IMPROVING THE CAPABILITIES OF COGNITIVE RADAR & EW SYSTEMS

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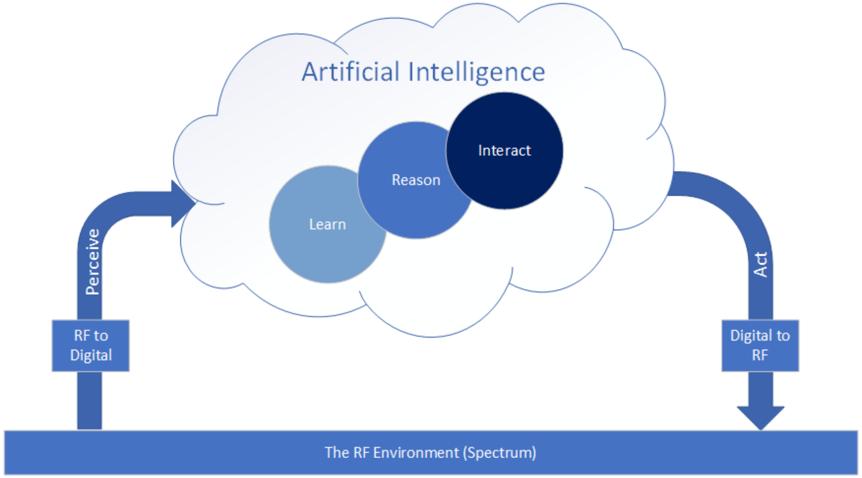
INTRODUCTION

- A cognitive RF system is designed to perceive the RF environment
  - System converts the RF spectrum and associated energy into a stream of RF IQ data
- Uses Artificial Intelligence & Machine Learning
  - Make autonomous decisions
  - Determines a course of action without recourse to any other systems or any human intervention
- Real world signals are tainted with uncertainty, such as noise, other emitters, multipath, overlap, RX blanking, fading etc.
- The end goal of the system is to:
  - Deny the use of the RF spectrum by an adversary (Electronic Attack - EA)
  - Protect a platform, for instance by employing anti-jam techniques to protect a communications link (Electronic Protect - EP)
  - Delivery of supporting information to another system (Electronic Support - ES)

COGNITION "GETTING TO KNOW, ACQUAINTANCE, NOTION, KNOWLEDGE"

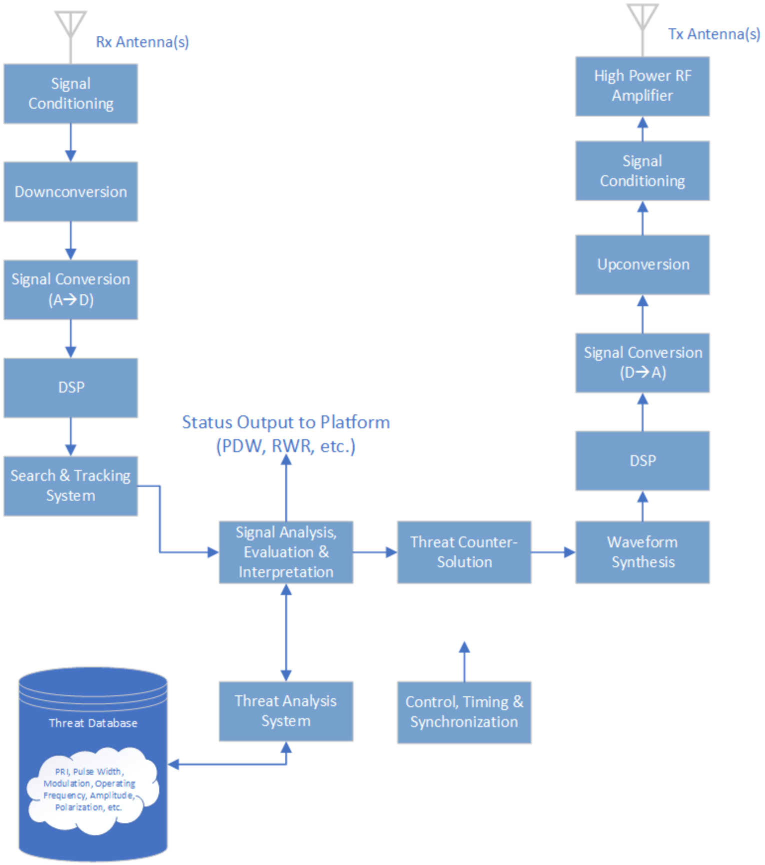
- A cognitive system uses a continuous loop
  - Situational perception
  - Learning
  - Reasoning
  - Interaction
  - Action
- The system literally learns from its interactions with the RF environment



EMERGING THREATS

- Traditional approaches utilize static threat libraries
  - E.g. RADAR Warning Receiver (RWR), Air surveillance RADAR or Surface to Air Missile RADAR
- Static threat library implementations compare signals against a library of threats
- The static library algorithm focuses on known, quantifiable and repeated signal characteristics such as:
  - Center Frequency
  - Occupied Bandwidth
  - Hopping Characteristics
  - Modulation
  - Pulse Repetition Interval (PRI)
- Once emitters are classified, they may be turned into Pulse Descriptor Words (PDWs)
  - PDWs are fed to other systems on the platform, which may deploy countermeasures
  - Countermeasures may be electromagnetic, kinetic, electro-optic, chaff, flares, etc.

TRADITIONAL STATIC LIBRARY RADAR/EW SYSTEM



PROBLEMS WITH TRADITIONAL THREAT LIBRARY SYSTEMS

- A new class of “Mode-Agile” RADAR/EW systems are emerging
- Also know as WARM (WArtime Reserve Mode)
  - Mode Agile/WARM systems switch into non-conforming/non-traditional operational modes
    - New operating frequencies
    - New modulation techniques
    - New Pulse Repetition Intervals (PRI)
    - New hopping schemes
    - New occupied bandwidths
  - These new modes do not match threats in the static library

    → Thus, the system cannot determine a counter to these new modes – platform is at risk

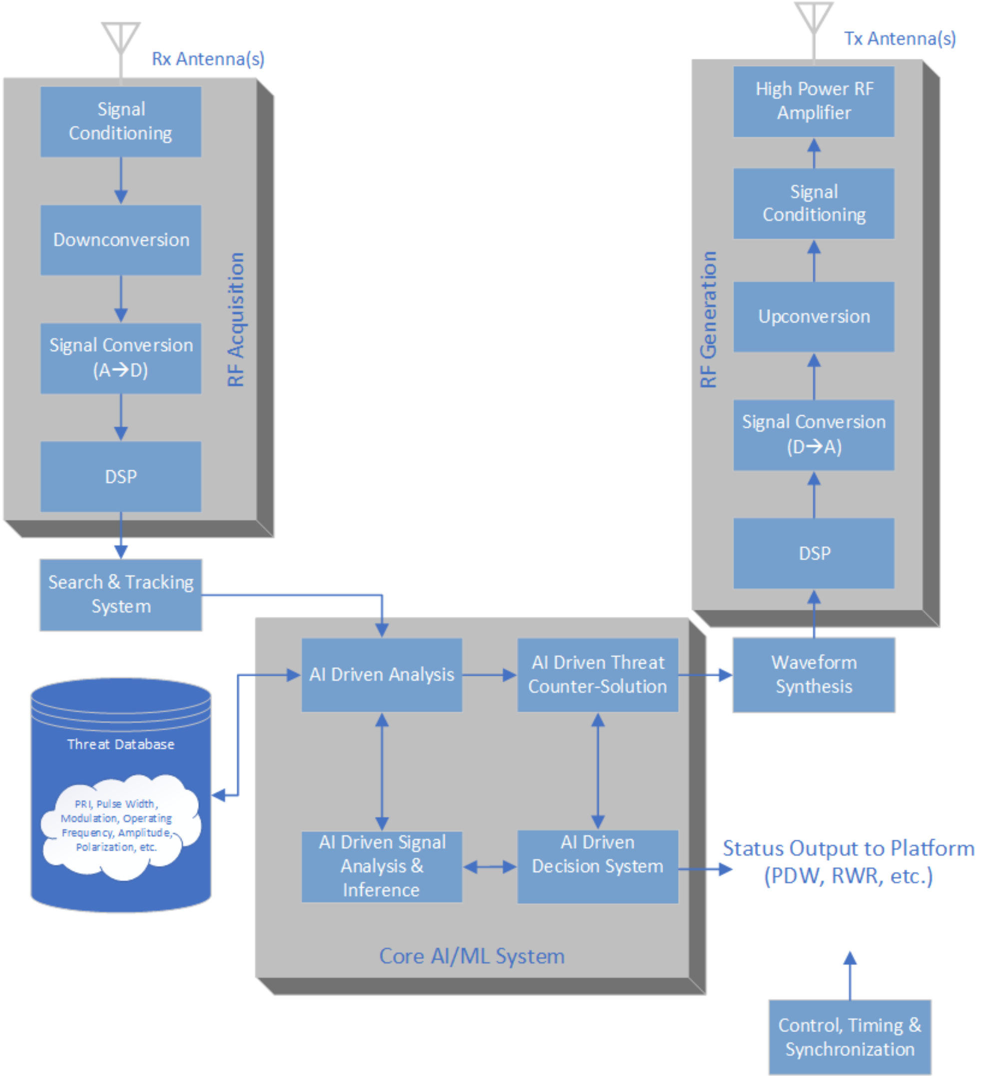
- New modes are unlikely to be seen ‘in the wild’ outside of a true conflict, hence the WARM designation

COGNITIVE RADAR/EW SYSTEMS

- Static threat algorithms are ineffective against adversaries utilizing WARM techniques
- In a cognitive RADAR/EW system Artificial Intelligence (AI) and Machine Learning (ML) techniques are applied to the incoming spectrum and to formulate a response
- Cognitive systems classify threats and develop a counter to that threat ‘on the fly’
- WARM emitters may utilize AI/AL to detect AI/ML actors
  - May cause a game of ‘cat and mouse’ between threat and counter system
  - AI/ML systems need to be flexible and continuously adaptable

SYSTEM DIAGRAM

- **RF Acquisition**
  - Converts RF into digital data stream
- **Search & Tracking System**
  - Determines angle of arrival
- **Core AL/ML System**
  - Determines key parametric information
  - Adds to the threat library
  - Includes previous signals of interest
  - Delivers suggested counters
- **Waveform Synthesis**
  - Converts threat counter solution into digital data stream
- **RF Generation**
  - Converts digital data stream into RF signal



AI/ML TECHNIQUES

- AI/ML use computer science to apply non-human intelligence to implement systems that emulate human reasoning and problem-solving skills

- The most commonly used AI techniques used in ML are:
  - **Artificial Neural Networks (ANN)**
    - A non parametric tool that is trained to perform pattern recognition, classification & sorting
    - Emulates biological neuron
    - Neurons are weighted and grouped to form networks, linked by synapses
    - ANN may use feed-forward or feedback
    - Some ANN implementations can process time-dependent signals
  - **Deep Learning (DL) or Deep Neural Networks (DNN)**
    - DL/DNNs improve feature expression by utilizing multiple layers to progressively extract higher-level features

A/ML TECHNIQUES CONT'D

- **Fuzzy Logic**
  - Fuzzy logic emulates human decision making, where decisions are often made with vague, imprecise or incomplete data
  - Fuzzy logic utilizes the concept that truth is not absolute and can be expressed as any value between 0 and 1 - unlike Boolean logic where values can only be 0 or 1
  - Fuzzy logic system have no learning capability or memory
  - Often combined with other ML techniques, e.g. Neuro-Fuzzy combines neural networks with fuzzy logic
- **Genetic Algorithms (GA)**
  - Emulates naturally occurring evolution process with 'survival of the fittest' logic
  - Derives optimum solutions through iteration and weighting of solutions
    - Lower weighted solutions are discarded
  - GA keeps pools of solutions, to reduce the risk of reaching a false solution
  - GA algorithms can take a variable amount of time, or never reach a solution
    - Not ideal where speed of response to a threat is paramount

CHALLENGES IN IMPLEMENTING COGNITIVE RADAR/EW SYSTEMS

- **Significant computational resources are required at the tactical edge, i.e. where the threat is encountered**
  - Systems may utilize GP-GPU, CPU and/or FPGA resources
  - Systems need to meet potentially harsh environmental operating conditions
- **The system needs to minimize the detect-to-counter time - RF in to RF out latency**
  - Can affect platform survivability
  - Modern GP-GPU and data converters technologies often exhibit long latencies
- **Mode-agile emitters may operate outside of expected frequencies**
  - Requires wideband spectrum ‘stare’ & fast turning emitters
  - Wider bandwidths are typically traded for lower dynamic range & increased noise floor
  - Wider bandwidths complicate data movement and processing within the system

CHALLENGES IN IMPLEMENTING COGNITIVE RADAR/EW SYSTEMS

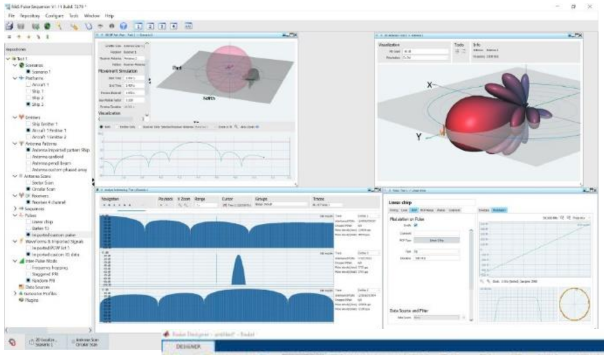
- **Wideband cognitive systems use more electrical power, compared to static library systems**
  - Affects Size, Weight, Power & Cost (SWaP-C) requirements
  - Smaller platforms such as Unmanned Aerial Systems (UAS) even more challenging
- **Mode-agile threats may also enter low-power RF modes**
  - Operate close to or even below the noise floor
  - Drives requirements for higher dynamic range in the cognitive system
  - But…. wider bandwidth and higher dynamic range are diverging requirements
- **Platforms need to share information**
  - Requires a reliable, jamming-resistant communication links
  - Requires a common time reference, such as GPS, in order to provide spatial and temporal information
    - Vital for geo tagging and direction finding
    - Assured Position, Navigation & Timing (A-PNT) needs to be integral to the platform

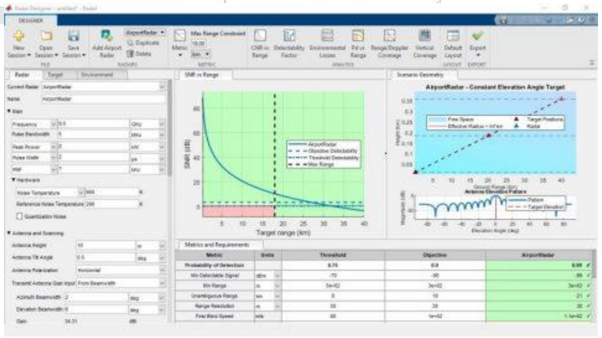
CHALLENGES IN IMPLEMENTING COGNITIVE RADAR/EW SYSTEMS

- AI/ML systems require rich and representative data sets to train the algorithms
- Training is the process of
  - ‘Feeding’ the algorithm with representative sample sets of signals
  - Analyzing the efficacy of the algorithm in identifying the correct solution
  - Modifying and improving the algorithm
  - Repeating this loop in an iterative manner
- This iterative process, when applied to physical RF hardware, is called RF In the Loop (RFIL), Hardware In the Loop (HIL) or System In the Loop (SIL)
- HIL/SIL testing is a long & onerous process → A prime candidate for automation
- HIL/SIL testing can be used to:
  - Develop & tune initial algorithms
  - Perform regression testing of newer techniques against established ones
  - Verify efficacy of mission data sets in reprogramming labs before deployment
  - Verify platform operational readiness before mission execution

ACQUISITION & GENERATION OF TRAINING DATASETS

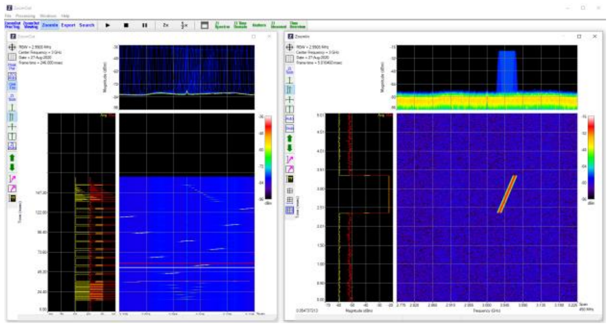
- Accurate algorithm implementation relies on varied and large amounts of training data
- Training data comes from 2 main sources:
  - Real-world collect
    - Signals may be poor quality, sometimes this is desirable, other times it is not….
  - Modelling & Simulation Tools
    - Matlab®
    - Simulink®
    - R&S Pulse Sequencer
    - R&S Win IQSim2
    - Allows almost infinite variation & experimentation in a controlled lab environment

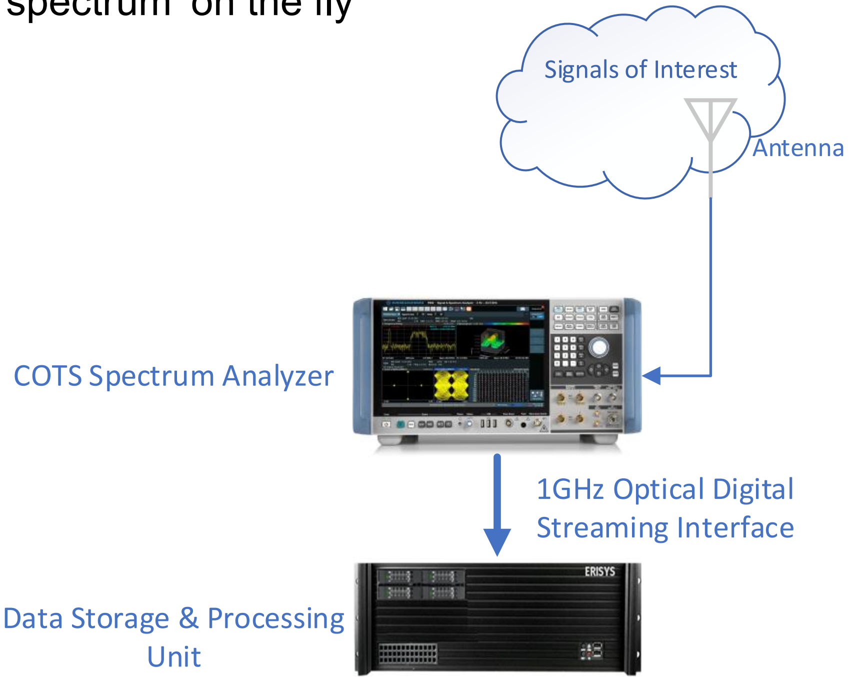




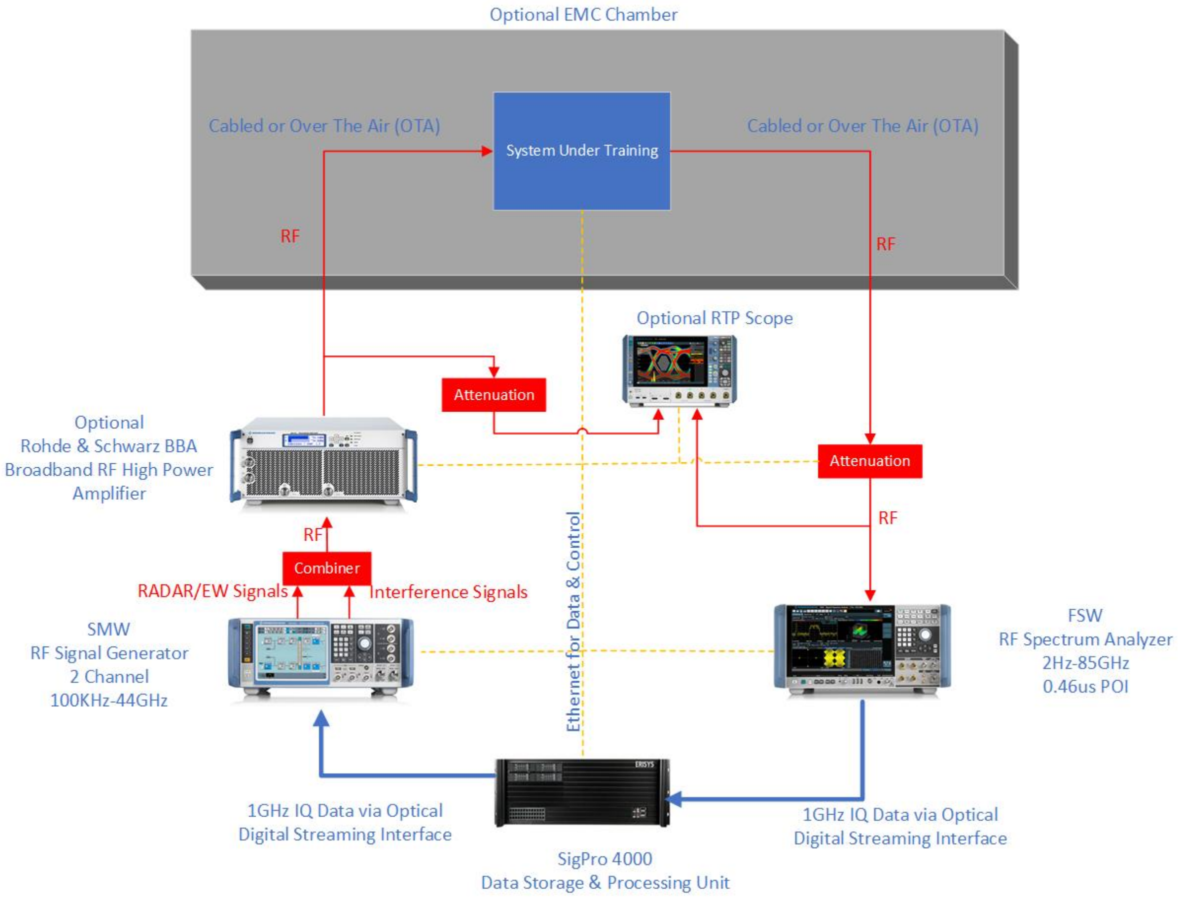
REAL WORLD COLLECT SYSTEM

- A system such as the one pictured can be used for collect missions
- Can collect and analyze/segment incoming RF spectrum ‘on the fly’
- >3 Hours of record capability
- 1GHz end-to-end IBW
- Removeable storage
- Intuitive operator interface

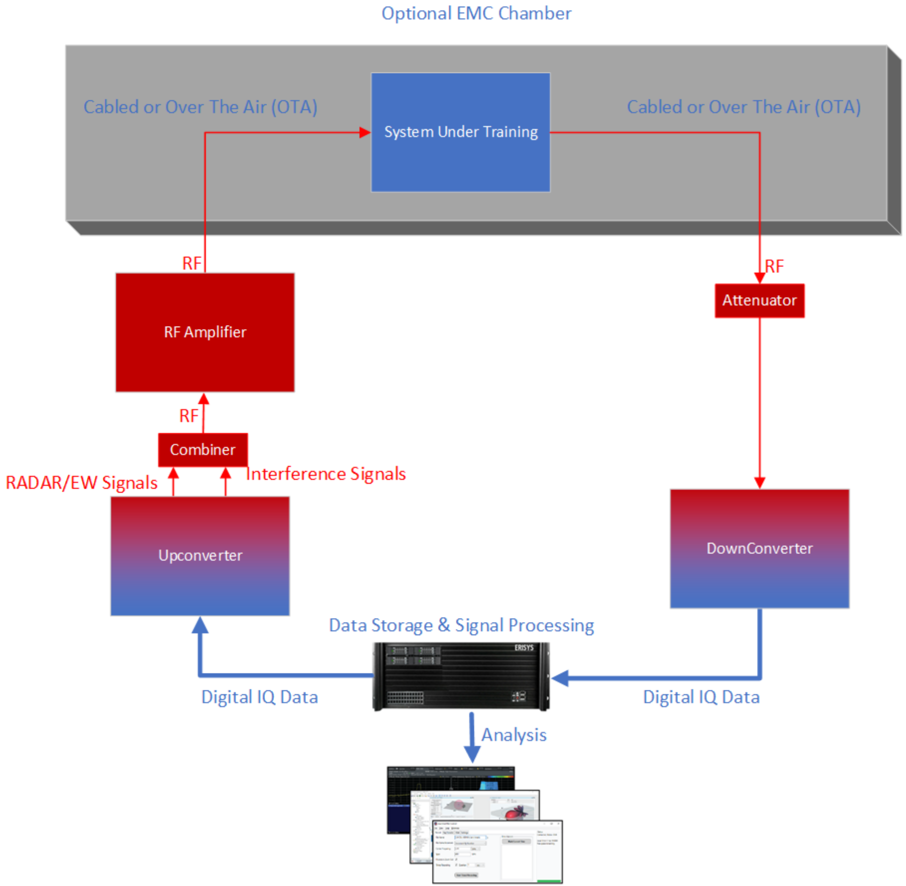




RFHIL TRAINING SYSTEM BLOCK DIAGRAM



RFHIL SIGNAL FLOW



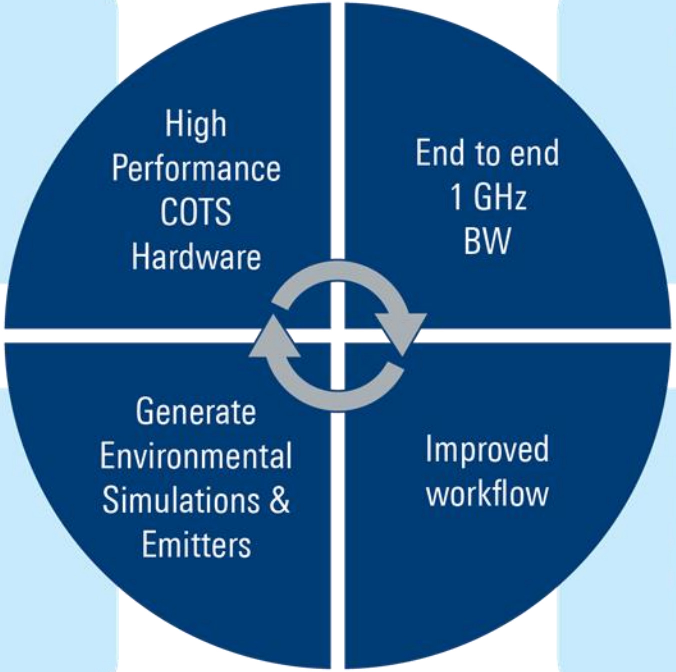
HIL/SIL TRAINING SYSTEM DESCRIPTION

- The RFIL system is built around the Integrated Record, Analysis & Playback (IRAPS) system, consisting of
  - Multi-channel Vector Signal Generator (SMW)
    - Channel 1 - Generates to RF waveform from IQ training files stored on the SigPro
    - Channel 2 - Generates interference, commercial RF signals etc.
  - Optional broadband RF Amplifier - Amplifies RF signal to produce real-world RF levels
  - Wideband Vector Signal Analyzer (FSW)
    - Acquires the RF spectrum and converts it into an IQ stream to be processed by the SigPro
  - SigPro - Storage, processing and controller
  - For over the air training an EMC chamber might be needed
- Optional multi-channel wideband oscilloscope to accurately assess the temporal and latency response of the system under test
- IRAPS plays IQ files that train the system Under Test, captures the response from the SUT
- IRAPS can also be used to analyze the response using commercial M&S software

INTEGRATED RECORD ANALYSIS PLAYBACK SYSTEM (IRAPS™)

- Discrete instrument functionality
- Hi-fidelity recordings and playback

- Extract signals of interest
- Extract PDWs
- Playback RF Signals



- Extractable PDW tables
- Sequenced pulse files
- Moving emitters

- Simultaneous analysis and record
- Quickly find signals of interest
- In line dedicated processing
- IQ and PDW real-time streaming

APPLICATION SCALABILITY

Discrete H/W + S/W

Moveable Rack System

Rugged Fieldable System

ZOOMOUT – JOINT TIME-FREQUENCY ANALYSIS SOFTWARE

Powerful Analysis Software

Analyze massive signal captures

Simple and fast

1-button push to record, view, and analyze

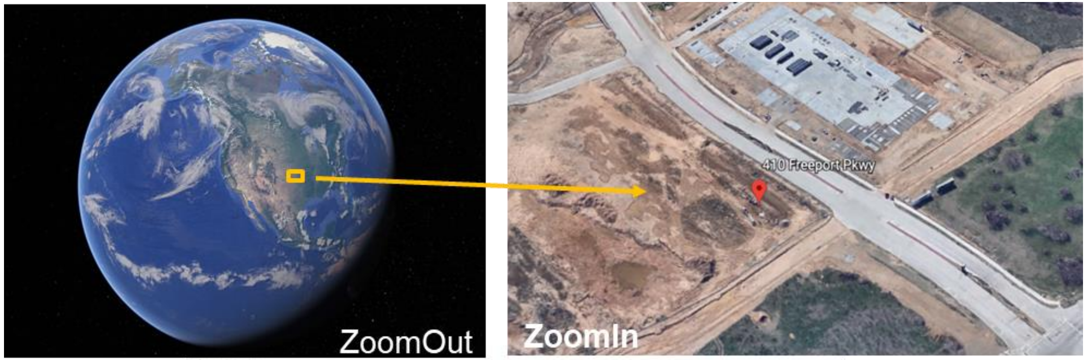
Fast Drill down

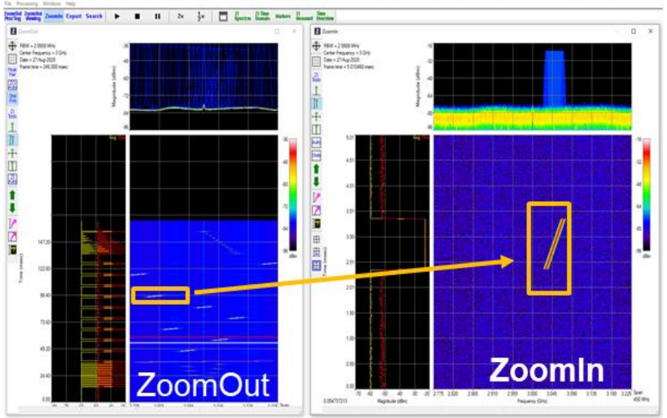
View entire recording and quickly drill down for detailed analysis

.83ns signal detection

100% detection on signals greater than .83ns in duration

Optional FSW RTSA 100% POI at .46µs





ZoomOut

Big Picture capture

Small signal close to noise

ZoomIn

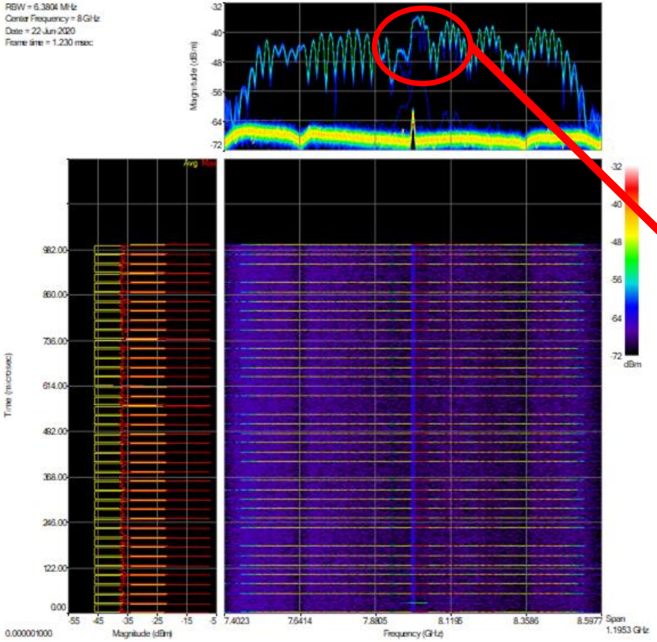
Closer Look

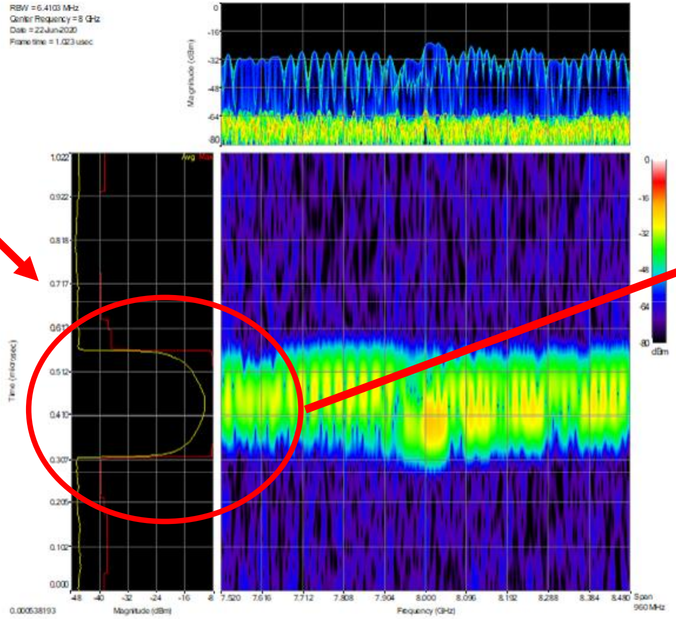
Hi-Fidelity recording allows detection

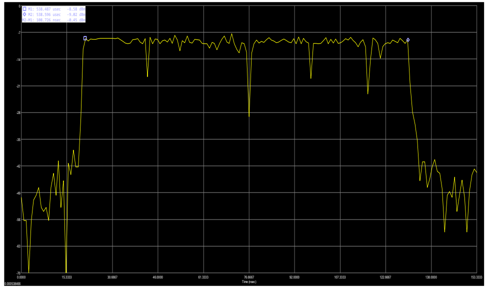
World Class POI

Analyze signal of interest

100ns Barker Code







CONCLUSION

- Testing and training of cognitive AI/ML EW and RADAR systems is complex and time-consuming
- The key to success is feature-rich training datasets
- Modelling & Simulation tools can be used to generate the training data
- Real-world collect can also be used to capture & process training data
- Sigpro and FSW can be used for real-world wideband collect
- A system such as the IRAPS can be used to train, analyze and improve the efficacy of algorithms running on the cognitive EW system
- IRAPS can be used as a truly independent RF In the Loop (RFIL) system with OTA testing in a controlled environment
- FGPA in IRAPS can be used for dedicated in-line DSP, low-latency processing, DDC, DUC, etc.