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December 2020 Vol. 43, No. 11

JED

Journal of Electromagnetic Dominance

Russia Brings Radioelektronnaya bor'ba to the Fore

- Solving the Curse of Interference
- The Development of JEMSO Doctrine
- EW 101: Space EW – Jamming Downlinks

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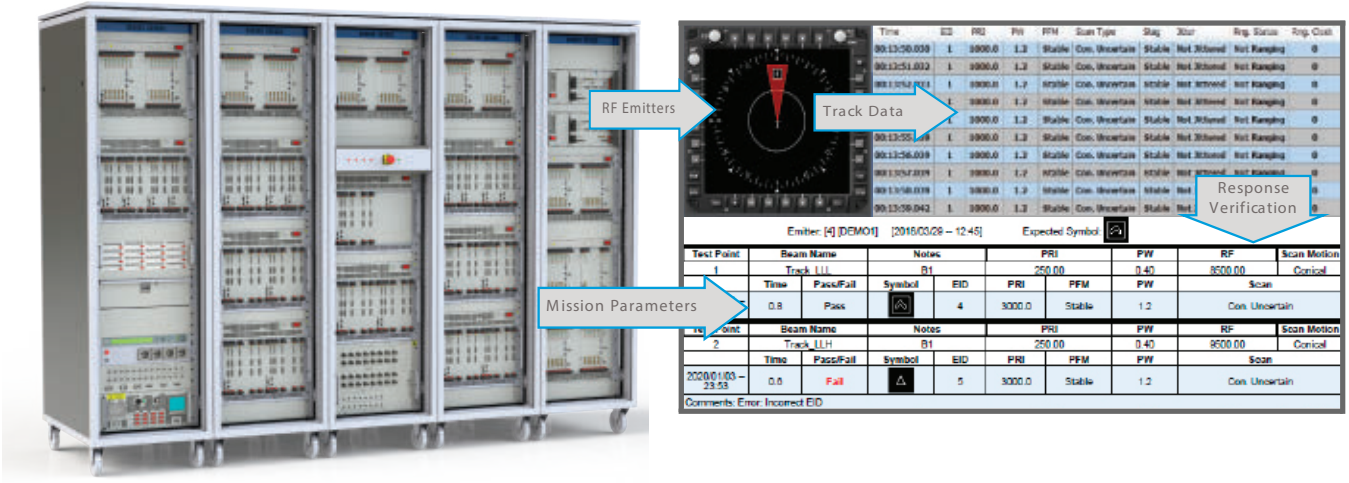

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ULTRA

JED
Journal of Electromagnetic Dominance
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Tuning in, Turning on: Russia Brings Radio-Electronic Combat to the Fore
By Richard Scott

Operations over the past decade have served to demonstrate the importance Russia attaches to electronic warfare – or radio-electronic combat (radioelektronnaya bor'ba - REB) – as an intrinsic part of its military doctrine. Fortunately, the reinvigoration of Russian EW – and its implications for military thinking across the NATO alliance – have not gone unnoticed by strategic think tanks and research institutes in the west. RUSSIAN MOD

15 News

- DOD OFFICIALLY ROLLS OUT ITS EMS SUPERIORITY STRATEGY
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A US Navy E/A-18G Growler, from the "Cougars" of Electronic Attack Squadron (VAQ) 139, flies over the US Central Command area of responsibility in support of Operation Inherent Resolve Sept. 25, 2020. This photo was taken as the aircraft approached a KC-135 tanker for refuelling. U.S. AIR FORCE PHOTO BY STAFF SGT. JUSTIN PARSONS

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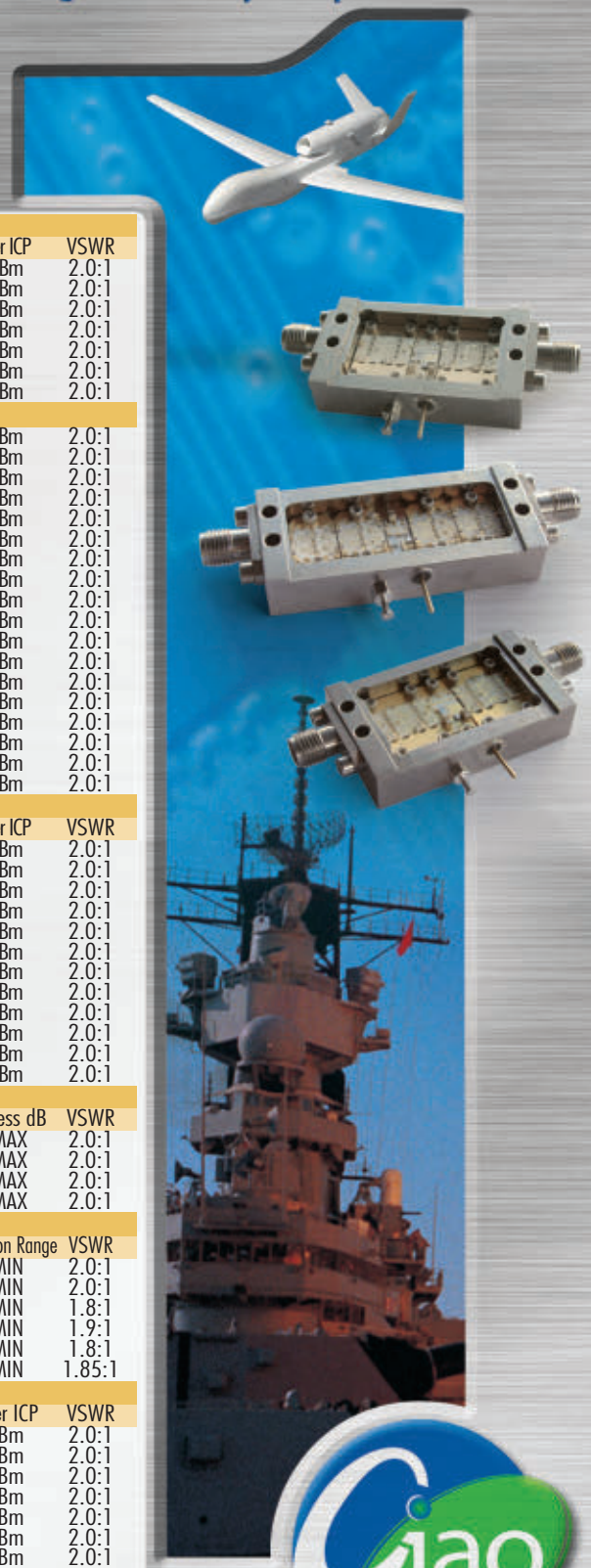

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
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

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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A TALE OF TWO PARTNERS

In October, the Royal United Services Institute (RUSI) released an interesting "Whitehall Report" by Research Fellow Justin Bronk. Titled "Russian and Chinese Combat Air Trends," the study includes several findings, especially about the relative capabilities of Chinese and Russian combat aircraft. While China for decades had depended on Russian aerospace and electronics technology, it has now begun to surpass Russian technology in several key areas. Using the Su-27/30 Flanker family (and its derivatives) as a baseline, Bronk discusses how China's Flankers (featuring Chinese-made AESA radars, datalinks, EW systems and air-to-air missiles, etc.) are now more capable than Russia's Flanker aircraft. The report suggests that China – not Russia – will be the most prominent non-western exporter of combat aircraft technology in the coming decades. In fact, Russia may someday find itself turning to China for radars, EW systems and datalinks, as well as missile seeker technology.

Western governments have been focused on Russian military technology for so many decades that some of them may find it difficult to recalibrate their thinking and understand China as a dominant defense technology supplier. For the global defense electronics market, China's emergence as a leading exporter represents a shifting of the tectonic plates, and it will no doubt affect geopolitical strategy for the US and its allies.

What also struck me about the RUSI report was the way it illustrated the technological stagnation of Russia's defense electronics industry. Since the end of the Cold War, Russia has focused its national strategy on controlling its near abroad. Many of these countries were equipped with Cold War-era Soviet weapons systems. Modernization opportunities in these countries were limited, and for many years, Russia's weak economy could not drive a lot of defense technology innovation. As a result, Russia depended on its strategic relationships with China and India to drive new defense technology investment. Even with Russia's more recent focus on defense modernization (spurred by its humiliating performance during the 2008 conflict with Georgia) this has not fueled a lot of new technology development – certainly not on the same level as China's.

If there are larger lessons to draw from the RUSI report, I think one of these is that any country's defense industrial base is extremely fragile. It doesn't take too many years of neglect for a technology leader to fall behind its competitors. And once that country falls behind, generating the momentum needed to recover a leading position requires at least a decade of resolve, focus and money.

This month, as we look back at what 2020 was (glad to see it in the rearview mirror) and look forward to what 2021 will be, western governments must remain focused on what it takes to compete in the global defense market. These countries will spend many, many years paying their respective bills for the COVID-19 pandemic. The strategic challenge for each of them is to ensure that their defense industries do not become "strategic" bill payers. – *J. Knowles*

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Journal of Electromagnetic Dominance

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Calendar *Conferences & Courses*

This month, we have combined *JED*'s courses and conferences calendars in an effort to provide readers with the most comprehensive list of upcoming EW, SIGINT and related EMSO learning opportunities and events. Conferences will be denoted next to event dates; all calendar listings not labeled as a conference will be courses or webinars.

Due to the disruptions caused by COVID-19, some event organizers have chosen to change the dates and/or venues of their events and courses. Please check the organizers' websites, or contact the event or course provider to receive the latest details.

DECEMBER

EWONLINE: 13TH Electronic Warfare Symposium
Conference: December 1-2
www.cranfield.ac.uk

SIGINT Fundamentals – Online
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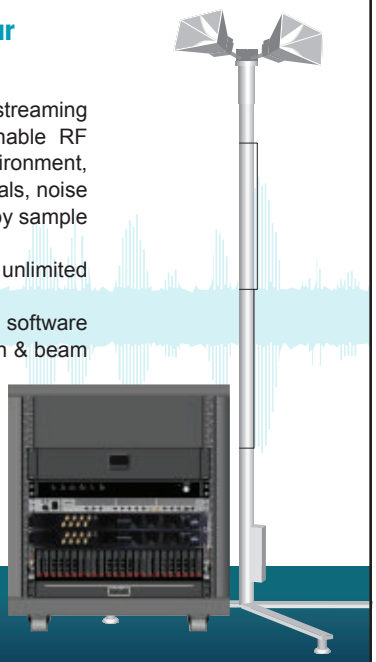

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Swindon, UK
www.cranfield.ac.uk

Surface Navy Association 33rd Annual National Symposium
Conference: January 12-14
Arlington, VA
www.navysna.org

AOC Virtual Series Webinar: An Overview of IADS (Integrated Air Defense Systems)
January 14
1400-1500 EST
www.crows.org

Fundamentals of Radar Signal Processing – Online
January 25-28
www.pe.gatech.edu

TechNet Augusta – Online and In-Person
Conference: January 25-28
Augusta, GA
www.afcea.org

AOC Virtual Series Webinar: When Crows Break Codes
January 28
1400-1500 EST
www.crows.org

FEBRUARY

DEPS Joint Conference on T&E Support to Prototyping and Experimentation
Conference: February 1-4
Albuquerque, NM
www.deps.org

Radar Electronic Warfare
February 1-5
Swindon, UK
www.cranfield.ac.uk

Aero India 2021
Conference: February 3-7
Bengaluru, India
www.aeroindia.gov.in

AOC Virtual Series Webinar: From Sarissa to Cyber Warfare
February 11
1400-1500 EST
www.crows.org

AFCEA West Conference and Exhibition
Conference: February 16-18
San Diego, CA
www.westconference.org

IDEX 2021
Conference: February 21-25
Abu Dhabi, UAE
www.idexuae.ae

Communications Electronic Warfare
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continued on page 10

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AFA Aerospace Warfare Symposium
Conference: February 24-26
Orlando, FL
www.afa.org

AOC Virtual Series Webinar: HF Meets Big Data – Intercept in an Era of HF Renaissance
February 25
1400-1500 EST
www.crows.org

MARCH

Advanced Radar
March 8-12
Swindon, UK
www.cranfield.ac.uk

AOC Virtual Series Webinar: CEMA and SIGINT: a Command and Control framework
March 11
1400-1500 EST
www.crows.org

MILIPOL Qatar 2021
Conference: March 15-17
Doha, Qatar
https://en.milipolqatar.com

Aircraft Survivability
March 15-19
Swindon, UK
www.cranfield.ac.uk

AUSA Global Force Symposium and Exposition
Conference: March 16-18
Huntsville, AL
www.ausa.org

Dixie Crow Symposium 45
Conference: March 21-24
Warner Robins, GA
www.dixiecrowsymposium.com

Counter IED
March 22-26
Swindon, UK
www.cranfield.ac.uk

AOC Virtual Series Webinar: The Year in Review – GPS/PNT Disruptions and Improvements
March 25
1400-1500 EST
www.crows.org

Counter-UAS Winter Summit – Online
Conference: March 31-April 2
www.idga.org

APRIL

AOC Professional Development Live Web Course: Fundamental Principles of Electronic Warfare
April 5-28
www.crows.org

LAAD Defence & 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

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

2021 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
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AOC events are noted in red. For more info or to register, visit crows.org. Items in blue denote AOC Chapter events.

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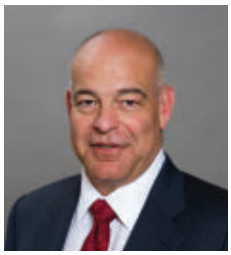

SUCCESS AND SUCCESSION

This month, the AOC Presidency will change hands virtually – a first, due to the global COVID-19 pandemic. Every AOC President has a vision for the organization and sets goals at the beginning of their term. As we look at the progress that our community has made, we can be proud of the influence and the impact AOC has had as we have balanced the need for continuity with the desire to respond to emerging challenges and opportunities.

Regardless of their strategic goals/tenets (advocate, educate and support), the AOC President has one tremendous resource they can rely on, which is the diversity of our membership. Where can you find a Crow? We are everywhere, and there is no single identity within our AOC membership. We represent many different communities and backgrounds, but under AOC, we all work together as one community focused on Electromagnetic Spectrum operations (EMSO). Our AOC members span the globe. We can be found in many types of jobs – academia, military service, industry, government, research, etc. We work across many disciplines, such as EW, SIGINT, Cyber and IO/IW. We develop a wide range of technologies across the Electromagnetic Spectrum (EMS). We operate and support all types of platforms that perform many types of missions across EMSO. We are the corps of professionals who have and will continue to drive EMS recognition, prioritization, and use as a maneuver space to ensure superiority and success in current and future warfare. This year was a challenge as COVID significantly impacted the way we do business and forced the cancellation or postponement of many of our key events. Still, we continue to push forward as a relevant and visionary organization. AOC staff worked hard to implement technologies and processes that enabled us to work in a virtual environment. We succeeded in providing relevant and timely events, webinars and training opportunities to our international community. As we enter an uncertain future, the AOC Board of Directors and staff continue to plan and prepare to react to the environment and execute our mission to support you, whether it is in a virtual, hybrid, or live face-to-face environment.

In closing, as we mark this transition from one AOC President to another, it is worth reflecting on the progress we have made and the challenges that still remain. Our success depends on your participation. So, please continue to inform, educate, mentor, collaborate, network and, above all, communicate the importance of our endeavors in the EMS. *Together* we will continue to make this organization better and keep AOC relevant and vibrant as we adapt to changing environments and requirements. *Together* we'll keep this great world in which we live safe and prosperous. "Thank you for a great two years." – *Muddy Watters* (retiring AOC President) and "Looking forward to a great two years." – *Glenn "Powder" Carlson* (incoming AOC President)

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Feb. 10 | 1 PM ET

General David "DT" Thompson

Vice Chief of Space Operations, United States Space Force
Jan. 13 | 2 PM ET

Gen. Charles Q. Brown, Jr.

Chief of Staff, Air Force
Jan. 27 | 1 PM ET

Air Chief Marshal Sir Stuart Peach

Chairman of the NATO Military Committee, NATO Headquarters
Feb. 3 | 10 AM ET

Vice Admiral Jeffrey Trussler

Deputy Chief of Naval Operations for Information Warfare, N2/N6, Office of the Chief of Naval Operations/Director of Naval Intelligence
Feb. 24 | 10:30 AM ET

Register at crows.org/discussions

DOD OFFICIALLY ROLLS OUT ITS EMS SUPERIORITY STRATEGY

The DOD formally released its Electromagnetic Spectrum Superiority Strategy (EMSSS) in late October. As reported in the November *JED* (p. 15), the EMSSS focuses on five goals, and it establishes a new governance framework for the DOD. Last month, the DOD issued a press release that provided more details about the strategy.

The five goals of the EMSSS are: 1) develop superior EMS capabilities, 2) evolve to an agile, fully integrated EMS architecture, 3) pursue total force EMS readiness, 4) secure enduring partnerships for EMS advantage, and 5) establish effective EMS governance.

In the November 3 press release accompanying the EMSSS announcement, Fred Moorefield, deputy chief information officer for command, control and communications explained what spectrum superiority means. "Superiority means being able to access the spectrum, use any frequency you want to, be able to maneuver…and deny the enemy access to the spectrum at the same time," he said. The EMSSS, he said, is driven by the "Cs": a contested environment, spectrum congestion and spectrum constraint.

With regard to a contested spectrum, Moorefield said, "We have to figure out how to be smarter than them and develop capabilities to allow us to be able to get access to the spectrum whenever we need it, and however we need it and to also be able to deny the enemy the same access. We call that 'freedom of maneuver' within the electromagnetic spectrum."

Of congested spectrum, he said, "The spectrum space is getting more and more crowded. That includes 5G, the next G coming, SATCOM, tactical radios, commercial and federal – everybody's using spectrum more and more. So, we have a congestion problem, everything is crowded."

Finally, he addressed EMS constraints, explaining, "We don't have that big access and use that we used to have. DOD used to use a spectrum any way they wanted to. Those days are over. That constraint is limiting us in our ability to train as we fight."

One major aspect of the EMSSS is to change the way DOD and other parts of the US government manage EMS access. "Today, spectrum is managed by static frequency assignments and licenses. We have to get dynamic, flexible and cognitive to be dynamic enough to be able to move around at different frequency bands." Going forward, the DOD wants to utilize wideband cognitive systems (radars, radios, EW, GPS, etc.) that can sense congested frequencies and shift their activity to less congested frequencies. "We're trying to get to autonomous kinds of operations, meaning machine-to-machine," Moorefield said. "You've got the machines talking to each other. You won't have to have segregated allocations. You'll have the machine built to be able to tune across a variety of different frequency bands. It'll listen within the environment. And it'll be talking to another machine and say I'm using this frequency; you move to another frequency."

If cognitive systems are widely implemented, this will enable the DOD to embrace spectrum sharing – giving up sole access to some DOD spectrum while gaining access to other portions of spectrum it currently does not have access to. This marks a significant change in DOD spectrum policy, and it will drive significant investment and cognitive innovation for future defense electronics systems. "We have to be able to reform acquisition [policies] so that they know that they can build capability to do that — to be able to be dynamic," he said. "Today we can't do that. The regulations don't support it. We have to reform the regulations to allow dynamic spectrum operations. We have to inform acquisition so they can now acquire those kinds of capabilities. We need to inform research and engineering so they can do the research and development, so that acquisition can purchase it."

The EMSSS was written by the EMS Operations Cross Function Team (EMSO CFT), and it lays out the new governance framework that the DOD will operate within. The DOD's Chief Information Officer will be responsible for EMS governance and policy. However, much of the strategy's success depends on the EMSSS Implementation Plan that the EMSO CFT is currently developing. The Implementation Plan will be released in the spring of 2021. – *J. Knowles*

US AIR FORCE ANNOUNCES EMSO-RELATED ORGANIZATION CHANGES

US Air Force leaders have announced two organizational changes as part of a larger strategy to focus more attention on EMS Operations (EMSO). An October 23 news release from the Office of the Secretary of the Air Force stated that the Air Force Spectrum Management Office (AFSMO) (Fort Meade, MD) had officially transferred from Air Combat Command's Communications Directorate (ACC/A6) to the Air Staff's Cyberspace Operations and Warfighter Communications Directorate under the Deputy Chief of Staff for Intelligence, Surveillance, Reconnaissance and Cyber Effects Operations. According to the announcement, "This is a vital move in a larger plan to support, from a Headquarters Air Force perspective, the synchronization of Information Warfare functions; a move which is happening at the right time for on-going developmental work to enable all-domain operations." The move follows 18 months after the Headquarters Air Force merged its ISR and Cyber Effects Operations directorates into a single staff entity.

"This is a critical step to information warfare integration and synchronization because command, control, communications, computers, intelligence,

surveillance and reconnaissance (C4ISR) is inextricably linked to EMS management," said Lt Gen Mary O'Brien, deputy chief of staff for ISR and Cyber Effects Operations. "To compete and win in competition as well as a high-end fight, our Air and Space Force activities and capabilities like EMS must not only be de-conflicted, but integrated with our service counterparts. The heart of JADC2 (Joint All Domain Command and Control) is that military activities in one domain must enhance the effectiveness of those in other domains and compensate for vulnerabilities, and I believe this move will help us in this area."

"Given the Air Force-wide scope of AFSMO's roles and responsibilities, bringing it back to the Air Staff is a natural fit," said Brig Gen Eric DeLange, director of Cyber Operations and Warfighter Communications, who will oversee the AFSMO efforts as part of the HAF Staff. "As we look to advance our efforts in Information Warfare, and with our focus squarely on cyberspace and warfighter communications that so heavily depend on the electromagnetic spectrum, I have no doubt that bringing AFSMO into the Directorate fold will create new and important synergies."

In a separate move, then Vice Chief of Staff Gen. Stephen W. "Seve" Wilson said during an Air Force Association streaming event shortly before he retired on November 13, that the Air Force will be standing up a new Spectrum Warfare Wing at Air Combat Command (ACC). While *JED* had reported on the new wing in its September 2020 issue (p.25), this marks the first official acknowledgement from senior leadership. In discussing EMS-related organization changes at ACC General Wilson said that ACC Commander Gen Mark Kelly will have "a spectrum warfare wing standing up down there under ACC with the right talent to be able to pull the resources in and get after this electromagnetic spectrum and be able to dominate across that spectrum." General Wilson also said, "As we look to the future – and I'm a passionate zealot on Spectrum Superiority – if we don't dominate the spectrum, we will lose across all the domains. It doesn't matter what domain you have – Air, Space, Cyber, Maritime, Land…it's a critical aspect of warfighting." The new 350th Spectrum Warfare Wing will incorporate units from the 53rd EW Group at Elgin AFB, FL, and like the 53rd EW Group, it will be organized under the Air Force Warfare Center. – *J. Knowles*

LACROIX ADVANCES VESTA ACTIVE OFFBOARD DECOY PROJECT

French countermeasures and pyrotechnics group Lacroix has embarked on a package of studies and associated risk reduction activities aimed at demonstrating the feasibility of an active offboard decoy deployed using an unmanned aerial vehicle (UAV).

The year-long concept development effort, known as VESTA (Véhicule Ejecté Support Tactique d'Autoprotection), is being funded under a call released in 2019 by France's Agence Innovation Défense. The project, being undertaken in partnership with specialist UAV house Aviation Design, is intended to establish the feasibility of a soft-kill anti-ship missile defense decoy that employs a maneuvering multi-rotor UAV carrier vehicle to deploy a jamming payload.

According to Lacroix, the VESTA decoy is intended to provide an additional and complementary layer of ship self-protection, operating inside the envelope of hard-kill anti-air guided missiles but further offboard than typical soft-kill seduction decoys. The current program is focused on the launch system and the performance of the multi-rotor carrier vehicle: the EW payload itself falls outside the scope of the project.

In Lacroix's concept, a rocket boost motor is used to power the VESTA round offboard. Once deployed to range, the air vehicle extends six rotor arms and transitions to controlled flight. The EW payload, housed in the forward section of the flight vehicle body, then begins to transmit a suitable jamming modulation.

Lacroix at this stage declines to comment on the payload, power and endurance envisaged of the flight vehicle, or whether it will incorporate a command link to enable maneuver commands to be received during flight. Options to use VESTA in either recoverable or expendable modes remain under consideration.

The current phase of the VESTA project is expected to conclude in early 2021.

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By this point, Lacroix intends to have finalized a preliminary design and architecture together with a full description of function and capability. – *R. Scott*

ROHDE & SCHWARZ ON CONTRACT FOR DUTCH TESLA-M PROGRAM

Rohde & Schwarz Benelux has been awarded a €1.8 million contract by the Netherlands Defence Material Organization to provide signal and spectrum analyzing and recording solutions for the TESLA-M (TESt Lane Analysis Mobile) program.

Under the terms of the contract, Rohde & Schwarz will provide equipment to be installed in a 4x4 Mercedes Sprinter van. Rohde & Schwarz Benelux has teamed up with Contour Advanced Systems for the integration and assembly of the TESLA-M vehicle.

The TESLA-M project will provide the Netherlands Ministry of Defence with a high-fidelity mobile measurement facility to test various types of electronic countermeasures configurations designed to protect troops from a wide variety of remote-controlled improvised explosive devices. Entering service in 2021, the TESLA-M capability is expected to have a minimum lifespan of nine years.

Rohde & Schwarz Benelux's scope of supply includes the R&S FSW signal and spectrum analyzer (offering analysis bandwidth for wideband-modulated or frequency agile signals); the R&S SMW200A vector signal generator (for digitally modulated signals required for the development of new wideband communications systems); and the R&S IQW wideband I/Q data recorder (offering wide recording bandwidth and high sampling rate and bit depth). – *R. Scott*

IN BRIEF

The **US Army Combat Capabilities Development Command (CCDC),** Aviation and Missile Center (AvMC), Technology Development Directorate - Aviation (TDD-A) is has issued a Request for Information (RFI) to solicit technical and cost proposals to conduct a science and technology (S&T) effort entitled Air Launched Effects Configurations, Trades, and Analyses (ALE CTA). This RFI focuses on the air vehicle portion of the ALE program. (Other aspects of the ALE program will focus on the ALE sensor and effects payloads to be integrated on the ALE air vehicles.) The Army wants to develop ALE as part of a manned/unmanned teaming concept that will use manned next-generation rotary-wing aircraft, such as the Future Attack and Reconnaissance Aircraft (FARA) and the Future Long Range Assault Aircraft (FLRAA) to launch ALE unmanned platforms from stand-off ranges and use them to remotely detect, iidentify and engage adversary air defenses, integrated fires complexes and EW systems. TDD-A wants to gather information about the development of advanced technologies to inform Air Launched Effects (ALE) Unmanned Aerial Systems (UAS) investment decisions. The ALE UAS CTA is planned to be a FY21-22 science and technology (S&T) effort (including conceptual designs and trade-space analyses) that will support ALE requirements and enable the Army to determine an an ALE acquisition strategy. Responses to the RFI are due by December 7. The point of contact is Kenny Hood, e-mail kenneth.m.hood.civ@mail.mil.

Leidos (Reston, VA) has won a contract valued at $10.3 million from the Air Force Research Lab, Directed Energy Directorate (Kirtland AFB, NM) for Pulsed and Continuous Wave Innovation for Integration and Effects Research (PACIFIER). This contract provides for enhanced experimental and predicative capabilities to address existing and emerging laser systems and to quantify the effects of high power continuous-wave lasers interacting with a variety of materials and targets. The scope of the work includes intelligence coordination for target and threat coordination; developing and demonstrating state-of-the-art engagement and engineering models for predicting laser effects; model verification, validation, and accreditation; and target vulnerability assessment. If the Air Force exercises all contract options, the work could extend to September 2025.

L3Harris Technologies Inc. (Clifton, NJ) has won a $97.5 million contract from the US Air Force to provide repair and return (R&R) services for line-replaceable items for the ALQ-211(V)4/8/9 Advanced Integrated Defense Electronic Warfare Suite (AIDEWS). These AIDEWS systems are flown on F-16s in service with the air forces of Chile, India, Oman, Pakistan, Poland, Turkey, Iraq and Morocco. The US Air Force Life Cycle Management Center (Robins AFB, GA) sustains these AIDEWS systems under the Foreign Military Sales (FMS) program. The contract will run through October 2025.

India's Ministry of Defence said that its **Defence Research and Development Organisation (DRDO)** has successfully conducted the latest round of flight tests of its New-Generation Anti-Radiation Missile (RUDRAM-1) and successfully hit an emitting target "with pinpoint accuracy." The missile, which began development in 2012, is India's first indigenously developed air-launched anti-radiation missile. The RUDRAM-1 uses GPS/INS navigation for mid-course guidance, as well as an anti-radiation homing seeker and a millimeter-wave active seeker for terminal guidance. The missile's range is reportedly 100 km. The first flight tests of the RUDRAM-1 against an emitting target took place in January 2019. During the recent tests, the missile was launched from am SU-30MKI fighter aircraft at a radiation target located on Wheeler Island off the coast of Odisha. India's SU-30MKIs are also equipped with Russian-made Kh-31 anti-radiation missiles, which the RUDRAM-1 would likely replace.

More than 75 technical experts from 10 **European Defence Agency (EDA)** member states, as well as Norway and Switzerland, took part in an online workshop in early October as part of an ongoing EDA study on high-power electromagnetic munitions (HPEMs). The HPEM study, which began in April, "will assess the key technology gaps and associated scientific challenges to develop future HPEM, with the aim to defeat electronics onboard systems deployed to future battlefield. Additionally, it will offer an overview of the European supply chain capabilities in this field, including its possible dependencies," according to a news release from the EDA. "It will also make recommendations how military users could best benefit from the op-

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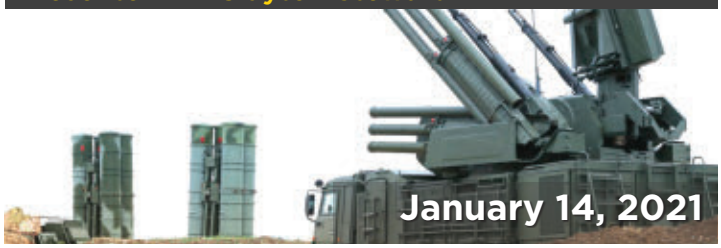

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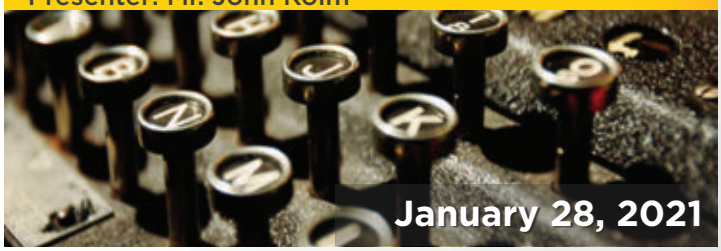

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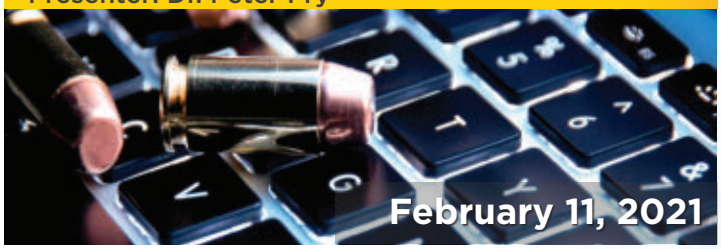

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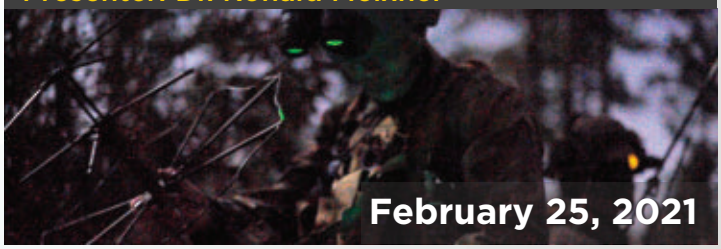

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Presenter: Claudio Santo Malavenda

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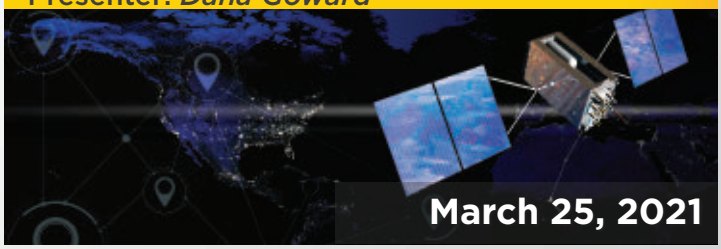
Presenter: *Dana Goward*



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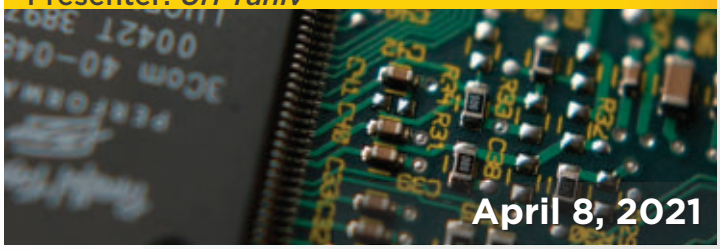
Presenter: *Uri Yaniv*



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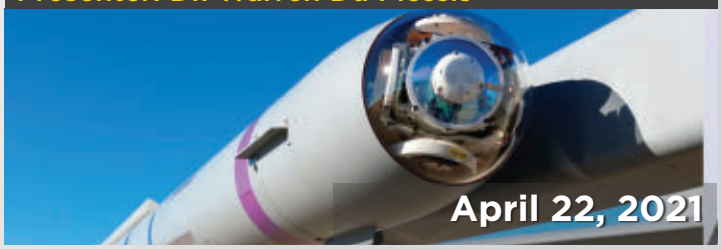

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portunities HPEM will offer for future warfare. Finally, the study will also help to better understand the HPEM-related vulnerabilities of military systems equipped with electronics, and identify areas where improvements are needed to toughen up future military equipment when facing HPEM threats." The study team plans to hold a second workshop in the spring of 2021. It is scheduled to publish its findings in October 2021.

The Taipei Economic and Cultural Representative Office in the United States (TECRO) has requested the sale of four weapons-ready MQ-9B remotely piloted aircraft (RPA) via DOD Foreign Military Sales (FMS) channels. The deal includes two fixed ground-control stations and two mobile ground-control stations. The MQ-9Bs will be equipped with **Leonardo's** SAGE 750 ESM system, **Raytheon's** SeaVue Maritime Multi-Role Patrol Radar, and **L3Harris's** MX-20 Multi-Spectral Targeting System, as well as datalinks and IFF systems. The total package is valued at $600 million.

In a separate FMS agreement, the United Arab Emirates has requested the sale of 18 weapons-ready MQ-9B RPAs. The proposed sale includes 18 **L3Harris** RIO COMINT systems, 25 **Raytheon** Multi-Spectral Targeting Systems-D (MTS-D) EO/IR sensors; and 19 **General Atomics** Lynx AN/APY-8 synthetic aperture radars (SAR) with ground moving target indicator (GTMI). The deal also includes an unspecified number of SAGE-750 ESM systems, SeaSpray 7500 maritime radar systems, anti-submarine warfare sensors, data links, IFF systems and various munitions in a package valued at $2.97 billion.

The US Army has announced that the Aviation and Missile Technology Consortium (AMTC) has issued a Request for Enhanced Whitepapers (RWP) that covers several helicopter and air defense topics. One topic (Requirement AV-20-03-06) addresses a Directional Countermeasures Dispenser. The description states the Army is seeking proposals to develop "...a prototype next-generation expendable countermeasure dispensing system..." and to "...demonstrate the ability to rotate and dispense expendable countermeasures in a predetermined orientation based upon threat system angle of arrival. The intent is to maximize expendable countermeasure effectiveness and increase platform survivability." The design also should minimize aerodynamic drag, integrate a communication interface to "smart" expendable countermeasures and implement a Future Airborne Capability Environment (FACE)-compliant architecture. Other topics include Aided Target Detection/Recognition (Requirement AV-20-03-03), Common Data Link Subsystem (Requirement AV-20-03-04), Mission Computer Subsystem (Requirement AV-20-03-05) and Air and Missile Defense Radio Frequency Sensor Prototypes (Requirement GM-20-03-07). More information is available from AMTC at www.amtcenterprise.org.

The US Air Force has issued a Request for Information (RFI) for counter unmanned aerial systems (C-UAS) capabilities with a specific focus on directed energy (DE) solutions. The **Air Force Life Cycle Management Center,** Architecture and Integration Directorate, (AFLCMC/XA) released the RFI for C-UAS capabilities for fixed-site Air Base Air Defense (ABAD) against Group 1 and 2 UAS threats. The Air Force is seeking C-UAS "Kill Chain" (Detect/Track/ID/Defeat/Exploit) improvement – either with improved technology, reduced kill chain timeframes, and/or operator interface and situation awareness. The RFI lists nine technology areas of interest. These include increased high-power microwave (HPM) lethality; EO/IR performance (tracking, targeting and identification); directed energy weapon (DEW) automation (identification, slew-to cue and aimpoint selection); integrating a DEW with existing C2, C3, or C4I network feeds to improve airspace surveillance and deconfliction; user interfaces; and threat track report generation. White paper responses were due November 17. However, one or more RFPs are expected to follow the RFI. The contracting point of contact is Christian Ryan, e-mail Christian.Ryan@us.af.mil.

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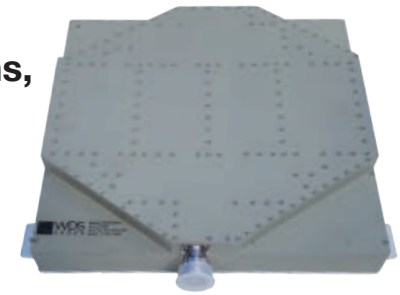

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Tuning in, Turni
Russia Brings R
Combat to the

By Richard Scott

While the western media has in recent years made much of the Kremlin's investment in advanced kinetic capabilities – notably hypersonic missiles, new strategic weapons, a nuclear-powered cruise missile, nuclear-armed torpedoes and laser weapons – it has given far less attention to another area of warfare where the Russian military poses an increasing challenge to the US and its NATO allies. Operations over the past decade have served to demonstrate the importance Russia attaches to electronic warfare (EW) – or radio-electronic combat (*radioelektronnaya borba - REB*) – as an intrinsic part of its military doctrine.

Fortunately, the reinvigoration of Russian EW – and its implications for military thinking across the NATO alliance – have not gone unnoticed by strategic think tanks and research institutes in the west. Recent studies in the unclassified realm, based on extensive surveys of open source literature, have provided valuable insights into how both political and military leadership in Russia has come to embrace REB as an enabler and a force multiplier.

Russian operations in eastern Ukraine and Syria since 2015 have enabled specialist EW ground force units to put theory into practice. The application of REB in these campaigns – in support of both kinetic and non-kinetic operations – has provided NATO with a very real and immediate demonstration of the importance of EW in a "hybrid" battlespace, and highlighted significant gaps in the Alliance's own capabilities.

During the Cold War, NATO recognized the criticality of EW supremacy and, conscious that any confrontation with Warsaw Pact forces would almost certainly be in a dense and hostile Electromagnetic Operational Environment (EME), invested accordingly in doctrine, equipment and training. The potency of this capability was demonstrated to great effect in 1991, as a US-led coalition air campaign systematically blitzed Iraqi air defenses.

However, the two decades of "violent peace" that followed the fall of the Berlin Wall saw the Alliance's EW capabilities and doctrines steadily atrophy. With no peer competitors to speak of, US forces and its NATO partners largely found themselves involved in counter-insurgency, crisis response and peace support operations in which they enjoyed a significant technological advantage. Adversaries, such as Serbia, Afghanistan and Libya, were equipped with aging and degraded integrated air defense systems, few (if any) naval defenses and a very limited ability to challenge NATO ground forces. From a threat perspective, this enabled NATO forces to operate in very permissive air, ground and naval environments.

As a result, NATO's EW focus during operations in Afghanistan and Iraq, for example, was largely confined to aircraft self-protection against IR-guided man-portable air defense systems (MANPADS) and protecting ground forces against remotely controlled improvised explosive devices (RCIEDs). All the while, the use of the EME for sensing, communications, navigation and targeting was becoming steadily more important to NATO forces.

> "Moscow's interest in boosting EW capabilities vis-à-vis NATO has its origins in seeking to asymmetrically challenge the alliance on Russia's periphery and maximise its chances of success in any operation against NATO's eastern members"
>
> *– Roger McDermott.*

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To this end, unhindered access to the EME became something of an article of faith rather than a strategic imperative.

Over the past decade, the return to great power competition, and particularly the resurgence of Russia as a military power, has forced NATO and other western militaries to confront a new set of challenges in the EME. Indeed, it is widely argued that Russia's EW strategy is an integral component of a wider anti-access/area denial (A2/AD) strategy that puts NATO's frontline states at risk.

This concern was front and center of Roger N. McDermott's report, *Russia's Electronic Warfare Capabilities to 2025: Challenging NATO in the Electromagnetic Spectrum.*[1] Published in 2017 by the Tallinn-based International Centre for Defence and Security in conjunction with the Estonian Ministry of Defence, the study outlined the scale of Russian EW investments in the context of its wider military capabilities, examined the organizational structure of its REB forces, and considered the practical implications for NATO's eastern flank using evidence from Russia's use of EW in recent conflicts.

"Moscow's interest in boosting EW capabilities vis-à-vis NATO has its origins in seeking to asymmetrically challenge the alliance on Russia's periphery and maximise its chances of success in any operation against NATO's eastern members" writes McDermott in the report's introduction. "Russia has consistently invested in EW modernisation since 2009, with modernised EW systems entering service across strategic, operational and tactical levels to augment capabilities of all service branches and arms."

He continues: "Modernisation of the EW inventory is set to continue in the State Armaments Programme up to 2025, which means Russia's military will benefit greatly from further advances in EW capability."

ASYMMETRY

For Russia, the big attraction of EW is its asymmetric impact in the face of Western technological supremacy. "REB is asymmetric in that it is not so much a force on force concept but rather a way to unravel a force simply through an indirect method [of] attacking frequencies," says Timothy Thomas in his introduction to MITRE's September 2020 report, *Russia's Electronic Warfare Force: Blending Concepts with Capabilities*[2] He goes on to describe how Russian EW practitioners seek a targeted and coordinated electronic blizzard to degrade sensors and communications, and so induce "disorganization" in adversary command and control.

This broad theme was also expounded in the American Security Project's (ASP's) April 2020 report, *Russian Electronic Warfare: A Growing Threat to US Battlefield Supremacy*, in which author Patrick Smith argues that Russia's investment in REB attempts to level up the technical superiority enjoyed by the United States – and by definition its NATO partners - in command, control, communication, computers and intelligence (C4I).[3] "EW can target communications the US uses to coordinate operations in multiple domains, or it can disrupt or degrade the navigation systems used by US forces to locate themselves and identify targets for precision guided munitions," he writes, adding: "In a struggle against a highly advanced foe like NATO, EW could help to level the playing field. Indeed, Rus-

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sia's interest in boosting its capabilities originated in an effort to asymmetrically challenge the more vulnerable member states on the alliance's periphery and maximize the chances of success in an operation against eastern NATO members before the alliance could organize a coordinated response."

Smith also sets the contribution of EW in the wider context of psychological operations (psyops) and cyber warfare. "The adage holds that armies march on their stomachs, but, today, modern militaries rely just as much on data feeds," he suggests. "In this environment, Russia thinks EW can play an integral role in a holistic approach to warfighting."

REB REGENERATION

While President Vladimir Putin had endorsed a long-term EW strategy and policy document as far back as 2002, most analysts trace the regeneration of Russian EW capability back to 2008, when the poor performance of forces and equipment in Georgia drove the Kremlin to launch major reform and modernization of the military. Since then, there have been sweeping changes to the training, force structure and integration of EW forces, and a substantial modernization of equipment capability (most notably in the ground forces).

In the Swedish Defence Research Agency's (FOI's) September 2018 report, *Russian Electronic Warfare: The Role of Electronic Warfare in the Russian Armed Forces*, author Jonas Kjellén points out that the formation of the EW Troops in 2009 was critical in that it elevated the status of the branch to that of other combat support arms.[4] "The immediate and probably single most important result of this was the formation of a headquarters for the EW commander within the General Staff," Kjellén says. "Since 2009, this enlarged EW command structure has been essential for the general development of Russian EW forces. It has enhanced coordination within the EW domain, provided better means of integration with other force structures and facilitated the comprehensive rearmament programme."

McDermott's earlier study detailed the transformation of Russian EW forces between 2009 and 2015, with previously disparate EW units spread throughout the military being reorganized at operational and strategic levels into brigades. "As a result, Russia currently has five EW brigades across its Military Districts, with two located in Western Military District – though this may well change in the future as demand for EW capacity increases," says McDermott. "Each of these brigades consists of four EW battalions and one company."

He continues: "Russia's most powerful EW systems— such as the Krasukha, Leer-3, Moskva and Murmansk-BN— are located in the Ground Forces' EW brigades; these systems offer ranges of several hundred kilometres. These brigades are tasked with providing combat support to the manoeuvre brigades, and can be broken down into smaller parts depending on the size of force and type of mission for which it is tasked."

Organizational change has been accompanied by significant investment in modernized equipment, says Kjellén. "Since 2009, new EW units have been

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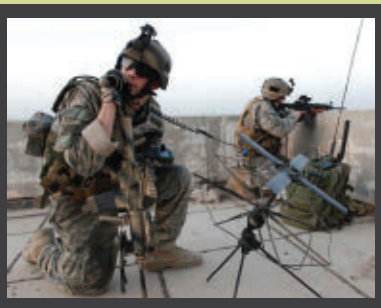

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formed, a large number of new EW systems have been procured, and new roles and tasks have been given to the EW Troops. Taken together, these form the 'new look' of Russian EW capabilities which has been enthusiastically propagated by members of the Russian EW community."

The last decade has also seen a significant recapitalization to upgrade the EW equipment inventory. "Not only have new pieces of EW equipment been procured in large numbers, but the number of different systems and complexes developed is also high," observes Kjellén in his FOI study. "In an interview in 2014, the EW commander [Major General Yuriy Lastochkin] disclosed that 18 new EW complexes had completed state trials in the period 2010-2013, 14 of which were mentioned by name: the Borisoglebsk-2, Alurgit, Infauna, Krasukha-2O, Krasukha-S4, Moskva-1, Parodist, Lorandit-M, Leer-2, Leer-3, Lesochek, Less, Magnii-REB and Pole-21.

"In addition to these 14 complexes, around ten new complexes have completed state trials since 2013, or are as yet unfinished projects that are publicly known about. It is also quite possible that recently fielded EW equipment exists that is not known about for reasons of greater secrecy or because numbers are low."

FOI's report also draws attention to the importance attached to command and control of EW complexes. "The main purpose is to increase the combat efficiency of EW units through information sharing and automated processes, but the aim is also to increase coordination of surveillance in the [electromagnetic spectrum] in peacetime," writes Kjellén. "This is an area that relies on technological capacities to create and field such EW command and control systems, but it is largely also an organizational issue that implies closer interaction among EW assets at different levels of subordination."

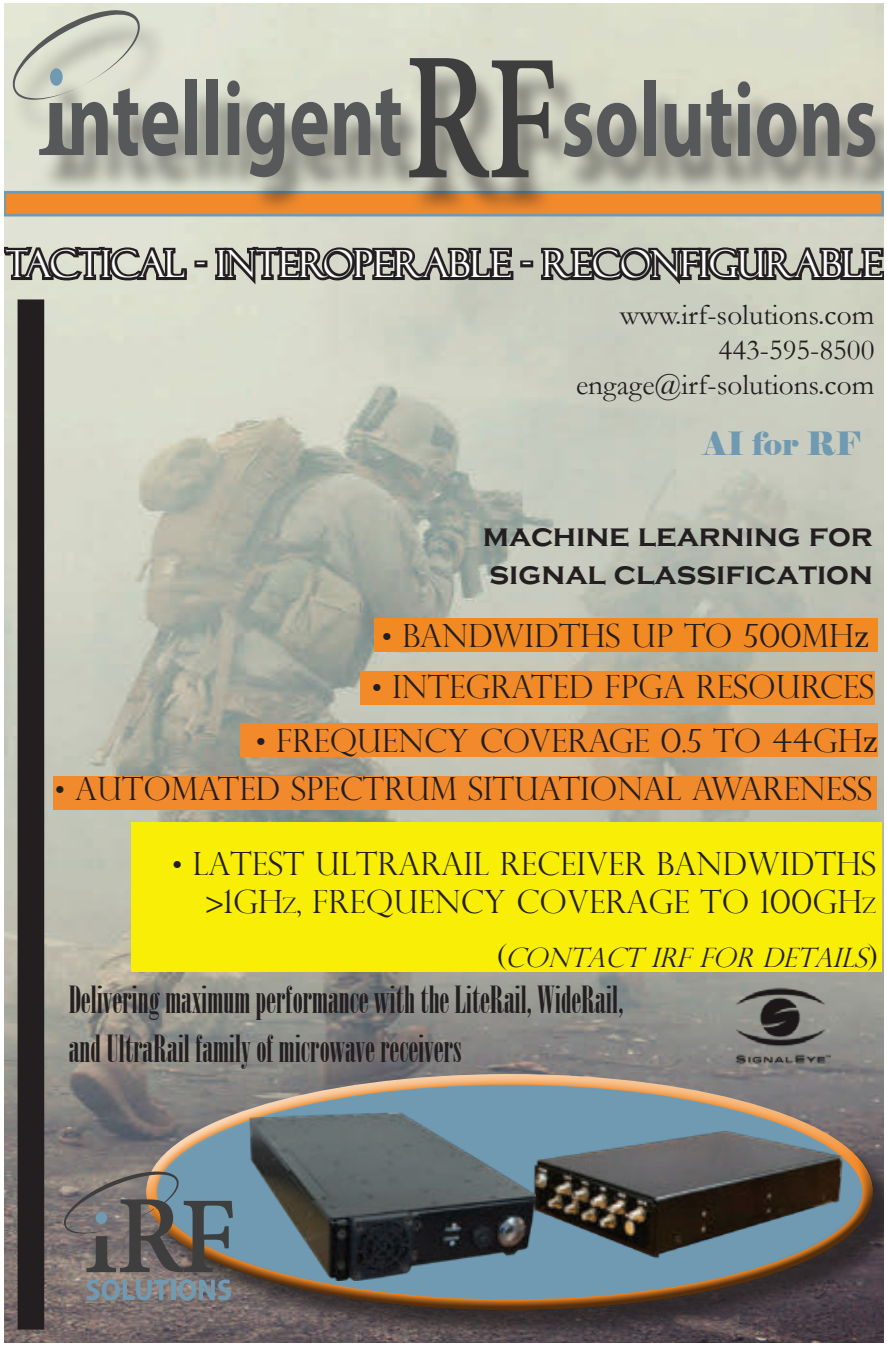
He adds: "The EW command and control systems will also be able to feed into, and retrieve information from, the non-EW command and control systems within the different branches of service and independent combat arms."

Another important waypoint in the regeneration of Russia's EW capability was a consolidation of the military industrial complex in 2009. This saw a number of companies brought under the umbrella of a single holding company known as JSC Concern Radio-Electronic Technologies (Kontsern Radioelektronnye Tekhnologii – KRET). A member of the State Corporation Rostec, KRET today has over 70 member companies, employing over 50,000 staff across Russia, engaged in engineering and manufacture of electronic systems for military, aerospace and civil markets.

PROVING GROUND

Russia's annexation of Crimea, and operations in the Donbass region of Ukraine, have offered an insight into Russia's employment of EW in a contemporary warfare environment. Indeed, the conflict in eastern Ukraine has been frequently described as a proving ground for Russian ground-based EW capability.

In his recent ASP report, Smith highlights how EW had been used to support kinetic operations in Ukraine, noting



that "Russia has managed to disrupt the Ukrainian military's communications equipment [forcing] Ukrainian soldiers to rely on their cellphones to communicate." Furthermore, while Russia uses EW to jam some communication, "it also used EW tools to intercept enemy communications and triangulate Ukrainian forces to target them with rocket artillery."

Effective application of EW also managed to turn some technology used by the Ukrainians against them. "Due to jamming and hacking, Ukrainian forces found US supplied Raven RQ-11B drones more of a liability than an asset," says Smith. "An advisor to the Ukrainian military noted the drones were no longer in use on the front lines because, among other things, they allowed the enemy to see Ukrainian military positions." Russia has also used EW as a tool in support of psychological operations, identifying Ukrainian military personnel through their cellphones and then sending intimidating text messages.

It is also no secret that the Organization for Security and Cooperation in Europe (OSCE) Special Monitoring Mission to Ukraine (SMM) has frequently found its UAV-based airborne surveillance operation disrupted by hostile jamming. As a result, some of the Scheibel S-100 Camcopters used by the OSCE SMM have crashed, while others have entered auto-return mode. In other cases, Camcopter missions have been disrupted by GPS jamming.

McDermott's ICDS study digs deeper into the Russian employment of REB in Ukraine. He points out that while much of the Russian EW activity in the Donbas region was clandestine – given that it was being undertaken in support of separatist elements – there is no doubt that it has allowed the Russian military to gain vitally important experience in exploiting EW assets in a range of operational settings. He identifies a number of use cases: EW to target Ukrainian unmanned aerial systems by jamming control links or GPS signals; electronic countermeasures to disrupt electronically-fused munitions fired from artillery and mortars; the disruption and degradation of enemy communications such that there were localized blackouts; and the detection and geo-location of electromagnetic emissions to support counter-targeting.

Russia has deployed both in-service EW systems and new equipment undergoing trials into theater. Based on open sources and his own interviews, McDermott's report identifies a number of novel aspects to operations. For example, the use of highly mobile tactical EW groups constantly changing location to avoid destruction under fire, and experimentation with new EW algorithms. However, he saw the chief innovation being the much larger scale use of EW in support of operations, with the Russian General Staff apparently assigning considerable importance to the testing of new tactics, and evaluating the effectiveness of automated and mobile systems.

The ICDS report also refers to two occasions during the Ukraine conflict when Russian units and equipment intervened directly to support separatists. "These were marked by typical combined-arms approaches to warfare," says

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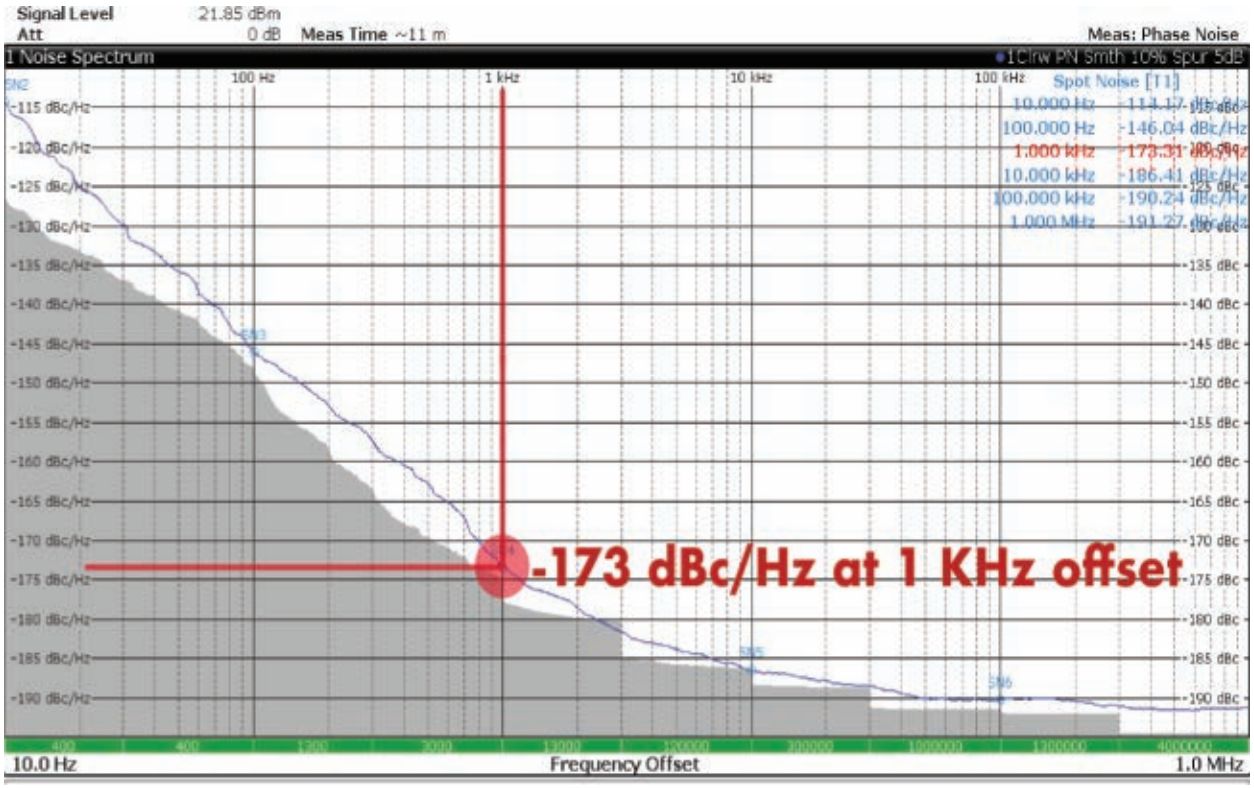

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McDermott, "and in each case, Russian and proxy forces quickly secured local victory. However, also present in each instance were EW assets and the use of EW in preparing, conducting and completing the local operation."

The first instance, in August 2014, was in Ilovaysk, located 25 km east of Donetsk. In this case, says McDermott, "a series of kinetic contacts precipitated the encirclement of Ukrainian forces by Russia's Armed Forces units from Pskov and Kursk; this involved the deployment of battalion tactical groups, reconnaissance and sabotage groups including EW units, transferred from Russian territory to the conflict zone. Ahead of the engagement, EW assets were also arriving in the area in preparation for the ensuing operation; these were to be used to suppress enemy communications."

Systems deployed included Leer-2, Rtut-BM and Lorandit (to intercept, geo-locate and jam GSM networks), Krasukha-2 and Krasukha-4 (for suppression of hostile surveillance/fire control radars) and Borisoglebsk-2 (designed to disrupt C2 networks). Russian EW assets

Russia places significant emphasis on training its EW operators. RUSSIAN MOD

were tasked with suppressing radio communications at tactical and operational levels, fixing and locating enemy forces by identifying EMS usage, disrupting C2, blocking mobile phone networks, and spreading false information as part of psyops.

McDermott highlights two particularly important areas of Russian EW use in Ilovaysk: fixing and targeting for artillery; and the complementary exploitation of EW to facilitate psyops. "Russian EW systems would detect enemy communications transmissions, including mobile phones, to provide target information to conduct artillery strikes. Moreover, by disrupting [the] enemy's mobile networks and transmitting data, some instances involved Ukrainian personnel receiving negative text messages on their phones, aimed at undermining morale. Such psyops and EW integration may not have been on a wide scale, but it certainly took place sporadically and among significant numbers of [Ukrainian] personnel."

The second case of direct support occurred in January-February 2015, when the area around Debaltseve witnessed a surge in fighting. "As in Ilovaysk, Russian EW systems were deployed in advance to prepare the battlefield and during the combat operations," said McDermott. What differed on this occasion was the use of a comprehensive technical EW monitoring group tasked with monitoring the EMS, apparently using the experience gained earlier in Ilovaysk. "EW assets were deployed by Russia's armed forces for direction-finding/geo-location, disrupting enemy communications among other features. This also used automated jammers," he writes.

According to McDermott, the overall scheme of EW operations implemented a highly automated degree of spectrum

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monitoring, interception, jamming and intelligence analysis, working closely with SIGINT and providing information in real time. "Russian groups again used EW systems, most likely Leer-3, to facilitate psyops...with numerous reports of Ukrainian military servicemen receiving text messages aimed at undermining their morale. Likewise, the high level of accuracy in artillery fire stemmed from successful employment of EW to fix and locate enemy targets by identifying mobile phone emissions in communications between [Ukrainian] servicemen," he writes, adding: "The importance of Russian EW in these kinetic operations in Ukraine offers deeper insight into how such assets will be exploited in future conflict."

McDermott concluded that Russia's military involvement in the Donbas region, more than any previous conflict, provided not only valuable opportunities for experimentation "but also marked a closing of the gap between the theory underlying EW and its application in support of combat operations." This ranged from "warping information in support of psyops, to jamming, blocking and disrupting the adversary's communications and radars, and disorganising the enemy's ability to conduct C2 during operations."

While President Vladimir Putin had endorsed a long-term EW strategy and policy document as far back as 2002, most analysts trace the regeneration of Russian EW capability back to 2008, when the poor performance of forces and equipment in Georgia drove the Kremlin to launch major reform and modernization of the military.

CONCLUSIONS

There is a broad consensus that NATO must sit up and take notice of how Russia's revitalized EW capabilities have fundamental and long-term implications for NATO. That said, analysts also voice caution regarding the true nature of the threat, pointing out that Russian media is prone to over-exaggerate the performance of domestic systems.

For example, Kjellén points out the difficulties in accurately assessing Russian EW capabilities. "Much of EW is often shrouded in military secrecy, and the often complex technological nature of EW breeds misconceptions that occasionally create and fuel myths," he writes. "The deterioration in relations between Russia and the West, involving both deliberate Russian disinformation and a 'Russia scare', has added to this problem."

However, Kjellén suggests that changes in organization support the view that EW now enjoys higher in status in Russian military thinking. "The formation of EW Troops is the most important factor, but the weight of EW in the Russian armed forces has also generally increased. There are now larger and more capable EW sub-units in both the Ground Forces' and the Airborne Troops' major combat formations.

"Denying a high-tech adversary the ability to make use of its command and control system undisturbed is now perceived as crucial to modern warfighting, at both the tactical and the operational level. Moreover, the creation of large EW formations and an expanded EW command structure represent an unprecedented capability for the Russian Armed Forces to conduct EW combat support operations at the theater level."

MITRE's report also identifies the targeting of NATO C2 as a priority for Russian EW forces given the impact this could have on decision-making. According to Thomas, while the West worries about Russian A2/AD concepts, "it is more likely that Russia is putting together a program that will cause chaos in Western control systems through the disorganization of adversary command and control." He continues: "The Russians are now expanding the use of REB as an independent branch, experimenting with REB maneuver units, and focusing on developing a disorganization plan for use in each REB brigade."

In his ICDS report, McDermott argues that Russia's exploitation of EW assets in support of operations in southeastern Ukraine "offers very limited lessons for NATO as such, since the alliance can field advanced technological assets way beyond anything that [Ukraine] can bring to bear.

"Moreover," he adds, "some Russian claims to be able to completely technologically degrade the EMS are palpably false."

That said, McDermott fully acknowledges that, through force multipliers such as EW, the continued transformation of the Russian armed forces "will offer a conventional capability way beyond that possessed by the Soviet legacy force" at the end of the Cold War. He continues, "If conflict with Russia ever erupts on NATO's Eastern Flank, the first sign of activity will be in the EMS – and in this spectrum the initiative and advantage will be determined.

"Moscow appears to perceive this as an area of possible weakness on the part of the alliance, and has therefore invested in further strengthening this capability. This means that NATO must change its approaches to policy, doctrine, organisation, capabilities, training, tactics and procedures, and exercise scenarios."

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Solving the Curs

By Barry Manz

Interference is the bane of every system, from EW to radar, communications and GPS, and it is one of the most difficult problems to defeat because it can result from an enormous number of sources. Interference comes not just from adversaries (in the form of jamming) but also from friendly forces, from equipment interfering with itself (i.e., self-interference), and from passive intermodulation distortion (PIM) that is often not only exceedingly difficult to locate but appears seemingly out of nowhere. Facing challenges like this, it is no wonder that developers of military technology are addressing interference mitigation more aggressively than ever.

AN EARLY PROBLEM

From an historical perspective, interference has been around since 1844, when Samuel F. B. Morse tapped "What hath God wrought" and sent it over wires from Washington to Baltimore. Once the table radio became widely available, beginning in the 1920s, it was a must-have household appliance, and listeners were happy enough just to receive broadcasts despite a level of interference that would intolerable today.

Early radio listeners had to contend with atmospheric noise, as well as electrical interference created by household electrical appliances with no shielding, along with the buzz from power lines. In addition, AM broadcast transmitters, which generated increasing amounts of RF power, created very strong harmonics and spurious emissions that became worse after sundown, when stations could be heard for thousands of miles.

The invention of the superheterodyne receiver by French officer Lucien Lévy and American officer Edwin H. Armstrong (who got there first is still disputed) allowed radios to receive signals from much further away, paving the path for more advanced commercial and military RF systems. Unfortunately, with longer reception came even more interference.

It became such an important issue that in 1933 the International Special Committee on Radio Interference (CISPR) was created within the International Electrotechnical Commission to harness it. In 1934, CISPR began to release the first of what would ultimately become a massive number of requirements for allowable emissions levels and immunity limits for electronic devices that today govern every type of electrical product and covers frequencies from DC through 400 GHz.

In 1967, the Department of Defense (DOD) created Mil-STD-461A, which established testing and verification requirements for electronic devices being used in defense systems, as well as emissions and susceptibility limits for new military electronic equipment. The FCC in 1979 added legal limits on EMI for digital equipment. Avionics and aerospace engineers investigated EMI-related issues to better understand interference sources, first using Faraday cages and eventually implementing better electronic designs and layouts, as well as shielding and filtering. These regulations have continued to evolve over the years as systems have become faster, smaller and more powerful with a greater propensity to interfere with each other.

Nevertheless, even with all these requirements, the world is still plagued by interference – and it is getting worse as the densely populated spectrum below 6 GHz becomes saturated with more signals from a variety of military and commercial radars, telecommunications devices and towers, as well as other systems and devices. As these technologies expand their use to higher frequencies, greater interference will come with them.

THE BASIC PROBLEM

Interference is most widely discussed in terms of its effect on commercial wireless systems whose problems are inherently well defined. In contrast, those of defense systems are as unpredictable as the adversaries they face, and they are deluged by interference from licensed, unlicensed, unintentional, self-induced, and sometimes outright bizarre sources, such as PIM. The transition from analog to digital modulation techniques, as well as direct RF sampling receivers, have created new hurdles to overcome, too.

At a high level, the problem appears simple: keeping interfering signals from degrading receiver performance. But achieving this is extremely difficult. For example, transmitters cause intermodulation distortion, harmonics and spurious emissions that can overwhelm the receiver's front end. When this occurs, its signal-noise ratio is degraded and it can, in the worst cases, make it impossible for the receiver to detect the desired signals.

Well-known techniques for reducing these emissions include operating amplifiers below their saturation point (back-off), as well as analog and digital pre-distortion and reducing phase noise. Increasing the linearity of the receiver also aids in preventing intermodulation products from interfering with the desired signals.

In the receive chain, the most effective solution for reducing interference has long been the venerable analog bandpass filter, whose ability to reject out-of-band signals is exceptional. The bandpass filter **(Figure 1)** passes frequencies within a narrow range while rejecting (attenuating) frequencies outside that range. The level of rejection can be very high – 50 dB or more – effectively reducing the signal strength of interferers to manageable levels. But a bandpass filter rejects signals only over a specific range of frequencies. Switched filter banks are another solution often used to cover multiple frequencies, but they can become large. Digitally tunable filters, which can provide greater protection over wider bandwidths, offer yet another approach.

Even though they are sometimes considered archaic, filter technology offers an effective solution to interference. Filters, addition to interference cancel-

e of Interference

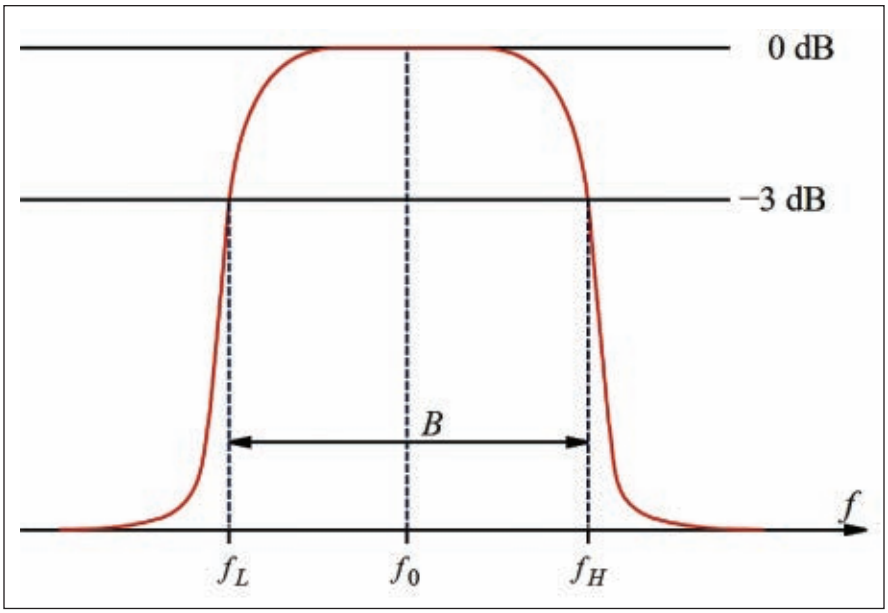

Fig. 1: *The bandpass filter has served every RF application well for decades, as it reduces interference to a significant degree outside the frequency of interest.* WIKIPEDIA

lation, are the primary mechanisms by which the most advanced interference mitigation systems are constructed.

Remedies such as these can obviously be applied only to systems over which the owner has control, and obviously are not applicable to those of adversaries or even operators of licensed and unlicensed systems. As a result, they represent a solution to just one set of interference problems, but this is more than enough to keep designers up at night.

THE COMPLEX PROBLEM

There is also the onerous problem of interference caused by PIM that is different from other forms of intermodulation distortion. PIM is not generated by active (non-linear) components, such as amplifiers, but rather by components normally considered linear, such as antennas, attenuators, cables, duplexers, diplexers, filters, and connectors, in which oxidation or other effects may cause them to become non-linear.

PIM appears when two or more signals are present in a passive non-linear device and they mix to produce other signals related to them. Unlike mixers, in which such a result is desired, in the case of PIM the effect is undesirable. If these unintentionally mixed signals are significantly weaker than the desired signal, they may have no effect on a receiver. But if they occur after the combining stage, for example, they can reach levels high enough to form distortion products at amplitudes high enough to degrade receiver performance. While active components like amplifiers can produce extremely high levels of distortion, this type of interference can be removed by filtering. PIM typically cannot be removed in this way, because it can be generated late in the transmit signal path or outside the system entirely.

PIM has typically been considered a problem for systems generating high RF power levels, a misnomer that has remained in its definition primarily because high-power systems, such as the radars and satellite communications systems on surface combatants and AM, FM, and TV broadcast installations, were

Fig. 2: *The rusty bolt effect has been a major source of problems on navy ships for decades.* WIKIPEDIA

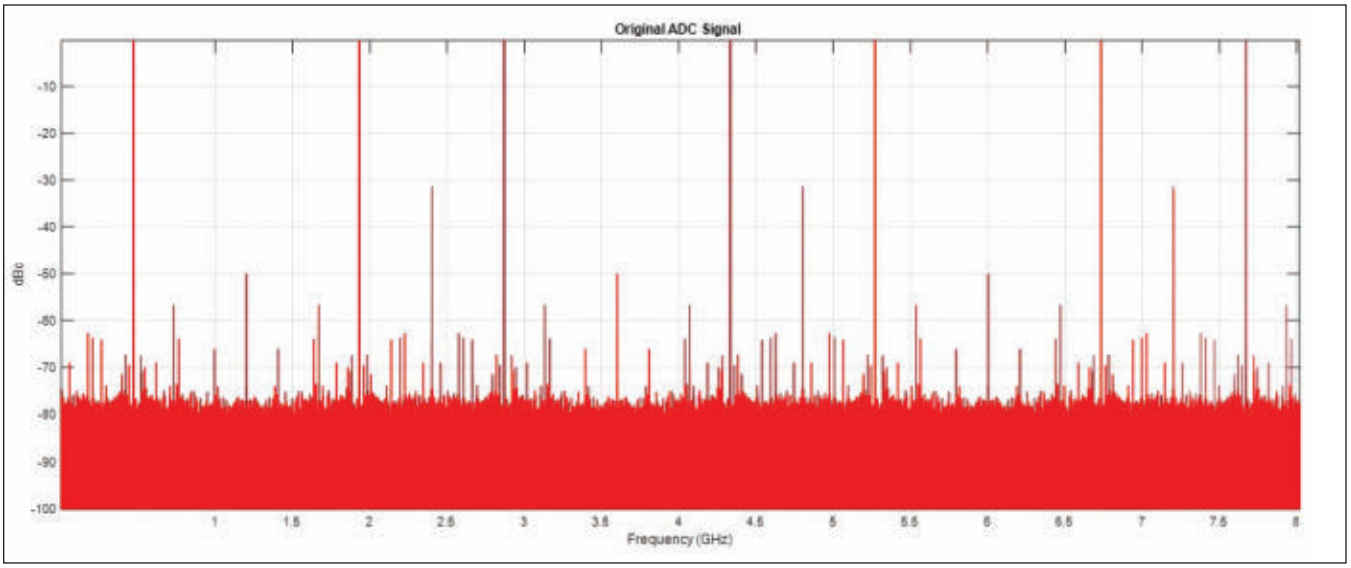

Fig. 3a

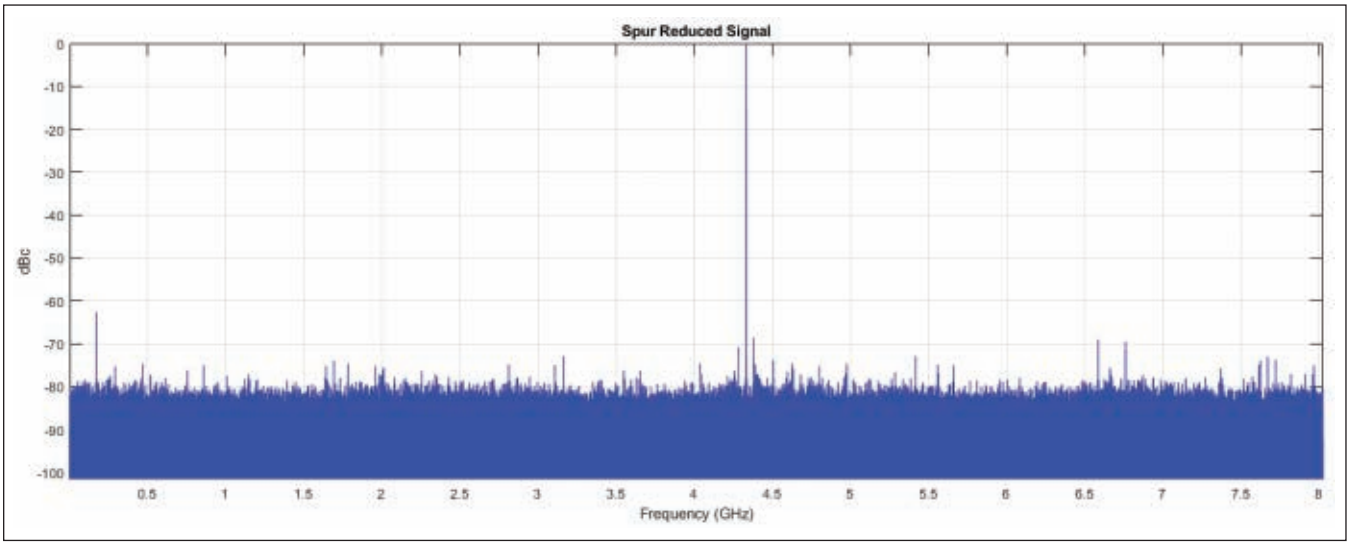

Fig. 3b: *Spurious signals without the use of HDRR (a) and with it employed (b).* PRECISION RECEIVERS, INC.

the first to experience it. In practice, studies have shown that components producing PIM can cause damaging effects several miles away, even when their signal strength is low.

The problem on surface combatants has been so severe for so long it received its own moniker – the rusty bolt effect **(see Figure 2),** in reference to the corrosion and rust present almost anywhere on a ship where interactions of electromagnetic energy with dirty connections or corroded parts cause the same effect as a diode. As more and more discrete transmit and receive systems have been added to surface combatants over the years, in combination with the ship's structure they are a breeding ground PIM generation.

The wide variety of ways PIM can be generated makes it extremely difficult to detect. However, over the last 15 years or so, the availability of portable PIM analyzers have made identifying this problem much easier. Resolution of the problem typically requires inspection and repair and replacement of the offending component. When PIM is generated by a ship's infrastructure, however, it can require extensive measures, such as repainting large surfaces of the superstructure.

TACKLING INTERFERERS HEAD ON

Generally speaking, there are two primary means of achieving interference mitigation: filtering and interference cancellation. These approaches can be used alone and together, and the solutions described later in this article use either one or both of them. However, as noted earlier, the design of receivers is changing rapidly from their traditional architecture, which relies on analog components that include a mixer and local oscillator in the front end, to direct RF sampling that eliminates one of both of them in favor of digitizing the incoming signal directly when it is captured over the air. While this approach has enormous benefits, it also introduces a problem related to the use of very-high-performance analog-to-digital converters.

Direct RF sampling is becoming the architecture of choice for applications ranging from electronic warfare (EW) and signals intelligence (SIGINT) systems to radar and communications systems. As this approach eliminates nearly all RF components in the signal chain before the input signal is digitized, a

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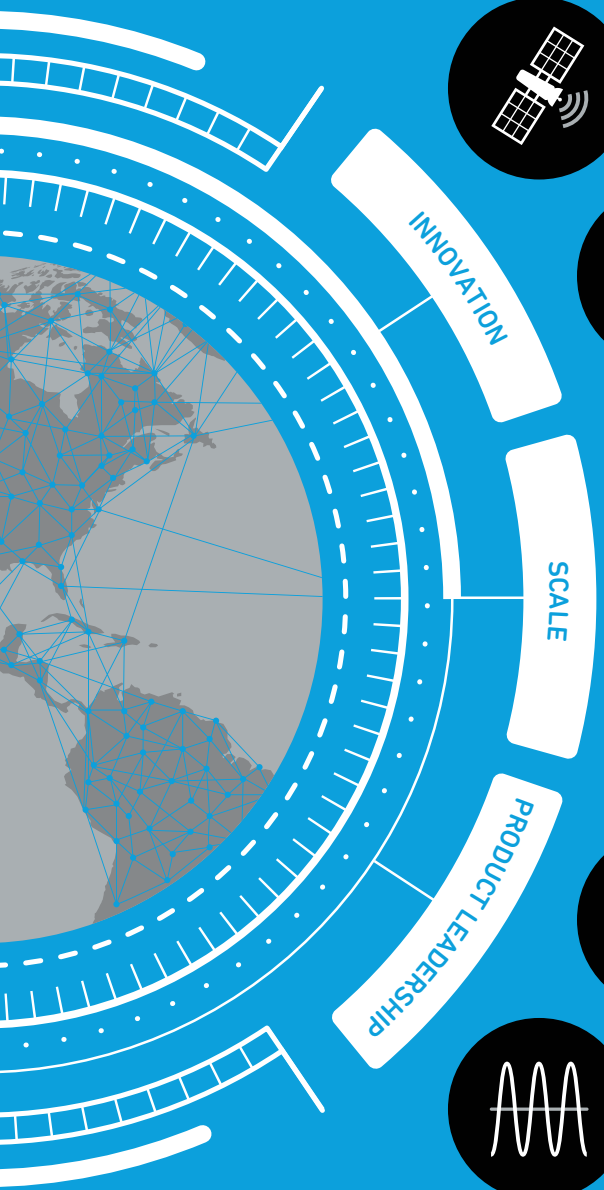

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system can be smaller and less complex, because once in the digital domain, the functions traditionally performed by several analog components can instead be performed digitally in a digital signal processor or an FPGA.

In these receivers, high performance can only be obtained when its signal-to-noise ratio (SNR) and spurious-free dynamic range (SFDR) are extremely high. The component most important for achieving this is the analog-to-digital converter (ADC) because, as the first signal processing component after signal capture, it defines the performance that the entire receiver can achieve.

One of the most common and useful measurements of ADC performance is its effective number of bits (ENOB). Ideally, in a 12-bit ADC for example, the ENOB figure is close to 12. But there are a number of factors that can diminish the ENOB in an ADC. For instance, an ADC encounters errors in quantization, offset, gain, linearity and timing that create spurious signals in its output. Even the most impressive examples of today's ADC boards pose significant design challenges, especially as sampling rates and instantaneous bandwidth increase and when time-interleaving of ADCs is employed.

If the strength of these spurious signals is high enough, it becomes difficult and sometimes impossible to separate the signals of interest from the noise. Techniques, such as clock dithering, calibration and commutating the ADC at lower rates, have been used to mitigate the issues in the ADC, but each one of these techniques has significant drawbacks that can often cause as many problems as they attempt to solve and require considerable computing power, as well.

One of the most recent approaches to solving this problem is the High Dynamic Range Receiver (HDRR) solution developed by Precision Receivers Inc. (Marshall, VA). The HDRR does not have the shortcomings of other methods, according to the company, and it is most effective when acting on signals with high dynamic range and wide bandwidth. It can achieve an order-of-magnitude improvement in reducing unwanted spurious signals, improving spurious-free dynamic range (SFDR) by up to 15 dB and optimizes the ADC's ENOB as well.

HDRR can be used in any direct-sampling system regardless of its ADC and at any frequency of interest. It also does not require self-calibration, reduces anti-aliasing filter complexity, and minimizes the required amount of post-processing and signal analysis. It is based on the fact that an RF input signal from an antenna consists of desired signals and noise, and that digitization in the ADC introduces another noise-distortion component. HDRR modifies this additional noise component in part by manipulating the ADC's control signals using an approach developed by the company over several years. The process effectively removes the noise contributed by the ADC, producing an output signal with much less distortion, which is then passed to an FPGA for processing or to a mass storage device, depending on the application (see **Figure 3**).

YET ANOTHER PROBLEM TO SOLVE

Defense and commercial wireless systems both face the challenge of increasing spectral efficiency, as there is precious little of it to waste within the communication sweet spot between about 600 MHz to 7 GHz. The "ideal" of achieving greater spectral efficiency is through full duplex rather than half-duplex communication. By enabling transmission and reception to be performed in the same channel at the same time – known as same-frequency simultaneous transmit and receive or SF-STAR – a system can effectively double its spectral efficiency.

However, achieving full-duplex operation is extremely challenging and, owing to the emergence of 5G and the requirements of next-generation military communications systems, it has become an extremely important problem to solve. The result has been a flurry of journal articles extolling the virtues of various approaches taken by the wireless industry and academia.

The most difficult challenge is the self-interference from the transmitted signal power to the simultaneously received signal. Unfortunately, this creates an overlapping of the strong signal with the much weaker received signal of interest, producing considerable self-interference. This signal can theoretically be removed by subtracting the transmitted signal from the received waveform, but the signal will be linearly and nonlinearly distorted while propagating to the receiver. The problem is the result of RF power amplifier non-linearities, transmitter and receiver in-phase/quadrature (I/Q) imbalance, the phase noise of the local oscillator, and ADC quantization noise. To be effective, an approach must ensure that the self-interference power level is below the noise floor, and if not, then it must be self-canceled by at least 70 dB.

If the approach works, the system can cancel its own transmitted signal in its receiver, and what it transmits does not impact what it simultaneously receives, which requires that changes in the time-varying self-interference channel must be tracked in real-time, so the system must be self-adaptive. Some of the most impressive STAR work has been conducted at Stanford University, whose researchers have achieved self-interference cancelation greater than 100 dB, and its architecture is widely used as the foundation of other approaches.

Full-duplex capability will have a profound effect on spectral efficiency, and it could not come at a better time for both the wireless industry and DOD, which are inextricably intertwined. The DOD "owns" an enormous amount of spectrum, some of which it has reluctantly offered to the FCC for auction, which will help the wireless industry in the US still where there is less commercially unused "mid-band" spectrum available than almost every other first-world country. Every bit of it will be required for 5G to be realized.

OTHER APPROACHES

These efforts toward interference cancellation are far from the only ones either in progress or in service. One recent initiative is the Defense Research Projects Agency's (DARPA's) Wideband Adaptive RF Protection (WARP) program. The objective of WARP is to "harden" wideband receivers operating in congested and contested EM environments using adaptive filters and signal cancellers that selectively attenuate or cancel signals. In addition to countering intentional jamming, WARP addresses interference caused by a transceiver's transmitter, sniffing the EM environment, and us-

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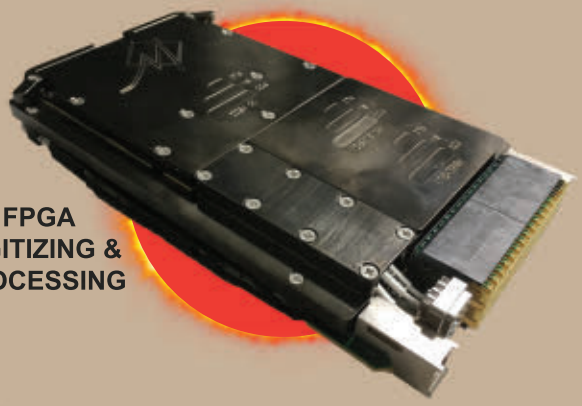

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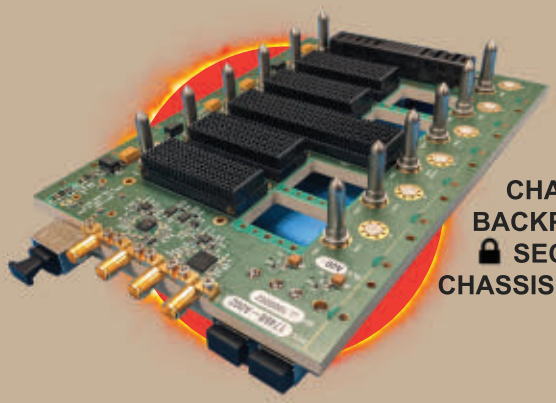

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ing wideband tunable filters to maintain the receiver's dynamic range without decreasing its sensitivity. That is, a WARP solution would reduce the effect of large signals on the desired signal without reducing the receiver's performance.

In addition to filtering, the program also addresses adaptive signal cancellation technology. The traditional means of doing this is by using a duplexer to separate signals on different bands. But this approach is not effective when radios transmit and receive on the same frequency (i.e. SF-STAR) in order to increase spectral efficiency. Unfortunately, some SF-STAR systems can create the risk of self-interference caused by the transmitted signal unintentionally disrupting the receiver input.

Conventional techniques for self-interference mitigation in these situations requires minimizing the coupling between the transmitter and receiver or employing a controllable auxiliary path between the two ports to cancel the signal coupling. But these techniques sometimes fail to achieve the required amount of cancellation and are not reconfigurable or scalable across a wide range of frequencies.

Researchers have already proposed using a full-duplex antenna that achieves self-interference cancellation through polarization duplexing, and the WARP program is attempting to improve on this by sampling and canceling it in the digital domain. This technique is already being used by several companies, such as L3 Harris, which has been working on interference mitigation for many years. Its solution employs various tools depending on the type of threat, such as multiplexing and RF filters, as well as interference cancelation.

The latter samples interfering signal and creates the opposite of it in real-time and, when combined, they cancel each other out, leaving only the desired signal. It also cancels out noise and spurious signals even if they are on the same frequency. The result can be 100 dB or of interference cancellation. Its latest versions use the company's Advanced Interference Mitigation System (AIMS) that makes it possible to quickly enable solutions for a wide range of interference profiles.

Cobham's mINCAN interference cancellation system injects an anti-phase version of the interfering signal, similar to the approach used for acoustic noise cancellation in smartphones, headsets and hearing aids. However, this system can handle very high levels of received interference and accommodates the high speeds of frequency-agile transmitters.

A sample of the signal from the transmitter in a co-located situation is taken using a directional coupler in the transmit antenna path and is scaled in phase and amplitude before being mathematically being added to the receive path to cancel out the interference. Multiple interferers can be canceled by allocating a module to each one, and cancellation takes place before the interfering signal reaches its full amplitude to avoid receiver blocking.

Another technique developed at MagiQ called Agile Interference Mitigation System (AIMS – not to be confused with L3Harris's solution) identifies high-level signals that would otherwise lead

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to distortion in the receiver and sets up frequency-agile, very-high-Q filters to quickly suppress them. The AIMS device is located between the antenna and receiver and discriminates signals of interest from interferers and suppresses the latter signals before reaching the receiver without effect on the desired signal.

AIMS monitors the spectrum in real-time, identifies unwanted interference signals, invokes the high-Q filter technology to allow removal of about 60 dB of interference while leaving nearby signals of interest uncompromised. The tunable filters can be continually updated to adapt to rapidly changing EM environments.

Septentrio's AIM+ system is focused on satellite-based navigation systems and mitigates the effects of narrow-band interference using three notch filters that remove a narrow part of the RF spectrum around the interfering signal. The power spectrum plot AIM+ technology detects and neutralizes interference resulting in faster set-up, reduced downtime and secure operation. AIM+ protects against simple narrowband interference, as well as more complex wideband interference, including jamming and spoofing.

Kumu Network's self-Interference cancellation technology is also designed to allow radios to transmit and receive on the same or adjacent channels. Its canceller suppresses the interference a transmitter presents to a co-located receiver even if the two radios operate with no guard band between them. The solution adapts in real-time to the changing environment to ensure consistently high isolation between the two radios.

The technology is also available in chip form with frequency-agnostic taps for self-interference cancellation or FIR filtering. Digital cancellation taps can be used where analog cancellation alone does not provide sufficient cancellation or where longer delay reflections impact the receiver and need to be canceled. It has four FIR filter chains organized as 12 programmable taps per chain with a maximum of 350-nsec aggregate delay through each chain.

Two chains can be cascaded for a maximum of 24 taps for a total delay of up to 700 nsec, or the chains can be configured to support 2x2 MIMO operation. The IC supports a range of signal processing applications where analog signal manipulation is required to avoid the delay and resolution problems that digital conversion introduces. For example, the chip can be used to implement full-duplex systems or to improve co-existence between co-located radios.

CUTTING THROUGH THE NOISE

At some time in the very (very) distant future, all types of interference may somehow be resolved, but until then, DOD, industry and academia will continue to throw every possible resource into reducing it. This will not be easy, as there are so many types available to work on at every level. The interference cancelation techniques described in this article may be the most widely used or potentially promising, but there are others as well, and with so much work becoming conducted to eliminate it, new ones will continue to be continuously revealed.

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The Development of JEMSO Doctrine

By Daniel Rocha and Mitch "Hooch" Houchin

After nearly 12 years in the making, the Department of Defense (DOD) has published the "first-ever" doctrine on Joint Electromagnetic Spectrum Operations (JEMSO) with the release of Joint Publication (JP) 3-85 JEMSO. This is a giant leap forward in the advancement of JEMSO. For the JEMSO community, it's like Steve Martin in the movie "The Jerk," "The new phone book's here! The new phone book's here!" JEMSO are somebody now!

You may be wondering: What are JEMSO? Why is JEMSO doctrine so important? What does JP 3-85 bring to the fight? To answer these vexing questions, one must start from the beginning...

WHAT ARE JEMSO?

Not long ago, the term "Joint Electromagnetic Spectrum Operations" wasn't well known to many both outside and inside the Electromagnetic Spectrum (EMS) community, and this is probably still true, even today. Rising out of operations in congested, constrained and contested environments, and exercises, lessons learned, assessments, studies and the Army's first joint doctrinal push in 2008, the JEMSO concept was born.

JEMSO consists of military actions that the joint force executes in order to exploit, attack, protect and manage the electromagnetic environment. In other words, the integrating, deconflicting and dynamically controlling fluid military operations in the EMS achieves EMS superiority. Although not identified as a domain, the EMS can be considered a center of gravity for all domains. In fact, the EMS is a maneuver space that must be controlled in order to achieve EMS superiority and success across all domains and missions. This sounds like a great idea; however, the idea of controlling the EMS is not new. For example, in 1973, Soviet Admiral Sergei G. Gorshkov stated, "The next war will be won by the side that best exploits the electromagnetic spectrum."

This need for coordinated operations in the EMS has been generally acknowledged, but the question was, "how to proceed?" Doctrine to guide joint force operations in the EMS would be a key component to answering this question. The modern battlespace is filled with myriad transmitters and forces (friendly, commercial, allied, neutral and adversary) vying for use of the same bands in the EMS. In order for the joint warfighter to be effective in this battlespace, JEMSO need to work across the competition continuum to deconflict spectrum usage and move toward controlling EMS use in the electromagnetic operational environment (EMOE) with the goals of achieving freedom of action and the commander's objectives. Additionally, it was recognized that as military operations were becoming more dependent on the EMS, its use was becoming more constrained and congested and fratricide was becoming more prevalent.

JP 3-85 describes JEMSO doctrine and replaces earlier EW and spectrum management doctrine. DOD

WHY IS JEMSO DOCTRINE SO IMPORTANT?

First and foremost, per Joint Doctrine, it "...presents fundamental principles that guide the employment of US military forces in coordinated and integrated action toward a common objective. It promotes a common perspective from which to plan, train and conduct military operations. It represents what is taught, believed and advocated as what is right (i.e., what works best). It provides distilled insights and wisdom gained from employing the military instrument of national power in operations to achieve national objectives." Also, JEMSO doctrine needed to precede DOD policy (which had already been released), and the community needed doctrinal guidance to justify the requirements for JEMSO and Joint EMS Operations Cell

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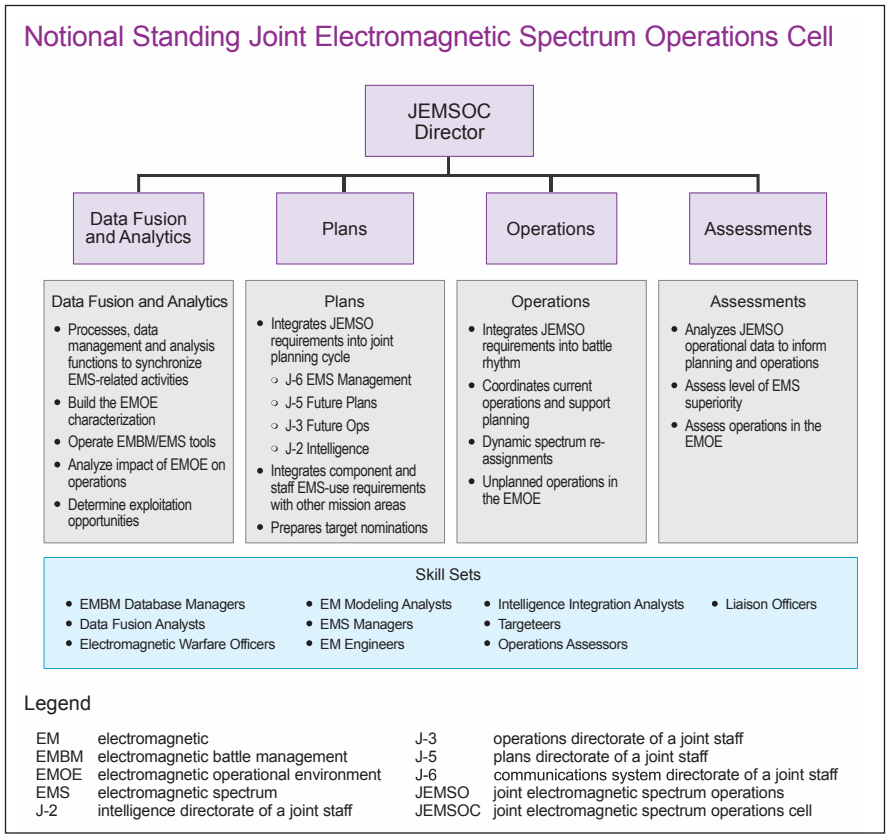
(JEMSOC) development to include staffing and resources.

Following the Army's initial doctrine recommendation in 2008, over the next 10-plus years several other efforts were pursued to develop JEMSO and associated doctrine. Most of these efforts were slow to develop or stalled due to myriad issues that included lack of understanding, support, organizational lane definitions and lack of JEMSO extant practices. That all changed in November 2017, when USSTRATCOM J3E presented a proposal at the Joint Doctrine Planning Conference to develop the first Joint Publication on JEMSO and received unanimous approval to proceed.

The JEMSO doctrinal push culminated on May 22, 2020, as JP 3-85 JEMSO was officially signed into joint warfighting doctrine. This marked the beginning of a new chapter in institutionalizing JEMSO across the joint force. The publication also superseded and cancelled JP 3-13.1, Electronic Warfare; JP 6-01, Joint Electromagnetic Spectrum Management Operations; and Joint Doctrine Note 3-16, Joint Electromagnetic Spectrum Operations. Although these publications were cancelled, EW and spectrum management remain critical mission areas within JEMSO that were incorporated into JP 3-85.

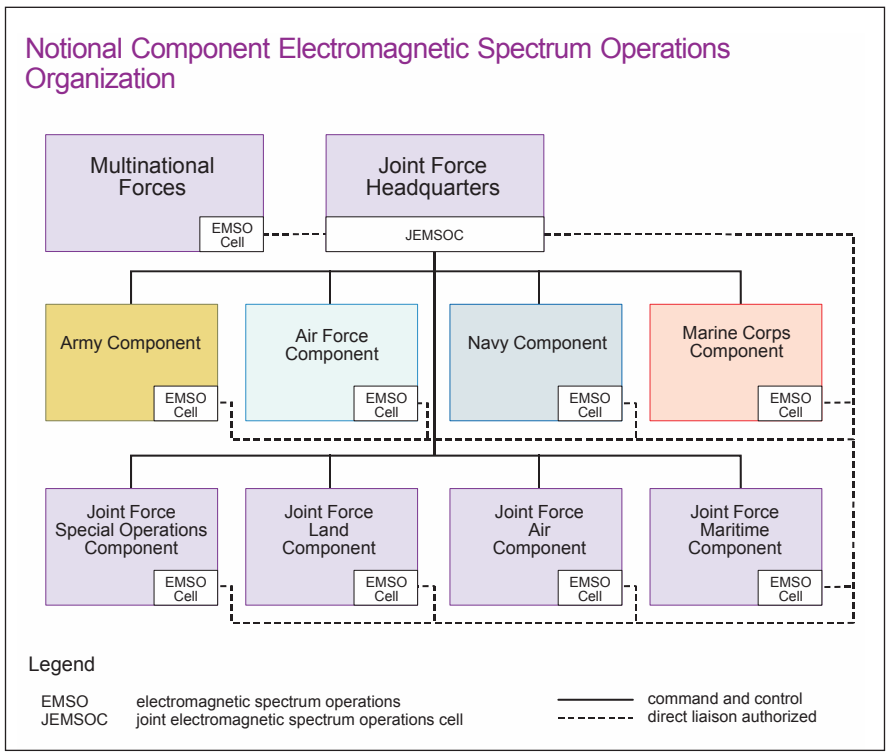


JEMSOCs conduct planning, monitoring and assessing operations. DOD

WHAT DOES JP 3-85 BRING TO THE FIGHT?

While JP 3-85 does not provide actual capability to the joint warfighter to defeat a great power adversary, it is the cornerstone document that formally defines and provides the doctrine warfighters have needed in order to build and execute tenets of JEMSO. Bottom line: joint forces cannot succeed in any domain or mission without achieving EMS superiority. As such, this publication establishes the framework and provides joint forces with the fundamental principles and guidance for planning, executing, and assessing joint electromagnetic spectrum operations. Furthermore, it brings forward an understanding of JEMSO to the DOD, agencies, allies and partners.

JP 3-85 describes a Joint Force Commander's (JFC's) command-specific guidance on duties and responsibilities and suggested organization for JEMSO. JP 3-85 lays out how Services and intelligence organizations support and execute EMSO in support of commander's objectives. The publication covers how JEMSO planning should be accomplished to ensure unity of effort in operations. It also discusses how JEMSO follow the plan,



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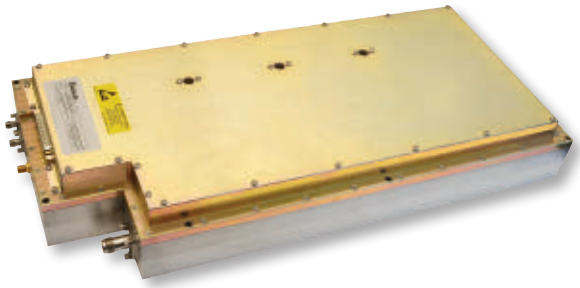

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execute and assess format in executing operations in the EMS.

The publication details the establishment of a JEMSOC to execute operations in the EMS. JEMSOCs conduct planning, monitoring and assessing operations in order to track the effectiveness in achieving EMS superiority. It further describes recommended JFC and JEMSO Cell composition, duties and responsibilities. In conjunction with JEMSO doctrine development was the alignment with the Operational Employment Guide – JEMSO Cell. This guide was pivotal to the development of JP 3-85's discussion on JEMSOC roles and responsibilities. This Joint Electromagnetic Warfare Center (JEWC)-led effort provides combatant commands with the organizational framework, processes and procedures necessary to establish and operate a JEMSOC capable of establishing EMS superiority in their areas of responsibility.

Additionally, JP 3-85 brings forth Electromagnetic Battle Management (EMBM) – the heart of JEMSO – which is critical to achieving EMS superiority. EMBM is both a function and a system currently under development by the Defense Information Systems Agency's (DISA) Defense Spectrum Organization, with USSTRATCOM as the operational sponsor levying system requirements. The system will be used by JEMSOCs to dynamically monitor, assess, plan and direct EMS operations to support the commander's objectives. The function of EMBM includes facilities, equipment, software, communications, procedures and personnel that provide dynamic management of military EMS operations key to JEMSO execution and support to joint forces. JEMSO executed through EMBM will be a "dynamic weapon" commanders can employ in order to achieve EMS superiority across all domains and missions. Additionally, EMBM will enable joint force operations in the EMS, including among others: EW; spectrum management; Cyberspace and Space operations; targeting; command and control (C2); processing, exploitation, and dissemination (PED); positioning, navigation, and timing (PNT) (e.g., Global Positioning System [GPS]); identification, friend or foe (IFF); etc. In order to understand how critical EMS superiority is to the joint force, one only has to imagine executing any of the above activities without it.

Service, DOD, and national Intelligence organizations' support, roles and responsibilities are also described in JP 3-85. Another critical aspect to EMS superiority for the US in military operations depends on integration with multinational forces and partner nations. JP 3-85 identifies JEMSO and EMSO coordination requirements and processes, and the interactions with host nations by the Joint Frequency Management Office on spectrum usage of joint forces. This coordination is a "must do" to legally operate EMS-dependent equipment in other nations.

NEW LEXICON

A major lexicon change also occurred in JP 3-85, as the term "Electronic Warfare" was changed to "Electromagnetic Warfare." Wait, what?! Yes, you read that correctly. After some 75 years of using the term "Electronic Warfare" since WW II,

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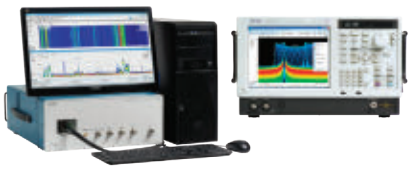

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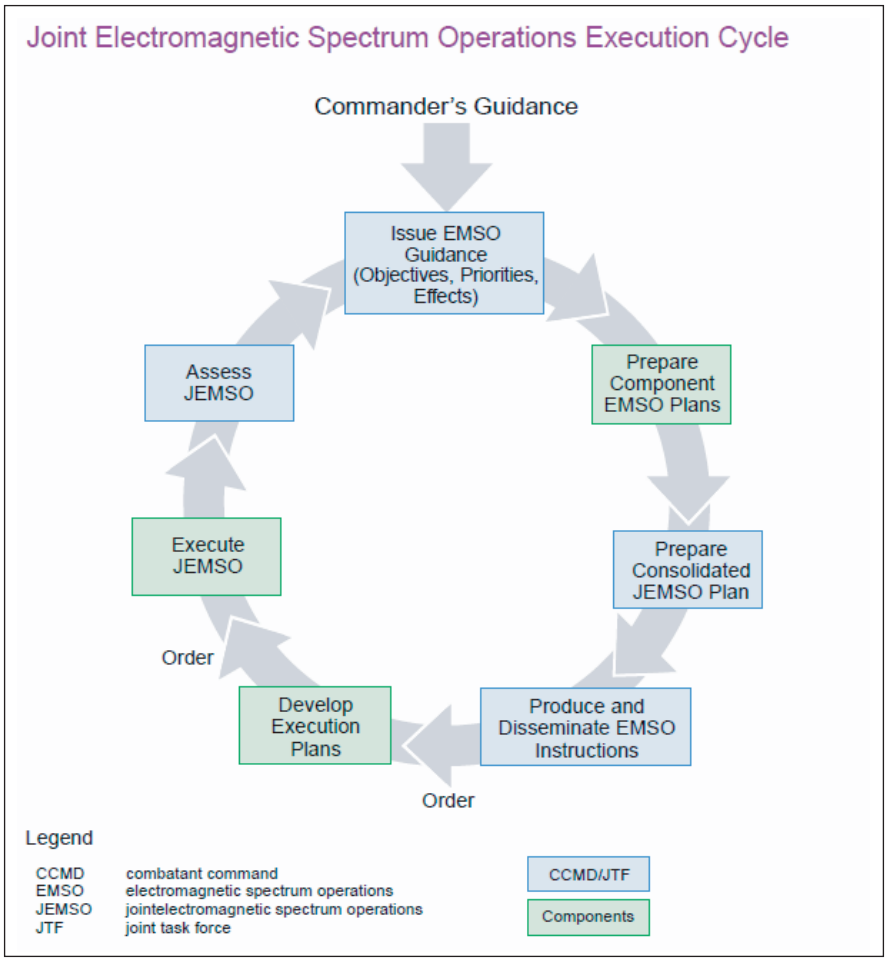

The JEMSO Execution Cycle will be coordinated and executed throughout a Combat Command and its components.

it will now be known as Electromagnetic Warfare. Revising the term focuses on "electromagnetic" versus "electronic" and aligns it more accurately with what activities are actually being conducted: warfare in the maneuver space of the electromagnetic spectrum. This definition change also carries through associated EW divisions of electromagnetic attack (EA), electromagnetic protect (EP) and electromagnetic support (ES). Note that the new doctrine aligned ES with EA and EP by eliminating the legacy "warfare" term.

The introduction of JP 3-85 to doctrine was a fundamental step to guide EW, spectrum management, intelligence, space, cyberspace and other mission areas together in pursuit of EMS superiority. Today, there are myriad JEMSO and EMSO efforts ongoing: Service doctrine, tactics, techniques, and procedures (TTP) development, establishment of combatant command JEMSOCs, EMBM development, and data integration, consolidation, and access to data repositories are all grounded with this new JEMSO doctrine. The long road traveled to build this publication is a testament to the entire EMS community's recognition and support of the importance of JEMSO and EMS superiority in today's congested, constrained and contested battlespace.

About the Authors: Daniel Rocha is a Retired USAF Lieutenant Colonel, former RC-135 Raven, and B-52 Electronic Warfare Officer. Today, as a Contractor for Calvert Systems, he supports the USSTRATCOM J3E JEMSO Office, where he has been for over nine years, and is a member of the initial USSTRATCOM JEMSO cadre. He has been a key contributor in developing Joint Doctrine Note 3-16 JEMSO and JP 3-85 JEMSO. He also initiated and led the development of the first JEMSO Universal Joint Task.

Mitch Houchin is a retired Navy EA-6B Naval Flight Officer/Electronic Countermeasures Officer and has been at USSTRATCOM since 2004. He is also a member of the initial command JEMSO cadre. As a consultant and now government civilian he has worked on IO, cyber, EW and JEMSO in the J8, J5 and J3 directorates and is currently the J3E JEMSO Office operations coordinator. He is additionally assigned to the SecDef EMSO Cross Functional Team in Crystal City, VA as the USSTRATCOM member.

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Space EW – Part 25

Jamming of Downlinks

By Dave Adamy

Jamming the downlink from a satellite to a ground station involves transmitting a jamming signal into the ground station. This is typically accomplished from an airborne jammer that is looking down at the ground station site (as shown in **Figure 1**) or it is at least above the local horizon from the ground station.

It's also worth noting that a ground-based jammer may also be able to disrupt a satellite downlink, but only if the jamming system is *extremely* close to the ground station. In this month's column, however, we will only be looking at airborne jamming of the ground station.

JAMMING DOWNLINKS

Since we have already done the hard work of calculating distances from the aircraft last month, let's look at the jamming of downlinks by that same aircraft. For convenience, let's put the aircraft and ground stations in the same location and keep the aircraft and ground antennas the same and jam at the same frequency. The jammer transmitter has 10 Watts (40 dBm) effective radiated power. The distance from the jammer to the ground station (from last month's EW101 column) is 156 km. The satellite is in a 1000-km-high orbit and its sub-vehicle point is 55° North latitude, 108° East longitude. The satellite's downlink effective radiated power is 10 Watts (40 dBm).

As always in this column, these values do not represent any specific satellite system. They are just chosen as reasonable values so we can look at the math. When you are performing design or analysis of a real-world satellite system, you can plug the real-world values into the equations we will discuss here.

THE SATELLITE DOWNLINK

We start with **Figure 2.** The sub-vehicle point of the satellite, the ground station and the North Pole form a spherical triangle.

- *Side c* is 90° – the latitude of the aircraft sub-vehicle point
- *Side b* is 90° – the latitude of the ground station location
- *Angle A* is the difference in longitude between the aircraft and the ground station.

Using the spherical law of cosines for sides, we can calculate the geocentric angle from the aircraft to the ground station as:

Side a **= arccos[(cos b)(cos c) + (sin b)(sin c)(cos A)]**

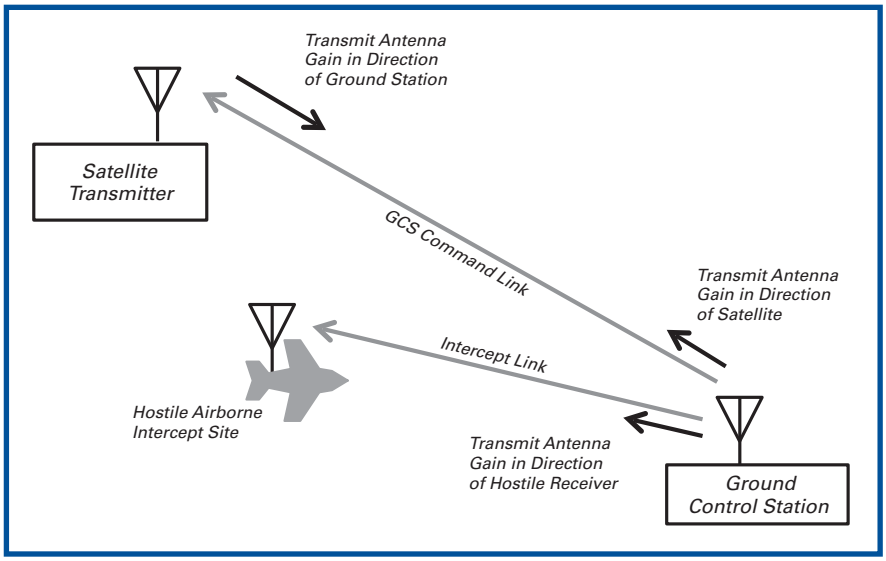

Fig. 1: *A hostile airborne jammer can jam any satellite downlink as long as the aircraft is above the local horizon from the ground station it is jamming.*

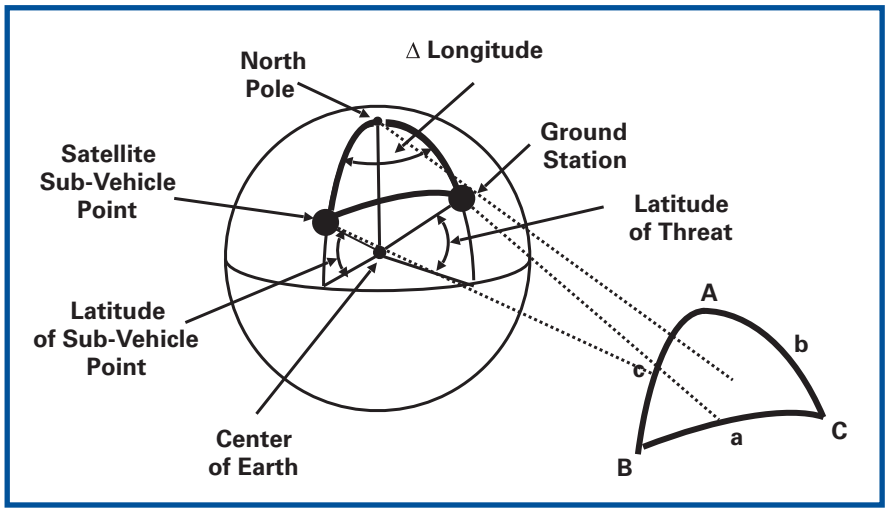

Fig 2: *A spherical triangle is formed between the North Pole, the sub-vehicle point and the ground station location.*

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Now consider **Figure 3,** which is a plane triangle formed by the aircraft, the ground station and the center of the Earth.

- ***Side d* is th**e radius of the Earth increased by the altitude of the ground station
- *Side e* is the radius of the Earth increased by the altitude of the satellite
- *Angle F* is the same as side a from **Figure 2**.
- *Side f* is the range from the satellite to the ground station

The range is found using the planar law of cosines for sides:

Let's plug in some orbit numbers:

The sub-vehicle point is at longitude 108° east of the Greenwich Meridian and 45° North latitude. The ground-station location is at 100° East longitude, 55° North latitude.

The satellite has a 1000-meter-high circular orbit and the radius of the Earth is 6,371 km.

For the spherical triangle in **Figure 2**:

Angle A = 8°
Side b is 90° - 55° = 35°
Side c is 90° - 45° = 45°

We find *Side a* from the spherical law of cosines for sides:

Side a = arccos[(cos 35°)(cos 45°) + (sin 35°)(sin 45°)(cos 8°)]
= arccos[(.819)(.707) + (.574)(.707)(.990)] = arccos[.579 + .402] = arccos [.981] = 11.2°

Now consider the plane triangle in **Figure 3**. Using the law of cosines for sides for plane triangles:

***Side g* = sqrt[e2 + f2 – 2efcos(G)]**

Let's plug in some numbers:

Side f is 6371 km + 1000 km = 7371 km
Side e is 6371 km
Angle G is the same as *side a* in 2 = 11.2°
Side g = SQRT[$(7371)^2$ +$(6371)^2$ – 2(7371)(6371) cos(11.2°)]
= SQRT[54331641 + 40589641-46066285] = SQRT [48854997] = 6990 km

This is the downlink distance.

Now, using the law of sines for plane triangles, the elevation angle from the satellite to the ground station is:

Angle E = arcsin[e (sinG/g)]
Angle E = arcsin[6371 (sin (11.2°)/ 6990] = arcsin[6371) (.1942)/6990] = arcsin[.1770] = 10.2°

The elevation of the satellite from the ground station is the angle above the local horizon. From **Figure 3**, the local horizon is shown to make a 90° angle to *Side e* at the ground station location. This means that the elevation of the satellite from the ground station is *Angle F* - 90°.

Since this is a plane triangle, the sum of the three internal angles is 180°, and we know the *Angle E* is 10.2° and *Angle G* is 11.2°.

Thus, *Angle F* is:

180° - 10.2° - 11.2° = 158.6°

The elevation above the local horizon is 158.6° - 90° = 68.6°

At this high angle, the atmospheric and rain losses are negligible at 5 GHz

The line-of-sight loss from the satellite to the ground station is:

32.4 + 20 log(d) + 20 log(F) = 32.4 + 76.5 + 74 = 182.9 dB

THE JAMMER

The jammer line-of-sight-loss is:

32.4 + 20 log (d) + 20 log (F) = 32.4 + 20 log(156) + 20 log(5000) = 32.4 + 43.9 + 74 = 150.3 dB

J/S FORMULA

The formula for communications jamming is:

$J/S = ERP_J - ERP_S - LOSS_J + LOSS_S + G_{SJ} - G_S$

Where: *J/S* is the jamming to signal ratio in dB,
ERP_J is the effective radiated power of the jammer in dBm,
ERP_S is the effective radiated power of the jammed signal in dBm,
$LOSS_J$ is the loss between the jammer and the jammed receiver in dB,
$LOSS_S$ is the loss between the desired signal transmitter and the jammed receiver in dB,
G_{SJ} is the gain of the jammed receiver's antenna in the direction of the jammer in dB, and
G_S is the gain of the jammed receiver's antenna in the direction of the desired signal transmitter in dB.

Plugging in the values for this problem:

J/S = 40 dBm – 40 dBm – 150.3 dB + 182.9 dB + 21.3 dB – 41.3 dB = 12.6 dB

This is effective jamming.

WHAT'S NEXT

Next month we will consider jamming satellite uplinks. For your comments and suggestions, Dave Adamy can be reached at dave@lynxpub.com.

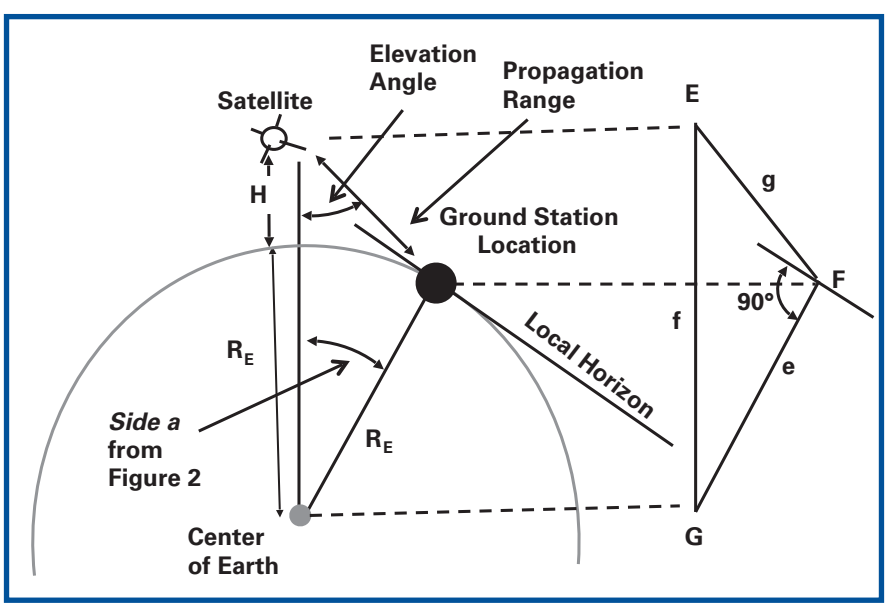

Fig 3: *The elevation and range to the satellite from the ground station can be determined from the plane triangle defined by the satellite, the ground station and the center of the Earth.*

Industry Spotlights

This month, *JED* is pleased to feature a range of information about defense electronics companies and the technologies they offer. In light of COVID-19 and the widespread cancellation of events this year, including the AOC Annual Symposium and Convention, we at *JED* wanted to offer industry a new way to feature products and services in lieu of in-person events. Please enjoy this information.

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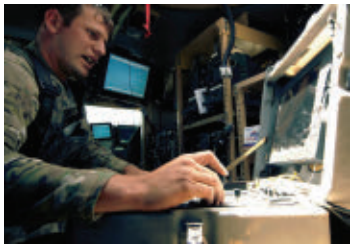

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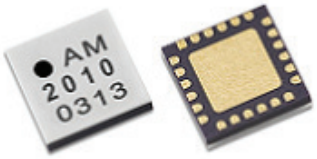

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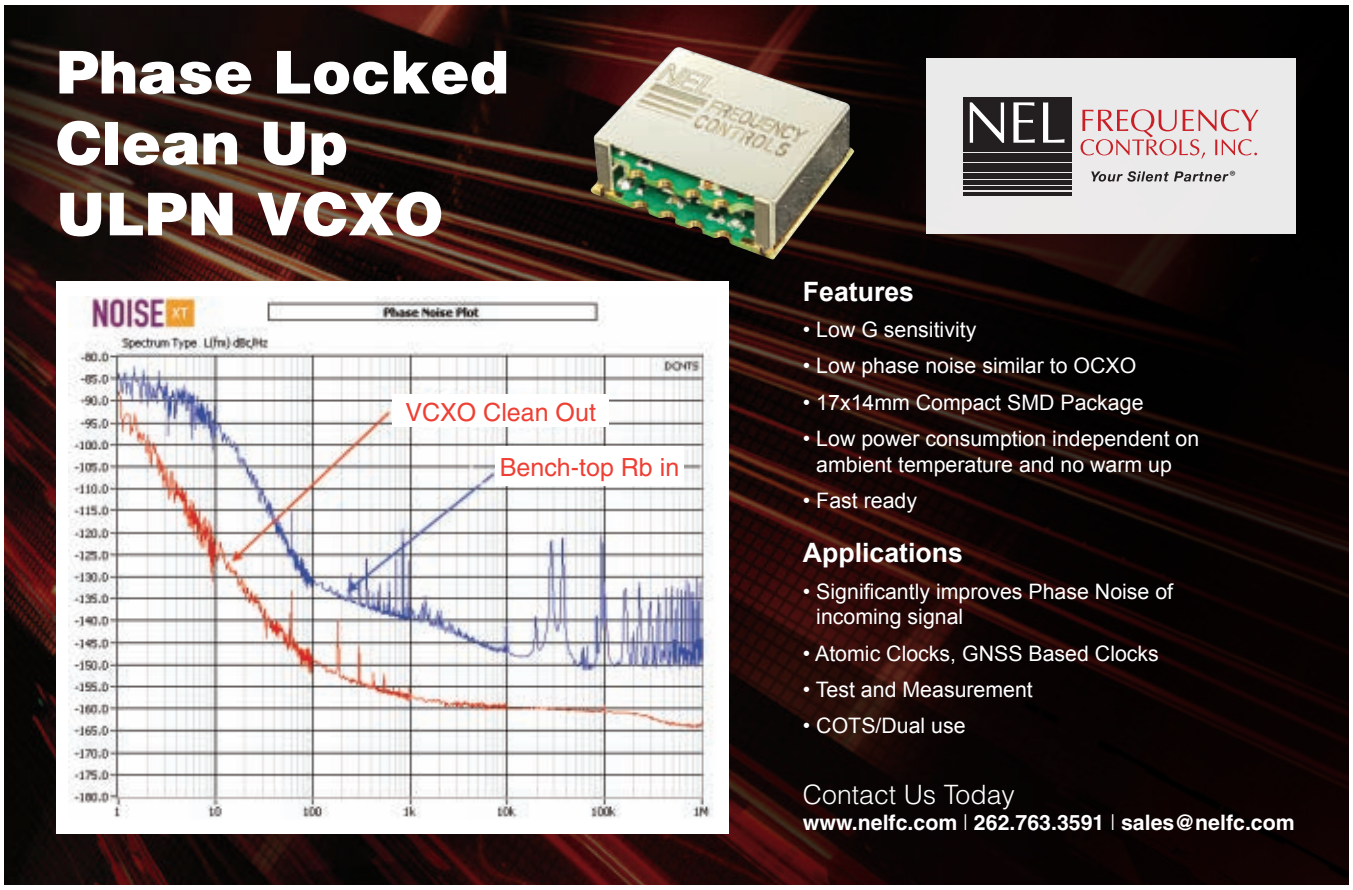
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A TRIBUTE TO DR. JIM WICKES

October 22 2020
AOC UK Chapter

Dr. Jim Wickes, consulting fellow for survivability at Dstl, UK, and friend to many in the AOC, passed away on Thursday October 22 after a long battle with cancer.

During a lifetime in EW, Jim made huge advances in EW for platform survivability, benefitting the whole free world and saving numerous lives and assets. He had especially close relations with many teams and individuals in the US and 5-Eyes Community, and throughout NATO's science and technology organizations.

After gaining a PhD in Atomic Physics, Dr Wickes joined the UK Ministry of Defence (MOD) as a research scientist in 1972. By 1988, he had become assistant director in the UK's Defence Intelligence staff, leading a Branch focused on advanced EW systems and directed energy weapons. In 1991, he worked closely with US colleagues in the run-up to the first Gulf War, thereby establishing an enduring relationship with the US.

In 1992, he returned to the research establishment as the head of Novel Weapons Systems, and following a major reorganization, he became head of the EO/IR CM Division. A highlight of his career was the initiation of the world's first DIRCM program to meet an urgent operational requirement (UOR). Jim ensured that a powerful EW capability was maintained in the UK Defence Science & Technology Laboratory (Dstl) when he became Chief Technologist Survivability at its formation in 2001.

Jim was central to all the UK's military operations, and his role expanded significantly as he became the trusted source of advice to the MOD key stakeholders across Defence. The UK Chief Scientific Advisor commended Jim for his work, and he received many accolades throughout his career from the highest level in the UK, from the US and 5-Eyes community and from NATO. Jim was tireless in promoting EW and platform protection, and his enthusiasm continued unabated with numerous cooperative initiatives and innovative solutions, along with close links to the US Army, USAF, USN, USMC and SOCOM/SOAR.

Jim was instrumental in setting up the UK EW SME Working Group in 2005, working closely with primes and UK Dstl and MOD frameworks, ensuring that EW was championed at all levels in industry as well as in the military domains. The opportunities offered to the group members have certainly led to an enhancement of the overall EW capability in the UK, which would be unlikely to have existed without Jim's initial influence.

Jim was a great supporter of the AOC, encouraging his staff to join the association and to attend AOC events. He spoke at AOC UK and International events and took part in the annual symposium for many years. Jim enabled many UK chapter visits to UK research facilities and provided expert personnel to brief at AOC events. He was on the editorial advisory board for the *Journal of Electromagnetic Dominance* (*JED*), and in 2016, Jim received the Joseph W. Kearney pioneer award.

Jim is survived by his wife, Pam, and will be sadly missed by his many AOC friends from around the globe.

OFFICIAL AOC NOMINATIONS & ELECTIONS REPORT FOR 2020 ELECTIONS

The following information contains the Nominations & Election (N&E) Committee's tabulated results of the 2020 Election held during October 2020. The results have been validated and presented to the International Association of Old Crows Board of Directors.

Thank you to all those who ran for an office this year. The quality of the volunteers and their dedication to the organization really shows how fortunate we are to have such leadership available to us.

We'd also like to thank everyone who voted!

Total number of eligible voters – 13,106
Total members voted – 1,465
Percentage of Voters – 11.18%

– **At-Large Director** – 10 Candidates – Only two could be selected (Individual percentages are based on the total 1,465 votes cast)

Greg Patschke – 29.22%
Mike Ryan – 27.24%
3rd Place – 21.50%
4th Place – 19.45%
5th Place – 14.13%

– **Northeastern Region** – 4 candidates (1514 Eligible voters, 213 votes cast)

Myles Murphy – 30.99%
2nd Place – 30.05%
3rd Place – 20.19%
4th Place – 15.02%
Made no selection – 3.75%

– **Southern Region** – Unopposed

Karen Brigance

– **International Region II** – 2 candidates (752 eligible voters, 90 votes cast)

Jurgen Opfer – 60.00%

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NLR – Royal Netherlands Aerospace Centre

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