of how the architecture supports scalability, modularity, and extensibility for various platform types and other component applications, such as ALEs; description of how the open system architecture design supports future hardware and software upgrades both internal and from third party applications; and a description of how the system design is based on open system architecture standards and principals; and the capability to easily and rapidly reprogram ECM techniques.

The Army is expected to announce an Industry Day for the RF ECM program, but the date was not yet announced when this issue of JED went to press. The Points of Contact are: Christopher B. Williams, email: christopher.b.williams94.civ@mail.mil and Scot M. West, email: scot.m.west.civ@mail.mil. – *J. Haystead*

IN BRIEF

Dr. David Tremper took up his new posting last month as Director, Electronic Warfare, OUSD for Acquisition & Sustainment/A/Platform & Weapon Portfolio Management (P&WPM). Over the previous three years, Dr. Tremper was a program manager at the Defense Advanced Research Projects Agency's Strategic Technology Office. Prior to his DARPA role, he was an EW program manager at the Office of Naval Research from 2009 until 2017 and a Section Head at the Naval Research Lab's Tactical EW Division from 2002 to 2008. Dr. Tremper replaces Dr. William Conley, who left his OSD position in September to become Chief Technology Officer at Mercury Systems.

A consortium of Dutch and Norwegian research centers has awarded a contract to **NanoAvionics** (Midland, TX) to build two nanosatellites that will be used to detect, classify and geolocate terrestrial radars. The Royal Netherlands Aerospace Center (NLR – Nationaal Lucht- en Ruimtevaartlaboratorium), the Netherlands Organisation for Applied Scientific Research (TNO – Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek) and the Norwegian Defence Research Institute (FFI – Forsvarets Forskningsinstitutt) tapped the company as part of its Binational Radiofrequency Observing Satellites (BROS) demonstration program. The satellite integrator, which will perform some of the work at its Harwell Campus (Oxfordshire, UK) location, will host the radar ESM payloads on a pair of pre-configured M6P nanosatellite buses. Each M6P weighs approximately 10 kg and provides a deployable solar panel, a high-precision attitude determination and control system (ADCS) and a propulsion system. The two nanosats, dubbed "Birkeland" and "Huygens," will be

placed into a polar low Earth orbit (LEO) with an altitude range of 450 to 600 km. This will enable the satellites to cover any point on the Earth's surface at least four times per day and up to 15 points per day in northern areas. According to the company, the pair will be positioned in the same orbital plane with a separation of 15-25 km, allowing the two nanosatellites to simultaneously detect emissions from radar systems using time difference of arrival (TDOA) and angle-of-arrival (AOA) techniques. However, the labs will also experiment with separation distances up to 500 km. The launch of the two satellites is scheduled for the second quarter of 2022.

US Space Command's Space and Missile Center, Special Programs Directorate (Los Angeles, AFB, CA) has issued a Request for Information (RFI) (Notice ID SP-2020-01) for production of Counter Communications System (CCS) Meadowlands systems. The Meadowlands program is an upgrade from the CCS Block 10.2 system, a deployable jammer that counters satellite communications. US Space Command is in the process of fielding sixteen CCS Block 10.2 systems at Peterson Air Force Base, CO; Vandenberg Air Force Base, CA; Cape Canaveral Air Force Station, FL; and other locations outside the US. According to the RFI, the Meadowlands systems (Block 10.3), which is under development through the end of FY2020, is more modular, scalable than the Block 10.2 systems, and it reduces the operational footprint from 14 racks of equipment to 3 to 4 equipment racks. The CCS Meadowlands production program aims to deliver 28 systems over 54 months (FY2021-FY2025) at an estimated cost of $242.1 million. The program point of contact is Capt Cameron Webster, (310) 535-2709, e-mail cameron.webster@us.af.mil, and the contracting point of contact is Ms. Doreen Barnett, (310) 416-1538, doreen.barnett@us.af.mil.

The Air Force Life Cycle Management Center's Helicopter Program Office, Combat Rescue Helicopter (CRH) Division (AFLCMC/WIH) issued a Sources Sought Synopsis (SSS) (Notice ID WIHK-20-002) for an RF Threat Simulator System (RFTSS) for the 36th Electronic Warfare Squadron (EWS) at Eglin AFB, FL. The 36th EWS is seeking a new HardwareIn-The-Loop (HITL) RFTSS for the test and evaluation of radar warning receiver (RWR) and defensive aids controller (DAC) mission data (MD) to support multi-threat, dynamic testing of the ALR-52 and ALR-56M RWRs and ALQ-213A(V) DAC systems. These EW systems are used on HH-60 Combat Rescue Helicopters and C-130J aircraft. The point of contact is Kyle West, e-mail kyle.west.10@us.af.mil.

Northrop Grumman (Rolling Meadows, IL) received a $123.5 million contract modification from the US Navy for Department of the Navy Large Aircraft Infrared Countermeasures (DoN LAIRCM) hardware, systems engineering, technical support, analysis and studies. The option covers Advanced Threat Warning (ATW) sensors, IR missile warning sensors, Guardian Laser Transmitter Assemblies (GLTAs), Multi-Role Electro-Optical End-to-End Test Sets (MEONs)

and other hardware for the US Navy, US Air Force, US Army, the Norwegian Air Force (P-8A) and the Royal New Zealand Air Force (C-130J).

The **US Air Force Life Cycle Management Center** (AFLCMC) (Wright-Patterson AFB, OH) announced plans to restructure parts of its organization in the coming months. It will split its current Fighters and Bombers Directorate into a Bombers Directorate and a Fighters & Advanced Aircraft Directorate. PEO for Bombers will be led by Brig Gen John Newberry, and based at Wright-Patterson AFB. He will have responsibility for B-52, B-1B and B-2 programs, as well as "organize, train and equip" responsibilities for the Air Force Rapid Capabilities Office's B-21 personnel assigned to the AFLCMC. PEO for Fighters & Advanced Aircraft will be led by Brig Gen (Sel.) Dale White and also will be based at Wright-Patterson AFB. This directorate will be responsible for A-10 Warthog, F-15 Eagle, F-16 Viper, F-22 Raptor, Attack Systems, Skyborg, and Next-Generation Air Dominance Program Offices. It will also have organize, train and equip responsibilities for the Air Force's F-35 program. In addition, the re-organization returns the Tanker Directorate's three tanker program offices to the Mobility and Training Aircraft Directorate under Lynda Rutledge. This moves all mobility aircraft under a single directorate. There will be no changes to its Air Force Nuclear Weapons Center and Air Force Sustainment Center.

Mercer Engineering Research Center (Warner Robins, GA) has received a $9 million task order on a previously awarded Air Force contract to provide Laboratory Intelligence Validated Emulators-Virtual-Constructive (LVC) closed-loop engineering test and evaluation of newly developed electronic warfare (EW) systems. According to the contract announcement, "This order provides integration of gold-standard Intelligence Community threat definitions into the Electronic Warfare and Avionics Integrated Support Facility, where LVC closed loop operational test – vertical testability demonstration simulations and testing will be conducted to inform the baseline capability and to identify growth areas for improving operational survivability, reliability and mission success of fielded EW systems in support of airborne U.S. warfighting elements." The contract runs through May 2022.

Strategic Airborne Operations JV (Newport News, VA) won a US Navy contract valued at $146.8 million to provide High Endurance Electronic Warfare Jet (HEEWJ) training services. The contract calls for the company to deliver "offensive air support for training that provides regionally based, geographically distributed aviation with a variety of airborne threat simulation capabilities to train shipboard and aircraft weapon systems operators and aircrew to counter enemy electronic warfare and electronic attack operations in today's electronic combat environment in support of Department of the Navy, other Department of Defense (DOD) agencies, non-DOD government agencies and Foreign Military Sales customers."

European Air Forces Generation Airborne

By Andrew White

As NATO seeks to enhance its mission effectiveness across an increasingly complex and contested operating environment, Airborne Electronic Attack (AEA) is rapidly becoming a critical capability for armed forces throughout the Alliance. As a result, both the US Department of Defense (DoD) and partnering defense ministries in Europe continue to address demand signals arising from the contemporary operating environment (COE) calling for the ability to deny, neutralize, disable and disrupt hostile electromagnetic systems using non-kinetic solutions.

AEA solutions include stand-off jammers (SOJ), stand-in jammers (SIJ) and escort jammers (EJ), as well as lethal suppression of enemy air defense (SEAD) solutions. Throughout the Cold War and up to the present day, NATO has remained heavily dependent upon US AEA capabilities, with only a "few" European armed forces currently capable of fulfilling such requirements. Officials at NATO's Joint Electronic Warfare Core Staff (JEWCS) at Royal Naval Air Station Yeovilton in the UK, explained the importance placed by the Alliance upon AEA – something which they described as a required capability which must be promoted and developed by member states. "AEA is a key defense planning capability to degrade enemy sensors and/or communications systems including the SEAD mission," a NATO JEWCS official said. "It plays a vital role in an Anti-Access Area Denial (A2AD) threat scenario, or in normal to large-scale and high intensity warfare environments."

"AEA capabilities have strong dependencies with but [are] not limited to Joint Intelligence, Surveillance and Reconnaissance (JISR), robust Command and Control (C2), Joint Electronic Warfare (EW), Cyber, Navigation Warfare (NAVWAR), Information Operations (IO) and Joint Effects (for kinetic or non-kinetic effects) like Direct Energy Weapons (DEW), e.g., lasers or high-power microwaves and SEAD missions against Integrated Air Defense Systems/IADS," the JEWCS official continued.

However, NATO JEWCS also highlighted a series of capability gaps currently facing many European armed forces in terms of AEA, with the spokesperson describing existing shortfalls in the full adaptation of AEA technology in addition to education and training. "One of the challenges for air forces is adding AEA capability to existing multi-role platforms and enabling existing weapons systems to be survivable and highly capable in operating in the congested and contested environment," the spokesperson explained. "Education & Training for AEA is challenging for the Alliance. Robust, regular Education & Training is key. Data analysis and weapon system efficiency require a very high level of Education & Training. Complex EMO (Electromagnetic Operations) complicates making choices in real time on very short decision windows in any AEA mission."

Consequently, AEA remains a limited capability for many European nations, although commitments remain in place to achieve such a capability in 2025 and beyond. Requirements call for armed forces to integrate AEA payloads on board fast jets, in particular, in order to allow them to attack enemy IADS and ensure freedom of movement across an area of operations (AO).

Describing an operational scenario which involved air defense radars exploring an airspace to detect aircraft penetrating borders, Elettronica's (ELT's) Vice President for Corporate Europe and Consortia, Gianni Zoccali, noted, "Once the penetrating aircraft are detected, they are engaged by surface-to-air missiles or by air defense aircraft. [By] reducing the detection range of the radar, the penetrating aircraft can pursue the designated target with a 'first shot' opportunity and without disturbance in order to achieve desired effects." However, Zoccali also warned how enemy aircraft could also intercept the penetrating NATO aircraft, suggesting, "This is the reason why the penetrating aircraft also need an electronic escort capability to take out countering aircraft. The reduction of the detection range of the countering aircraft therefore acts as a force multiplier by enabling your own aircraft to employ their weapons always first. This Escort Jammer needs to detect the radars to be jammed as early as possible in order to program the AEA technique, so the Escort Jammer needs to detect and measure the radars on the side lobes that are much more week than the main lobe. The escort jamming mission requires the deliberate use of electromagnetic energy to defend friendly assets even when the adversary radars are not detected or transmitting," he added.

AEA EVOLUTION

According to Jason Cowell, Vice President, Capability and Chief Technology Officer, EW at Leonardo Electronics, the past decade has seen the likes of China and Russia developing their IADS capabilities to counter NATO air dominance in both combat air and intelligence, surveillance and reconnaissance (ISR) roles. "The effect of the sophisticated IADS is the achievement of A2AD preventing NATO forces achieving full deployment of forces into a contested region, typical-

Pursue Next-
Electronic Attack

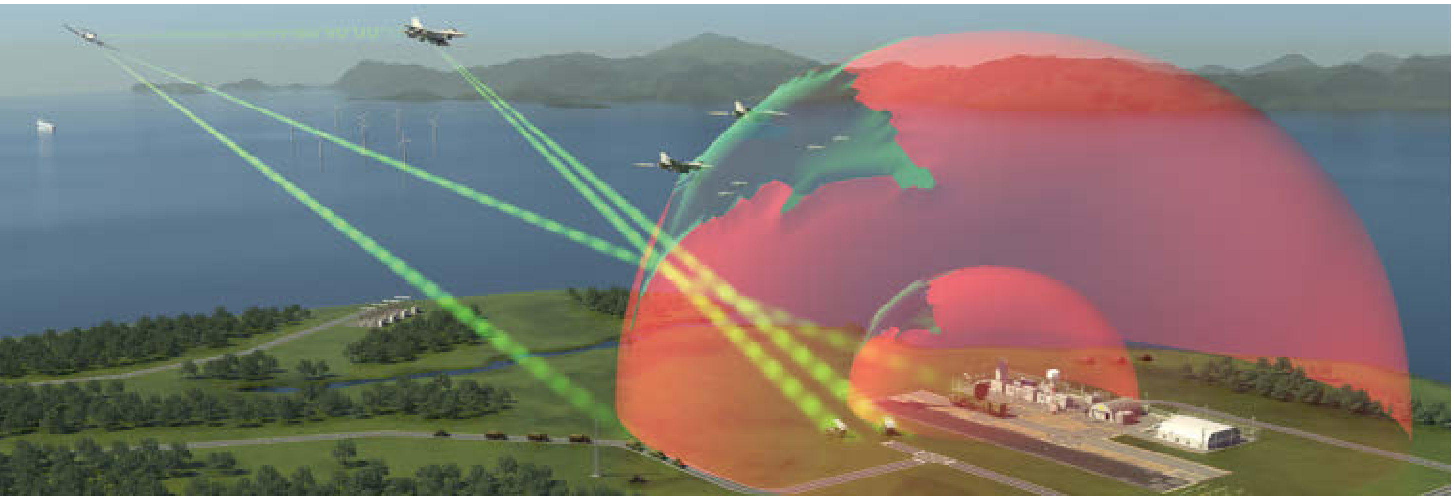
Boeing's EA-18G has been selected as a next-generation AEA capability for the German Air Force. US NAVY

ly through the use of Air Power and then delivery of Joint Services. The long-range SAMs have pushed back long-range ISR targeting platforms and affected delivery of shorter range air-launched weapons. The successful delivery of AEA degrades this A2AD enabling the delivery of effective air-power, which is a critical enable to an effective multi-service campaign," Cowell explained. "At the heart of these systems is a sophisticated network of short, medium and long ground-based radars operating over a wide frequency band."

Cowell described how AEA is evolving into a more complex mission with multiple AEA platforms employing multiple effectors in a coordinated fashion. "The AEA [system of systems], which is likely to be a mixture of approaches including drones, air launched decoys, support jamming pods and stand-off jamming capability, must cover the full spectrum of the radar systems of interest, which can be broad, and then deliver force level effective techniques in order to mask the signatures of the aircraft the system is protecting," he explained.

Historically, European air forces have struggled to invest in the AEA mission, and NATO partners have relied heavily on US capabilities throughout the Cold War and certainly over the past 30 years. This is due mostly to the high cost of developing and fielding all of the sensor platforms, datalinks and networks needed to support AEA aircraft, as well as buying the AEA platforms and effectors themselves. This includes SIGINT aircraft that can detect, identify and geolocate various types of air defense radars and the high-speed, wideband datalinks needed to move the emitter information to the AEA aircraft. The AEA aircraft must feature mission systems that can fuse offboard and onboard information and be able to cue onboard jammers, offboard jammers and hard-kill weapons. This is a considerable materiel investment for relatively small national air forces that, from 1990 through 2010, had not needed to invest very much in its SEAD mission because the threat environment had not evolved. Indeed, Cowell suggested it had been the deployment of longer range and more sophisticated Russian SAM systems, such as the S-400, which had triggered AEA developments in Europe.

Highlighting differences between AEA capabilities in the US and Europe, Cowell continued: "The US retains the largest defense budget in the world by



In April, Hensoldt unveiled its Kalaetron Attack AEA concept to support the German Air Force's LuWES requirement. HENSOLDT

some margin and continues to provide a significant contribution to NATO air capability. The US has a dedicated AEA platform in the EA-18G Growler, which is able to perform both escort and stand-off jamming roles. The US Navy's investment in the Next Generation Jamming Pods to replace the AN/ALQ-99 pods will also enhance the platform's capability over the next few decades."

"In Europe," Cowell explained, "Germany retains the Tornado ECR fleet, which will be replaced in the coming years with a more modern capability. In the UK, there is continued investment in Typhoon to deliver more capable AEA both on board and off board. The European NATO nations have all recognized the need for enhanced AEA capabilities and are investing to develop their capabilities and create balance between US and non-US systems in the near future." Cowell also added that European NATO nations continue to lack sufficient C2 infrastructure to coordinate EW efforts throughout their platforms as part of a coalition in a theater of operations.

DEVELOPING NEW AEA SOLUTIONS

Critical to the deployment of any AEA capability is technology which continues to be designed and manufactured by EW companies and aircraft primes across the US and Europe.

According to NATO JEWCS, such technologies must comprise agile, multi-functional networking, adaptive and small-sized sub-systems in order to optimally support an integrated and networked system of systems approach to AEA.

Examples of recent AEA capability additions across Europe include the April announcement by the German Armed Forces to procure a total of 15 E/A-18G Growlers from Boeing Company in support of its upcoming Luftgestützte Wirkung im Elektromagnetischen Spektrum (LuWES) AEA program. Any AEA capability for the E/A-18 Growler — should the acquisition receive final go-ahead from the German government — is likely to be provided by German company Hensoldt which announced the development of its Kalaetron Attack solution in April.

Capable of neutralizing enemy fire control radars, Hensoldt's solution is designed to preserve freedom of movement of air forces in the face of "state-of-the-art" air defense systems through the employment of electronic countermeasures (ECM), a company statement proclaimed. "Due to its fully digital design, Kalaetron Attack detects and identifies air defense positions very quickly over a wide frequency range. The unit uses artificial intelligence (AI) techniques to recognize new threat patterns from a huge amount of collected pulses. This is especially important for identifying the latest air defense radar systems which cover an extremely wide frequency range or hop between particular frequencies in fractions of a second," the statement concluded.

Hensoldt's Sales Manager for Spectrum Dominance, Ralph Schnell, described how AEA had become a "very important" capability are for the German Armed Forces. "We have to put emphasis on this topic with better technology, particularly if we take a close look at our near peer opponents," he explained. "AEA is the major effort of the German Procurement Agency and Ministry of Defense, hence why were are developing products for this commitment."

Kalaetron Attack has been designed to support multiple EMO areas, including Stand-Off Jamming and Escort Jamming. A third EMO capability centered around Air Launched Decoys and Stand-In Jamming will also be released by Hensoldt in the "late 2020s", Schnell said. The reconfigurable Kalaetron Attack payload comprises a suite of EW Active Electronically Scanned Array (AESA) antennas, Electronic Support Measure (ESM), Gallium-Nitride (GaN) amplifier, Core Processor and Digital Radio Frequency Memory (DRFM) technologies to generate signals and jam enemy networks.

Flight tests of the entire Kalaetron Attack system are due to take place in the first quarter of 2021 although the German Procurement Agency has yet to confirm which aircraft will be used to support the evaluation, Schnell added. Germany's LuWES capability is due to begin supporting NATO operations in 2025.

In the UK, Leonardo is working with MBDA to develop the Selective Precision Effects At Range - Electronic Warfare (SPEAR-EW) system, a stand-in jammer, for use on for Royal Air Force (RAF) Typhoon air frames. SPEAR-EW comprises an electronic attack variant of the SPEAR 3 precision surface attack missile, which

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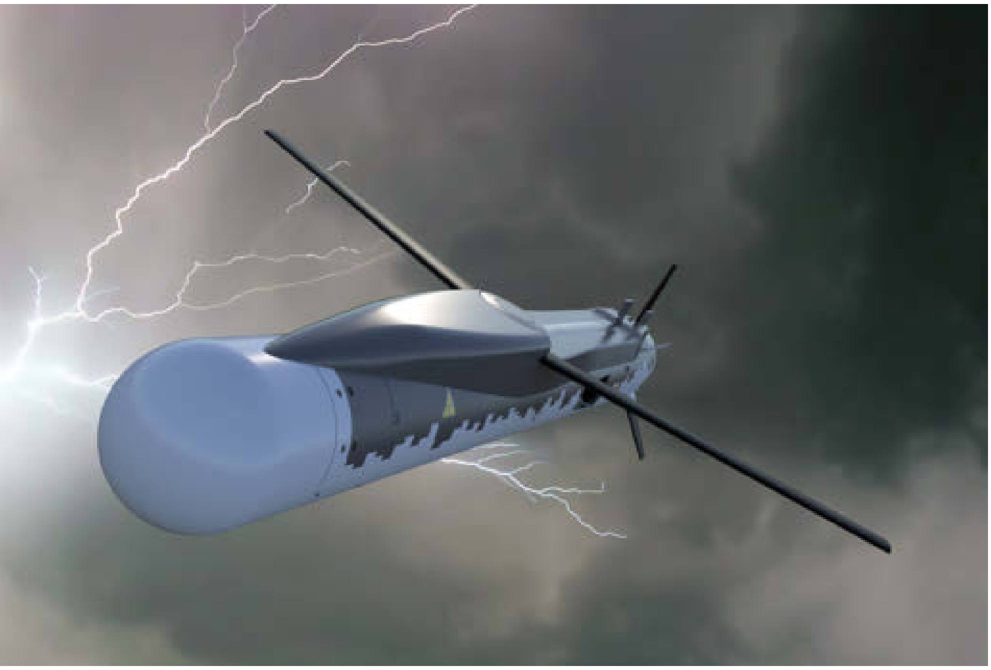


MBDA and Leonardo have co-created an EW payload for the SPEAR missile, providing an unmanned stand-in jamming capability for RAF Typhoons and F-35s. MBDA

offers an operational range of at least 100 km. SPEAR-EW integrates a miniaturized DRFM-based jamming payload from Leonardo that is based on the company's Brite Cloud RF self-protection decoy. In the SPEAR air frame, the small EW payload provides extra capacity for fuel to extend the weapon's range. The concept is to launch multiple SPEAR-EW weapons and use them in a networked fashion to attack air defense systems.

SPEAR-EW remains in development under a Technical Demonstrator program with the UK MoD. Comprising less than 100kg in weight and measuring less than 2m in length, a single F-35 Joint Strike Fighter is expected to be capable of carrying up to four SPEAR missiles within each of its two weapons bays. The Eurofighter Typhoon should be capable of carrying a total of three missiles on each weapons station.

In Italy, ELT continues to develop its EDGE escort jamming pod, which can be carried on Tornado and Eurofighter aircraft. As Gianni Zoccali explained, EDGE is a pod-mounted jammer that combines AESA technology with wideband GaN amplifiers. Designed as a fully autonomous system that can provide self-protection and support jamming, the EDGE pod is capable of providing simultaneous jamming capability on multiple individual threats. The EDGE's receiver subsystem offers an ELINT capability, automatic threat acquisition and emitter location based on phased DF techniques.

"We expect EDGE to be used as a combination of capabilities covering SOJ, SIJ and EJ requirements, based on the new technological solutions like fully digitalized hardware, software defined, artificial intelligence, radar interoperability," Zoccali said. EDGE can also be augmented with ELT's EW Manager which has been designed as a central processing element for the payload. This capability, Zoccali added, allows the optimal integration of available resources installed on the hosting pod as well as other EDGE equipped platforms involved in the mission. "The EW Manager provides the control of the EM Environment, monitoring and analyzing the emitters of interest, activating the jamming action when required," he concluded.

In Sweden, Saab is pushing forward with new AEA solutions. Jonas Grönberg, Head of Marketing & Sales for Fighter Aircraft EW, said the last five to 10 years has witnessed an "...increase in interest for advanced EW systems. This is driven by changes in the operational environment for our military forces. Today the potential opposition is extremely well equipped, especially when it comes to exploiting the electromagnetic spectrum, as was clearly visible during recent conflicts such as Ukraine and Syria."

"Many air forces are starting to operate platforms that are using low-observable technologies to avoid detection," Grönberg explained. "That also implies not using any active sensors, but relying on data links to provide real-time situational awareness. Those data links are of course an interesting target for different types of EW." He also described the increasingly complex electromagnetic operating environment: "To counter low-observable designs, long range surveillance radars at VHF are now re-emerging, as most stealth designs lose their low observability properties at low frequencies. Different types of radars cooperating in networks, combined with extremely long-range missiles, constitute A2AD systems which effectively restrict air operations within their engagement ranges."

According to Grönberg, several approaches are available to air forces seeking to operate in A2AD environments, including lethal SEAD approaches where missiles can be used to attack air defense threats. "As we see it, the most effective way for Europe to counteract A2AD is to have a capability of coordinated AEA, able to create a safe bubble around the formation of aircraft operating in the European airspace," he said. "Currently, we see real and growing opportunities, both in Europe and on the global market, to provide air forces with the tools they need against the backdrop of growing threats."

"In order to get optimal operational effect from these AEA assets and to be a true force multiplier, planning and coordination of effects is required," Grönberg explained. "This can be obtained by an EW Command and Control function allowing coordinated electronic attacks by various platforms, in addition to improved situational awareness and geo-location through exchanging valuable information between them. This function can be implemented in different ways. Combining airborne mission systems in a wide body aircraft with ground-based C2, as well as a EW weapon system officer in the back seat of a fighter carrying an escort jammer to mention a few."

Saab's EAJP conducted its maiden flight test in November 2019 ahead of integration on board Gripen E/F aircraft. SAAB

In November 2019, Saab conducted the first flight test of its Electronic Attack Jammer Pod (EAJP) on a Gripen demonstrating its ability to interface with aircraft hardware, software and cockpit controls. The low-band EAJP is designed to protect the Gripen from acquisition, tracking and surveillance radars. It forms part of Saab's Arexis family of electronic warfare systems and will be integrated on board Gripen E/F aircraft as an option in addition to the AREXIS EW self-protection system.

"As a supplement, Saabs EAJP can be used for penetrating escort aircraft to suppress low band surveillance radars together with an operator's concept in the backseat of the aircraft," Grönberg explained. "Based on the AESA-based development within the field of ECM, Saab will be able to deliver both standoff for wide body aircraft and escort jamming capability for fighter platforms," he added before suggesting Saab is considering increased power capabilities for AESA radars to "widen the operational range for EA assets as well as smart tools for planning and time coordination of jammer platforms."

A BUSY DECADE AHEAD

As NATO's European partners work toward meeting the Alliance's future AEA goals, European EW companies are continuing to develop and evolve new AEA solutions and integrate them into a "system of systems." A central concept in these efforts is the need to create solutions that fit within multi-platform AEA operational concepts, comprising a mix of manned fighter aircraft and unmanned combat aircraft. "The challenge is the effective co-ordination of these assets utilizing autonomy and machine learning to deliver coordinated and timely effect," Leonardo's Cowell explained.

Also considering future developments, the NATO JEWCS described how fast emerging will also influence AEA. "All the combat domains rely more than ever on the ability to detect the enemy ahead of time, so it seems obvious that EW capabilities offer decisive operational advantages," a JEWCS official explained. "In a well-built, long-term strategy, the technological combinations between EW, NAVWAR, Cyber, Info Ops and AI will be identified in a multi-skill, visionary, multi-level, agile and adaptive working group, not separated but as a continuum strategy."

The official added, "In addition, AEA will expand as advanced technologies enable UAVs to take a growing role. Unmanned systems offer the ability to execute missions you can't conduct with a manned aircraft, such as projecting further and supporting coherent operations with more manned and unmanned platforms. Using manned and unmanned systems together offers many opportunities, but needs a lot of computing power for information sharing, situational awareness, coordination and synchronization. AI, Cyber and the 5G technology will have a preponderant role in order to synchronize the effects of AEA and to respond to some automatic functionalities, automatic recognition of activities and frequency agility already seen in radios, radars, jammers and decoys. 5G technology will also play an increasing role in operating across multiple bands and frequencies as we move toward the software-centric battlespace."

FEATURED LIVE COURSES

EW Modeling and Simulation

Dave Adamy

Mondays & Wednesdays

13:00 – 16:00 EDT | June 1 – 17, 2020

This is a practical course in which the basic concepts and techniques of Electronic Warfare modeling and simulation are presented and applied to practical problems.

Missile Design, Development, and System Engineering

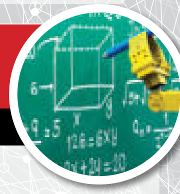
Eugene Fleeman

Mondays, Wednesdays, & Fridays

13:00 – 16:00 EDT | July 13 – 31, 2020

Missiles provide the essential accuracy and standoff range capabilities that are required in modern warfare. Technologies for missiles are rapidly emerging, resulting in the frequent introduction of new missile systems.

Machine Learning for EW



Kyle Davidson

Mondays, Wednesdays, & Fridays

13:00 – 16:00 EDT | September 14 – 30, 2020

This course introduces students to the fundamentals of machine learning and its application to modern Electronic Warfare (EW) and cyber solutions.

Electro-Optical/Infrared Sensor Engineering

Dr. Phillip Pace

Mondays & Wednesdays

13:00 – 16:00 EDT | October 5 – 28, 2020

This course presents the fundamentals of electro-optical (EO) & infrared (IR) sensor technology, its analysis and its application to military search, track and imaging systems.

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Dr. Clayton Stewart

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Kyle Davidson

Friday & Saturday

09:00 – 17:00 EST | Dec 11 – 12, 2020

Hands-on Introduction to Radar and EW

Dr. Warren Du Plessis

Sunday & Monday

09:00 – 17:00 EST | December 6 – 7, 2020

Tactical Battlefield Communications

Dave Adamy

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09:00 – 17:00 EST | Dec 11 - 12, 2020

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TECHNOLOGY SURVEY
A SAMPLING OF POWER AMPLIFIERS

By John Knowles and Ollie Holt

This month's technology survey looks at power amplifiers for electronic warfare (EW) applications. Today's EW system designers can choose from a number of power amplifier technologies, such as traveling wave tubes (TWTs), LDMOS, microwave power modules (MPMs) and gallium arsenide (GaAs) or gallium nitride (GaN)-based solid-state power amplifiers (SSPAs). Framed in the wrong way, this can seem like a daunting decision for the design engineer. Which one is best for which type of EW application? Framed in a different way, however, the good news is that there are many power amplifier suppliers that are combining these technologies in their products to exploit the best performance traits of each one for meeting just about any EW requirement.

For many decades, the traveling wave tube (TWT) was the leading PA choice for EW design engineers. TWTs could provide enough power for offensive EW systems, such as a ground-based communications jammer or a support jamming aircraft. They were also small enough for use in self-protection EW systems, such as an airborne jamming pod on a fighter aircraft or an onboard EW system for a helicopter. In the 1990s, the MPM made its debut, mainly for radar jamming applications. As TWTs and MPMs were reduced in size, they found new EW applications, such as airborne towed decoys.

The 1990s also saw the beginning of GaN technology development for a variety of applications, including power amplifiers. GaN-based SSPAs were the technology of choice when the US and its coalition partners needed to develop large quantities of low-power (10-25W) communications jammers to defeat remotely-controlled improvised explosive devices (RCIEDs) in Iraq and Afghanistan. By the 2010s, GaN performance was climbing higher in frequency and finding applications in many radar jamming systems, such as the EA-18Gs Next-Generation Jammer Mid-Band pod and the SEWIP Block 3 EA system on surface combatants. Today, both TWT and GaN technologies are pushing into the Ka-Band for EW applications.

The requirements for military power amplifiers will continue to evolve. Over the coming decade, the DOD will develop a new-generation of multifunction RF systems (combining communications, radar, EW, and other functions.) that are designed for small, autonomous unmanned vehicles that can operate together in swarms. These requirements are driving companies to develop new power amplifiers that are smaller, lighter weight and use less power. Because these autonomous weapons platforms may not be recovered after their mission is completed, the cost of the power amplifier is also an important consideration.

THE SURVEY

This month's survey includes nearly 70 products from 26 companies. The first column lists the model name or number. The next column provides the unit's operational frequency range. Most EW power amplifiers must cover a wide frequency range (several hundred megahertz or several gigahertz) with consistent performance over that span.

The third column shows which technologies the power amplifier features. Note that MPMs can use either TWTs or SSPAs. The next column lists the output type(s): pulsed or continuous wave (CW). Many EW requirements call for CW performance in addition to pulsed output for some radar jamming techniques.

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

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

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

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

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

Next month, we will look at airborne jamming systems.

SOLID STATE POWER AMPLIFIERS

MODEL	OPERATING FREQ	TECHNOLOGIES	OUTPUT TYPE	OUTPUT PWR/ GAIN	HARMONIC AND SPUR LEVELS
Aethercomm Inc.; Carlsbad, CA, USA; +1 (706) 208-6002; www.aethercomm.com					
SSPA 0.020-1.000-1000	0.02-1 GHz	Class AB GaN	CW and pulsed	1000W (60 dBm) / 70 dB	-19 dBc harmonic/ -60 dBc Spur
SSPA 2.0-6.0-400	2-6 GHz	Class AB GaN	CW and pulsed	400W (56 dBm) / 77 dB	-64 dBc harmonic/ -60 dBc Spur
SSPA 2.0-18.0-100	2-18 GHz	Class AB GaN	CW and pulsed	100W (50 dBm) / 56 dB	-15 dBc harmonic/ -60 dBc Spur
Analog Devices Inc; Norwood, MA, USA; +1 (781) 329-4700; www.analog.com					
HMC7748	2-6 GHz	*	*	25W / 43 dBm/ 58 dB	*
HMC8113	2-6 GHz	*	*	500W / 57 dBm/85 dB	-12 dBc harmonic; -60 dBc spur (@ Pin = 0 dBm)
HMC8114	5.8-18 GHz	*	*	100W / 49.5 dBm/68 dB	-16 dBc harmonic; -60 dBc spur (@ Pin = 0 dBm)
ASELSAN; Ankara, Turkey; +90-312-592-10-00; www.aselsan.com.tr					
AD-0000-0123	20-500 MHz	LDMOS+GaN	CW	46 dBm / 48 dB	Harmonics< -12 dBc / Spur < -50 dBc
MW-0000-1341	500-3000 MHz	GaN	CW	52 dBm / 52 dB	Harmonics< -6 dBc / Spur < -40 dBc
MW-0000-1998	2-6 GHz	GaN	CW and pulsed	46 dBm / 50 dB	Harmonics< -8 dBc / Spur < -50 dBc
Comtech PST Corp.; Melville, NY, USA; +1 (631) 777-8900; www.comtechpst.com					
BME2969-300	2-6 GHz	*	*	Psat: >300W, Gain: >55 dB	2fo: <-20 dBc, spur: < -60 dBc
BME49189-50	4-18 GHz	*	*	Pout 3 dB: >50W, Gain: >49 dB	2fo: < -19 dBc, 3fo: < -35 dBc; spur: < -60 dBc
BME69189-100	6-18 GHz	*	*	Psat: >100W, Gain: >46 dB	2fo: < -12 dBc, 3fo: < -22 dBc; spur: < -60 dBc
CPI; Palo Alto, CA, USA; +1 (650) 846-3900; www.cpii.com					
VTF-6130C1	2-8 GHz	TWT	CW	80W	*
VTM-6196R5	4-18 GHz	TWT	CW	25W	*
VTA-6193A4	26.5-40 GHz	TWT	CW and pulsed	40W / 37 dB	*
CTT Inc.; San Jose, CA, USA; +1 (408) 541-0596; www.cttinc.com					
AGM/060-5056	2-6 GHz	GaN	CW	100W (+50 dBm)	-60 dBc
AGX/0218-3946	2-18 GHz	GaN	CW	8W (+39 dBm)	-60 dBc
AGX/0318-4656	3-18 GHz	GaN	CW	40W (+46 dBm)	-60 dBc

SUPPLY VOLTAGE	EFFICIENCY	RELIABILITY	SIZE (HxWxL inches/mm)	WEIGHT (lb/kg)	FEATURES
270 VDC	40-50%	65k hr	6.0 x 13.0 x 10.0 in.	38 lb	Electronic Attack Broadband, High Power, SSPA.
MIL-STD-704	20-35%	75k hr	4.0 x 8.0 x 14.5 in.	10 lb	Electronic Attack Broadband, High Power, SSPA.
28 VDC	18-20%	100k hr	1.5 x 4.0 x 6.0 in.	2 lb	Electronic Attack Broadband, High Power, SSPA.
12V/28V	30%	*	0.61 x 3.23 x 3.75 in.	*	Internal voltage regulation and sequencing (protection); external enable.
220 VAC	20%	*	8.7 x 19 x 21 in. (rack mount)	100 lb	DC blocked RFin/out, 1,2,4,8,16,32 dB attenuation stepping, current, Temp, VSWR an d supply monitoring with alarm.
48 VDC	10%	*	2.65 x 10.5 x 17.6 in.	32.2 lb	DC blocked RFin/out, 1,2,4,8,16,32 dB attenuation stepping, current, Temp, VSWR an d supply monitoring with alarm.
28V	> 35 %	MTBF>20000 hr	95 x 90 x 22 mm	0.25 kg	Forward and reverse power monitoring, enable control.
36V	> 25 %	MTBF>20000 hr	300 x 156 x 28 mm	2.2 kg	Forward and reverse power monitoring, temperature monitoring, enable control.
28V	> 12 %	MTBF>20000 hr	160 x 94 x 20 mm	0.7 kg	Includes isolator, forward and reverse power monitoring, enable control with fast switching.
18-32 VDC	18% (typ)	*	15.2 x 7 x 2.7 in.	17 lb	Extreme temperature & high altitude usage.
28 VDC	15% (typ)	*	6.6 x 3.5 x 0.84 in.	1.5 lb	Ultra-wideband operation; rugged and reliable.
28 VDC	10% (typ)	*	8 x 6 x 2.5 in.	5.5 lb	Ultra-wideband operation; rugged and reliable.
800 W	*	*	13.4 x 1.75 x 2.28 in.	3 lb	*
300 W	*	*	12.27 x 0.8 x 1.75 in.	1.5 lb	Conduction cooled
675 W	*	*	16.0 x 2.75 x 3.35 in.	7 lb	*
+30V / 17.2A (Typ) @ Psat, +30V / 2.4A (Typ) @ SSG	19.4% (Typ)	*	6.32 (L) x 4.50 (W) x 0.84 (H) in.	<2.0 lb	TTL On/Off Option, Rack-Mount Configuration Available.
+32V / 3.1A (Typ) @ Psat, +33V / 1.4A (Typ) @ SSG	17% (Typ)	*	4.25 (L) x 3.25 (W) x 0.88 (H) in.	<1.0 lb	TTL On/Off Option, Rack-Mount Configuration Available.
+32V / 16.8A (Typ)	7.4% (Typ)	*	5.16 (L) x 4.90 (W) x 0.82 (H) in.	<1.0 lb	TTL On/Off & Heatsink Options, Rack-Mount Configuration Available.

SOLID STATE POWER AMPLIFIERS

MODEL	OPERATING FREQ	TECHNOLOGIES	OUTPUT TYPE	OUTPUT PWR/ GAIN	HARMONIC AND SPUR LEVELS
dB Control; Fremont, CA, USA; +1 (510) 656-2325; www.dBControl.com					
dB-3201H	30-38 GHz	Millimeter Wave Microwave Power Module (MPM)	Pulsed or CW	125W CW/51 dB	Harmonics -10 dBc max, spurious -50 dBc max
dB-4127	6-18 GHz	Wide, High Band Microwave Power Module MPM	Pulsed or CW	150W CW/53 dB at 6.0-6.5 GHz, 200W CW/53 dB at 6.5-18 GHz	Harmonics -2 dBc @ 6 GHz, spurious -50 dBc max
dB-3774B	6-18 GHz	Wide, High Band Pulsed Microwave Power Module MPM	Pulsed	1000W min 5% duty cycle/60 dB	Harmonics -1.5 dBc max, spurious -45 dBc typical
Diamond Microwave; Shipley, UK; +44 (0)113 278 9793; www.diamondmic.com					
DM-SC100-02	2-6 GHz	GaN	CW & pulsed	100W / 55 dB	Harmonics -70dbC@6GHz
Elbit Systems EW and SIGINT - Elisra; Bene Beraq, Israel; +972-3-6175411; www.elbitsystems.com/elisra					
4500A40000	30-520 MHz	GaN	*	1000W	Spur higher than 60 dBc
4600A40000	1-3 GHz	GaN	*	100-200W	Harm in band 60 dB (with filter bank)
SSPA	2-6 GHz, 6-18 GHz, 32-38 GHz	*	*	1000-2000W	*
Empower RF Systems; Los Angeles, CA, USA; +1 (310) 412-8100; www.EmpowerRF.com					
Model 2214	2.9-3.5 GHz	GaN on SiC	Pulse	8kW / 70 dB	-12 dBc / -60 dBc
Model 2223	500 MHz - 6 GHz	GaN on SiC	CW	150W / 53 dB	-15 dBc / -60 dBc
Model 2225	5.2-5.9 GHz	GaN on SiC	Pulse	90kW / 80 dB	-40 dBc / -60 dBc
ERZIA; Santander, Spain; +34 942 29 13 42; www.erzia.com					
ERZ-HPA-0600-1800-40-E	6-18 GHz	GaN	CW	15W / 46 dB	*
ETM Electromatic, Inc.; Newark, CA, USA; +1 (510) 797-1100; www.etm-inc.com					
TWTA-XM	2-6 GHz	TWTA	CW and pulsed	300W CW 500W CW 1000W CW	-60 dBc
SSPA-L	S-Band C-band X-Band Ku-Band	GaN SSA	CW and pulsed	200W to 40kW CW 1kW to 150kW Pulsed	-60 dBc
Suite-ODU	0.5-40 GHz	TWTA + SSPA	*	100-500W CW	-60 dBc

SUPPLY VOLTAGE	EFFICIENCY	RELIABILITY	SIZE (HxWxL inches/mm)	WEIGHT (lb/kg)	FEATURES
270 VDC (or 28 VDC or 3-Phase AC optional)	900 W max power consumption	*	11 (L) x 9.38 (W) x 2.38 (H) in.	8.5 lb	Milimeter Wave, Pulsed or CW operation, High PRF pulse modulation.
270 VDC (or 28 VDC or 3-Phase AC optional)	750 W max power consumption	*	11 (L) x 9.38 (W) x 2.15 (H) in.	8.5 lb	Wideband Operation, Pulsed or CW operation, High PRF pulse modulation.
270 VDC (or 28 VDC or 3-Phase AC optional)	800 W max power consumption	*	18 (L) x 7 (W) x 3 (H) in.	18 lb	Wideband Operation, Pulsed operation, Very Low Phase Noise and Spurious.
28 VDC	20-40%	*	24mm x120mm x137mm (0.8"x4.7"x5.4")	1.65lb/0.75kg	Ultra Compact Wide-band GaN SSPA; currently part of a manportable electronic attack system.
48V	23% (typ)	10k hr MTBF	7U x 19 x 28 in.	71 kg	*
48V	23% (typ)	10k hr MTBF	5U x 19 x 28 in.	42 kg	*
115V 3Phase 400 Hz	*	*	140 x 240 x 270 mm	13 kg	Phased array; CW and pulse transmitter; air cooled; low SWaP; applicable to airborne , ground and naval platforms.
208V 3P	30%	4000 hr	17 x 33.25 x 28 In.	425 lb	NEWEG compatible. Up to 20% duty cycle and 500 usec pulse widths. CW capable at lower output power.
208V 1P	33%	5500 hr	17 x 8.75 x 22 In.	95 lb	Built-in jamming and threat sim modes include frequency hopping, multitone, AM, FM, pulse, QAM and broadband noise. Single band.
208V 3P	25%	10 Yr MTT 1 dB loss	82 x 46 x 40 In.	2240 lb	Liquid-cooled scalable architecture with hot swapping. Asymmetrical pulse widths from 100ns to over 500usec.
28V nominal	20%	*	80 x 100 x 21 mm	0.3 kg	*
*	20%	*	5.25 (3U) x 19 x 24 in. (300W HPA)	*	Integral air cooling; Ethernet control; compliant with Mil-Std-810 and Mil-Std-461.
*	15%	*	5.25 (3U) x 19 x 24 in. (200W CW HPA)	*	Liquid cooling; Ethernet control; compliant with Mil-Std-810 and Mil-Std-461.
*	20%	*	10 x 12.5 x 24 in. (per subband)	*	Full outoor rated; integral air cooling; compliant with Mil-Std-810 and Mil-Std-461.

SOLID STATE POWER AMPLIFIERS

MODEL	OPERATING FREQ	TECHNOLOGIES	OUTPUT TYPE	OUTPUT PWR/ GAIN	HARMONIC AND SPUR LEVELS
Exodus Advanced Communications; Las Vegas, NV, USA; +1 (702) 534-6564; www.exoduscomm.com					
AMP2041-1	1-2.5 GHz	GaN	CW	2.2kW 1600W P1 dB	-20 dBc max at rated Pout; -73 dBc max spurious
AMP2030A	700 MHz - 6 GHz	GaN	CW	300W 200W P1 dB	-20 dBc max at rated Pout; -60 dBc max Spurious
AMP2065-3	6-18 GHz	GaN	CW	100W 50W P1 dB	-20 dBc max at rated Pout; -60 dBc max Spurious
General Microwave Corporation; Syosset, NY, USA; +1 (516) 802-0900; www.kratosmed.com					
SGN-X5-30	6-12 GHz	GaN	CW and pulsed	30W / 45 dB	-20 dB harm / -70 dB spur typ.
L3Harris Technologies - Electron Devices; Torrance, CA, USA; +1 (310) 517-6000; www2.l3t.com/edd/; www.L3Harris.com					
M1201	2-6 GHz	MPM	CW and pulsed	70W min (2.0-2.5 GHz) 80W min (2.5- 6.0 GHz) 50 dB	-40 dBc spur
M1245	6.5-18 GHz	MPM	CW and pulsed	200W min / 60 dB	-50 dBc spur
M2842	18-40 GHz	MPM	CW and pulsed	60W min (18-40 GHz) 100W min (20-36 GHZ) 40 dB min	-50 dBc spur
Leonardo; Palermo, Italy; +39 0916482945; www.leonardo.com					
ET3407	4-8 GHz	TWT	CW and pulsed	280W	*
MPM3580	4.5-18 GHz	MPM	CW and pulsed	150W	*
Mercury Systems; Andover MA, USA; +1 (866) 627-6951; www.mrcy.com					
DM-HPSC-150-101	2-6 GHz	GaN	CW	140W	Harmonics at Psat: -15dBc
DM-HPMB-10-101	2-18 GHz	GaN	CW	10W	Harmonics at Psat: -15dBc
DM-HPKA-20-102	29-31 GHz	GaN	CW	15W	Harmonics at Psat: -15dBc
Microwave Amplifiers Ltd.; Bristol, UK; +44-01275-853196; www.microwaveamps.co.uk					
AM8-20-520-50-50	20-520 MHz	GaN	*	100W	-13 dBc typ (20-200 MHz); -20 dBc typ (200-520 MHz) (har); -80 dBc min (spur)
AM6-0.5-2.5-50-50	0.5-2.5 GHz	GaN	*	100W	-15 dBc max (har); -80 dBc min (spur)
AM9-2-6-50-50	Reverse power protection; reverse polarity protection +L76+A78	GaN	*	100W	-15 dBc typ @ 90 W (har); -90 dBc min (spur)

SUPPLY VOLTAGE	EFFICIENCY	RELIABILITY	SIZE (HxWxL inches/mm)	WEIGHT (lb/kg)	FEATURES
208 VAC	20%	*	32U Rack Cabinet	600 lb Nom.	Class A/AB linear design; high power advanced GaN devices.
208 VAC	20%	*	8.75 (H) x 19 (W) x 25 (D) in.	80 lb Nom.	Class A/AB linear design; high power advanced GaN devices.
208 VAC	20%	*	10.5 (H) x 19 (W) x 25 (D) in.	70 lb Nom.	Class A/AB linear design; high power advanced GaN devices.
22.5 V & ±12 V	20% typ.	>30k hr @ 70°C AUF	124 x 105 x 25mm 4.9 x 4.2 x 1 in.	0.5 kg	RF on/off switching. RF output sample port, thermal sensor output and thermal shutdown.
28 VDC	19%	*	10.75 x 7 x 1.25 in.	< 6 lb	Low-noise, compact, wideband MPM for airborne, shipboard and ground military EW applications. This MPM contains a TWT, an SSA and a power supply within a single conduction-cooled package.
270 VDC	22%	*	8.5 x 9.75 x 1.5 in.	< 8 lb	Designed for high SWAP value airborne EW applications, yet also suitable for ground and naval platforms; additional options include active cooling, phase matching, linearization and space-conformal packaging.
28 VDC	28%	*	8.5 x 9.75 x 1.75 in.	< 8 lb	Essential 100 W broadband mmW stand-alone or building block module for airborne, ground and naval EW platforms.
*	*	*	*	*	ECM applications
270 VDC	*	*	250x220x40 mm	3.6 kg	ECM applications
28V	25%	*	7.85 x 6.00 x 1.00 in.	*	TTL control.
32V	15%	*	2.50 x 2.75 x 0.45 in.	*	TTL control.
20V	15%	*	3.50 x 4.50 x 0.78 in.	*	TTL control.
28 VDC	40% @ 100 W	*	220 x 100 x 34mm	*	Reverse power protection; reverse polarity protection.
28 VDC	40% @ 100 W	*	220 x 100 x 28mm	1250 g	Reverse power protection; reverse polarity protection.
28 VDC	22% @ 90 W	*	300 x 127 x 51mm (module)	*	Reverse power protection; reverse polarity protection.

SOLID STATE POWER AMPLIFIERS

MODEL	OPERATING FREQ	TECHNOLOGIES	OUTPUT TYPE	OUTPUT PWR/ GAIN	HARMONIC AND SPUR LEVELS
Microwave Dynamics; Irvine, CA, USA; +1 (949) 679-7788; microwave-dynamics.com					
MPA00518-30	0.5-18 GHz	GaN	*	30 dBm/ 30 dB	*
MPA0612-40	6-12 GHz	GaN	*	40 dBm/ 33 dB	*
MPA0618-40	6-18 GHz	GaN	*	40 dBm/ 35 dB	*
NuWaves Engineering; Middletown, OH, USA; +1 (513) 360-0800; www.NuWaves.com					
NuPower 13G05A	0.8-2.5 GHz	GaN	CW	50W (Psat)	-17 dBc (2nd harmonic)
Ophir RF; Los Angeles, CA, USA; +1 (310) 306-5556; www.ophirrf.com					
4135	2-30 MHz	Latest Gen LDMOS	EIA 1 5/8	20,000W	-80 dBc
5303133-001	20-1000 MHz	Latest Gen LDMOS	Type N	100W	-20 dBc
5304043-020	2-6 GHz	GaN	Type SMA	50W	-20 dBc
Photonis Defense, Inc.; Lancaster, PA, USA; +1 (717) 295-6000; www.photonisdefense.com					
9106B	6-18 GHz	MPM	CW	100W / 50 dB	-6 db @ 7 GHz/-40 dBc
9123	2-8 GHz	MPM	CW	200W / 53 dB minimum	-6 db @ 3 GHz/-40 dBc
9124	6-18 GHz	MPM	CW	200W / 53 dB minimum	-6 db @ 7 GHz/-40 dBc
Teledyne Microwave Solutions – TWT Products; Rancho Cordova, CA, USA; +1 (916) 638-3344; www.teledynemicrowave.com					
MEC-5889	4-8 GHz	TWT	CW	250W / 46-59 dB	-8 dBc harmonic separation
MEC-5508	6-18 GHz	TWT	CW	200W / 26-27.5 dB	-3 dBc harmonic separation @ 6 GHz
MEC-5493	18-26.5 GHz	TWT	CW	50W / 26-28 dB	-8 dBc
Thales Electron Devices; Velizy-Villacoublay, France; +33 (0)1 30 70 35 00; www.thalesgroup.com					
TH 24512	4.5-18 GHz	MPM	CW	80-200W	-8 dBc harmonic @ 8 GHz; -50 dBc spur
TH 24445	6-18 GHz	MPM	CW	100-200W	-8 dBc harmonic @ 8 GHz; -50 dBc spur
TMD LLC: Baltimore, MD: +1 410 242 4290: www.tmdus.com / TMD Technologies Ltd: Hayes, Middlesex UK: +44 208 573 5555:					
PTS9925	2-6GHz	SSPA	SMA-F	100W	-50dBc
PTXM9754	6-18GHz	TWT	TNC	100W	-50dBc
PTX8807	26.5-40GHz	TWT	WR-28	100-200W	-45dBc
Triad RF Systems, Inc; East Brunswick, NJ, USA; +1 (855) 558-1001; www.triadrf.com					
TA1220	20 MHz - 6 GHz	GaN	CW	20W / 64 dB	*
TA1216	300 MHz - 6 GHz	GaN	CW	32W / 45 dB	2nd harmonic: -35 dBc at Psat
TA1056	20-1000 MHz	GaN	CW	40W / 50 dB	2nd harmonic: -31 dBc at Psat

SUPPLY VOLTAGE	EFFICIENCY	RELIABILITY	SIZE (HxWxL inches/mm)	WEIGHT (lb/kg)	FEATURES
28V @ 0.9A; 12V @ 0.25A	*	*	3 x 2.125 x 0.812 in.	2 lb	Benchtop (MDPA) model with fan & heatsink (120/220VAC), size: 6.7 x 6.1 x 2.1 in.
24V@2.4A	*	*	3 x 2.125 x .812 in.	2 lb	Benchtop (MDPA) model with fan & heatsink (120/220VAC), size: 6.7 x 6.1 x 2.1 in.
20V @ 6A	*	*	3 x 2.125 x .812 in.	2 lb	Opt. pulse modulation, heatsink and input limiter.
27-30 VDC	40%	*	0.61 x 3.50 x 4.50 in.	9 oz	GaN, low SWaP, ruggedized chassis.
208 VAC	25%	*	Qty 4 6-ft. Tall Cabinets	2400 lb	Switched filter bank
28 VDC	25%	*	1.1 x 11.5 x 4.5 in.	1.8 lb	Airborne/Ground based
28 VDC	30%	*	1.0 x 6.0 x 3.0 in.	1.2 lb	Airborne/Ground based
28 VDC / 400 W max 115 VAC 3ø 400 Hz option	30%	*	2.6 x 7 x 6.1 in.	5.8 lb	Conduction Cooled; -40°C to +85°C Baseplate; Altitude 50,000 ft.
115 VAC 3ø 400 Hz / 1000 W max	25%	*	4 x 5 x 11.5 in.	12.7 lb	Self-Contained Air Cooling; -40°C to +70°C Air Temperature; Altitude 40,000 ft.
115 VAC 3ø 400 Hz / 1000 W max	25%	*	4 x 5 x 11.5 in.	12.7 lb	Self-Contained Air Cooling; -40°C to +70°C Air Temperature; Altitude 40,000 ft.
1300 W	19%	*	2.5 x 2.8 x 20.6 in.	*	Phase match available.
840 W typ, 1000 W specified	28%	*	2.8 x 1.47 x 11.08 in.	*	*
450 W	11%	*	3.4 x 2.76 x 16.1 in.	*	*
650 W	30%	*	9.84 x 9.13 x1.37 in.	3 kg	CW/ pulsed; built-in modulator; PRF 100 kHz continuous; 1-MHz burst mode.
650 W	30%	*	9.84 x 9.13 x1.37 in.	3 kg	Fully qualified for airborne applications, including EMC MIL STD 461 E.
www.tmd.co.uk					
28V	20%	Exceeds MIL-HDBK-217	137 x 120 x 24 mm	0.75kg	
270V	25%	Exceeds MIL-HDBK-217	203 x 197 x 36 mm	2.6kg	
270V	25%	Exceeds MIL-HDBK-217	450 x 224 x 55 mm	8.5kg	
12-32 VDC	30% avg	>50k hr MTBF	6.25 x 5.80 x 1.25 in.	< 3 lb	Wideband, high gain
12-28 VDC	25% at Psat	>50k hr MTBF	3.75 x 2.30 x 0.95 in.	< 1 lb	Wideband, high power
28 VDC	45% at Psat	>60k hr MTBF	0.85 x 2.30 x 3.99 in.	< 1 lb	High power JTRS amplifier.

SURVEY KEY – SOLID STATE POWER AMPLIFIERS

MODEL
Product name or model number

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

TECHNOLOGIES
Types of technologies used in the amplifier

OUTPUT TYPE
Types of output the amplifier provides

OUTPUT POWER/GAIN
P1 dB or gain in dB

LEVELS
Harmonic and spurious levels in dBc

SUPPLY VOLTAGE/INPUT POWER
In Watts, VAC or VDC

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

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

SIZE
H x W x L in inches or millimeters

WEIGHT
Weight in lb/kg

FEATURES
Additional features

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

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

UPCOMING TECHNOLOGY SURVEYS
- **JULY 2020: AIRBORNE RADAR JAMMERS**
- **SEPTEMBER 2020: RF TUNERS FOR SIGINT**

Participation in JED *Technology surveys is open and free to all manufacturers whose products fit the parameters of each survey. Please e-mail JEDeditor@naylor.com to request a questionnaire and specify which survey(s) your company would like to participate in.*


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qorvo QPA2211
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US Army Air-Launched Effects Effort Accomplishes Major Goal

By John Haystead

In March, the US Army Combat Capabilities Development Command (CCDC) Aviation & Missile Center Technology Development Directorate (AvMC TDD) launched an unmanned aircraft system (UAS) from both a UH-60M Black Hawk helicopter and from a moving ground vehicle. Conducted at Yuma Proving Ground, AZ, the successful launch of the Area-I (Marietta, GA) Air-Launched, Tube-Integrated, Unmanned System 600 (ALTIUS 600) Air-Launched Effects (ALE) system represented the latest accomplishment in the Army's pursuit of "leap-ahead technological advances aimed at dominating its adversaries and reaching its Multi-Domain Operations goal," according to a CCDC statement.

ALEs, which will perform electronic warfare (EW) and intelligence, surveillance and reconnaissance (ISR) functions, will be a critical element of the Army's future airborne capabilities and an integral element of its overall Future Vertical Lift (FVL) goals. As described in *JED*'s April 2020 article, "FVL Program Aims for Overwhelming Advancement of Aircraft Survivability Capability," the Army's FVL program is both ambitious and multi-faceted, encompassing multiple aspects of the Service's mission areas and the role of both manned and unmanned aircraft in accomplishing them. In particular, the unmanned portion of the effort, which includes ALEs, deserves specific attention, as this in itself entails multiple requirements, systems and solutions.

As explained by LTC Anthony Freude, Future Attack Reconnaissance Aircraft (FARA) Integration Lead at the FVL Cross Functional Team (CFT), there are four main efforts within the FVL CFT. Two of these involve manned platforms – the Future Attack Reconnaissance Aircraft (FARA) and the Future Long Range Assault Aircraft (FLRAA). The other two efforts are the Future Unmanned Aircraft System (FUAS), and the Modular Open System Architecture (MOSA).

Under FUAS, there are three additional sub-efforts. These are the Future Tactical UAS (FTUAS), Air Launched Effects (ALEs), and the Scaleable Control Interface (SCI). Colonel Freude emphasizes that "there is a lot of crossover back and forth between elements, because everything we're doing is complementary to each other." Specifically with regard to Capset 1, he notes that there is tandem work going on with both ALEs and with long-range precision munitions.

"When you take the FARA platform and add these two additional unique capabilities, your reach, lethality, endurance and survivability are all absolutely enhanced." The FLRAA platform will also have the ability to launch ALEs, which brings the mission of the scaleable control interface into the discussion. The SCI will be used to manage and control all variations of unmanned platforms from the FTUAS to Gray Eagle, to ALEs. But as pointed out by Lieutenant Colonel Freude, "Instead of an overbearing large-footprint system that you might see in a large truck or shelter, the SCI will be small and light enough to be carried by individual soldiers on the ground." Although they're still working on developing the requirement, ultimately, Freude says they envision scaling down the capability to the size of a laptop, or "even pulling the information down to something like a handheld device."

In an Army press release covering the ALTIUS test launch, Carvil E.T. Chalk, CCDC AvMC TDD Deputy Director for Aviation technology, stated that, "The thing that makes it unique… first of its kind is the fact that it's done at a tactical altitude in forward flight, which means that as the ALE comes out of the tube in forward flight, the rotor system is producing downwash to keep the helicopter aloft and to move it forward … and the ALE must fly through that. It's even more remarkable due to all the factors that must be accounted for during programming – when to deploy the wings, when to start the propulsion system – getting all of that right, is the tricky part."

Intended for use in gathering real-time intelligence information, ALTIUS can be manually flown with a handheld remote or pre-programmed with a target destination by a ground control station. Although the ALTIUS is designed to be recoverable, it is considered "attritable enough" to not need to be recovered.

Specific to the overall discussion of ALEs, which is one of LTC Freude's additional supporting efforts, it's important to note that the ALE effort is separate from the FTUAS program, which is specifically aimed at developing a replacement platform for the RQ-7 "Shadow" UAS for Army Brigade Combat Teams (BCTs). This was not made clear in the April *JED* article. As described in the article, there are currently four companies working on the FTUAS, which is following a "try, buy, inform" acquisition approach. Lessons learned from the FTUAS prototypes will be used to write the official requirement to replace the Shadow.

In contrast, there are currently no contractors specifically involved with the ALE effort, as the Army continues to work through that requirement. As explained by LTC Freude, however, they have determined that the plan will include acquiring four different categories of ALE payloads addressing DILR (Detect, Identify, Locate, Report); Disrupt; Decoy; and Lethal (kinetic capability) missions. "We haven't yet actually picked the payloads by name, type or company, as we're just getting up and starting. But all together, the effects will be quite profound."

ALEs will ultimately be employed across both the future and enduring fleets of the Army's airborne platforms. This will not include the FTUAS platform, however, as the planned form factor for the Shadow replacement is not intended to be able to carry the same payload capabilities as ALEs will. As mentioned in the announcement of the ALTIUS test, currently the surrogate platform for ALE experimentation and risk reduction work is the UH-60M Black Hawk helicopter.

Evolving DEW Technologies and Operational Understanding

By David C. Stoudt, Ph.D.

In our previous DE 101 column (April 2019 JED, p. 36) we introduced some of the basic concepts about directed energy weapons (DEWs), especially high-energy lasers (HELs) and RF weapons (RFWs). In this column, we will take a deeper look at what is required to make DEWs operationally viable.

A CHANGING TECHNOLOGY PARADIGM

During decades of DEW development, sponsoring organizations and the Directed Energy (DE) technical community have primarily focused on increasing one DEW parameter (*power*) without significant consideration of any of the other effectors, such as propagation, target lethality, tactical decision aids, modeling and simulation (M&S), and platform and combat-system integration. For example, beginning in the 1970s, DARPA and the US Navy led development of the megawatt-class CW Mid-Infrared Advanced Chemical Laser (MIRACL) with an integrated beam-control system and the SeaLite beam director. The underlying assumption of DEW developers at the time was that "more power was operationally better." While great technological advancements were made during the power-scaling efforts of the MIRACL program, and many targets including supersonic Vandal missiles were successfully shot down, the Navy ultimately decided to cancel the program and sign the hardware over to the Army. The Navy made its decision mainly due to poor laser propagation issues in a maritime environment at the MIRACL wavelength, the hazards and logistics challenges of handling the MIRACL's chemicals in shipboard operations, and an insufficient understanding of HEL lethality against targets of interest.

A similar outcome occurred with the Missile Defense Agency's Airborne Laser (ABL) program (started in 1996) that also suffered from the logistics burden of chemical lasers and changing mission objectives over the life of the program, combined with the added complexity and cost of integrating that technology into a Boeing 747 aircraft. Even though the ABL did demonstrate an ability to shoot down ballistic missiles during boost phase, the program was cancelled in 2014.

The situation for HEL weapons changed abruptly with the emergence of a new type of laser, the electrically driven solid-state fiber laser initially developed to support the need for commercial industrial laser welding. The Navy used multiple kW-class fiber lasers in the 30-kW Navy Laser Weapon System (LaWS) deployed on the USS Ponce (AFSB(I)-15) in 2014. LaWS remained on board until the ship was decommissioned in 2017. While LaWS may have been the first operational deployment of an HEL DEW, this was just the first in a line of HEL weapons that have been deployed or are currently under rapid development.

OPERATIONAL EFFECTIVENESS

The DEW technology continues to mature and achieve performance parameters to address extant and emerging threats, and the acquisition community and warfighters are expressing increased interest in their operational employment. As a result, there has been a significant expansion in focus from DEW technical-parameter objectives, such as power, to operational effectiveness.

The Defense Acquisition University Defense Acquisition Guidebook defines *operational effectiveness* as the:

"Measure of the overall ability of a system to accomplish a mission when used by representative personnel in the

Army's Tactical High-Energy Laser (THEL) program DOD environment planned or expected for operational employment of the system considering organization, doctrine, tactics, supportability, survivability, vulnerability, and threat."

To determine operational effectiveness of a DEW, it is paramount to demonstrate its capability to successfully engage a target and generate desired effects within a timeline that matters to warfighters. The warfighter gets the deciding vote. If there is any question on the effectiveness of a DEW capability, we should expect them to quickly return to the weapons and procedures that they are more comfortable using. This change in focus from technology development (the so-called "if we build it, the warfighter will want it" approach) to a desire to understand and provide capabilities that matter to warfighters is – or should be – causing substantial changes in activities across the DEW technical community.

Lethality knowledge is critical for convincing operators that a DEW will have the desired effect on a target. In the past, DEW lethality efforts were primarily funded out of DEW development programs, which typically resulted in just enough lethality data to support the continued funding for development of the DEW system and the associated program. One of several problems with this approach is the vast difference between the lethality data needed to maintain a sponsor's interest in funding the science and technology or R&D, and the data a warfighter needs to determine if a DEW would accomplish its mission.

There are two notable exceptions to DEW-program sponsored lethality investigations. The High Energy Laser Joint Technology Office (HEL JTO), which became the Joint Directed Energy Transition Office (DE JTO) in 2017, has consistently dedicated a small portion of their yearly budget to HEL lethality efforts executed by the service laboratories. JTO-led efforts have substantially increased collaboration between the services and our understanding of HEL lethality against a limited number of targets. Similarly, the Joint Non-Lethal Weapons Directorate (JNLWD) has funded a number of RF weapon (RFW) lethality efforts.

Looking at the percentage of resources dedicated to developing lethality data relative to funding dedicated to DEW hardware development, one will find it to be much less than 10%, and probably closer to 1%. This funding imbalance is particularly disturbing considering current understanding of DEW lethality, which has been sporadically funded over mere decades, compared to our understanding of kinetic-weapon effects, which has been studied for centuries.

Thankfully, both OUSD(T&E) and OUSD(R&E) are working to increase funding in this critical area. OUSD(T&E) oversees and funds the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) that develops and maintains Joint Munitions Effectiveness Manuals (JMEMs). JMEMs enable users to plan operational missions by determining the effectiveness of a kinetic weapon, with a defined probability of kill (P_k), against a specified target for a range of weapon delivery modes. A JMEM product is currently under development with the objective of providing a joint non-kinetic effectiveness capability for military planners and targeteers. This DE JMEM will need to have necessary lethality data and tactics, techniques, and procedures for using DEWs in combat, as well as procedures for producing Collateral Damage Estimates (CDE) to support their use.

The YAL-1A Airborne Laser (ABL) provided valuable insight into beam control and stabilization.
DOD

THE HEL DETECT-THROUGH-ENGAGE KILL CHAIN

For determining HEL operational effectiveness, it is not sufficient to simply have all of the required lethality data for targets that will be engaged by a particular HEL weapon. Even for the HEL detect-through-engage kill chain for a subsonic airborne target, a number of critical steps must be accomplished in a very short period of time. After detection by a wide-area search capability, the target must be identified, either by the laser system or by some other means. When HEL lethality data for the identified target is available, the target pose or aspect must also be determined to enable the selection of a viable aimpoint, keeping in mind that typical laser spot sizes on the target are smaller than the target dimensions. Another critical factor for HEL engagement is the impact of atmospheric propagation on the laser power density [in Watts/cm^2] that reaches the target. Given all this information is available, the lethality data will dictate the required dwell time on the designated aimpoint to deposit a sufficient energy density [Joules/cm^2] to kill the target. Once this dwell-time requirement is determined, the HEL DEW must be designed to maintain the designated aimpoint throughout that engagement time. At this point, an operator would have sufficient information to make a determination that the HEL weapon could successfully engage the target.

While the HEL kill chain may seem exceedingly complicated, it has been successfully exercised on numerous occasions during developmental and operational testing of HEL weapon systems. Although HEL engagements have been demonstrated during testing, the technical community has not developed the necessary Tactical Decision Aids (TDAs) a warfighter will require to use a defensive HEL weapon in actual combat conditions. All of the subcomponents of HEL TDAs, including *in situ* atmospheric monitoring, should be fully funded to support the deployment of HEL weapon systems. Fortunately, most near-term deployments of HEL weapons have focused on shorter engagement ranges and slow threats such as small unmanned air systems (sUAS) and fast-inshore-attack craft (FIAC) that permit warfighter decision-making and reduce HEL propagation impacts. Other near-term HEL deployments have focused on simpler targets, such as mortars, which have an obvious aimpoint due to their simple geometry and well-known lethality mechanism.

As DEW systems increase their effective range and demonstrate the ability to engage higher-end threats with shorter engagement timelines, TDAs will be required to assist warfighters in real-time weapon-target pairing. DEW systems also will likely benefit from the incorporation of Artificial Intelligence (AI) and Machine Learning (ML) algorithms to be more effective in combat. It is important to keep in mind that the DEWs in a warfighter's arsenal must be weighed against the cost, magazine depth and effectiveness of other kinetic capabilities, such as missiles, during the weapon-target pairing process, even though during the "fog of war," the "cost-per-shot" metric is not at the forefront of a warfighters mind. However, a sufficient store of available weapons is critically important to warfighters' survival in a protracted conflict.

THE RFW DETECT-THROUGH-ENGAGE KILL CHAIN

Provided sufficient lethality data exists, the case for using RFWs in combat will be much more straightforward – to a certain degree – than the case for HEL weapons. As discussed in the April 2019 "DE 101" column, an RFW may take advantage of a threat receiver's antenna gain to deposit enough energy to disrupt, degrade or damage the target's front-end components, such as low-noise amplifiers. Other RFW concepts may produce gigawatt to terawatt ERP resulting in conventional, EW-like target effects at extended ranges. Many RFW concepts engage targets by coupling RF energy directly into the electronics of the target system. Such back-door coupling can be achieved on targets both with and without an intended RF front end; however back-door coupling offers the most significant differentiation between conventional-EW and RFW effects.

Unlike HEL weapons that can focus a tight laser beam over distances of tens to hundreds of kilometers, an RFW suffers from a 1/range^2 loss in power density that significantly reduces the effective range of the weapon. However, this beam spreading phenomenon also greatly reduces the RFW pointing-accuracy requirement compared to HEL weapons. HEL propagation from the laser to the target is a very complicated process that is heavily dependent on atmospheric conditions. In contrast, propagation from the RFW to the target is very straightforward and not significantly impacted by weather conditions, particularly given its fairly short engagement ranges from hundreds of meters to potentially tens of kilometers.

Depending on the targets to be engaged, the RFW will either be used in a point-defense mode at fairly close ranges (e.g., ship defense, ground based air defense, or boat or car stopping), or the RFW may be mounted in an airborne platform and delivered to a target location. One example of this latter approach was the Air Force Research Laboratory's (AFRL's) Counter-electronics High-powered microwave Advanced Missile Project (CHAMP), which was designed to deliver microwave energy from a missile flown over the target.

It is a safe assumption that all electronic systems can fail if they are illuminated with sufficient RF energy. The critical consideration is whether or not that RF energy threshold can be achieved with an operationally viable weapon. The world continues to be covered by an "electronic crust" of information and data storage technology, industrial controls, automated systems and the growing web of the internet of things (IoT). This reality equates to a growing number of viable targets for RFWs, and if their electronics are not made robust against Intentional EM Interference (IEMI), the RFW target population will continue to grow exponentially.

Conventional EW techniques take full advantage of target knowledge and front-end RF gain. By contrast, the significant uncertainties associated with an RFW back-door attack tend to greatly increase the power density on the target or *target surface* required to get an acceptable P_k. Here we must be careful on how we define what the target surface actually is. For an RFW engagement, target surfaces can include the outer surface of a missile, sUAS, ship, automobile, or boat motor, as well as a radar system, an integrated air defense system, an improvised explosive device (IED), or even a building full of computers or industrial controls.

To determine weapon effectiveness, we must further break down the target surface into the critical subsystems, or target elements, that may be affected by RF energy. For a missile or sUAS, target elements may be flight control or navigation electronics or the seeker. For vehicles, target elements may be engine control modules or computers, and for a building, the target elements may be computer or network hardware or various industrial control electronics. With the critical target elements defined, empirical testing of RF effects can be conducted using parameters like frequency, pulse width, repetition rate, and power level that are consistent with the RFW under consideration. In some cases, such as the case of a missile or vehicle, the entire target is used for testing RF effects. At other times, individual target elements, like computer systems or industrial controls, are tested. Models are then used to place them in the buildings that might be engaged by the RFW.

In our next column, we will look at DEW collateral damage determination and DEW modeling and simulation.

About the Author: *Dr. David Stoudt, is president of the Directed Energy Professional Society (DEPS) and Senior Executive Advisor and Engineering Fellow for Directed Energy at Booz Allen Hamilton Inc.*

Space EW (Part 20)

Link Vulnerability *cont.*

By Dave Adamy

This month, we will consider polarization and rain losses between the satellite and its ground station and also between the satellite and a target transmitter or receiver.

POLARIZATION LOSS

Figure 1 shows examples of commonly used antennas found in electronic warfare systems (EW), target systems and links. As shown, these antennas can be linearly or circularly polarized. Commonly used antennas with linear polarization are whips and dipoles. Military antennas are very often whips (in ground systems) or monopoles (in airborne systems). They are vertical unless the vehicles on which they are mounted are tilted. Ground jamming antennas are often log-periodic with vertical, horizontal, or some arbitrary polarization. Radar or data-link antennas can also be linearly polarized – typically dipoles or horns.

Circularly polarized antennas can be characterized as broadcasting or receiving linearly polarized signals that rotate as they propagate – one full turn to the right or left over one wave-length. If the rotation is clockwise, this is a right hand circularly polarized (RHC) antenna. If the rotation is counterclockwise it is a left hand circularly polarized (LHC) antenna. Circularly polarized antennas are used for links between satellites and ground stations to avoid the losses

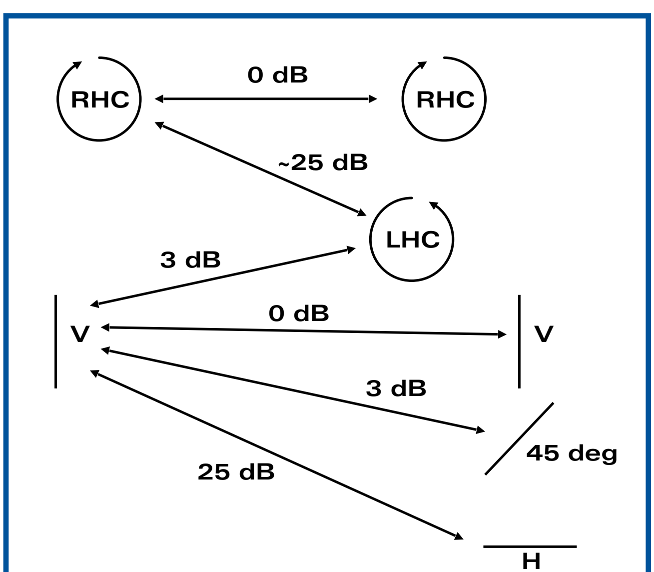


Fig. 2: Polarization mismatch losses.

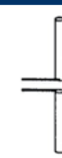
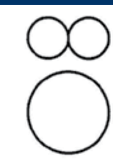
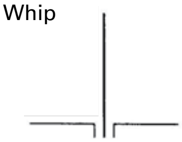
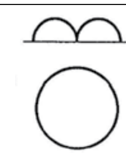
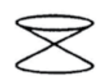
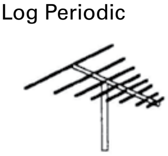
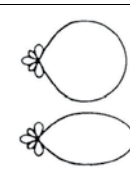
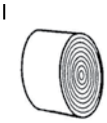
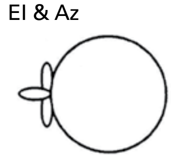
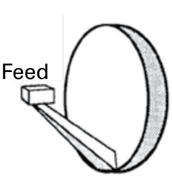
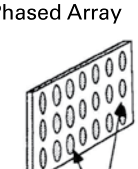
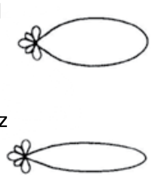
ANTENNA TYPE	PATTERN	TYPICAL SPECIFICATIONS
Dipole 	El Az 	Polarization: Vertical Beamwidth: 80° x 360° Gain: 2 dB Bandwidth: 10% Frequency Range: Zero through µw
Whip 	El Az 	Polarization: Vertical Beamwidth: 45° x 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Biconical 	El Az 	Polarization: Vertical Beamwidth: 20° to 100° x 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: 80° x 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through µw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° x 60° Gain: -15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: µw
Parabolic Dish Feed 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to 360° Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to µw
Phased Array  Elements	El Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 360° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to µw

Figure 1: *Common antenna types.*

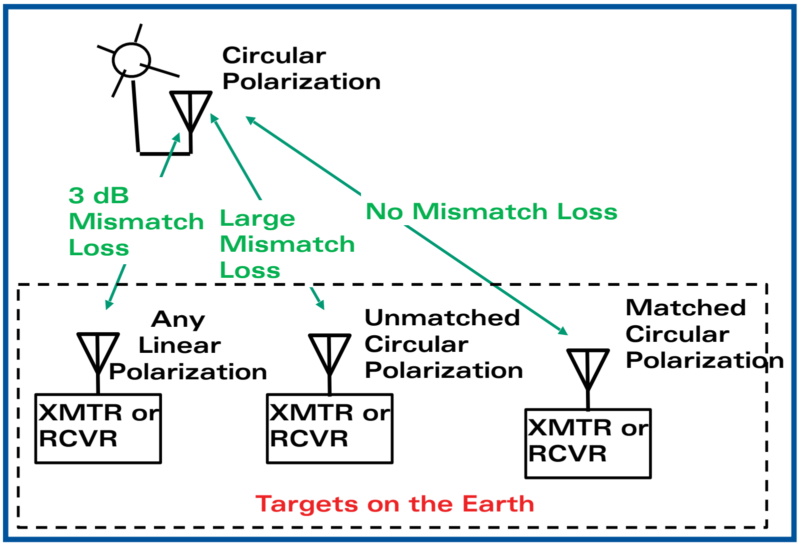


Fig. 3: *Satellite link polarization mismatch loss is zero for matched circular polarized antennas, large for mismatched circular polarized antennas, and 3 dB for circular to linear polarized antennas.*

caused by polarization changes as the signals pass through the upper atmosphere.

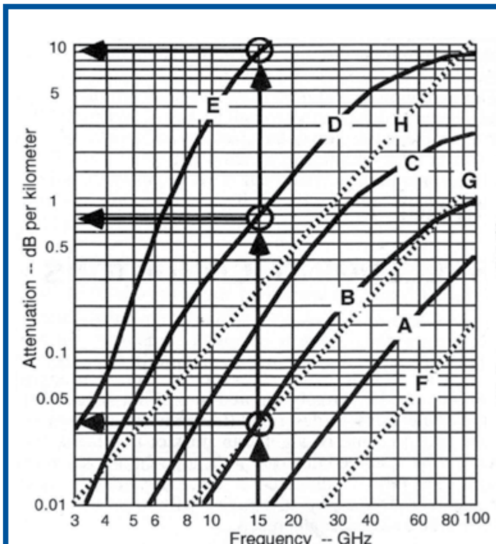
As shown in **Figure 2**, if the two link antennas have matched linear or circular polarization, they cause no polarization loss. If they are circularly polarized with opposite sense, they cause link loss that varies from about 10 to 31 dB depending on how carefully the antenna is designed. The small cavity backed spiral antennas shown in Figure 1 have about 10 dB cross-polarization loss, and communication satellites typically have much greater cross polarization loss. If there is a circularly polarized antenna at one end of the link and a linearly polarized antenna at the other, the cross polarization loss is only 3 dB.

Now consider some geometry. If a circularly polarized antenna is viewed from an off-axis direction, it presents an elliptical polarization. If a linear antenna is tilted 45 degrees to the linear antenna at the other end of the link, is causes a 3 dB polarization loss.

Figure 3 shows the polarization loss for various antennas on ground-based target receivers against a circularly polarized transmit antenna on the satellite.

RAIN LOSS

Polarization loss is highly dependent on the location of the satellite relative to the ground part of the link. The rain loss depends on the density of the rain and the distance that the link passes through the rain.



RAIN	A	0.25 mm/hr	.01 in/hr	Drizzle
RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
RAIN	C	4.0 mm/hr	.16 in/hr	Moderate Rain
RAIN	D	16 mm/hr	.64 in/hr	Heavy Rain
RAIN	E	100 mm/hr	4.0 in/hr	Very Heavy Rain
FOG	F	0.032 gm/m ^{3}		Visibility greater than 600 meters
FOG	G	0.32 gm/m ^{3}		Visibility about 120 meters
FOG	H	2.3 gm/m ^{3}		Visibility about 30 meters

Fig. 4: *Rain loss is a function of frequency and the rate of rainfall.*

Figure 4 shows the loss per kilometer (km) caused by various rain densities. First, chose the rain density from the table included in the figure. This will indicate which curve on the graph to use to determine the loss per km of path length through the rain. Start with the frequency on the abscissa. Then move up to the appropriate curve. Then move left to the ordinate to determine the loss per km. For example, if the link is at 15 GHz and there is heavy rain, use curve D. Moving to the left, you see that the rain loss is 0.73 dB per kilometer. It there were light rain (curve B) the loss per kilometer would be .033 dB per kilometer.

Now, it is necessary to determine the distance over which the link passes through that level of rain. If the satellite is near the horizon, for example, there will be significant distance in the rain.

First consider **Figure 5**. Rain falls from the altitude at which the temperature is zero degrees Celsius. This occurs

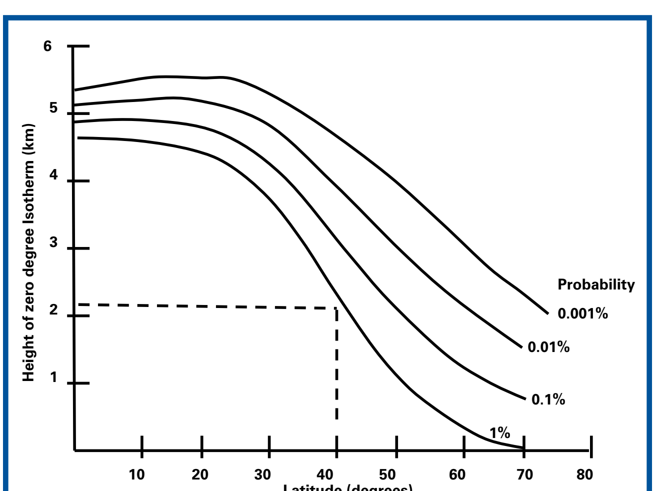


Fig 5: *The probability that the zero-degree isotherm falls below a given altitude is a function of the latitude.*

at the "zero degree isotherm." Above that altitude, the rain is frozen, and thus causes negligible attenuation. This figure shows the probability that the zero degree isotherm is at a particular altitude vs. the latitude. Start at the latitude of the ground station and move vertically to the appropriate probability curve, then move left to the height of the zero degree isotherm on the ordinate. For example at 40 degrees latitude, the 1% probability curve indicates approximately two km altitude for the zero-degree isotherm.

Now go to **Figure 6**. Draw the elevation angle to the satellite from the ground station. For example, let's use 15 degrees. The elevation vector crosses the zero-degree isotherm at two km elevation. The length of the path from the ground station to the zero degree isotherm is:

Path through rain = (isotherm altitude /sin Elevation)

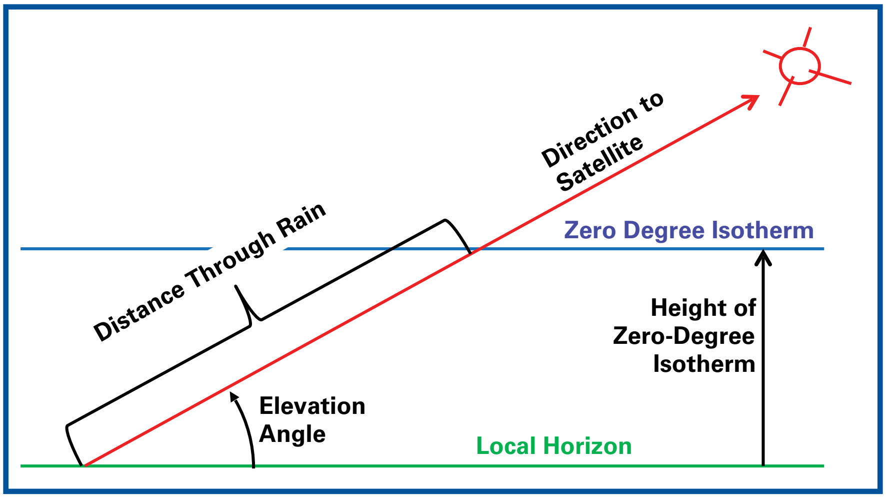


Fig. 6: *The distance over which rain loss applies is the part of the link below the zero-degree isotherm.*

= 2 km / sin 15° = 2 km / 0.259 = 7.7 km

The rain loss is thus 7.7 km x 0.73 dB/ km = 5.6 dB

If there had been light rain, the loss would be 7.7 km x 0.033 dB/ km = 0.25 dB

WHAT'S NEXT

Next month we will start dealing with the vulnerability of satellite links to intercept by ground based receivers. For your comments and suggestions, Dave Adamy can be reached at dave@lynxpub.com.

Remembering a Pillar of Our EW Community: John Clifford OBE, AOC UK Chapter President

John receives his Officer of the Most Excellent Order of the British Empire (OBE) medal from Queen Elizabeth II in 2006.

John Clifford OBE, retired RAF Wing Commander and Association of Old Crows (AOC) UK Chapter president, passed away May 6. John will be sorely missed by all who had the privilege to know him, and his contributions to the electronic warfare (EW) community will be felt for years to come.

John worked tirelessly to advance our community's conversation surrounding EW strategy and operations at every stage of his career, from the RAF to the UK Ministry of Defence (MOD), and later as an EW consultant and active leader within the AOC. In 2006, John was awarded an Officer of the Most Excellent Order of the British Empire (OBE) by Her Majesty Queen Elizabeth II for his EW work, and in 2013, he wrote the UK MOD's EW Policy, which is still used to this day.

John graduated from the University of Manchester Institute of Science and Technology in 1972 with a BSc (with honors) and achieved an MSc (with distinction) in Computer Aided Engineering from Nottingham Trent University. He was also a Chartered Engineer (CEng) and Chartered IT Professional (CITP) with the British Computer Society, The Chartered Institute for IT, a professional society for those working in engineering and IT.

In the late 1970s, John became the first and only Navigator EW Instructor on the RAF V-Force and was recognized as a leader in advancing EW training and practices. John graduated from the Aerosystems course at RAF College Cranwell in 1981 before serving as Senior Avionics Specialist at No. 6 Flying Training School at RAF Finningley, where he was responsible for all RAF Navigator EW training. John was later promoted to Deputy Squadron Commander of Radar Research Squadron at Royal Aircraft Establishment (RAE) Bedford before leading EW systems and flight tests for the Tornado GR1 and GR4 at Tornado Management Agency in Munich.

After graduating from the Joint Service Defence College in 1992, John continued to specialize in EW, becoming the Wing Commander of the Joint Warfare Staff at Royal Marines Poole (RM Poole) Naval base.

From 1996 to 2008, John was recognized as an EW expert within the UK MOD, serving as the lead desk officer in joint and air EW for five successive operational tours with the MOD. In this role, he truly became a pioneer in EW, helping to stand up the UK's first Information Warfare/Operations (IW/IO) directorate, which included EW and cyber, and leading the way in EW operations and training, policy, doctrine, and strategy with NATO and the UK MOD.

After retiring from the RAF in 2008, John worked from 2009 to the time of his passing both as a consultant with ESP (Engineering Support Personnel), Inc. and as the director of his own international defense consultancy company, JMC Defense Ltd, providing EW and EM Domain operations consultancy services to the UK MOD, the US Army and NATO. In 2013, John simultaneously worked on the UK Electromagnetic Environment (EME) Review while helping to write the UK MOD's current joint EW Policy.

John first joined the AOC in 1996 as a UK Chapter Air member and senior military officer, and he went on to serve as the UK Chapter president from 2009 to the time of his passing. During his tenure, John worked to increase chapter membership and engage new, young members. Through his efforts, the UK Chapter has successfully partnered with 20 UK universities in the EM Special Interest Group (EMSIG) and EMSIG Focus Group, participating in lecture series and enhancing STEM outreach efforts. Under John's stewardship, the UK Chapter was awarded Chapter of the Year in the large chapter category for eight years straight.

John also served as the AOC Global Conferences and Global Operations Director beginning in 2011, organizing and speaking at conferences in Europe and Southeast Asia, including DSEI (Defence and Security Equipment International) in London. John's background in directing conferences served him well in this role with AOC, drawing from years of experience organizing conferences all over the world during his time in the RAF and as an EW consultant. In recognition of his commitment to EW, John received two AOC awards – the International Achievement Award in 2002 and the Board of Directors Award in 2018.

John at an AOC UK Chapter awards ceremony. John served as chapter president beginning in 2009.

John is survived by his wife, Jane, their four children, and their grandchildren, including the newest member of the family, Bella Jane, born in March of this year.

John's legacy in the EW community will continue to be honored by his friends across the globe, and he is ever revered by his fellow AOC presidents:

"John was a pillar in the EW community and played a significant role in the common transatlantic work of protecting our soldiers from harm's way through EW measures. He also gave a helping hand to many European chapters to achieve influence in the AOC."

"He will be remembered by his many friends from all over the world in the AOC family. His passion for our organization and his unstinting enthusiasm for the UK chapter and the wider AOC community will not be forgotten." – Contributed by the AOC UK Chapter and edited by *H. Swedeen* and *J. Knowles*

ARMY CYBER SCHOOL CELEBRATES HISTORIC EW GRADUATION AT FORT GORDON

SCOTT ANDERSON, US ARMY CYBER SCHOOL HISTORIAN

On March 25, the US Army Cyber School celebrated yet another milestone with the first ever graduation for the 17E (Electronic Warfare Specialist) AIT course. With most CCoE graduations currently curtailed in some fashion due to COVID-19 safety precautions, the Cyber School and Cyber Training Battalion's (CTB) Bravo Company felt this occasion was too historic to cancel.

While the Soldiers of Class 19-001 could not share the moment with family and friends due to current restrictions, the leadership of CTB Bravo Company properly honored the graduates during the ceremony at Signal Theater. The Army's Electronic Warfare (EW) professionals officially became members of the Cyber Branch in October 2018. The previous EW 29 series career field transitioned to the Cyber 17 series with 17B (EW Officer), 170B (EW Warrant Officer), and 17E (Enlisted EW Specialist). Prior to this transition, an enlisted Soldier could only enter the EW career field after becoming a noncommissioned officer (NCO), but now Soldiers can become EW Specialists directly after basic training.

After Cyber School course developers worked for many months to create this new course, the twenty Soldiers in this inaugural 17E AIT course arrived at Fort Gordon in August 2019. With most of the Army's EW training taking place at the Cyber School's EW College at Fort Sill, OK, bringing EW training to Fort Gordon was yet another milestone.

The guest speaker for this first graduating class was SGM Sean Beaupre, a fellow 17E currently serving as the Cyber Protection Brigade's Operations Sergeant Major. SGM Beaupre remarked that the ceremony was not only memorable being the first of its kind, but also because the graduates would normally be packed in their seats shoulder to shoulder and not six feet apart due to the current safety guidelines. SGM Beaupre also encouraged the graduates to build off of what they learned at the Cyber Center of Excellence because their commanders will rely on that knowledge, and to "be an inspiration for all the Soldiers that come behind you."

Before the ceremony's conclusion, Cyber School Commandant COL Paul Craft took to the stage for an impromptu charge to the graduates. COL Craft stated that he was very proud of all the class accomplished and that they had "set the initial rung on a much larger and longer ladder for how we will succeed in this space." He concluded by explaining to the graduates that where they are going and what they will be doing is very important for our military, as the Army is looking to fill EW capability gaps within a variety of units, including at Fort Drum, NY; Fort Hood, TX; Fort Bragg, NC, and Joint Base Lewis-McChord, WA, among others. - *Scott Anderson, US Army Cyber School Historian*

DIXIE CROW CHAPTER PROMOTES CROW'S N.E.S.T. AT ELEMENTARY SCHOOL

The Dixie Crow Chapter was delighted to have the opportunity to provide 2020 Crow's N.E.S.T. (Novel Experiments with Science & Technology) t-shirts to the children picking up lunches at Tucker Elementary School in Perry, Georgia, on Friday, April 24.

We truly appreciate all of our Crow's N.E.S.T. sponsors and know that presenting these t-shirts helped put smiles on the kids' faces. We know they will be worn proudly! Thank you Robert Usher for coordinating this opportunity.

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