July 2022
Vol. 45, No.7

ASSOCIATION OF OLD CROWS
Advancing Electromagnetic Warfare TOGETHER
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# JED
Journal of Electromagnetic Dominance

# Rethinking the Relationship Between EW and EMSO


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JED
Journal of Electromagnetic Dominance

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US AIR FORCE

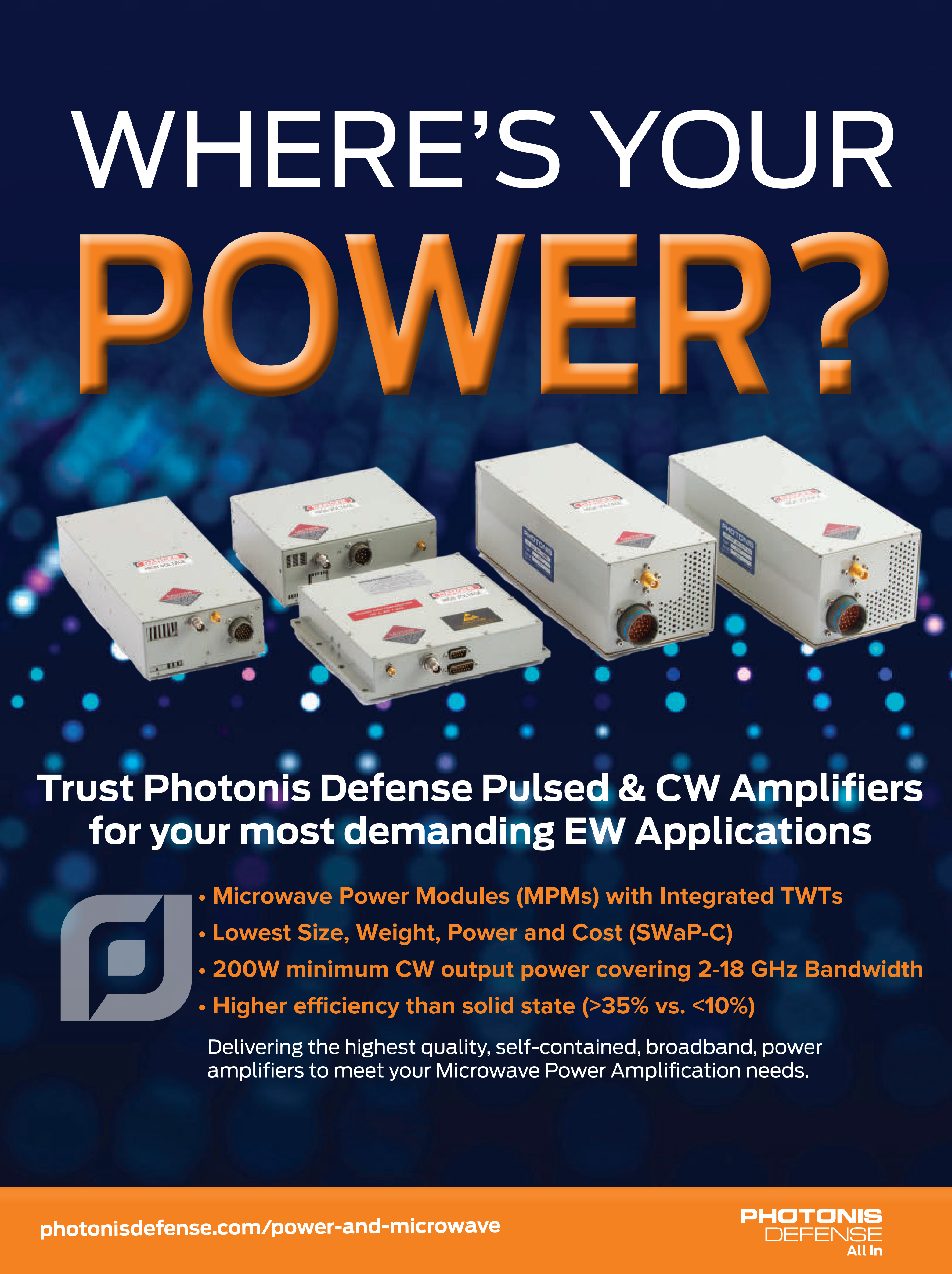


## Departments



*US Army Sgt. Galen Craig, 44th Expeditionary Signal Battalion-Enhanced SNN 540 Team Chief, checks the status of a field spectrum analyzer during Exercise LIGHT RAIN conducted in April at Ramstein Air Base, Germany. Soldiers from the 44th ESB-E took part in the multi-day exercise, which was designed to enhance readiness in a digitally simulated contested electromagnetic environment. The 44th ESB-E was challenged to protect their information networks against adversary jamming and other sources of interference. The 1st Combat Communications Squadron led the exercise, which provided an opportunity for participants to mitigate credible simulated EW threats during large-scale combat operations.* US ARMY PHOTO

COVER PHOTO COURTESY OF US NAVY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# GETTING IT RIGHT

**Our cover story** this month, written by Dr. J.B. Lange and Maj G.R.F. Massie, RCAF, takes an interesting look at some of the terms and meanings at the very heart of our profession's lexicon. Do we have Electromagnetic Spectrum Operations (EMS) and Electromagnetic Warfare (EW) right? For many of us, it's very tempting to say, "yes," and simply move on. After all, the DOD just issued new EMS Operations (EMSO) doctrine in 2020. It can't be stale yet, right? But there are other perspectives that are worth listening to.

It's easy to digest this month's article on its own – and I certainly hope you will take time to read it. But I hope you will also consider it within a larger context alongside other *JED* articles that have addressed concepts and doctrine. These include "A (Pragmatic) Future for Joint Electronic Warfare," by Lt Col Jesse Bourque, USAF (*JED,* September 2008); "EW, the EMS Doman and Air Superiority," by Lt Col Jeffrey Fischer (*JED,* September 2010); and "What Electronic Warriors Should Know About Physics, Language and Concepts," by Wg Cdr John Clifford OBE, RAF (*JED,* March 2011).

Whether you agree or disagree with the main points in this month's cover story, my hope is they will at least stimulate a response in you. What do you agree with in this article, and what do you disagree with? More importantly, *why* do you agree or disagree with their points? Please tell us what you think, either in a letter to the editor or perhaps with another article.

It's important to remember that those articles from Bourque, Fischer, Clifford and others were a small but important part of an essential debate that started in 2006-2008. We asked questions of ourselves and these helped us to form new ideas, such as the EM Environment and EMS Domain concepts. We started to think of the EME/EMS Domain as a maneuver space and see EW as a discipline that was not simply shaped by technology. Eventually, we earned the attention of senior leaders. Within NATO, this has helped to shape its Electromagnetic Operations (EMO) concepts. In the US, this process that culminated in new EMS strategies and new EMSO doctrine at the Joint and Service levels. It has helped to shape some organizational changes, as well. Overall, this process moved the needle just a bit in the right direction.

With the DOD's EMS Superiority Strategy (EMSSS) Implementation Plan now in place, it's time for the EMSO community to start this process again and to begin discussing and debating our "big ideas" once more. If it takes us another 10-12 years to complete the cycle, it puts us pretty close to 2035, when we are facing a different China, a different Russia and a different Iran to name a few of the known challenges. 2035 is not as far away as we might think. – *J. Knowles*

JED
Journal of Electromagnetic Dominance

EDITORIAL STAFF
**Editor:** John Knowles
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PRODUCTION STAFF
**Layout & Design:** Barry Senyk
**Advertising Art:** Elaine Connell
**Contact the Editor:** (978) 509-1450, JEDeditor@naylor.com
**Contact the Sales Manager:**
(800) 369-6220 or kkrewson@naylor.com
**Subscription Information:**
Please contact Glorianne O'Neilin
at (703) 549-1600 or e-mail oneilin@crows.org.

*Journal of Electromagnetic Dominance*
is published for the AOC by
NAYLOR
ASSOCIATION SOLUTIONS
550 SW 2nd Avenue
Gainesville, FL 32601
Tel (800) 369-6220
www.naylor.com



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PUBLISHED JUNE 2022/JED-M0722/3283

# Calendar *Conferences & Trade Shows*

## JULY

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

## AUGUST

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

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

## SEPTEMBER

**4th Azerbaijan International Defence Exhibition**
Sept. 6-8
Baku, Azerbaijan
www.adex.az

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

**MSPO**
Sept. 6-9
Kielce, Poland
www.spie.org

**SPIE Laser Damage**
Sept. 18-21
Rochester, NY
www.targikielce.pl

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

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

## OCTOBER

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

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

**International Telemetry Conference 2022**
Oct. 24-27
Glendale, AZ
www.telemetry.org

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

**SOFEX 2022**
Oct. 31 – Nov. 3
Amman, Jordan
www.sofexjordan.com

## NOVEMBER

**MAST Med 2022**
Nov. 2-4
Athens, Greece
www.mastconfex.com

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

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

**2022 Directed Energy Systems Symposium**
Nov. 14-18
La Jolla, CA
www.deps.org

**11th International Defence Exhibition and Seminar**
Nov. 15-18
Karachi, Pakistan
https://ideaspakistan.gov.pk

**EXPONAVAL 2022**
Nov. 29 – Dec. 2
Valparaiso, Chile
www.exponaval.cl

*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*

## JULY

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

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

## AUGUST

**How to Conduct 30+ Capability Demonstrations on CMOSS Mounted Form Factor Prototype in 12 months Without Breaking the Bank**
Aug. 4
Time TBA
www.crows.org

**EMBM Situational Awareness: Data Integration, Visualization and Analytics**
Aug. 11
Time TBA
www.crows.org

## SEPTEMBER

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

**RWR Fundamentals**
Sept. 13-14
Atlanta, GA
www.pe.gatech.edu

**SIGINT Fundamentals**
Sept. 13-14
Atlanta, GA
www.pe.gatech.edu

**Test and Evaluation of RF Systems**
Sept. 13-15
Lake Buena Vista, FL
www.pe.gatech.edu

**Basic Electromagnetic Warfare Modeling**
Sept. 13-16
Online
www.pe.gatech.edu

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

## OCTOBER

**Modeling and Simulation of Phased Array Antennas**
Oct. 18-20
Online
www.pe.gatech.edu

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

## NOVEMBER

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

**RWR System Design and Analysis**
Nov. 15-17
Atlanta, GA
www.pe.gatech.edu

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

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

# LESSONS LEARNED OR ONLY OBSERVED!

**As the Ukraine-Russian** war grinds on and we see more "lessons" from the war, I ask myself, are we observing or are we actually learning lessons. If the latter, are they the correct lessons, especially about the EMS, EMSO and EW? Are we equipping our soldiers, sailors, airmen, marines and coast guardsmen with the needed equipment, assets and capabilities to fight successfully within and across the spectrum? We need to make sure that we are learning the correct lessons and not jumping to conclusions or making assumptions as to why the Russian EMS capabilities have had challenges in Ukraine. I believe there are many factors, ranging from quality, training, interference from similar/same systems, and operational assumptions that the Ukrainians would put up minimal resistance or not fight at all.

Among western governments, I grow concerned when I see the pendulum of needed capabilities swing drastically back and forth between those required for a peer/near-peer fight versus an asymmetric fight. This is why our warfighters need multi-function capabilities that can work across the other warfighting domains and adapt to ever-changing EMS operational environments.

I also get concerned when the DOD and Services focus mainly on the "high-end" fight and let systems and capabilities atrophy and die when they could be adapted for the next fight. I question the DOD's focus and commitment to execute its EMS Superiority Strategy when the EC-37B (EC-130H Compass Call replacement) ends up on the Air Force's Unfunded Priority List and at the same time the Navy proposes the retirement of expeditionary EA-18G Growlers. While I hope these are primarily budgetary moves, they highlight how the DOD is not strongly focused on EW. This is a major concern of mine, as I was on active duty when the Services let EW atrophy for 25 years following the end of the Cold War, and I am concerned that we once again are becoming too focused on niche capabilities and "buzzwords" like AI/ML/cognitive while the DOD also tries to slot EMSO and EW under Information Warfare and Cyber Operations.

We must have state-of-the-art EW capabilities, but we also need to ensure sufficient capacity by utilizing and upgrading legacy EW systems that provide effects in today's EMS and EMOE. If we develop the most advanced EW systems, but we only buy and field small numbers of them (i.e., EC-37B and EA-18G), then what do we do when we need those capabilities in multiple areas – because with small numbers, we will have zero capability in those other areas.

We also need to ensure our forces are well trained in EMSO and in employing these EW capabilities so that when they are needed they can use those capabilities to maximum effect. We must also remember that well trained EMSO operators will develop EW tactics and techniques that the engineers haven't considered when designing these systems.

So I ask whether we are learning or just observing. I sincerely hope we are truly learning important lessons from this conflict. – *Glenn "Powder" Carlson*

ASSOCIATION OF OLD CROWS

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This regularly scheduled podcast, hosted by Ken Miller, AOC's Director of Advocacy and Outreach, features interviews, analysis, and discussions covering leading issues of the day related to electromagnetic spectrum operations (EMSO).

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SCAN ME

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*The Navy believes that extending the frequency range of the NGJ Mid-Band pod (shown above outside of the underwing fuel tanks) provides the fast path to upgrading the EA18G's high-band jamming capability.*

## HASC DRAFTS FY2023 DEFENSE POLICY BILL

As this issue of *JED* went to press, the House Armed Services Committee (HASC) was in the process of marking up its version of the FY2023 National Defense Authorization Act (NDAA). The various HASC subcommittees drafted language and issued reports on their respective portions of the NDAA ahead of a full committee mark-up scheduled for June 22. Several of these subcommittees addressed Electromagnetic Spectrum Operations (EMSO)-related issues.

The Subcommittee on Tactical Air and Land Forces focused on two Navy EW programs: the proposed EW upgrade for F/A-18E/F Block III aircraft, as well as the Next-Generation Jammer (NGJ) High-Band program.

### *F/A-18E/F ADVEW*

Regarding the Super Hornet's EW upgrade, the subcommittee's report states, "The committee notes there is an operational need for an integrated electronic warfare suite to ensure the F/A-18 E/F Block III strike fighter aircraft fleet remains relevant and survivable in highly contested, anti-access/area denial environments. The committee recognizes that the Commander for Naval Air Forces (CNAF) noted on the CNAF's fiscal year 2023 annual priorities list a requirement for F/A-18E/F to be equipped with an advanced electronic warfare (ADVEW) suite. The committee notes the ADVEW suite is intended to serve as an upgrade for the existing AN/ALQ-214A(V) radio frequency countermeasure and AN/ALR-67(V) radar warning receiver (RWR) systems and is integrated with the APG-79 wide band receiver, active electronically scanned array (AESA) radar that is scheduled to be deployed on F/A-18E/F Block III configured aircraft as well as on the next generation of naval aviation platforms. The committee is aware of the need to expand the service life of the F/A-18E/F fleet and supports the Navy's efforts to improve the F/A-18E/F readiness and capabilities beyond 2030."

With this in mind, the subcommittee called for the respective commanders of US European Command (EUCOM) and US Indo-Pacific Command (INDOPACOM) to brief the HASC on the Navy's ADVEW plans by May 1, 2023. The language is very particular about what the briefings should cover. This includes a description of the mission systems; "how the Navy will leverage highly advanced compact, electronic antenna solutions that provide low-risk modifications on aircraft size, weight, and power"; and "how new ADVEW capabilities will fully integrate with current and expanded APG-79 AESA radars."

### *NGJ High Band*

Noting that the Navy views the NGJ High Band program as a priority, it stated, "The committee concurs with this assessment and recognizes the need for an upgraded high band jamming capability for the Navy's EA-18 Growler. In its response to the committee report accompanying the National Defense Authorization Act for Fiscal Year 2022 (H. Rept. 117-118), the Navy outlined three potential courses of action to address the high band threat and acknowledged that extending the frequency range of the current [NGJ] mid-band array represented the fastest path to an operational high band capability.

"The committee notes that the NGJ Mid-Band program includes a cooperative agreement with a partner country [Australia], which has already contributed funding to the mid-band development effort. The committee is aware of interest on the part of the cooperative partner to begin investing in high band capability through a mid-band frequency extension effort. The mid-band frequency expansion course of action could provide a two-fold benefit: enhanced airborne electronic attack capability for the EA-18 Growler community and an opportunity for further technology collaboration. The committee directs the Secretary of the Navy to provide a briefing to the House Committee on Armed Services not later than Dec. 15 on the status of U.S. Navy-partner collaboration on NGJ, to include options for cooperative investment in an expanded frequency mid-band capability beginning in fiscal year 2024 and an assessment of any other resources or authorizations required to pursue this course of action."

### *CMOSS*

Other items of interest for the Subcommittee on Tactical Air and Land Forces include the Army's approach to Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance, Reconnaissance (C5ISR)/Electronic Warfare Modular Open Suite of Standards (CMOSS) and threat simulator upgrades for the Utah Test and Training Range (UTTR).

Regarding CMOSS, the subcommittee's report stated, "The committee remains concerned that the Army has not planned for appropriate resourcing to evaluate Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance, Reconnaissance (C5ISR)/Electronic Warfare Modular Open Suite of Standards (CMOSS) compliance in future CMOSS embedded computing-related procurements, such as that of the forthcoming CMOSS Mounted Form Factor. The committee is also concerned about the Army's available resources to evaluate third-party software offerings for compliance to the multiple CMOSS software standards. Given CMOSS is intended as a regularly evolving suite of standards, failure to resource regularly assured compliance with these standards before, during, and after procurement risks the interoperability of entire Army systems."

To address these concerns, the subcommittee directed the Secretary of the Army to submit a report to the HASC and the Senate Armed Services Committee (SASC) by Dec. 23 about the Army's plans "to ensure appropriate evaluation and certification of Army modular open systems architecture (MOSA) standards." It further said, "This report shall include, but is not limited to, plans to establish, fund, and manage dedicated engineering technical responsibility, and the acquisition and competition plan for CMOSS Mounted Form Factor capability."

### *THREAT EMITTER*

The subcommittee also expressed its commitment to upgrade the threat emitters at the Air Force's UTTR. Its report stated, "The committee supports providing realistic training opportunities for fourth- and fifth-generation [fighter] pilots to improve readiness levels and weapon systems capabilities, and hone the skills of combat air forces training required for deterrence and combat activities associated with great power competition. The committee is concerned that the Air Force and joint forces lack a high- fidelity, X-band surface-to-air missile (SAM) threat simulator at the UTTR for aircrews to train against. The committee supports Air

## OUSD R&E Issues EMSO Technology RFI

The Office of the Under Secretary of Defense, Research & Engineering (OUSD R&E) has released a Request for Information (RFI) for next-generation technologies that will support Electromagnetic Spectrum Operations (EMSO). According to the RFI, the goal is to "…identify disruptive technologies or concepts that contribute to the achievement of electromagnetic spectrum superiority by 2030-35."

The effort is focused around three technology categories. According to the RFI, "OUSD R&E plans to develop disruptive Electromagnetic Spectrum Operations (EMSO) technologies that provide capability in the areas of (a) spectrum sensing, (b) communicating and (c) electronic warfare including countermeasures against adversary capabilities."

In the spectrum sensing area, proposed technologies should support active or passive sensing schemes with the following characteristics: geo-distributed; opportunistic; beyond line of sight; edge processing power; difficult targets; novel light matter interactions; coherent fusion; and quantum sensing.

In the communications category, program officials are seeking technologies that enable dynamic spectrum access; orchestration with sensing and electronic warfare systems; neuromorphic edge computing; simultaneous transmit and receive (STAR); interference cancellation; combined apertures, including metamaterials; increased range/data rates; and mobile ad hoc networking.

Finally, in the electronic warfare topic, areas of interest include multi-function, expendable RF decoys and jammers; synthetic aperture radar (SAR) jamming; simultaneous jam and communicate; and distributed systems.

The RFI also sates, "It is expected that some technologies may have applicability to more than one capability. OUSD R&E is particularly interested in non-conventional approaches across the sciences including quantum, material science, biology, chemistry, physics, computing, and additive manufacturing."

Responses to the RFI are due by June 30. Program officials expect to hold an industry day in the July/August timeframe. The Notice ID is HQ0034HQ0287EMSOFY22RFI. The program point of contact is Mr. Ash Sharma, Director of Electronic Warfare and Countermeasures, C5ISR-EW Directorate, OUSD R&E, e-mail ashley.sharma.civ@mail.mil. – *JED Staff*

Force efforts to develop these capabilities with new programs but is concerned that this future capability may not be available in the near term and that the UTTR is not currently prioritized to receive these developmental systems." "Therefore," the report continued, "the committee directs the Secretary of the Air Force to provide a briefing to the House Committee on Armed Services not later than March 1, 2023, on efforts to field a non-developmental, high-fidelity, full-effective radiated power, X-band threat emitter capability that would be suitable for aircrew training at the UTTR."

***DIRECTED ENERGY***

The Subcommittee on Cyber, Innovative Technologies, and Information Systems (CITIS) focused attention on directed energy technology. Its report said, "The committee is aware of recent testing at White Sands Missile Range that successfully demonstrated a directed energy system with continual shot availability and low technical downtime. The committee notes the relevance of this capability to a number of threats raised by geographic combatant commanders, including unmanned systems, rockets, artillery, mortars, and missiles, and the importance of continued research and development into deeper magazines and higher power levels with reduced size and weight." The subcommittee encouraged the DOD to "support research and development into high duty cycle technologies for directed energy systems," and it directed the Under Secretary of Defense for Research and Engineering to deliver a briefing the HASC by Dec. 31 on "recently developed technologies and capabilities for high duty cycle directed energy systems, including those supported through private sector internal research and development funds, compare with currently planned technologies."

The CITIS Subcommittee also placed a limitation on certain DOD funds until the Department "develops a joint lexicon for terms related to information operations, including information environment, operations in the information environment, and information-related capabilities in compliance with section 1631(g) of the National Defense Authorization Act for Fiscal Year 2020 (Public Law 116–92)."

***AIRCRAFT IR SUPPRESSION SYSTEMS***

Finally, the Subcommittee on Seapower and Projection Forces addressed infrared suppression improvements for transport aircraft. Its report stated, "The committee notes that current infrared (IR) missiles and man-portable surface-to-air missile systems (MANPADS) are outpacing the existing IR countermeasure flare dispensing and directed energy defensive systems associated with military aircraft. Given the increase of this threat, the committee believes there is merit in providing a wider range of military aircraft that are capable of reducing engine IR baselines to decrease their IR signature and increase the effectiveness of their existing IR countermeasures (IRCM) systems."

"The committee understands that with the installation of a highly cost-effective and proven IR suppression system (IRSS), special operations AC-130J gunships have successfully decreased their IR signatures by at least 95 percent, substantially increasing their survivability and exponentially increasing the effectiveness of their existing IRCM systems."

It went on to say, "As adversary missile capabilities continue to evolve and their proliferation increases globally, the committee believes the Air Force, Navy, Marine Corps, and the Air National Guard should leverage enhanced IR suppression systems to achieve greater heat signature reduction capabilities for its aviation fleets. Therefore, the committee directs the Secretary of the Air Force, in coordination with the Secretary of the Navy, to provide a briefing to the House Committee on Armed Services by Oct. 3 on what planning and programming actions the Air Force, Navy, Marine Corps, and the Air National Guard are taking to reduce the IR signatures for each military service's C-130s and C-17 aircraft, and identify the resources necessary to implement an expanded IRSS installation program for these aircraft."

Full HASC mark-ups, as well as SASC NDAA mark-ups were scheduled for later in June. – *J. Knowles*

## IN BRIEF

The F-35 Joint Program Office (JPO) is continuing its EW data analysis efforts under Project Heisenberg. In 2019, it awarded a Project Heisenberg contract to **BAE Systems** (Nashua, NH) which saw the ESM portion of the F-35's AN/ASQ-239A EW suite installed on a surrogate aircraft (Lockheed Martin's Boeing 737-based Cooperative Avionics Test Bed (CATbird)) to perform data analysis in support of the program's Continuous Capability Development and Delivery (C2D2)/Block 4 EW capabilities. Last month, the JPO announced plans to continue that work by awarding a cost-plus fixed-fee contract to BAE Systems for additional analysis on flight intercept data collected via flight demonstrations of the modified AN/ASQ-239A EW system integrated onto another surrogate aircraft: the RC-135U Combat Sent. The company will conduct analysis of flight test/demonstration data and evaluate mission data files to ensure the ASQ-239A system is performing in the operational environment as designed.

The Air Force Life Cycle Management Center's (AFLCMC's) Electronic Warfare and Avionics Division (Robins AFB, GA) plans to award a sole source contract to **Communications and Power Industries (CPI)** for repair of Mid/High Band Mini-Traveling Wave Tubes (TWTs) used on ALQ-184 jamming pods. The contract could cover up to 1,500 units (as many as 300 units in the base year and 300 units for each of the four option years).

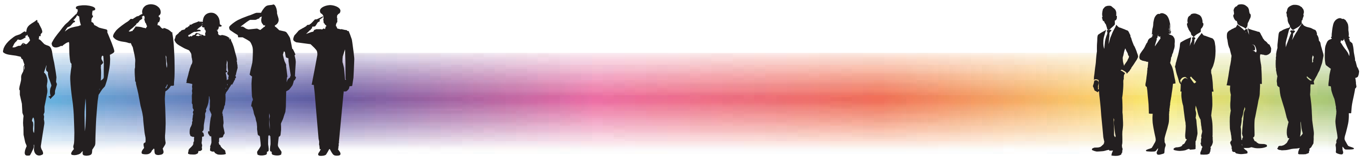
The Naval Information Warfare Center, Pacific (NIWC Pacific) is awarding a firm fixed-price purchase order on a sole source basis to **HawkEye360, Inc.** (Herndon, VA) for commercial radio frequency (RF) data and analytics subscriptions covering the South China Sea and Pacific Island territorial waters. Hawkeye360 operates RF monitoring satellites that detect and track radar, positioning and communications emissions from ships. The contract provides for licenses for up to 150 end users, on-site training and analytical support to assist with interpreting and understanding data. The contract, valued at $38.5 million, covers one base year and one option year.

**Georgia Tech Research Institute** (Atlanta, GA) won a $14.7 million contract from the AFLCMC (Robins AFB, GA) to perform Defensive Avionics Systems Sustainment Studies. The studies will be are scheduled to be completed by June 2025. In a separate effort, AFLCMC awarded a $10 million task order under a previously awarded contract to **Mercer Engineering Research Center** (Warner Robins, GA) for EW test and engineering work. MERC will perform Laboratory Intelligence Validated Emulators Virtual-Constructive 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 simulations and testing will be conducted to improve operational survivability, reliability and mission success of fielded EW systems in support of airborne U.S. warfighting elements." The contract runs through December 2024.

**Northrop Grumman's Mission Systems Sector** (Linthicum, MD) received a $254.4 contract modification from Naval Sea Systems Command (Washington, DC) for continued production of the AN/SLQ-32 Surface Electronic Warfare Improvement Program (SEWIP) Block 3 systems.

## WHO SHOULD ATTEND?

AOC 2022, the Association of Old Crow's International Symposium & Convention, brings together the *full spectrum of people* working in electromagnetic spectrum operations.



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## SYMPOSIUM AGENDA

### The EMSO Playbook: Maneuvering to Win in a New Era

Global security is changing rapidly from Russia's invasion into Ukraine to growing tensions in the Pacific. The EMSO fight will be complex in all future conflicts, it is a critical way we can invest to improve our ability to maneuver in the next five years. The symposium will explore the playbook required for successful EMSO for US and coalition partners.

### Symposium Sessions

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

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

**As of June 7, 2022 – Subject to Change*

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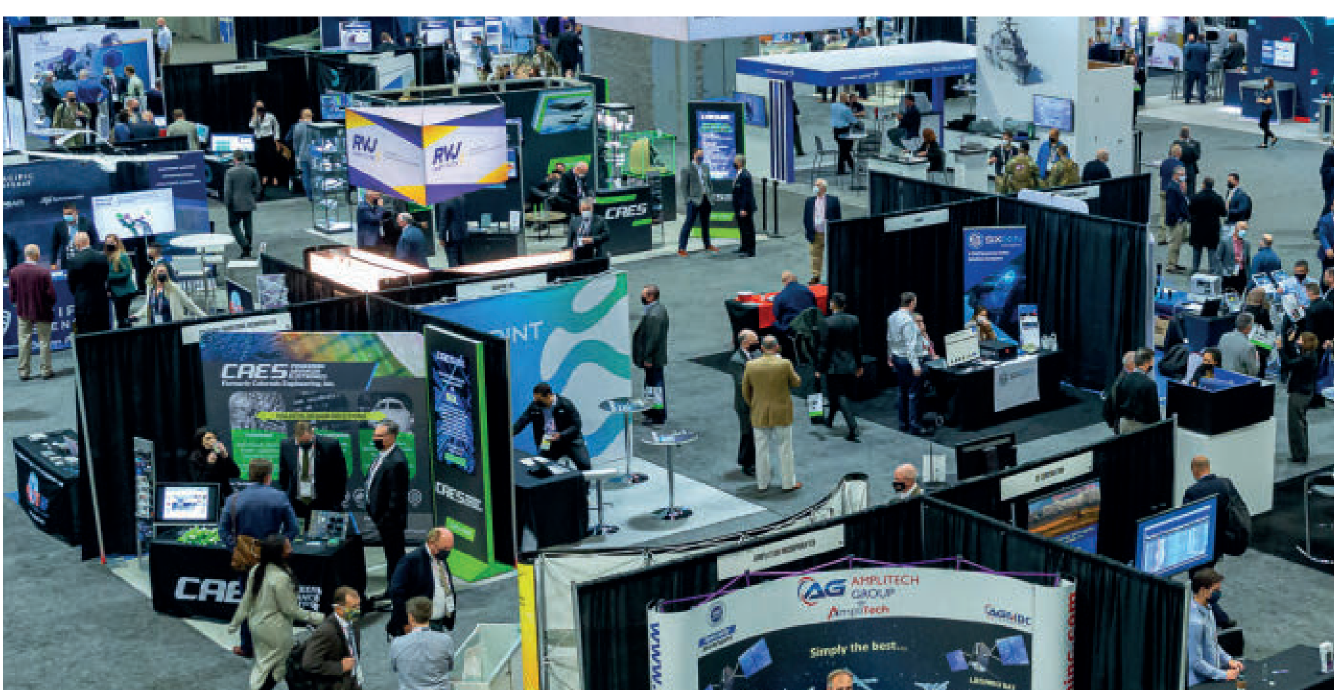


#CROWS2022

# The Relationship Between Electronic Warfare and Electromagnetic Spectrum Operations

**By Dr. J.B. Lange and Major G.R.F. Massie (RCAF)**


## ABSTRACT

Every so often, new concepts on the conduct of military actions are developed as the understanding of the nature of warfare evolves. These are largely driven by advancements in technology, as well as new concepts in how they are best employed. In May 2020, the Unites States Department of Defense (US DOD) introduced the concept of Electromagnetic Spectrum Operations,[1][2][3] which combines the functions of Electromagnetic Spectrum Management and Electromagnetic Warfare under a single banner. While the US DOD was articulating how it will operate in the Electromagnetic Operational Environment, a rethinking of the nature of Electronic Warfare was reported, migrating from a set of action-based definitions to a more fundamental, physics-based concept. This paper seeks to reconcile these two new perspectives into a coherent paradigm.


## INTRODUCTION

The Electromagnetic Operating Environment (EMOE) has been described as the environment of first contact due to both the speed and reach of electromagnetic transmissions. It is also an environment that is becoming increasingly occupied, both from civilian, commercial users as well as military operators from allied, neutral and adversarial nations.[4][5][6] This drives a need for coordination, not only to prevent interference (at best) or fratricide (at worst) but also to ensure a coherent application of force in the presence of other actors. These are the drivers for the Electromagnetic Spectrum Management (EMSM) and Electromagnetic Battle Management (EMBM) concepts.

Recent US Defence Department documents outlining the Electromagnetic Spectrum Operations (EMSO) paradigm asserts that it subsumes Electronic Warfare (EW) and renders electronic warfare a legacy concept.[7] We will demonstrate, however, that the scope of EW extends beyond the EMOE and that as a result, intersections of the Electromagnetic Warfare (EMW) and EMSO constructs with EW are not as complete as US DOD policy document purports. To do this, we must understand the nature of EW,

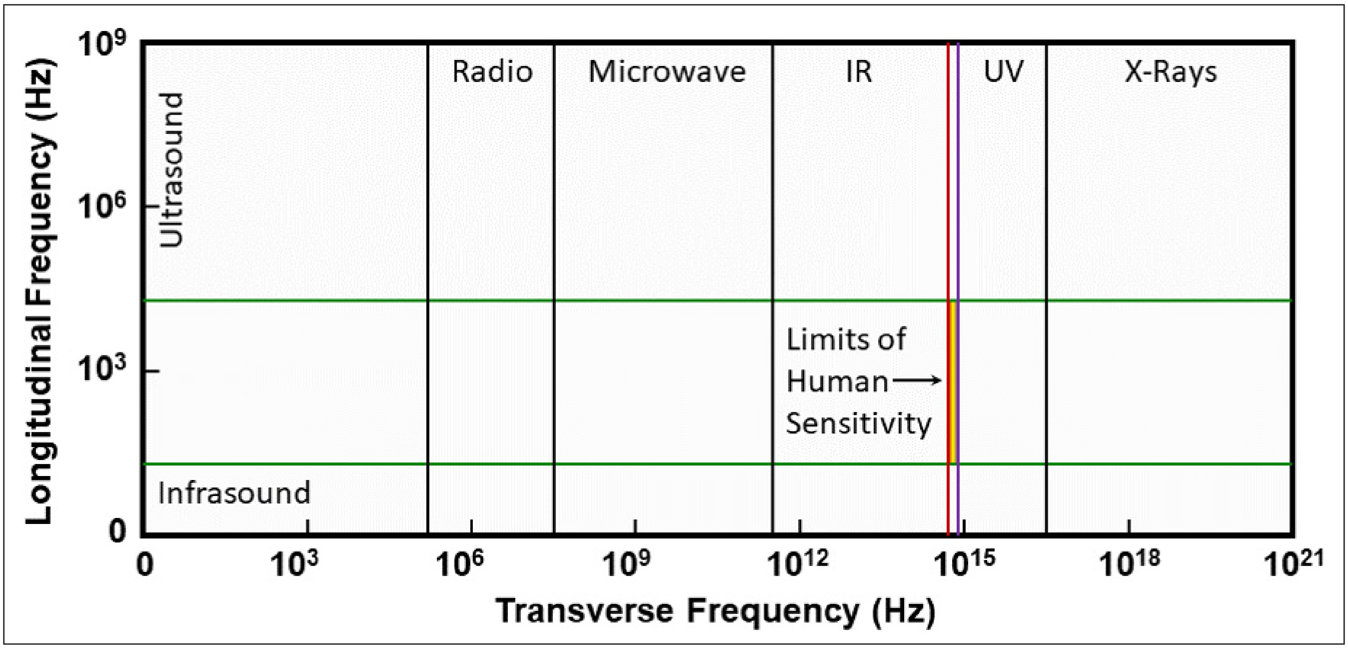


***Figure 1:*** *The boundaries of natural human sensitivity.*

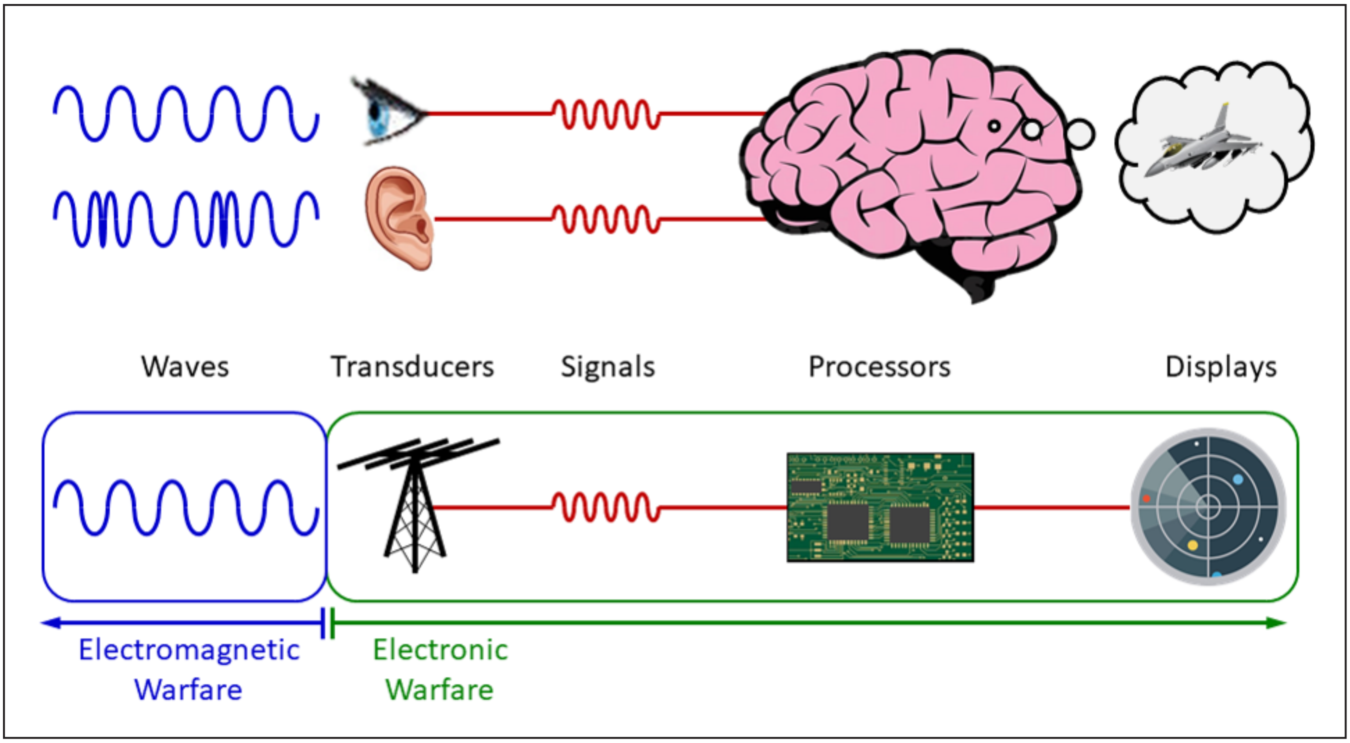


***Figure 2:*** *The junction between electromagnetic warfare and electronic warfare.*

what it comprises and what it does not, at a fundamental level.

## ELECTRONIC WARFARE

As shown in **Figure 1,** human senses are capable of detecting only a very small fraction of the waves that surround us. Once the enabling technologies were developed, people began to design, build and operate electronic devices to exploit these unexploited frequency bands, thus initiating the specialty of EW. This concept is illustrated in **Figure 2.** In the top half of the figure, human eyes and ears detect waves and convert them to electrical signals which our brains process and then interpret to form an image. In EW, antennas and transducers replace human sensory organs while electronic devices fulfill the signal processing and display functions.

A recent article in the Royal Canadian Air Force's (RCAF) Inform series examines the nature of EW as the employment of electronic systems by humans to engage in warfare. From this perspective, only the elements within the green box at the bottom of Figure 2 involve electronic devices and thus comprise EW. Waves and waveforms, once transmitted, no longer fall into the realm of EW and are better understood as being part of the EMOE and thus fall under the area of EMW, which is indicated by the blue box in the bottom half of the figure. This suggests the following definition for EW:

- Electronic Warfare – In the context of military operations, the use of electronic equipment for the processing and conversion of signals to and from waves.

Traditionally, EW has been divided into the following three functions:

- Electronic Support (ES) – Sensing to gain situational awareness,
- Electronic Attack (EA) – Actions taken to affect or inhibit an opponent's ability to operate in the EMOE, and
- Electronic Protection (EP) – Actions taken to mitigate the effects of EA from an adversary on one's own equipment and thus maintain one's own operating capabilities.

These functions are generally considered in terms of radars and weapon systems,[1] but they are practiced in other applications, chiefly Communications Electronic Warfare (Comms EW) and Navigation Electronic Warfare (NAVWAR).

## ELECTROMAGNETIC WARFARE

The US DOD Electromagnetic Spectrum Superiority Strategy[3] describes EMSO as the integrations of the EMSM and EMW function and defines these concepts as:

- Electromagnetic spectrum management – The operational, engineering, and administrative procedures to plan, and coordinate operations within the electromagnetic operational environment. [previously Spectrum Management][2]
- Electromagnetic warfare – military actions involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy. Also called EW. [previously Electronic Warfare][2]

The document also describes EMBM as a comprehensive framework for dynamic monitoring, assessing, planning, and directing of operations in the EMOE in support of the commander's concept of operations.

The EMBM and EMSM functions both point to planning and coordination of actions taken within the EMOE, but not their execution. Similarly, EMW points to the use of waves and energy, not electronics and signals. This places the discipline of EMW more in the theatre-level and less at the platform-level, and is consistent with the separation of EMW from EW as depicted in the bottom half of Figure 2.

So, if EMW and EW are different, what then is the relationship between EMSO and EW?

## ANALYSIS

A subtlety of the above description on EW is that while it refers to waves, no limitation on the nature of the waves has been required. Hence, the concept of EW maps equally well onto both transverse (electromagnetic) and longitudinal (acoustic) waves. Interestingly, the Russian concept of Electronic Warfare specifically includes acoustic waves as well as the electromagnetic.[8]

**Figure 3** depicts a mapping of the functions of EW (green box) and provides examples of equipment as each function relates to either transverse (blue box) or longitudinal (red box) waves. Under transverse waves, we have placed Signals Intelligence (SIGINT) together with Radar Warning Receivers under the banner of passive ES. This is because, while their implementations, history and timescales are different, they both employ passive sensors. Radars, on the other hand are a form of active sensing because, with some notable exceptions, they sense the echoes of their own transmissions. In the acoustic spectrum, both instances of the ES function are achieved with SONAR systems, technology that is not commonly associated with EW. However, the role of SONAR operators, for example, is not different from that of radar operators. Only the details of the technology and the nuances of the operational environment (atmosphere versus ocean or ground) are different, and neither of these are specified within the definition of EW above. Under EA, jammers are the quintessential electronic devices on both the Electromagnetic (EM) and acoustic environments. For mechanical jamming, where electronic devices are not used, readers of this journal will be familiar with chaff, but perhaps less so with bubblers, which are devices that create 'clouds' of air pockets underwater to distract wake-homing torpedoes. The function of EP is by and large a matter of advanced signal processing techniques. As stated previously, all three of the ES, EA and EP functions are also carried out under Comms EW and NAVWAR. For these branches of EW we provide examples of relevant equipment. The abundance of examples of equipment types. Figure 3 clearly demonstrates that the EW functions apply equally well to both the acoustic and electromagnetic environments. Other applications of the acoustic technology used in military operations are for the detection of nuclear detonations[7] and as a potential cause of Havana Syndrome.[9]

The orange box in Figure 3 contains the coordination and management functions such as EMBM and EMSM. Together with the portion of EW that maps onto the EMOE, they combine to form EMSO, which is depicted by the yellow box. The usefulness of the EMSO concept, besides bringing together the management and execution tasks of EW into a complete package is that it clearly involves only that part of EW that maps onto the EMS, but not the part that maps onto the acoustic spectrum. Similarly, in May 2020 this journal changed names from the Journal of Electronic Defence to the Journal of Electromagnetic Dominance.[10] The rebranding squarely places the focus of the journal onto the intersection of the blue and green boxes where it has traditionally dwelled. This is a good thing since the technology and environments are different enough to separate. The relationship between EW and EMSO can thus be summarized as follows:

*One engages in electromagnetic activities to generate either electronic warfare effects or cyber effects. Similarly, one engages in electronic warfare activities to generate effects in one of the acoustic, cyber or electromagnetic environments. EMSO restricts the aspects of EW to only those that relate to the EMOE.*

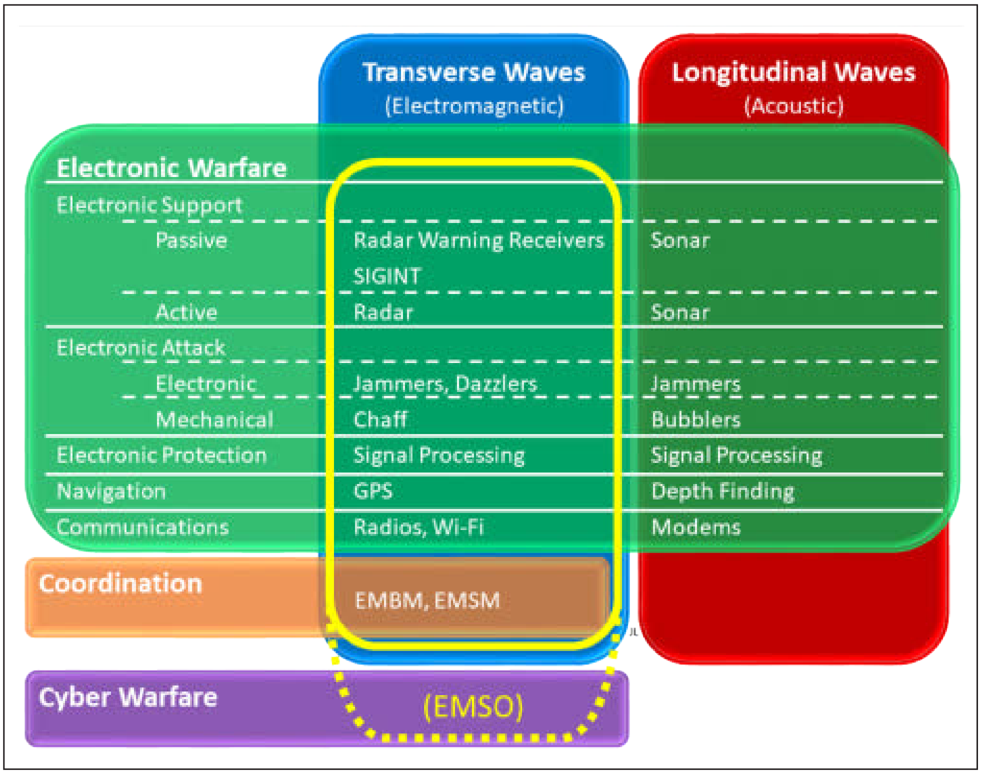


***Figure 3:*** *The mapping of electronic warfare and the electromagnetic spectrum operations concept*

## THE RELATION OF EMSO WITH CYBERSPACE

What is less clear, however, is the relationship between EMSO and Cyberspace. The US Joint EMSO publication[2] suggests that while there is a requirement to coordinate functions, the overlap between EMW activities and the Cyberspace domain are largely limited to wireless transmissions, such as Wi-Fi. This is a clear mapping of Cyberspace onto Comms EW. AFDP 3-51,[1] however, states: "It is important to realize that EMSO includes not simply radio and radar emanations, but all EM energy propagating through free space as well as EM signals transmitted through contained mediums such as wiring or optical fiber." This statement suggests that EMSO does not just touch Cyberspace, it subsumes it entirely. We suggest that this is over-reach and that the limitation to wireless communications provides an intuitive demarcation. Either way, the existing documentation is contradictory and would benefit from greater degree of consistency. It is for this reason that the mapping of the EMSO concept onto Cyberspace is indicated by a dotted line in Figure 3.

## THE CASE FOR AN ELECTROMAGNETIC OPERATING DOMAIN

In regard to the mapping of EMSO onto operational domains, US DODs Electromagnetic Spectrum Superiority Strategy states that, "The EMS is not a separate domain of military operations because the EMS is inseparable from the domains established in joint doctrine. ... As U.S. forces are organized around domains, the EMS not only provides the critical connective tissues that enables all-domain operations, but represents a natural seam and critical vulnerability across joint force operations."[3]

However this statement, which applies equally well to Cyberspace, is unsupportable since the US DOD has never defined the term 'domain' nor developed any criteria which can be used to exclude any particular environment. In arguing that the concept of domains is too restrictive for environments such as Cyberspace, Kreuzer[11] offers the following definition:

- Domain of warfare – a sphere of the operating environment that has physical characteristics requiring unique doctrines, organizations, and equipment for military forces to effectively control and exploit in the conduct of military operations.

Although it is characterized primarily by energy, the EMOE still has physical aspects to it, including physical propagation, power densities in watts per unit area, as well its own distinguishing physical constants: the permittivity and permeability of free space. What it does not have, unlike the recognized physical domains, is its own unique propagation medium such as free space, atmosphere, ground, or ocean, and so it is not a tangible environment per se. Actions taken within the EMOE require specialized equipment as indicated in Figure 2, and there is ample evidence of modern militaries having developed specific policies, concepts and doctrine dedicated to the conduct of warfare within the EMOE.[1][2][3] Finally, the requirement to control and exploit the EMOE is stated frequently in the justification for the EMSO and EMSM concepts.

It should be understood that the purpose of this discussion is not to campaign for recognition of the EMOE as a domain of warfare because we recognize that this carries organization ripple effects in some countries. Rather, we are merely demonstrating that the EMOE does satisfy the requirements necessary for such a designation.

## TERMINOLOGY

The term Electromagnetic Spectrum (EMS) is widely misused to describe the Electromagnetic Operating Environment. The EMS is not an environment in and of itself. Instead, it is an organizational tool used to situate entities within the EMOE. Hence, the EMS is to the EMOE what altitude is to the Air domain and depth is to the Maritime domain (see **Table 1**). In addition, the EMOE also encompasses the concept of space, which supports phenomena such as wave propagation and localized power densities, both of which are critical to the conduct of EMW. Hence, the EMSO concept might be better described as either Electromagnetic Warfare Operations (EMWO) or Electromagnetic Environment Operations (EMEO). Notably, NATO is now moving towards the term Electromagnetic Operations (EMO).

The acronym of Electromagnetic is EM, but its use in the acronyms of compound terms is troublingly inconsistent. Terms like electromagnetic spectrum (EMS), electromagnetic battle management (EMBM) and electromagnetic spectrum operations (EMSO) all clearly indicate the word electromagnetic in their short form, whereas other terms in common usage within US DOD documentation such as electromagnetic warfare (EW), Electromagnetic Spectrum Management (ESM) do not. There is no readily apparent justification for such inconsistency, especially when it creates overlaps with other entrenched terms such as electronic warfare (EW) and electronic support measures (ESM). For this reason we strongly encourage that EM and only EM be used to denote electromagnetic in acronyms, for consistency if not correctness, and we have followed this guidance within this article.

It is important that correct terms be used at all time. While it is true that the descriptor "electronic" does not reflect all aspects of concepts such as EMSM, it is equally true that "electromagnetic" is a poor fit for concepts such as electronic protection measures. This is not a surprise when one realizes that these two descriptors have different scopes. This is why the assertion that "electronic" is a legacy descriptor is incorrect; it is just as relevant today as it ever was. The only difference is that the scope of application can now be understood in a new way than we have done historically.

## CONCLUSION

We have explored and reviewed both electronic and electromagnetic warfare from a physical phenomenon standpoint, and clarified the relationship between them. Although not in line with current definitions, we propose that this construct conserves the concepts associated with both EW and EMW, both from a historical and future capability perspectives. We have shown that electronic warfare touches the acoustic, cyber and electromagnetic environments and that the concept of electromagnetic warfare

***Table 1:*** *Terminology comparison between the air, electromagnetic and maritime environments*

| CONTEXT | AIR | ELECTROMAGNETIC | MARITIME |
|---|---|---|---|
| Position | Altitude | Frequency / Spectrum | Depth |
| Environment | Atmosphere | Electromagnetic | Ocean |

provides an efficient means to restrict the EMSO concept to only the portion of EW that touches the EMOE. Descriptions of the EMSO concept should recognize this. We have also sought to clarify the inconsistent terminology practices that arose with the advent of the electromagnetic warfare concept and argued that the descriptor "electronic" is still germane to today's warfighting concepts. Finally, we had pointed to the inconsistency of existing documentation with regard to the overlap of EMSO and cyber-warfare and encourage US policy makers to adequately clarify their intention. Better definition of phenomena, and the terms associated with them, can only help ensure proper implementation of new capabilities, especially at the joint and combined levels.

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## ABOUT THE AUTHORS


**DR. JEFF LANGE** IS A SENIOR DEFENCE SCIENTIST WITH DEFENCE R&D CANADA'S OTTAWA RESEARCH CENTRE.

**MAJOR GABRIEL MASSIE, RCAF,** IS A CERTIFIED TEST ENGINEER WITH THE RCAF AEROSPACE WARFARE CENTRE.



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# TECHNOLOGY SURVEY

## A SAMPLING OF AIRBORNE RWRS AND RADAR ESM SYSTEMS

**By John Knowles**

**This month, we're** focusing on radar warning receivers (RWRs) and radar electronic support measures (RESM) systems that are used in airborne applications.

During World War II, in the European theater, airborne RWRs first came into regular use as a response to the introduction of radars installed on British and German night fighters. After the war, radar technology continued to evolve, and by the mid-1950s, radars were able to guide surface-to-air missiles (SAMs) and air-to-air missiles (AAMs). These developments spurred further development of RWRs for self-protection applications on some aircraft, such as bombers. These radar and missile developments also drove new requirements, which resulted in the US Marine Corps fielding the EA-6A "Electric Intruder" to conduct support jamming missions and US Air Force adapting F-100 and F-4 aircraft for Wild Weasel missions. These types of missions required more than a simple "warning" system, and the US began developing RESM systems that could provide greater detection range, identify the radar type and (roughly) geolocate ground-based radars, allowing aircrews to employ support jamming or cue anti-radiation missiles.

As radar technology continued to improve and radars began to perform detection, tracking and missile guidance at much longer ranges, RWR/RESM developers responded by incorporating digital receivers to handle the longer detection ranges and the more complex signal environments that came with them. As you'll see in the survey table, nearly all of the RWRs and RESM systems currently on the market use some form of digital receiver technology – sometimes in conjunction with other receiver technologies. Some of these are marketed as "all digital" RWRs and RESM systems which suggests that they are digitizing incoming signals immediately after the antenna.

The advent of digital receiver technology in RWRs has also focused more attention on software, especially their signal processing algorithms. This software trend has continued with the introduction of Artificial Intelligence and Machine Learning (AI/ML) algorithms into RWR/RESM systems to improve their performance against cognitive radars.

Today, one important thrust of EW technology development is focused on smaller, attritable platforms, and RWRs are certainly part of this trend. Digital receiver technology has enabled companies to introduce very capable RWRs with very low size, weight, power and cost (SWAP-C) metrics. As this trend toward small, autonomous platforms continues, we can expect RWR technology to continue in this direction. However, many emerging requirements are looking to integrate RWR and RESM as a function (rather than a stand-alone system), alongside radar, communications, FPS, IFF, etc., on a multifunction RF system. Thus, the number of discrete RWRs and RESM systems introduced to the market is likely to trail off, even as RWR and RESM technology continues to evolve.

### THE SURVEY

In the survey table, the first column indicates the RWR or RESM model number. The systems included in this survey are sold as stand-alone items, even if they are integrated into a single type of suite. An example would be the ALR-56C, which is only used in one application: the Tactical EW Suite (TEWS) on legacy F-15C/E aircraft. The ALR-56M, on the other hand, is integrated into many different EW suites across multiple aircraft types.

The second column describes the type of receiver technology (or technologies) used in the RWR. The third column shows the RWR's frequency range. While in the past, most RWRs covered the 2- to 18-GHz range, some modern air defense radars now operate in the lower regions of the UHF band and some missile seekers now operate across the entire Ka band. Thus, many RWRs now cover 0.5-40 GHz either as part of their core design or via optional frequency extensions.

The next three columns cover instantaneous bandwidth (IBW), typical installed sensitivity and total dynamic range. IBW indicates how much spectrum the RWR can cover without retuning. Systems that feature larger IBW usually provide quicker response times (which is important in a missile engagement) because they can search a set frequency range faster than a receiver with less instantaneous bandwidth. However, the trade-off for high IBW is usually lower installed sensitivity, which limits the RWR's detection range. The receiver's total dynamic range describes its ability to detect low-power signals in the presence of stronger signals.

The next column indicates if the system supports direction finding. RESM systems support DF, although some RWRs may not.

The next three columns describe the systems' power requirements, size and weight.

### NEXT MONTH

Our August technology survey will look at analog-to-digital converter (ADC) boards and digital-to-analog converter (DAC) boards.

## AIRBORNE RWRS AND RADAR ESM SYSTEMS

| MODEL | REC TYPE | OP FREQ | INST BWIDTH | TYP INST SENS | TOTAL DYN RANGE |
|---|---|---|---|---|---|
| **Aeronix, Inc.; Melbourne, FL, USA; +1 (321) 984-1671; www.aeronix.com** | | | | | |
| FinderPlus | Hybrid | 2-18 GHz | 2-18 GHz | * | >100 dB |
| **ASELSAN A.S.; Ankara, Turkey; +90 (312) 592 10 00; www.aselsan.com.tr** | | | | | |
| RWR | Digital | C-J | * | * | * |
| **BAE Systems Australia; Edinburgh Parks, SA, Australia; +61 3 9918 4000; www.baesystems.com** | | | | | |
| Mantlet™ | Digital | <0.1-18GHz | switchable >750MHz/>1500GHz | Better than -75dBmi | >95dB |
| **BAE Systems Electronic Solutions; Nashua, NH, USA; +1 (603) 885-6065; www.baesystems.com** | | | | | |
| ALR-56C | | | | | |
| AN/ALR-56M | Superhet | C-J bands | * | * | * |
| **Elbit Systems - Elisra EW and SIGINT; Bene Beraq, Israel; +972-3-6175111; www.elisra.com** | | | | | |
| AES-212/V1 - V5 (ESM-ELINT) | Superhet, DIFM | 0.5-40 GHz; | 0.5-40 GHz | <-65 dBm | >60 dB |
| Spectrolite SPS-65 V5 | Digital | 0.5-18 GHz | * | * | * |
| **Elettronica S.p.A.; Rome, Italy; +39-0641541; www.elt-roma.com** | | | | | |
| ELT/741 Family | IFM | C-J + K | Wide open | High | * |
| ELT/160 Family | IFM | E-J + K | Wide open | Medium | * |
| ELT/800 Family | DIFM and superhet | C-J + K (option) | Wide open | High | * |
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| EL/L-8385 ESM/ELINT UAV Payload | Digital | 2-18 GHz | * | * | * |
| EL/L-8265 RWL- Radar Warning & Threat Location | Digital | 2-18 GHz | * | * | * |
| **ESROE Ltd.; Fareham, Hampshire, UK; +44 (1329) 237285; www.esroe.com** | | | | | |
| MICRO ESM V2 | Analog/digital hybrid | 2 - 18 GHz | 8 GHz | -60 dBm to -70 dBm | 40 dB |
| **Hensoldt Sensors; Ulm, Germany; +49.731.392-0; www.hensoldt.net** | | | | | |
| Kalætron RWR Family | Digital | RWR-S: 2-18GHz<br>RWR-M: 2-40 GHz<br>RWR-L : 2-40 GHz | * | * | * |
| **INDRA; Madrid, Spain; +34-914-806-032; www.indra.es** | | | | | |
| ALR-400 RWR | Digital | 0.5-42 GHz | 4 GHz | -65 dBm | 60 dB |
| AMES-C ESM/ELINT | DIFM and superhet | 0.5-18 GHz | 16 GHz | -90 dBm | 60 dB |
| AMES-800 ESM/ELINT | Digital | 0.5-42 GHz | 16 GHz | -90 dBm | * |

| SUPPORT DF | PWR (W) | SIZE (in. or mm) | WEIGHT (in lb/kg) | FEATURES |
|---|---|---|---|---|
| | | | | |
| Yes | <400 W | 15.75 x 17.25 x 22 in. | <115 lb | Includes analysis tools for identification of exotic signals; BIT; two Ultra Sparc IIe Processors (650 MHz w/ 256 MB RAM) |
| | | | | |
| * | * | * | * | Self Protection Electronic Warfare System (SPEWS) jointly developed with BAE Systems. |
| | | | | |
| Yes | 110 W | 191 x 95 x 64 mm | <2.5kg | DF better than 2 degrees RMS in Phase and TDOA configurations; geolocation; pulse-on-pulse measurement; LPI/LPD; Comms ESM capable. |
| | | | | |
| | | | | Operational on some F-15C/E aircraft. |
| * | * | * | * | Operational on F-16 and C-130. |
| | | | | |
| Yes | <800 W | One small ATR and ant. | 44 lb | ECM add-on ready. Geolocation available. |
| Yes | * | One Small Central LRU and Ant. | <8 kg | Including EW Suite Controller (EWC) and Interference Blanking Unit (IBU). Offered with embedded Laser Warning Receiver (LWR) and CMDS. |
| | | | | |
| Yes | * | 1 ATR | 50-70 kg | ESM with ELINT and fine DF capability. |
| Yes | * | 1 ATR | 15-20 kg | Wband RWR with unknown threat and recording. |
| Yes | * | * | * | ESM with ELINT, fine DF and localization capability. |
| | | | | |
| Yes | * | * | * | Intelligence, surveillance, target acquisition, and reconnaissance (ISTAR) |
| Yes | * | * | * | Threat location on surface. |
| | | | | |
| Yes, amplitude comparison | < 20 W | 5 x 5 x 8 in. | < 1.5 Kg | Fully automatic processing of full range of emitter types; emitter identification via user defined library; plug-and-play networking for wider area coverage and emitter geolocation; battery powered. |
| | | | | |
| Yes | * | Dig. front-end Rx: 120 x 250 x 90 mm; Central processor: 200 x 128 x 320 mm | * | Artifical Intelligence; adaptive filtering for high PRF emitters; data recording for unknown emitters. |
| | | | | |
| Yes | 200 W | * | 10.2 kg | LPI capability; wideband digital reception; EW suite controller embedded capability. |
| Yes | 1,000 W | 15 x 10 x 25 | 90 kg | 18-40 GHz option; detailed intrapulse analysis capability. |
| Yes | 200-800 W | 15 x 10 x 25 | 25 kg | 360-deg instantaneous coverage; high-accuracy DF measurement; modular design and flexible architecture. |

## AIRBORNE RWRS AND RADAR ESM SYSTEMS

| MODEL | REC TYPE | OP FREQ | INST BWIDTH | TYP INST SENS | TOTAL DYN RANGE |
|---|---|---|---|---|---|
| **L3Harris Technologies; Clifton, NJ, USA; +1 (973) 284-4543; www.l3harris.com** | | | | | |
| ALR-95/97/98 family of Maritime Patrol ESM/ RWR Systems | Wideband DIFM and superhet channel | 0.5-18 GHz | 16 GHz | * | * |
| ALQ-211 (V) 4 AIDEWS RWR | Digital | C-J | * | * | * |
| Disruptor SRx | Digital | A-K | * | * | * |
| **Leonardo Airborne and Space Systems; Luton, Bedfordshire, UK; +44-0-1582 886478; www.leonardocompany.com** | | | | | |
| Seer RWR Family | Wideband DIFM | C-J, E-J, and E-K band configs. | Wide open | -55 dBmi | High |
| SAGE ESM Family | DIFM plus channelizer | 0.5-40 GHz; | Wide open | -60 dBmi | High |
| **Lockheed Martin RMS; Owego, NY, USA; +1 (607) 751-7089; Syracuse, NY, USA +1(315) 456-3333; www.lockheedmartin.com/ew** | | | | | |
| AN/ALQ-217 | ESM superhet | * | * | * | * |
| AN/APR-48B | Digital targeting ESM | * | * | * | * |
| AN/APR-52 | Digital RWR superhet | * | * | * | * |
| **Northrop Grumman Corp.; Rolling Meadows, IL, USA; +1 (224) 625-6777; www.northropgrumman.com** | | | | | |
| AN/APR-39(D)V2 | Digital | C-M band | * | * | * |
| **Raytheon Company; Goleta, CA, USA; +1 (310) 647-1000; www.raytheon.com** | | | | | |
| ALR-67(V)3 Radar Warning Receiver | Superhet, channelizer and digital | 0.65-18 GHz, 28-40 GHz | * | * | * |
| ALR-69A Radar Warning Receiver | Digital channelizer | C-J | * | * | * |
| **Raytheon Deutschland GmbH; Freising, Germany; +49-81-61-902-222; www.raytheon.com** | | | | | |
| ARDS (Advanced Radar Detection System) | Digital | 1 - 40 GHz | 1 GHz | CW -84 dBm<br>Pulse -65 dBm<br>(for 1 GHz IBW) | > 52dB |
| AREXIS | Digital UWB | 0.15-40 GHz | UWB DRX | -90 dBmi | >70 dB |
| HES | Digital FFT channelizer, superhet and IFM | 0.7-40 GHz | Wide open | -75 dBmi | >85 dB |
| **Sierra Nevada Corporation; Sparks, NV, USA; +1 (775) 331-0222; www.sncorp.com** | | | | | |
| AE-4500 | * | 0.5-40 GHz | * | * | * |
| **Thales DMS; Elancourt, France; +33-0-1-348195 96; www.thalesgroup.com** | | | | | |
| CATS Family | IFM, superhet and digital | E-J band | Wide open | -80 dBmi | 80 dB |

| SUPPORT DF | PWR (W) | SIZE (in. or mm) | WEIGHT (in lb/kg) | FEATURES |
|---|---|---|---|---|
| | | | | |
| Yes | <500 W | * | 200 lb | Frequency extension available. Threat warning plus emitter analysis. |
| Yes | * | * | 90 lb | For fighter attack self-protection. |
| * | * | * | 0.35 - 1.65 lb | Modular and scalable design, available in three form factors. |
| | | | | |
| Yes | 200-350 W | Half ATR and 2 digitizing heads (5.9 x 2.3 x 10.6 | 10-20 kg | C/D- and K-band extensions; can be powered by 28V or 400 Hz 3 phase aircraft supply; DF 10° RMS. |
| Yes | 350 W | Half ATR and 4 units (5.9 x 2.3 x 10.6) | 12-23 kg | C/D- and K-band extensions. Single- and multi-platform geolocation. For larger platforms; DF 1° RMS (typ.); demonstrated on MQ-9 Reaper UAS. |
| | | | | |
| Yes | 537 W | 28 x 8.8 x 14.2 | 86 lb | Re-programmable emitter library; installed on E-2C/D; similar to ALQ-210 on MH-60R. |
| Yes | 250 W | 11 x 8.6 x 7.8 | 39 lb | Installed on AH-64D/E. |
| Yes | 431 W | 7.7 x 10.1 x 13.5 | 39 lb | High performance RWR installed on USAF Combat Rescue Helicopter (HH-60W). |
| | | | | |
| Yes | 250 W | | 47 lb | ASE suite controller. |
| | | | | |
| Yes | 600 W | DCR: 3.7 x 11.3 x 13;<br>Proc.: 7.6 x 4.8 x 13.5.<br>Quad Rx 6.2 x 1.7 x 7 in.;<br>Ant.: 4.6 x 6.8 x 9 | 79 lb | Digital receiver, fully integrated on F/A-18 A-F. Exportable versions. |
| Yes | 500 W | Proc.: 7.63 x 5 x 14.6; Rx: 1.72 x 6.7 x 7.5 in. | 46 lb | NTISP, separately loadable MDFs; light weight, fully digital channelized receiver. |
| | | | | |
| Yes, phase | 1 kW<br>(incl. Heaters) | 8 x 9 x 52 in. (antenna)<br>3/4 ATR<br>1/2 ATR | 67 kg | High precision DF (< 1 degree); short baseline Interferometer. |
| Yes | * | * | 140 kg | RWR/ESM can be integrated with self-protection system including ECM. |
| Yes | 150 W | * | 100 kg | * |
| | | | | |
| Yes | * | * | * | Provides single-ship geolocation and supports multi-ship geolocation by triangulation or TDOA methods; processes pulsed, CW, FMCW and LPI emitters; a typical AE-4500 System configuration consists of two RPAs and two interferometer antenna arrays. |
| | | | | |
| Yes | 150 W | * | * | C/D-, D- and K-band options. Geolocation option; built-in EW system controller. |

# SURVEY KEY – RWR/ESM SYSTEMS

### MODEL
*Product name or model number*

### REC TYPE
*Receiver type*
- superhet = superheterodyne
- IFM = instantaneous frequency measurement
- CVR = crystal video receiver
- DF = direction finding
- DIFM = digital instantaneous frequency measurement
- SAW = surface acoustic wave
- LPI = low probability of intercept
- FFT = Fast Fourier Transform

### OP FREQ
*Operating frequency*
- VHF = very high frequency

### INST BWIDTH
*Instantaneous bandwidth (if different from operating frequency)*

### TYP INST SENS
*Typical installed sensitivity*

### DYN RANGE
*Total dynamic range*

### SUPPORT DF
*Does it support direction finding?*

### PWR (in W)
*Power dissipated in Watts per channel*

### SIZE (in inches)
*Size by height x weight x length, or diameter, in inches*
- *ATR = air transport rack*

### WEIGHT
*Weight in lb/kg*

### FEATURES
*Additional features*
- ASE = aircraft survivability equipment
- BIT = built-in test
- ECM = electromagnetic countermeasures
- ELINT = electronic intelligence
- ESM = electromagnetic support measures
- LPD = low-probability of detection
- LPI = low probability of interception
- TDOA = time difference of arrival

### OTHER ABBREVIATIONS USED
- < = greater than
- > = less than
- config = configuration
- deg = degree
- dep = dependent
- freq = frequency
- max = maximum
- min = minimum
- nband = narrowband
- opt = option/optional
- wband = wideband

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

**AUGUST 2022 TECHNOLOGY SURVEY: ADC AND DAC BOARDS**

This survey will cover analog-to-digital converter (ADC) boards and digital-to-analog converter (DAC) boards. Please e-mail JEDeditor@naylor.com to request a survey questionnaire.


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## Abc Electromagnetic Protection – Part 3

# Pulse Compression by LFMOP

By Dave Adamy

**In this part** of our series on Electromagnetic Protection, we are going to discuss pulse compression in radars. Pulse compression causes a pulse to have reduced pulse duration when it is processed, as compared to the duration of the pulse actually transmitted by a radar. Note that this discussion is limited to pulsed radars; we will talk about continuous wave radars in a later column.

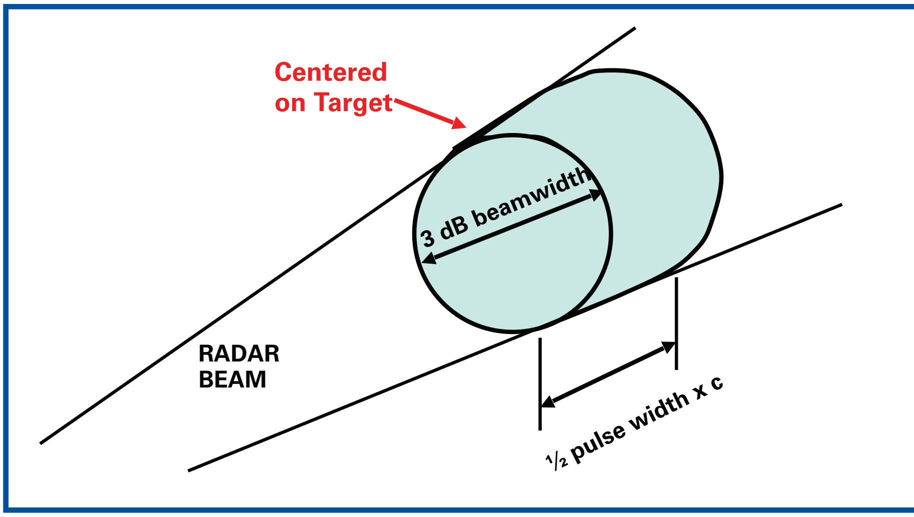


*Fig. 1:* *A radar's resolution cell is centered on the location at which the radar believes the tracked target is present. However, the radar cannot distinguish multiple targets within the cell.*

Radars work on energy, which is *power* multiplied by the *time* over which a signal is sent or received. Thus, a radar with longer pulses has more energy, so it can acquire and track targets at longer range. The radar range equation (which will be covered in detail in a later column) includes both a power term and an illumination time term. The energy of a radar signal can be increased either by increasing the pulse repetition frequency (PRF) or by increasing the pulse width (PW) (i.e., the pulse duration). Because the maximum unambiguous range of a radar is reduced by increasing the PRF, long range radars typically have low PRF and high PW.

**Figure 1** shows the radar resolution cell. The radar centers the resolution cell on the perceived target. This cell is the physical space within which the radar cannot detect multiple targets. If two or more targets are present within the resolution cell, the radar assumes that there is only a single target located between the two. The range dimension of the resolution cell is half the pulse width multiplied by the speed of light (*c*). The cross-range dimension of the resolution cell is commonly defined as the angular area inside the half-power beamwidth (the 3-dB beamwidth) of the radar's antenna.

The problem with long radar pulses is that they reduce the ability of the radar to detect multiple targets that are close to one another. An important case is an RF decoy that is deployed to protect a potential target. If the resolution cell is large, the decoy may not be identified, and it will normally present a significantly larger radar cross section than the target, as shown in **Figure 2.** As the decoy moves away from the target, the radar's tracking will be seduced away from the target to the decoy, and the resolution cell will center on a location between the target and the decoy (proportionally closer to the object with the larger cross section – the decoy). When the cell moves far enough to eliminate the actual target, the radar is tracking only the decoy.

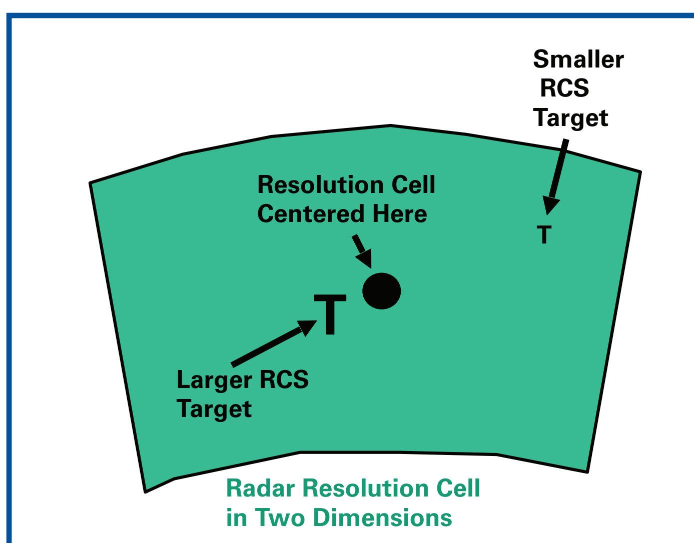


*Fig. 2:* *When there are two targets within the resolution cell, the radar centers the cell proportionally between the targets.*

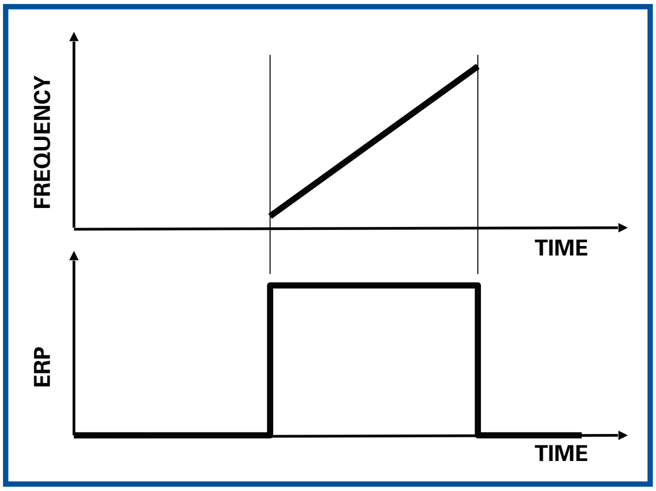


*Fig. 3: A chirped pulse has a frequency modulation across the whole pulse duration. It need not be linear, but is often called linear frequency modulation on pulse (LFMOP).*

## CHIRPED PULSES

**Figure 3** shows a "chirped" pulse. There is a frequency modulation (FM) applied to the signal over the duration of the pulse. Although the FM need not be linear, this technique is often called linear frequency modulation on pulse (LFMOP).

**Figure 4** shows the processing of the chirped pulse in the radar's receiver. The pulse is passed through a compressive filter that has a delay vs. frequency. This collects the energy of the pulse in a time period much shorter than the original pulse. The time compression is by the ratio of the frequency modulation range to the characteristic bandwidth of the pulse. The characteristic bandwidth is one over the pulse duration. For example, if the pulse is 10 microseconds long, the characteristic bandwidth is 100 kHz. The formula for pulse compression by chirped pulses is: **Compression Ratio = FM excursion x pulse width**

This is a unitless ratio, because the units of the FM excursion are 1/second and the units of the pulse width are seconds. If the frequency modulation on the pulse is 50 MHz wide, this makes the compression radio 50 MHz divided by 100 kHz, which is a factor of 500 (i.e., 27 dB). So a 9-microsecond pulse would be compressed to 18 nanoseconds in processing.

**Figure 5** shows the energy vs. time in the compressed pulse. If a *non-compressed* jamming signal is received by the *compressed* pulse radar, the amount of jamming energy will be reduced by the compression ratio. Following up on the above discussion, if the received return signal and jamming signal would provide a 10-dB jamming-to-signal ratio without pulse compression, the effective jamming-signal-to-noise ratio would be reduced by 27 dB to -17 dB with pulse compression applied. Note that the radar will only be accepting 18 nanoseconds of the jamming signal energy vs. 9 microseconds in the whole jamming pulse.

Returning to the RF decoy discussion: A decoy must be within the resolution cell for the radar to acquire it. If the resolution cell is compressed in the radar processing, the decoy has a smaller target area, so capturing the radar's tracking becomes significantly more difficult. This, along with the reduction of the jamming-to-signal ratio with pulse compression, is the value of this EP technique.

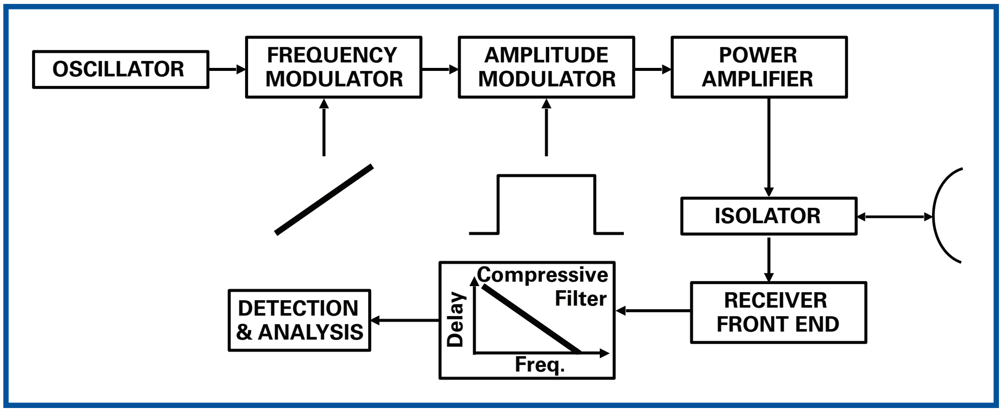


*Fig. 4: When a chirped pulse is returned from a target, it is passed through a compressive filter that has a delay vs. frequency with the same slope of delay vs. frequency as the frequency vs. time slope in the transmitter.*

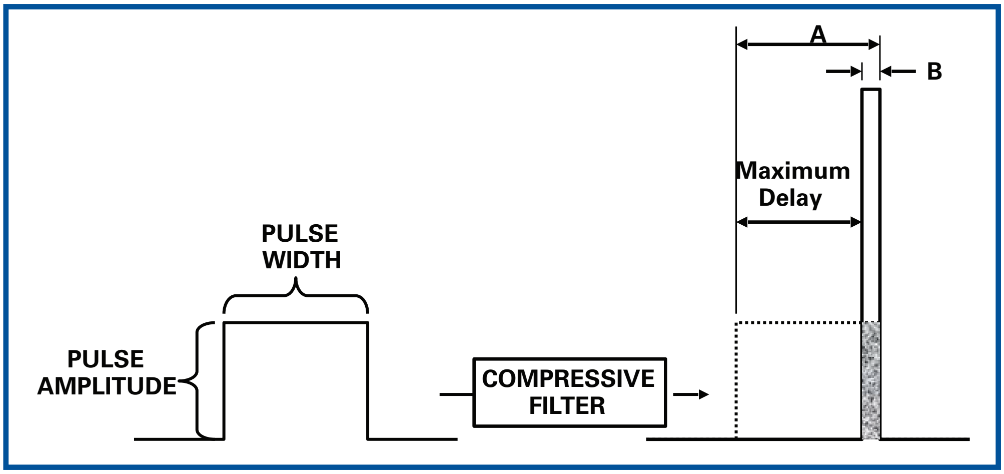


*Fig. 5: The effect of the compressive filter is to collect the energy from the whole pulse in a small time period near the end of the pulse, thus narrowing the pulse width. If a jammer does not have this compression, the jamming-to-signal ratio is reduced by the amount of pulse compression.*

## WHAT'S NEXT

Next month, we will continue our Radar Electromagnetic Protection discussion by considering a second technique to implement pulse compression: modulation of the pulse with a Barker code. Dave Adamy can be reached at dave@lynxpub.

# NSWC CRANE EXPERTS PARTICIPATE IN AOC'S ANNUAL ELECTROMAGNETIC WARFARE CONFERENCE

**By Sarah K. Miller, NSWC Crane Corporate Communications**

Naval Surface Warfare Center, Crane Division (NSWC Crane) Electromagnetic Warfare (EW) experts participated in the Association of Old Crows (AOC) EW Capability Gaps and Enabling Technologies 2022 Conference, which took place May 10-11 in Crane, Indiana.

The conference brought together EW professionals from the military, government, industry and academic fields to discuss the essential role of EW and EMSO in Joint All-Domain Command and Control (JADC2), joint long-range fires, information advantage and how innovative technologies such as artificial intelligence and machine learning are needed to advance collaborative and agile solutions to persistent gaps in our joint warfighting capabilities.

Force Level EW was the 2022 conference theme and included technical panels and government and military leaders across the Department of Defense, each addressing EW and EMSO requirements and emerging technologies necessary to support joint warfighting and achieve an enduring advantage in the electromagnetic spectrum.

"Through this venue, we raised the awareness of EW challenges and capabilities gaps across the services," Stacey Mervyn, the Chief Strategist for Spectrum Warfare Systems Department at NSWC Crane, and conference chairwoman said. "We brought together senior-level leaders from across the Department of Defense and private industry to discuss EW warfighting needs. Bringing the right people together creates a collaborative forum to help us think about where EW needs to go and innovative solutions we need to pursue to achieve Force Level EW."

Vice Admiral Sean Buck, the Superintendent of the United States Naval Academy, was a keynote speaker at the conference and shared how midshipmen are learning critical concepts to meet future fleet needs.

"I'm thrilled to have had the opportunity to speak to a community of practitioners and experts on how we're preparing the next generation of naval officers for the challenges and opportunities presented by EMSO and EW," Vice Adm. Buck said. "At the US Naval Academy, through classroom instruction and project-based learning, our Midshipmen are learning how the electromagnetic spectrum touches every aspect of warfare today so that they can leverage the spectrum for dominance in any battlespace in the future."

Brian Hinkley, the President-elect of AOC, said Vice Admiral Sean Buck spoke to the importance of the future Navy leadership development.

"Vice Adm. Buck's opening keynote address set the perfect stage to advocate for a strong EW and Cyber capability," Hinkley said. "Vice Adm. Buck gave us an encouraging look at what the US Naval Academy is doing through rigorous engineering curriculum to prepare our next generation of naval leaders. Vice Adm. Buck detailed how the curriculum allows midshipmen to fully comprehend the physics of the new EMS battlespace and to ultimately fight and win in increasingly complex electromagnetic spectrum operating environments (EMOE)."

"The AOC and NSWC Crane EW Capability Gaps and Enabling Technologies conference proved once again how critical it is to follow NSWC Crane's Spectrum Warfare Department's motto, 'Control the Spectrum, Control the Fight,'" Hinkley said. "As evident in current world events, the ability to conduct effective EMSO is a game changer to the outcome of the battle."

Mervyn said the conference creates a unique opportunity to discuss rapid EW solutions for the warfighter.

"What is unique about this conference is not only the expertise we bring in from industry, military, and government, but we hold the event at the classified level," Mervyn said. "NSWC Crane is a recognized leader in EW and the conference provides the opportunity to have discussions at the necessary levels to better understand the EW capability gaps, have meaningful discussions, and have collaborative discussions around rapidly evolving challenges."

Mervyn said meeting future threats requires spectrum expertise.

"As we see in the CNO's NAVPLAN guidance, National Defense Strategy, and the EMS Superiority Strategy, the Electromagnetic Spectrum is paramount to successful military operations and to ensure Electromagnetic Spectrum Superiority and Dominance," Mervyn said. "Force Level EW is focused on the integration of EW and EMSO capabilities across the armed services platforms and systems in all domains and integrated with kinetic and non-kinetic capabilities. It is imperative that the US Navy's EW capability is integrated and interoperable with the other services to achieve Joint Warfighting Concepts such as JADC2, joint long-range fires and information advantage. This year's conference was designed around these central themes. The speakers did an outstanding job conveying to the audience the challenges that need to be addressed and enabling technologies that we need to leverage more rapidly. It is incumbent upon all of us, as leaders in EW, to work together and solve the hard EW and electromagnetic spectrum operations problems and to put the best capabilities into the hands of the young men and women who serve our nation."

# AOC WRAPS-UP CEMA 2022

On May 3-4, the Association of Old Crows (AOC) hosted its annual Cyber Electromagnetic Activity (CEMA) Conference, in collaboration with the local AOC APG Susquehanna Chapter. This signature AOC conference dives deep into the US Army's plans to field an integrated electromagnetic warfare (EW), signals intelligence (SIGINT), and Cyber capabilities for EMS and Cyberspace superiority.

EMS superiority is the backbone to mission success across all warfighting domains. It is the only maneuver space we can substantially affect by 2027. This perspective permeated briefings throughout the conference adhering to the theme, "The Invisible Battlefield: Deterrence During Competition, Dominance Throughout the Conflict." These interdependent objectives highlight the fact that the invisible, complex, and congested electromagnetic spectrum is today where battles are won or lost. There is no more "down the road" perspectives, only today's imperative for EMS Superiority.

The Army should be applauded for its comprehensive organizational approach to EMS and Cyberspace superiority. It has long advocated for driving decision-making and maneuverability down to the division and supporting the warfighter with technologically agile and digitally-driven capabilities to maneuver and "always on" EMS and Cyber environment anywhere around the world.

CEMA featured a keynote address by Mr. Joseph Welch, SES, Director of DEVCOM C5ISR, and several presentations focusing on network resiliency, the role of artificial intelligence (AI) and machine learning (ML), the integration of AI/ML in future into multi-function systems. Specifically, Mr. Welch discussed the trend toward "Intelligent EW" – moving from legacy coordinated EW systems to collaborative systems, to intelligent systems that provide predictive actions, adaptive EA, distributed electromagnetic support and attack, anticipatory response to agile threats, and quantum sensing. Brigadier General Jeth Ray, Director of the Network Cross Functional Team (CFT) focused his remarks on the need to invest in network resiliency that underpins all Army modernization efforts. As we've seen with Russia's invasion of Ukraine, an adversary will seek to draw the fight into the most complex EMS environment, making resiliency paramount for network connectivity.

A keynote address by Mr. Mark Kitz, SES, PEO Intelligence, Electronic Warfare and Sensors (IEW&S) was followed by presentations from Defense Information Systems Agency (DISA), US Army Cyber School, Army Futures Command, DAMO-SO and other industry partner solutions. Mr. Adam Nucci, SES, Deputy Director, U.S. Army Strategic Operations (DAMO-SO) directly discussed the imperative that the US Army must transform its warfighting capabilities to become a technologically agile and digitally driven Army. The reality is that while we look to 2030 and beyond in broad strategic terms, global security today suggests we will likely need to call upon many of the innovations discussed at CEMA sooner than planned or anticipated. Mr. Nucci continued, "We must innovate and modernize at speed and scale, immediately improving our current capabilities and posturing the Army for the future. It is more important than ever to hold innovation and modernization as top priorities for our Army. It is vital for our force to evolve at a pace faster than current and future adversaries. Transformation and convergence are foundational elements that will require organizations to integrate across mission areas, warfighting functions and get to integrated mission command based on a data centric unified network to maximizing operational value."

Mr. Ken Strayer, Project Manager for EW and Cyber at PEO IEWS reinforced this call to action by laying out present-to-future program funding priorities and expectations to equip the Army for Multi-Domain Operations. This includes continued investment in the EW Planning and Management Tool (EW PMT), Multi-Function EW-Air Large (MFEW-AL), an airborne EW pod employed on Army manned or unmanned aircraft systems, and the Terrestrial Layer System – Brigade Combat Team (TLS-BCT) and Echelons Above Brigade (TLS-EAB), a next generation tactical vehicle based system that delivers an integrated suite of SIGINT, EW, & Cyberspace Operations overmatch capabilities to enable Joint All-Domain Operations.

The US Army has a difficult task ahead to innovate, invest, develop, deliver, and modernize its force for Cyber and EMS superiority required for mission success today. It is critical that Army leadership and all senior stakeholders collaboratively embrace the tough decisions that must be made to ensure its CEMA vision is implemented with the urgency that the global security environment dictates today. The AOC will continue to engage throughout the EMS community to advocate, educate and connect to ensure all warfighters who use and operate within the EMS have the capabilities and knowledge to do so throughout the coming years.

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*JED, Journal of Electromagnetic Dominance* (ISSN 0192-429X), is published monthly by Naylor, LLC, for the Association of Old Crows, 1001 N. Fairfax St., Suite 300, Alexandria, VA 22314.

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

**POSTMASTER:**
Send address changes to
*JED, Journal of Electromagnetic Dominance*
c/o Association of Old Crows
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**Subscription Information:**
Glorianne O'Neilin
(703) 549-1600
oneilin@crows.org

## *JED Sales* Offices

NAYLOR
ASSOCIATION SOLUTIONS
1430 Spring Hill Road, 6th Floor
McLean, VA 22102
Tel (800) 369-6220
www.naylor.com

**Project Manager:**
Kira Krewson
Direct: +1 (770) 810-6982
kkrewson@naylor.com

**Project Coordinator:**
Alexandra Lewis
Direct: +1 (352) 333-3409
alewis@naylor.com

**Advertising Sales Representatives:**
Shaun Greyling
Direct: +1 (352) 333-3385
sgreyling@naylor.com

Robert Shafer
Direct: +1 (770) 810-6986
rshafer@naylor.com

Chris Zabel
Direct: +1 (352) 333-3420
czabel@naylor.com

**NAYLOR (Canada) Inc.**
200 – 1200 Portage Ave.
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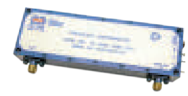

FD-160M-100M-1515


FD-1G-500M-55-SFF

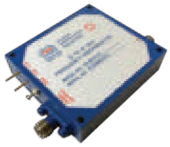
## IF Models

| PMI Model No. | Frequency Range (MHz) | Analog Output | Linearity | Input Dynamic Range (dBm) | Size (Inches) / Connectors |
|---|---|---|---|---|---|
| FD-30M-6M-1515 | 30 | 1000 mV/MHz | ±5% Max | -10 to 0 Min | 4.625" x 1.5" x 0.47" SMA (F) |
| FD-70M-50M-1212 | 70 | 100 mV/MHz | ±5% Max | -10 to 0 Min | 4.625" x 1.5" x 0.47" SMA (F) |
| FD-74M-10M-1212 | 690 - 790 | 100 mV/MHz | ±5% Max | -10 to 0 Min | 4.625" x 1.5" x 0.47" SMA (F) |
| FD-160M-100M-1515 | 160 | 9.5 - 10 mV/MHz | ±5% Max | -10 to 0 Min | 4.625" x 1.5" x 0.47" SMA (F) |

## High Frequency Models

| PMI Model No. | Frequency Range (GHz) | Analog / Digital | Output | Accuracy | Input Power (dBm) | Size (Inches) / Connectors |
|---|---|---|---|---|---|---|
| FD-1G-500M-55-SFF | 0.75 - 1.25 | Analog | 10 mV / MHz | ±10 MHz | -10 to 0 Min | 2.5" x 1.0" x 0.4" SMA (F) |
| DFD-2G18G-5512 | 2 - 18 | Digital | 14 Bits | 4.5 MHz (Average) | -50 to +15 | 5.98" X 5.79" x 1.28" SMA (F) |
| FD-0518-10-2G4G | 2 - 4 | Analog | 1 V/GHz Nom | ±100 MHz | 10 ± 0.1 | 2.0"x 1.82" x 0.5" SMA (F) |
| FD-0518-10-3D1G3D5G | 3.1 - 3.5 | Analog | 50 mV/GHz | ±20 MHz Max | 10 ± 0.1 | 2.0"x 1.82" x 0.5" SMA (F) |
| FD-0518-10-48 | 4 - 8 | Analog | 50 mV/GHz | ±200 MHz | 10 ± 0.1 | 2.0"x 1.82" x 0.5" SMA (F) |
| FD-0518-10-610 | 6 - 10 | Analog | 50 mV/GHz | ±200 MHz | 10 ± 0.1 | 2.0"x 1.82" x 0.5" SMA (F) |
| FD-0518-10-618 | 6 - 18 | Analog | 50 mV/GHz | ±200 MHz | 10 ± 0.1 | 2.0"x 1.82" x 0.5" SMA (F) |
| FD-0518-10-812 | 8 - 12 | Analog | 50 mV/GHz | ±200 MHz | 10 ± 0.1 | 2.0"x 1.82" x 0.5" SMA (F) |
| FD-0518-10-1218 | 12 - 18 | Analog | 50 mV/GHz | ±200 MHz | 10 ± 0.1 | 2.0"x 1.82" x 0.5" SMA (F) |


DFD-2G18G-5512


FD-0518-10-2G4G


FD-0518-10-3D1G3D5G
FD-0518-10-48


FD-0518-10-610
FD-0518-10-618


FD-0518-10-812
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Quantic™ PMI
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**West Coast Operation:**
4921 Robert J. Mathews Pkwy, Suite 1
El Dorado Hills, CA 95762 USA
Tel: 916-542-1401, Fax: 916-265-2597

**East Coast Operation:**
7311-F Grove Road
Frederick, MD 21704 USA
Tel: 301-662-5019, Fax: 301-662-1731

sales@pmi-rf.com • www.pmi-rf.com