EMSO ENVIRONMENTAL GENERATION

Bill Kardine – Radar/EW BDM

ROHDE&SCHWARZ

Make ideas real

OVERVIEW

- What is an EW environment (EMSO)
- What kind of System do you need to generate an EW environment
- What is a “model”
- Common DUTS/SUTS

SCENARIO GENERATION & BUILDING

- How do you build environments from models?
- Common Simulation environments?
- What is an “emitter”
- How do you define moving emitters
- Real-time variation? User Input? Joystick?

EMSO AND ELECTRONIC WARFARE (EW)

- **EMSO – (E)lectro(M)agnetic (S)pectrum (O)perations**
- **Military - EW is a term that is used to describe any method that is used to control the EM Spectrum**

  – Electronic Attack (EA) – Attacks or degrades an enemy’s electronic systems
    - Jamming, can include Anti-Radiation Missiles (ARMS)

  – Electronic Support (ES) – Passive Intercept and location of an enemy’s Radar signals. ES is more commonly known as RESM

  – Electronic Protection (EP) – Protects allied systems from enemy EA
    - Techniques either built into the Radar or Operational Techniques
    - Emission Control (EMCON) (ECCM)

WHAT IS EW ENVIRONMENT SIMULATION?

- Electronic Warfare Environmental simulation

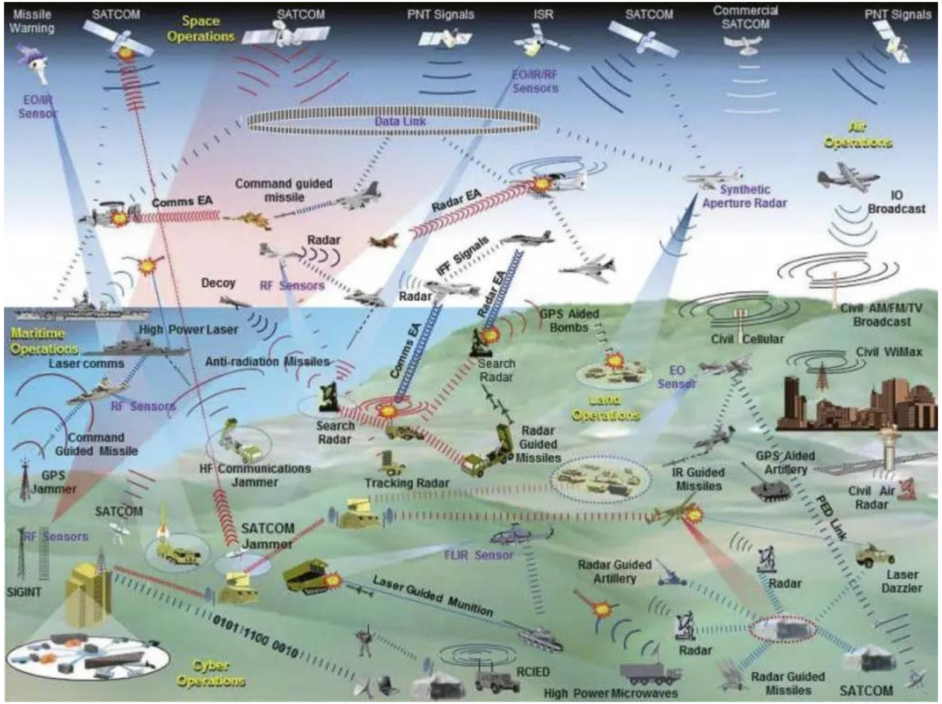
- The total EM spectrum - Comprises of everything that could be in your environment

- Environment includes:
  - Friendly EM signals (comms, radars, satellite links, etc)
  - Un-friendly EM signals (jammers, radars,
  - Neutral signals (terrestrial comms, satellite signals, interfering RF signals)

WHY DO WE WANT TO SIMULATE?

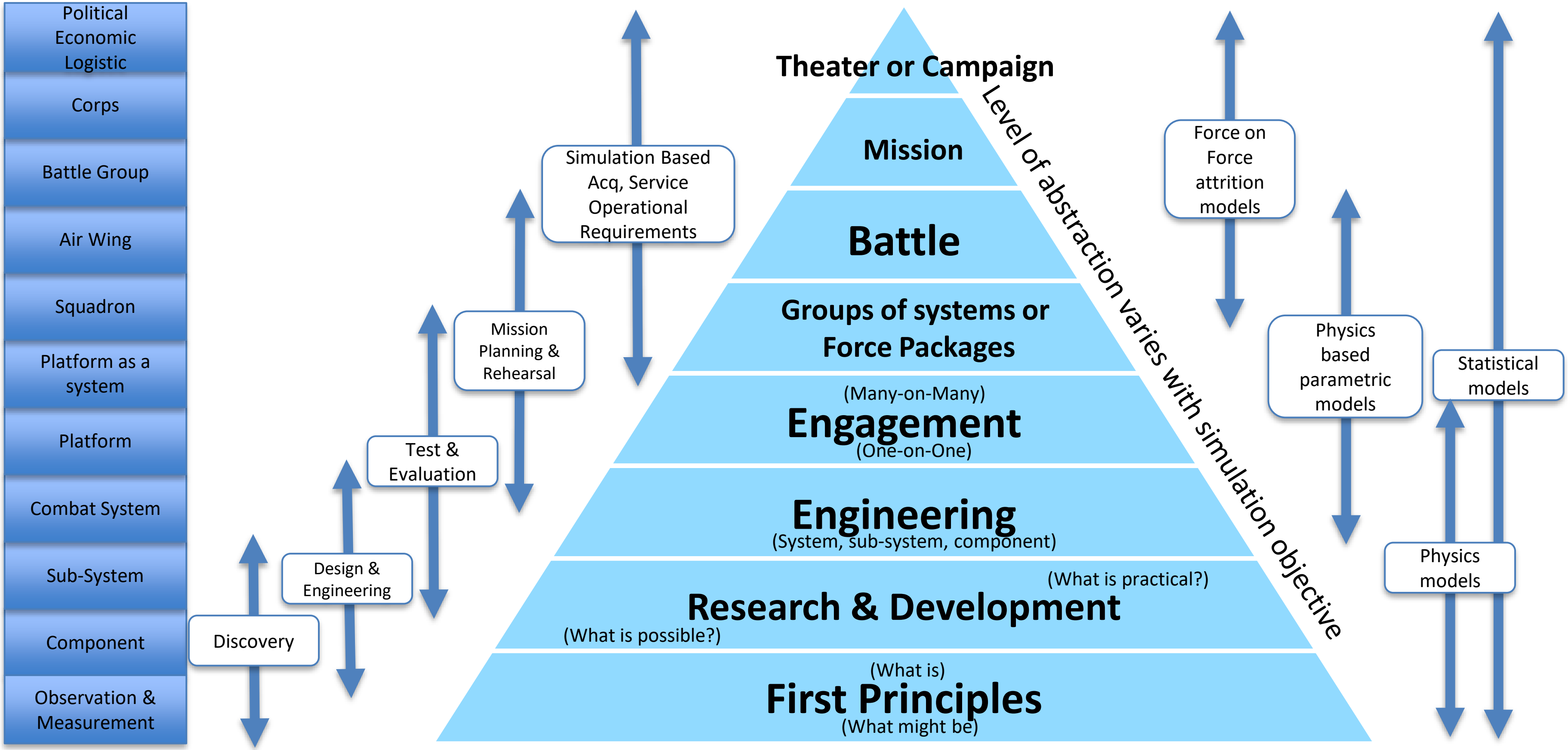
- Real world testing is:
  - Expensive
  - Uncontrolled
  - Not repeatable, logistically challenging
  - Unsecure
- Fly-Fix-Fly method is unaffordable

- Simulation is:
  - Finite & scalable
  - Flexible
  - Precise
  - Less risky (schedule, scope, cost)



https://www.japcc.org/wp-content/uploads/JAPCC_J27_screen.pdf

SIMULATION ABSTRACTION



WHAT IS TRUTH?

Simulation Truth

What is the objective environment that the simulation is trying to create?

Chamber Truth

Raw data presented to SUT/DUT

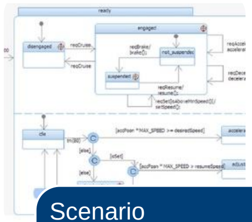
SUT or DUT Truth

Perception of the System or Device under test (SUT/DUT)

These "truths" are not always the same, and it is up to the test engineer to monitor these three truths and validate their test models and methodology

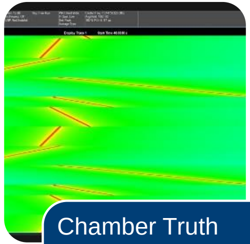
SIMULATION ABSTRACTION HIERARCHY

Planning
- Purpose & objectives
- Context
- Resources
- MOP/MOE/COI
- VV&A processes
- Mitigations

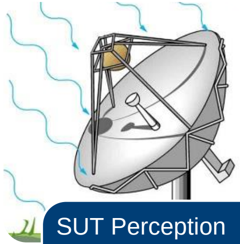


Scenario
- Contextual description of.
  - Environment
  - Order of Battle
  - Tactics & behavior
  - Relevant assumptions

Tactical Simulation
- Dynamic scenario execution
- Platform motion
- Sensors and comms
- Environmental factors
- Tactics and behavior
- Interactions



Chamber Truth
- Raw data presented to the SUT
- Multi-spectral sensor stimulators
- Navigation
- Communications
- Etc…

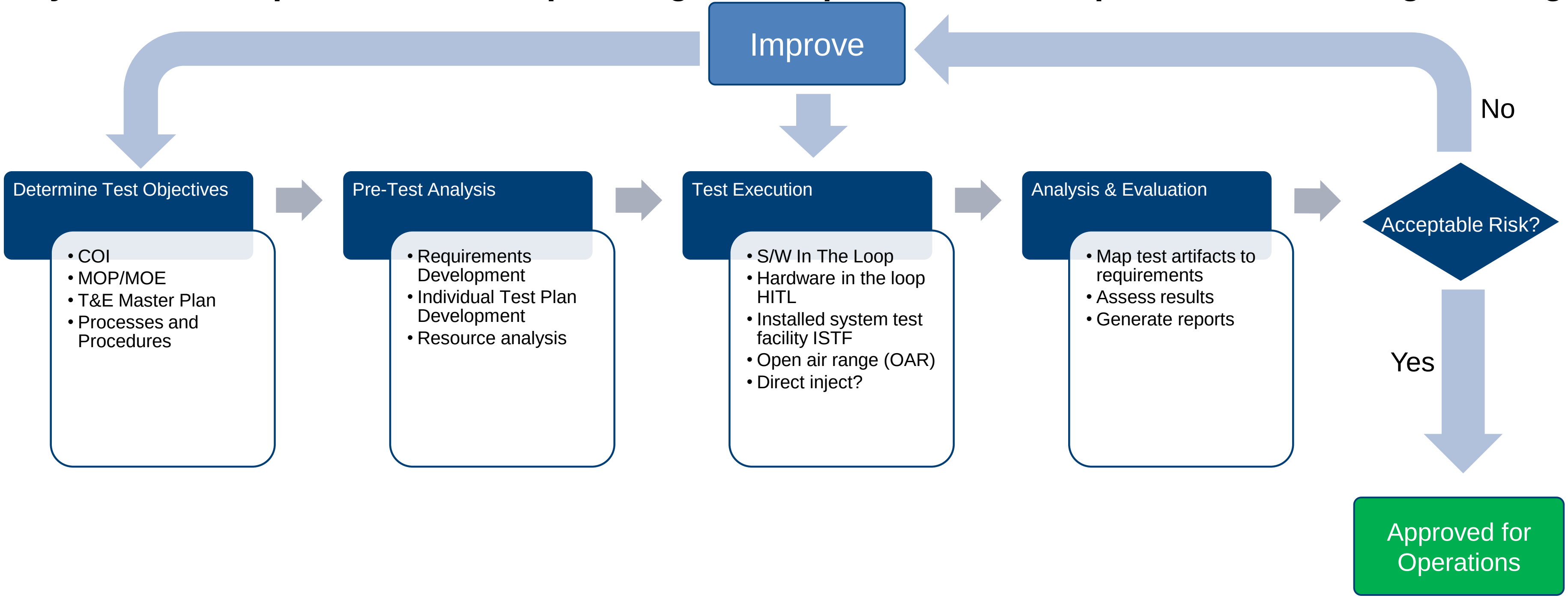


SUT Perception
- Colorization and transforms that result from system design
- Platform data bus info
- System logs
- Instrumentation

Simulation Truth	Chamber Truth	SUT/DUT Truth

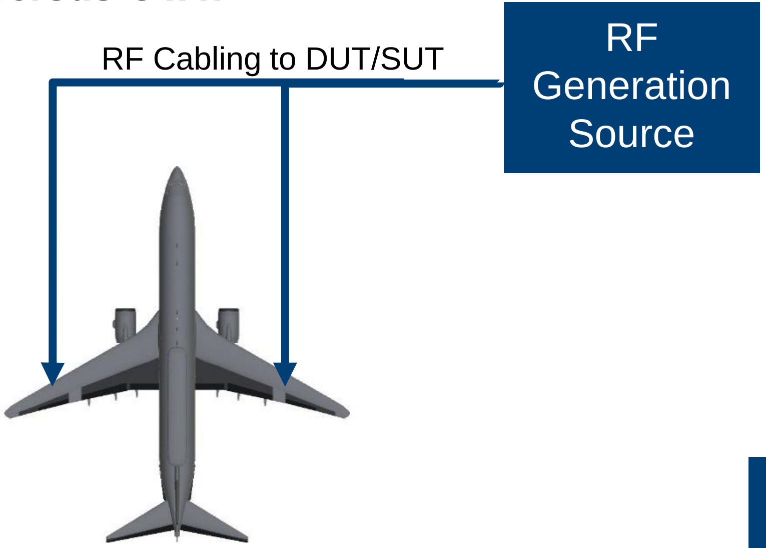
TEST AND EVALUATION (T&E)

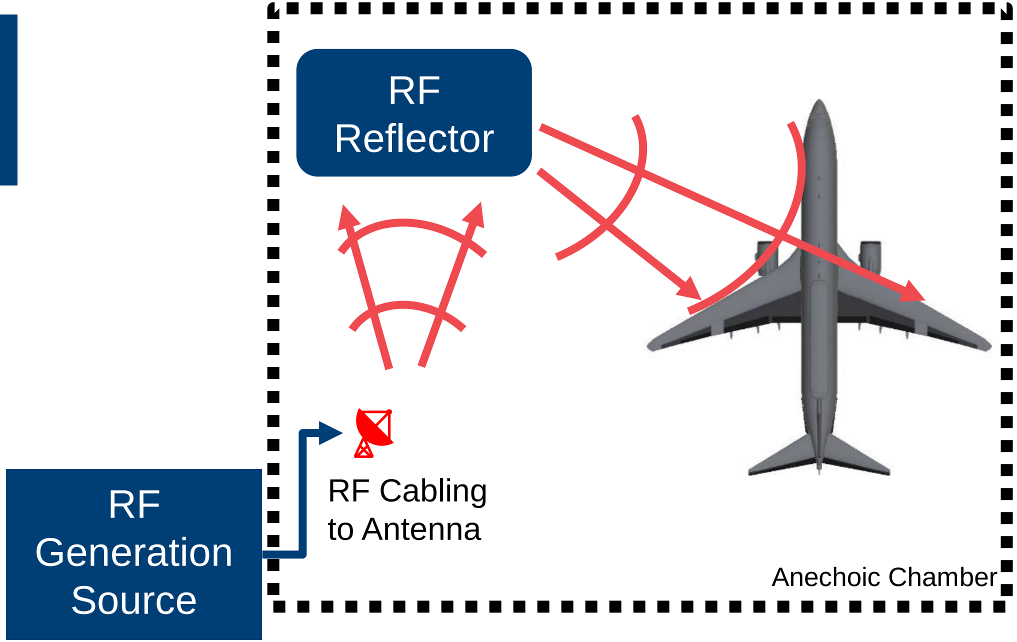
System or components are compared against requirements and specifications through testing



DIRECT INJECTION VS OVER THE AIR?

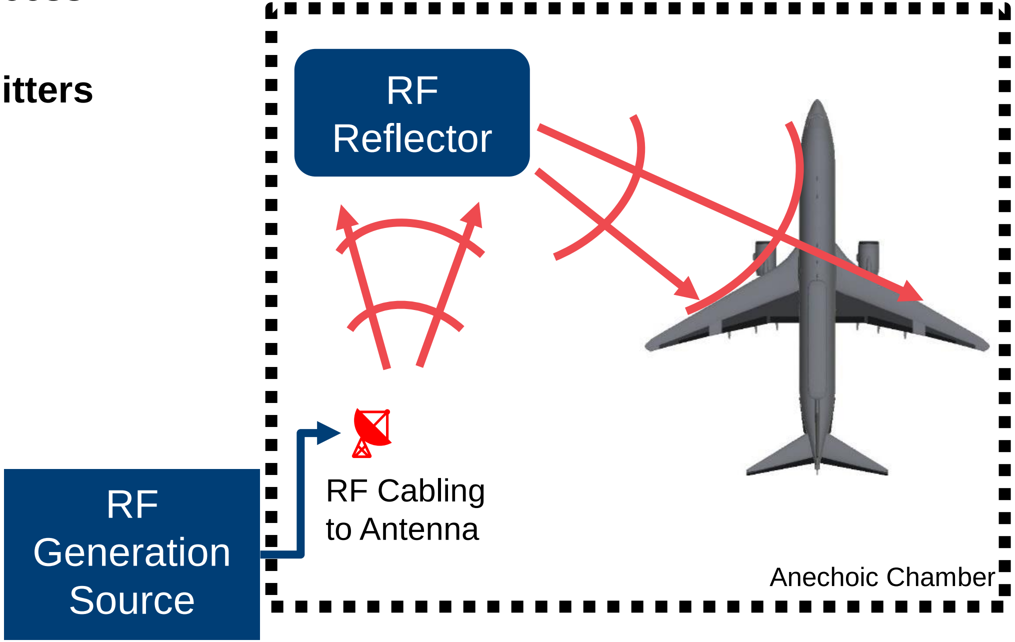
DI versus OTA?





BENEFITS OF OVER THE AIR?

- **Ideal for situations with limited test port access**
- **Ideal for small functional tests with few emitters**
  - Operational testing
  - Response testing
- Reduced testing and RF complexity



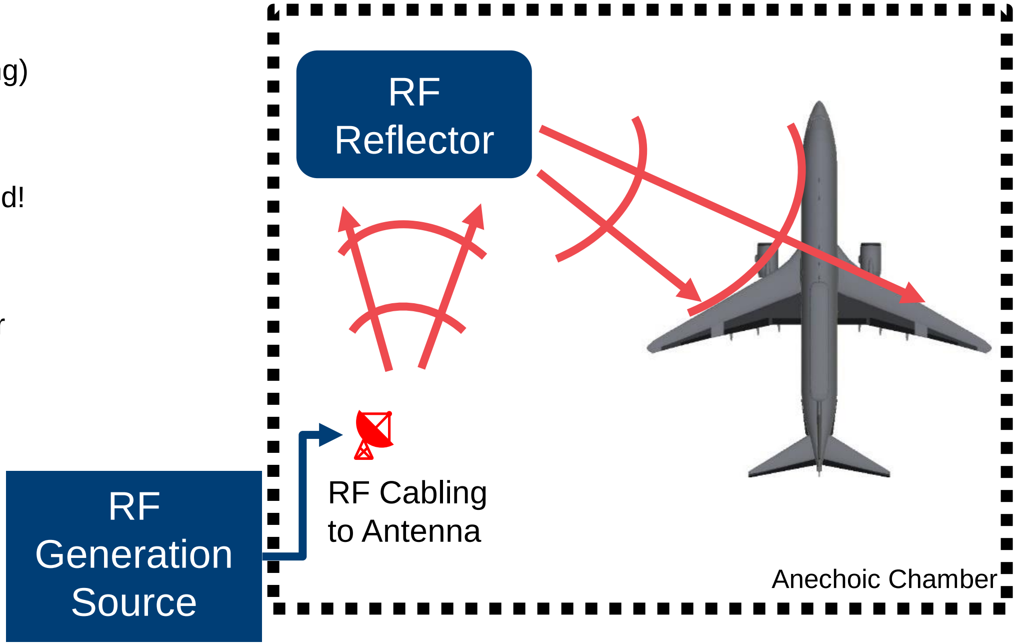
DOWNSIDES OF OVER THE AIR?

- Chamber calibration & isolation
  - Zeroing out RF noise in the chamber
  - Minimizing input from outside the environment (shielding)

- Security
  - if you are radiating and not shielded, it can be measured!

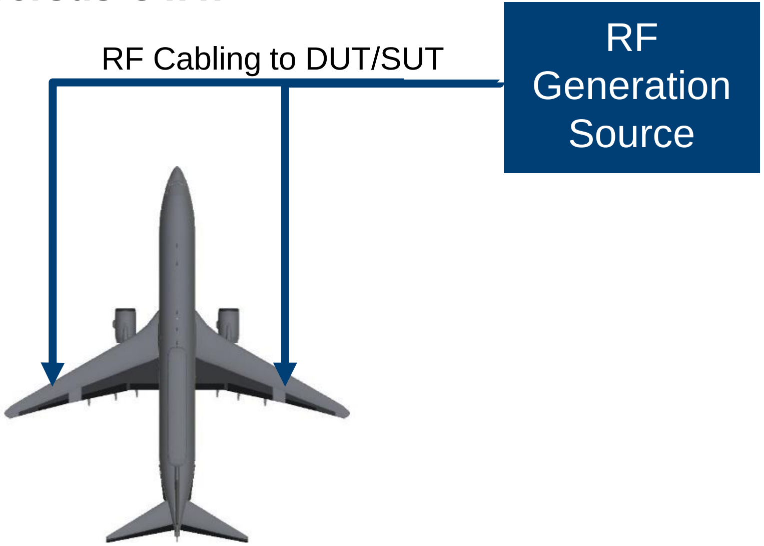
- Simulating far-field wave patterns in compact space
  - Use of RF reflectors typical – some ranges are open air and significantly far-field

- Mechanical/logistical challenges
  - How do you simulate an emitter in all azimuths and elevations?
  - How do you simulate multi-emitter configurations all moving in space?



BENEFITS OF DIRECT INJECTION

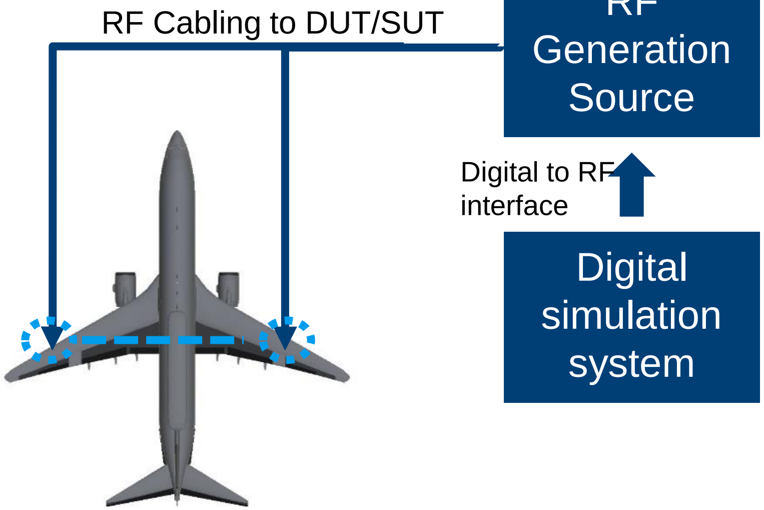
DI versus OTA?



- Scalable
  - Can simulate multi-emitter scenarios
  - More ports = more test equipment
- Flexible
  - Can operate infinite variations of environment, geometries, movement profiles
- Secure
  - Very little radiated emissions – shielding excellent
- Repeatability
  - Excellent test to test parameter accuracy
  - Can make minor changes to scenario to flesh out key SUT/DUT effectiveness parameters

DOWNSIDES OF DIRECT INJECTION

DI versus OTA?



- Calibration
  - Need to calibrate phase, amplitude and power level at the end of the RF cables (circled)
  - Temperature drift effects long cable runs
- Need a robust and accurate simulation sub-system with beefy digital interface to RF Generation
  - More software, updates, equipment
- Often times more costly for higher performance

SUBCOMPONENTS OF AN EW SCENARIO GENERATION

Libraries
- Real world threat data
- Waveforms with a purpose

Scenario creation
- Taking threats and building environments and simulations
- Mission Data creation

Digital Generation subsystem
- Take environments and simulations and build a digital output

Receive digital output and create RF
- Calculate scenarios and streamline digital output
- Digital to Analog RF, at band
- Calibration, phase and amplitude corrections

DUT / SUT
- EW Receivers
- Jammers
- Radar warning receivers
- Multi-technology arrays
- Aircraft

COMMON DEVICES AND SYSTEMS UNDER TEST (DUT/SUT)

TYPICAL CUSTOMER EW RECEIVER TYPES

PURPOSE / RECEIVER COMPONENT	RWR*	ESM*	ELINT
PURPOSE	**WARN AIRCREW** OF RF-GUIDED THREATS & CUE COUNTERMEASURES	**DETECT/IDENTIFY & PRECISELY LOCATE** RF-GUIDED THREATS AT LONG RANGE. ECM CUEING.	**INTERCEPTION & ANALYSIS** OF HOSTILE NON-COMMUNICATIONS EMITTERS. DETERMINE ENEMY EOB. NO ECM CUEING.
ANTENNAS (FREQUENCY SUB-BANDED)	4 SPIRALS/FREQUENCY BAND FOR AZIMUTH. 4 MORE FOR ELEVATION	INCREASED No./TYPES OF ANTENNAS, INCLUDING PHASED ARRAYS, SPINNERS	USUALLY MULTIPLE, FREQUENCY-BANDED OMNI AND DF ANTENNAS
RECEIVERS, ANALYSIS & PROCESSING	WIDEBAND & SUB-BANDED, CHANNELISED RECEIVERS. ANALYSIS SHARED WITH STAND-ALONE PROCESSOR	AS RWR + OTHER TYPES, e.g. IFM. BETTER DF TECHNIQUES. INTEGRATED PROCESSING	MULTIPLE FREQUENCY SUB-BANDED SEARCH/ACQUISITION & SET-ON/ANALYSIS RECEIVERS. INTEGRATED PROCESSING NOW COMMON
RECORDING	RARE	BECOMING COMMON	DATA ALWAYS RECORDED
DISPLAYS & CONTROLS	OFTEN STAND-ALONE	OFTEN PART OF INTEGRATED AIRCRAFT D&C	PER-RECEIVER D&C COMMON. LATEST HAVE INTEGRATED D&C

*ECM RECEIVERS HAVE RWR/ESM CAPABILITY

Taken from NATO „Electronic Warfare Test and Evaluation" AC/323(SCI-203)TP/471, Pages - NATO Science & Technology Organization

TYPICAL CUSTOMER EW RECEIVER TYPES

Receiver Type	Advantages	Disadvantages
Channelized Receiver (some 10 – MHz to 100 MHz channels), often used for ELINT	Narrow bandwidth Resolve pulse on pulse situations Detailed signal analysis	Narrow bandwidth Detailed signal analysis
Instantaneous Frequency Measurement (IFM) receivers from 500 MHz to 18 GHz, used in RWR for threat protection	Relatively simple Frequency resolution instantaneous High Probability of Intercept	Simultaneous signal problem Overlapping signals cannot be isolated in frequency domain No Pulse on Pulse detection capability Blind if CW or FMCW signals occur Relatively poor sensitivity
Narrowband (up to some GHz instantaneous bandwidth) super heterodyne receiver	High sensitivity Good frequency resolution No simultaneous signals problem	Slow Response Poor Probability of Intercept (POI) Poor against frequency agility Narrow bandwidth

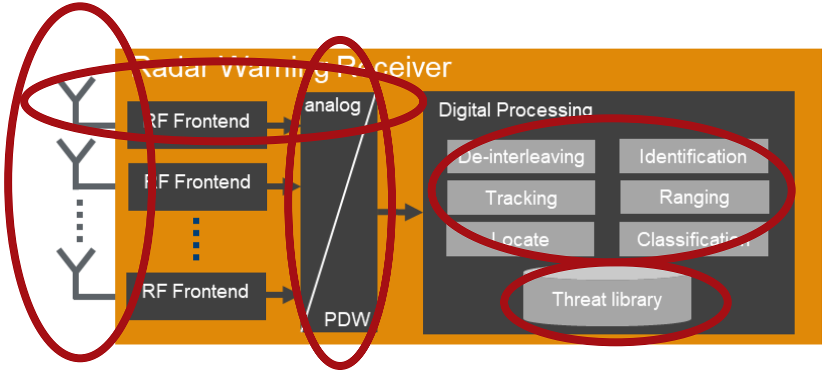
EXAMPLE PERFORMANCE DATA OF RWR

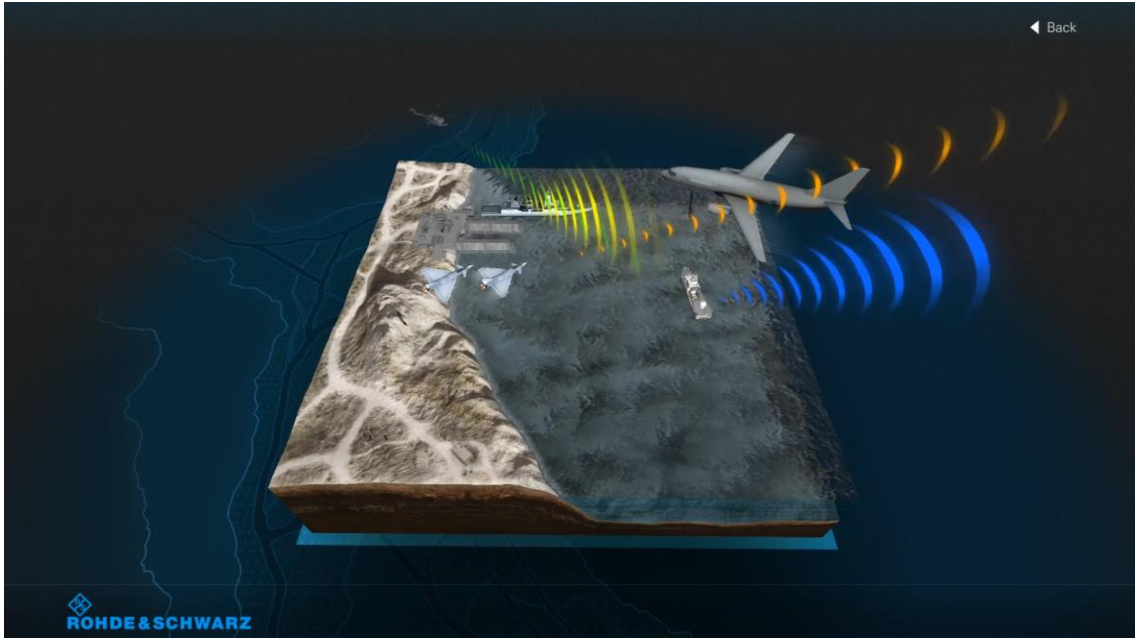
MODEL	REC TYPE	OP FREQ	INST BWIDTH	TYP INST SENS	TOTAL DYN RANGE	SUPPORT DF	PWR (W)	SIZE (in.)	WEIGHT (in lb/kg)	PLATFORM	FEATURES
INDRA; Madrid, Spain; +34-914-806-032; www.indra.es											
ALR-400 RWR	Digital	0.5-42 GHz	4 GHz	-65 dBm	60 dB	Yes	200 W	*	10.2 kg	air	LPI capability. Wband digital reception. EW suite controller tembedded capability.
AMES-C ESM/ELINT	DIFM and superhet	0.5-18 GHz	16 GHz	-90 dBm	60 dB	Yes	1,000 W	15 x 10 x 25	90 kg	air	18-40 GHz option. Detailed intrapulse analysis capability.
AMES-800 ESM/ ELINT	Digital	0.5-42 GHz	16 GHz	-90 dBm	*	Yes	200-800 W	15 x 10 x 25	25 kg	air	360-deg instantaneous coverage. High-accuracy DF measurement. Modular design and flexible architecture.
MRSR-800/MRGR-800 ESM	Digital	0.5-18 GHz	17.5 GHz	-85 dBm	60 dB	Yes	<3,500 W	Proc.: 19 x 23.6 x 12.2; ant.: 21.5 x 22.5	70-195 kg	shp/grd	18-40 GHz option. Enhanced BIT.
MRGR-ELINT-FD	Digital and superhet	0.5-18 GHz	>500 MHz	-90 dBm	55 dB	Yes	2,000 W	Rx: 23 x 11.4 x 9.4; proc.: 15 x 25 x 10; ant.: 37 x 52.5	178 kg	shp/grd	18-40 GHz option. Flat-DF ant. with high rotation speed (maximizing POI).
Lockheed Martin MST; Owego, NY, USA; +1 (607) 751-7089; www.lockheedmartin.com											
AN/ALQ-210	ESM/RWR superhet	*	*	*	*	Yes	400 W	7.7 x 10.1 x 15.3	57 lb	air	Re-programmable emitter library. Installed on MH-60R.
AN/ALQ-217	ESM Superhet	*	*	*	*	Yes	537 W	28 x 8.8 x 14.2	86 lb	air	Re-programmable emitter library. Installed on E-2C/D.
AN/ALQ-507	ESM Superhet	*	*	*	*	*	*	*	*	air	Installed on Int'l P-3.
AN/APR-48B	Digital Targeting ESM	*	*	*	*	*	*	*	*	air	Installed on AH-64D/E.
Digital RWR	Digital RWR Superhet	*	*	*	*	Yes	431W	7.7 x 10.1 x 13.5	39 lb	air	High performance RWR installed on rotary wing platform.
Northrop Grumman Corp.; Rolling Meadows, IL, USA; +1 (224) 625-6777											
AN/ALR-93	CVR, IFM and digital	0.5-20 GHz	*	*	*	Yes	198W	*	60 lb	air	*
AN/ALQ-218	Digital	*	*	*	*	*	*	*	*	air	Look-through capability. Geolocation.
LR-100	Superhet	2-18 GHz	*	*	*	*	219	*	73 lb	air, grd-mob, grd-fix, shp, sub	1,500-hr MTBF rate. Geolocation.
Rafael Advanced Defense Systems Ltd; Haifa, Israel; +972-4-8795143; www.rafael.com											
Top Scan	Digital	0.5-40 GHz	32 GHz	-65 dBm	90 dB	Yes	850 W	11 x 10.6 x 16.5 in	30 kg	air, grd	UAV, HELI, HADF, MPA, ESM. Geolocation optional.
C-Pearl	Digital	0.5-40 GHz	Wide open	-65 dBm	90 dB	Yes	1,100 W	*	*	shp, sub	Wband digital receiver. Geolocation optional.

Source: JED Magazine June 2015

EXAMPLE STRUCTURE OF RWR

Radar Warning Receiver – Multi-port example - Simpified



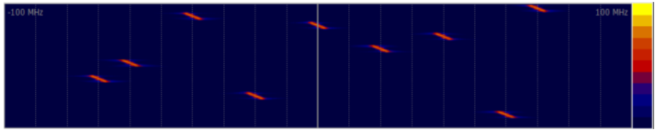


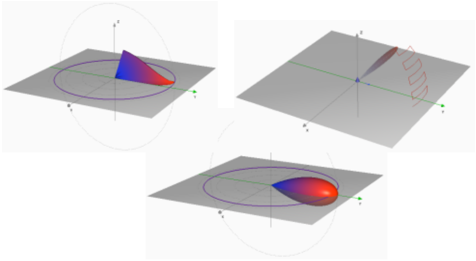
SCENARIO GENERATION AND BUILDING

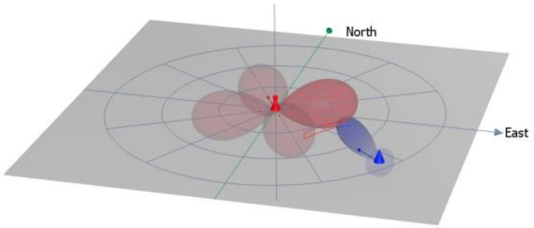
SIMULATING REAL WORLD EW SCENARIOS

What needs to be simulated?

- Signal waveform
  - Pulses, sequences of pulses, bursts, modulation on pulse,
  - inter pulse modulation, frequency agility, PRI agility, …
- Transmitter and receiver with antenna patterns and antenna scans
  - Pencil beam patterns, cosecant antenna patterns, phased array antenna patterns, etc.
  - Spiral, helical, conical, scans, etc.
  - Antenna polarizations
- Single and multi channel moving receivers
- Location of emitters and receivers, movement and attitude information & antenna pointing
- Propagation model consideration







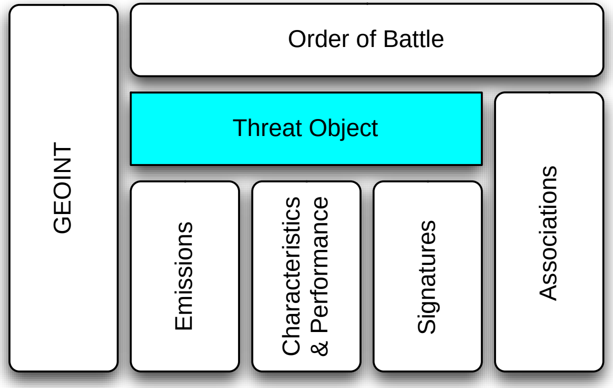
THREATS…

Threats are typically “models” of real world signals

- The main purpose of EW environmental simulation is to experiment with how DUT or SUTs respond under stress from known ***threats***

- A threat can be a model of a friendly or an adversary waveform

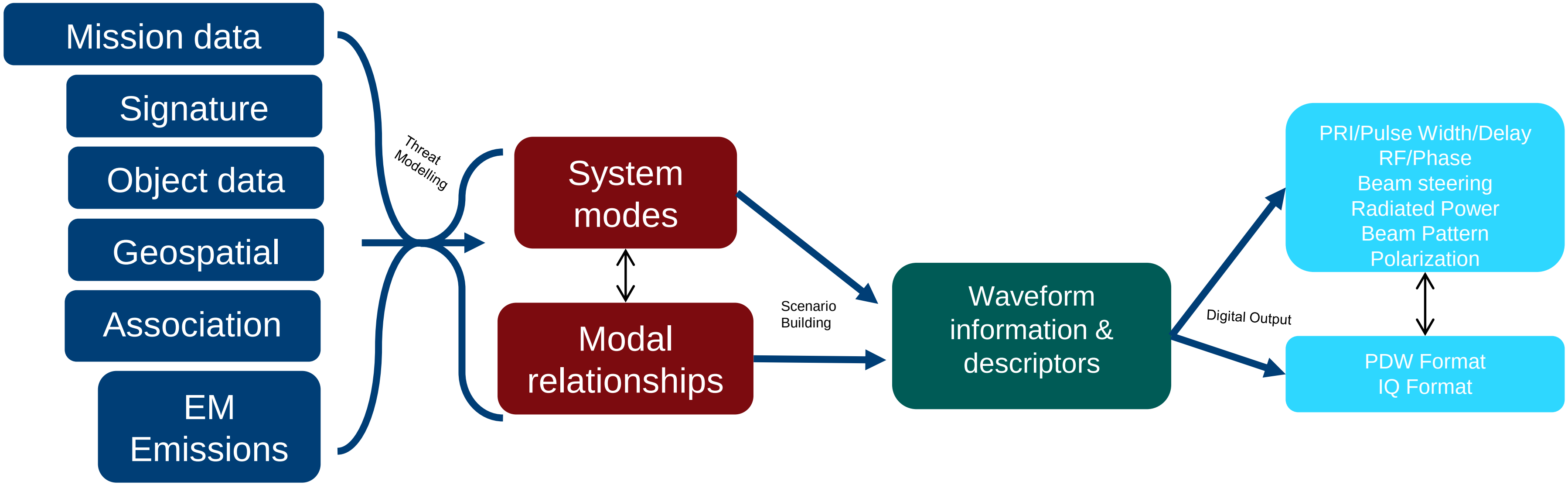
- Threat data can be combined with other meta data surrounding that waveform to form *threat models*



THREATS MODELLING

Threat models can be very detailed, very complex representations of real-world signals

► Some threat models include data such as:



WHAT IS AN EMITTER?

An emitter is a compilation of waveform characteristics and physical characteristics that manifest as an RF characteristic

Pulses and sequences

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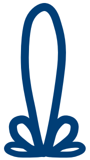

Antenna diagram

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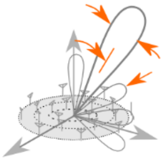

Antenna Scan(s)

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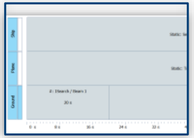
- Δf
- Elevation
- Azimuth

Beam specific offsets

⊕



Mode changes

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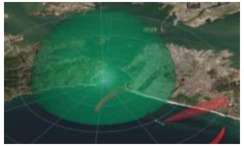


Map and trajectories

⊜

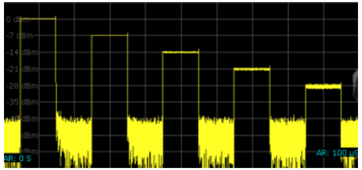
Emitter

PRI/Pulse Width/Delay
RF/Phase
Beam steering
Radiated Power
Beam Pattern
Polarization

↔

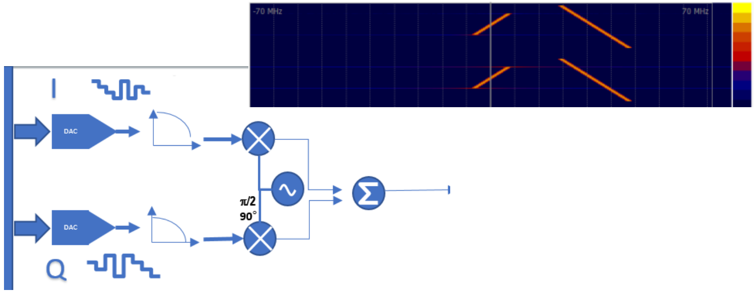
PDW Format
IQ Format

HOW DO YOU REPRESENT A WAVEFORM?



IQ

- Digital Baseband
- Exact waveform – data intensive
- Plays back *everything*
  - *Includes off-time of signal*



PDW

- Representative waveform (idealized)
- Great for long scenarios
  - Avoids saving and storing "*off-time*"
  - Data-efficient
- THE language for radar systems and components
- Allows for easy comparison to stored radar characteristics and ID and classification
- Need a PDW – RF signal generation platform

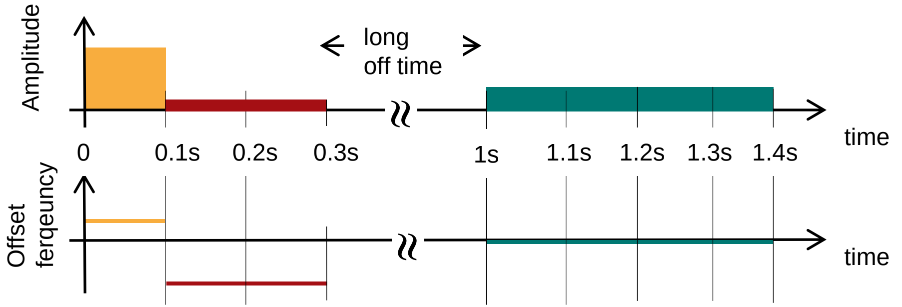
PDW CONTENT
ENABLING REALISTIC SIGNALS IN A PULSE DESCRIPTOR WORD

Signal defined by pulse parameters

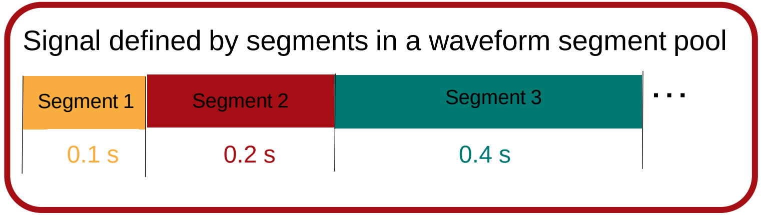
Pulse 1	Pulse 2	Pulse 3
0.1, 0, 10k …	0.2, 10, -1M, …	0.4, 3, 0, …

Sequencing list

Time	Mode	PW	Attenuation	Offset frequency	Offset phase	MOP	rate
0 s	RT	0.1s	0 dB	10 kHz	0 deg	LFM	1 MHz/us
0.1 s	RT	0.2s	10 dB	-1 MHz	0 deg	LFM	1 MHz/us
1 s	RT	0.4s	3 dB	0 Hz	0 deg	LFM	1 MHz/us
…	…	…	…	…	…	…	…



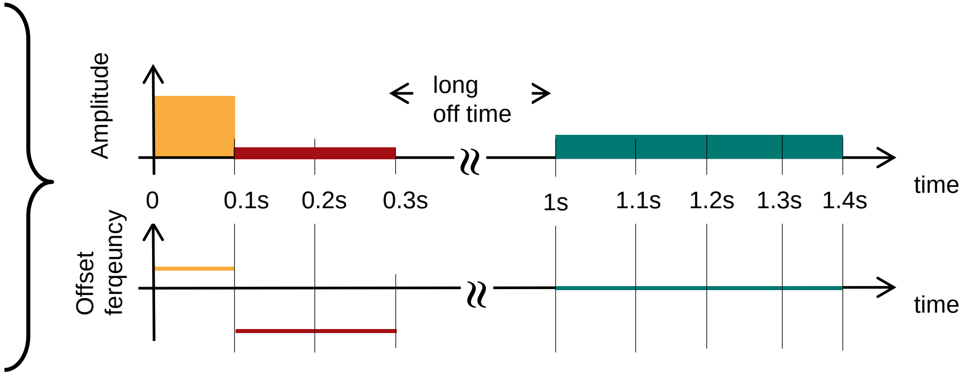
PDW CONTENT
ENABLING REALISTIC SIGNALS WITH IQ CONTENT



Used for all complex signals that have unique I&Q profile
- Mission data (WARM)
- Real world captured data

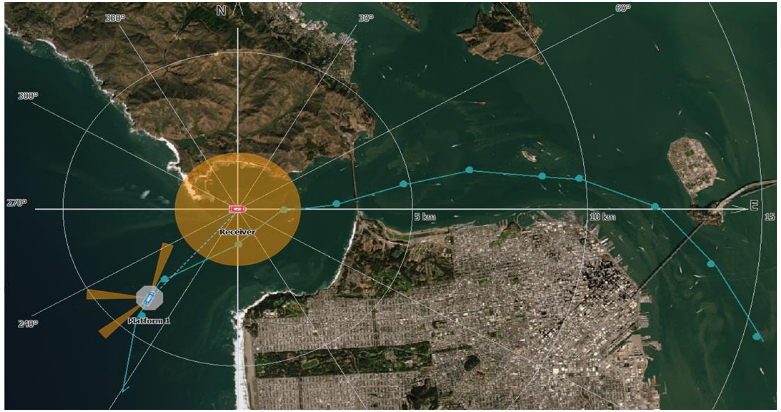
Sequencing list

Time	Mode	Attenuation	Offset frequency	Offset phase
0 s	Segment 1	0 dB	10 kHz	0 deg
0.1 s	Segment 2	10 dB	-1 MHz	0 deg
1 s	Segment 3	7 dB	0 Hz	10 deg
…	…	…	…	…

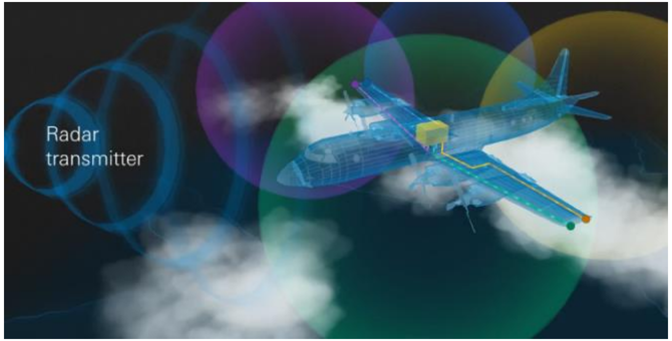


SCENARIOS - BASIC

- Designed to support testing of MOP/MOE/COIs
- Start simple
  - Static, no motion or mode change
  - “1 v 1” test case (e.g. System Under Test and ONE emitter)
- Increase complexity as needed to test MOP/MOE/COI
  - Mode changes
  - Simulate AoA
  - Motion
  - Additional emitters and platforms
  - Environment – terrain, propagation,
- OT&E scenarios replicate expected mission and battlespace



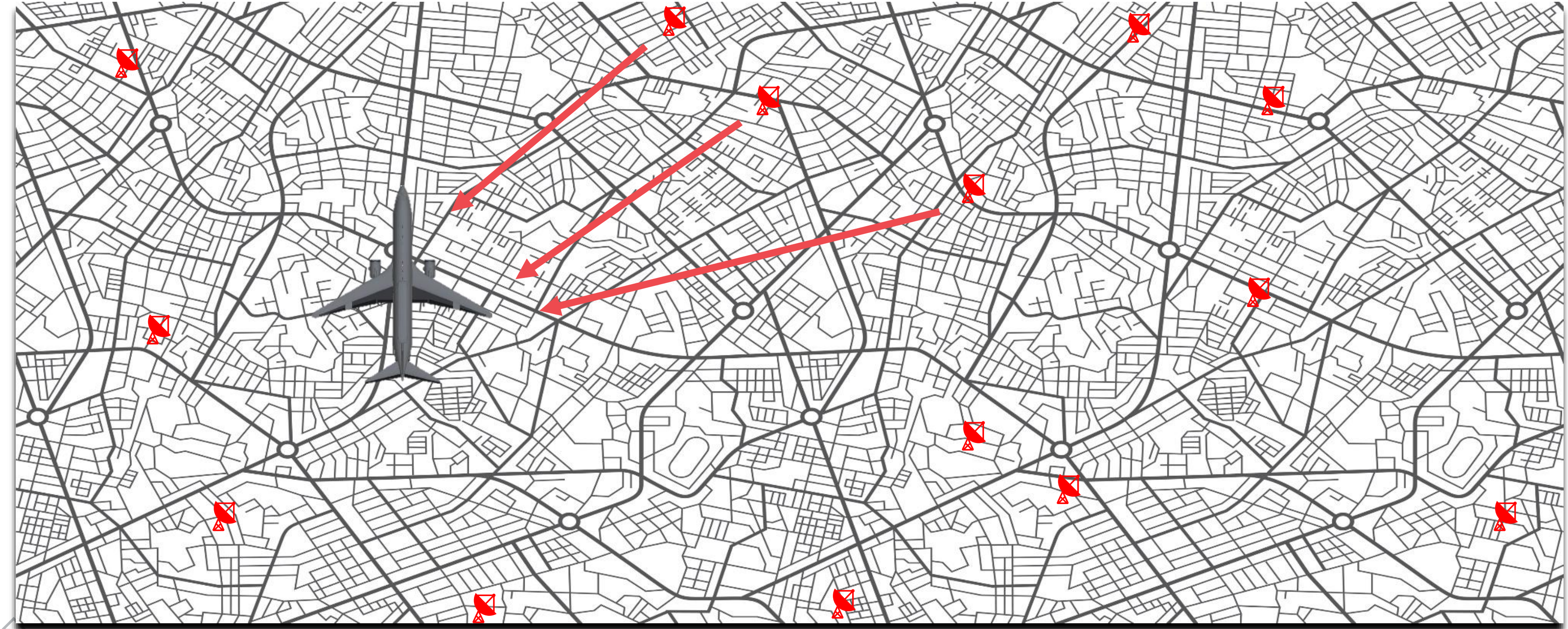
Straight forward 1v1 scenario w/ movement



Simulate AoA on platform

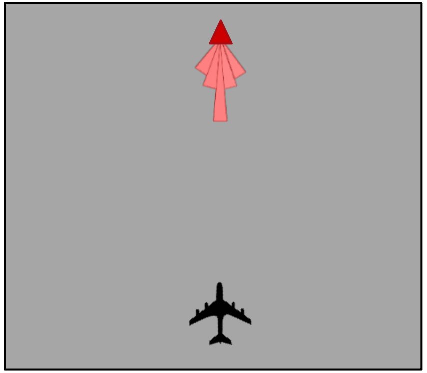
SIMULATING ENVIRONMENTS

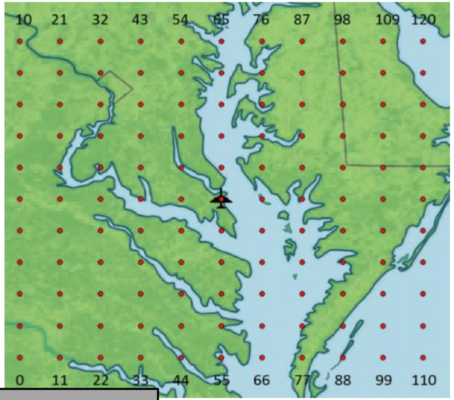
Multi-emitter scenarios

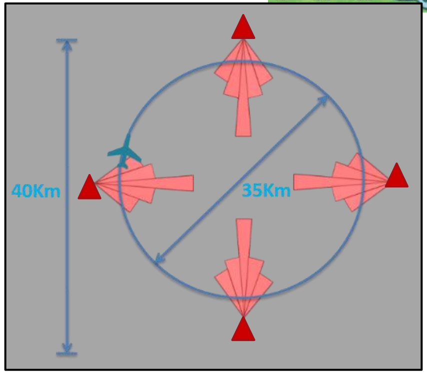


TEST SCENARIO EXAMPLES

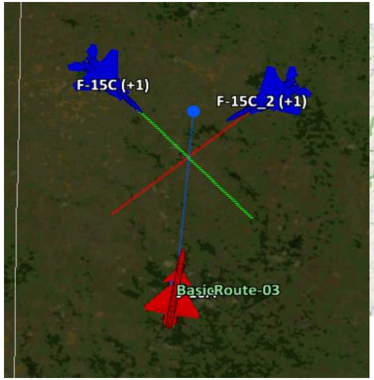
DT&E

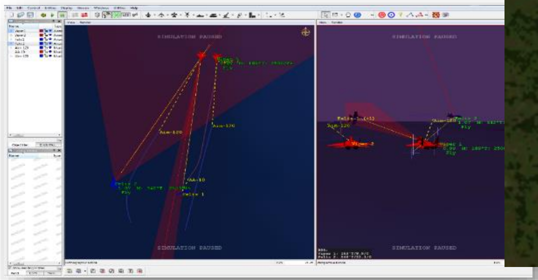






OT&E

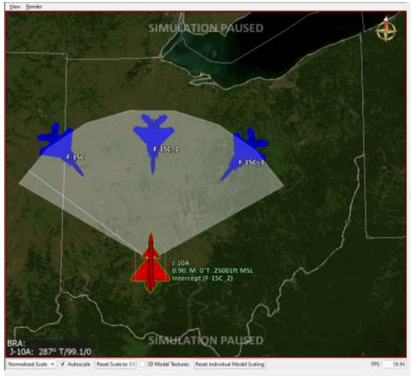


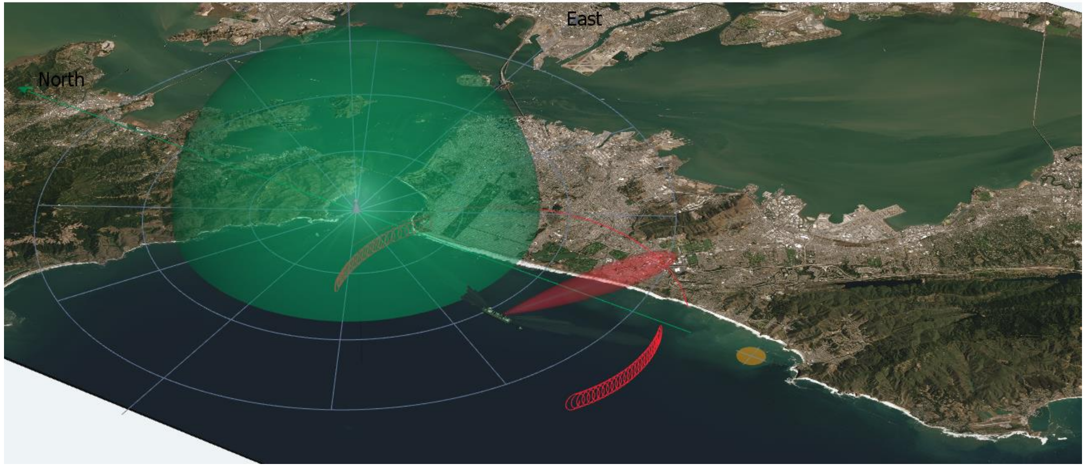


THESE EMITTERS, THEY CAN MOVE!

Creating environments where threats move

► Testing a DUT or SUT response when a threat emitter is moving in 3D-space is a common operational test





EMITTER PARAMETERS

Common figures of merit for emitters

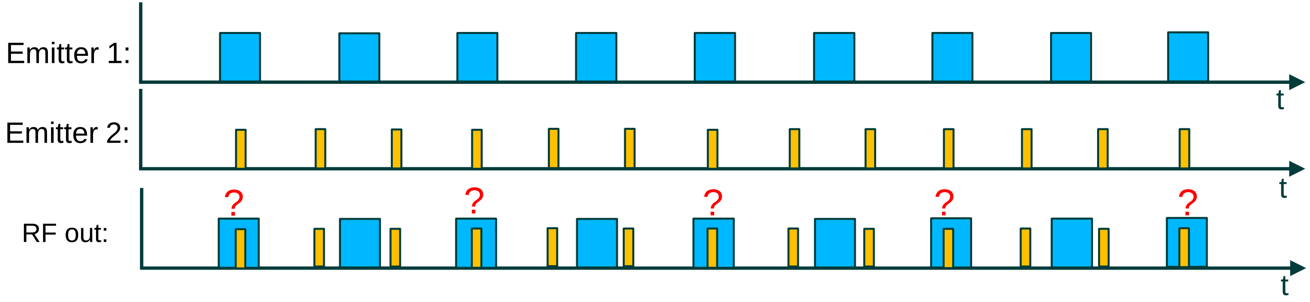
- Pulse Density, bandwidth (agile), bandwidth, power level
  - (A lot of these parameters that we can define in the emitter)

- Dropped Pulses, Pulse on Pulse (multi-emitter)

- Movement data
  - Doppler shift

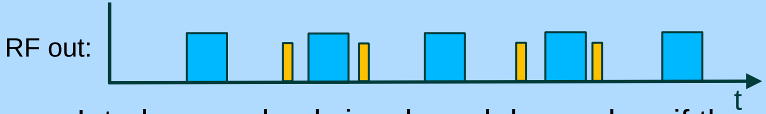
MULTIPLE EMITTERS IN PARALLEL
WHAT IS THE CHALLENGE?

- **Customer task:** Two emitters need to be simulated and generated at the same time on one RF



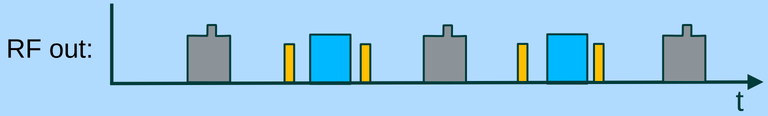
- **Question:** Which RF signal should be generated if two pulses occur at the same time?

Interleaving/Pulse Dropping



Interleave pulsed signals and drop pulses if they overlap according to a priority scheme with optimized low drop rate

Pulse-on-Pulse

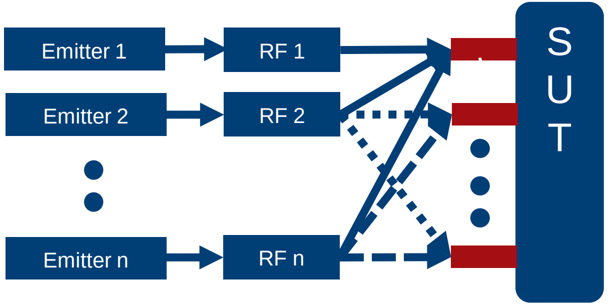


Generate both pulses together (co pulse or pulse on pulse signals)

AVOIDING PULSE DROP OUT – MULTIPLE EMITTERS

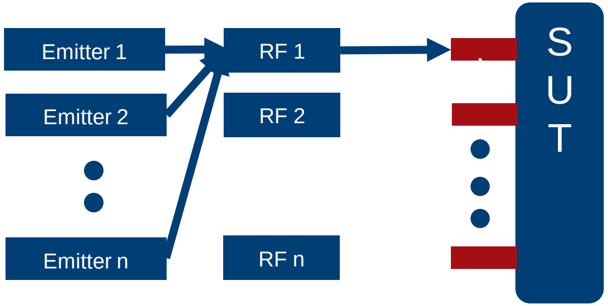
Multiple RF Sources

- A single RF source can be defined for each emitter and SUT port



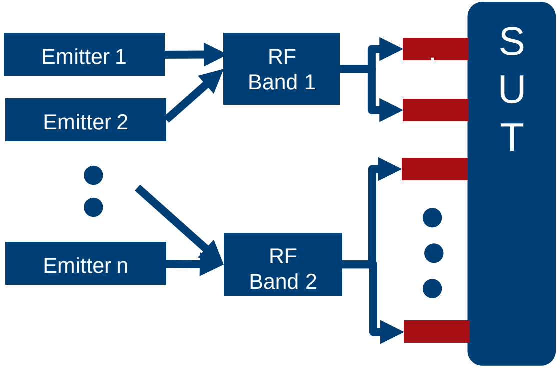
Digital Signal Combination

- A single RF source can be fed by multiple emitters (multiplexed)



Multi-band sources

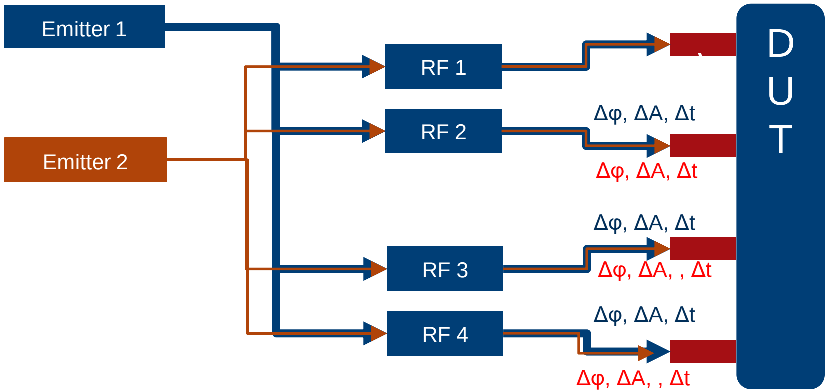
- SUT inputs can be fed by Digitally combined emitters in a single banded solution

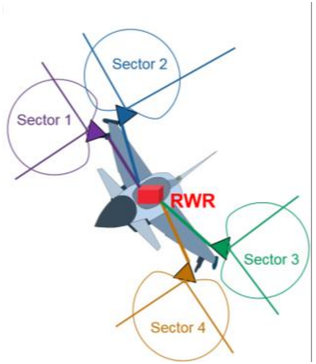


ADDING ANGLE OF ARRIVAL

Adding Angle of arrival to multi-channel receivers increases test complexity

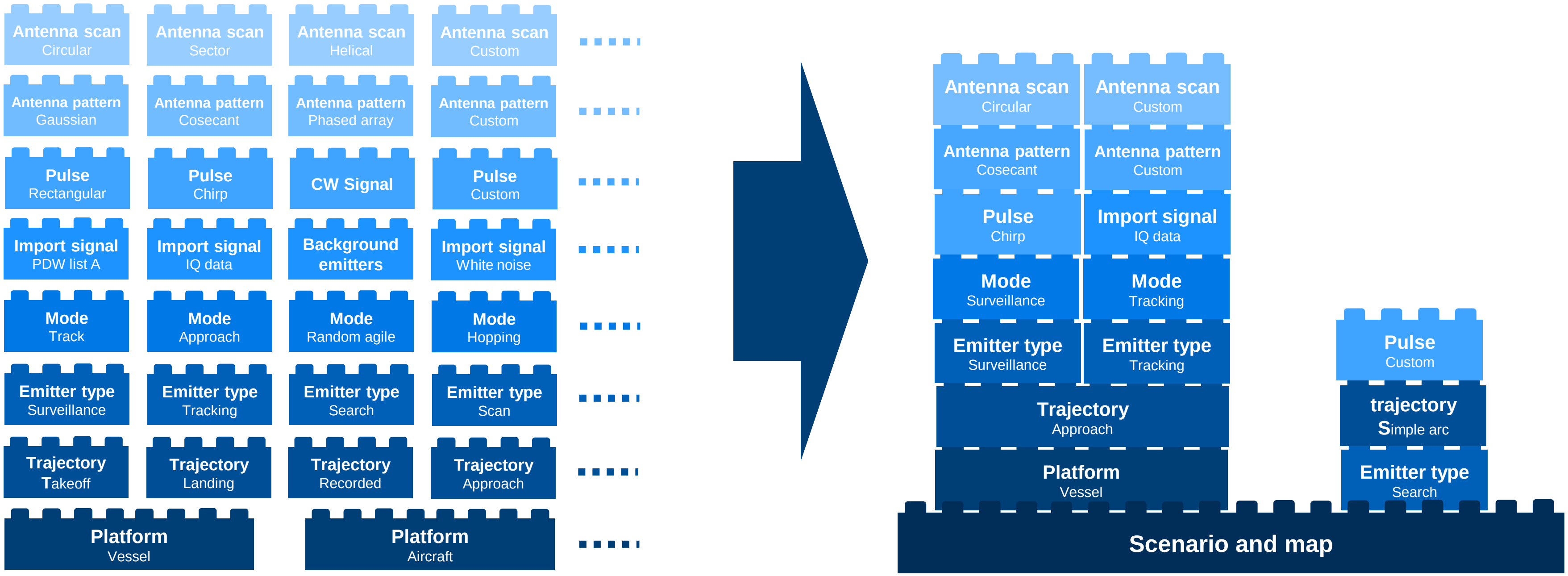
- Each emitter needs to present a different phase and amplitude of the same signal to each DUT input





PUTTING IT ALL TOGETHER

EW Environment Generation



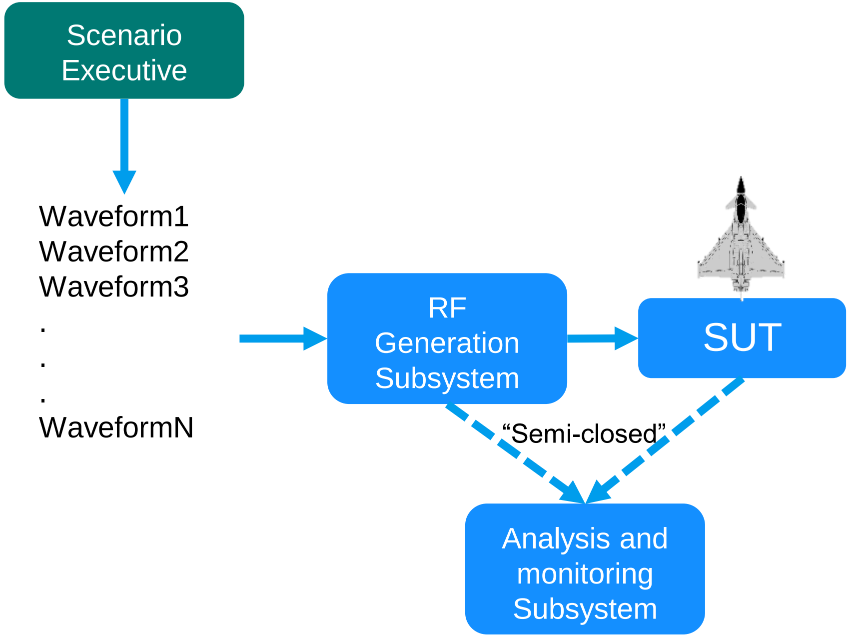
NOTIONAL TEST SCENARIO PROGRESSION

- DT&E – Focus on testing component function and performance
  - Scenario 1 – SUT and “Emitter 1”No motion, clean env, one mode (basic waveform)
  - Scenario 2 – As above, add emitter modes (parameters selected as function of receiver test needs)
  - Scenario 3 – “1 v Many” add multi-mode emitters
  - Scenario 4 – As above, add SUT motion. Straight path
  - Scenario 5 – As above, add threat platform motion
- OT&E – Focus on testing system and mission effectiveness
  - Scenario 6 – 2 v 2 maneuvering (DCA/OCA example)
  - Scenario 7 – 4 v Many, 2 SUT/wingman pairs vs SAM sites and red air
  - Scenario 8 – Day 0 – Blue OCA, DCA, Strike, C2, and Red DCA, SAM sites, C2
- Add scenarios as data needs dictate! (CM and traceability is critical)

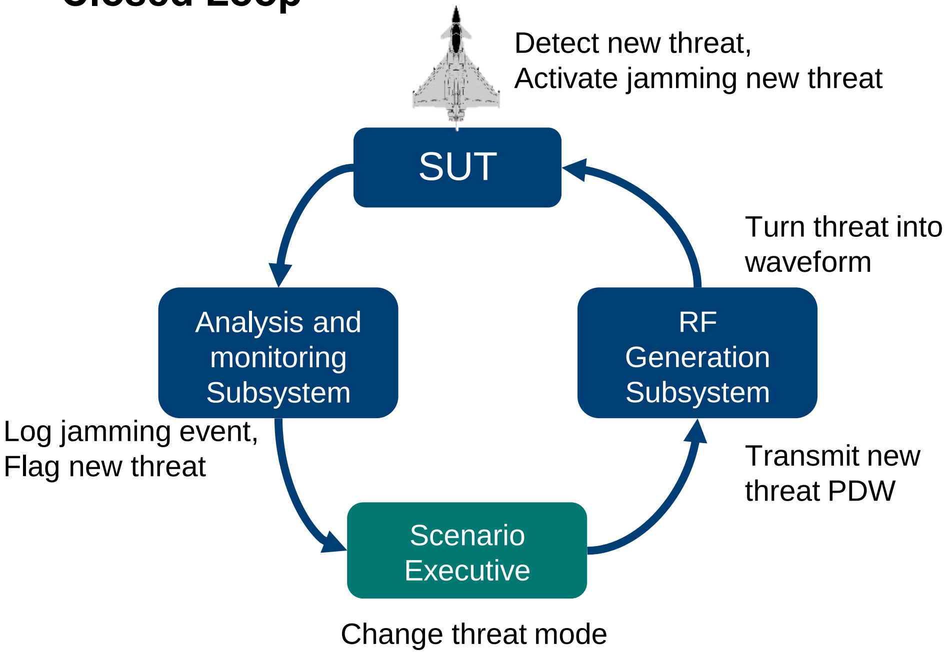
Real Time can mean mainly two different things

WHAT DOES “REAL TIME” MEAN TO YOU?

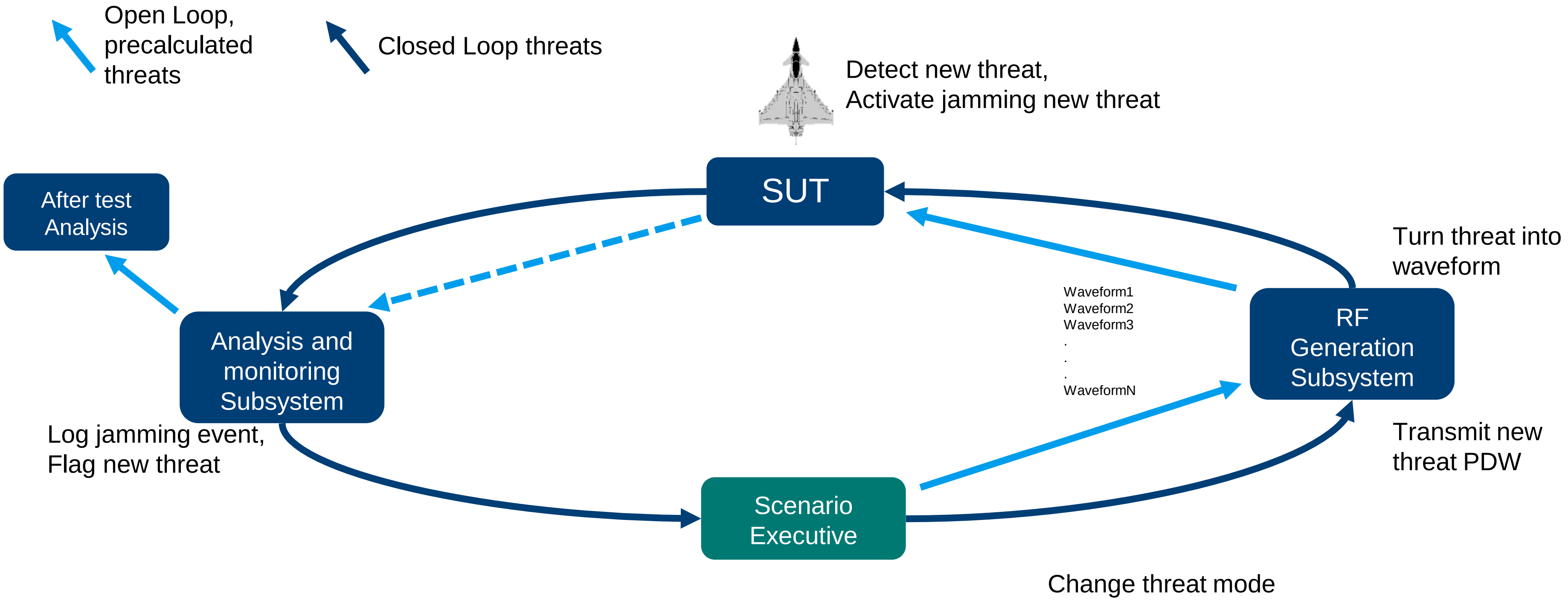
Long pre-calculated scenarios
“Open Loop”



System or Device in the Loop (SIL / HIL)
“Closed Loop”



WE CAN COMBINE THE TWO TYPES OF REAL-TIME



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