ASSOCIATION OF OLD CROWS
Advancing Electromagnetic Warfare TOGETHER
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February 2021 Vol. 44, No. 2

JED

Journal of Electromagnetic Dominance

Tracking Emitters from Space

- Technology Survey: Analog-to-Digital Converter (ADC) Boards
- EW 101: Space EW Uplink Jamming
- News: NGJ Low-Band EMS Contract Awarded

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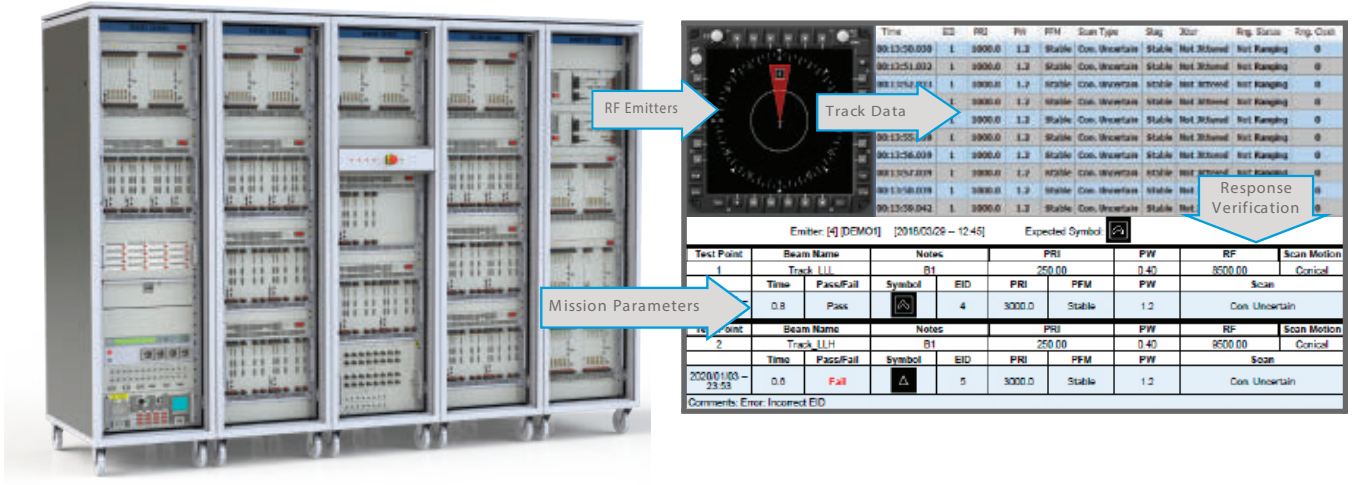

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Detecting, identifying and geolocating earth-based emitters from space was once the exclusive purview of a handful of governments. Now, commercial providers are aiming to provide satellite-based RF monitoring as a service to military and commercial customers.

HAWKEYE 360

US Air Force Capt. Aaron "Brutus" Tindall (back row, third from left), 390th Electronic Combat Squadron EA-18G weapons officer, became the first Airman to graduate from the US Navy's Airborne Electronic Attack weapons school (featured in the January JED*). Here, he poses with naval aircrew and electronic warfare officers at Point Mugu Naval Air Station, CA.*

US AIR FORCE

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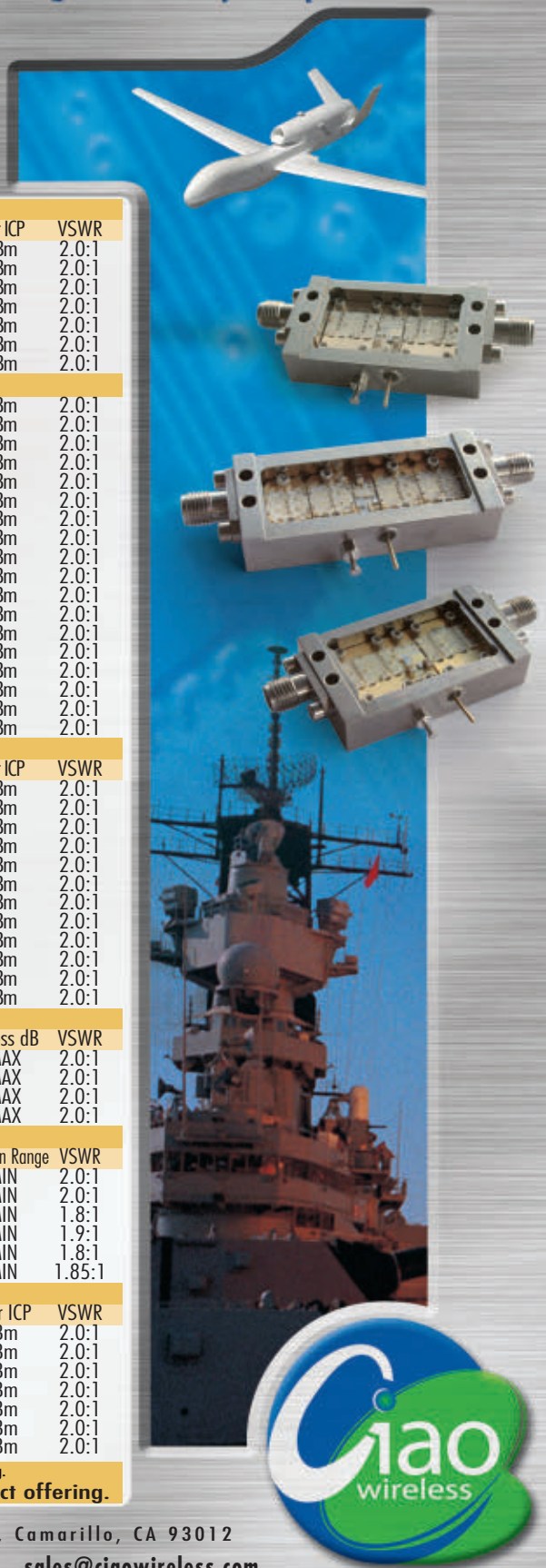

OCTAVE BAND LOW NOISE AMPLIFIERS

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

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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NEW SPACE

This month's cover story focuses on spaced-based electonic support measures (ESM) and signals intelligence (SIGINT). If *JED* had published this article five or ten years ago, we would have focused exclusively on military space programs based in the US, UK, France, and Israel to name a few. These nations, along with Russia and China, have been the main players in space-based SIGINT. However, this month's article is about commercial space operators who are selling RF reconnaissance as a service to military and commercial customers. What happened over the past decade that makes this possible?

The answer is "New Space," a term that describes the rapid commercialization of the space sector. Private companies have been part of the space market almost since the beginning of space operations. But space launch was usually expensive, satellites were relatively large, and they had to provide a long service life in order to be economically viable. In the New Space paradigm, space launch is much cheaper with re-usable launch vehicles, such as those from Space X and RocketLab. The satellites themselves have become much smaller and less expensive as companies have embraced the CubeSat concept, which was first conceived in the late 1990s. This combination of developments enables a single launch vehicle to carry and deploy 30-60 CubeSats before it returns to earth. In many cases, each of these satellites is only expected to remain in service for 5 years or so before it will run out of the propellant it needs to maintain its orbit. The satellite will then fall out of orbit and eventually burn up as it re-enters the atmosphere. Before this happens however, it will be replaced by another CubeSat. Five years. Most of us will own our car for longer than five years. Yet these companies are able to sell services (communications, EO/IR imagery, RF mapping, etc.) to commercial users based on these economics.

The New Space concept has removed the historic barriers of space operations and enabled many new companies to enter the space market with a range of commercial services. For example, most of the satellite RF reconnaissance companies covered in this month's article did not exist before 2015. At the same time, these companies are quickly finding a wide range of military customers who want their RF reconnaissance services because it is far more economical than launching and maintaining their own national SIGINT constellations. This is something few of us would have been able to envision a decade ago.

It is important to recognize that the satellite RF reconnaissance market is just beginning. Right now, most of these companies are covering maritime signal traffic. Of course, this leaves out most of the signal environment, which is land based. But, I think if we give these companies a little more time to learn from their first generation of satellites, they will eventually close the gap and launch future satellite constellations that cover a much larger set of emitters anywhere on the earth's surface. After just a few years in business, they're off to a great start. – *J. Knowles*

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Abstracts due February 26

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FEBRUARY

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Albuquerque, NM
www.deps.org

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

AOC Program Manager Briefing Session 5
February 2
1300-1400 EST
www.crows.org

AOC EMSO Leadership Discussion: Air Chief Marshal Sir Stuart Peach
February 3
1000-1100 EST
www.crows.org

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

AOC EMSO Leadership Discussion: Honorable Dr. Bruce D. Jette
February 10
1300-1400 EST
www.crows.org

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

AOC Program Manager Briefing Session 6
February 16
1300-1500 EST
www.crows.org

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

Communications Electronic Warfare
February 22-26
Swindon, UK
www.cranfield.ac.uk

AOC EMSO Leadership Discussion: VADM Jeffrey Trussler
February 24
1030-1130 EST
www.crows.org

AFA Aerospace Warfare Symposium – Virtual 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

AOC Program Manager Briefing Session 7
March 2
1300-1500 EST
www.crows.org

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

AOC Virtual Series Webinar: Cyber Electromagnetic Activities and Signals Intelligence: 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
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PEC2-50M2500M-2DBM-LM-SFF

PEC-150M6G-17LM-SFF
PEC-100M20D1G-20LM-SFF
PEC-100M16G-17LM-SFF

PEC-85-0R32R5-15LM-12-SFF

PEC2-1G12G-60-21DBM-LM-PP

PMI Model No.	Freq Range (GHz)	Noise Figure (dB)	Input Power (dBm)	Output Power (dBm)	Output Power Flatness (dB)	Size (Inches) / Connectors
PEC2-50M2500M-2DBM-LM-SFF https://www.pmi-rf.com/product-details/pec2-50m2500m-2dbm-lm-sff	50 MHz - 2.5	10 dB Typ above 500 MHz	-50 to +30	+2 Nom	±3.5	2.98" x 0.78" x 0.26" SMA (F)
PEC-100M16G-17LM-SFF https://www.pmi-rf.com/product-details/pec-100m16g-17lm-sff	100 MHz - 16	< 6 dB Above 1 GHz, < 9 dB Below 1 GHz	-12 to +16	+16 Min, +21 Max	±2.0 Max	1.91" x 0.70" x 0.36" SMA (F)
PEC-100M20D1G-20LM-SFF https://www.pmi-rf.com/product-details/pec-100m20d1g-20lm-sff	100 MHz - 20.1	< 6 dB Above 1 GHz, < 9 dB Below 1 GHz	-12 to +16	+19 Min, +24 Max	±2.5 Max	1.91" x 0.70" x 0.36" SMA (F)
PEC-150M6G-17LM-SFF https://www.pmi-rf.com/product-details/pec-150m6g-17lm-sff	150 MHz - 6.1	< 6 dB Above 1 GHz, < 9 dB Below 1 GHz	-12 to +16	+16 Min, +21 Max	±2.0 Max	1.91" x 0.70" x 0.36" SMA (F)
PEC-85-0R32R5-15LM-12-SFF https://www.pmi-rf.com/product-details/pec-85-0r32r5-15lm-12-sff	300 MHz - 2.5	5.0 dB Typ	-65 to +10	+15	± 2.5	5.0" x 1.5" x 0.51" SMA (F)
PEC2-1G12G-60-21DBM-LM-PP https://www.pmi-rf.com/product-details/pec2-1g12g-60-21dbm-lm-pp	1 - 12	8 dB Typ	-61 to +15	21 Min	±2.0 Nom	2.98" x 0.78" x 0.26" RF PIN / PIN
PEC2-1G18G-60-9DBM-LM-SFF https://www.pmi-rf.com/product-details/pec2-1g18g-60-9dbm-lm-sff	1 - 18	8 dB Typ	-61 to +30	+7 to +11 Max	±2.0	2.98" x 0.78" x 0.26" SMA (F)
PEC3-40-1D6G2D7G-15LM-SFF https://www.pmi-rf.com/product-details/pec3-40-1d6g2d7g-15lm-sff	1.6 - 2.7	5.5 dB Max	-25 to +5 Min, -30 to +5 Typ	+15 Min	±1.5	1.91" x 0.78" x 0.36" SMA (F)
PEC3-40-2G6G-15LM-SFF-HS https://www.pmi-rf.com/product-details/pec3-40-2g6g-15lm-sff-hs	1.85 - 6.25	5.5 dB Max	-15 to +17	+15 Min	±1.5 Max	1.91" x 0.78" x 0.36" SMA (F)
PEC2-2G18G-80DB-21DBM-LM-SFF https://www.pmi-rf.com/product-details/pec2-2g18g-80db-21dbm-lm-sff	2 - 18	10 dB Max	-55 to +10	+21 to +25 Nom	±2.0	2.98" x 0.78" x 0.26" SMA (F)
PEC2-2G18G-2DBM-LM-SFF https://www.pmi-rf.com/product-details/pec2-2g18g-2dbm-lm-sff	2 - 18	10 dB Max	-50 to +30	+2 Nom	±2.0 Max	2.98" x 0.78" x 0.26" SMA (F)
PEC2-2G18G-21DBM-LM-SFF https://www.pmi-rf.com/product-details/pec2-2g18g-21dbm-lm-sff	2 - 18	5 dB Max	-45 to +10	+21 to +25 Nom	±2.0 Max	2.98" x 0.78" x 0.26" SMA (F)
PEC2-3D1G3D5G-60-10DBM-LM-SFF https://www.pmi-rf.com/product-details/pec2-3d1g3d5g-60-10dbm-lm-sff	3.1 - 3.5	8.0 dB Typ	-61 to +30 Min	+8 Min, +11 Max	±1.0 Typ	2.98" x 0.78" x 0.26" SMA (F)

PEC3-40-1D6G2D7G-15LM-SFF
PEC3-40-2G6G-15LM-SFF-HS

PEC2-1G18G-60-9DBM-LM-SFF
PEC2-2G18G-80DB-21DBM-LM-SFF
PEC2-2G18G-2DBM-LM-SFF

PEC2-2G18G-21DBM-LM-SFF
PEC2-3D1G3D5G-60-10DBM-LM-SFF

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2020

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www.ausa.org

Dixie Crow Symposium 45
Conference: March 21-24
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Counter IED
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Swindon, UK
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AOC Virtual Series Webinar: The Year in Review – GPS/PNT Disruptions and Improvements
March 25
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Counter-UAS Winter Summit – Virtual
Conference: March 31 – April 2
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APRIL

AOC Professional Development Live Web Course: Fundamental Principles of Electronic Warfare
April 5-28
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LAAD Security
Conference: April 6-9
Rio de Janeiro, Brazil
www.laadsecurity.com.br

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April 8
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2.0 EMS Virtual Summit
Conference: April 13
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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
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MAY

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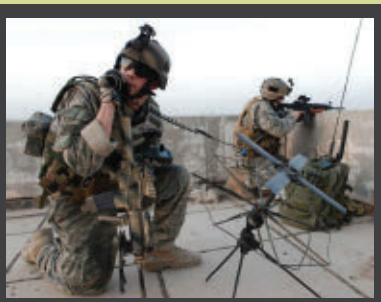

ASSOCIATION OF OLD CROWS

30 YEARS SINCE DESERT STORM

It's hard to believe that it has been 30 years since Desert Storm, and a lot has changed since then. Desert Shield saw the deployment of approximately 670,000 troops from 28 countries (there were 39 countries in the coalition) and 2,250 combat aircraft. Electronic Warfare (EW), was a major factor during this conflict, and we had multiple assets that had specific EW roles – RC-135s, F-4Gs, EF-111s, EA-6Bs, EC-130Hs, just to mention a few. The number and types of attack aircraft (fixed-wing and rotary-wing) was vast and large, and most had RWR and self-protection systems, either internal or on an external pod. B-52s, F-15s F-16s, A-10s, F-18s, A-6s, A-7s, AV-8Bs, AC-130s, Mirage, Jaguar, Buccaneers, Tornados, Mirage, AH-64, AH-1S and Gazelles all had some type of EW system that had to be programmed, maintained and repaired; no small task. The F-117 "Stealth Fighter" made its major combat debut (not their first combat missions, but the first time they were deployed and employed in force). EW was critical to the successful Desert Storm Air Campaign resulting in minimal loss of allied aircraft and aircrew, and facilitating the "100 hour" land campaign.

After Desert Storm, the United States invested heavily in stealth technology and aircraft (F-117, B-2, F-22 and F-35), and so have our allies and adversaries. One consequence of the Air Force's emphasis on stealth was that it led to more than two decades of atrophy of EW assets and capabilities. Fortunately, today we have seen this change with the realization that stealth is one tool in the EW toolbox, not the only one. We are also seeing a resurgence in what we now call Electromagnetic Warfare in all three pillars: Electromagnetic Support (ES), Electromagnetic Attack (EA) and Electromagnetic Protect (EP). Legacy aircraft are receiving new systems, including F-15 Eagle Passive Attack Warning Survivability System, new RF countermeasure systems for F-16s and AC/MC-130Js, EA-18G Growler Next Generation Jamming Pods, EC-37Bs will replace EC-130H Compass Call aircraft, and an EW modernization plan for F-35s across lifecycle. It is truly an exciting time to be a part of the EW and EMSO community.

Just as a reminder, our "AOC Discussions," where we talk with senior military leaders about EMSO and larger EMS-related issues, kicked off last month with Vice Chairman of the Joint Chiefs of Staff Gen John Hyten, USAF; Gen David Thompson, Vice Chief of Space Operations, United States Space Force; and Gen Charles Brown, Chief of Staff, US Air Force. This month, we have Air Chief Marshal Sir Stuart Peach, Chairman of the NATO Military Committee, on February 3; Hon. Dr. Bruce Jette, Assistant Secretary of the Army for Acquisition, Logistics & Technology (ASA(ALT)) & Army Acquisition Executive (AAE), on February 10; and VADM Jeffrey Trussler, Deputy Chief of Naval Operations for Information Warfare, N2/N6, Office of the Chief of Naval Operations/Director of Naval Intelligence, on February 24. This is an outstanding opportunity to hear from our senior leaders, and I hope you will participate in this forum.
– Glenn "Powder" Carlson

FEATURED LIVE COURSES

RF Theory for ES Operations

Dr. Patrick Ford

Tuesdays & Thursdays
1:00 - 4:00 PM ET | March 22 - 26, 2021
This course will also provide a survey of propagation modeling techniques and an update on modern RF operating trends.

Fundamental Principles of Electronic Warfare

Dave Adamy

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

Advanced Principles of Electronic Warfare

Dave Adamy

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

C4ISR Requirements, Principles, and Systems

Dr. Clayton Stewart

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

Aircraft Radar Cross Section Engineering

Renan Richter

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

Direct Energy Weapons

Kyle Davidson

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

Introduction to Satellite Communications (Satcom)

Dr. Patrick Ford

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

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US NAVY AWARDS NGJ LOW-BAND EMD CONTRACT

The US Navy has selected L3Harris Technologies (Salt Lake City, UT) as the developer for the Engineering and Manufacturing Development (EMD) phase of the Next-Generation Jammer Low-Band (NGJ-LB) program. It awarded a $495.5 million cost-plus incentive fee contract to the company in December.

The NGJ-LB pod will replace the legacy ALQ-99 low-band pod on US Navy and Royal Australian Air Force (RAAF) EA-18G Growlers. It represents an important upgrade that will enable the Growler to protect low-observable aircraft against detection by VHF radars and other types of low-band radars at much longer distances than the ALQ-99 can currently provide. As it did with the ALQ-99, the Navy will field three variants of the NGJ. Its NGJ Mid-Band pod, under development with Raytheon, is approaching the end of its EMD program and is currently undergoing Navy flight testing. Also, the Navy will soon begin early development of the NGJ High-Band pod.

The NGJ-LB EMD contract, which is managed by the Airborne Electronic Attack Program Office (PMA-234) at Naval Air Systems Command (NAVAIR), calls for L3Harris to deliver eight prototype pods and two mission system prototypes, as well as ten pod simulators, six mass model pods (four jettison and two captive carry) and two technique development systems. Most of the work will be carried out by the company's facility in Salt Lake City, UT, which has a long track record developing datalink systems. Several years ago, the company developed and demonstrated some promising low-band jamming technologies under Naval Research Lab programs. In late 2018, the Navy selected L3Harris and Northrop Grumman to participate in a two-year NGJ-LB Demonstration of Existing Technologies (DET). The DET phase, which included hardware demonstrations at the Navy's Air Combat Environmental Test and Evaluation Facility (ACETEF), wrapped up in late 2020. Concurrent with the DET phase, PMA-234 also worked on transitioning the NGJ-LB acquisition strategy from a Mid-Tier Acquisition effort (which at the beginning of the program provided for a quicker schedule) to a Major Defense Acquisition Program (MDAP) Acquisition Category (ACAT) IB program. The Assistant Secretary of the Navy approved the program for Milestone B on December 8, and the EMD contract was awarded to L3Harris on December 18.

NGJ-LB is a joint development effort between US Navy and the RAAF, which also flies the EA-18G. A joint development agreement was signed between the US and Australian governments last summer. The program is expected to undergo Preliminary Design Review in mid 2021 and Critical Design Review in late 2022. – *J. Knowles*

DOD EMS PRIORITIES – WHERE ARE WE NOW?

Speaking at an Association of Old Crows (AOC) Discussions event January 6, Gen John E. Hyten, Vice Chairman of the Joint Chiefs of Staff, Joint Requirements Oversight Council (JROC) Chairman, and Senior Designated Official (SDO) for the Electromagnetic Spectrum Operations (EMSO) Cross Functional Team (CFT), took stock of recent advances in EMSO capabilities and addressed the long road ahead to achieving EMS superiority.

Responding to FY21 NDAA Requirements

Section 152 of the FY21 National Defense Authorization Act (NDAA) calls for the transition of EMS and EW responsibilities currently under the purview of the Joint Electromagnetic Warfare Center (JEWC) under the US Strategic Command (USSTRATCOM) to a new entity within the DOD in the next two years. This new entity will adopt all responsibilities that are "germane to EMSO, including advocacy for electronic warfare, providing contingency electronic warfare support for other combatant commands, and supporting combatant command joint training and planning for EMSO."

Before this requirement from Congress can be met, however, General Hyten said, "The first thing we have to do is make STRATCOM whole in the EW community because they're under-resourced, under-manned and not fully capable of performing the EMSO duties they've been given by the department." He continued, "We've told STRATCOM [to] fix the problem, but we give them no resources. If we hand it off to someone new, they'll have no resources, and we won't fix the problem."

While the DOD works to strengthen and properly resource the JEWC so that it may effectively assume and then pass on its responsibility over EMSO, USSTRATCOM will work, in so far as it is capable, to implement the Cross Functional Team (CFT) EMS Superiority Strategy (EMSSS) released in October of 2020.

Bolstering Services' Involvement in EMS Strategy Implementation

General Hyten pointed out that while the Joint Staff has a significant role in ensuring the EMSSS goals are achieved, much of the responsibility of bolstering

the EMS enterprise should and will fall to the Services rather than to the Joint Staff or the Office of the Secretary of Defense (OSD).

General Hyten said that in the past, the Services have been slow to respond to EMSO priorities. Looking back to 2012-2015, he said, "We were missing a critical expertise that we needed as we moved into the future." However, changes were slow-moving. He said, "I thought we'd be further along right now than we are. I thought once we pointed out the obvious inside the Air Force, the Air Force would embrace it and move quickly, and that didn't happen. I thought the Joint Force would embrace it and move quickly, and that didn't happen."

The EMSSS encompasses five goals: 1) developing capabilities; 2) training and equipping an agile, integrated EMS infrastructure; 3) pursing total EMS readiness; 4) building partnerships to ensure future integration with allies; and 5) establishing effective EMS governance. The first two goals, in particular, according to General Hyten, are imperative. Without accomplishing these, he said, "We will fail in the execution of that strategy."

That said, General Hyten said that, recently, "We've had a lot of success in those areas, both in developing capabilities…and in organizing effectively." Among these successes are the new Air Force Spectrum Warfare Wing, the Space Force's Space EW "Delta" (the equivalent of a wing), the Army's Terrestrial Layer System, and the Navy's work on its Next Generation Jammer (NGJ) pods.

Achieving EMS Superiority in All-Domain Operations

Presently, the JROC is working to create a new Joint Warfighting Concept (JWC) to guide All-Domain Operations (ADO), which will be "critically enabled by spectrum operations and EW." The JWC will include four underlying concepts (joint global fires, Joint All Domain Command and Control, contested logistics and information advantage), each with their own Joint Requirements created by JROC.

General Hyten said that in late spring of this year, the JROC will release these new requirements and will hold the Services accountable for meeting them. "We're going to define the broad based standards and structures that all the Services have to fit in so that when they build their…unique Service capabilities and they come together in the Joint fight, they'll be able to effectively fight and win together." He added, "That's what the JROC was mandated to do decades ago, and we've never fully lived up to that requirement."

According to General Hyten, the fourth concept, information advantage, is the EMSO community's primary focus. He said, "Under information advantage is the ability to achieve spectrum superiority in all domains…If you can't do that, you will fail – you will fail in your mission." He continued, "In the challenges of the future, whoever we are in contest with, we have to be able to effectively fight and win the [EMS] fight right from the beginning." – *H. Swedeen*

KAZAKHSTAN SEEKS SPECIAL MISSION KING AIR B300ER AIRCRAFT

The White House has approved given the green light to Kazakhstan to buy a pair of signals intelligence (SIGINT)-configured King Air special mission aircraft from the US Government. This marks the first time the central Asian nation has been approved to buy US-sourced SIGINT aircraft.

According to the notice from the Defense Security Cooperation Agency, the Foreign Military Sales (FMS) case, covering two King Air B300ER Scorpion aircraft with intelligence, surveillance, reconnaissance mission systems plus related equipment, is valued at an estimated US$128.1 million. The mission suite includes a Raytheon AST TITAN communications intelligence (COMINT) suite, a Sierra Nevada Small SWAP Auto electronic intelligence (ELINT) system, a Leonardo Osprey 30 active electronically scanned array radar and an L3Harris Wescam MX-15HDi electro-optical/infrared turret. The proposed FMS package, for which Sierra Nevada Corporation (Hagerstown, MD) would be principal contractor, also includes secure communications; fixed and transportable ground control stations; ground support equipment; aircraft integration and test support; personnel training; spare, component and repair parts; and software and software support. – *R. Scott*

US NAVY SEEKS PASSIVE TARGETING CAPABILITY FOR MQ-8C FIRE SCOUT UAS

The US Navy is looking to introduce an electronic intelligence (ELINT) system onto the Northrop Grumman MQ-8C Fire Scout rotary-wing unmanned aerial system (UAS) to confer a capability to detect, classify, and geo-locate surface targets.

In a sources sought notice issued in early January, the Naval Air Systems Command's (NAVAIR's) Multi-Mission Tactical Unmanned Air Systems Program Office (PMA-266) said it intends to procure up to 43 Passive Targeting (PT) hardware kits over the course of five years. NAVAIR has initiated a market survey activity for candidate solutions.

The addition of an ELINT capability will enable the MQ-8C to exploit the electromagnetic spectrum for maritime indications and warning; intelligence, surveillance, reconnaissance, and targeting; and support passive threat detection and targeting capability to enhance the operational commanders capability to conduct effective, long-range operations.

An initial procurement of PT hardware is planned for the second quarter of FY22. The Navy is currently completing a trade study analysis for the integration of a PT system so as to assess a suitable hardware solution to meet MQ-8C capability, design and operational requirements.

NAVAIR's outline requirement calls for a mature (TRL 7) system incorporating a precision direction finding capability and meeting the following size, weight, and power constraints: a maximum volume (processor/receiver) of 2 cubic feet; a maximum weight (pro-

cessor, receiver and antenna) of 100 lb; and an electrical power draw of 28 VDC/ max 1000 W.

Potential bidders with hardware meeting these criteria have been asked to provide additional detail on their technical solutions. This includes antenna field of view/system field of regard, search/scan capability, and frequency bandwidth.

NAVAIR said the required delivery date for the initial PT hardware (laboratory and prototype kits) is no later than 18 months after contract award. The period of performance from contract award to completion of flight test support is anticipated to be approximately 42 months, with a potential 24 months for integration and test support of the selected hardware. – *R. Scott*

TERMA AWARDED IDIQ CONTRACT FOR AN/ALQ-213 EW CONTROLLER

Terma North America, the US-based subsidiary of Danish systems and sensors house Terma A/S (Lystrup, Denmark), has secured a 10-year indefinite-delivery indefinite-quantity (IDIQ) contract worth up to $306 million to provide support to EW countermeasures controller equipment used by the US Air Force (USAF).

Awarded by the Defense Logistics Agency (DLA)-Aviation at Warner Robins in December 2020, the enterprise-level agreement covers AN/ALQ-213 Electronic Countermeasures System (ECMS) self-protection hardware, sustainment, and engineering services applicable to the F-16, A-10, and C-130 aircraft operated by the USAF. The contract will also address the ECMS requirements of international F-16 customers under Foreign Military Sales (FMS).

The AN/ALQ-213 ECMS enables radar warning, jamming and countermeasures dispensing systems to be integrated into a single federated EW suite. The system provides threat processing and selection of the optimum threat response techniques (jamming and dispense of appropriate countermeasures) in manual, semi-automatic and automatic modes.

Originally designed and developed by Terma to meet the needs of the Royal Danish Air Force, the AN/ALQ-213 was first selected for USAF aircraft in the late 1990s following a successful Foreign Comparative Test. Since its original selection, the system has been installed on F-16 aircraft (Block 25, 30, 32, 40, 42, 50 and 52), A-10 and HC-130N aircraft, totaling almost 950 installations. Additionally, there are several FMS customers operating AN/ALQ-213 systems supported by the Air Force Life Cycle Management Center Electronic Warfare and Avionics Division.

According to a justification and approval document released concurrent with the award, the USAF has a minimum buy requirement for the first year of the contract to support AN/ALQ-213 trial installations and kitproof integration with the AN/ALR-69A radar warning receiver on select F-16 aircraft. Production buys are expected to cover 530 ALQ-213 new systems to install on high block F-16s. In addition, production buys are expected to purchase 835 new countermeasures signal processor line replaceable units currently fielded on ALQ-213-configured A-10 and F-16 low block aircraft. – *R. Scott*

IN BRIEF

The US Air Force, acting through the Systems of Systems Consortium (SOSSEC) (Salem, NH), awarded a $250 million contract to **Northrop Grumman** (Rolling Meadows, IL) in November to complete the final development and testing phase of a new EW suite for the F-16. The Other Transaction Authority (OTA) effort calls for a new digital radar warning receiver (RWR) integrated with a jamming system (including a fiber-optic towed decoy system) for Air Force and Air National Guard F-16s, which currently fly with ALR-56M RWRs and ALQ-131 jamming pods developed in the early 1980s. Originally, the Air Force planned to buy nearly 900 EW suites, but Air Force Magazine (HT to John Tirpak) reported that the buy is now likely to be for 450 systems, which would bring the total contract value to approximately $2.5 billion. Northrop Grumman squared off against L3Harris (Clifton, NJ) in the prototyping and demonstration phase of the program.

The Kuwaiti Government has requested the sale of 8 new AH-64E Apache attack helicopters and the upgrade of its current fleet of 16 AH-64D helicopters to the -E model standard in a $4 billion Foreign Military Sale package from the US Government. In addition to new radar, EO/IR targeting and communications systems, the deal would include multiple EW systems: 27 AAR-57 Common Missile Warning Systems and countermeasures dispensers **(BAE Systems)**, 17 APR-48B Modernized RFI ESM systems **(Lockheed Martin)**, 27 APR-39(D)V2 radar warning receivers **(Northrop Grumman)** and 27 AN/AVR-2 laser warning receivers **(Collins Aerospace)**.

The **US Army Research Office** (ARO) has released a Broad Agency Announcement (BAA W911NF-21-S-0003-01) seeking proposals for establishing a multidisciplinary research center for extreme RF electronics (x-RF electronics) based on ultra-wide bandgap (UWBG) semiconductors and related emerging materials. According to the BAA, the UWBG RF Electronics Center will facilitate collaboration between extramural academic researchers and the Army in pursuit of a mutual goal: generating the foundational knowledge in solid-state physics, device structures, integrated circuit design, materials discovery and development, and physics-based machine learning needed to enable the next generation of RF electronics with unprecedented power, bandwidth, frequency agility, and size-weight-and power (SWaP) requirements. The Center will provide the Army with a new ability to create advanced RF technologies across its modernization priorities for robust multidomain operations in highly contested electromagnetic (EM) environments. The BAA consists of three main topics: Ultra-wide Bandgap (UWBG) Semiconductor Physics and Devices, UWBG Materials, and Physics-Driven Machine Learning for UWBG Materials and RF Device Development. Whitepapers are due by February 15 and full proposals are due by June 1. The contracting point of contact is Kevin Bassler, (919) 549-4297, e-mail kevin.j.bassler.civ@mail.mil.

EW Goes Comme

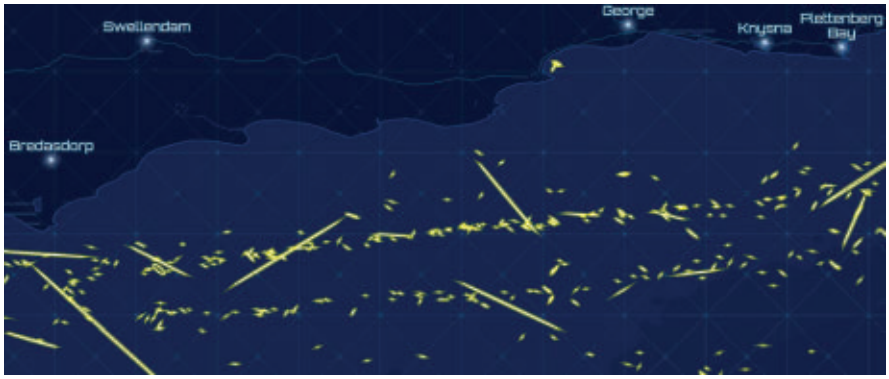
By Barry Manz

Not too long ago, some very enterprising people asked themselves a question: If almost anyone can access spacecraft-delivered, high-quality images, and accurate geolocation of most places on Earth for a fee, why not add RF signals to the mix? The answer, as it turns out, is that this is not just an interesting idea but a potentially lucrative market. As readers of *JED* would quickly conclude, such a service would seem to infringe on defense and intelligence agencies throughout the world who would take a dim view of commercializing space-based electromagnetic warfare (i.e., ESM) and signals intelligence (SIGINT) services. However, these same agencies are already expressing interest in the business as an adjunct to their existing resources. And they're not alone, as potential commercial uses range from tracking poachers and illegal fishing vessels to vessels used for human trafficking.

But first, keep in mind that for the US Department of Defense (DOD), the use of commercial space assets is nothing new. DOD and other government agencies spend millions of dollars every year for the use of commercial satellite communications and other services to complement their own formidable capabilities. The major satellite service providers, such as Inmarsat, Viasat, and Iridium, have long relationships with DOD and other government agencies throughout the world.

Peraton, the former government services business unit of Harris Corp. now owned by Veritas Capital, in October added to its already substantial government satcom business with a $10-million, 5-year contract from the Space Force for orbital analysis services. However, defense agencies aren't the only entities that could benefit from commercial space-based SIGINT services.

In fact, the commercial market represents space-based RF tracking opportunities that, if not as lucrative as defense, are more diverse, from shipping to poaching, and piracy, to name a few. The most likely commercial target is the shipping industry, the world's largest user of commercial satellite services for geolocation and communications. This includes more than 50,000 registered container ships, bulk cargo carriers, oil, gas, and chemical tankers, and passenger ships traveling through international waters. Tracking them is obviously essential, especially in congested waterways, and the basic tool for achieving this is the Automatic Identification System (AIS).



HawkEye 360's RFGeo product can track X- and S-Band radar emissions from "dark" ships.

HAWKEYE 360

The International Maritime Organization's Safety of Life at Sea (SOLAS) regulation requires all vessels of 300 gross tons more and passenger ships of any size to have AIS transceivers installed. AIS originally sent signals from boats to land stations over a distance of about 20 miles, but more recently low-earth orbiting (LEO) satellites are used for this purpose and can be harnessed for other uses, such as search and rescue operations.

The automated system broadcasts signals to and from transponders operating at VHF frequencies, with the data displayed via monitors on each ship and at land-based monitoring stations. The complete data package is extensive and includes the ship's unique identifier that fully describes its position, a timestamp, and its cargo, destination and route plan. Position and timing information is derived from GPS, and other information is obtained from shipboard equipment.

In an ideal world, AIS information would be sufficient to authenticate each vessel and ensure ships don't collide. But not all ships and their cargos are what they say they are. Pirates, fishing vessels operating in protected waters, and oil tankers from nations under sanction use spoofing, hijacking for deception, and some will also turn off their AIS transponder. Although the AIS is supposed to be switched on at all times, ship captains have the discretion of turning them off for various reasons. And when AIS is off, the ship effectively goes "dark," to many vessel traffic monitoring systems and no exchange of information takes place, which for obvious reasons creates a very dangerous maritime environment.

Of course, manipulating AIS does not preclude a vessel's detection by space-based optical and RF sensors. Historically, satellite imagery and SIGINT collection has only been available to military users and intelligence agencies. The first real-time satellite imagery was provided by a US KH-11 satellite in 1977. The history of SIGINT satellites is even older, going back to 1960, when the US launched the first of five low earth orbit Galactic Radiation and Background (GRAB) satellites to monitor Soviet radar emissions.

As the commercial space market began to evolve beginning the 1960s, more payload types were gradually introduced into orbit. Commercial satellite imagery became widely available in the early

rcial...From Space

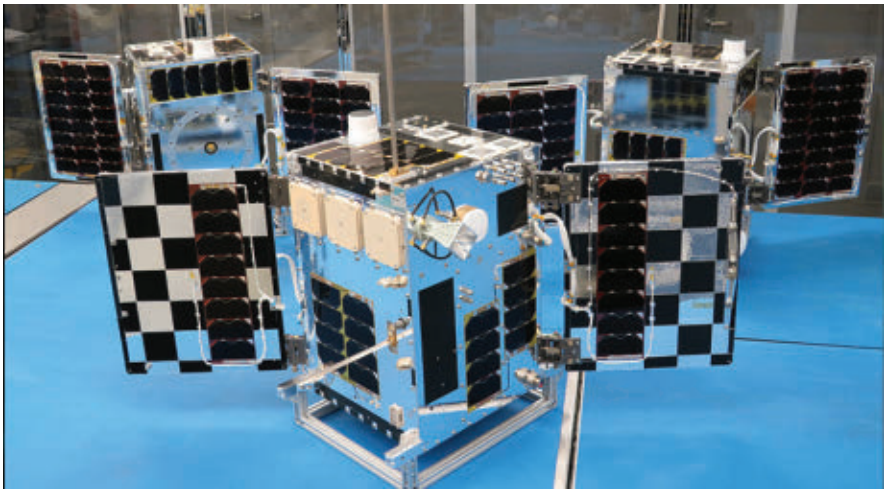
2000s. Today, companies such as DigitalGlobe provide high-resolution still and video images for a fee, a market that has grown to $5 billion today with projected growth to more than $7 billion by 2024. Their services are used by a diverse array of organizations from the shipping industry, defense agencies, environmental groups, the World Health Organization, and hundreds more – including resourceful investigative journalist consortiums like Bellingcat – that combine their images with data from other sources to provide forensic analysis of events such as Russia's role in the downing of Flight MH17 over Ukraine in 2014.

AIS and commercial digital mapping services provide an extraordinary amount of real-time information, but one other element has been missing: monitoring RF emissions from the Earth's surface – a hole that a new cadre of companies hopes to fill. The barrier to entry into this market would have until recently been the extremely high cost of building and launching satellites, but the emergence of very small satellites has stripped this impediment away.

CUBESATS: MAKING SPACE-BASED SIGINT POSSIBLE

These spacecraft, collectively called CubeSats based on their form factor, are classified according to their weights. Femtosats weigh less than 0.1 kg, picosats 0.1 to 1 kg, nanosats 1 to 10 kg, microsats from 10 to 100 kg, and minisats from 100 to 1000 kg. Their small size allows them to be densely packaged inside a rocket so that dozens can be carried and deployed in a single launch. They cost a small fraction to build and launch when compared with their traditional satellite counterparts, and they can be manufactured faster and placed in orbit cost-effectively by piggybacking on the launch of larger payloads.

Although CubeSats aren't new, having first been developed at Stanford University in 1999, advances in various technologies have transformed them into small but powerful platforms. The basic unit for the first satellite proposed by the Stanford researchers was defined as a 1U cube with dimensions of 10x10x10 cm. Using this as its basis, CubeSats can range in size from 1U to 16U, so a 2U nanosat could weigh 2.66 kg and measure 10×10×20 cm. CubeSats are restricted to a maximum radiated RF power of 1 W (30 dBm) for establishing downlink communication to earth stations, while earth stations can deliver to 100 W (50 dBm) in the uplink direction.



Hawkeye 360 delivered its Cluster 2 satellites to Cape Canaveral, FL, in mid-December. They are expected to launch on a Space X Falcon 9 rocket in the first quarter of 2021. HAWKEYE 360

The coverage provided by a CubeSat mission depends on the number of satellites, the number of orbital planes, the elevation angle, the inclination, the altitude, the orbital plane spacing, and the eccentricity of the orbit. All current CubeSats have been deployed in LEO in part to mitigate the platform cost and complexity, but also to support low-latency communications from the satellite to Earth stations and back to the satellite.

A good example of current CubeSats is the SpaceX Starlink program, which is dedicated primarily to providing commercial broadband service everywhere on Earth. Although the Starlink constellation does not provide SIGINT, the program illustrates how cost-effective this approach can be. The program has piqued the interest of the Army, which is examining the possibility of using the Starlink constellation as a low-cost, highly accurate, and almost unjammable alternative to GPS. The Army already has a relationship with Starlink to explore moving data across military networks.

SpaceX launches 60 satellites into low Earth orbit from a single Falcon 9 rocket. They are designed to deorbit in 5 years or less, mitigating what would otherwise add to the increasing amount of space junk. Elon Musk says the entire cost of the program is expected to be about $10 billion, and although his projections are sometimes optimistic, even if the actual cost is five times that much the program would still be comparatively cheap.

Last November, SpaceX began sending out email invitations for public beta testing of the service, which Musk calls "Better Than Nothing Beta." The company currently has nearly 900 satellites in orbit and plans to continue launching them until it achieves its goal of downlink latency between 16 and 19 msec by this summer. To no one's surprise, Jeff Bezos plans to develop its own satellite constellation, called Project Kuiper, adding yet another arrow to Amazon's quiver. The company announced in December that it has developed and tested

a 12-in.-diameter K-band phased array antenna for the user terminal that can deliver downlink speeds of 400 Mbps.

There are at least 20 companies throughout the world that design and build CubeSats, a number that does not include government research organizations, universities, prime government contractors, or any companies in China, so the total is much, much larger. Each one competes on one or more factors that differentiate it from others, and the result is a very competitive market.

A NEW BUSINESS MODEL EMERGES

"We thought, there are commercial electro-optical and radar observation assets, so why not RF domain commercialization," says John Serafini, CEO of HawkEye 360, the first company to enter the space-based RF monitoring market and one of the very few with satellites in orbit. After its founding in 2015, the company launched this first three-satellite constellation less than 3 years later in 2018. "We set out to build a constellation of small satellites flying in formation in clusters of three", says Serafini "with two in the front and one in the back that oscillates back and forth to gain a 3D view of the emitter and to perform accurate geolocation. Our differentiator is our ability to process and analyze the data using Machine Learning and other tools," says Serafini."

"As this is a brand-new market that has never existed outside of the classified domain, we're building the market from scratch, split between the government and commercial entities for RF interference detection," he continues. "Potential markets include RF analytics for spectrum monitoring, maritime tracking and analytics, insurance, fishing companies, and cruise ship operators. Our goal is to have a balance between defense the humanitarian activities, such as anti-poaching."

Citing spectrum monitoring, Serafini notes that it is difficult to collect terrestrial spectrum data from the ground because the interfering signal has to be pinpointed by driving around in trucks of three to triangulate and achieve geolocation. Satellites can deliver this capability every 15 minutes or so. Dark ships are also a major problem, from human smuggling to drug trafficking, oil transport, and other activities. "As they cannot be found and there is no law enforcement capability for tracking those vessels," says Serafini, "we can provide these capabilities by monitoring their radars, radios, and other emitters."

"As this is a brand-new market that has never existed outside of the classified domain, we're building the market from scratch, split between the government and commercial entities for RF interference detection."

The company developed its first three satellites, known as Hawk-A, -B and -C, under the Pathfinder mission. The company contracted with the University of Toronto's Institute for Aerospace Studies, Space Flight Laboratory to design the platform based on its 15-kg NEMO microsatellite bus. Deep Space Industries (San Jose, CA), which is now part of Bradford Space, developed the propulsion system. The three satellites were launched aboard a Space X Falcon 9 rocket into LEO on a 97-degree, 590-km orbit in March 2018.

The company has built three subscription packages to serve various types of companies. RFGeo is HawkEye 360's RF signal mapping product. The RFGeo analytics package provides global geospatial data to enable RF spectrum awareness and uses the data generated by the satellites to identify and geolocate RF signals of interest from VHF through Ku-band including VHF marine radios, UHF transceivers, V-and S-band radars, AIS, and EPIRB beacons.

The Regional Awareness Subscription is the company's RF signal mapping product that identifies, geolocates, monitors and analyzes RF emitter behavior over time. The SEAker service is dedicated to the maritime environment and locates vessels even if they attempt to hide by deactivating their AIS or spoofing its signal. The company plans to add the ability to include sanctions data to vessel information, as well as providing fused data sets. These include independent RF geolocation of VHF and maritime signals, spoofing detection to indicate when a vessel's self-reported GPS location doesn't match the one detected by Hawyeye360, as well as a vessel registry that contains a continuously-updated record of RF signatures and activity over time.

HawkEye360 has gained significant momentum in the US defense market and has five more satellite clusters under development for launch this year and next. The growing constellation identifies and precisely geolocates emitters from a broad set of signals transmitted by VHF marine radios, UHF push-to-talk radios, maritime radar systems, AIS beacons, L-band satellite devices and emergency beacons.

Another company is Kleos Space, founded in Luxemburg in 2017 with the goal of serving the maritime market. Their offering is intended to provide a global picture of hidden maritime activity, enhancing the intelligence capability of government and commercial entities when an AIS signal is not available, imagery is unclear, or vessels are out of patrol range.

The company delivers "RF reconnaissance data as a service," collecting information about maritime emitters and selling it to defense organizations and agencies, including those that undertake search-and-rescue operations, as well as commercial customers. Kleos launched its first four RF reconnaissance satellites – collectively called the Scouting Mission (KSM1) – in November on an Indian Space Research Organisation Polar Satellite Launch Vehicle (PSLV). The KSM1 cluster, manufactured for Kleos by GomSpace A/S (Aalborg East, Denmark), were deployed in a diamond formation on a 37-degree inclined orbit that enables them to cover areas such as the Strait of Hormuz, South China Sea, Africa, the Southern Sea of Japan and the Timor Sea. The satellites, which are built around

Kleos Space launched its Scouting Mission KLM1 cluster in November. It plans to launch its second cluster in mid-2021. KLEOS SPACE

software defined radios, will monitor VHF signals and geolocate them via time-difference-of-arrival (TDOA) techniques. Additional monitoring capabilities could eventually cover satellite phones.

Following their November 7 launch, the first four Scouting Mission satellites underwent a three-month commissioning process, known as the Launch and Early Orbit Phase (LEOP). Once the KSM1 cluster is fully commissioned, the company's mission operations team will take over responsibility sometime this month. The notion of providing space-based ESM is very attractive to many defense and commercial organizations, and Kleos has already signed agreements with several customers. In May, the company said it had received a contract award from the Utah State University Space Dynamics Laboratory (SDL) in collaboration with the US Air Force Research Laboratory (AFRL) under the Micro-Satellite Military Utility Project Arrangement (MSMU PA). The company will deliver its RF emitter data to MSMU PA members, which include defense and intelligence organizations in Australia, Canada, Germany, Italy, Netherlands, New Zealand, Norway, the UK and the US. The MSMU PA is forging a pathway to a larger effort, known as the Multinational Heterogeneous Space Enterprise (ISR Enterprise), which will provide a range of satellite-generated information (electro-optic, synthetic aperture radar, AIS) to international partners.

Another recent customer is the Chilean Air Force, which in December signed on for a trial evaluation of the company's service. With Chile's 6,000 km of Pacific coastline and several islands far off shore, the Chilean Air Force will use Kleos data to help it monitor maritime activity in its territorial waters and beyond. Brazil's Agência Nacional do Petróleo, Gás Naturale Biocombustíveis (ANP) has also signed on for a trial demonstration. It hopes to use the company's emitter data and combine it with other space-based sensor data to identify illegal pollution and other environmental crimes. Kleos Space has also signed a contract with Intelligence Management Support Services Ltd (IMSL) in the UK, which will buy purchase Kleos Scouting Mission data and sell it along with analytics services to government and industry customers.

As the KSM1 satellite cluster becomes fully operational, the company is readying its next satellite deployment in June aboard a Space X Falcon 9 launch vehicle. This cluster, the Polar Vigilance Mission (KSF1), also comprises four satellites. They will be deployed in a 500-km Sun-synchronous orbit to monitor the northern and southern polar regions. For the KSF1 satellites, Kelos is working with a new partner, Innovative Solutions in Space (ISISpace), in Delft, The Netherlands. Kleos is raising funds to build a third satellite cluster by the end of 2021. Its ultimate aim is to launch 20 satellite clusters.

A third company pursuing this market is Unseenlabs based in Rennes, France. Founded by two brothers in 2015, the company has developed and launched three Breizh Reconnaissance Orbiter (BRO) satellites that are used track maritime vessels via their RF emissions (the company will not disclose which types of frequencies it is monitoring) and sell the data as a service to various types of customers. Its receiver also performs specific emitter identification (i.e., RF fingerprinting) of each signal, which enables its tracking system to follow specific ships through an area.

Unseenlabs launched its first satellite (BRO-1), a 6U CubeSat, on a Rocket-Labs Electron launch vehicle in August 2019. BRO-1, which was manufactured by GomSpace, was deployed in a 540-km, 45-degree orbit. The next two satellites (BRO-2 and -3) were launched in Novem-

ber 2020 into a 500-km, 97-degree orbit to provide further coverage. The company is building three more satellites, which it plans to launch by the end of 2021.

Another company hot on the heels of HawkEye 360 is Horizon Aerospace Technologies headquartered in the UK, whose CEO John Beckner basically built the company from scratch based on a long career in the aerospace industry and various projects that culminated in a SATCOM monitoring product called Flying Fish. The product got its name from a system called Marlin that is a tactical satellite intercept system for passive monitoring of communications networks and built by L3Harris TRL Technology in the UK.

Based on his relationship with L3Harris TRL, Beckner created Flying Fish, which can be configured for use in platforms ranging from ground vehicles to unmanned aerial systems, fixed-winged aircraft, and CubeSats, and passively monitors communications on the Thuraya or IsatPhone Pro networks as well as L-band signals. The company's latest entry is its AMBER constellation of CubeSats, yet to be launched, that will offer SIGINT as a service (SAAS) for maritime domain awareness (e.g., illegal fishing, smuggling and trafficking, piracy, and terrorists.

The payload will be able to locate and track vessels worldwide by detecting their RF emissions using the FlyingFish system along with X-and S-Band sensors and an AIS receiver. Revisit times are expected to be 4 to 7 to each covered global region per day, with the second generation reducing this to 1.5 to 2 hours, and the full constellation to less than an hour.

Most entrants in this market are concentrating on signal identification and analysis (i.e., ESM) and staying away from demodulating the signals to gain traditional SIGINT insights into their waveforms and other characteristics. However, Horizon Technologies (Reading, UK) will offer these SIGINT capabilities, as long as the subscribing country falls into the "friendly" category and Horizon gets approval to serve them.

The data would need to pass directly to the subscriber in raw form that can be used within the country's existing SIGINT analysis platforms. This approach not only provides the required security but also eliminates the need for Horizon to develop an interface to serve each customer.

The company announced in November that it shipped its first AMBER 6U CubeSat payload (known as IOD-3) to AAC Clyde Space in Glasgow, Scotland, which is now undergoing testing and will be integrated into the AAC Clyde Space bus in preparation for launch in the middle of this year. Once deployed and operational, the AMBER satellite will be operated from the company's Technologies' Amber Ground Exploitation Station (GES) in Newquay, UK.

The most important factor in this RF reconnaissance market is that its primary customer base is the commercial sector rather than military users. While this article covers the early entrants into this market, there is nothing stopping companies such as Inmarsat with enormous space assets to add SIGINT capabilities to their service portfolios. Not surprisingly, one of the other question marks concerns China, which has the benefit of enormous state-funded resources, formidable technology, and the unique ability to price its services at any level likely to secure a customer. The leader in China

In November, AMBER Horizon Space Technologies delivered its first AMBER CubeSat payload to AAC Clyde Space in preparation for a scheduled launch in mid-2021.

´AMBER HORIZON SPACE TECHNOLOGIES

IN ORBIT

The space-based RF reconnaissance industry is, if not embryonic, then certainly in the early stages of development. It is emblematic of the "New Space" market – exploiting a number of innovations, such as commercial launch platforms, smaller satellite form factors and turn-key satellite designs and manufacturing. This market will in no way replace the space sensing capabilities of major space nations. But no one expects them to do that, either. More likely, these RF emitter monitoring services will complement the ISR capabilities of some defense organizations, and they will likely enable smaller countries that cannot afford to develop, sustain and upgrade their own space-based monitoring capabilities to obtain real-time data on maritime traffic.

is HEAD Aerospace, whose three-axis-stabilized Skywalker satellites are built by the Shanghai Academy of Spaceflight Technology and employ a high-performance AIS receiver capable of processing 2 million AIS short messages every day and identify 60,000 ships. The Skywalker constellation is expected to consist of 48 satellites in various orbits.

This being said, the basic concept of providing space-based EW and SIGINT is undeniably sound. What remains to be seen is how these companies can differentiate themselves, how much DOD and other national defense agencies are likely to use their services, and the ability of small countries with limited signal monitoring capabilities to afford them. Regardless, this is a market to watch.

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TECHNOLOGY SURVEY

A SAMPLING OF ANALOG-TO-DIGITAL CONVERTER (ADC) BOARDS

By Barry Manz

As the gateway from analog signals to the digital domain, the digitizer board plays a critical role in every modern EW, signals intelligence, communications and test system. Its core component, the analog-to-digital converter (ADC), is arguably the most important element, as it is the first processing component in the signal path. So, its performance defines the performance the entire system can achieve, and each new device is studied in detail by designers.

ADCs have come a long way in the last decade. Ten years ago, the world's fastest ADC with 12-bit resolution sampled at 500 Megasamples per second (Msps). Today, an "off-the-shelf" 12-bit ADC can sample 6.4 Gigasamples per second (Gsps), and the more esoteric variety used in the most advanced digital receivers and test equipment can sample at even higher rates. When multiple ADCs are employed in an interleaving configuration, the sampling rate can be increased even further. And, as the Shannon-Nyquist sampling theorem mandates, in order to accurately reconstruct an analog signal in digital form, that sampling frequency must be twice the input signal's highest frequency. This means that it is possible to directly digitize signals even at millimeter-wave frequencies.

Advances in ADCs have arguably made direct RF sampling receivers possible, as they make the receiver much simpler by eliminating many analog components; this reduces cost, size, weight and power requirements. The reduction of analog components also eliminates their contribution of non-linearities, noise, image signals, phase noise and other errors while also providing the benefits of programmability and reconfigurability available when a signal is in the digital domain. As a result, designers are rapidly replacing analog receivers in most commercial and defense applications.

However, there is a lot more to this story; optimizing ADC performance in particular and sampling theory in general is not trivial and requires meticulous steps along with consideration of other factors. These include signal-to-noise ratio (SNR), effective number of bits (ENOB) and other metrics, all impacting achievable spurious-free dynamic range (SFDR), and thus the ability of the system to detect and process even very weak signals in the presence of stronger ones. Achieving the highest possible SFDR is a key goal, especially in Electromagnetic Warfare (EW) and Signals Intelligence (SIGINT) applications, as the higher the SFDR, the greater the ability of the receiver to detect weak signals of interest from stronger ones nearby.

Digitizers have typically been added as mezzanine cards on larger boards in various form factors, such as Open VPX, AXIe and PCIe. However, ADCs are sometimes integrated within the main board itself, and the latest multiprocessor SoCs from Xilinx integrate the ADC within a single device. At the high frequencies at which these devices operate, this is important because signal traces on the board are very tricky to work with. The problem is effectively eliminated when the converter is no longer a discrete device.

This being said, there are good reasons why digitization continues to be offered by many manufacturers as an independent board. For example, as the ADC determines overall system performance, it is desirable to have a choice of digitizers from various manufacturers (thanks to the increasing trend toward open systems), allowing the designer to match it to the needs of a specific application.

As illustrated by our survey, the features and configurations of digitizer boards vary widely among manufacturers, so there are plenty of choices, from single to multiple channels, narrow to very wide bandwidths, resolutions up to16 bits, and in many cases, an integrated FPGA for onboard, real-time signal processing. Others combine the ADC with a digital-to-analog converter (DAC), and all manufacturers provide ample software development tools, reference designs and other resources.

In the following survey table, we list the product name and the ADC model that it uses. This is followed by the number of channel, the number of bits and the effective number of bits (ENOB) the ADC provides. It is important to note that the number of bits figure and the ENOB are not the same. An eight-bit device quantizes the input into 256 unique steps, where a 12-bit device would quantize the same input into 4,096 unique steps. The greater number of bits provides improvement in Spur Free Dynamic Range (SFDR). The ENOB defines the number of bits that actually contain useful information. The reason the ENOB figure does not equal the actual number of bits is because analog-to-digital performance is degraded by noise distortion. Next we list the board's sample speed and the input bandwidth in megahertz or gigahertz, as well as the spurious free dynamic range (SFDR). The sample speed defines the maximum rate at which the A/D converter can be operated without distortion in the measurements. It can be operated at slower clock rates, but the vendor does not support faster rates. Input Bandwidth defines the input frequency bandwidth limit. The SFDR defines the range between the power level of the highest spur and the maximum input level.

An item not listed in the survey but very important to the fidelity of the analog-to-digital measurements is the sampling clock performance. Most modules will support locking to an external clock and provide some on module clock filtering. As the sampling speeds get faster, clock jitter needs to be keep very low or the fidelity of the samples will be impacted.

Our next survey, in the May *JED,* will focus on counter-UAS systems.

ANALOG-TO-DIGITAL CONVERTER (ADC) BOARDS

PRODUCT NAME OR MODEL NUMBER	ADC MODEL NUMBER	CHANNELS	BITS	ENOB	SAMPLE SPEED	INPUT BANDWIDTH
Abaco Systems, Inc.; Huntsville, AL, USA; +1 866-652-2226; www.abaco.com						
FMC172	ADC12DL3200	2	10	*	6.4 Gsps	>6 GHz
FMC163	ADC12D2000RF	2	12	*	4 Gsps	4.5 MHz - 3 GHz
FMC134	ADC12DJ32000	4	12	*	6.4 Gsps	5 MHz - 4 GHz 1.7 GHz - 6.7 GHz
Annapolis Micro Systems; Annapolis, MD, USA; +1 410-841-2514; www.annapmicro.com						
WILDSTAR 3XR0 3U OpenVPX FPGA Processor	ZU43DR Zynq UltraScale+ RFSoC	4 or 8	14	*	5.0+ Gsps	*
WILD FMC+ GM62 ADC & DAC	ZU27DR, ZU28DR, or ZU47DR Zynq UltraScale+ RFSoC	8	14	*	5.0+ Gsps	*
WILD FMC+ QM60 ADC & DAC	AD9082 Analog Devices	4	12	*	6.0 Gsps	*
ApisSys SAS; Archamps, France; +33 450360758; www.apissys.com						
AV133	EV12AS350	1	12	9 @ 2.1 GHz, -10 dBFS	5.4 Gsps	5.4 GHz
AV138	Xilinx Zynq UltraScale+ RFSoC: ZU25DR, ZU27DR, or ZU47DR	4	14	7.7 @ 5.9 GHz, -1 dBFS	5 Gsps	6 GHz
AV140	AD9082	4	12	8.3 @ 2.7 GHz, -1 dBFS	6 Gsps	8 GHz
BittWare; Concord, NH, USA; +1 603-226-0404; www.bittware.com						
RFX-8440	Zynq ZU43 RFSoC	4	14	11	ADC: 5 Gsps; DAC: 10 Gsps	5 GHz*
Curtiss-Wright Defense Solutions; Ashburn, VA, USA; +1 703-779-7800; www.curtisswrightds.com						
VPX3-534	ADC12DJ3200	4 or 2	12	8.7 @ 513 MHz (3 Gsps)	6 or 3 Gsps	8 GHz
VPX3-530	ADC12D2000RF	4 or 2	12	8.6 @ 498 MHz (2 Gsps)	4 or 2 Gsps	1.5 GHz
XMC-518	ISLA214P50	4	14	11.6 @ 105 MHz	500 Msps	400 MHz
Delphi Engineering Group; Irvine, CA, USA; +1 949-537-7701; www.delphieng.com						
ADF-D3030	AD9208	2	14	*	3.0 Gsps	*
ADF-Q3114	AD9208	4	14	*	3.1 Gsps	*
DAC-Q30	AD9172	4	16	*	12.6 Gsps	*
DynamicSignals LLC; Lockport, IL, USA; +1 800-567-4243; www.gage-applied.com						
EON Express	*	1 or 2	12	8.7	6 Gsps	1.75 GHz
RazorMax Express	*	2 or 4	16	11	1 Gsps	700 MHz
Razor Express	*	2 or 4	16	11.7	200 Msps	125 MHz

SFDR	FORMAT	ENVIRONMENT	FEATURES
*	FMC+	*	Provides two 10-bit A/D channel at 3.2 Gsps or one channel at 6.4 Gsps, and one 10-bit D/A channel at 6 Gsps.
*	FMC	0°C to +70°C (commercial) -40°C to +85° (industrial)	Provides one 12-bit A/D channel at 4 Gsps and one 14-bit A/D channel at 5.7 Gsps: low latency LVDS interface.
*	FMC	0°C to +50°C (commercial) -40°C to +71° (industrial)	Provides four 12-bit A/D channels at 3.2 Gsps or two channels at 6.4 Gsps; JESD204B interface.
*	3U OpenVPX	-55°C to +85°C (air, conduction, or air-flow-through cooled)	Supports third-party/customer-designed Analog Interface Cards for direct RF digitization or 18+ GHz superhet tuning.
*	FMC+ or 3U-S VPX	-55°C to +85°C (air or conduction cooled)	Operates as a standalone "brick" that is 1/3 smaller and lighter than 3U VPX, or pair with 3U or 6U Baseboard for additional processing.
*	FMC+	-55°C to +85°C (air, conduction, or air-flow-through cooled)	Allows for 8 ADC and 12 DAC channels in one 6U OpenVPX slot, or 4 ADC and 6 DAC channels for 3U.
55 dBc @ 2.1 GHz, -1 dBFS	3U OpenVPX	0°C to 55°C (air cooled), -40°C to 85°C (conduction cooled)	Ultra low latency ADC/DAC (EV12DS460) DRFM with Virtex UltraScale+ FPGA VU13P.
75 dBc @ 5.9 GHz, -1 dBFS	3U OpenVPX	0°C to 55°C (air cooled), -40°C to 85°C (conduction cooled)	Standalone 4-channel transceiver with processing capabilities and NVMe storage on board.
68.5 dBFS @ 2.7 GHz, -1 dBFS	3U OpenVPX - SOSA aligned	0°C to 55°C (air cooled), -40°C to 85°C (conduction cooled)	Wideband 4-channel transceiver with quad 16-bit 12 Gsps DAC and Virtex UltraScale+ FPGA VU13P.
86 dB	PCIe/standalone	5°C to 35°C	4 ADC channels, 14-bit 5.0 Gsps; 4 DAC channels, 14-bit 10.0 Gsps; ultra-low-jitter PLL; Variable gain down to -40 dBm; Xilinx Zynq RFSoC FPGA and dual ARM; 200 Gbps digital I/O. *Preliminary information.
(preliminary)	> 62 dBc @ 1.013 GHz (3 Gsps)	3U VPX	-55°C to +71°C (conduction cooled)
62 dBc @ 498 MHz (2Gsps)	3U VPX	0°C to 50°C or -40°C to 71°C (air cooled) -40°C to +85°C (conduction cooled)	Dual or quad ADC channels, dual DAC channels, user programmable Virtex-7 VX690T FPGA.
81 dBc @ 105 MHz	XMC; FMC available	0°C to 50°C or -40°C to 71°C (air cooled)	-40°C to +85°C (conduction cooled)
*	FMC	Convection and Conduction	Dual ADC/Dual DAC 3.0 Gsps.
*	FMC+	Convection and Conduction	Quad 3.1 Gsps Channels with DDC.
*	FMC+	Convection and Conduction	12.6 Gsps with Interpolation.
70 dB	PCIe	0°C to 50°C (air cooled)	6 Gbps continuous data streaming rate; eXpert FPGA or CUDA processing options; 8 GB onboard RAM.
75 dB	PCIe	0°C to 50°C (air cooled)	6 Gbps continuous data streaming rate; eXpert FPGA or CUDA processing options; 8 GB onboard RAM.
86.6 dB	PCIe	0°C to 50°C (air cooled)	2 Gbps continuous data streaming rate; eXpert FPGA or CUDA processing options; 16 GB onboard RAM.

ANALOG-TO-DIGITAL CONVERTER (ADC) BOARDS

PRODUCT NAME OR MODEL NUMBER	ADC MODEL NUMBER	CHANNELS	BITS	ENOB	SAMPLE SPEED	INPUT BANDWIDTH
Interface Concept; Quimper, France; +33 298 573 030; www.interfaceconcept.com						
IC-ADC-FMCPa	*	4	14	9.6 (Fin dep.)	2.6 / 3 Gsps	10 MHz - 4 GHz
IC-ADC-FMCb	*	4	14		400 Msps	1400 MHz
IC-ADC-FMCd	*	4	16	10.8 to 12.0 (Fin dep.)	80 to 310 Msps	400 MHz
ISI-Molex; California, USA; +1 805-482-2870; www.isipkg.com						
XA-500	AD9684	2	14	10.7	ADC: 500 Msps DAC: 625 Msps	1 GHz
XA-RX	AD9653 (x2)	8	16	12.6	125 Msps	150 MHz
FMC-1000	AD9680-1250 (or AD9680-1000)	2	14	10.8	ADC: 1250 (or 1000) Msps DAC: 1230 Msps	1.3 GHz
Mercury Systems; Andover, MA, USA; +1 978-967-1401; www.mrcy.com						
DCM3220	ADC12DL3200	2	12	8.5 bits @ 1.5 GHz	6.4 Gsps	2 GHz
DCM6122	ADC12DL3200	4	12	9 bits @ 1.5 GHz	3.2 Gsps	1 GHz
DCM6222	ADC12DL3200	2	12	8.5 bits @ 1.5 GHz	6.4 Gsps	2 GHz
Pentek; Upper Saddle River, NJ, USA; +1 201-818-5900; sales@pentek.com						
Model 5950	*	8	12	*	4 Gsps	4 GHz
Model 71141	TI ADC12DJ3200	2	12	*	6.4 Gsps	8 GHz
Model 71141	TI ADS42LB69	8	16	*	250 Msps	700 MHz
Per Vices Corporation; Toronto, ON, Canada; www.pervices.com						
Crimson TNG	ADC16DX370	4 TX, 4 RX	16	11 at full sample rate	Up to 370 Msps	Near DC to 6 GHz
Cyan	ADS54J60IRMP	Up to 16 combined TX and RX	16	10 at full sample rate	Up to 1 Gsps	Near DC to 18 GHz
Sundance DSP; Reno, NV, USA; +1 775-827-3103; www.sundancedsp.com						
FMCP-ADC3p0	AD9208 (pin compatible with AD9689)	4	14	9.6	3 Gsps	5 GHz
FMC-DAQ2p5	ADC12J2700	1	12	8.8	2.7 Gsps	3.2 GHz
VadaTech, Inc.; Henderson, NV, USA; +1 702-896-3337; www.vadatech.com						
VPX570	EV12AS350A	1	12	8.9	5.4 Gsps	5.7 GHz
AMC598	AD9208	4	14	9.6	3 Gsps	5 GHz
AMC587	TI ADC12DJ3200	2 or 4	12	9	6.4 or 3.2 Gsps	8 GHz

SFDR	FORMAT	ENVIRONMENT	FEATURES
70-80 dBFS (Fin dep.)	FMC - VITA57.1/57.4	std/ext	SMP-Lock / 50Ω AC coupled, 2* Clock inputs, Clock source : ext. or FPGA.
	FMC - VITA57.1	std/ext	SSMC coax jacks / 50Ω AC coupled, Clock & Trig inputs, Clock source : onboard or ext.
75-88 dBFS (Fin dep.)	FMC - VITA57.1	std/ext	SSMC coax jacks / 50Ω AC coupled, Clock & Trig inputs, Clock source : onboard, ext. or FPGA.
Up to 82 dB	VITA 42 XMC Module	0°C to 50°C	2 ADC channels, 14-bit 500 Msps; 2 DAC channels, 16-bit 625 Msps; ultra-low-jitter PLL; Xilinx Artix-7 FPGA; 16 Gb (2GB) DDR3 Memory; PCIe 2.0 (4 lanes).
Up to 83 dB	VITA 42 XMC Module	0°C to 50°C	8 ADC channels, 16-bit 125 Msps; ultra-low-jitter PLL; Xilinx Artix-7 FPGA; 8Gb (1GB) DDR3 Memory; PCIe 2.0 (4 lanes).
Up to 84 dB	VITA 57.1 FMC Module (HPC)	0°C to 50°C	2 ADC channels, 14-bit 1250 (or 1000) Msps; 2 DAC channels, 16-bit 1230 Msps; ultra-low-jitter PLL.
>60 dBc @ 2.3 GHz	3U OpenVPX	Conduction Cooled	Configurable, low-latency, coherent 3U OpenVPX module for SWAP constratined environments - 2Rx + 2Tx, V67 Rear I/O. One Xilinx Virtex® Ultrascale+™ VU9P and one Ultrascale+ ZU11EG.
>60 dBc @ 2.3 GHz	6U OpenVPX	Air Cooled, Conduction Cooled or Air Flo-By	Configurable, low-latency, coherent 6U OpenVPX module - 4Rx + 4Tx, Front I/O and V67 Rear I/O options. Two Xilinx Virtex® Ultrascale+™ VU9Ps and one Ultrascale+ ZU11EG.
>60 dBc @ 2.3 GHz	6U OpenVPX	Air Cooled, Conduction Cooled or Air Flo-By	Configurable, low-latency, coherent 6U OpenVPX module - 2Rx + 2Tx, Front I/O and V67 Rear I/O options. Two Xilinx Virtex® Ultrascale+™ VU9Ps and one Ultrascale+ ZU11EG.
<-70 dBFS @ 900 MHz	3U VPX	-20°C to 65°C (L2) -40°C to 70°C (L3)	Also features 8-channel, 14-bit D/A offering 6.4 Gsps; includes dual 100 GigE optical interface.
-67 (-1 dBFS) @ 347 MHz	XMC	-20°C to 65°C (L2) -40°C to 70°C (L3)	Also features 2-channel 14-bit D/A offering 6.4 Gsps.
-87 (-1 dBFS) @ 170 MHz	XMC	-20°C to 65°C (L2) -40°C to 70°C (L3)	Dual channel A/D & D/A with Kintex UltraScale FPGA.
60-64 dB	1U form factor	5°C to 40°C	Stand-alone unit with fully integrated radio front end, ADC, FPGA for on-board DSP, and dual 10G backhaul.
60-64 dB	3U form factor	5°C to 40°C	Stand-alone unit with up to 16 receive chains, fully integrated radio front ends, ADC, FPGA for on-board DSP, and quad 40G backhaul.
71 dBFS	FMC+	Ambient temperature (TA) range of -40°C to +85°C	AC coupled differential (or single ended as a build option) input module, without input balun. Trigger and external clock input connectors are available on the module. The trigger input allows user to add a time stamp to sample stream from ADC.
71.6 dBFS	FMC	TA Ambient temperature -40°C to 85°C temperature grade. -E extended -I industrial	FMC-DAQ2P5 is a High Pin Count (HPC) FMC module with a single 12-bit ADC @ 2.7 Gsps and dual 16-bit DAC @ 2.8 Gsps. FMC-DAQ2P5 is a JESD204B compliant module. 4 differential low-speed lane and 10 single ended IO. LM95233 for ADC temperature monitoring.
*	VPX	-40°C to +85°C	Also features 6 Gsps 12-bit DAC and Xilinx UltraScale+ XCVU13P FPGA with 8 GB DDR4.
*	AMC	-40°C to +85°C	Features four DAC channels providing 16-bit resolution at 12 Gsps.
67 dB	AMC	-40°C to +85°C	Also features 2-channel DAC w/ update rate of 12 Gsps.

SURVEY KEY: ANALOG-TO-DIGITAL CONVERTERS AND ADC CARDS

MODEL
Product name or model number

ADC MODEL
Specific analog-to-digital model number; if on a circuit card, indicates the A/D part number.

CHANNELS
Number of analog-to-digital channels

BITS
Number of analog-to-digital bits

ENOB
Effective number of bits

SAMP SPEED
Sample speed in MHz or GHz
Msps = mega samples per second
Gsps = giga samples per second

INPUT BANDWIDTH
The input bandwidth in kHz, MHz or GHz

SFDR
Spur free dynamic range (SFDR) in dB, dBC or dBFS

FORMAT
If circuit card, 6U, 3U, PMC, XMC or component package type
AMC = Advanced Mezzanine Card
FMC = FPGA Mezzanine Card
XMC = Switched Mezzanine Card

ENVIRONMENT
Operating temperature and cooling method

FEATURES
Other functionality for circuit cards
OTHER ABBREVIATIONS USED
- LVDS = low-voltage differential signaling

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

MAY 2021 PRODUCT SURVEY: COUNTER-UAS SYSTEMS

This survey will cover electromagnetic warfare (EW) and directed energy (DE)-based counter-UAS systems. Please e-mail JEDeditor@naylor.com to request a survey questionnaire.

ADCs are the heart of a SIGINT receiver and in many ways define the overall performance of a SIGINT system, such as the RAF RC-135W aircraft (above). ALAN WILSON

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Space EW – Part 27

Jamming Satellite Uplinks *cont'd.*

By Dave Adamy

Editor's note: This is a continuation of the problem from part 26 last month.

THE SATELLITE UPLINK

Figure 1 is a spherical triangle formed by the satellite sub-vehicle point, the ground station location and the North Pole. *Side g* is the geocentric angle between the satellite sub-vehicle point and the ground station. *Side k* is 90° – the latitude of the sub-vehicle point. *Side j* is 90° – the latitude of the ground station. *Angle G* is the difference in longitude between the sub-vehicle location and the ground station.

Side k = 90° - 40° = 50°
Side j = 90° - 42° = 48°
Angle G = 3°

The spherical law of cosines for sides is:

Cos g = (cos b)(cos c) + (sin b)(sin c)(cos A)
= (cos 50°)(cos 48°) + (sin 50°)(sin 48°)(cos 2°)
= (0.643)(0.669) + (0.766)(0.743)(0.999)
= 0.430 + 0.569 = 0.999

So *side g* = **2.828°**

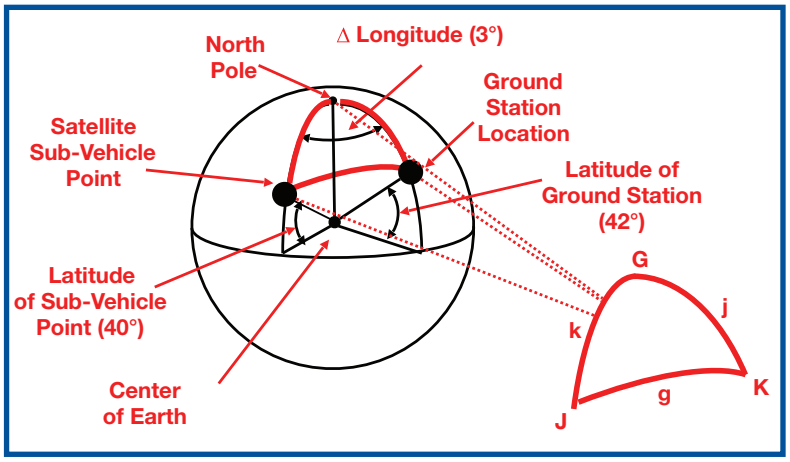

Fig 1: *A spherical triangle is formed between the North Pole, the satellite sub-vehicle point and the ground station location.*

Angle J in **Figure 1** is the azimuth from the satellite to the ground station. We can calculate this angle from the law of sines for spherical triangles:

Sin J = (sin j)(sin G)/(sin g) = sin(48°)(sin(3°)/sin(2.83°)
= (.743)(.0323)/(.0492) = .488

Angle J = **29.2°**

Gain of 2-meter uplink transmitter antenna is:

G = -42.2 + 20 log D + 20 log F

For the satellite uplink transmit antenna:

G = -42.2 + 20 log(2) + 20 log(5000)
G = -42.2 + 6 + 74 = **37.8 dBi**

UPLINK ERP

The ERP of the uplink transmitter is 40 dBm + 37.8 dBi = **77.8 dBm**

Now consider **Figure 2**. This is a plane triangle formed by the satellite, the center of the Earth and the ground station location. *Side p* is the range from the satellite to the ground station. *Side n* is the radius of the Earth (R_E) plus the elevation of the satellite (H). *Side m* is the radius of the Earth. Angle *P* is the same angle we calculated as side *g* in the spherical triangle of **Figure 1**.

Angle P is 2.828°
Side n is 6,671 km
Side m is 6,371 km

The law of cosines for sides in plane triangles is:

$p^2 = n^2 + m^2 - 2mn \cos P$
= (6,671 km)² + (6,371 km)² – 2(6,671)(6371) cos 2.828°
= 44,502,241 + 40,589,641 – 84,916,880 km²
= 175,002 km²
p = sqrt(175,002 km²)
= **418 km**

UPLINK LOSS

The loss in the satellite uplink is line-of-sight:

$Loss_S$ = 32.4 + 20 log(418) + 20 log(5000)
= 32.4 + 52.4 + 74
= 158.8 dB
= 32.4 + 52.4 + 74 = **158.8 dB**

Gain and beamwidth of uplink receiving antenna on the satellite:

The bore-sight gain of the antenna is:

G = -42.2 + 20 log D + 20 log F
G = -42.2 + 20 log(1) + 20 log(5000)
G = -42.2 + 0 + 74 = **31.8 dB**

The average side-lobe gain is 20 dB below the bore-sight gain.

Antenna 3 dB beamwidth:
α = Antilog [(86.8 – 20 log D – 20log F) /20]
Where: α is the 3 dB beam-width in degrees,
D is the diameter of the antenna in meters, and
F is the operating frequency in MHz,

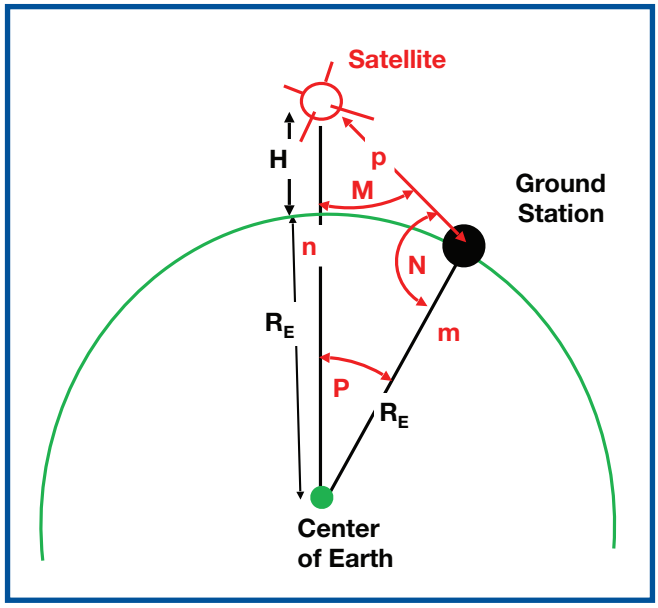

Fig 2: *The propagation distance between a receiving satellite and its ground station on the Earth's surface can be calculated from the plane triangle formed by the satellite location, the ground station location and the center of the Earth.*

$$\alpha = \text{Antilog}\,[(86.8 - 20\log(1) - 20\log(5000)) / 20]$$
$$= \text{Antilog}\,[(86.8 - 0 - 74) / 20] = \mathbf{4.4^\circ}$$

Still in **Figure 2**, we can determine *angle M* from the law of sines for plane triangles:

$$\text{Sin M} = m \sin P / p = 6371 \sin(2.82^\circ) / 418 = (6371)(.0492)/(418)$$
$$= .750$$

Angle M = **48.3°**

BORESIGHT OF DOWNLINK RECEIVING ANTENNA

Now we will determine the angle between the boresight of the downlink receiving antenna and the jammer.

Figure 3 is a right spherical triangle with the satellite as the origin of the sphere.

Side aa is the difference in azimuth between the ground station and the jammer.

Side bb is the difference in elevation between the ground station and the jammer.

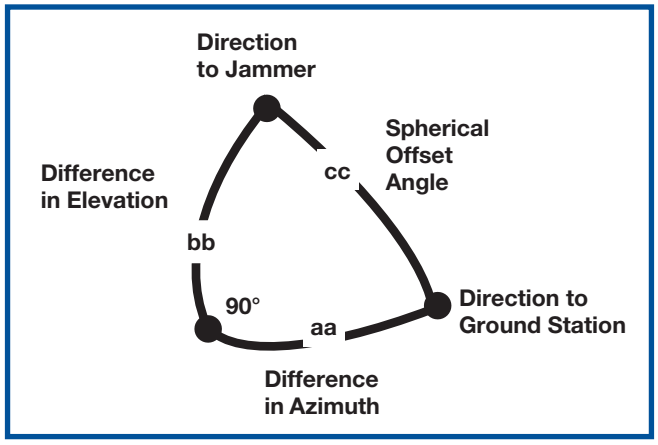

Fig 3: *The right spherical angle formed by the jammer and the ground station can be defined by the difference in azimuth and difference in elevation both, as seen from the satellite.*

Side cc is the "satellite-central" angle between the ground station and the jammer.

The uplink receiving antenna has its boresight aimed at the ground station, so the jammer is in a side lobe offset from the boresight by the *angle cc*.

In this problem:

The azimuth from the satellite to the jammer is 14.4° from **Figure 1** in the January 2021 EW 101 column.

The azimuth from the satellite to the ground station is 48.3 from **Figure 2** (above).

The difference between the azimuth values is **19.5°**

This is *side aa* in the spherical triangle of **Figure 3**.

The elevation from the satellite to the jammer is 60.6° from **Figure 2** in the January 2021 EW 101.

The elevation from the satellite to the ground station is 48.3° from **Figure 2** (above).

The difference between the elevation values is 12.3°.

This is *side bb* in the spherical triangle of **Figure 3**.

From Napier's rules for right spherical triangles:

$$\text{Cos}\,(\textit{side cc}) = [\cos(\textit{side aa})]\,[\cos(\textit{side bb})] = [\cos(19.5^\circ)][\cos(12.3^\circ)]$$
$$= [.923]\,[.977] = .902$$

Angle cc = **25.5°**

Since this offset angle is much wider than the 4.4° receiving antenna beamwidth, the gain of the uplink receiving antenna toward the jammer will be reduced to its side-lobe level, which is 31.8 dB – 20 dB = **11.8 dBi**.

THE JAMMER TO SIGNAL RATIO

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 (103.8 dBm),

ERP_S is the effective radiated power of the jammed signal in dBm (77.8 dBm),

$LOSS_J$ is the loss between the jammer and the jammed receiver in dB (163.6 dB),

$LOSS_S$ is the loss between the desired signal transmitter and the jammed receiver in dB (158.8 dB),

G_{SJ} is the gain of the jammed receiver's antenna in the direction of the jammer in dB (11.8 dB), and

G_S is the gain of the jammed receiver's antenna in the direction of the desired signal transmitter in dB (31.8 dB).

Plugging in the values for this problem:

$$J/S = 103.8 \text{ dBm} - 77.8 \text{ dBm} - 163.6 \text{ dB} + 158.8 \text{ dB} + 11.8 \text{ dB}$$
$$- 31.8 \text{ dB} = \mathbf{1.2 \text{ dB}}$$

This is effective jamming if we assume that FM noise jamming modulation is used.

WHAT'S NEXT

Next month, we will look at measures the satellite could employ to prevent an enemy from intercepting or jamming the link signals. For your comments and suggestions, Dave Adamy can be reached at dave@lynxpub.com.

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MARCH 21-24, 2021 // MUSEUM OF AVIATION, ROBINS AFB, GA

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Glenn "Powder" Carlson,
AOC President

BANQUET SPEAKER
Gen Ellen Pawlikowski,
USAF (ret)

KEYNOTE SPEAKER
Mr. Edward W. Ayer, SES, DAF,
Associate Director, Engineering and Technical Management Directorate, Robins Air Force Sustainment Center

7TH ANNUAL THE CROW'S

N.E.S.T.

(Novel Experiments with Science & Technology)

VIRTUAL EVENT

Already in progress: The Dixie Crow Chapter's approach to our 7th Annual Crows N.E.S.T. will be focused on providing monetary donations to surrounding schools to supplement the teacher's STEM classroom planning. (Unfortunately, there will be NO student STEM event during our Symposium as in years past.) However, we will still provide all participating schools' students with t-shirts displaying Industry logos and names of our Dixie Crow Chapter Education Foundation Donors! We greatly appreciate your support educating our "Leaders of Tomorrow!"

SCHEDULE OF EVENTS

SUNDAY, MARCH 21

Registration	Best Western Plus Executive Residency, Warner Robins, Georgia	5:00 PM-8:00 PM
Hospitality Suite	Best Western Plus Executive Residency, Warner Robins, Georgia	5:00 PM-8:00 PM

MONDAY, MARCH 22

Registration	Southern Landings Golf Course, Warner Robins, Georgia	11:30 AM-12:55 PM
Registration	Century of Flight Hangar, Museum of Aviation	2:30 PM-5:00 PM
Spring Golf Tourney	Southern Landings Golf Course, Warner Robins, Georgia	1:00 PM Tee Time

TUESDAY, MARCH 23

Registration	Century of Flight Hangar, Museum of Aviation	7:30 AM-6:00 PM
Plenary Session	Century of Flight Hangar, Museum of Aviation	8:00 AM-11:00 AM
Exhibits Open	Century of Flight Hangar, Museum of Aviation	10:00 AM-7:00 PM
Exhibitor Reception	Century of Flight Hangar, Museum of Aviation	5:00 PM-7:00 PM

WEDNESDAY, MARCH 24

Registration	Century of Flight Hangar, Museum of Aviation	9:00 AM-2:00 PM
Exhibits Open	Century of Flight Hangar, Museum of Aviation	9:45 AM-3:00 PM
Crows N.E.S.T.	VIRTUAL EVENT	
AOC Chapter President's Mtg	Century of Flight Hangar, Museum of Aviation	11:30 AM-1:00 PM
Banquet	Nugteren Exhibit Hangar, Museum of Aviation	Cocktails – 5:30 PM-6:30 PM Dinner – 6:30 PM-8:30 PM

WELCOME TO DIXIE CROW SYMPOSIUM 45!

Our Symposium Committee, Dixie Crow Chapter President, Adam Delestowicz, and the Chapter Directors cordially invite you to join us for all the exciting events described here. Thank you in advance for your support of this important electronic warfare/information operations trade show.

Sincerely, Lisa Frugè-Cirilli, *Chair* | lisa.fruge@baesystems.com

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Report from the 9th Annual Pacific Information Operations & Electronic Warfare Symposium

19-23 October, 2020 at Honolulu and Camp H. M. Smith, Hawaii

By COL Ret. Arthur N. Tulak, Ed.D.
Vice President, Hawaii AOC Diamond Head Chapter

The theme for the 2020 IO & EW Symposium, "All Domain Operations from Competition into Conflict," focused on how IO and EW contribute to all-domain warfighting challenges, as well as their contributions to achieving a Free and Open Indo-Pacific during competition. The symposium took place during the global COVID-19 pandemic, which essentially eliminated the possibility of a live and in-person conference in the manner that was done for the last eight years at the Army's Hale Koa Hotel in Waikiki and at Camp H. M. Smith. U.S. Indo-Pacific Command (USINDOPACOM). Rather than cancel this important event, the AOC Chapter proposed a major shift from a live and in-person event to one delivered virtually over the unclassified internet and via secure VTC for the classified portion. This requirement presented a daunting challenge to the Hawaii AOC Chapter, as orchestrating an international conference online had never been attempted by USINDOPACOM J39, the co-sponsor. Fortunately, the Federal Business Council, which has operated as an on-site event manager on behalf of the AOC for this event since 2017, stepped in promptly to host the unclassified presentations over its conference delivery platform. The structure of the symposium was modified to have a three-day unclassified plenary with Allies, partners, academia and industry from 19-21 OCT, followed by a two-day classified plenary with restricted participation.

As a result of the change of venue, registration numbers shot up, and the agenda filled up quickly, as it became clear that the COVID-19 pandemic would not derail this important annual symposium and presentations could be delivered from anywhere on the globe. This year saw the highest number of participants in the unclassified plenary sessions – a total of 325, which represented a 30% increase over 2019's attendance figures. Over the course of the three-day unclassified plenary sessions, attendees received three senior leader addresses from LtGen Loretta Reynolds, USMC Deputy Commandant for Information; LTG Stephen G. Fogarty, Commanding General of Army Cyber Command; and Ambassador Jennifer Zimdahl Galt, the USINDOPACOM Foreign Policy Advisor. The unclassified plenary speaker lineup included 35 speakers and a very well-received Roundtable on EW and EMS Superiority, moderated by Mr. Ken Dworkin with senior leaders in the field, including: Mr. David Tremper (SES), EW Director, OUSD(A&S); Brig Gen David Abba, Director, F-35 Integration Office; Brig Gen (select) Michael Manion, Director, HAF/A5L Spectrum Superiority Directorate; Col. William Young, Special Advisor for Spectrum Warfare, USAF Air Warfare Center (AWC); and Dr. Ilya Lipkin, Technical Lead, Sensor Open Systems Architecture (SOSA), Air Force Lifecycle Management Center (AFLCMC).

The INDOPACOM J39 team gathered at the HQ for bilateral engagements with Allies. Standing, from left to right: Dr. Arthur Tulak, CDR Cole Roberts, MAJ Tony Nicolas, Ms. Jessica Sablon, Mr. Jim Mishina, LtCol Jennifer Kukla and Maj. John Salvador. Seated: COL Jason Wright and Col Brian Hill.

Many of the AOC National leadership team were able to attend remotely, including Then-President Muddy Watters, who commented on this year's event:

"In my opinion, this symposium, out of all the symposia that the AOC does, is one of the most important. And the reason is because, this is...warfighter based...We are out with the Combatant Command...the program is both unclassified and classified...when I have been out there [in Hawaii] and participated and observed, this is the one conference that really brings the other warfighters in, the other individuals that are doing IO and EW, bringing them together to share information, to share tools techniques and to really talk and discuss about what is going on. So out of all the symposia that the AOC does, that we put together to bring together this professional community, this society together, this one, warfighter-focused, in a very relevant near-peer area, becomes very important."

The annual Pacific IO and EW Symposium also provides USINDOPACOM the ability to interact with Allies and partners, and the switch to a virtual platform significantly increased Ally and partner participation, hitting a record in 2020, with 128 personnel from 12 countries registered to attend the unclassified plenary. This was the first year the militaries of Colombia, Malaysia and Peru participated, with a strong showing of 29 personnel between these three militaries in attendance. Providing insightful perspectives via presentations in the unclassified plenary were LTC HSU, Ming-Cheng, from the Taiwan Ministry of Defense, and Maj Romulo Dimayuga of the Philippines Marine Corps. Both officers delivered presentations addressing Communist Chinese political warfare threats. The annual Pacific IO & EW symposium has historically provided USINDOPACOM an opportunity for in-person bilateral meetings with IO and EW counterparts of the visiting Ally and partner delegations. This critical

component was preserved with the Philippines, Singapore and Taiwan engaging in bilateral meetings via VTC, where another Ally and partner 25 military personnel participated.

The classified plenary of the symposium was conducted 22 and 23 October and began with a U.S.-only Global Combatant Command J39 roundtable discussion led by INDOPACOM J39 Col. Brian Hill. Although normally held at the HQ U.S. Indo-Pacific Command at Camp Smith, due to restrictions on assembly in the on-island military conference centers, the classified plenary was conducted via secure VTC over classified networks at the SECRET level, with IO and EW staff officers from Australia, Canada, France, Japan, New Zealand and the United Kingdom. Several exchange and liaison officers from these countries assigned to USINDOPACOM and its subordinate commands also attended the classified plenary from conference rooms in their HQs in Hawaii. The Keynote address for the classified plenary was delivered by MajGen Tom Copinger-Symes, Director of Military Digitisation, UK Ministry of Defence, who delivered his remarks from the Permanent Joint Headquarters in Northwood.

The symposium provided a great opportunity for the Chapter to reach out to the communities it serves, both the professionals engaged in IO and EW, as well as the next generation who are engaged in academic study of relevant disciplines. The Chapter partnered with the Information Professionals Association, who assisted in recruiting speakers and also presented the Hermes Award to COL, Ret. Dave Grohowski, Chief of Staff, Marine Corps Information Operations Center, for his exceptional service and contributions in the field of cognitive security and information operations. The Chapter's scholarship program continues with generous contributions from Chesapeake Technology International (CTI), the Federal Business Council (FBC), Inc, and AOC National, providing scholarships to deserving students since 2016. The symposium agenda includes the presentation of scholarships to recognize deserving students. This year's four CTI & AOC scholarship winners, Frendy Lio Can, Spencer P. Young, Brooke Maeda and Kaysie L. Ho, were nominated by Dr. Choi from the University of Hawaii's Engineering Department, where they are pursuing degrees in technical fields with application to electronic warfare.

The theme for next year's 10th Annual Pacific IO & EW Symposium, "Defending Forward in a New Era of Great Power Competition," is shared with the Naval Postgraduate School's Symposium on Information Strategy and Political Warfare, due to be held in June, and USCENTCOM's IO Conference in March. The Hawaii Diamond Head AOC Chapter is planning to incorporate some level of online delivery of presentations in conjunction with the live and in-person plenary sessions. This may be in the form of posting for viewing at a later time for registered participants. Likewise, the use of VTCs is anticipated again for next year's classified plenary sessions, as this allows greater participation by the Allies, who will be able to remotely join via VTC with their colleagues who will make the trip to Hawaii 18-22 October 2021.

AOC Virtual Series Webinars

AOC Virtual Series has been a tremendous asset providing the AOC's audience with learning, advocacy, and the exchange of information. Register today to hear from subject-matter experts on all things EW!

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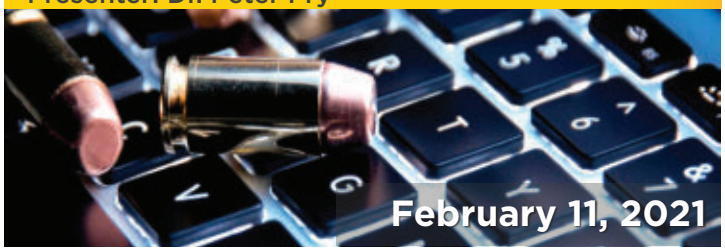
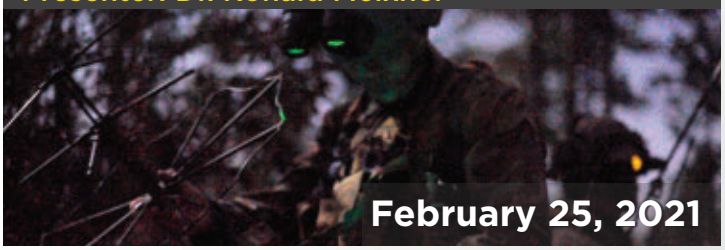


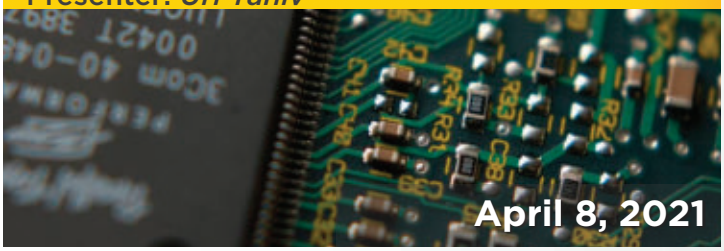
HF meets Big Data – Intercept in an era of HF Renaissance
Presenter: Dr. Ronald Meixner



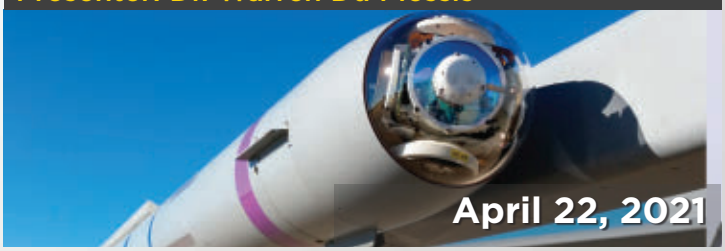
Cyber Electromagnetic Activities and Signals Intelligence: a Command and Control framework
Presenter: Claudio Santo Malavenda

The Year in Review - GPS/PNT Disruptions and Improvements
Presenter: *Dana Goward*

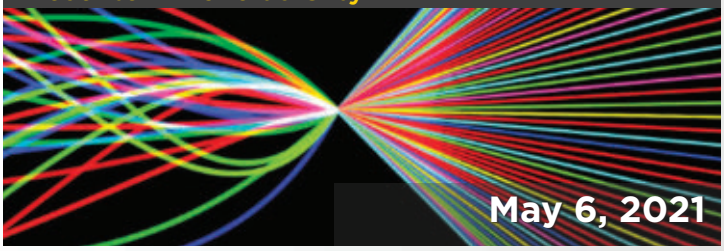
Fast Switching Synthesizers for Emerging EW Systems
Presenter: *Uri Yaniv*



Reticle Based Seekers
Presenter: Dr. Warren Du Plessis



AI Guided Spectrum Operations
Presenter: Nicholas Ortyl



5G for Non-Terrestrial Networks
Presenter: Reiner Stuhlfauth

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AOC Raytheon STEM Student of the Year Scholarship

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US Army Cyber Corps Warrant Officer Scholarship Program

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

DIXIE CROW CHAPTER UPDATES

Karen Brigance: 2020 Exemplar Award Recipient

Ms. Karen Brigance was recently presented with the 2020 Dixie Crow Exemplar Award for her work with AOC and within the EW community. Ms. Brigance joined AOC in 1982, and she has since served two terms as Dixie Crow Chapter president, as well as past president, and chairperson for four Dixie Crow EW/IO Technical Symposiums. She has served as southern regional director on the AOC board of directors for three years and begins her second three-year term in 2021. Ms. Brigance was chair for the AOC Audit and Inspection Committee and is an active member of the AOC Membership and Awards committees.

Ms. Brigance began her EW career in 1982 and continues to lend her vision and leadership to the field today. Presently, Ms. Brigance is the chief engineer of EW at the Mercer Engineering Research Center (MERC), providing critical engineering support to the B-1, B-52 and KC-46 EW systems. Karen's exemplary career paved the way to her selection as the 2020 Dixie Crow Chapter Exemplar Award Recipient of the Year.

Chapter Aids Habitat for Humanity

The Dixie Crow Chapter Chuck Wagon crew, led by "Chef Roadkill," aka Mark Leslein, assembled on Saturday, November 21, to feed the Habitat for Humanity crew working on homes #63 and #64 off Hickory Street in Warner Robins, GA. The crew prepared and served over 40 volunteers. Dixie Crow

Members in attendance included: Mark Leslein, Adam Delestowicz, Brooke Horka, Robert Usher, Lynwood and Betsy Moore, Lisa Frugé-Cirilli, Katlyn Frugé Kline, Cole & Leyton Harris, Scott Wolf, Jim Hundley, Bob and Mary Thrower, and Rodney Brooks.

Chapter Sponsors National STEM Benefit Tournament

The Dixie Crow chapter sponsored the 2020 Museum of Aviation Foundation National STEM Academy Benefit and Georgia Invitational with a $5,000 contribution. This year's event raised more than $158,000, which will be dedicated to critical support for STEM education programs. Last year, more than 50,000 students and teachers benefited from programs offered through the National STEM Academy.

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