Complex Source Detection & Threat Simulation In An Ambiguous Era

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New ultra-complicated **Advanced Battle Management & Surveillance (ABMS)** system is coming by 2040s

E-3A AWACS
USAF / NATO Airborne Early Warning & Control (AEW&C) aircraft (Produced 1977-92)
68 Units (~ 57 operational)

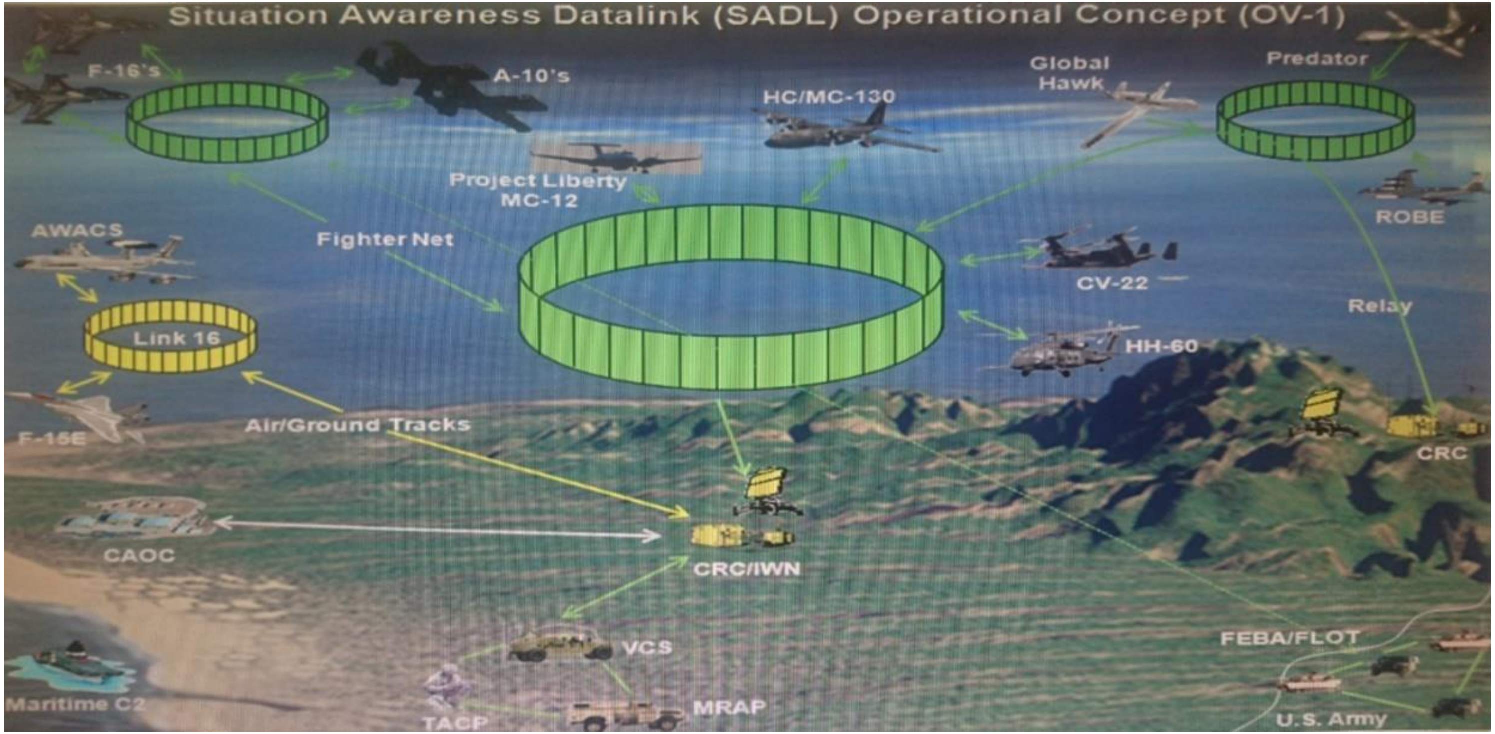
E-8C JSTARS
USAF Airborne ground surveillance, battle management and command & control aircraft (Produced 1991-2005) [17 Units]

This initiative delineates a path forward for AF Joint Surveillance Target Attack Radar System (JSTARS) platform. The emerging plan reflects AF considerations about whether the large and “not-so-stealthy” manned JSTARS platform would remain functionally useful in a modern high-tech/threat environment. For past decade USAF considered alternatives for its replacement.

ABMS expects to use latest ISR technologies from current and emerging systems and ultimately connect satellites, drones, ground/space sensors and manned surveillance aircraft seamlessly in real time over fast-changing, dispersed combat area of operations.

A. McCullough, “Life After JSTARS,” *Air Force Magazine*, Apr 2019, http://www.airforcemag.com/MagazineArchive/Pages/2019/April%202019/Life-After-JSTARS.aspx

Currently Situational Awareness Data Link (SADL) Communications occur thru Link-16 & Newer / Complementary Link-22



The new ABMS system will utilize different more modern communications

The New **ABMS** system will utilize different means of identifying communications signals

With the Multitude and Complexity of signals out there (Communications, command, control, navigation, telemetry, etc) and the ever increasing use of software, it becomes more and more difficult determining which ones are real and which are artificially introduced while the real ones are being Blocked / Denied, which belong to a **Friend** and which to a **Foe** ?!

Thus, as technology becomes more advanced and complicated, **Complex Signal Source Detection / Identification** becomes more and more of an issue .

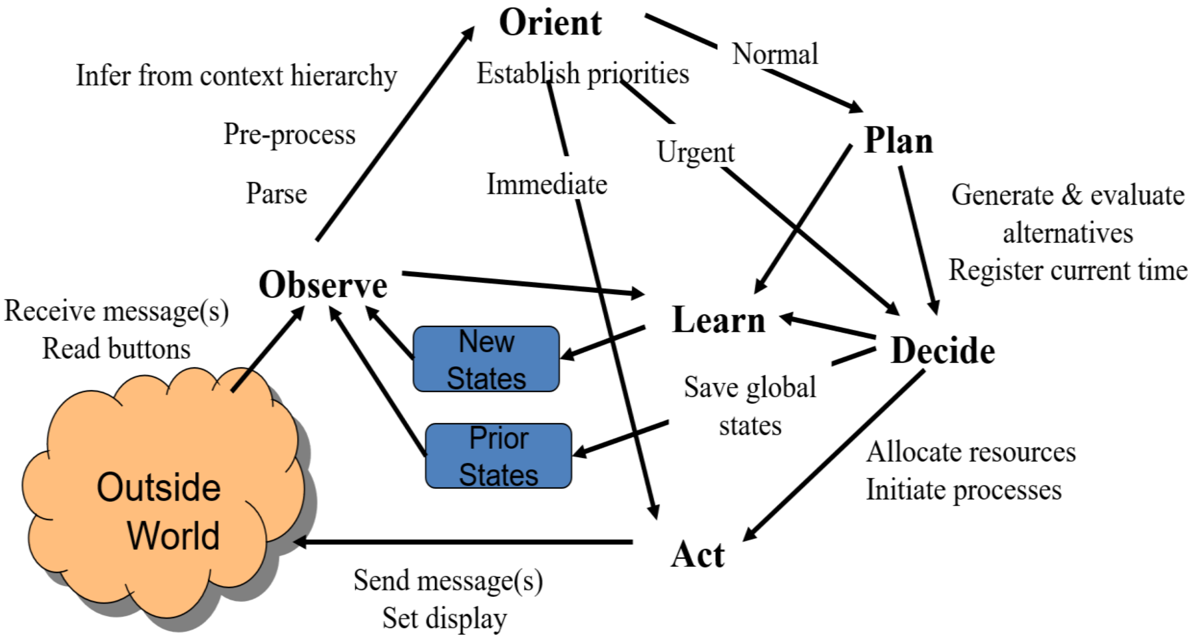
To accomplish this task, various **Automatic Modulation Recognition (AMR)** techniques have been developed for the past **3 decades**, which are an intermediate step between Signal Detection and Demodulation / Use .

However, until recently most of these techniques were developed for **Single Input Single Output (SISO)** communications. But the most recent systems increasingly use **Multiple Input Multiple Output (MIMO)** concept even on a very **massive** scale, such as the new **Active Electronically Scanned Array (AESA)** phased-array antennas .

In Multi-User MIMO, certain element groups / sections of an AESA antenna can be dedicated to specific / different users simultaneously.

Automatic Modulation Recognition (AMR) originated as part of Cognitive Software Radios research

The main framework for operation of cognitive radios is the **cognition cycle** employing model-based reasoning
Every Modern Intelligent SDR Receiver Employs this scheme



[J. Mitola III, "Cognitive Radio for Flexible Mobile Multimedia Communications," *IEEE Workshop on Mobile Multimedia Communications*, pp.3-10, Nov 1999.]

The „Godfather" of Software-Defined Cognitive Radios

Joseph Mitola III

Dr. Mitola graduated from KTH Royal Institute of Technology, Stockholm.
Currently at Virginia Tech, Arlington
Director of Hume Info Systems Lab.

Modern Communications Signals

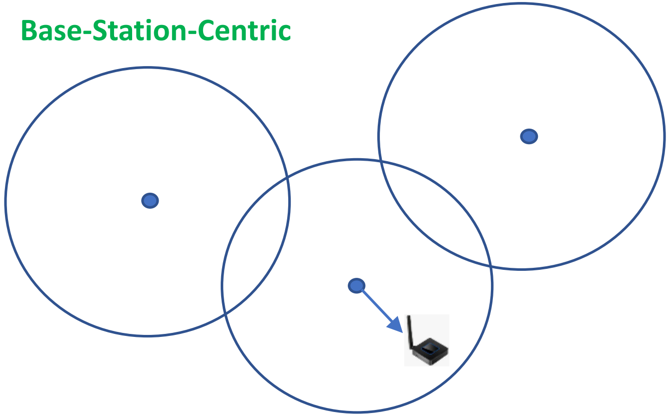
In the latest **5G** Communications to be introduced, as compared to the current **4G** Standard:

⇒ There is an underlying shift from **Base-Station-Centric** to **User-Centric** Communications

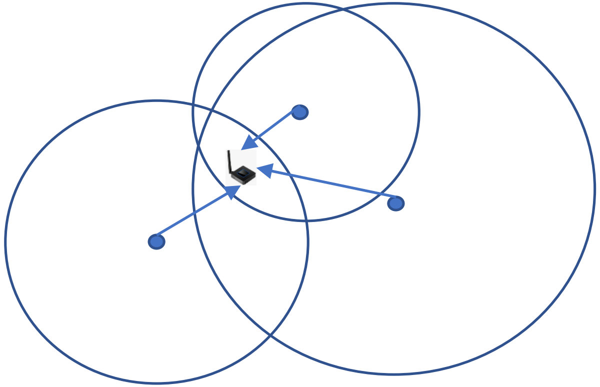
Where a device/user may be connected to several Base Stations (BS) / Control Centers (CC) / Transmitters (Instead of 1) with varying distances and signal strengths in between

The Number of BS/CC and Devices/Users/Sensors is expected to grow dramatically in near future ➔ Internet of Things / Everything (**IoT** / **IoE**)

Base-Station-Centric



User-Centric



Complex Signal Source Detection / Identification Process for Modern Communications Signals

<u>A 2-Step Process:</u>

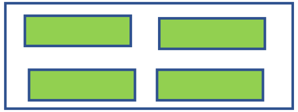
1) Discrimination between **Single Carrier (SC)/SISO** & **Multi Carrier (MC)/MIMO** signals
   => Detection of absence/presence and type of **Space-Time Block Codes (STBCs)** & Number of Transmit Antennas
2) Determination of actual **Modulation Format** employed by signal (**AMR** Techniques)

Three types of STBCs:

1. Spatial Multiplexing

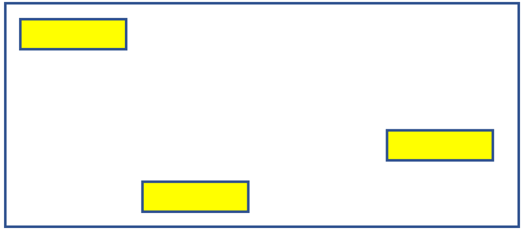
Serial Data Blocks

2. Alamouti



Matrix-Wise Data Blocks

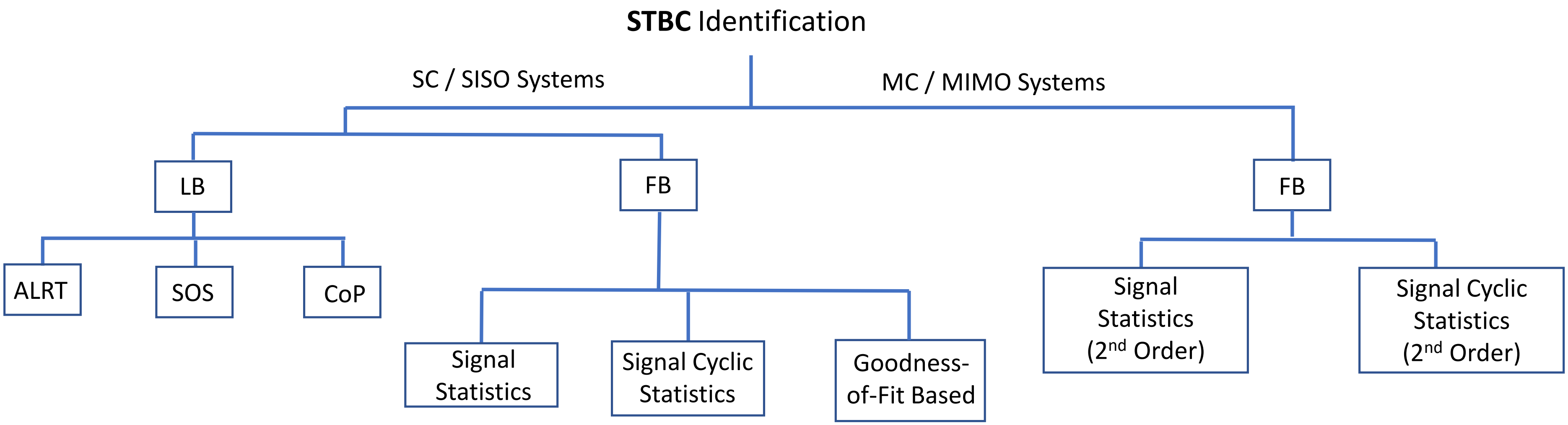
3. Index Modulation



Random Index Data Blocks

E. Basar, "Index Modulation Techniques for 5G Wireless Networks," *IEEE Communications Magazine*, pp.168-175, July 2016.

Overview of Complex Signal Source Detection / Identification Techniques – STBC



Legend

LB – Likelihood-Based
FB – Feature-Based

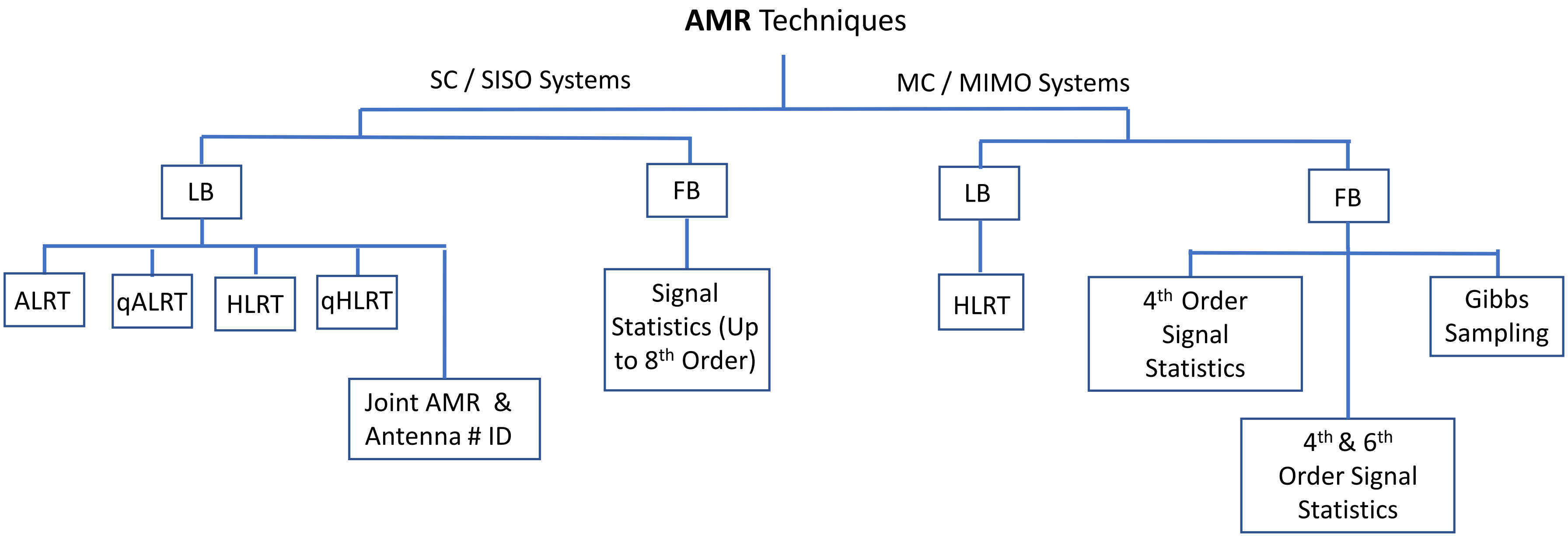
ALRT – Average Likelihood Ratio Test

SOS – Second Order Statistics

CoP – Code Parameter

Y.A. Eldemerdash, O.A. Dobre, M. Oner, "Signal Identification for Multiple-Antenna Wireless Systems: Achievements and Challenges," *IEEE Communications Surveys & Tutorials*, p.1528 (Fig.3), Vol.18, No.3, Third Quarter, 2016.

Overview of Complex Signal Source Detection / Identification Techniques – AMR



Legend

LB – Likelihood-Based
FB – Feature-Based

q/ALRT – quasi / Average Likelihood Ratio Test

q/HLRT – quasi / Hybrid Likelihood Ratio Test

Y.A. Eldemerdash, O.A. Dobre, M. Oner, "Signal Identification for Multiple-Antenna Wireless Systems: Achievements and Challenges," *IEEE Communications Surveys & Tutorials*, p.1536 (Fig.14), Vol.18, No.3, Third Quarter, 2016.

Summary of Authors Previous Research on SISO AMR Techniques

All of the first 5 FB techniques were found to be universally applicable to any conceivable SISO Modulation Format; however, the 1st – Signal Statistics had very poor noise performance and the 4th – Multifractal Features had very high computational complexity . The other 4 were not simulated and compared as they did not have universal applicability.

FB Technique	Applicability	Computational Complexity	Performance/ Classification Probability	Noise Tolerance	Comments
Signal Statistics	Universal	Medium	Degrades fairly rapidly with SNR	Degrades with SNR	Needs noise reduction
Higher Order Statistics (Cum.)	Universal	Low	Very Good	Excellent	The best technique overall
Cyclostationary Features	Universal	Medium	Very Good	Excellent	Computation cost considerable
Multifractal Features	Universal	High	Good	Excellent	Can produce too similar features
FT of CWT	Universal	Low	Very Good	Very Good	Another good technique
Wavelet Transform-DWT	Limited: MPSK, MFSK	-	-	-	Not simulated
Constellation Shape	Digital signals only	-	-	-	Not simulated
Zero Crossing	No Amplitude Discrimination	-	-	-	Not simulated
Radon Transform	Only Square or Diamond shaped Constellations	-	-	-	Not simulated

S. Sobolewski, W. L. Adams Jr, R. Sankar, "Effective and Efficient Compound Feature Vectors Applicable To Discrimination Of Any Conceivable Bandpass Modulated Waveforms," *Proc. IEEE BlackSeaCom*, pp.1-5, 2016.

Threat Testing / Simulation Methods

1. **Model-in-the-Loop (MIL)** testing and simulation is a technique used to abstract the behavior of a system or sub-system in a way that this model can be used to test, simulate and verify that model.

2. **Software-in-the-Loop (SIL)** testing is used to describe a **test** methodology where executable code such as algorithms or even an entire controller strategy, usually written for a particular mechatronic system, is tested within a modelling environment that can help prove or **test** the **software**.

3. **Hardware-in-the-Loop** (HIL) simulation is a technique that is used in the development and test of complex real-time embedded control systems.

In addition to running a typical **Built-In-Test** program, which mainly ensures that software / firmware is loaded and all signal connections are intact, to further verify the correct operation of an EW system it is desirable to run a true test signal thru the system that mimics the signals that would be observed in a real electromagnetic environment (Tones, pulse trains, chirps, etc).

For this purpose EW simulators were created, either flightline or handheld, for a variety of spectrums, such as UV, IR, laser.

The following table summarizes some of the important EW simulation hardware available on the market.

O. Holt, “Technology Survey: Flightline and Portable EW Simulators,” *AoC Journal of Electronic Defense*, pp.63-68, Vol.39, No.12, Dec 2016.

Latest EW Simulator Hardware (Part 1)

MODEL	SIMULATOR PURPOSE	SPECTRUM	COUPLED	# OF SIGNALS	SIMULTANEOUS SIGNALS	PROGRAMMABLE	POWER (W)	SIZE (HxWxL inches/cm)	WEIGHT (lb/kg)	FEATURES
Dragoon ITCN; Dayton, OH, USA; +1-937-439-9223; www.dragoonitcn.com										
CM2-T-47 CMDS Tester	CMDS	•	•	•	•	Yes	40-50 W	5.5 x 7.5 x 8.2 cm	8 lb	CM2-T-47 tester works with CM2-C-16 Collector unit; simulates all munitions firing pins in up to 16 buckets (480 signals).
CM2-T-130 CMDS Tester	CMDS					Yes	40-50 W	5.5 x 7.5 x 8.2 cm	8 lb	CM2-T-130 tester works with CM2-C-16 Collector unit; simulates all munitions firing pins in up to 16 buckets (480 signals).
DRS Network, Computing and Test Systems; Melbourne, FL, USA; +1-888-872-1100; marketing@drs.com; www.drs.com										
Electronic Combat End-to-End Test System	RWR, RF Jammer,MAWs	500 MHz-40 GHz	Coupled and Free space,	Multiple	12	Yes and Encrypted	1,600	13in x 24in x 30in	260lbs.	Hand Held Terminal (HHT) allows for walk around aircraft or sit in the cockpit for testing.
Enhanced EW End to End Tester	RWR, UV/ IR, CMDS, RF Jammer, MAWs	100 MHz - 40 GHz	Coupled and Free space,	Multiple	4 - 8	Yes and Encrypted	1,000	13in x 24in x 30in	180lbs	Hand Held Terminal (HHT) allows for walk around aircraft or sit in the cockpit for testing. Modular design supports configuration of test capabilites to support specific aircraft platform requirements.
Enhanced Common Optical Test Set (eCOETS)	Simulates: Laser Range finder, Laser Designator and Beam Rider Threats	UV (solar blind), eye safe class 2 emissions. 850 / 1550 nm Laser class 1, 2, 3R (eye safe at 10" distance) Pulse width 10ns – 1000ns	Free Space and Light Tight Attachment to Sensors.	2	2	Yes and Encrypted	*	6.5in x 6.5in x 10in	> 5lbs	Realistic IR Laser simulation to Missile Warner systems for detection of Laser Range Finder, Laser Designator and Beam Rider threats. Provides repeatable on -aircraft test set to sensor and a consistent light tight testing environment when required to baseline sytem performance and measure sensor degradation over time.
Handheld Threat Simulator	RWR, Laser & Missile Threat Simulation	.625-18 GHz and 26 to 40 GHz, Laser, Solar Blind	Coupled and Free space,	Multiple	1	Yes and Encrypted	*	12in x 6.6in x 10in	8lbs	All in One Threat Emissions, Radar, Laser & Missiles. RF programmabel CW, Pulse, Staggered Pulses. Fully menu driven system tailoed to different languages. MOPPR friendly interface.
Harris Electronic Systems; Fort Wayne, IN, USA; +1 (260) 451-4600; www.harris.com										
AN/PLM-4 Radar Signal Simulator(RSS)	RWR, ELINT, ESM, MWS, Jammer	500 MHz to 18 GHz,options to add 50-500Mhz, 26-40Ghz and W-band: UV	Free space, direct, antenna coupler	Fully programmable, able to store 100 threats in removable module	16	Fully programmable (Frequency, PRI, PRI type, PW, Scan type, Scan Parameters, Power out, etc)	90-240V, 50-400Hz or battery powered (internal battery charger)	40 x 30 x 30 cm with cover on	12 kg	Operates from internal batteries or external AC power; extensive Built-In-Test and designed to MIL-T-28800; Class C; Type II specifications. Over 2000 units already fielded
CIED Field Test Set (CFTS)	IED jammer	•	Free space or direct couple	1	No	Yes	•	15 x 34 x 29 cm	4.3 kg	Tunable across the RF spectrum of interest, with amplitude threshold adjustment; programmable for EW system growth, new systems and legacy systems.
My-konsult; Solna, Sweden; +46 (0)70 344 03 50; www.mykonsult.com										
TEMPO MY-03	RWR/ESM/ Jammer test	2 - 18 GHz	Free space,	*	*	Yes	max +20 dBm	320 x 170 x 90 mm	4.5 kg	LHCP, RHCP.Handheld, 4-hr battery life,
Northrop Grumman Amherst Systems; Buffalo, NY, USA; 800-631-0610; www.es.northropgrumman.com										
OMNI Pulseman Portable Combat Electromagnetic Environment Simulator (CEESIM)	RWR, jammer, ELINT	0.5 GHz to 18 GHz Synthesized Source	Free space, direct, antenna coupler 1-2 Channels	128	128	Yes	1440W (12 A)	5.2 x 17.5 x 24.5 in.	50 lb (single)	Full suite of signal programming tools. TWTA Control Interface, video output
OMNI Pulseman Portable Combat Electromagnetic Environment Simulator (CEESIM)	RWR, jammer, ELINT	2 GHz to 40 GHz Synthesized Source	Free space, direct, antenna coupler 1-2 Channels	128	128	Yes	1800W (15 A)	5.2 x 17.5 x 24.5 in.	90lb (dual)	Full suite of signal programming tools. TWTA Control Interface, video output
AOA Pulseman Portable Combat Electromagnetic Environment Simulator (CEESIM)	RWR, jammer, ELINT	0.5 GHz to 18 GHz Synthesized Source	Up to 24 Amp/TDOA Ports Up to 12 Amp/ phase/TDOA Ports	128	128	Yes	1800W (15 A)	5.2 x 17.5 x 24.5 in.	90lb (dual)	Full suite of signal programming tools. TWTA Control Interface, video output
AOA Pulseman Portable Combat Electromagnetic Environment Simulator (CEESIM)	RWR, jammer, ELINT	2 GHz to 40 GHz Synthesized Source	Up to 16 Amp AOA Ports	128	128	Yes	1800W (15 A)	5.2 x 17.5 x 24.5 in.	90lb (dual)	Full suite of signal programming tools. Fully dynamic scenario with platform motion and geometry calculations.
Environment Generation Analysis (EGA)	RWR, jammer, ELINT	50 MHz - 40 GHz	Digital	128	128	Yes	100W	17 x 12 x 1	5 lb	Full suite of signal programming tools. Fully dynamic scenario with platform motion and geometry calculations.

Latest EW Simulator Hardware (Part 2)

MODEL	SIMULATOR PURPOSE	SPECTRUM	COUPLED	# OF SIGNALS	SIMULTANEOUS SIGNALS	PROGRAMMABLE	POWER (W)	SIZE (HxWxL inches/cm)	WEIGHT (lb/kg)	FEATURES
Textron Systems (AAI Corp.); Hunt Valley, MD, USA; +1 (410) 628-3434; www.textronsystems.com										
AN/USM-670 (JSECST)	EW, comms, and navigation systems	10 MHz - 18.5 GHz	Antenna coupler	Multiple	16	Yes	>20 dB	26 x 19 x 22 in./ 66 x 48 x 56 cm	98 lb/ 44.5 kg	Fully automated test of complex, modern electronic combat and avionics systems; cable sweep. Full Frequency Receiver included.
Advanced Architecture Phase, Amplitude and Time Simulator (A2PATS)	High density, high fidelity laboratory EW simulator	20 MHz - 22 GHz through 40 GHz	Direct Couple	Multiple: 2048	>256	Yes	Modular Configuration Dependent	Modular Configuration Dependent	Modular Configuration Dependent	Continuous automatic alignment; Physics-based geolocation; High resolution doppler and Time Direction of Arrival capability
AN/GLM-11 Universal Test Set (UTS)	IED jammer	Communications	Free space, direct couple	Multiple	•	Yes	•	7 x 14 x 9.5 in./ 17.8 x 35.5 x 24 cm	<12 lb/<5.4 kg	Able to simultaneously measure and analyze background electromagnetic environment; 8-hour battery operation.
Integrated Tester for Aircraft Survivability Systems (ITASS)	DIRCM, LWR, RWR, MWR	RF Freq Range:Low 100 -1Ghz, High 1Ghz-18Ghz, Millimeter 26 – 40Ghz EO/IR Range: Laser 905nM, Laser 1550nM, UV 275nM, IR 3 -5 uM	Free-space, direct connect cable	Multiple	8	Yes	External Power: +15VDC, 52W, 3.5A nominal Internal Power: 14.4-volt rechargeable Lithium Ion battery pack	16.8 x 13 x 9.75 in./ 42.7 x 33 x 24.8 cm	21 lb/ 9.5 kg	Typical operating range 10-60 m; includes countermeasures detector. Fully integrated multi-spectral testing
Model 527 Radar Signal Simulator	RWR	500 MHZ - 18 GHZ, 28 GHz - 40 GHz 10-500 MHz option	Free space, antenna coupler, direct connect	Multiple	8	Yes	•	12 x 14 x 8.5 in./ 30.5 x 35.5 x 21.6 cm	27 lb/ 12.2 kg	Typical operating range 120 feet from aircraft; DC or AC powered.
Textron Systems (ESL Defence Ltd.); Southampton, Hampshire, UK; +44-2380-744272; www.esldefence.co.uk										
IR Baringa	IR MWS testing	MWIR (2 colour)	Free space	2	2 simultaneous signals (IR)	Yes (8 signatures)	Removable rechargeable battery or external 12 V supply	5.3 x 4.5 x 13.8 in/ 135 x 115 x 350 mm (exc handle)	<10 lb/ < 4.5 kg	Effective range typically 5-30 m. Hand held or remote controlled
Baringa 5.5	UV MWS testing	UV	Free space	1	1 signal (UV)	Yes (8 signatures)	Removable rechargeable battery or external 12 V supply	5.3 x 4.5 x 13.8 in/ 135 x 115 x 350 mm (exc handle)	<10 lb/ < 4.5 kg	Effective range typically 5-30 m. Hand held or remote controlled
Multi-Spectral Test Set (MSTS-EO/IR) - UDL	UV MWS, LWS, DIRCM/IRCM testing	UV, MWIR, NIR (2 bands)	Free space	4	4 simultaneous signals (UV, NIR, MWIR) + 1 detector	Yes (>1000 signatures)	Removable rechargeable battery or external 12 V supplyy	5.9 x 7.5 x 11.8 in/ 150 x 190 x 300 mm (exc handle)	<8.8 lb/ < 4 kg	Effective range typically 5-100 m; includes countermeasures detector Hand held or remote controlled Can be networked and synchronised with other units
Multi-Spectral Test Set (MSTS-EO/IR) - UI3L	UV/IR MWS, LWS testing (DIRCM/IRCM option available)	UV, MWIR (2 bands), NIR (2 bands)	Free space	5	5 simultaneous signals (UV, NIR, MWIR)	Yes (>1000 signatures)	Removable rechargeable battery or external 12 V supply	5.9 x 7.5 x 11.8 in/ 150 x 190 x 300 mm (exc handle)	<8.8 lb/ < 4 kg	Effective range typically 5-30 m; countermeasures detector optional Hand held or remote controlled Can be networked and synchronised with other units
Phantom	UV MWS, LWS testing/aircrew training	UV, NIR	Free space	2	2 simultaneous signals	Yes (>1000 signatures)	Removable rechargeable battery or external 12 V supply	5.9 x 7.5 x 22.8 in/ 150 x 190 x 300 mm (exc handle)	<22 lb/ < 10 kg	Effective range typically 500-5000 m Shoulder mount or remote controlled Can be networked and synchronised with other units
Ultra Electronics - EW Simulation Technology Ltd.; Farnborough, Hampshire, UK; +44-1252-512951; www.ewst.co.uk										
PTS 8000 Multi Spectral Test Set	RWR	500 MHz-18 GHz, 32-40 GHz	Free space, antenna coupler	6 pulsed/CW per RF band	No	Yes	10.8v 4.5AH NiMH battery	22 x 17.5 x 25.5 cm	4 kg	Modular design; offline software allows user to program hundreds of complex emitters.
PTS 8000 UV	UV MWS	Solar blind UV region	Free space	8	No	Yes	4 x AA battery	10.3 x 10.3 x 21.0 cm	1.5 kg	Uses UV LED technology to reproduce MWS/HFI threat profiles; lightweight; battery powered.
PTS 8000 LWR	LWR	525nm,905nm,1550nm	Free space	8	No	No	4 x AA battery	10.3 x 10.3 x 21.0 cm	1.5 kg	Compact and lightweight.

Threat Simulators Key Terms / Parameters

MODEL
Product name or model number

PURPOSE
What function of the EW or SIGINT System does it test?
- *CMDS = countermeasures dispenser system*
- *COMINT = communications intelligence systems*
- *DIRCM = directed infrared countermeasures system*
- *ELINT = electronic intelligence system*
- *IED = improvised explosive device jammer*
- *IR = infrared*
- *LWS = laser warning system*
- *MWS = missile warning system*
- *RWR = radar warning receiver*
- *UV = ultraviolet*

SPECTRUM
RF frequency range; EO/IR bands
- *MWIR = mid-wave infrared*

COUPLED
How are the threat signals delivered into the EW system for test or evaluation?
- *Direct = directly injected*
- *Antenna coupler = RF coupler/hat*
- *Free space = free-space radiation*

NUMBER OF SIGNALS
One specific signal or able to simulate many different signals?

SIMULTANEOUS SIGNALS
How many signals can the device transmit simultaneously?

PROGRAMMABLE
Can the user program different signals?

POWER
Power drain in Watts, VDC or VAC

SIZE
H x W x L in inches/mm

WEIGHT
Weight in lb/kg

FEATURES
Additional features

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

Conclusions

- As the technology continually advances, the communications systems become more complex, requiring ever more complex identification methods to determine whether the received signals are friendly or hostile

- With the increasing use of software in EW and Comm systems, there are now numerous cyber vulnerabilities to worry about also

- Much more research needs to be done in the emerging area of MIMO and 5G systems signal identification and this will increasingly be the case as time goes by

- Developing new and improved EW Simulators with High Dynamic Range / Sensitivity will always be desirable

Questions / Comments