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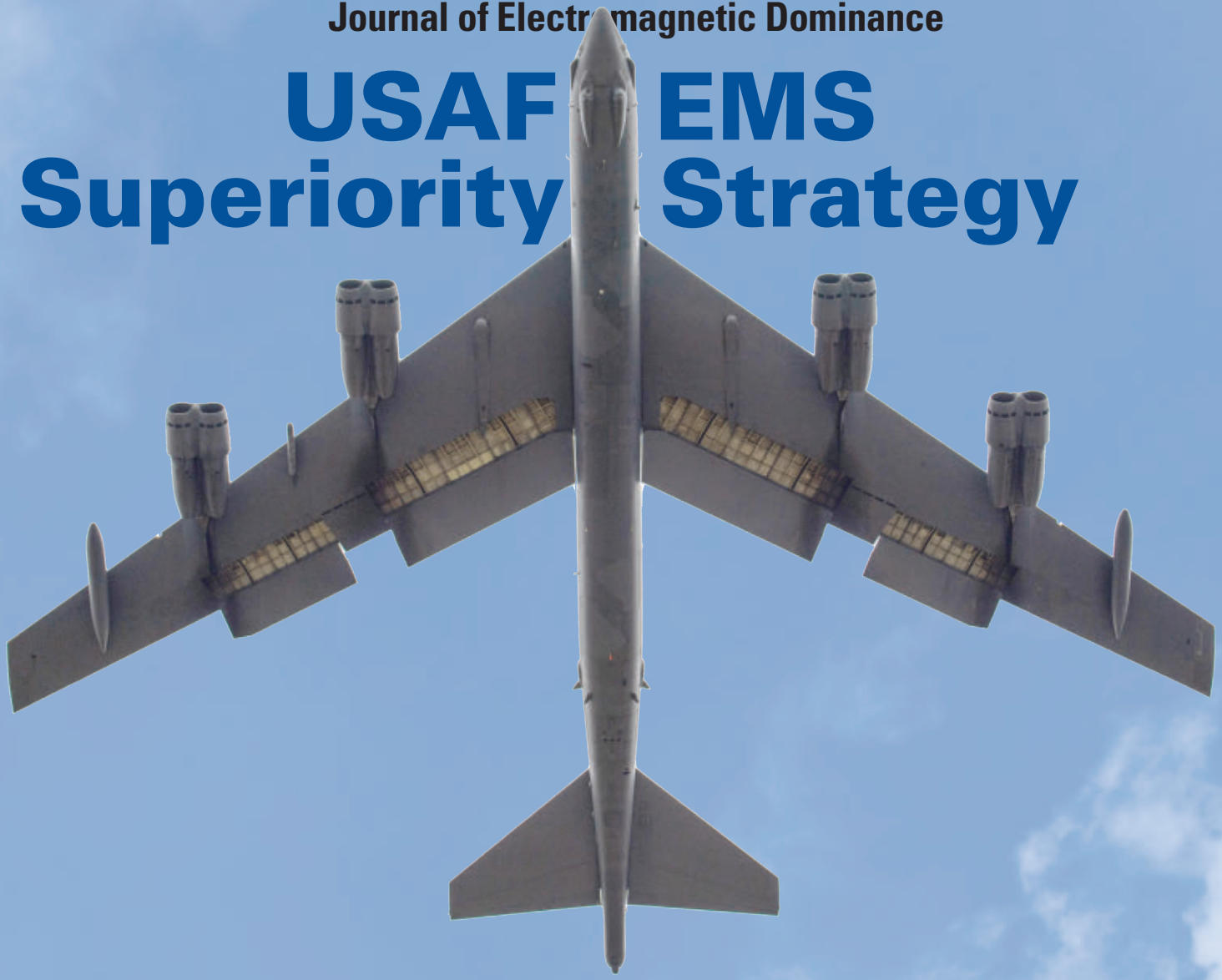
April 2021 Vol. 44, No. 4

JED

Journal of Electromagnetic Dominance

USAF EMS Superiority Strategy



Also In this Issue:

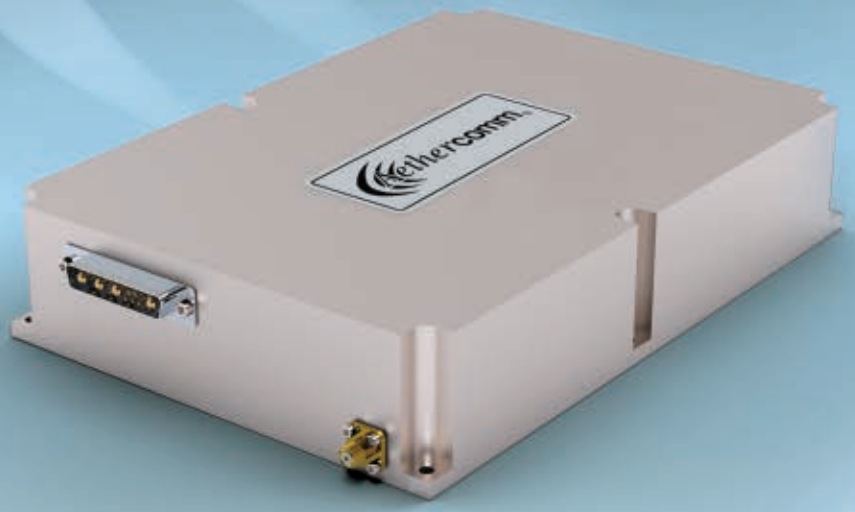
US Air Force Mission Planning in the EMS

US Army: Rethinking Emissions Control

EW 101: 5G Communications and EW

Super Broadband
High Power GaN SSPA

SSPA 2.0-18.0-100



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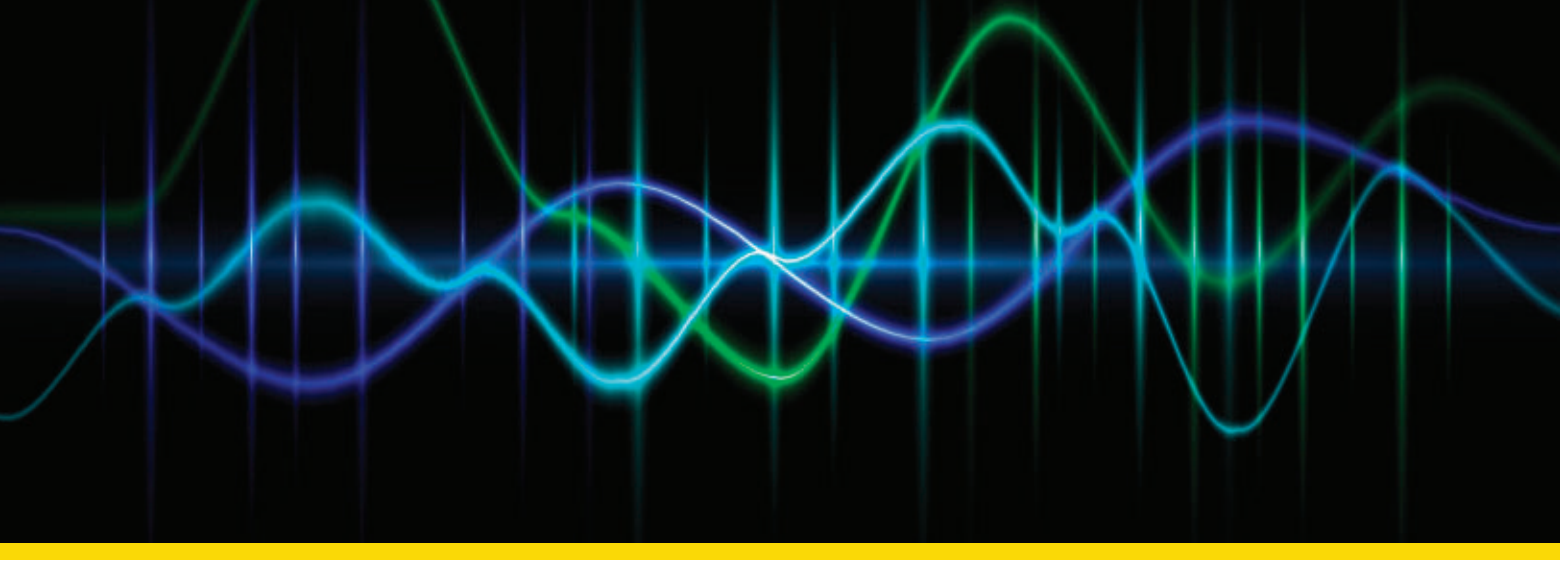

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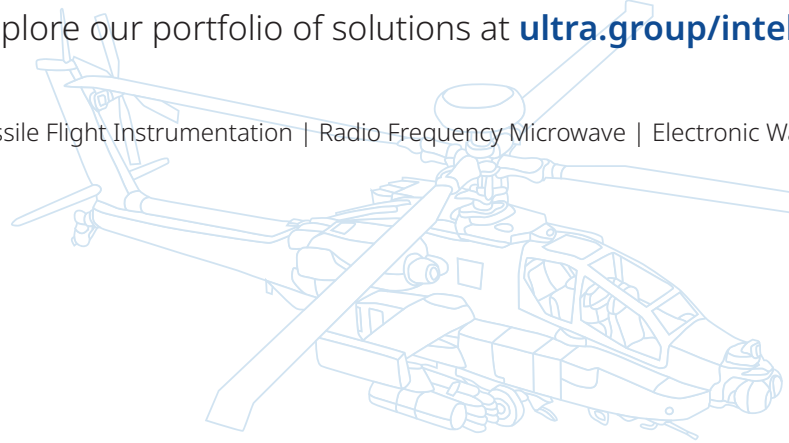

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JED
Journal of Electromagnetic Dominance
April 2021 • Volume 44, Issue 4

CONTENTS

20 Cover Story

Not Just Recognizing, But Aggressively Addressing the Challenge – US Air Force EMS Strategy Coming to Fruition
By Col Lisle H. Babcock, USAF, and Col Ryan C. Conner, USAF

Weapons platforms, such as the F-35, are not just using lots of data in their sensor systems, their sensors are also collecting lots of RF and EO/IR data. This makes data management an important aspect of the Air Force's EMS Superiority Strategy. US AIR FORCE

15 News

- US AIR FORCE ISSUES RFI FOR SENSOR SYSTEMS AND NON-KINETIC WEAPONS FOR NEXT-GEN MULTI-ROLE UAS FAMILY
- MDA RECEIVES CSC LASER WARNER AND COUNTERMEASURES CONTRACT
- US AIR FORCE ISSUES BAA FOR "CYBER-PHYSICAL SENSING AND EW-KINETIC EFFECTS"
- THOR HPM SUPPORTS ARMY INDIRECT FIRE PROTECTION EFFORT

Features

26 USAF EW Working Group Ensures That EW is Central Component of Overall Mission Planning
By John Haystead

US Army personnel assigned to "Wild Bill" Platoon, 1st Squadron, 7th Cavalry Regiment, conduct electronic warfare training during Combined Resolve XV, Feb. 23 at the Hohenfels Training Area in Bavaria, Germany. The multinational exercise, which wrapped up on March 5, included 4,700 participants from Bosnia-Herzegovina, Georgia, Italy, Kosovo, Lithuania, North Macedonia, Poland, Romania, Slovenia and the United States. It was conducted to assess readiness and develop interoperability among the partner nations.

US ARMY PHOTO BY SGT JULIAN PADUA

29 EMCON: Using Mission Command Systems for True Mission Command
By MAJ Luke Plante, CW3 James Turner, LTC Edward Ortiz and MAJ Richard Purcell

32 Elettronica Launches the EMSOpedia

Departments

6 The View from Here
8 Conferences and Courses Calendar
12 President's Message
34 EW 101
38 AOC News
40 AOC Industry and Institute/ University Members
41 Index of Advertisers
42 *JED* QuickLook

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ENGAGING WITH LEADERS

Many of the older members in our Electromagnetic Warfare (EW) Community have probably heard the phrase, "EW is a friend in war and a victim in peace." This goes back many, many decades, and it refers to the inconsistent resourcing and attention that EW has seen throughout its history. This statement isn't just about funding EW technology and programs. It also refers to many other aspects of the EMS Enterprise: leadership, organizations, personnel and training, to name a few. It's normal for any military discipline to grow in response to the demands of a war and shrink afterward, and in this sense EW is no different. However, the degree to which the EMS Enterprise typically expands during war and contracts during peace has been pretty severe. For the US, the UK and Canada, this began with an expansion during World War II, followed by a contraction immediately afterwards. The US saw other EMS Enterprise expansions during the Vietnam War, the Gulf War and the Iraq War. Aside from these conflicts, a longer-term EW expansion was fueled by peer competition with the Soviet Union during the Cold War (especially in the 1980s) and by emerging competition with China and Russia beginning in the mid-2010s.

In between these expansions were EW contractions, both large and small. The US Army, for example, had developed a cadre of EW experts in its Combat Electronic Warfare and Intelligence (CEWI) Battalions during the late Cold War era, but this was lost in the 1990s. The most severe EMS Enterprise contraction was the post-Cold War period in the 1990s. During that decade, the US Air Force retired its F-4G Wild Weasels and its EF-111A Ravens, and it was training far fewer EW Officers (EWOs), which has led to a tremendous loss of knowledge and expertise at the command staff level. Our cover story this month, written by Col Lisle Babcock and Col Ryan Conner, discusses the Air Force's efforts to rebuild its EMS Enterprise via its EMS Superiority Strategy.

Another aspect of this expansion and contraction cycle is the EW Community's relationship with senior government and military leaders. Most EW career paths top out at the field officer level (O-6, or OF-5 in NATO), and there has historically been a significant "rank" gap between the most senior EW leaders and the general officers and flag officers who have the authority to solve the cyclical challenges that have faced the EW Community. Today, however, the situation is beginning to improve. In recent years, the DOD has started to establish new EMS Operations (EMSO) organizations, led by a small number general officers or flag officers who can more easily connect with Service chiefs and Joint Staff leaders. From January to March, the AOC hosted its EMS Discussion series, which saw senior military and government leaders provide their perspective on EMSO and take questions from the audience. These are positive developments, but we need to continue engaging with senior leaders to advocate for structural changes that will stabilize our EMS Enterprise and begin to "smooth out" our uneven history of expansions and contractions. – *J. Knowles*

JED
Journal of Electromagnetic Dominance

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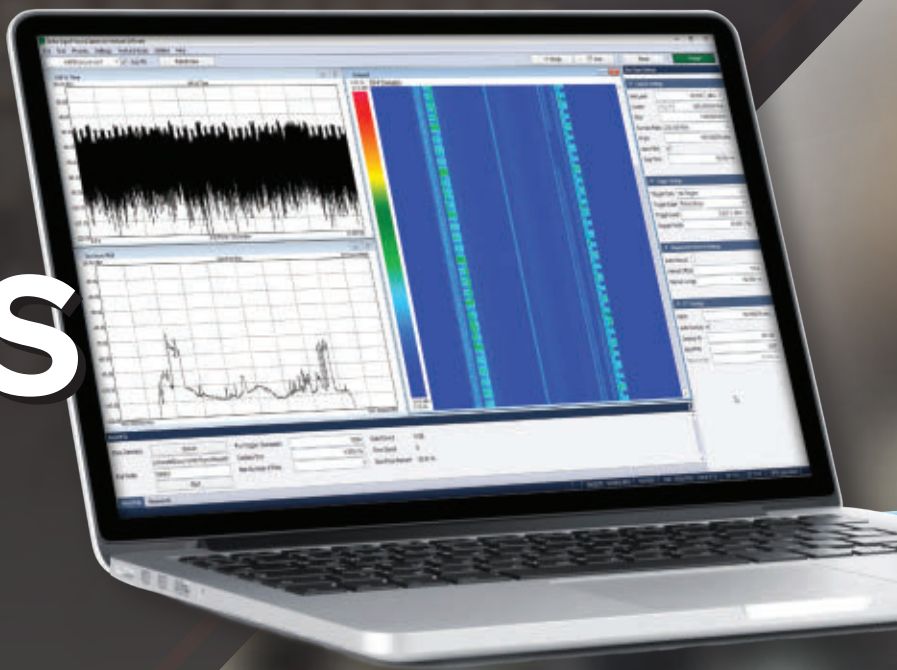

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April 6-8
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Atlanta, GA
April 6-9
www.pe.gatech.edu

LAAD Security
Conference: April 6-9
Rio de Janeiro, Brazil
www.laadsecurity.com.br

AOC Virtual Series Webinar: Fast Switching Synthesizers for Emerging EW Systems
April 8
1400-1500 EST
www.crows.org

AOC Virtual Series Webinar: All in a Spin About Reticle-Based Seekers
April 11
1400-1500 EST
www.crows.org

2.0 EMS Virtual Summit
Conference: April 13
www.crows.org

Electronic Warfare Data Analysis
Atlanta, GA
April 19-22
www.pe.gatech.edu

Threat Radar Systems
Atlanta, GA
April 19-23
www.pe.gatech.edu

2021 Virtual Army Aviation Mission Solutions Summit (AAAA)
Conference: April 21-23
Nashville, TN
www.quad-a.org

AOC Virtual Series Webinar: All in a Spin about Reticle-Based Seekers
April 22
1400-1500 EST
www.crows.org

Phased Array Radar Systems – Online
April 27-29
www.pe.gatech.edu

MAY

Cyber Warfare/EW Convergence
Atlanta, GA
May 3-5
www.pe.gatech.edu

AOC Professional Development Live Web Course: Advanced Principles of Electronic Warfare
May 3-26
www.crows.org

Modeling and Simulation of Phased-Array Antennas – Online
May 4-6
www.pe.gatech.edu

Modern Day Marine
Conference: May 4-6
Quantico, VA
www.marinemilitaryexpos.com

Radar Warning Receiver System Design and Analysis
Atlanta, GA
May 4-6
www.pe.gatech.edu

AOC Virtual Series Webinar: AI Guided Spectrum Operations
May 6
1400-1500 EST
www.crows.org

Electromagnetic Materials and Measurements: RAM, Radome, and RAS
Atlanta, GA
May 11-13
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continued on page 10

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CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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2021 Special Operations Forces Industry Conference (SOFIC)
Conference: May 17-21
Tampa, FL
www.sofic.org

Military Electronic Warfare
May 17-21
Swindon, UK
www.cranfield.ac.uk

Signals Intelligence (SIGINT) Fundamentals
Atlanta, GA
May 18-19
www.pe.gatech.edu

Adaptive Arrays: Algorithms, Architectures and Applications
Atlanta, GA
May 18-21
www.pe.gatech.edu

AOC Virtual Series Webinar: 5G for Non-Terrestrial Networks
May 20
1400-1500 EST
www.crows.org

Cyber Electromagnetic Activity (CEMA) 2021
Conference: May 25-26
Belcamp, MD
www.crows.org

AOC Virtual Series Webinar: Technology Advancements Enabling Test & Evaluation Capabilities to Keep Pace with Modern and Future EW and Radar Systems
May 27
1300-1400 EST
www.crows.org

JUNE

Land Forces 2021
Conference: June 1-2
Brisbane, Australia
www.landforces.com.au

AOC Virtual Series Webinar: Introduction to Direct Energy Weapons
June 3
1400-1500 EST
www.crows.org

International Microwave Symposium (IMS 2021)
Conference: June 6-11
Atlanta, GA
www.ims-ieee.org

Basic RF Electronic Warfare Concepts
Atlanta, GA
June 7-9
www.pe.gatech.edu

Electronic Warfare Technology Conference
Conference: June 7-10
Shrivenham, UK
www.cranfield.ac.uk

Modeling and Simulation of Radar Systems
Atlanta, GA
June 7-10
www.pe.gatech.edu

AOC Professional Development Live Web Course: C4ISR Requirements, Principles, and Systems
June 7-30
www.crows.org

2021 EW Live
Conference: June 14-16
Tartu, Estonia
www.electronic-warfare-live.com

Basic EO-IR Concepts
Las Vegas, NV
June 15-17
www.pe.gatech.edu

Adaptive Arrays: Algorithms, Architectures and Applications
Las Vegas, NV
June 15-18
www.pe.gatech.edu

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

FEATURED LIVE COURSES

Fundamental Principles of Electronic Warfare

Dave Adamy

Mondays & Wednesdays
1:00 – 4:00 PM ET | April 5 – 28, 2021
This is an introductory Electronic Warfare course in eight three hour sessions. It provides insight into the whole electronic warfare field at the systems and operational level.

Advanced Principles of Electronic Warfare

Dave Adamy

Mondays & Wednesdays
1:00 – 4:00 PM ET | May 3 – 26, 2021
This Advanced Electronic Warfare course has eight three hour sessions. It is designed for individuals who have completed a fundamental EW course or have significant experience in the field.

C4ISR Requirements, Principles, and Systems

Dr. Clayton Stewart

Mondays & Wednesdays
1:00 – 4:00 PM ET | June 7 – 30, 2021
This 24 hour web based course delivers a thorough overview promoting an understanding and building a successful Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance (C4ISR) architecture.

Aircraft Radar Cross Section Engineering

Renan Richter

Mondays, Wednesdays & Fridays
1:00 – 4:00 PM ET | July 12 – 30, 2021
This course introduces students to Radar Cross Section (RCS) engineering and its basics fundamentals inside the modern EW context. Stealth technology will be addressed by presenting current challenges and future perspectives.

Direct Energy Weapons

Kyle Davidson

Mondays & Wednesdays
1:00 – 4:00 PM ET | August 2 – 18, 2021
This course introduces students to the fundamentals of Direct Energy Weapons (DEW) across the electromagnetic spectrum. The goal is to provide an understanding of the operation of laser and high-power microwave DEWs in military applications, including their design trade-offs, and target effects.

Introduction to Satellite Communications (Satcom)

Dr. Patrick Ford

Mondays & Wednesdays
1:00 – 4:00 PM ET | September 1 – 22, 2021
This course will cover the core material required for participants to understand and discuss basic Satcom theory and operations.

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THOUGHTS ON EW TERMINOLOGY AND EW SPEAK

I've been thinking about EW definitions, and how they have evolved over the years. When I was the B-52 Reprogramming Branch Chief in the 513th Engineering and Test Squadron at Offutt AFB in 1994, I found AFM 51-3 Electronic Warfare Principles (15 September 1970) in my desk; I still have it today. Now fast forward to the Joint Pub 3-85 Joint Electromagnetic Spectrum Operations (22 May 2020). How do the definitions compare from 50 years ago to today for EW and its three pillars (EA, ES and EP)?

Definitions from the 1970 AFM 51-3:

Electronic Warfare (EW) – Military action involving the use of electromagnetic energy to determine, exploit, reduce or prevent hostile use of the electromagnetic spectrum; and action which retains the friendly use of the electromagnetic spectrum

Electronic Warfare Support Measures (ESM) – Division of EW that involves actions to search for, intercept, locate, record, and analyze radiated electromagnetic energy for the purpose of exploiting such radiations in support of military operations.

Electronic countermeasures (ECM) – Encompass all actions to prevent or reduce an enemy's effective use of the electromagnetic spectrum. ECM includes both jamming and deception techniques.

Electronic counter-countermeasures (ECCM) – Division of EW involving actions taken to ensure friendly electromagnetic systems operate effectively despite an enemy's use of ECM.

Joint Pub 3-85 22 May 2020:

Electromagnetic Warfare (EW) — Military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy.

Electromagnetic Support (ES) — Division of EW involving actions tasked by, or under direct control of, an operational commander to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated electromagnetic energy for the purpose of immediate threat recognition, targeting, planning and conduct of future operations.

Electromagnetic Attack (EA) — Division of EW involving the use of electromagnetic energy, directed energy, or antiradiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability and is considered a form of fires.

Electromagnetic Protection (EP) — Division of EW involving actions taken to protect personnel, facilities, and equipment from any effects of friendly or enemy use of the electromagnetic spectrum that degrade, neutralize, or destroy friendly combat capability.

When I look at these remarkably similar definitions, which over 50 years have stood the test of time and combat, it says that our predecessors got it right. So why did ESM evolve into ES, ECM into EA and ECCM into EP? I believe that ES, EA and EP articulate what the three pillars do: Support, Attack and Protect the overarching EW mission set. In addition, transitioning to the term "electromagnetic" cements the linkage of EW to the EMS. EW represents "fires" within the EMS maneuver space.

Our next EMS Virtual Summit is on April 13, and I would encourage you to attend and actively participate. I also want to highlight AOC Awards; please nominate your best and brightest so that they have a chance to be recognized by their peers, fellow Crows and AOC. – *Glenn "Powder" Carlson*

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PMI Model No.	Frequency Range (GHz)	Gain (dB)	Noise Temperature	Phase Balance	Size (Inches) Connectors
MPC-20R2G21R2G-CD-LNF https://www.pmi-rf.com/product-details/mpc-20r2g21r2g-cd-lnf	20.2 - 21.2	0 to +10	100 K	±3°	6.25" x Ø4.8" x 2.0" SMA (F)

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PMC-24-7D5-SFF https://www.pmi-rf.com/product-details/pmc-24-7d5-sff	2 - 4	7.5	18	±10°	±1.0	3.23" x 3.23" x 0.43" SMA (F)
PMC-2D22D4-6D8-SFF https://www.pmi-rf.com/product-details/pmc-2d22d4-6d8-sff	2.2 - 2.4	6.8	25	±4°	±0.4	3.56" x 3.56" x 0.43" SMA (F)
PMC-3G3D5G-6D8-SFF https://www.pmi-rf.com/product-details/pmc-3g3d5g-6d8-sff	3 - 3.5	6.8	23	±5°	±0.4	3.23" x 3.23" x 0.43" SMA (F)
PMC-33D7-6D8-SFF https://www.pmi-rf.com/product-details/pmc-33d7-6d8-sff	3 - 3.7	6.8	24	±7°	±0.5	3.23" x 3.23" x 0.43" SMA (F)
PMC-56-SFF https://www.pmi-rf.com/product-details/pmc-56-sff	5 - 6	7.0	20	±5°	±0.5	3.48" x 3.48" x 0.43" SMA (F)
PMC-9G10G-7D9-SFF https://www.pmi-rf.com/product-details/pmc-9g10g-7d9-sff	9 - 10	7.9	18	±6°	±0.6	3.48" x 3.48" x 0.43" SMA (F)
PD-CD-001-1 https://www.pmi-rf.com/product-details/pd-cd-001-1	9.3 - 9.9	8.0	30	±7°	±0.5	2.35" x 1.7" x 0.5" SMA (F)
PMC-9D5G10D1G-7D6-SFF https://www.pmi-rf.com/product-details/pmc-9d5g10d1g-7d6-sff	9.5 - 10.1	7.6	20	±5°	±0.5	3.48" x 3.48" x 0.43" SMA (F)
PMC-9D5G10D5G-7D6-SFF https://www.pmi-rf.com/product-details/pmc-9d5g10d5g-7d6-sff	9.5 - 10.5	7.6	20	±5°	±0.5	3.48" x 3.48" x 0.43" SMA (F)
PMC-12G13G-1D6-SFF https://www.pmi-rf.com/product-details/pmc-12g13g-1d6-sff	12 - 13	7.6	18	±5°	±0.5	3.48" x 3.48" x 0.43" SMA (F)


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US AIR FORCE ISSUES RFI FOR SENSOR SYSTEMS AND NON-KINETIC WEAPONS FOR NEXT-GEN MULTI-ROLE UAS FAMILY

The Air Force Life Cycle Management Center (AFLCMC) (Wright-Patterson AFB, OH) has released a Request for Information (RFI) seeking responses from companies about sensors, datalinks and non-kinetic weapons that can be integrated on its Next-Generation (Next-Gen) Multi-Role Unmanned Aerial System (UAS) Family of Systems (FoS). The Next-Gen Multi-Role UAS FoS is envisioned to complement manned aircraft and perform ISR, strike and counter-air missions in permissive, contested, and highly contested environments.

The AFLCMC's Intelligence, Surveillance, and Reconnaissance/Special Operations Forces (ISR/SOF) Directorate, Medium Altitude UAS Division (WII) issued an earlier RFI in June 2020 which sought industry input about Next-Gen Multi-Role UAS FoS air vehicle technologies. The latest RFI is a follow-on query that concentrates on Electromagnetic Spectrum (EMS)-related technologies that support three focus areas: 1) Air Domain Awareness; 2) High Value Airborne Asset Protection (HVAAP); and 3) rapidly reconfigurable payloads, interoperable software/hardware, and on-board edge processing capabilities.

In the Air Domain Awareness focus area, the Air Force is seeking information about "sensors or sensor networks that provide early warning and fire control quality track/ID of enemy air operations in highly contested and contested environments," as well as low cost "platform agnostic" sensors, such as radar (including moving target indication), electronic support measures (ESM) and infrared sensors. In addition, the RFI requests information about "resilient communications suites" that support Joint All Domain Command and Control (JADC2) and Battle Management Command and Control (BMC2) integration.

The Next-Gen Multi-Role UAS FoS will also perform a defensive counter-air role to escort and protect high-value airborne assets (HVAAs), such as airborne early warning and control aircraft, manned stand-off ISR aircraft and tankers, from attacks by long-range enemy fighters, as well as other kinetic and non-kinetic threats. The HVAAP focus area is looking at "next-generation platform-agnostic weapons, sensors, electronic warfare, directed energy, and other capabilities." This includes self-protection systems for the UAS.

The RFI's third focus area covers some of the characteristics the Air Force is seeking for the sensors and other UAS payloads. Program officials are seeking information about the payloads' adherence to "open mission systems government owned architectures," as well as "software and algorithms to support data sharing, integration, secure processing, automation, and AI assisted management among on single or multiple UAS." In addition, the RFI calls for information about "modularity concepts to support rapid reconfiguration of UAS in the field between sorties to support unique mission requirements."

The RFI's notice identification is Next_Gen_Multi_Role_UAS. Responses are due by April 9. The contracting point of contact is Erin VanCise, e-mail erin.vancise@us.af.mil. – *J. Knowles*

MDA RECEIVES CSC LASER WARNER AND COUNTERMEASURES CONTRACT

Lockheed Martin Canada has contracted MDA to provide the Laser Warning and Countermeasure (LWCM) system for the 15-ship Canadian Surface Combatant (CSC) program.

Announcing the award in late February, MDA said the initial LWCM production award could grow to over CAN$60 million over time. The company is already under contract to Lockheed Martin Canada as the EW suite systems integrator for the CSC program.

Irving Shipbuilding Inc. is prime contractor for CSC, which will recapitalize the RCN's surface fleet by replacing the modernized *Halifax*-class multirole frigates and now-retired *Iroquois*-class destroyers with a single class of multi-role warship. Lockheed Martin Canada Rotary and Mission Systems – bidding a BAE Systems' Global Combat Ship design derived from the UK Royal Navy's Type 26 frigate – was in October 2018 selected as CSC ship design and combat system partner.

MDA in April 2019 announced that it had signed a CAN$4 million contract with Lockheed Martin Canada for the initial phase of design work for the EW suite. The company at this time said that it had partnered with L3Harris Wescam to develop a LWCM system to protect the CSC against laser and optical guided threats.

Alongside the LWCM system, the full EW suite for CSC will include radar and communications electronic support measures systems, an electronic attack system (being developed with Lockheed Martin Canada) and an offboard decoy system. – *R. Scott*

US AIR FORCE ISSUES BAA FOR "CYBER-PHYSICAL SENSING AND EW-KINETIC EFFECTS"

The Air Force Research Lab Sensors Directorate (Wright-Patterson AFB, OH) has issued a Broad Agency Announcement (BAA) to solicit white papers for research and analysis that will help it understand how cyber-connected devices that are used in a variety of industries interact with the physical environment. This research effort, known as Enabling

Cyber-Linked Physical Sensing Exploitation (ECLPSE), will also grow the Air Force's understanding about how to deliver cyber effects to adversary devices and to protect friendly devices from adversary cyber attacks.

The Directorate's Multi-Domain Sensing Autonomy Division (AFRL/RYA) is managing the ECLPSE program. According to the BAA, "This effort will support research and analysis on cyber-physical sensing and EW-kinetic effects to enable understanding how cyber-connected devices interact with the physical environment found in manufacturing automation, utilities, transportation, agricultural, medical and other common applications. Through kinetic attacks on cyber/EW-physical devices, it is possible to enable, deter or deny cyber operations such as limiting efficient exfiltration methods through channel herding. Understanding these interactions will enable commanders to induce kinetic effects through cyber or vice versa such as disabling bridges, airports, troop movement, etc."

In addition, ECLPSE will also "... support research and analysis regarding the prevention and exploitation of information leakages similar to electromagnetic security (EMSEC) vulnerabilities in the cyber/EW-physical domain. For instance, using Measurement and Signature Intelligence (MASINT) against EM emissions, it is possible to produce actionable intelligence against emitting systems. AFRL Sensors Directorate describes Cyber-Physical-MASINT as an area being developed by the US Air Force involving phenomena transmitted through cyber-physical devices and the interconnected data networks to infer information through effects such as digital noise, bit errors or latencies." The BAA describes this as Cyber/EW-MASINT. It states, "Cyber/EW-MASINT is the ability to collect MASINT by measuring ancillary signatures induced in cyber/EW-physical systems by anomalous events reported through state-of-health (SoH) communications or as adverse signal noise in digital products. The information derived will come from a combination of sensors, controls, or secondary/tertiary system effects (e.g., noise, bit errors, etc.)."

Specific ECLPSE technical objectives include:

- Understanding sensing effects across multiple domains: This specifically includes techniques by which objects and events can be sensed or manipulated via transducers and kinetic actuators on cyber-connected devices.
- Small unmanned systems exploitation (SUSEX): Conduct flight test experiments and data collections involving small unmanned systems to meet desired cyber-physical, EW-kinetic sensing, as well as distributed sensing research and analysis outcomes.
- Cyber research and development: Conduct experiments in support of research into the basic and applied principals and phenomena of cyber-domain information-processing, communication, and kinetic actuation systems.
- Electronic warfare research and development: Conduct experiments in

support of research and development of EW techniques with an emphasis on multi-domain operations and on the basic and applied principals and phenomena of EW information processing, communication, and kinetic actuation systems.

- Machine learning: Apply machine learning to multiple sensors, INTs and domains to create mission-essential knowledge (i.e., detection, tracks, IDs, patterns, behaviors, intents) for military applications.
- Hard and Soft Information Fusion: Utilize combinations of both physics-based "hard" information (e.g., sensors, INTs) and human-based "soft" information (e.g., social media, human-generated reports).
- Multi-Level Fusion: Fuse information sources at multiple levels (e.g., decision, feature, signal). Information sources can be collocated or distributed; passive or active; and cooperative or non-cooperative.

ECLPSE is estimated to be 15% basic, 70% applied and 15% advanced research, and the projected Technology Readiness Level (TRL) for the various technology objectives range from TRL 1 to TRL 4. The BAA runs through FY2026, and the total program value is estimated at $92 million.

The Multi-Domain Sensing Autonomy Division is pursuing ECLPSE under a two-stage BAA in which it is soliciting white papers and then selecting specific submissions for more detailed cost and technical proposals. The BAA number is FA8650-21-S-1016. The contracting point of contact is Jessica Ward, (937) 713-9853, e-mail jessica.ward.15@us.af.mil. – *J. Knowles*

THOR HPM SUPPORTS ARMY INDIRECT FIRE PROTECTION EFFORT

The US Army has disclosed that it is leveraging the Air Force Research Laboratory's (AFRL's) Tactical High-Power Microwave Operational Responder (THOR) system as part of its Indirect Fire Protection Capability rapid prototyping effort.

Managed by the Army Rapid Capabilities and Critical Technologies Office (RCCTO), the Indirect Fire Protection Capability program is intended to mature directed energy technology for site defense against emerging threats, such as drone swarms. Both high power microwave (HPM) and high energy laser (HEL) technology is being pursued.

According to Lt Gen Neil Thurgood, the director for Hypersonics, Directed Energy, Space and Rapid Acquisition who oversees the RCCTO, the combination of HPM and HEL systems is designed to provide a layered defense with complementary effectors. "High-energy lasers kill one target at a time and high-powered microwaves can kill groups or swarms," he said in an Air Force news release, "which is why we are pursuing a combination of both technologies for our Indirect Fire Protection Capability rapid prototyping effort."

To accelerate its program, the RCCTO is working with the AFRL's Directed Energy Directorate to gain insights from the THOR system. Developed by BAE Systems in partnership with Leidos, Verus Research and AFRL, THOR is a prototype

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HPM weapon designed to be able to disable the electronics in multiple unmanned aerial vehicles, so providing a capability against swarm attacks. The technology is housed in two standard 20-ft containers that can be deployed by air and assembled by a crew of just two people.

THOR was demonstrated to the RCCTO at Kirkland Air Force Base, NM, in February prior to an overseas deployment. During and after the THOR deployment, the RCCTO will continue to partner with the Air Force on THOR in support of the Army's aim to provide a prototype Indirect Fire Protection Capability - High Power Microwave system to a platoon by FY2024.

Additionally, the Army will deliver a prototype Indirect Fire Protection Capability - High Energy Laser capability in FY2024. This system will use a 300-kW-class laser for fixed site defense. – *R. Scott*

IN BRIEF

BAE Systems (Nashua, NH) has begun Low Rate Initial Production (LRIP) of the F-15 Eagle Passive Active Warning and Survivability System (EPAWSS) for the US Air Force under a $58 million contract from Boeing (St. Louis, MO). EPAWSS leverages multispectral sensors and countermeasures, offering radar warning, geolocation, situational awareness and self-protection capabilities. The system will be installed on F-15E and F-15EX models to improve aircraft survivability, allowing pilots to monitor, jam and deceive threats. BAE began working on EPAWSS in 2015 and received a follow-on contract in 2016 during the program's Engineering and Manufacturing Development phase to deliver updates to the EPAWSS flight software with new geolocation and threat identification capabilities. EPAWSS has been run through a series of ground and flight tests, with updates offering incremental improvements to the system's performance. Work on the program takes place at BAE Systems facilities in Nashua, NH; Austin, TX; and Totowa, NJ.

Leonardo's Electronics Division (Luton, Bedfordshire, UK) announced that it has conducted the first "live" launch of its BriteCloud 218 DRFM RF decoy from a remotely piloted air target system (target drone). The tests were conducted by the German Armed Forces with support from Airbus, Leonardo and the German analysis and testing firm IABG. The test saw the BriteCloud ejected from the RPATS during flight, allowing the drone to evade RF-guided missiles equipped with semi-active seekers. The 218 variant is compatible with the ALE-47 countermeasures dispenser. This BriteCloud 218 is also part of a Foreign Comparative Testing program with the US Air National Guard and has successfully performed during "carriage and release" trials conducted from a self-protection pod fitted to a General Atomics MQ-9 Reaper. Leonardo and General Atomics are working toward a "live" decoy test on the MQ-9.

"Clarification: In the March issue of *JED*, the 2021 AOC Industry and Institute/University Member Guide should have listed the RVJ Institute in the Institutes/Universities section."

Not Just Recognizing, Addressing, the Challe Superiority Strategy C

By Col Lisle H. Babcock, USAF, and Col Ryan C. Conner, USAF

It is now crystal clear throughout the Services and across the DOD that achieving and maintaining Electromagnetic Spectrum (EMS) superiority is integral to gaining advantage against our adversaries in Great Power Competition and executing our National Security Strategy. Our platforms, weapon systems, communication capabilities and execution of warfighting kill chains rely on our ability to use and control the EMS. At the same time, however, our competitors and adversaries understand our dependence on maneuvering in the EMS, and they are developing strategies and capabilities to exploit this. We must continue to build our understanding of EMS Operations (EMSO) and enable our forces to achieve EMS Superiority along the competition continuum.

This level of appreciation for the strategic importance of the EMS has not always been the case, however. While the US built a formidable Electromagnetic Warfare (EW) capability during the Cold War, the next 25 years of post-Cold War operations allowed the Joint Force to become accustomed to relatively uncontested EMS operations in many warfighting domains. Not only did this period lead to relatively limited EW investments that were tailored to meet irregular warfare requirement, but it also led to a generation of Airmen, Soldiers, Sailors and Marines whose operational experience and training was mainly focused on relatively permissive threat environments. During this same period, Russian and Chinese EMS capabilities evolved, however.

From the Air Force's perspective, the picture we saw was not good. By the 2015 timeframe, we were looking at a near-peer threat, and it is clear that our 25 years since the end of the Cold War had left us unprepared for this new era of near-peer competition. We no longer have capabilities like the F-4G Wild Weasels, the EF-111, the F-117, or backseat EWOs, as part of our non-kinetic fires. The pool of EW expertise has narrowed to Compass Call and Rivet Joint EW operators, as most aircraft self-protection systems are now automated. To address the gap between how our adversaries are preparing for operations in the EMS and how the Air Force is pursuing EMS superiority, the first task was to get the Air Force to understand why the EMS is important – to understand that our peer adversaries are heavily invested in these areas, and if we don't address this, we will be crushed.

AN EMS OF BOTH FRIENDS AND FOES

In addition to an ever-expanding use by military systems, spectrum-dependent commercial applications have also become ubiquitous since World War II. This dependence now necessitates that future conflict will drive the Joint Force to contend for EMS superiority in every phase of the competition continuum.

In 1970, a majority of the EMS was dedicated to military operations, with the civilian sector primarily using the EMS for radio transmissions. There was plenty of available bandwidth for growing sectors of both military and civilian usage.

Now, with the EMS being repurposed for commercial technologies to bolster economic growth and prosperity, the Joint Force's freedom of action is further restricted. These sophisticated technologies represent new opportunities. However, they also present new challenges across the competition continuum as the electromagnetic operational environment becomes increasingly congested, contested, and constrained. The EMS typically encountered today is congested due to the increasing density of electromagnetic emitters. Numerous private sector interests, such as cell phone and wireless internet providers, continue to expand into EMS frequencies that must be vacated by military users, reducing the open areas within the spectrum conducive to military use and maneuver. Other civil uses, as well as other government entities, consume large portions of the spectrum outside of the Department of Defense. This means that the now congested spectrum is even more open to use by potential adversaries competing for the limited bandwidth, as well as actively finding ways to challenge our use of the EMS. As a result, the Joint Force has been losing its competitive advantage in the electromagnetic spectrum which it needs achieve freedom of action while denying the adversary that same freedom of action. We are critically dependent on the EMS across all functions and domains. Our adversaries recognize this, and they have organized, invested and trained in order to maneuver in and control the EMS for their military operations.

JOINT ALL DOMAIN OPERATIONS – JADO

An integral part of successfully navigating Joint All-Domain Operations (JADO) has been lacking in our military strategies: the importance of EMS superiority. The EMS is defined as "the entire range of electromagnetic radiation." This includes all electromagnetic radiation – manmade (radios, radars, cell phones, etc.) and naturally occurring (solar winds, gamma radiation, etc.) – that exists from below the earth's surface and continuing deep into space. It is critical for connecting our Joint and coalition forces and as a medium for creating convergence of effects. The

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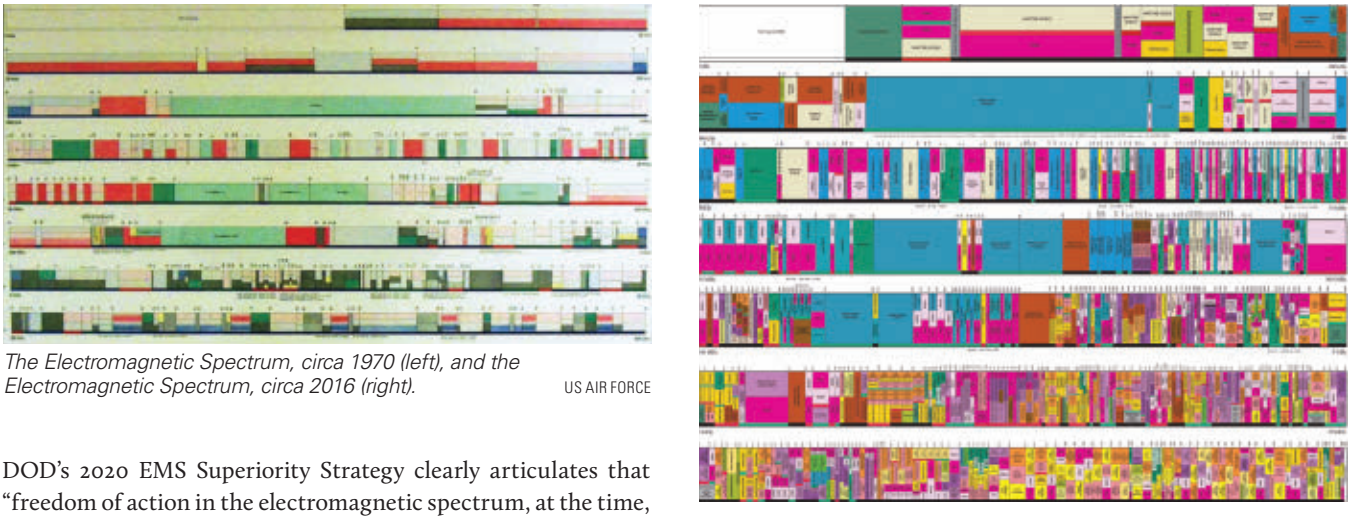

The Electromagnetic Spectrum, circa 1970 (left), and the Electromagnetic Spectrum, circa 2016 (right). US AIR FORCE

DOD's 2020 EMS Superiority Strategy clearly articulates that "freedom of action in the electromagnetic spectrum, at the time, place, and parameters of our choosing, is a required precursor to the successful conduct of operations in all domains."

The EMS is part of the physical environment characterized by frequency, energy and time. It can be managed, occupied and selectively controlled. It's also pervasive and permeating, linking all the other domains. Natural and man-made factors affect actions in and through the EMS just as in the other warfighting domains.

The wide range of effects that are executed through the EMS make it a potent force multiplier, and it is dynamic in speed and scope. Superiority in the EMS is integral to decision advantage, enabling joint force leaders and commanders to make informed decisions, while conducting operations that create multiple dilemmas through convergence of effects more rapidly than our adversaries.

The attributes of EMS operations create effects throughout the operational environment and competition continuum. The Joint Force employs EMS capabilities that are able to bypass geographical limitations or strike with precision at critical vulnerabilities within adversary centers of gravity at long ranges, on short notice and for sustained periods. Thus, the Joint Force must figure out how to effectively converge kinetic and non-kinetic effects seamlessly, with the timing and tempo required to meet the threats emerging in Great Power Competition. Only after the Joint Force masters this convergence of effects, can the service component commanders support the Joint Force Commander's objectives through JADO.

AN EW ECCT AND CFT

As was stated earlier, the Joint Force had been, for some time, losing its competitive advantage in the electromagnetic spectrum to achieve freedom of action while denying the enemy that same freedom of action. The Air Force recognized this and took action in the fall of 2017. During a capability development council (CDC), chaired by now retired, Gen Stephen Wilson, Air Force Vice Chief of Staff, three options were brought forward to select an enterprise-wide study to solve a major issue within the Air Force. There had previously been two other Enterprise Capability Collaboration Teams (ECCTs), one called Air Superiority 2030 and the other focusing on Multi-Domain Command and Control. The three options brought forward this time were Position Navigation and Timing (PNT), Adaptive Basing, and Electronic Warfare. While all three were recognized as very important issues, General Wilson chose Electronic Warfare to be the next ECCT.

Soon after the selection of EW for the next ECCT, the Air Force chose a General Officer to lead the 12- to 18-month effort. Brig Gen David Gaedecke, who at the time was the Director of Cyberspace Operations and Warfighting Integration, was given the task, and he quickly established a cross functional team (CFT) to begin solving the problem. Within this, he established seven lines of effort (LOE) led by members from across the Air Force.

The first LOE was intelligence to provide us with the current and future states and also to help guide the other LOE's through the effort. Next was Concepts of Operations and Gaps.

This effort resulted in a 45-day quick-look into what we can do today, where we were lacking, and what we might be able to due in the future if we could fill the gaps. This was followed by Concepts and Experiments that was to look at novel ideas and "new/new" capability concepts. It was also to look at rapid experimentation concepts and ideas. Supporting this, the Science and Technology LOE was to look at what advanced technologies were out there in industry and the Air Force laboratories. It also looked at analytic capabilities and tools, as well as trade space analysis. The Education Training and Policy LOE was to investigate how to restore EW core competencies and to rebuild EW and EMS knowledge, while the Investment Strategy LOE would look to determine a coherent investment strategy for EW/EMS. Finally, the seventh LOE was called "Champion," and it looked to determine leadership and organization for the EW/EMS enterprise.

The ECCT effort lasted through all of 2018, with participation of several hundreds of subject-matter-expert participants from across the Air Force, sister Services and partner nations. The study concluded with an out-brief in January 2019 to the then Chief of Staff of the Air Force, Gen David Goldfein. In attendance were the MAJCOM Commanders, as well as other Air Force General Officers and Senior Executive members. General Gaedecke made three recommendations to the Chief: 1) establish an EW/EMS organization within the Headquarters Air Force led by a General Officer; 2) consolidate and modernize our Air Force reprogramming efforts; and 3) establish a culture of EW/EMS awareness. General Goldfein approved these recommendations and established an implementation plan to lead the way for the three efforts.

DOCTRINAL CHANGES

The LeMay Center for Doctrine Development, Lessons Learned and Education at Maxwell AFB, AL, has played a central role in moving the ECCT recommendations forward, from updating and modifying doctrine, to being a part of the ECCT itself, to advancing professional military continuing education, and more importantly, developing EMS training for inclusion in the accessions process to ensure a common EMS knowledge for all Airmen.

> An integral part of successfully navigating Joint All-Domain Operations (JADO) has been lacking in our military strategies: the importance of EMS superiority.

As expected, the results of the ECCT necessarily led to the need for key changes to the Air Force's EW Doctrine Document (Annex 3-51 – Electromagnetic Warfare and Electromagnetic Spectrum Operations), most notably the terminology change from "electronic warfare" to "electromagnetic warfare." Released in July 2019, the revised doctrine also addressed EW structure, which was rewritten to describe EW as a subset and specialized form of EMS Operations (EMSO), essentially combining and consolidating information in equivalent Joint publications (JPs) 3-13.1, Electronic Warfare, and 6-01, Joint Electromagnetic Spectrum Management Operations (JEMSO).

The updated doctrine also included "enhanced information on EW in space and cyberspace, with additional material discussing the integration of EMSO across all domains, including air, land, and maritime." And, it also added new material on organizing, planning for, executing and assessing EMSO, which was not previously included in the doctrine.

Importantly, as noted in its introduction, the document was intended to serve toward the 2019 NDAA mandate of "cementing the base of Joint EMS capability with a dedication to the education and training of the whole force and the staffing of a dedicated professional force fluent in EMS operations."

There is customarily a two-year review cycle at the LeMay Center for reviewing and updating doctrine documents. This usually entails about a nine-month process to get all the players involved reviewing proposed changes and providing feedback. However, in the event of a significant development coming in from the field, or a Major Command (MAJCOM) indicating that a current doctrine is inadequate, this can be moved up and a short-notice working group convened. This is how Annex 3-51 was developed.

The ECCT revealed that the existing doctrine contained a large amount of out-of-date or antiquated information, which led to the immediate formation of an electromagnetic spectrum working group of 40-45 experts from across the Air Force. Right away, it was decided we were going to rename "electronic warfare"; it would be electromagnetic warfare and electromagnetic spectrum operations. The focus would not be just on air domain operations, which is well written but not very inclusive; it needed to include cyber operations and space operations.

One of the biggest things was really talking about how to integrate EMS fires as part of a larger non-kinetic operations capability, merged with cyber and space to provide a counterpart to the kinetic options. Although the Air Force does very well at EW training and preparedness at the tactical level and in a very scripted way, in which we know "what" and "where" most of the threats are and "how" we will address them, we don't know how to do this very well at the operational level, which is the level at which the LeMay Center doctrine is written – the operational level.

The doctrine team also realized early on in the process that, for the most part, the Joint Force Air Component Commander (JFACC) staff did not take non-kinetic capabilities seriously across the Geographic Combat Commanders (GCCs), not because they didn't think it was important, but because, over the past 25 years, the fight had been in CENTCOM, and EW was largely relegated to RCIED detection and insurgent suppression – not air, space and cyber operations against a near-peer competitor. It was clear that the revised doctrine needed to address big-picture topics, such as the Air Force's reprogramming efforts as highlighted by the ECCT. It was evident that people didn't fully understand this important element, and the current doctrine didn't explain it. We needed people to understand that when you're talking about

the EMS Enterprise, you've got to include the programming/and reprogramming of all of the systems.

Recognizing that EMS and EMS Operations are also a central part of the Department of the Air Force's role in JADO operational doctrine, with EMS superiority clearly articulated as an integral part of gaining and maintaining superiority in the other domains, in May, 2020 the Chairman of the Joint Chiefs of Staff (CJCS) published a new "Joint Electromagnetic Spectrum Operations (JEMSO)" document, followed in June with the LeMay Center's release of the Air Force's first doctrine annex on JADO outlining how the Service expects to maintain competitive advantage with the reemergence of near-peer competition. Air Force Doctrine Publication (AFDP) 3-99, "Department of the Air Force Role in JADO," builds on the doctrine note signed by General Goldfein in March of that year, as well as direction included in the National Defense Strategy. One of the specific goals of the annex was to look at dynamic tasking orders – to truly go after converging kinetic and non-kinetic effects from the highest levels of planning all the way to tactical level execution. Both Pacific Air Forces (PACAF) and US European Command (USEUCOM) are now currently using the JADO annex during exercises to obtain real-world feedback. The LeMay Center was responsible for developing and providing MAJCOM input into the JEMSO document, as well as the JADO document to help ensure their consistency and that they tie well together.

ELECTROMAGNETIC SPECTRUM SUPERIORITY DIRECTORATE (A5L) ESTABLISHED

As per the ECCT's three principle recommendations, the first accomplishment was the stand-up, in August of 2020, of the Electromagnetic Spectrum Superiority Directorate, Headquarters Air Force (A5L). A5L replaced what was a Division known as A5RE led by a Colonel with three branches. The new Directorate is run by a General Officer, with General Goldfein initially selecting General Gaedecke to be the lead. Brig Gen (Sel.) Michael Manion has now assumed this role. The Directorate also established three Divisions led by two Colonels and one GS-15: Enterprise Engagement, Management and Integration, and Special Programs. The new Directorate would be responsible for gaining and maintaining EMS and EW superiority, orchestrating enterprise-wide actions and unity of effort in developing and synchronizing multi-domain EMS operations doctrine, strategy, policy, requirements, capability development, and Planning, Programming, Budgeting & Execution across all Air Force core functions. The standup of A5L would also offer additional leadership opportunities for the EW/EMS career field.

Currently, following on the heels of the release by OSD of a DOD-wide "Electromagnetic Spectrum Superiority Strategy" published in September of 2020, and ongoing work on a follow-on EMS Implementation Plan, the Air Force has also developed an EMS Superiority Strategy plan in line with that document. This is currently being staffed and is expected to be released within weeks. The Air Force is also concurrently developing an Air Force EMS Implementation Plan for the strategy that is projected for release this summer.

CONSOLIDATING AND MODERNIZING REPROGRAMMING

Also per the ECCT, the Commander of Air Combat Command (ACC) announced plans to stand-up a Spectrum Warfare Wing that would be able to consolidate and modernize the Air Force reprogramming enterprise. Currently, the Air Force's EW reprogramming efforts are done mostly for combat air forces, with Air Combat Command (ACC) being the lead for reprogramming of combat aircraft systems. However, there are also other Air Force platforms requiring this capability, such as those of Air Force Special Operations Command (AFSOC) and Air Mobility Command (AMC). These commands work together to reprogram their systems. Now, with Space system reprogramming also needing to be addressed, the goal is to bring all of these together under one umbrella and eliminate duplication of effort. Currently, this effort is led by the 53rd EW Group, and its responsibilities will be encompassed by the new 350th Spectrum Warfare Wing, which is expected to officially stand up at Eglin AFB this summer

On the modernization front, the Air Force is moving from a hardware-centric focus, such as library-based systems, to a software-centric system. This allows for much more rapid changes and updates.

EW/EMS CULTURE

The third ECCT recommendation was to establish an EW/EMS culture. To that end, the Air Force is currently developing an education plan for Airmen

as well as EW/EMS experts to enhance their development. The Air Force is also looking at ensuring that EW/EMS is fortified in training and wargaming. This effort is the first stepping stone toward taking back our advantage in EW and the EMS. As General Gaedecke said, "To be a lethal force of the future, we need to lead in research, technology and innovation, and superiority in the spectrum underpins all of these."

Following the revisions to the Air Force doctrine in 2019, the next step was to develop the EMS 100, 200, 300 and 400 academic series to start teaching at basic training levels as well as well as get advanced knowledge out into the field. Among these ongoing initiatives, the 19th Air Force under Air Education and Training Command is developing an EMS 100 course, providing basic EMS fundamentals to USAF accessions, as well as Wing-level basic training programs. This will enable the USAF to develop "multi-capable Airmen," as directed by Chief of Staff of the Air Force, Gen Charles Brown Jr., "that understand how their EMS footprint is both a force multiplier to operations, as well as a vulnerability if not understood."

In addition, the LeMay Center has developed new EMS operational doctrine that meets the FY19 NDAA directives, and is the foundation for EMS academics taught at Air University's ACSC Joint All Domain Symposium (JADS) seminars, GOFO Senior Joint Information Operations Course (SJIOAC) Professional Continuing Education (PCE) course, as well as the O-5 and below (officer and enlisted) Contingency Wartime Planning Course (CWPC), Joint Air Operations Planning Course (JAOPC) and Joint Task Force Staff Basic Course (JTFSBC) PCE courses.

> We needed people to understand that when you're talking about the EMS Enterprise, you've got to include the programming/and reprogramming of all of the systems.

GETTING THERE

Although, it's been too long coming, the Air Force has already made substantial progress in addressing the gaps and shortfalls in its EMSO capabilities. The EW ECCT was the start, and the expeditious implementation of its recommendations is now well underway. Establishing a Directorate for Electromagnetic Spectrum Superiority at the General Officer level has, in particular, driven home the reality of an entirely new recognition of the importance of EMS dominance to our National Security. The creation of a Wing dedicated to Spectrum Warfare is further reinforcement. As General Goldfein has said, "When we got rid of the F-4G, we not only got rid of airplanes, but also the pilots, all the EWOs, all the maintenance, and the entire culture of EW expertise that went along with that." We now have to reestablish all of that, and the new Directorate and formation of the 350th Wing provides an opportunity to expedite that process, as well as to create more leadership opportunities in the EW field. It's a significant step forward in rebuilding our EW/EMS culture.

ABOUT THE AUTHORS:

Col Lisle H. Babcock is the Commander, Curtis E. LeMay Center for Doctrine Development, Lessons Learned, and Education, Maxwell Air Force Base, AL. The Center is responsible for the research, development, and production of Air Force doctrine, lessons learned, and coordination with Joint and multinational doctrine development activities. The Center is also responsible for advocating the proper doctrinal representation of air and space power in exercise scenarios, war games, models and simulations, and providing policy and guidance of Air Force doctrine through education and focused outreach.

Col Ryan C. Conner is the Chief, Management and Integration Division (HAF/A5LI), Electromagnetic Spectrum Superiority Directorate (HAF/A5L), Headquarters Air Force, Pentagon. A5LI acts as liaison with HAF/A8 and MAJCOMs overseeing execution on program objective memorandum (POM) development and readiness issues. A5LI conducts force development and funding through the POM process and acts as program element monitor for selected EMS-related program elements. A5LI also co-chairs the Spectrum Integration Group (SIG), which manages implementation of the Air Force EMS Superiority Strategy.


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SOSA
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USAF EW Working Group Central Component of O

By John Haystead

There are a number of factors dramatically impacting the importance and complexity of EW systems and their operations in the modern Electromagnetic Spectrum (EMS) environment. These include increasingly advanced and capable threats, the introduction of a next generation of highly capable and versatile aircraft platforms, and the continuous technological advancement of our own EW systems and capabilities. All of these factors come together to drive a critical component of mission success – planning.

Mission planning for EW systems and the integration of this planning data with other onboard aircraft systems, as well as the efficient delivery of this information for insertion across the full complement of mission aircraft of all of the Services, is the focus of the Mission Planning – Electronic Warfare Working Group (MP-EWWG).

As described by Tim Moulton, Mission Planning and EW and FMS Engineering at AFLCMC (Hanscom AFB, MA) for support contractor Leidos (Reston, VA), and who leads and facilitates the MP-EWWG on behalf of the Airspace Mission Planning Division (AFLCMC/HBM), the MP-EWWG is multi-Service and multi-discipline. "The introduction of 5th Gen aircraft platforms has made mission planning that much more critical. 5th Gen aircraft have an incredible amount of capacity for sensors and surveillance, self-protection, with network-enabled weapons – all operating in the Electromagnetic Spectrum. Everything going on in the EMS needs to be planned for in cooperation with other assets in a strike package. And, there are also cross-organizational requirements that must be addressed to achieve total integration. This is the vision that started the MP-EWWG with participation by all of the Services."

Moulton says the EWWG first began by looking at what kinds of data, and what kind of tools and services, were needed to be in place to support the warfighter. "This spawned a series of different conversations all the way from the warfighters' desires in requirements to plan and execute a mission, as well as the infrastructure to support that. There are always issues in terms of cross-domain, high-low classifications, different Service and organizational boundaries, as well as the Intelligence Community. So, there are a number of challenges that we're looking at in terms of the system in order to facilitate the information that the warfighters need in order to plan missions in a timely fashion."

EWWG co-lead for the Airspace Mission Planning Division, Kathy Cahill, says, "The users are our main interest. The EWWG has grown from initial interest in sharing data with the Navy, and then the Army became interested, and then the Intelligence Community. It's simply everyone wanting to collaborate to make it less expensive and more useful for the warfighter. In addition to the emergence of 5th generation platforms, another impetus for the MP-EWWG, was to improve collaboration, to save the taxpayers money by leveraging each other's capabilities to the fullest extent possible."

The EWWG conducts an annual meeting that seeks to bring together a wide range of participants across the EW mission planning field. Says Moulton, "Our approach is multi-fold. First, leadership introduction and where the Services are relative to EMS activities. Then we begin to break it down and bring the warfighters in for each one of the domains to talk about what they're seeing and what their issues are. Then we start getting into the working part, which is the systems and all the underlying pieces of the infrastructure needed to support them."

Although the initial MP-EWWG meetings were specific to the Air Force, Moulton says that was never the group's goal in its formation. "We didn't want to become just an Air Force event, and we try to rotate sponsorship. The Navy sponsored our second Service-wide event and the Army sponsored the last one."

In fact, Moulton says some of the takeaways from their last February 2020 meeting in Smyrna, GA, included building some strong synergies with the Army based on a common data architecture. "It hasn't been settled on yet, but we're finding pockets of activity going on and we're starting to tighten the loops on who is doing what and how they relate to each other. There is a lot of good work going on out there, but it's just not well shared. We're starting to share at both a high level in terms of execution and at the intermediate level operating from a common strategy, and then tactically with the tools that we have today. We've already shared tools between the Services to leverage capability. It's ongoing all the time. We have some EMS analytical tools that were developed by the Air Force that the Navy and Army are now also looking at, and we're doing other things in terms of Artificial Intelligence (AI) and in data sharing and data reduction. Why do it twice when we can do it faster and cheaper if we focus?"

Col Jason Avram, Senior Materiel Leader for the Airspace Mission Planning Division, PEO Digital, AFLCMC at Hanscom, AFB (see sidebar) is a strong advocate of the MP-EWWG's work. Avram attended his first MP-EWWG meeting in June of 2019 at Barksdale, AFB, LA. "I was impressed right away with how many different organizations were there and how interested they were in the topic. We had Air Force, Navy,

Ensures That EW is verall Mission Planning

Army people there with all different types of communities and all extremely engaged in the topic. The level of engagement struck me right away."

Colonel Avram notes that the MP-EWWG was originally conceived as a forum to share EMS battlespace mission, vision and objectives along with sharing the current and planned Service development efforts shaping requirements. "There's a lot of different stakeholders doing various things in the EMS realm and if you don't do something to integrate or synchronize those efforts you will be both wasting resources through redundant work, as well as in many cases, missing opportunities if you don't know what others are doing. So the plan was to drive that collaboration and relationships, the synchronization of efforts. We're only going to be successful if we are leveraging the collective capabilities that everyone brings to bear."

Colonel Avram believes that the EWWG has already shown substantial success in one important area – highlighting where there may be overlapping efforts and, through that process, allowing for all the Services to do a better job of leveraging resources. "It has also, in quite a few cases, identified where something was on one Service's wish list but was unfunded, was actually being developed, or fielded in some way by another Service. So it helped to connect those dots and created opportunities that could be leveraged across multiple stakeholders."

The EWWG is organizing itself around a number of focused sub-working groups. Says Moulton, "There's a lot of complexity in terms of how we implement these systems, and we're trying to drive a common vision as to what the end-game needs to look like and drive it to the sub-working groups with specific skills on how to make it happen in a coordinated way so we're not duplicating efforts. We're trying to accelerate the pace through collaboration."

5th Gen aircraft feature a number of sensors. From a mission planning perspective, they don't just consume a lot of data, they also produce a lot of data. US AIR FORCE

Moulton says that getting people to take ownership of, and set up, sub-working groups is one of the EWWG's major objectives, and a number of sub-working groups have already been spawned. One such group is focused on data. As pointed out by Moulton, "Data is in many forms. It's the actual sourcing and production and delivery of the data to the system. It's a system to receive it and it's the system to update it, and the system to distribute it. It needs to be done right, because these 5th Gen platforms and systems don't just consume data, they produce it. The Data Working Group is working to standardize on data formats and data packages so that they are comprehensive and are delivered on a routine basis incorporating an expanding scope of coverage."

Other sub-groups include one directed at ensuring a comprehensive EMS strategic data architecture. "We need an architecture that spans the entire life-cycle of data from its source in an intel collection area including operational, battle damage assessment, even some of engineered data that is specific to an operation. We want to have a data architecture that ties it all together so that someone from the Army on the ground can see what the Air Force and Navy are seeing. Everyone sees the same Common Operation Picture (COP). Today, with so many assets out there emitting, everyone needs to be able to see the big picture, including the impact of what everyone is doing to each other. Mission planning is that connection point."

Says Cahill, "Our challenge is to spawn off enough implementation planning teams that work on these focused issues between the big working groups and have them report out. We need more leaders and users. Last year, we walked away with about five requirements defined by users on the EW side that we have just about completed."

As observed by Colonel Avram, another point relative to the MP-EWWG, and its annual meeting in particular, is that "the structured discussion driven by the formal agenda is just the beginning with continuing information sharing going on informally and continuously between participants throughout the event. This helps create and build relationships

driving a kind of culture of cross-organizational and cross-Service collaboration that will be long lasting." The Working Group is planning for another meeting in the summer timeframe, with a virtual meeting as a backup option.

Air Force Airspace Mission Planning Division

The Air Force's Airspace Mission Planning Division/Air Force Life Cycle Management Center (AFLCMC) (Hanscom AFB, MA) is one of 14 Divisions within the Program Executive Office (PEO) Digital. Its mission is to "deliver and support world-class integrated mission planning capability on any device, anytime, anywhere." As described by Col Jason Avram, Airspace Mission Planning Division (AMPD) Senior Materiel Leader (SML), the organization has been in existence for around 30 years progressing through a series of phases with different capabilities beginning with the now-retired Air Force Mission Support System (AFMSS), followed by the Portable Flight Planning System (PFPS) scheduled for sunset this year, and now the Joint Mission Planning System (JMPS).

Colonel Avram says approximately 90-percent-plus of the AMPD's mission involves software, specifically providing mission planning software for all Air Force platforms, as well as working collaboratively with the Navy for their platforms. "We basically provide three levels of JMPS software capability that is integrated together to support platforms in the Air Force and Navy. This includes a framework of core mission capability that provides the basic mission planning capability that every aircraft needs, such as route planning or takeoff-and-landing. Then there are common mission-specific components, for example, weapons and electronic warfare for fighters and bombers. Beyond this, there are platform-specific pieces that help coordinate their mission planning with the operational flight programs on the platforms. We build all the different pieces of mission planning for the various missions and aircraft types and then we integrate them together and provide them out as a mission planning environment to all the different platforms. We also have the responsibility of updating and refreshing the necessary hardware, such as desktop computers, printers and laptops that the mission planners and operators use."

The program management office is supported by a combination of Government, military and civilian personnel, as well as industry contractors that perform all of its various functions such as program management, engineering, financial management, contracting, logistics, and cost estimation. As noted by Avram, because they're largely a software-development organization, they have a large number of IT and software-development professionals and engineers. The AMPD has a Systems Engineering and Integration Contract (SEIC) with Leidos Inc. (Reston, VA) that provides engineering and integration software support, and it also receives significant support from the MITRE Corporation (McLean, VA).

Although the organization is located mainly at Hanscom AFB, it also has an operating organization at Eglin AFB, FL, co-located with test organizations for testing and mission planning training, as well as at Hill AFB, UT, where a core mission planning systems facility manages integration, logistics and deployment of the Division's capabilities in support of the operational users.

As outlined by Colonel Avram, the JMPS is structured around two primary baselines – one named Falconview that mainly supports large aircraft, such as those of Air Mobility Command (AMC), and another that supports combat aircraft such as those of Air Combat Command (ACC) known as the JMPS baseline. Together, the two baselines incorporate the core mission planning capability framework, as well as the common components specific to those missions. Says Avram, "We've actually transitioned these two baselines to an agile sustainment schedule that we put out on a three-month cadence. Then, the different platform Mission Planning Environment (MPE) managers can capture those baselines and integrate their unique platform-specific mission planning software into them. So, in effect, we have a three-month cadence that we provide for JMPS sustainment, but from the perspective of the individual platforms, especially for combat aircraft, the main driving factor for updating operational mission planning environment software is based on and aligned with the operational flight program updates that the platforms receive."

Avram says the extent of the EW element of the overall mission planning requirement is dependent on the type of platform and type of mission. The EW mission segment can be a central focus, in which case, the entire mission plan may include EW. In other cases, the EW mission planning segment may be a key enabler against various weapons systems. "In either case, you have to leverage the EW mission planning capabilities you provide to ensure mission success, but it's really dependent on the type of mission you're doing. Over the last 20 years, we've been doing more of the counter-insurgency types of operations with less of a classical need for EW capability, but as we move ahead into more of the near-peer environment, EW will be more and more critical."

Today, a major focus of the AMPD overall and EW specifically, is transitioning to agile mission planning software development and to a hybrid cloud-based mission planning execution capability. Says Colonel Avram, "This is the future, and as we do that, we're doing our best to make sure we include all of the required capabilities – including EW – that are of value and that they are interoperable across the Air Force as well as Navy and Army stakeholders. We want to make sure going forward that we're working aggressively to support the Joint All-Domain Command and Control (JADC2) vision as quickly as we can. It goes beyond EW or the EMS for us, but the requirements of successful operation in the EMS will continue to play a critical role." – *J. Haystead*

EMCON: Using Mission Command Systems for True Mission Command

By MAJ Luke Plante, CW3 James Turner, LTC Edward Ortiz and MAJ Richard Purcell

According to Army Doctrine Publication (ADP) 6-0, the US Army uses "mission command" to empower subordinate leaders to make decisions and execute operations in a decentralized manner. The idea behind mission command is to provide minimal guidance to lower echelons beyond task and purpose. We are supposed to tell subordinates what to do – not how to do it. Dictating how to perform a task can result in a lack of initiative, a misinformed approach from a disconnected command to solving a localized problem, and even a perception of toxic leadership that may lead to poor unit morale and performance.

In the context of the Army's adoption of Multi-Domain Operations (MDO), mission command is as important as it ever was. Having a robust battle rhythm over a distributed force requires a dangerously substantial electromagnetic footprint – one not at all based on thoughtful emissions control (EMCON). Conducting several meetings throughout a given day would be extremely perilous if done within the range of a near-peer adversary's electronic warfare (EW) and signals intelligence (SIGINT) systems. Just some of these daily meetings could include a battle update brief (BUB), commander's update brief (CUB), commander's update assessment (CUA), battle update assessment (BUA), targeting working group (TWG), targeting decision board (TDB) and an operations synchronization (OPSYNCH). Each of these meetings may last an hour or more, it could generally occur at the same time each day, and we would typically conduct these using the electromagnetic spectrum to ensure all units participate.

Ironically, we in the Army call our communications systems "mission command systems." The irony is that there is a rather widespread perception in the Army that we do not use these systems for mission command. Many of us have heard stories of, or directly experienced for ourselves, times where senior leaders wanted constant updates or want to control individual movements of Soldiers several echelons below them. This is the opposite of mission command.

US ARMY

After we transmit, we must assume that enemies have used electronic warfare support to locate us and call for fire on our positions.

To ensure our survivability in future large-scale ground combat operations (LSCGO), we need to be deliberate about using mission command systems for actual mission command. We must, as we often say, train as we will fight. We need to develop a more succinct battle rhythm, use burst transmissions when possible and ensure we move often. After we transmit, we must assume that enemies have used electronic warfare support (ES) to locate us and call for fire on our positions. Just as we are learning again to move after we shoot artillery, we also need to move after we emit electromagnetic radiation. More importantly, however, we need a culture shift away from constant updates from and control over subordinate units. Commanders and staffs at all echelons must become comfortable with accepting risks and truly empowering their subordinates. Trust takes time to build, and trust would make this culture shift easier for leaders; however, survivability will make this mission command a necessity in MDO. This change would tremendously alter staff work at culminating training

exercises (CTEs) and combat training center (CTC) rotations, and we need to make the change sooner rather than later.

We must also assume that our enemies will have significant capabilities in the EMS. Our adversaries will use not only ES and SIGINT, but also electronic attack (EA) and electronic protect (EP). Cyberspace and space are two additional domains in which adversaries will likely engage. Our enemies have not shifted focus away from EW to focus on two other demanding wars, as we have done. We must anticipate that our enemies will significantly disrupt our communications; radars; intelligence collection; and position, navigation, and timing (PNT); and we need to assume that the enemy will target our EMS emissions sources rapidly. Until we achieve at least air superiority, adversary airborne EW systems may be able to locate our EMS emissions within radio line of sight – perhaps from 50 km or more.

Additionally, our adversaries may be well-practiced at using deliberate EMCON. They will not transmit more than necessary, and they will accept more risk than we will – including for actions like clearance of fires. Our adversaries may be willing to risk losing a company or battalion of their infantry to fire from their own artillery in order to protect their rear command nodes. We need to learn from these adversaries and make strict EMCON a normal part of how we fight. Analog methods for battle tracking and clearing airspace and fires may need to become primary over digital means at times. It may even be necessary to prohibit cell phones in our formations to enhance operations security (OPSEC), as enemies will likely plan to use undisciplined social media posts against us.

> Just as we are learning again to move after we shoot artillery, we also need to move after we emit electromagnetic radiation.

Although our entire signature in the EMS is important to protect through EMCON, the most significant change the Army needs to make is in our expectations and culture surrounding battle rhythm events. We need to understand at all levels of leadership that decreasing our signature will increase our survivability. We need to become more comfortable with ambiguity and become more trusting of our subordinates. This will be a major change and will not come without its challenges, but ultimately we will make this change whether we like it or not, either while we have the time now, or in the heat of battle when it may be too late. Only after we make this culture shift will we truly use mission command systems the way we are supposed to use them – for mission command.

About the Authors: LTC Edward Ortiz, MAJ Luke Plante, MAJ Richard Purcell and CW3 James Turner are assigned to the 10th Mountain Division (Light Infantry) at Fort Drum, NY.

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Elettronica Launches the EMSOpedia

The Italian company will launch the world's first online electromagnetic support operations encyclopedia as part of its 70th birthday celebrations.

Founded in 1951 by the engineer Filippo Fratalocchi, Elettronica will launch the world's first EMSO encyclopedia – dubbed the EMSOpedia – on March 24, as part of its 70th birthday celebrations. Elettronica President and CEO Enzo Benigni said, "Over the years, Elettronica has built a robust reputation in the EMSO field. For our 70th birthday, as a gift to the EMSO community, we decided to create the EMSOpedia to promote the better understanding of this sometimes-complex subject, considering the increasing relevance the EMS will have to future air, land, naval, space and cyber operations."

Living Document

The online publication, written by experts within and without the company and by leading academics and practitioners, gives comprehensive, concise and clear definitions and explanations of the myriad of terms and concepts used in EMSO. The EMSOpedia will serve as a "living document" that will be updated throughout its life as concepts and terminology within the EMSO world evolve. The project has been realized with contributions from the Italian Armed Forces, members of the Association of Old Crows and academics. Opportunities exist for those not already involved in the project to collaborate: "We welcome contributions from electronic warfare experts," says Mr. Benigni. "The project extends an open invitation to contribute to its development for a common growth of knowledge. It will enlarge and develop to reflect changes and innovations in the discipline. Therefore, we will always need clear and concise writing from experts intimately connected with the discipline who can share their knowledge."

Relevance

The EMSO community did not have such a publication before, but it has needed one for a long time. The concepts and terms used in EMSO can be complicated – even for subject matter experts. The company stresses that the EMSOpedia will also appeal to a general readership, including both experts and for the more general audience of journalists and students.

Widespread Appeal

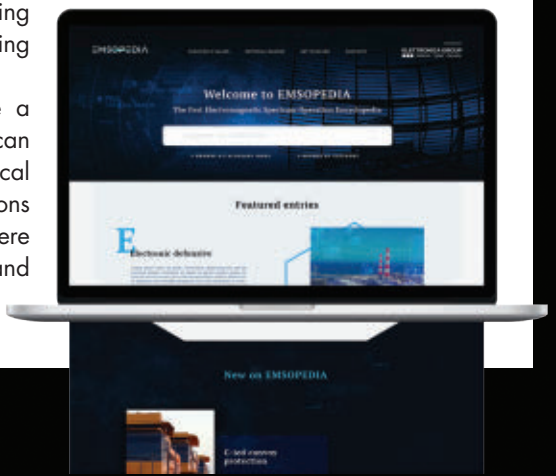
Recent and ongoing military operations in Ukraine and Syria involving so-called "near-peer" adversaries and similar concerns regarding the use of the electromagnetic spectrum by similar actors in the Middle East and Asia-Pacific regions have placed EMSO at the forefront of the global security agenda. An awareness and understanding of the use of the electromagnetic spectrum by militaries can no longer be confined to the EMSO community. "We expect that everyone from military personnel to analysts, students, academics, journalists and even politicians will find the EMSOpedia useful, says Mr. Benigni. Quite simply, if your work involves the military use of the electromagnetic spectrum, the EMSOpedia is for you. The company hopes the encyclopedia will help make EMSO clearer and more approachable by cutting through the jargon and explaining aspects of EMSO in a clear fashion using tangible real-world examples.

The EMSOpedia aims to provide a "one stop shop" where information can be found quickly, easily and in a logical way to clearly show all the connections that exist within the discipline "There are many excellent books, papers and presentations available on EMSO. What we are trying to do is to distil this knowledge in one place. Peoples' time is always short, and we believe that it will prove useful to be able to find definitions online in a searchable format," Mr. Benigni notes. Elettronica developed the encyclopedia from the outset as an online publication. Not only does this make it easy to update, but also easy to access, which is very useful as the ongoing COVID-19 pandemic requires many of us to work remotely from our offices. The EMSOpedia can be consulted on a PC, laptop, tablet or even on a smartphone, meaning that users have information at their fingertips whenever they need it.

Ease of Use

Clarity is central to the EMSOpedia's approach: "Electromagnetic Spectrum Operations are not always the easiest thing to understand," says Mr. Benigni. "We have tried to present the concepts and terms which underpin EMSO in an easy-to-read, uncluttered form. Readers will see that its entries are accompanied by images and even video content to help explain EMSO concepts. Those who want to know more about a particular subject can consult the further reading suggestions accompanying each entry."

The *EMSOpedia* can be found at www.emsopedia.org.



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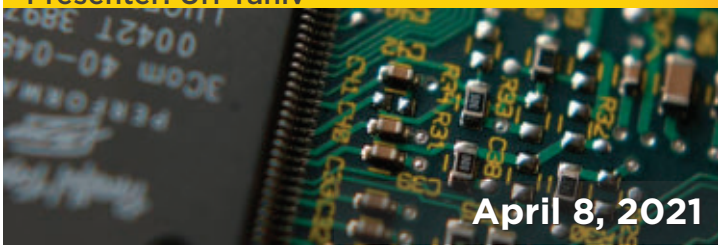

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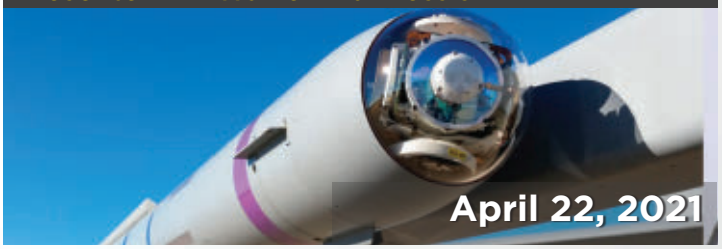

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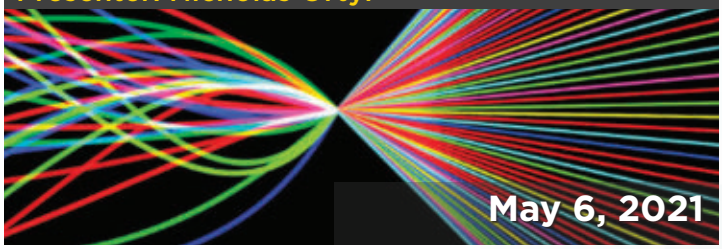

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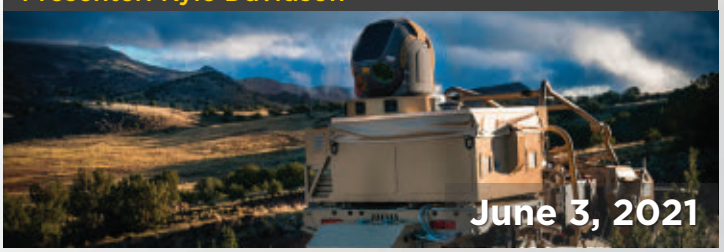

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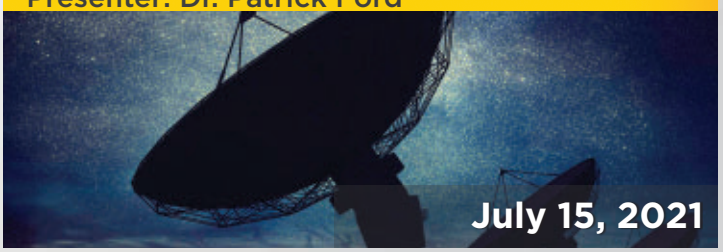

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5G Communications

By Dave Adamy

This month, we are beginning a new EW 101 series on 5G communication and electromagnetic warfare (EW). We will begin with a discussion of 5G netowrks and then move on to EW-related issues later in the series.

5G BASICS

The latest cell phone format is the fifth generation, called 5G. It provides higher data transfer rates and reduced latency compared with earlier generations. These two features improve the performance of cell phone connections and also have advantages for military applications. One important feature of 5G wireless networks is that their frequency range is increased to include millimeter wave (mmW) band channels.

The mmW channels are challenging because of propagation losses, but they will provide vast increases in data rates and improve data latency. As this is written, long-range 5G transmissions use the same channels previously used in the fourth generation (4G), and expansion into the mmW channels will require the construction of cell towers that are more closely spaced than those currently used for earlier generation cell phones. Near-future military systems will be designed to enable and take advantage of mmW features.

Once fully implemented, 5G will allow significant advantages in both civil and military applications. One example is the control of swarms of satellites. The satellites can communicate with each other at relatively short ranges outside the atmosphere and will enable significantly better satellite phone service. This will also significantly improve the ability to remotely control precision weapons anywhere on the Earth. Another advantage will be an enhanced ability to perform remote training because of the increased data rate and reduced latency.

5G FREQUENCY BANDS

Low-band 5G uses several channels in the 600- to 700-MHz frequency range. It uses cell towers that can be hundreds of miles apart and thus can serve widely spread stations in remote areas. It carries digital data at 30-250 Mbps. A commonly used rate is 225 Mbps, which is six to seven times faster than 4G operation. 5G will also allow for a significant increase in the number of simultaneous users compared to 4G.

Mid-band 5G operates over many channels in the 2.5- to 3.5-GHz frequency range between cell towers that are several miles apart. It carries data at 100-900 Mbps between significantly increased numbers of users compared to 4G.

Mid- and low-band 5G is called sub-6 GHz 5G. High-band 5G operates over several channels in the 26-, 28-, 38- and 60-GHz frequency ranges. It operates between cell towers that are just over 1 mile apart. However, buildings and urban area built-up can reduce the required spacing to 0.7 miles, and some kinds of glass and walls can prevent its transmission entirely. It typically carries 1-3 Gbps data and can operate up to 20 Gbps. High-band 5G operates in the mmW frequency range and thus has unique advantages and disadvantages, including much smaller antennas and significantly increased propagation loss.

Table 1 illustrates the 5G frequency ranges.

Band	Frequencies	Data Rate	Tower Spacing
Low band	600-700 MHz	30-250 Mbps	Hundreds of miles
Mid band	2.5-3.5 GHz	100-900 Mbps	Several miles
High band	28-60 GHz	1-3 Gbps	0.7 miles to 1 mile

Table 1: *5G Frequency Ranges*

5G ANTENNAS

Massive multiple input multiple output (MIMO) antenna arrays are practical because of the short wavelengths in mmW communications. This means that a relatively small mounting area can contain 64 to 256 antennas. This will enable antenna gain and directivity performance up to ten times that in current 4G networks.

Figure 1 compares the space required for a 256-element phased array antenna at 3.5 GHz (5G mid band) and 28 GHz (5G high band). For comparison, a square array with 16 elements on a side is chosen, and half wavelength spacing is assumed. It should be noted that the elements can be spaced wider than this if the beam steering is limited to 45- or 60-degree offset. However, the comparison remains valid.

The gain of a phased array antenna is given by the formula:

$$G = (4 \pi A n)/ \lambda^2$$

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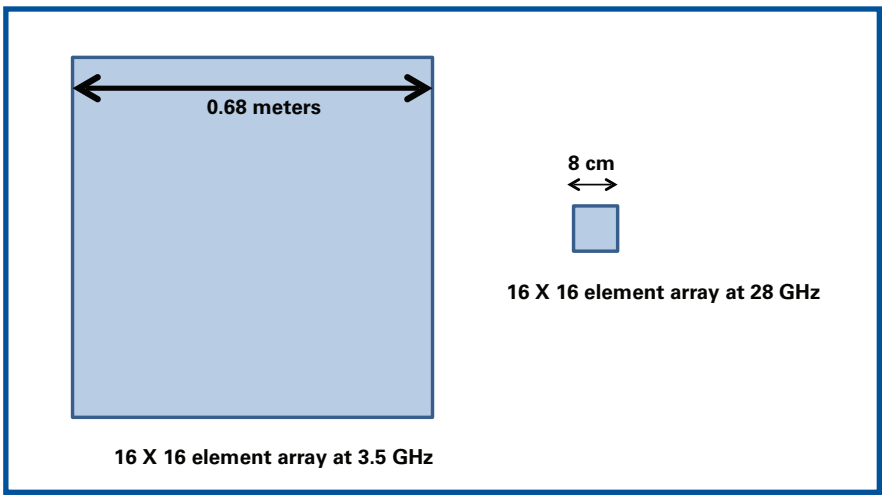

Fig. 1: *The physical size of a 256-element (16 x 16) antenna array changes significantly with frequency.*

Where: the area of the array is *A*,
the efficiency of the antenna is *n*, and
the wavelength is λ.

The wavelength of a 3.5-GHz signal is 0.085 meters, so 16 elements would require 0.68 meters with half wavelength spacing. The area of the array is thus 0.46 m^2. If the efficiency of the array is 40%, this would make the gain equal to 25 dB. At 28 GHz, the wavelength is 0.01 meters, so 16 elements half of a wavelength apart would require 0.08 meters, making the area of a square array 0.0064 m^2. The above equation yields 25 dB as the gain of the 28-GHz antenna.

With 40% antenna efficiency, the 3-dB beam width of either antenna would be 8 degrees, providing excellent angular selectivity, but of course the mmW antenna requires so much less space that it is practical for more applications.

5G MODULATION

The modulation used in 5G transmission is orthogonal frequency-division multiplexing (OFDM) with guard channels, which provides excellent channel isolation. By combining many low data rate channels, OFDM overcomes many long link propagation challenges. Each input from a user is modulated using quadrature amplitude modulation (QAM) or phase shift keying (PSK). The OFDM modulator combines the digital inputs into complex digital words. The OFDM signal is converted to analog format in an inverse fast Fourier transform (IFFT) circuit for transmission to other 5G towers. The received analog signals are returned to digital form in an FFT and then split into digital signals for the individual users.

Figure 2 shows a simple OFDM signal with only four inputs. **Figure 3** shows the signal formats as the information is passed through the 5G process between two towers.

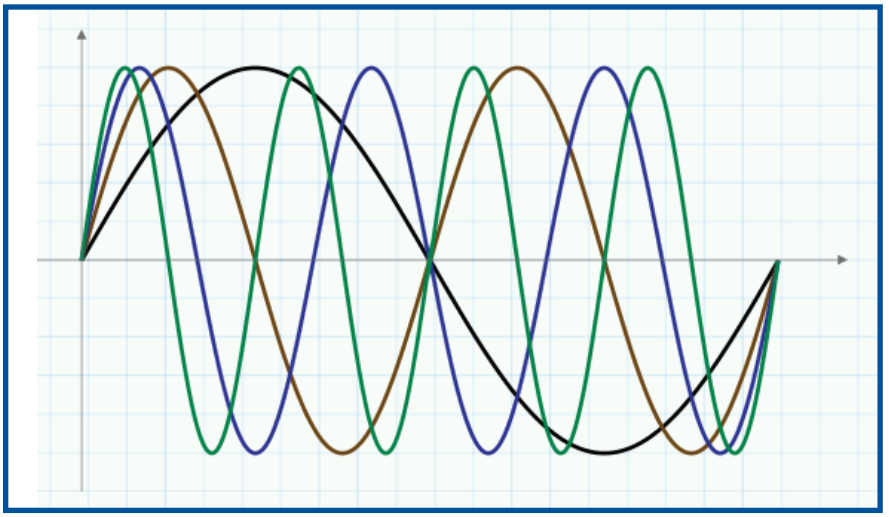

Fig. 2: *Achieve orthogonal signals with guard band spacing; do not cross modulate. The signals are at evenly spaced frequencies and phased to orthogonality.*

WHAT'S NEXT

Next month, we will continue our 5G discussion with a detailed description of mmW propagation. For your comments and suggestions, Dave Adamy can be reached at dave@lynxpub.com.

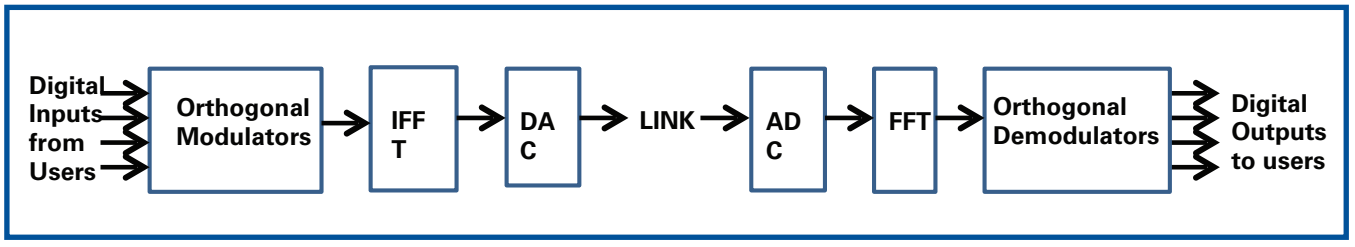

Fig. 3: *Digital inputs from many users are combined into complex symbols by orthogonal frequency-division multiplexing (OFDM). Then an inverse fast Fourier transform (IFFT) circuit converts this digital signal to analog for transmission over the 5G link to another tower. The signal at the receiving tower is converted back to digital form in an FFT, and the individual digital components are separated by orthogonal demodulators into the digital outputs to individual users.*

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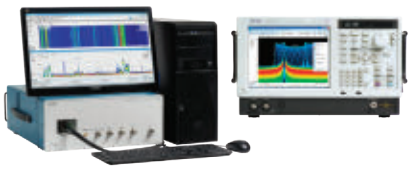

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GEORGIA TECH STUDENT, DIXIE CROW STEM SCHOLARSHIP RECIPIENT PLAYS IMPORTANT ROLE IN NASA MARS MISSION

A truly historic space event took place February 18; NASA landed its fifth rover, Perseverance, on the surface of Mars. The main mission is to search for signs of microbial life in the soil, collecting samples in the hopes a future mission can bring them back to earth – something that's never been done before.

Georgia Institute of Technology senior and Dixie Crow STEM Scholarship recipient Breanna Ivey tested out the math that helps the rover move during an internship last year.

"It [would] be exciting anyway, [even] if I didn't have a role in it, but it's even more exciting to know that I touched something that is going to land on Mars and be the first step in a mission to actually bring samples back," Ivey said. From Macon, GA, Ivey has been a recipient of the Dixie Crow Education Foundation STEM Scholarship for the last four (4) years while attending Georgia Tech in Atlanta, GA.

JOHN SHAWHAN: 2020 EXEMPLAR AWARD RECIPIENT

John Shawhan has been selected as a 2020 Dixie Crow Exemplar. The selection is long overdue but well deserved. John has been member of AOC since 1983 and has faithfully served the Dixie Crow Chapter since 1988. For more than six years, he has been the Chapter treasurer and has served as the Technical Programs Chairman for the annual Dixie Crow Symposium for many years.

John's government career spanned 38 years, during which time he held various positions as an electronics mechanic and equipment specialist for avionics systems and test equipment. He also served two tours of duty at Wright Patterson AFB, first as the Deputy Program Manager of Logistics Office as an acquisition logistician for development of radar, processors and displays on the F-15E. During his second tour, he helped stand up the Inter Command Electronic Warfare Management Office, where he interfaced with joint service Electronic Warfare Programs.

His tenure at Robins AFB includes 10 years as Chief of the Program Control Division in the Electronics Warfare Management Directorate, where he was responsible for Finance, requirements and administration. He served as chief of the B-52 ECM branch and Director of Tactical Airlift Squadron, where he was responsible for the Readiness Infrastructure of Air Force F-15, F-16, A-10, B-1, and B-52 fighter and bomber electronic warfare systems. His final assignment before retiring in 2009 was Squadron Director of the U-2 and Global Hawk Program.

AOC ACCEPTING SCHOLARSHIP APPLICATIONS

AOC Raytheon STEM Student of the Year Scholarship

Two $12,500 scholarships will be awarded in May 2021 to one male and one female student studying in the fields of engineering or engineering technology and interested in working in the Aerospace and Defense Industry. These scholarships are funded by a generous $25,000 donation from Raytheon Intelligence & Space. Scholarship applications are due by April 30, 2021.

www.crows.org/scholarship program.

US Army Cyber Corps Warrant Officer Scholarship Program

The Cyber Corps Warrant Officer Scholarship was established by the Laurie Buckhout Foundation August 2020 under the AOC Education Foundation (AEF) and registered as a Non-Profit status under 501(c)(3) of the Internal Revenue Code. The Cyber Corps Warrant Officers Scholarship Foundation is a non-profit organization dedicated to providing support to US Army Cyber Corps (i.e., 170A, 170B, and 170D) warrant officers by providing them with financial assistance in gaining various levels of formal higher education. Awards range from $1,500 to $3,000. To qualify, applicants must be a CW3 or under, demonstrate excellent promotion potential, be in the Cyber Warfare or Electronic Warfare (EW) workforce (i.e., 170A, 170B, and 170D), have a minimum of two years left on active duty, and be eligible and accepted to attend a Masters or PhD program. Applications are due by March 31, 2021. www.crows.org/USA_WO_Scholarship.

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Project Manager:
Tabitha Jenkins
Direct: +1 (352) 333-3468
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Project Coordinator:
Amanda Glass
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Advertising Sales Representatives:
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Textron Systems	TextronSystems.com	5
Ultra Electronics Limited – EWST	ultra.group/intelligence-communications	3

JED QuickLook

Details	Page #
19th Air Force, USAF, EMS 100 course	23
2021 AOC Scholarships	38
350th Spectrum Warfare Wing, USAF	23
5G communications basics	34
AFRL, Broad Agency Announcement (BAA) for Enabling Cyber-Linked Physical Sensing Exploitation (ECLPSE) program	15
Air Force Research Lab Sensors Directorate, Multi-Domain Sensing Autonomy Division (AFRL/RYA)	15
BAE Systems, contract for Low Rate Initial Production (LRIP) of F-15 Eagle Passive Active Warning and Survivability System (EPAWSS)	19
BAE Systems, Tactical High-Power Microwave Operational Responder (THOR) system	17
Brig Gen (Sel.) Michael Manion, USAF, Director, EMS Superiority Directorate (HAF/A5L)	23
Brig Gen David Gaedecke, outbrief of EW ECCT findings	22
Col Jason Avram, Senior Materiel Leader, Airspace Mission Planning Division, PEO Digital, Air Force Airspace Mission Planning Division/Air Force Life Cycle Management Center (AFLCMC)	26
Col Lisle H. Babcock, Commander, Curtis E. LeMay Center for Doctrine Development, Lessons Learned, and Education, Maxwell Air Force Base	20
Col Ryan C. Conner, Chief, Management and Integration Division (HAF/A5LI), Electromagnetic Spectrum Superiority Directorate (HAF/A5L), USAF	20
CW3 James Turner, US Army 10th Mountain Division	29
Cyber-physical MASINT	16
Dixie Crow Exemplar Award: John Shawhan	38
Eletrronica, The EMSOpedia	32
EW-kinetic effects	16
Gen Stephen Wilson, USAF, establishing Electronic Warfare Enterprise Capability Collaboration Team	22
Irving Shipbuilding Inc., Canadian Surface Combatant (CSC) program	15
Joint Pub 3-85 Joint Electromagnetic Spectrum Operations	12
Kathy Cahill, Airspace Mission Planning Division co-lead, Electronic Warfare Working Group (EWWG)	26
L3Harris Wescam, Canadian Surface Combatant (CSC) program	15
Leidos, Tactical High-Power Microwave Operational Responder (THOR) system	17
Leonardo, BriteCloud 218 DRFM RF decoy launch	19
Lockheed Martin Canada, Canadian Surface Combatant (CSC) program	15
Lt Gen Neil Thurgood; director for Hypersonics, Directed Energy, Space, and Rapid Acquisition; Army Rapid Capabilities and Critical Technologies Office (RCCTO)	17
LTC Edward Ortiz, US Army 10th Mountain Division	29
MAJ Luke Plante, US Army 10th Mountain Division	29
MAJ Richard Purcell, US Army 10th Mountain Division	29
MDA, contract for CSC program Warning and Countermeasure (LWCM) system	15
Tim Moulton, Mission Planning and EW and FMS Engineering, ADLCMC	26
US Air Force Life Cycle Management Center (AFLCMC), Intelligence, Surveillance, and Reconnaissance/Special Operations Forces (ISR/SOF) Directorate, Medium Altitude UAS Division (WII)	15
US Air Force Research Laboratory (AFRL), THOR system	17
US Army, Indirect Fire Protection Capability rapid prototyping program	17
USAF Annex 3-51 Electromagnetic Warfare and EMS Operations	22
USAF LeMay Center for Doctrine Development, Lessons Learned and Educations	22
USAF, Request for Information (RFI) for Next-Generation (Next-Gen) Multi-Role Unmanned Aerial System (UAS) Family of Systems (FoS) EMS technologies	15
Verus Research, Tactical High-Power Microwave Operational Responder (THOR) system	17

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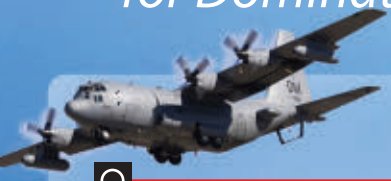

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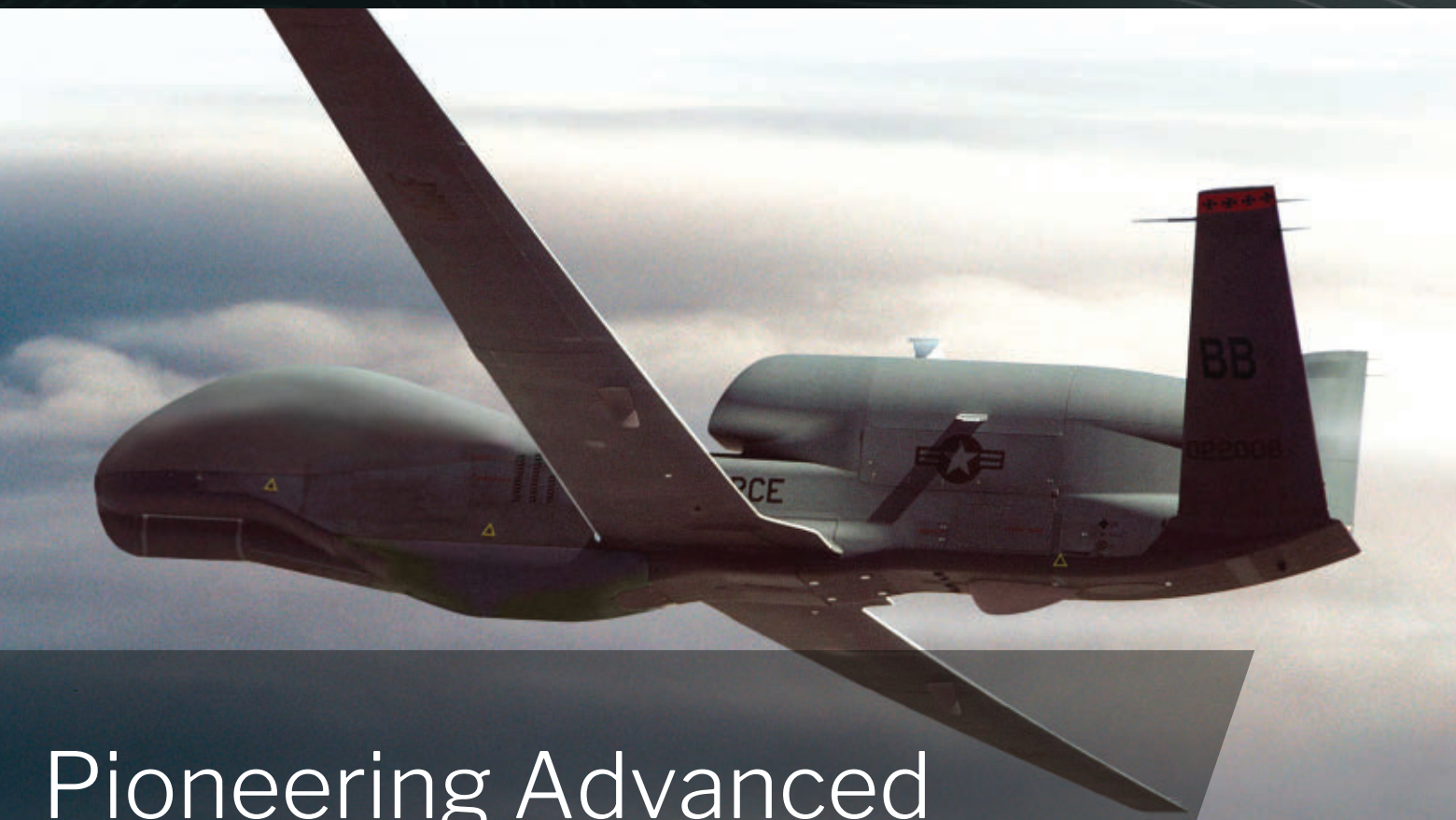

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