JANUARY 2020
Vol. 43, No. 1

ASSOCIATION OF OLD CROWS

JED

The Journal of Electronic Defense

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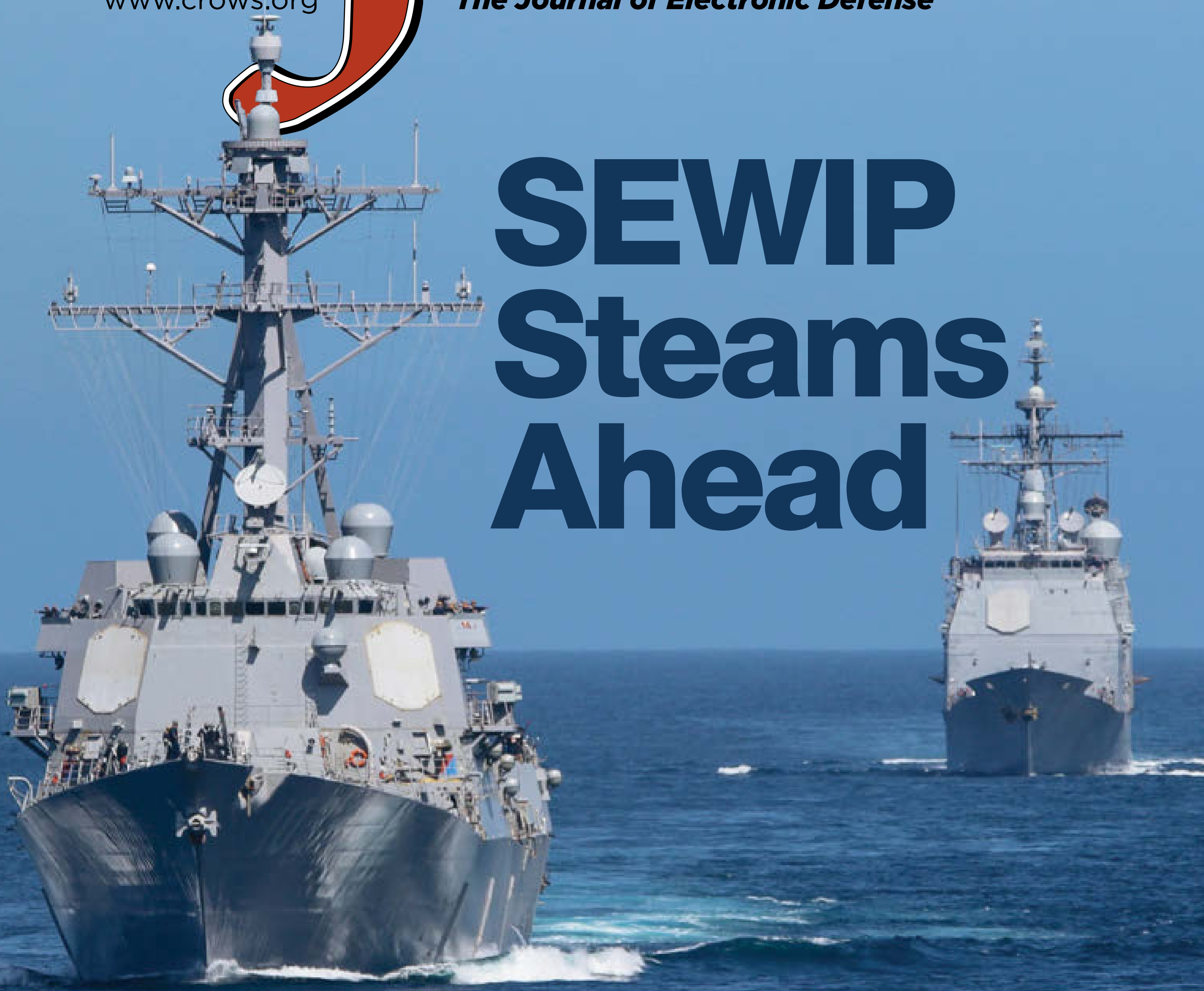

SEWIP Steams Ahead

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Cyber Situational Understanding

EW 101: New EA Techniques

Monitor: EMSO CFT Report Sent to Congress

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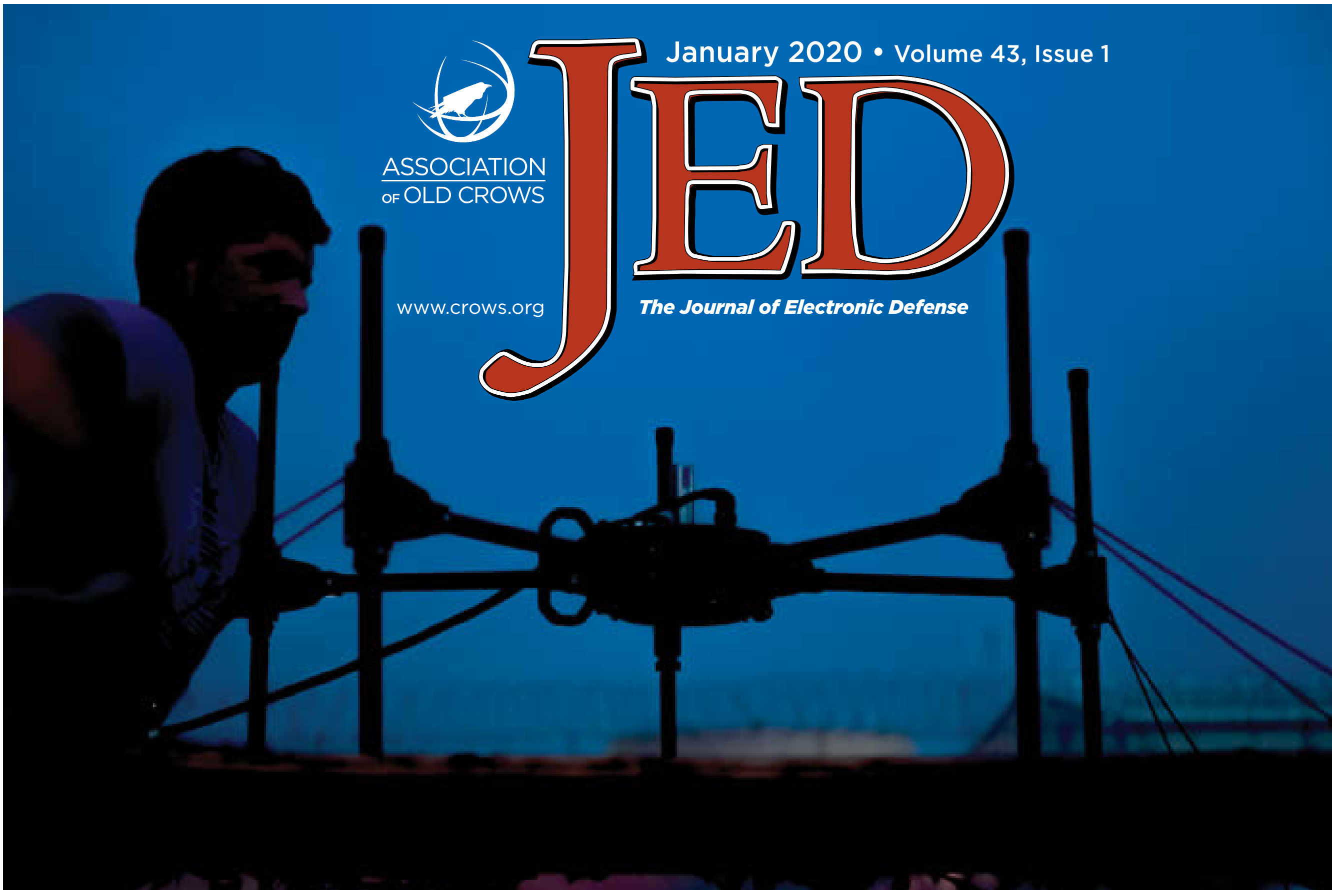

Senior Master Sgt. Paul Vinson, USAF, a spectrum manager from the Joint Spectrum Center, conducts radio frequency surveys in East Africa. The spectrum management team used a variety of mobile RF analyzers and took measurements across the CJTF-HOA area of responsibility. DOD PHOTO

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UNITY OF EFFORT

Last month, the AOC hosted a media roundtable with Maj Gen Lance Landrum, USAF, who serves as Deputy Director for Requirements and Capability Development (J8), Joint Staff, and as Deputy Director of the Electromagnetic Operations Cross Functional Team (EMSO CFT). General Landrum talked to reporters about the EMSO CFT, its goals and objectives and some of the areas where it wants to focus in order to bolster the DOD's EMS Enterprise.

The EMSO CFT was created at the behest of Congress in the FY2019 National Defense Authorization Act (NDAA), which outlined several specific EMSO areas on which it wants the DOD to focus. In the same legislation, it called on the DOD to name a senior designated official (SDO), who the Secretary of Defense named as the Vice Chairman of the Joint Chiefs of Staff (VCJCS). The SDO will report to Congress every 180 days about EMSO progress within the Department. The EMSO CFT was established by the Secretary of Defense in February 2019 and tasked to "identify EMSO gaps in capability, capacity, personnel, training, experimentation, and resourcing; and identify requirements and plans across doctrine, organization, training, materiel, leadership, personnel, facilities and policy to address these gaps." Last month, the DOD issued its first EMSO report to Congress. (See "OSD Sends EMSO Cross-Function Team Report to Congress" in this month's Monitor section.)

I'm very optimistic that the EMSO CFT can make a big difference. First, the EMSO CFT makes its recommendations to the SDO who, as VCJCS, certainly has the authority to make changes in the DOD. Second, EMSO is a key focus area for the Congressional defense committees. It is worth noting that the NDAA language called for the creation of an Electronic Warfare CFT. However, the OSD and the Joint Staff determined that it would be more beneficial to stand up an EMSO CFT with a wider mandate. Another reason I am optimistic is that many leaders in the DOD agree that EMSO is an important area and that the Department's EMS Enterprise needs to be improved.

Of course, if this were easy, the DOD would have accomplished a lot of its EMSO goals by now. Today, the DOD's EMS Enterprise is highly balkanized, under-resourced and poorly coordinated.

The good news is that a lot of the EMSO building blocks the DOD needs already exist, although some of them must be better resourced and modernized. The challenge for the EMSO CFT and for the larger EMSO Community is to identify how the Department can connect these building blocks and integrate them to create a stronger EMS Enterprise. This is not a euphemism for organizational consolidation. It's an acknowledgement that we in the EMSO Community can make a big difference in rebuilding the DOD's EMS Enterprise simply by speaking up and advocating for EMSO within our organizations. Each of us has the understanding and ideas we need in order to accomplish this. But we also have to adopt the mindset that we can effect change. – *J. Knowles*

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www.navysna.org

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January 27-30
Albuquerque, NM
www.deps.org

FEBRUARY

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

Defexpo 2020
February 5-8
Lucknow, Uttar Pradesh, India
defexpoindia.in

Singapore Airshow
February 11-16
Singapore
www.singaporeairshow.com

6th International Conference on EW – EWCI 2020
February 18-20
Bangalore, India
www.aoc-india.org

EW Releasability and Export Control Workshop
February 25-26
Washington, DC
www.crows.org

AFA Air Warfare Symposium
February 26-28
Orlando, FL
www.afa.org

MARCH

AFCEA West Conference and Exhibition
March 2-3
San Diego, CA
www.westconference.org

Annual Directed Energy Science and Technology Symposium
March 9-13
Destin, FL
www.deps.org

DIMDEX 2018
March 16-18
Doha, Qatar
www.dimdex.com

AUSA Global Force Symposium and Exposition
March 17-19
Huntsville, AL
www.ausa.org

Dixie Crow Symposium 45
March 23-26
Robins AFB, GA
www.dixiecrowsymposium.com

Directed Energy to DC Exhibition (DE2DC)
March 30 - April 1
Washington, DC
www.deps.org

49th Annual Collaborative Electronic Warfare Symposium
March 31 - April 2
Point Mugu, CA
www.crows.org

FIDAE 2020
March 31 - April 5
Santiago, Chile
http://www.fidae.cl/en

APRIL

Navy League Sea-Air-Space
April 6-8
National Harbor, MD
www.seaairspace.org

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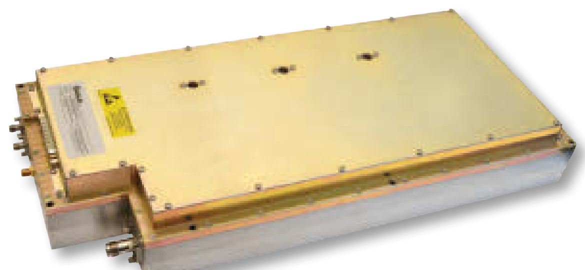

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MARCH

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message from the president

STRENGTHENING NATO AEA

After decades of relying heavily on US support jamming aircraft, NATO's European members are getting serious about the Airborne Electronic Attack (AEA) mission. *JED* wrote about this work in its May 2018 issue ("Europe Ponders SEAD Modernization as Russia Fields New Threats") and more recently in its November 2019 issue. Over the past several months, European industry has discussed two potential escort jamming candidates – based on the Gripen NG and the Typhoon ECR – in some detail. European industry is likely to put forward more AEA solutions (especially for stand-off and stand-in applications) in the coming months. So this started me thinking about NATO and the AEA mission.

The stakes are high. Potential adversaries, such as Russia, are fielding new air defense systems that feature extended ranges and the ability to track and engage more air targets simultaneously. Building a counter to this threat is challenging for NATO, in part because of its organizational structure, policies, procedures and investment planning process. In addition, there are other factors at play:

Issue 1 – There is a Rubik's Cube of trust between nations. Nation A may trust nations B, D and E, but not Nation C. This impairs the Alliance's ability to share sensitive information (such as classified data for threats, EW technologies, capabilities and CONOPs) between all the nations in the Alliance.

Issue 2 – Development of technologies is always challenging for NATO, as countries are required to balance between sovereign capabilities and joint efforts. This issue is further aggravated by the business cases for industry. What is the NATO requirement, and how large are the purchase orders that would be required to attract companies that are making investment decisions in research and development?

Issue 3 – Duplication of effort occurs when multiple nations are pursuing technology development without coordinating or collaborating based in part on the previous issues. For example, NATO (through the US Navy) already has the EA-18G.

Issue 4 – What happens when a NATO member buys major weapons systems outside of NATO? The most recent example is Turkey, which has bought the S-400 air defense system from Russia. How do Alliance members provide advanced technologies such as the F-35 to Turkey when there is a significant risk that the F-35 as a capability and everything on it will be compromised? This issue affects training, joint exercises, interoperability, CONOPs and warfighting plans, just to name a few.

At a basic level, NATO AEA planning demands a joint understanding of the threat environment and what the requirements are. From this, NATO can develop a technology roadmap that enables members to focus on AEA challenges without duplicating efforts. Finally, NATO can define requirements about security and compatibility with regard to Russian, Chinese and other weapons systems acquisitions. Most importantly, it will take investment (including the emotional capital) to strengthen NATO's AEA mission area. NATO AEA must focus more on multination engagement and collaboration, develop technology roadmaps and support multinational training and exercises. Establishing superiority in Electromagnetic Environment is critical for NATO, and we must to do better. – *Muddy Watters*

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Kyle Davidson

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57 AOC INTERNATIONAL SYMPOSIUM & CONVENTION

Dr. Patrick Ford

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CLASSIFICATION:

US Secret Only (Day 1) and Unclassified (Day 2)

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the monitor

news

OSD SENDS EMSO CROSS FUNCTIONAL TEAM REPORT TO CONGRESS

The Deputy Secretary of Defense has submitted a report to Congress outlining advancements in the development of the Electromagnetic Spectrum Operations Cross-Functional Team (EMSO CFT), including the "methodology and approach to updating the [Department of Defense's (DOD's)] strategy for EMS superiority" and information regarding "the way ahead for development, integration, and enhancement of the electronic warfare mission area." It is the DOD's first substantial communication to Congress regarding the EMSO CFT, which the DOD stood up in February 2019.

In the report, OSD states "The CFT, through operational analysis, created four Lines of Effort (LoEs): Governance; Organization; Capabilities and Gaps; and Training and Readiness. These LoEs provide a path to accomplish the mission, and realize the vision by establishing Enterprise Governance for assured U.S. superiority in the EMS."

The report was issued in response to the Guidance on the Electronic Warfare Mission Area and Joint Electromagnetic Spectrum (EMS) Operations, per sections 1053(d)(4) and 1053(d)(5) of the FY19 John S. McCain National Defense Authorization Act (NDAA). This language includes several specific reporting requirements covering funding, implementing the 2017 DOD EW Strategy, updates to the strategy, an assessment of EMS-related vulnerabilities, an assessment of Joint forces to conduct EMS operations against a near-peer adversary, and others.

With regard to implanting the 2017 DOD EW Strategy, the report states, "The Undersecretary of Defense for Acquisition and Sustainment (USO (A&S)) contracted for an EW Strategy Implementation Plan Study, which was delivered to the EW EXCOM in February 2019. The EW EXCOM staffed the report through the Department for comments and transferred it to the EMSO CFT for inclusion into the broader strategy effort." It said changes will be reflected in the DOD's EW Policy directive (DoD Directive 3222.04).

In terms of updates to the DOD's 2017 EW Strategy, the report states, "In order to harmonize the Department's approach to EMSO with national spectrum priorities, the EMSO CFT is working with DoD Chief Information Officer (CIO) on the DoD EMS Superiority Strategy, with an associated Roadmap and Implementation Plan (RM/IP). The 2017 DoD EW Strategy has not had any changes since its release. Future EW strategic priorities will be incorporated into the EMS Superiority Strategy." The DOD expects the EMS Superiority Strategy to be published in June 2020.

The NDAA language also asked the DOD to provide an assessment of the vulnerabilities identified in the Defense Science Board's (DSB's) 2015 EW Study. The DOD responded by stating that the DSB study cited the leading challenge in re-establishing the role of EW as leadership and governance. It added that the EMSO CFT's top priority is governance and that the EW EXCOM, in coordination with the EMSO CFT, is considering governance reforms.

On a related note, the NDAA directed a review of the roles and functions within the Joint Staff, OSD and combatant commands with regard to Joint EMS policy and operations. The DOD responded, "The EMSO CFT is in the process of analyzing the organizational structure, staffing, and authorities over EMS issues throughout the Department. Initial assessments indicate OSD is challenged by a lack of a full time position at a high enough rank level to provide overall guidance and unity of effort across the Department. The Joint Staff is challenged to create unity of effort across requirements development, operational planning, and execution. These challenges result in difficulty coordinating requirements, acquisition strategy, and integration of EMS forces. The EW EXCOM, in coordination with the EMSO CFT, is considering governance reforms that include options for OSD organizational changes as well as USSTRATCOM organizational and authority changes."

The NDAA also asked about development of an electromagnetic battle management (EMBM) capability. DOD responded, "The Department is completing three efforts aimed at risk mitigation for further development of a Joint EMBM capability. First, in FY18, USSTRATCOM sponsored a Joint Capability Technical Demonstration (JCTD) called Electromagnetic Spectrum, Visual Instance of the Environment for Warfighters (EMS VIEW). The JCTD is designed to evaluate the ability to share data between the US Army's EW Planning and Management Tool (EWPMT), the US Marine Corps' Spectrum Services Framework (SSF), and the Defense Information Systems Agency (DISA) Joint Spectrum Data Repository (JSDR). It is scheduled to be completed in calendar year (CY) 2020. Next, the U.S. Army conducted an assessment to determine if EWPMT can meet the Joint EMBM requirements. Finally, DISA, in conjunction with USSTRATCOM, conducted an Evaluation of Alternatives (EoA) on four Joint EMBM systems, assessing cost and risk, as well as operational benefit, associated with each option. The last two evaluations completed at the end of July 2019.

"These three evaluations will answer some of the technical and programmatic questions so an informed decision can be made as the Department proceeds towards development of a Joint EMBM capability. The Department is considering all options to reduce risk before establishment of a Program of Record to provide the tools required by the warfighter. The EW EXCOM established a Mission Area Working Group to track the progress of EMBM."

The NDAA asked about the establishment of Joint EMSO Cells (JEMSOCs) at combatant commands. The DOD responded, "Over the last few years several combatant commands have been working to establish JEMSOCs but have been hampered by a lack of personnel, resources, capability, training and guidance. However, the President's Budget for FY 2020 provided USAFRICOM, USCENTCOM, USEUCOM and USINDOPACOM FY20-21 funds to establish JEMSOCs. JEMSOCs are being established and will consist of one to seven core personnel along with other needed expertise matrixed from other organizations within their combatant command staff. Although USSOCOM lacks a JEMSOC, they have established a matrixed working group that accomplishes many of the JEMSO activities. Additionally, USSTRATCOM established a JEMSO Office with seven personnel to execute USSTRATCOM's JEMSO activities and to advocate for JEMSO across the Department.

"Concurrently, USSTRATCOM, as the DoD advocate for JEMSO, and with the assistance of the US Army Manpower Analysis Agency, initiated a manpower assessment to validate the manpower requirement for each of the combatant commands. They are scheduled to present their findings to the Manpower Validation Board in January 2020. Once the manpower requirement is validated for the combatant commands the Department will then address resourcing through the FY 2022 budget. Additionally, USSTRATCOM's Joint Electronic Warfare Center (JEWC) developed an Operational Employment Guide (OEG) to provide guidance to the combatant commands in development of EMBM and JEMSO processes."

Finally, the NDAA asked for a review of the DOD's testing and training infrastructure. The DOD's response stated, "Operational security (OPSEC), unrealistic threat replication, outdated infrastructure, and increasing physical range encroachment (airspace and EMS) have progressively reduced U.S. Forces' ability to conduct EMS training operations, system evaluation, or TTP validation. DoD must prioritize, adapt, and expand live and synthetic means of conducting EMS testing and training to the maximum extent possible." The DOD has for any years submitted Sustainable Range Reports to Congress, as well as the Director of OT&E's annual report. More recently, the Assistant Secretary of Defense for Sustainment led a Range Investment Forum to identify range capability gaps. "These reports as well as other ongoing EW infrastructure improvement programs make clear the current state of range infrastructure is insufficient to support the development of electromagnetic

NEW REPORT STATES DOD'S STRATEGY FOR EMS DOMINANCE IS MISGUIDED

A new report from the Washington D.C.-based Center for Strategic and Budgetary Assessments (CSBA), titled "Winning the Invisible War – Gaining an enduring U.S. Advantage in the Electromagnetic Spectrum," concludes that the "DOD cannot continue on its current path of attempting to gain EMS superiority by incrementally improving individual systems to avoid or target new threats as they emerge. Today's requirements-based approach to EW and EMSO systems development is too unfocused, will take too long to reach fruition, is potentially unaffordable, and cedes the initiative to America's great power competitors."

Instead, the report says the DOD should "focus its EW and EMSO efforts on the asymmetries between U.S. and Chinese and Russian forces that are likely to provide it a distinct and potentially enduring advantage, and accept the near-term shortfalls that may emerge." The asymmetries identified are: Home vs. Away Team; System of Systems (SoS) architectures vs. kill webs and mission command; Clients vs. allies; Civil-military fusion vs. military R&D; Whole of government/society vs. joint; Officer vs. senior enlisted technical management in EW and EMSO; and Deliberate planning vs. experimentation.

The report's recommendations to address these asymmetries are to: Implement new operational concepts that employ maneuver and complexity, enabling full exploitation of EW and EMSO. "DOD's operational concepts should be designed such that they heighten the benefit gained from effective EW and EMSO."

In addition, DOD should adopt more opportunity-based rather than requirements-based innovation. "DOD should pursue approaches to capability development that would improve its ability to incorporate commercial technologies and accelerate the transition of new EW and EMS technologies into fielded systems."

DOD should also implement maneuver warfare in the EMS, including shifting to predominantly passive and multistatic sensing, and treating the EMS as an operational domain. "A domain construct will support the implementation of maneuver warfare in the EMS rather than attrition warfare." Also, in this context, it is recommended that the DOD field more networked EW and EMSO systems and EMBM capabilities. Here it notes that "the most significant impediments to networked EW and EMSO and EMBM are creating interoperable data transmission standards and the varied security levels at which different EW and EMSO systems operate."

A fourth recommendation is that the DOD emphasize virtual and constructive EW and EMSO training at the expense of live events. "Attempting to upgrade live open air ranges to modern threats is an ineffective approach to improve operator proficiency and develop new tactics and operational concepts. Instead of upgrading its training ranges at great cost to gain a modest operational benefit, DOD should shift its emphasis for EW and EMSO practical training to virtual and constructive facilities." – *J. Haystead* spectrum capabilities. Efforts to correct these deficiencies will be addressed in the EMS Superiority Strategy and RM/IP [Roadmap and Implementation Plan]."

In its conclusion, the DOD report states, "A properly governed, organized, and resourced DoD EMS Enterprise is required as a precondition in order to sustain Joint Force superiority against near peer adversaries. The EMSO CFT is empowered by the Secretary to ensure reform is accomplished within this mission area in order to create the foundation for success of the 2018 National Defense Strategy." – *H. Swedeen* and *J. Knowles*

DARPA SEEKS NOVEL SIGNAL PROCESSING TECHNOLOGIES FOR SIGNAL DETECTION AND RECOGNITION

DARPA's Strategic Technology Office (STO) is pursuing a new effort dubbed "Coho," under which it will solicit proposals for advanced signal processing techniques and technologies for future RF systems. Last month, STO issued a Broad Agency Announcement (BAA HR001120S0001) and held a Proposers Day for Coho, which DARPA says is "a vital part of the Mosaic Warfare end-state vision."

DARPA expects that Coho will provide benefits to signal detection and recognition applications in the areas of:

- "Surveillance: Combine wide operating bandwidth with noise isolation for background electromagnetic search in the low signal to noise ratio environment.
- Filtering: Isolate signals based on modulation features to process signals in the presence of co-channel interference.
- Localization: Support low-latency execution of multi-aperture processing for discrimination of signals based on angle of bearing."

In the BAA, DARPA states that it is "…soliciting solutions that are implemented in a rack-mount chassis with size, weight, and power suitable for airborne platforms or ground installations." It also notes, "Coho is not an antenna development program, and innovation in antennas is not sought by this BAA. Coho seeks solutions that are agnostic to band breaks. Performers may indicate where solutions benefit from apertures with specific spatial geometries or spectral coverage."

The Coho program schedule is a 39-month development effort divided into two phases. Phase 1 is a 15-month development period that will include a Conceptual Design Review. Under Phase 2, which will run 24 months, the contractor will deliver a Coho brassboard design for testing. DARPA anticipates multiple Coho contract awards.

Proposals are due January 28. The program point of contact is Robert Saperstein, e-mail: HR001120S0001@darpa.mil. – *JED Staff*

IN BRIEF

The US Army's **Product Director Electronic Attack (PdD EA)** within the Program Executive Office for Intelligence, Electronic Warfare and Sensors (PEO IEW&S) has issued a pair of Requests for Information (RFIs) to gather information about currently available EW payloads that could be integrated onto the Army's RQ-7 Shadow and RQ-11B Raven unmanned aerial systems (UASs). Both RFIs describe mandatory system requirements, such as Technology Readiness Level (TRL) of 8 or 9; reprogrammability between flights; identifying or characterizing targeted emitters; and geolocating targeted emitters. Both RFIs also ask respondents to provide information about the system's size, weight and power; signal types identified by the EW system; RF receiver performance (range, number of channels, sensitivity, selectivity and bandwidth); geolocation accuracy; and the ability to record in-phase and quadrature (I/Q) data. In addition, the RFI for the Raven UAS (Solicitation Number W56KGY-20-R-E001) asks if the system can perform electronic attack. The RFI for the Shadow UAS (Solicitation Number W56KGY-20-R-E002) requires the EW system's ground station to be compatible with the Army's Electronic Warfare Planning and Management Tool (EWPMT) or capable of exporting data to EWPMT via the tactical network. The Shadow RFI also asks if the payload provides precision geolocation; can detect signals from Low Probability of Intercept (LPI) emitters (e.g. spread spectrum, FM CW); and how it performs against radars (PRI, pulse duration, intercepts complex scans, etc.) Responses to the RFIs were due December 23. The Army will use the data to determine how it will proceed with a potential acquisition program. The program point of contact is Dr. Leslie Litten, e-mail leslie.a.litten.civ@mail.mil, and the contracting point of contact is Eric Pyles, e-mail eric.c.pyles.civ@mail.mil.

The US Army's Project Manager Distributed Common Ground System – Army issued a Request for Information (RFI) to industry to assist in planning a new intelligence ground station that will replace several existing systems. The Tactical Intelligence Targeting Access Node (TITAN) will operate at Brigade, Division, Corps, and Field Army echelons, in vehicles and shelters organic to the formation. It would replace the Army's current Tactical-Intelligence Ground Station, Operational-Intelligence Ground Station, Advanced Miniaturized Data Acquisition System Dissemination Vehicle and Remote Ground Terminal. According to the RFI, "The future ground station will need to consolidate and/or reduce the footprint of existing Radio Frequency (RF) receiving/transmitting equipment, computing solutions, and provide the ability to dynamically scale solutions based on the user and echelon needs. The future ground station will leverage content delivery network technology and distributed storage architectures to provide a seamless, cloud enabled Common Operating Picture in both cloud and on premise environments. A key focus will be providing a user friendly ability to receive sensor data and provide timely targetable data directly to the fires network as well as provide multi-discipline intelligence support to targeting, and Situational Awareness (SA)/Situational Understanding (SU) in support of mission command." The Army is considering alternative acquisition vehicles – either the Consortium for Command, Control and Communications in Cyberspace (C5) Other Transaction Authority (OTA) or the Defense Innovation Unit (DIU) OTA process – for the TITAN program. The point of contact is Stephen Cutchin, e-mail stephen.g.cutchin.civ@mail.mil.

world report

AIRBUS LIFTS VEIL ON EUROFIGHTER ECR PROPOSAL

Eurofighter consortium partner Airbus has outlined plans to develop a two-seat electronic combat role (ECR) variant of the Typhoon multi-role combat aircraft to meet the airborne electronic attack (AEA) needs of Germany's Luftwaffe. An initial ECR capability is being targeted for 2026 to meet the needs of Germany's Luftgestützte Wirkung im Elektromagnetischen Spektrum (luWES) program. Eurofighter's roadmap envisions further incremental development and subsequent full integration into future combat air systems.

Airbus is leading an industry team that also includes Hensoldt, MBDA, MTU, Premium Aerotec and Rolls-Royce. The initiative is being supported by the German national industry bodies BDSV and BDLI.

Being pitched as a replacement for the Luftwaffe's current fleet of Tornado ECR aircraft, the Eurofighter ECR would be configured with a passive emitter location system and modular configurations for AEA and suppression/destruction of enemy air defenses (SEAD/DEAD). The concept also features a new twin-seat cockpit configuration with a multi-function panoramic touch display and a dedicated AEA mission cockpit for the rear-seat EW operator.

Eurofighter Typhoon ECR would be configured with up to three escort jammer pods carried on underwing and fuselage stations. The aircraft would also be equipped with effectors for the SEAD/DEAD mission. Images released by Airbus show Eurofighter ECR aircraft equipped with the AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) and the SPEAR-EW stand-in jammer.

NATO has identified a key shortfall in the Alliance's ability to operate in anti-access/area denial environments. Germany has committed itself to meeting this requirement, with the luWES program predicated on a three-tier AEA system-of-systems: a high power stand-off jammer carried by a large non-penetrating aircraft; an escort jammer to accompany strike packages in hostile airspace; and a stand-in jammer to jam hostile radar emitters from inside the tracking range of surface-to-air missiles. – *R. Scott*

US ARMY SELECTS STRIKESHIELD FOR TESTING

The US Army has awarded a contract valued at $11 million to a team of Rheinmetall Protection Systems and Unified Business Technologies (UBT) for testing of the StrikeShield active protection system (APS). The Army's recently formed Vehicle Protective Systems (VPS) program office will evaluate StrikeShield as part of a larger effort to characterize APS performance against a wide variety of anti-armor threats. Testing is scheduled to begin in October 2020 at Redstone Test Center (Huntsville, AL).

This contract award represents the first funded APS testing the Army will undertake of the StrikeShield system. It provides a pathway to potential utilization of the system on vehicles in the current Army vehicle fleet as well as vehicles fielded in the future.

The StrikeShield APS is a distributed reactive system developed to protect the host platform against anti-tank rockets and missiles, and also addresses the technical requirements of large-caliber kinetic energy defeat. Rheinmetall and UBT have teamed to pursue APS opportunities in the US market since 2015.

Live-fire testing of the StrikeShield system will be performed over a period of several months, with the objective being to gather performance data that can inform future selection of APS technologies for specific platforms. The Army anticipates that results will inform APS pursuits for both its fielded vehicle fleets and new vehicle programs, such as the Armored Multi-Purpose Vehicle, Mobile Protected Firepower, and the Optionally-Manned Fighting Vehicle. – *R. Scott*

RAAF C-130J DIRCM UPGRADE ACHIEVES FOC

The Royal Australian Air Force (RAAF) has announced achievement of Final Operational Capability (FOC) for the upgrade of its C-130J Hercules fleet with the Northrop Grumman AAQ-24(V) Large Aircraft Infrared Countermeasures (LAIRCM) directed infrared countermeasures (DIRCM) system.

Under Project AIR 5416 Phase 4B, the RAAF has rolled out an electronic warfare self-protection (EWSP) upgrade for its 12-strong C-130J Hercules fleet that encompasses both radar warning and IR countermeasure systems. Defence's Capability Acquisition and Sustainment Group's Airborne Self Protection System Program Office has taken responsibility for program delivery.

The LAIRCM upgrade has been delivered under AIR 5416 Phase 4B2. FOC was announced on 4 December, some three months ahead of schedule and significantly under budget.

Eight of the RAAF's 12 C-130J aircraft were modified in Australia by Airbus Australia Pacific under a local commercial licensing arrangement. CAE Australia has also modified the C-130J Full Flight Simulator to reflect the changes to the aircraft.

Logistics and operational support infrastructure has been constructed at RAAF Base Richmond, including a laser test firing facility, secure storage in compliance with Defence's obligations under ITAR, and an updated air base security system.

Project AIR 5416 Phase 4B1 had previously addressed the introduction of the BAE Systems AN/ALR-56M radar warning receiver (RWR). Covering the C-J bands, the ALR-56M RWR employs a wideband superheterodyne receiver architecture.

Australia's DST Group provided science and technology advice in support of the levels of survivability that could be delivered by various EWSP options, including the DIRCM. DST also provided advice on the performance and advantages of several fitment options, including turret location and various types of sensors for the RAAF's C-130J LAIRCM fit. – *R. Scott*

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Block by Block – Surface Na

By Richard Scott

As the concept of Electromagnetic Maneuver Warfare (EMW) becomes increasingly ingrained in US Navy operations and doctrine, so the critical importance of new surface ship EW capabilities is coming back to the fore. This reflects the underlying need to monitor and understand the Electromagnetic Environment (EME), exploit that awareness to gain control of the EME in order to achieve tactical advantage action across all mission areas, and deny its use to adversaries.

EMW has thus served as a vehicle to re-energize and refocus the Navy's tactics and capabilities in the electromagnetic battlespace as the Navy prepares to more effectively operate in the contested anti-access/area denial (A2/AD) battlespace. It has also raised the profile of equipment acquisitions, most notably the continued evolution of the Navy's Surface Electronic Warfare Improvement Program (SEWIP), and the delivery of new persistent soft-kill/active electronic countermeasures systems under the umbrella of the Advanced Offboard Electronic Warfare (AOEW) program.

BUILDING BLOCKS

SEWIP was born out of the April 2002 cancellation of the AN/SLY-2(V) Advanced Integrated Electronic Warfare System (AIEWS) program. Envisioned as the Navy's fleetwide replacement for the AN/SLQ-32(V) family of EW systems, the ambitious AIEWS development effort was axed as a result of what the Navy described at the time as program instability, cost growth and schedule delays.

Instead, the US Navy set its future surface ship electronic combat capability on a different course and in July 2002 established SEWIP as an ACAT II acquisition program. This time, rather than a "clean sheet" new development, the Program Executive Office – Integrated Warfare Systems (IWS 2.0) in the Naval Sea Systems Command (NAVSEA) chose to pursue a spiral development and incremental upgrade of the SLQ-32 installed base so as to mitigate obsolescence, improve sustainability, and progressively introduce advanced Electronic Support (ES) and Electronic Attack (EA) capabilities into the US fleet through four distinct "Blocks." This new acquisition model additionally provided IWS 2.0 with the opportunity to adopt an open competitive process for the procurement of successive increments.

The first increment, known as SEWIP Block 1, has focused on the rapid development and fielding of low-risk upgrades which enhance current AN/SLQ-32 warfighting capabilities while resolving critical hardware obsolescence issues residing in the legacy system. This program is in turn split into a number of sub-blocks: Block 1A addresses SLQ-32 sustainment by refreshing the display console and display/pulse processing computers with COTS technology; Block 1B1 adds a standalone Specific Emitter Identification (SEI) capability (exploiting the AN/SSX-1 Small Ship Electronic Support Measures [SSESM] module originated by the Naval Research Laboratory [NRL]) and the display of combat system tracks to the operator to improve threat correlation and situational awareness; Block 1B2 integrates SEI functionality, network centric and mission planning capabilities into the ICAD environment; and Block 1B3 introduces a High Gain High Sensitivity (HGHS) capability to SEI (again leveraging an advanced development model developed by the NRL), and allows the operator to launch both Nulka active offboard decoys and passive countermeasures on combat system tracks.

SEWIP Block 1B3 has introduced a High Gain High Sensitivity adjunct detection capability for detecting and classifying LPI signals. RICHARD SCOTT/NAVYPIX

General Dynamics Mission Systems has responsibility as SEWIP Block 1 lead systems integrator, a task encompassing systems engineering, architecture design, software engineering, development, integration and testing. Other participants in the development effort include Lockheed Martin (modifications to Q-70 console to support improved control and display [ICAD]), the Naval Surface Warfare Center (NSWC) Dahlgren Division (scenario/library testing of electronic surveillance enhancements [ESE] and test support) and the NRL. NSWC Crane Division, as in-service engineering agent for AN/SLQ-32, supported SEWIP Block 1A development testing at the Surface Combat Systems Center at Wallops Island, VA.

SEWIP Block 1B1 adds the AN/SSX-1 SSESM for SEI (AN/SSX-1 comprising the AS-1200A antenna, AN/UYX-4 processor unit, the CS-5020C receiver/tuner from L3 Harris, and a standalone laptop for display). Block 1B2 integrates SEI into the ICAD infrastructure. General Dynamics has completed delivery of 121 Block 1A systems, and 148 Block 1B1 and 1B2 systems.

Block 1B3 focuses on obsolescence mitigation and the introduction of a High Gain High Sensitivity (HGHS) adjunct detection capability for detecting and classifying special (low probability

vy EW Evolves Under SEWIP

of intercept) signals. This HGHS upgrade is based on an advanced development model developed by the NRL

Lockheed Martin was in 2008 subcontracted by General Dynamics to develop the HGHS module (including the topside antenna systems, the below decks signal processor as well as the processing algorithms residing in the processor). While Lockheed Martin delivered a small number of HGHS systems, General Dynamics subsequently took the work in-house for low-rate and full-rate production.

BLOCK 2 PRODUCTION

SEWIP Block 2 introduces a more substantive upgrade of the passive detection capabilities of AN/SLQ-32 – expanding frequency coverage, increasing sensitivity and introducing precision angle of arrival measurement – while at the same time re-architecturing the system to simplify future upgrades. The SEWIP Block 1B3 and Block 2 units are installed in conjunction to compose the AN/SLQ-32(V)6 system.

Lockheed Martin was in September 2009 selected to undertake SEWIP Block 2 Engineering and Manufacturing Development (EMD). "SEWIP Block 2 is an electronic surveillance system that provides the US Navy complete situational awareness of the electronic battlefield," said Joe Ottaviano, Lockheed Martin's director, electronic warfare. "Through the SEWIP Block 2 systems, the Navy continues to expand and deliver capabilities that can tackle evolving threats and achieve a complete tactical picture."

SEWIP Block 2 introduces an upgraded antenna, new digital receiver and an open combat system interface. The Block 2 hardware scope also includes the SLA-10D blanker, common processing system, common display system, a liquid conditioning unit and a data adaptation processor.

Adopting an "enterprise solution" that promotes the maximum use of COTS electronics, the Block 2 architecture is

SEWIP Block 2 introduces a major upgrade of the ES capabilities by expanding frequency coverage, increasing sensitivity and introducing precision angle of arrival measurement. RICHARD SCOTT/NAVYPIX

based on microwave tuner and digital receiver products supplied by Mercury Systems. Mercury has also collaborated on signal processing subsystem design.

Another key subcontractor for SEWIP Block 2 is Cobham Integrated Electronic Solutions, which is supplying interferometer-based antenna array panel assemblies for AN/SLQ-32(V)6. As well as providing fine angular resolution, SEWIP Block 2 also provides elevation measurement.

The increasing density and complexity of the EME has shaped the SEWIP Block 2 performance specification, according to Ottaviano. "Block 2 is delivering major improvements in range and resolution. The radar world is trying to bend the laws of physics. We see spread-spectrum signals and LPI radars coming onto the market. What is more, the processing on the receiver side is now so cheap.

"SEWIP Block 2 will become a 'sensor of choice' because it can find things of unique interest," he added. "It offers eye-watering performance."

The Block 2 program achieved Milestone C approval in January 2013, after which the system began land-based testing in preparation for ship installation. The DDG 51 Flight IIA guided-missile destroyer USS *Bainbridge* (DDG 96) was fitted with the SEWIP Block 2 system in July 2014, becoming the first ship to receive AN/SLQ(V)6. Commander Test and Operational Evaluation Test Force conducted the first phase of SEWIP Block 2 Initial Operational Test and Evaluation from August to November 2014 in the Virginia Capes operating area.

Following on from SEWIP Block 2 development and Low Rate Initial Production (LRIP), Lockheed Martin is currently on contract for a fourth year of full rate production (FRP). "[We] are building Block 2 and Block 2 Lite systems at a rate of two ship sets per month to the US Navy," said Ottaviano. "To date, we have delivered over 80 systems from our naval EW center of excellence facility in Syracuse, NY."

LITE FIT

The AN/SLQ-32(V)6 system is now in service on a number of DDG-51 guided missile destroyers, and is also being introduced to large deck amphibious ships and DDG-1000 destroyers. In addition, Lockheed Martin has delivered the first production examples of a compact SEWIP Block 2 system. Designated AN/SLQ-32(V)6C – and also dubbed SEWIP Lite – this scaled, lower-cost version of the AN/SLQ-32(V)6 equipment was originally conceived to meet the ship fit constraints of the Littoral Combat Ship (LCS).

Having performed prior architecture studies, Lockheed Martin was in September 2013 given the go-ahead to proceed with a fleet demonstration of the scaled-down SEWIP Lite variant. The accelerated development and deployment was undertaken in partnership with Cobham, ACIT, the Office of Naval Research (ONR) and NSWC's Crane and Dahlgren divisions.

"It's the SEWIP Block 2 architecture packaged to fit LCS, and it boasts the same capabilities as the AN/SLQ-32(V)6 SEWIP systems you find on larger vessels," said Ottaviano. "It's the same hardware as the large system [but] targeted for small platforms such as LCS."

The rationalized and repackaged SEWIP Lite architecture was developed inside eight months, demonstrating performance for the platform, with a production-representative system delivered to USS *Freedom* (LCS 1) in September 2014 for customer evaluation. The system successfully completed at-sea testing in fourth quarter 2014 and first quarter 2015.

Initial production of AN/SLQ-32(V)6C was included in the first SEWIP Block 2 FRP buy. Although NAVSEA is the customer for SEWIP Lite, the first end user is the US Coast Guard for its Offshore Patrol Cutter program.

ELECTRONIC ATTACK

The next instantiation of SEWIP, known as Block 3, integrates advanced EA functionality into the AN/SLQ-32(V)6 system. Following a protracted competition, NAVSEA in February 2015 selected Northrop Grumman to perform SEWIP Block 3 design and development.

SEWIP Block 3 will introduce an integrated EA subsystem to protect against RF-guided threats (the SEWIP Block 1B3, Block 2 and Block 3 units will in aggregate comprise the AN/SLQ-32(V)7 system). Two configurations are planned: the Hemisphere configuration is designated for installation on DDG-51 *Arleigh Burke*-class destroyers, while a Quadrant configuration is designated for the *Nimitz*- and *Ford*-class nuclear-powered aircraft carriers and *Wasp*-class amphibious assault ships.

"The advantage of an EA system like [SEWIP] Block 3 is that it provides you with an unlimited non-kinetic magazine to defeat inbound threats," Mike Meaney, Northrop Grumman's vice president, maritime electronic and information warfare, told *JED*. "If you try and take out everything inbound to you with missiles, then it's just a matter of time before you run out of missiles.

"With an EW system like SEWIP Block 3, you just keep firing electrons. And you won't run out of those."

Northrop Grumman's SEWIP Block 3 technical solution adopts active electronically scanned array (AESA)

Northrop Grumman's SEWIP Block 3 solution adopts GaN-based AESA technology, and leverages heavily from technology demonstrated under the ONR's Integrated Topside program. The Hemisphere configuration is designated for installation on DDG-51 destroyers. NORTHROP GRUMMAN

technology based on Gallium Nitride transmit/receive modules, and capitalizes on technology previously matured and de-risked under the Office of Naval Research's (ONR's) Integrated Topside (InTop) Innovative Naval Prototype (INP) program.

As part of this INP, Northrop Grumman built and delivered an integrated EW/IO/Comms prototype that is now installed at NRL's Chesapeake Bay Detachment facility. "InTop was meant to explore the edges of what you could do with multifunction multi-apertures," said Meaney. "How can I do the combined mission of electronic warfare, information operations and communications among other things?

"It provided us the opportunity to prototype a lot of the functionality and architectural approach for SEWIP [Block 3]. We learned a lot of lessons, and we carried the architecture – almost as is – into the Block 3 program."

Northrop Grumman and NAVSEA successfully completed the Performance Design Review (PDR) for SEWIP Block 3 in August 2015 following a six-month preliminary design period. The review assessed the state of the system architecture and preliminary design to validate technology maturity and technical development plans.

"Each quadrant of the system has four AESAs, and there are four quadrants on each ship," Said Meaney. "So that's 16 AESAs that work in concert together seamlessly to provide that total ship self-protection from RF threats from any angle."

NAVSEA in October 2015 awarded Northrop Grumman a $91.7 million target cost plus fee to complete the SEWIP Block 3 EMD phase. Under this award, the company has matured the system design, finalized integration, and produced two production-representative EDMs for laboratory and field testing.

It is no secret that the development program has experienced cost and schedule overruns, which resulted in the rebaselining of the EMD phase, late delivery of EDMs, and slippage in SEWIP Block 3 introduction to service. Meaney acknowledged that there have been engineering challenges to overcome.

"When we did our InTop architecture, and the build of those AESAs, we did much of that for the land-based [demonstrator] installation environment," he explained. "We thought we had addressed the shipboard needs.

"But when we actually got into the detailed design of the SEWIP Block 3 system, the full scope of what needed to be done [for] shipboard operations became clear to us. And that led to some delay in our completing the design of those different elements.

"That's what largely drove the delays that we've had with the program. The good news is that we're at the point in time where we have all the AESAs that we need completed, they're in test, and it's a very impressive system that we have under integration at the moment."

Northrop Grumman is now wrapping up the EMD phase. Last October the company revealed that its manufacturing team had completed build of EMD hardware, and that testing in a new high-bay facility anechoic chamber was proceeding well. "We're going through some test processes," said Meaney, "and then we will ship the system to Wallops Island [in 2020] so it can begin government testing."

In parallel, material procurement and manufacture work is underway on the first two LRIP systems. "We passed Milestone C in December [2018], and received an order for those two LRIP production units," Meaney said. "Those units are scheduled to be delivered for ship installation [on DDG-51 destroyers] in the 2021 timeframe."

While Northrop Grumman has been contracted for SEWIP Block 3 development and initial LRIP production, NAV-

SEA is pursuing an open "winner takes all" competition for SEWIP Block 3 production and AN/SLQ-32(V)7 integration. This covers Fiscal Year (FY) 20-24 full-rate production of the SEWIP Block 3 EA subsystem and ancillary equipment, including the integration of each EA Subsystem with a government-furnished AN/SLQ-32(V)6 to form and deliver a complete AN/SLQ-32(V)7 system.

A request for proposals (RFP) for SEWIP Block 3 production and AN/SLQ-32(V)7 integration was released by NAVSEA on November 19. Meaney believes that Northrop Grumman is well placed. "We are actively at work on our proposal," he said. "We've been heavily investing in our operational efficiency over the last couple of years to make sure we can produce the SEWIP Bock 3 systems in the fastest possible time, with the lowest amount of cost.

"We'll be putting our proposal in to the Navy towards the end of January 2020," he added. "The indications we get from the Navy is that they expect to make a decision and place an award for the first round of production in late 2020."

INTERIM TEWN FITS

Ahead of the delivery of SEWIP Block 3, the Navy has embarked on a "gap-filler" EA program that introduces instantiations of NRL's Transportable Electronic Warfare Module (TEWM) to address separate Urgent Operational Needs Statements (UONS) raised by the US Sixth Fleet (Europe) and Seventh Fleet (Pacific). Conceived by NRL's Tactical Electronic Warfare Division (TEWD) as a modular, portable and platform-agnostic testbed incorporating an ES receiver integrated with a wideband DRFM-based EA capability, TEWM has previously demonstrated noise jamming and high-resolution false targets with realistic amplitude and Doppler modulation, providing a capability to engage multiple threats simultaneously, and generate multi-component waveforms that combine false targets with obscuration jamming.

Under a so-called TEWM "Speed To Fleet" (TEWM STF) initiative, the AN/SLQ-62 system has been developed to meet a classified Sixth Fleet UON. TEWM

The DDG 51 Arleigh Burke class guided-missile destroyer USS John S. McCain *(DDG 56) departs Yokosuka in late October 2019.* McCain *is fitted with the AN/SLQ-59 system (the dual-mount antenna group is seen affixed to the upper platform of the bridge wing).* US NAVY

STF systems engineering has been performed by NRL and NSWC Crane Division. A capability enhancement upgrade for AN/SLQ-62 was developed in FY 2017.

Another TEWM exploitation, identified as the SEWIP Block 3T program, has introduced the AN/SLQ-59 system to address the 7th Fleet UONS. Harris (then Exelis) was in 2013 contracted by NRL to undertake production and install activities in support of SEWIP Block 3T.

A number of Pacific Fleet DDG-51 guided missile destroyers have been observed with the AN/SLQ-59 system (receiving a dual-mount antenna group affixed to the bridge wings port and starboard). Another variant of AN/SLQ-59 has also been fitted to CG-47 cruisers (this configuration features two separate single-mount antennas fitted on sponsons either side of the forward superstructure). An AN/SLQ-59 fit has also been observed on the CVN USS *Ronald Reagan* (CVN-76), with individual sponson-mounted antennas installed to cover all four quadrants.

CESARS INFORMS SEWIP BLOCK 4

SEWIP Block 4, for which funding is programmed from FY21, will provide a common EO/IR surveillance and countermeasure capability to all surface combatants and non-combatants outfitted with AN/SLQ-32(V)6 and (V)7 as well as select new construction platforms. ONR's Combined EO/IR Surveillance and Response System (CESARS) Future Naval Capabilities effort is informing SEWIP Block 4 requirements and de-risk enabling technologies.

CESARS embraces two distinct functional components: the Shipboard Panoramic EO/IR Cueing and Surveillance System (SPECSS); and Multispectral EO/IR Countermeasures for Advanced Threats (MEIRCAT). SPECSS is designed to perform wide field-of-view target detection and tracking, with subsequent cueing of MEIRCAT high-resolution sensors to perform target re-acquisition, tracking, classification/identification, 3-D ranging, threat assessment, countermeasures execution and countermeasures effectiveness monitoring. Multi-band capability against multiple targets in a single engagement is a MEIRCAT requirement.

CESARS is comprised of five distinct subsystems: SPECSS camera; SPECSS processing; MEIRCAT high resolution cameras (Product 1); MEIRCAT laser sources (Product 2) and MEIRCAT beam control, pointing and processing (Product 3). NRL's objective is to develop a TRL 6 maturity level system suitable for limited testing onboard a naval vessel.

L-3 Cincinnati Electronics was in February 2016 awarded a $8.9 million contract by the NRL for work associated with the SPECSS function of CESARS. Under this activity, L-3 is to design, develop and test both mid-wave IR and visible spectrum panoramic imagers. A second SPECSS contract, valued at $3.9 million, was placed with BAE Systems Information and Electronic Systems Integration in April 2016.

Three contracts have been let by NRL in support of the MEIRCAT portion of CESARS. BAE Systems Information and Electronic Systems Integration was awarded a $4.9 million in February 2016: Lockheed Martin's Aculight laser business was awarded a $10.6 million contract in March 2016; and L-3 Cincinnati Electronics received a $6.9 million contract in April 2016.

OFFBOARD AOEW

As well as providing an advanced ship-based EA capability, the AN//SLQ-32(V)7 system will embed a Soft Kill Coordination System (SKCS) to provide direction and scheduling for both onboard and offboard soft-kill effectors. SKCS functionality – for which the Applied Physics Laboratory of Johns Hopkins University is leading engineering design, algorithm development and prototyping – will provide a means to cue and control a planned helicopter-borne Active Offboard Electronic Warfare (AOEW) Active Mission Payload (AMP) offboard EA system via Link 16. AOEW AMP effects will be coordinated by SLQ-32/SKCS in conjunction with other soft-kill RF countermeasures during the engagement.

Lockheed Martin is under contract to develop and deliver the AMP, which has received the designation AN/ALQ-248. The system, which will be integrated on MH-60R and MH-60S multi-mission helicopters, is a self-contained pod hosting both high sensitivity receiver and EA subsystems. Intended to achieve an initial operational capability in 2021, the AMP is designed to be able to operate independently, or in coordination (using Link 16 messages) with the AN/SLQ-32(V)6/7 systems.

Lockheed Martin is under contract to develop and deliver the AN/ALQ-248 AOEW Active Mission Payload. LOCKHEED MARTIN

"The AOEW program is critical to the US Navy's surface fleet as it extends a commander's EW capability beyond a ship's line-of-sight limitations in the Electromagnetic Spectrum," said Lockheed Martin's Ottaviano. "It not only provides increased missile defense capability, but also counter-ISR capability."

He added: "The program is currently in the Engineering Development Model (EDM) production phase and is approaching a Milestone C decision in May 2020."

Two EDMs have now completed assembly according to Ottaviano. "Additionally, the Lockheed Martin AOEW team has successfully completed the first of a series of factory qualification tests witnessed and validated by the US Navy."

Looking ahead, ONR is currently funding small-scale concept design activities in support of a projected Long Endurance AOEW Platform (LEAP) to inform requirements for a potential follow-on Future Naval Capabilities program. LEAP envisions the development of both an expendable carrier flight vehicle and compatible countermeasure payload(s), which could achieve LRIP in the 2026-2027 timeframe.

Outline LEAP requirements include: the ability to deploy and transition to stable controlled flight while providing safe and stable separation from the ship; autonomous flight control capability, to include collision avoidance, with an ability to accept mission tasking at launch with waypoint updates from a shipboard control station and the ability to reposition and realign to maintain focus on the threat; ship-relative navigation with air and sea platform awareness with the ability to operate in a GPS-denied environment; a minimum flight endurance of one hour on station; the capability to employ modular EW payloads in both the primary RF and EO/IR domains; operation in conditions up to Sea State 5 (>20-kt steady winds); and secure bi-directional communication between the decoy and the control station (it is anticipated that the LEAP decoy will be cued by the SKCS to a particular threat and sector).

ONR has characterized the LEAP RF payload as an encapsulated, modular RF system capable of maintaining situational awareness in the electromagnetic spectrum, communicating with the host platform, and operating both autonomously and under direction from the host ship command system. In September 2019, ONR awarded BAE Systems Information and Electronic Systems Integration a contract to mature a payload concept known as LURE [LEAP Universal RF EW].

Regarding the EO/IR payload, ONR is envisioning components including visible and infrared receivers, internal fine pointing control, control electronics, processor and a local inertial navigation system. Raytheon businesses in Tucson, Arizona, and Tewksbury, Massachusetts, have been awarded study contracts in respect of a compact EO/IR payload.

Researchers from NRL successfully completed testing of the NOMAD flight vehicle off of USS Coronado *(LCS4) in August 2017.* US NAVY

ONR has not specified a particular carrier vehicle design, but one candidate is the Netted Offboard Miniature Active Decoy (NOMAD) low-cost rotary-wing mini-UAV previously demonstrated as part of ONR's NEMESIS (Netted Emulation of Multi-Element Signatures Against Integrated Sensors) Innovative Naval Prototype program. Developed by NRL, and successfully demonstrated at sea, the tube-launched NOMAD vehicle features flip-out counter-rotating coaxial rotors (which deploy post-launch) located at either end of a longitudinally-extending body. NOMAD vehicles can be deployed singly, or in a coordinated "nest" of multiple decoys.

As can be seen, the US Navy is in the midst of a major overhaul of its surface ship EW capabilities. These programs are essential to winning an electromagnetic contest against potential adversaries who are building their own long-range sensor-to-shooter networks and learning to operate more proficiently in the EME.

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2nd Annual Cyber Electro Workshop Targets Cyber

By Dr. Jacob Cox, CW4 Alex Adorno, and Mr. Jim Lopez

The United States has entered an era of Information Warfare. It is an era where technologically sophisticated adversaries deliver effects through cyberspace, the electromagnetic spectrum (EMS) and traditional fires, while also leveraging information-related capabilities (IRCs) to impact the information environment (IE) and disadvantage the US and its allies. These threats are driving the US Army to develop Cyber Situational Understanding (Cyber SU) capabilities that will allow Commanders and staff to see how the IE impacts their ability to achieve mission success. Currently, this capability only exists as a set of requirements; however, TRADOC Capability Manager-Cyber (TCM-Cyber) and Program Executive Office Command, Control, Communications-Tactical (PEO C3T) are working to transition these requirements into a prototype for warfighters in FY2020.

With Cyber SU, Commanders and their staff will see how events in the IE (e.g., cyberspace attack, jamming, social media campaigns, etc.) impact their overall mission and then respond with a suitable course of action (COA) during multi-domain operations (MDO). Cyber SU will also help warfighters to identify risks or possible impacts the IE poses to their mission. Accomplishing these goals, however, is no easy task. Cyber SU must ingest and correlate data from multiple and disparate data sources (including warfighter planning products), analyze it, and render visually understandable mission impact alerts, overlays, and recommended COAs to the Commander's common operating picture (COP).

There is also much coordination that must occur across the Army to fully realize Cyber SU's potential. Beyond integrating with systems like the Warfighter Information Network-Tactical (WIN-T), Distributed Common Ground System-Army (DCGS-A), Electronic Warfare Planning Managing Tool (EWPMT), Tactical Defensive Cyber Operations (DCO) Infrastructure (TDI), and others, Cyber SU must also integrate with the Command Post Computing Environment (CPCE) on the Tactical Server Infrastructure (TSI). The CPCE is a part of Mission Command's convergence strategy to collapse functionality of Command Post of the Future (CPOF), Tactical Ground Reporting (TIGR), Command Web, and Global Command and Control System-Army (GCCS-A) into an integrated system-of-systems (SOS) that creates situational awareness and mission command on the battlefield. As a part of this SOS, Cyber SU will provide alerts and graphics that overlay the Commander's COP without unduly complicating it.

As Cyber SU moves closer to deployment, it is important that the wider Army understand what Cyber SU is and is not **(See Figure 1)**. Equally important, program managers (PMs) for Cyber SU need to establish a feedback channel with users who will rely on the system to ensure it meets their operational requirements. To help establish these connections, in October 2019, TCM-Cyber and PEO C3T, with support from C5ISR (Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance and Reconnaissance) hosted a workshop, which bookended the 5th Annual Cyber Electromagnetic Activities (CEMA) Conference at Aberdeen Proving Ground (APG). The workshop allowed military and government leaders and researchers the opportunity to discuss PEO C3T's proposed Minimal Viable Product (MVP) for the Army's Cyber SU prototype. As a result, participants explored the potential capabilities of Cyber SU and the challenges of implementing it.

WHAT'S IN A NAME?

Initially, some CEMA Workshop participants struggled to understand what Cyber SU is intended to offer Commanders and how it differs from other systems supporting staff in the TOC (Tactical Operations Center). The confusion resided with the name: Cyberspace Situational Understanding. For many, cyberspace is associated with a narrow set of interrelated activities, including the Department of Defense Information Network (DODIN) operations, Defensive Cyberspace Operations (DCO), and Offensive Cyberspace Operations (OCO). However, Cyber SU brings a much more encompassing capability to the Commander that includes understanding the information environment, integrating electronic warfare (EW) capabilities, and applying IRCs to achieve SU that directly correlates with the unit's mission.

While its name may confuse some readers about its capabilities, at the time of its naming, the Cyber moniker aligned with the US Army's desire to converge Cyber and EW operations. For instance, Field Manual (FM) 3-12 calls for the incorporation of cyberspace electromagnetic activities (CEMA) throughout all phases of an operation. FM 3-12 further calls for CEMA to synchronize capabilities across domains and warfighting functions in order to maximize complementary effects through cyberspace and the EMS. Cyber SU is designed to help commanders converge these capabilities by synchronizing intelligence, signal, information operations (IO), cyberspace, space, and fires to identify the "so what" of events occurring in the information environment.

Soon, however, the name may no longer be an issue. During the 5th Annual CEMA Conference, in October 2019, multiple keynote speakers discussed a

magnetic Activities Situational Understanding

potential convergence of multiple capabilities, like cyber, EW, IO, and other IRCs, moving towards a new guidon of Information Warfare Operations. Since Cyber SU attempts to integrate with information from multiple IRCs, perhaps a more apropos name with respect to its capabilities will emerge. Possible names include CEMA SU, Information Warfare SU, Multi-Domain Operations Toolkit, etc. All of these names were mentioned at various times during the 5th Annual CEMA Conference.

Cyber SU	
IS:	**IS NOT:**
A tool that presents relevant cyber/ EW information into the Commander's common operating picture (COP) in an easily understood format to enable MDMP.	A Security Information and Event Management (SIEM) tool for finding or defending against cyber threats.
A mission analysis/impact tool that ties cyber threats to military tactical operations.	A cyber security sensor deploying PoR for tactical assemblages/ hardware.
A tool to display likely cyberspace and EW avenues of approach to Commander's key RF/network/ compute assets during MDMP.	A tool to execute actions within the cyber domain to counter or 'block' adversary avenues of approach.
Able to identify and display cyber terrain the Commander has direct control over.	A tool for configuring networks and compute nodes (DoDIN Ops/NETOPS tools).
Able to identify and display cyber-based risks to system/equipment dependencies that impact combat missions.	A tool for S2 intelligence analysis.
A tool to provide visualization of key terrain in cyberspace and high value assets with relevance in the Commander's area of operations.	An S6 tool for network monitoring and visualizations.
Capable of ingesting and analyzing information from existing systems (TSI, TDI, WIN-T, EWPMT, DCGS-A, etc.)	A tool to replicate or replace existing DoDIN Ops, DCO or OCO tools.

Fig. 1 – Cyber Situational Understanding

IT'S ABOUT MISSION IMPACT

Cyber SU seeks to communicate mission impact to Commanders and staff. If an adversary were to run an exploit that shuts down a unit's AFATDS (Advanced Field Artillery Tactical Data System), which is used to coordinate and execute fires, then a commander may want to know this information immediately in order to respond appropriately. Likewise, a commander may want to know when their ability to provide C2 is impacted by environmental factors, friendly forces or adversary actions, since tactical responses to each may vary.

There are many ways that events in cyberspace and the EMS can affect a commander's warfighting functions. As a result, Cyber SU seeks to allow staff, during the military decision-making process (MDMP), to select which systems (e.g., AFATDS) are to be deemed key terrain in cyberspace (KT-C) for their current mission based on the tasks (or warfighting functions) that are needed to complete it. Once these systems are identified, Cyber SU monitors these and multiple other systems for significant activity (SIGACT) reports, alerts, query results, network connectivity or network information flows, raw data (in some cases), and other sources of information. Using this data, Cyber SU applies analytics to determine the impact a CEMA event has on current warfighting functions and displays it to the Commander's COP, so the unit can understand these events, respond to them, and complete the unit's mission.

Two concept visualizations from the CEMA Workshop that were presented by TCM-Cyber and modified by workshop participants are depicted in **Figure 2.** These visualizations demonstrate how an event in cyberspace or the EMS could potentially be depicted for the Commander and staff. As previously stated, the Cyber SU system depends on information from key systems that support multiple warfighting functions, like WIN-T, DCGS-A, EWPMT, TDI, and other data sources and analytic platforms. The majority of these systems are destined to reside on the TSI as part of the Army's CPCE.

OVERCOMING CHALLENGES THROUGH CONVERGENCE

Cyber SU still has to overcome multiple data challenges before its vision can be fully realized. For instance, many of the systems that Cyber SU will eventually rely on are not yet integrated with the CPCE. Until they do, coordination across the Army's Programs of Records (PORs) is needed to ensure Cyber SU gains access to the data it will need to power its analytics. Within the next few years, many more tactical systems are expected to join the Army's Tactical Server Infrastructure, including the newly proposed Unified Network Operations (UNO) framework. As this happens, coordination for what and how data gets shared between systems must be agreed upon and codified across PORs. This eventual convergence was further emphasized when MG David G. Bassett, Program Executive Officer for PEO C3T, at the 5th Annual CEMA Conference, confirmed the Army's commitment to ensure vendor solutions align with the Army's Common Operating Environment (COE) if they are to be considered for future funding.

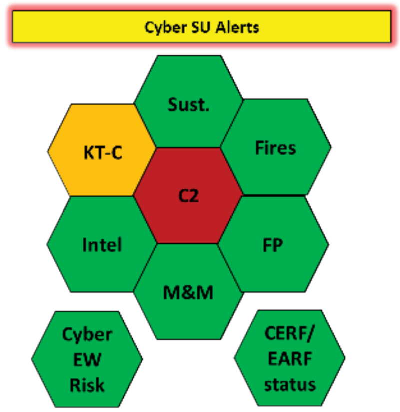

Fig. 2a - Impact to Warfighter Functions

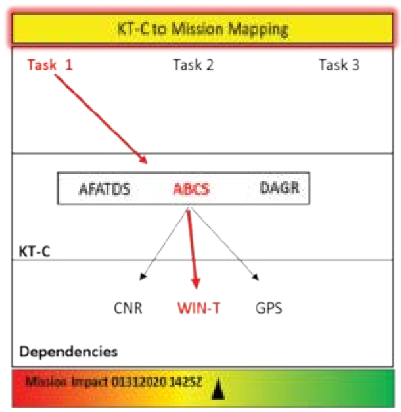

Fig. 2b - Mission Dependency Map

Currently, only limited data sharing is possible through the Army's Data Dissemination Service (DDS), which is a publish/subscribe messaging architecture for tactical communication environments. With DDS, military systems publish topics, like significant activities (SIGACTS), and other tactical systems, like Cyber SU, can subscribe to them. Another potential solution for sharing and distributing data may come from Army Cyber (ARCYBER) Command's data-implementation strategy, which includes pushing a Lower Echelon Analytics Platform (LEAP) to the TSI. LEAP offers a common data analytics platform with reachback to enterprise resources such as ARCYBER's Big Data Platform (BDP): Gabriel Nimbus (GN). Moreover, reachback to GN offers enterprise-level resources, like computationally intensive analytics and a cross-domain solution (CDS), which can be leveraged to bring relevant data from across security enclaves back to the tactical edge. As tactical systems (i.e., DCGS-A, EWPMT, WIN-T, etc.) begin to integrate with the CPCE and develop more robust topics for Cyber SU to consume, Cyber SU's ability to perform more complex analytics will also improve.

As an emerging capability, Cyber SU aligns with Mission Command's convergence strategy by directly integrating with the Army's CPCE to provide SU to the Commander's COP. It also limits overloading the Commander's visual real estate by implementing overlays that are toggled on or off. This convergence of data and analytics with Cyber SU will allow Commanders to move from hindsight in the IE to applied foresight in the operational environment. Moreover, with the correct foresight, these new capabilities will prove an integral force multiplier – making warfighters more mobile, agile and lethal – as the US Army builds out its future force.

ABOUT THE AUTHORS

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EM Domain

OPERATIONAL RESPONSIBILITY

The warfighter ultimately owns the operational responsibility for the EM Domain. Above, US Marines with electronic warfare liaison element and scout snipers with Marine Rotational Force-Europe 19.2, Marine Forces Europe and Africa, provide security at an objective rally point during exercise Valhalla in Blåtind Training Center, Norway. USMC PHOTO

So far in this EM Domain series, we've discussed some of the aspects of warfighting domains in general and the EM Domain in particular. We've looked at how other warfighting domains (Air, Land, Sea, and Space and Cyberspace) are characterized by unique physical environments and their strategic importance. Our last column discussed how technology does not define a domain, and more specifically, how electronics technology does not define the EM Domain. It went on to say that viewing the EM Domain through a technology lens can skew our understanding of the Domain, in part by elevating the significance of technological convergence.

So, what lens can we look through to truly understand any warfighting domain, including the EM Domain? The answer is "operational responsibility." If a warfighting domain is a strategically important maneuver space that is defined by unique physical characteristics, then some group within a military force must have operational responsibility for protecting friendly access to it, managing its use and controlling access to that domain. As a military domain becomes more strategically important, we typically create an enterprise approach to managing that domain. In the US, the enterprise for the Air Domain began to take shape in the 20 years between World War I and World War II. But the strategic importance of the Air Domain – using it, managing it and controlling it – was not fully formed until aircraft carriers in the Pacific and strategic bombing in Europe proved to be so vital in World War II. The Allied Powers could not have won the war without them.

We have also been using the EM Domain for warfare since World War I, and its strategic importance has developed in the ensuing century. In World War II, it became essential to counter the enemy's use of radio and radar. Since that time, EW has evolved as military operations have become more dependent on access to the EM Domain. We are now at a point where we need to take an enterprise approach to the EM Domain because of its strategic significance.

But there is another important aspect to viewing a warfighting domain through the lens of operational responsibility, and that is the simple fact that operational use expands across greater portions of a domain over time. For example, the Air Domain was only utilized for certain types of missions at relatively low altitudes for most of World War I. As aircraft technology improved over the ensuing decades, air crews were able to operate at higher altitudes (and farther and faster) until we were able to use rocket technology to reach the space domain in the 1950s. For the military, along with that expanded use of the Air Domain came expanded operational responsibilities, including the need for management via Air Operations Centers and more robust counter-air capabilities. The same is true of the other major warfighting domains: operational responsibilities grew with wider use of their domains.

In the case of the EM Domain, operational use also grows with new technology. Just look at any country's EM Spectrum allocation chart from 10, 20 or 30 years ago and compare it to a current EMS allocation chart. Not only are there far more licensed users in any given frequency from 20 MHz to 30 GHz, there is also growing use in millimeter wave frequencies (automotive radar and 5G communications) and the possibility for wider use in some portions of the terahertz region. As EM Domain use grows, so too will the need to protect friendly use, manage this use and deny access to adversaries. Technology may drive the use of the domain, but the reality that matters for the military is the expanded operational responsibility that results from this.

Going back to our previous EM Domain column that discussed Cyber-EM "convergence," it's clear that while cyber systems are becoming more dependent on access to the EM Domain to communicate information, the technological convergence we see in today's networked electronic systems, as well as the convergence in target effects, is not redefining the EM Domain or Cyberspace. These trends are not changing the fundamental operational responsibilities for the EM Domain or Cyberspace. Operational responsibility for the EM Domain is defined by radiant analog energy from "DC to light." Operational responsibility for Cyberspace is defined by digital processing inside computers and data packets moving across digital networks – which sometimes traverse the EM Domain as analog signals. The respective operational responsibilities for the EM Domain and Cyberspace are not converging because of technology or target effects.

OWNERSHIP

Although looking through the lens of operational responsibility can help us to visualize and understand warfighting domains, it raises another question: who owns the operational responsibility for a domain? At the basic level, this falls to the domain's users (who have to protect their access to the domain), the domain's managers (who set the rules for friendly use of the domain) and the domain's controllers (who protect friendly forces by denying or controlling adversary access to the domain). In the case of the EM Domain, the users (radars, radios, GPS receivers, etc.) must employ Electronic Protect (EP) measures in order to retain access to the EM Environment; the spectrum managers must develop spectrum plans to deconflict frequency usage between friendly users, as well as EW assets; and the controllers must employ Electronic Support and Electronic Attack measures to identify adversaries and deny their use of the EM Domain.

This "use, manage and control" model describes one aspect of operational responsibility for a domain. But in the US and many other Western military forces, there is an organizational distinction between the Armed Services and the Warfighters. In the US, the Armed Services "organize, train and equip" forces, and the Warfighters (the Combatant Commands – COCOMs) employ these forces and perform the actual warfighting. Because they do the actual fighting, it is the COCOMs which own the operational responsibility for the Warfighting Domains. For example, the US Air Force may organize, train and equip aviation units that fight under a COCOM, but the Air Force as an organization does not fight, and it does not directly "own" the operational responsibility for the Air Domain. The same is true of the Navy, Marine Corps and Army, even though they also supply aviation forces to the COCOMs.

This distinction between the Services and the COCOMs may seem pretty obvious to anyone who understands the Goldwater-Nichols DOD Re-organization Act of 1986. Yet it is the Services and not the COCOMs (the ones who own the operational responsibility for the EM Domain) who have carried most of the weight in the DOD's discussions about the EM Domain. When the DOD's EW EXCOM looked at the question of recognizing the EMS as a major warfighting domain in 2017 and 2018, it was the Services who were asked to weigh in and not the COCOMs. Because the "equipping" responsibility falls under the Services, they are more inclined to view the EM Domain through a technology lens and pay more attention to Cyber-EM technological convergence.

One reason the COCOMs have been relatively quiet in the EM Domain debate is because they have been historically understaffed in their EW billets – sometimes gapping the COCOM staff EW officer position for months at a time. With the recent establishment of Joint EMS Operations Cells (JEMSOCs), the COCOMs are just beginning to bolster their EW expertise and awareness on a permanent basis. This will hopefully re-align the EM Domain discussion with the organizations that own the operational responsibility.

New EA Techniques (Part 12)
Impact of Dicke-Fix

By Dave Adamy

AUTOMATIC GAIN CONTROL

In a radar, the received power of a target's skin-return signal is given by the formula:

$$P_R = ERP_R + G - 103 - 20 \log F - 40 \log R + 10 \log RCS$$

Where: P_R = the skin return power in dBm

ERP_R = the effective radiated power of the radar in dBm

G = the main beam boresight gain of the radar antenna in dBi

F = the operating frequency of the radar in MHz

R = the range from the radar to the target in km

RCS = the radar cross section of the target in m^2

Consider the maximum-size target at the minimum range and the minimum-size target at the maximum range. The difference between the received skin return power at these two situations is typically hundreds of dB.

The radar processor must analyze the timing of skin return pulses to determine the range to the target and, in non-monopulse radars, it must analyze the relative received magnitude of series of pulses to determine the angle to the target from the radar. To do this well, the radar processor must input the skin-return signal at a comfortable level. This requires automatic gain control to bring the processor input to that comfortable level as shown in **Figure 1**. It is necessary that the AGC have a *fast attack and a slow decay* characteristic. While the radar is searching for a target, there is no skin return. But when a target is found, the skin return will only be in the radar antenna for a brief time. Thus, the radar has only one pulse interval to bring the input to the processor to the optimum level. However this gain level must be maintained in order for the processor to see the time variation of the amplitudes of subsequent pulses.

AGC JAMMING

Figure 2 shows a pulse train produced by a radar with a conically scanning antenna which is tracking a target that is offset from the center of the scanned area. The skin return varies as a sine wave. When the antenna points near the target, the return is large, and when it is pointing away from the target, the return is smaller. The received power of the skin return varies inversely as the fourth power of the range to the target, the weapon controlled by this radar is steered toward the center of the scanned area so that the waveform approaches a constant pulse amplitude.

The AGC jammer produces a very strong, short pulse that captures the AGC function. As shown at the bottom of Fig-

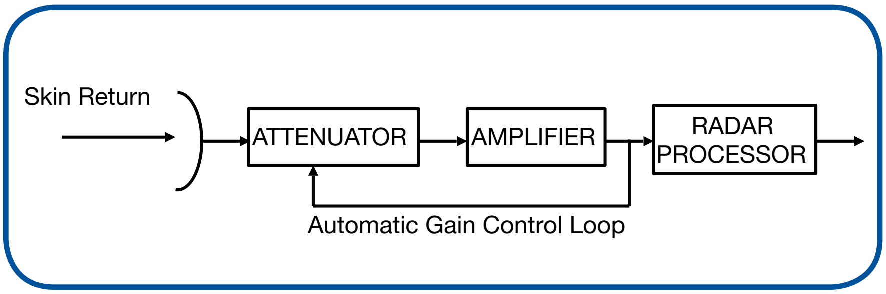

Fig. 1: The processor in a radar must determine timing of received skin-return signals in order to know the range to the target being tracked. For non-monopulse radars, it must also analyze the relative amplitude of series of pulses to determine the direction to the target. This requires optimum signal strength into the processor. Thus, Automatic Gain Control is necessary.

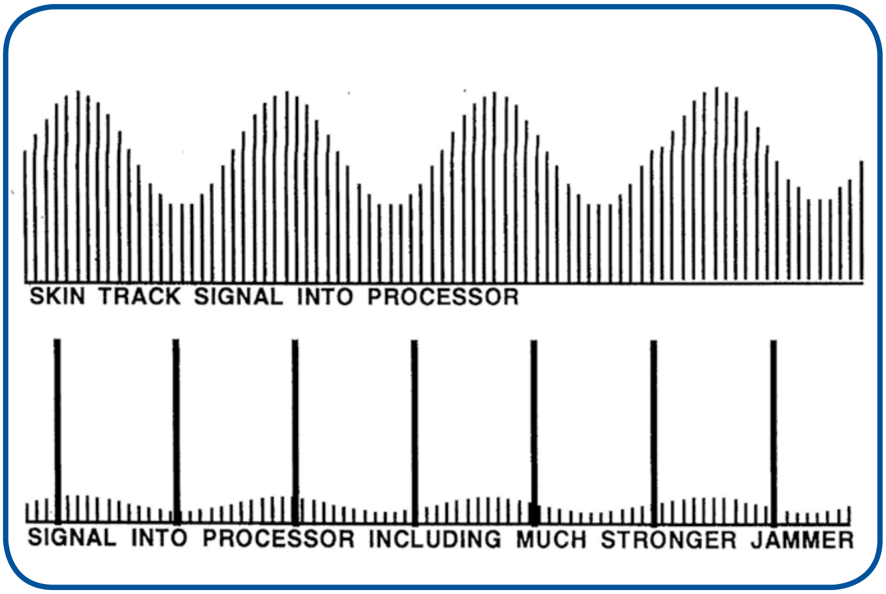

Fig. 2: By transmitting strong, narrow pulses at about the same rate as the radar antenna scanning rate, the AGC jammer "captures" the radar's AGC, reducing the amplitude variations from the antenna scan to an unusable level.


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ure 2, this causes the skin return signal to reduce its amplitude. This part if the figure is an under-exaggeration which is done deliberately to show that the AGC attenuates the received signal. Actually, the signal will be reduced so much that the radar will not be able to see it. The radar thus thinks there is no target return present. This jamming technique also works against radars with any type of tracking in which the antenna moves to determine the signal angle of arrival.

Figure 3 shows the "Dicke-fix" circuit. This was developed by Robert Dicke, a World War II physicist, to overcome AGC jamming. This circuit has a wideband amplifier that can receive the strong, narrow jamming pulses but limits them to reduce their ability to capture the AGC. The wideband amplifier is followed by an optimum bandwidth amplifier in which the AGC function can be performed. Thus, the radar's AGC function works properly.

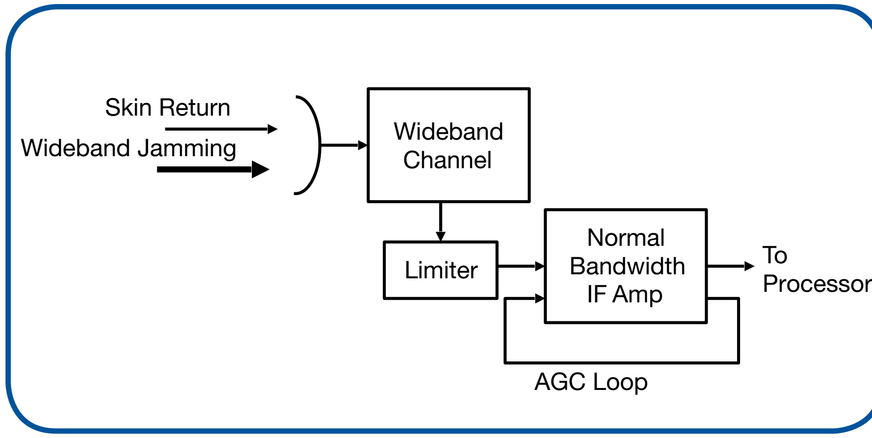

Fig. 3: The Dicke-fix feature in a radar limits the output of a wideband channel to reduce wideband signals before input to a narrow channel to protect the AGC function from strong wideband jamming.

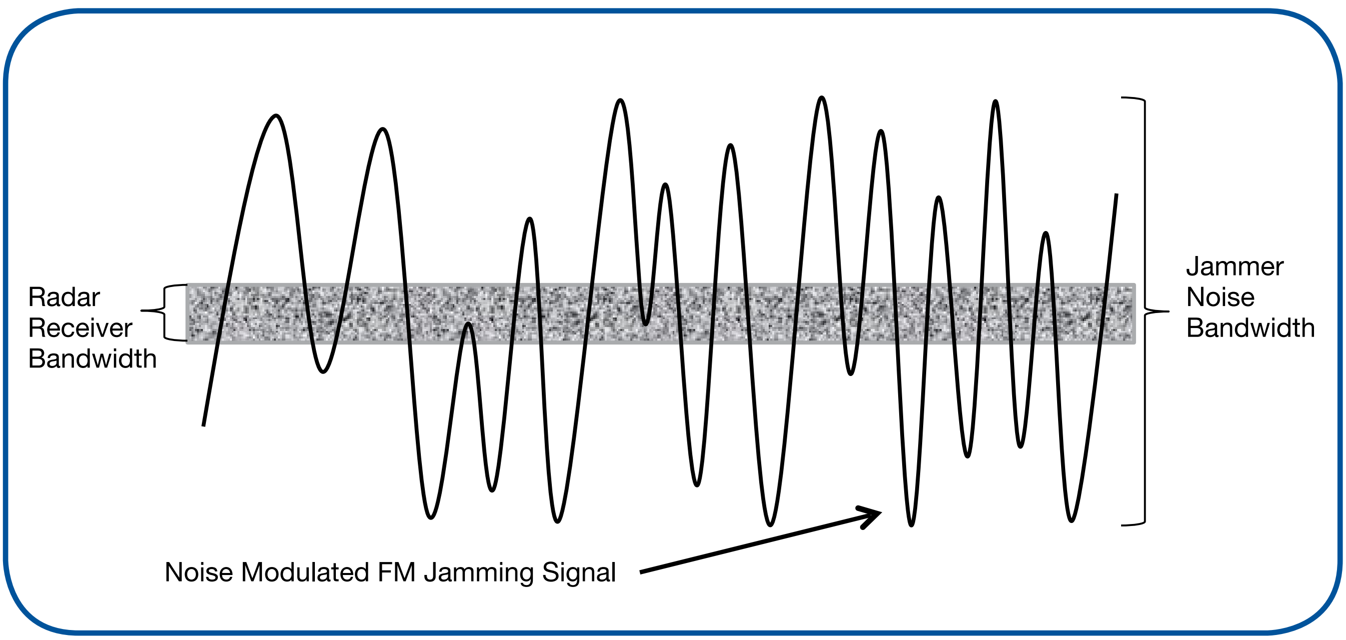

Fig. 4: If a jammer produces an FM noise signal that is much wider than the receiver bandwidth, it will be received as a very high quality noise signal in the receiver. This causes very effective jamming. The Dicke-fix reduces the effectiveness of this jamming.

PRODUCTION OF OPTIMUM NOISE

The effectiveness of noise jamming is a function of the quality of the noise, Gaussian noise is the most effective. One way to produce ideal Gaussian noise is shown in **Figure 4**. A noise-modulated FM jamming signal several times as wide as the radar's receiver bandwidth is transmitted. As the jamming signal passes through the receiver passband, impulses are generated. These are received by the targeted radar as an approximately Gaussian signal.

The Dicke-fix in the radar receiver significantly reduces the effectiveness of the jamming signal produced in this way.

DICKE-FIX IN PULSE-DOPPLER RADARS

The Dicke-fix is not employed in pulse Doppler radars.

WAVEFORMS SUGGESTED TO OVERCOME DICKE-FIX

Curtis Schleher's book, *Electronic Warfare in the Information Age* (ISBN 0-89006-526-8), presents a procedure for overcoming the effects of the Dicke-fix. This is to generate a jamming signal that alternates two sinewaves with amplitudes two and four times the level at which the wideband channel is limited.

WHAT'S NEXT

Next month, we will continue our coverage of the impact of electronic protection techniques by discussing burn-through modes, frequency agility, and PRF jitter. For your comments and suggestions, Dave Adamy can be reached at dave@lynxpub.com.

METROPOLITAN CLUB CHAPTER AWARDS STEM SCHOLARSHIPS

The Metropolitan Club Chapter of the AOC hosted our 54th annual STEM Scholarship Awards dinner on 14 November 2019. Scholarships were awarded to two worthy individuals from local colleges that excel in the areas of science, technology, engineering and math. The 2019 Scholarship award

winners were: Mayank Vanjani, NYU Tandon School of Engineering (GPA 3.95), and Michael Gregory Campiglia, Manhattan College (GPA 3.91).

The guest speaker of the night was CDR Brian "CHACHI" Arena, VAQ-209 commanding officer.

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	2215	1900 - 6000	200	R5U
Pulse	2210	150 - 450	12000 Pulse 20%	R19U
	2211	2700 - 3100	1200 Pulse 20%	R3U
	2217	5200 - 5900	8000 Pulse 20%	R17U
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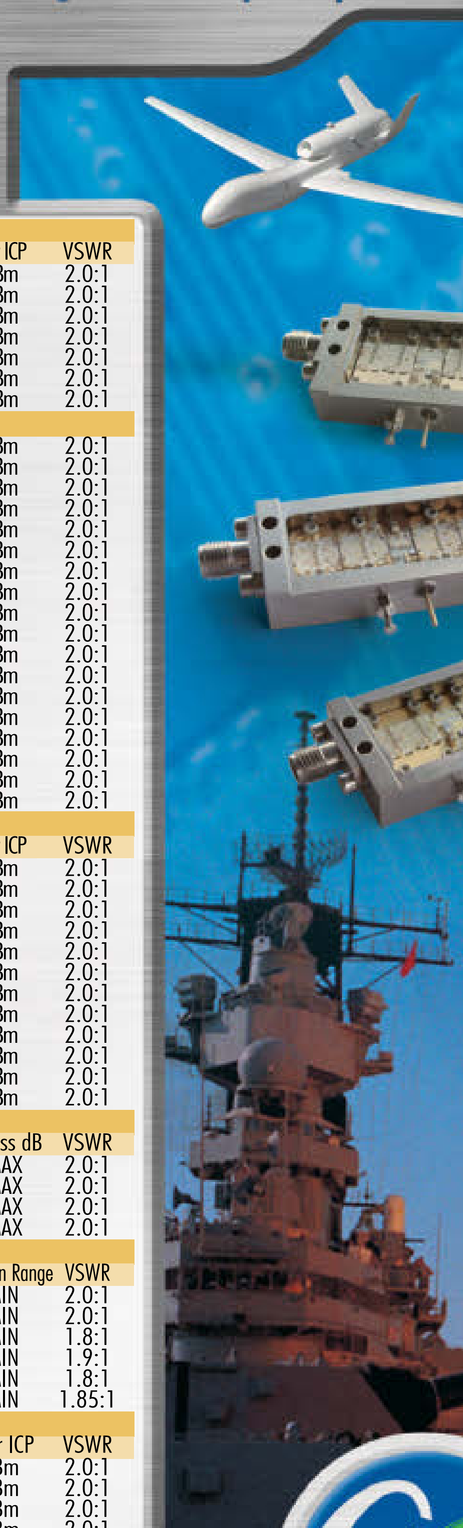

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CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

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CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

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CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

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CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

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CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

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CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
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