

Closed-loop adaptive EW simulation

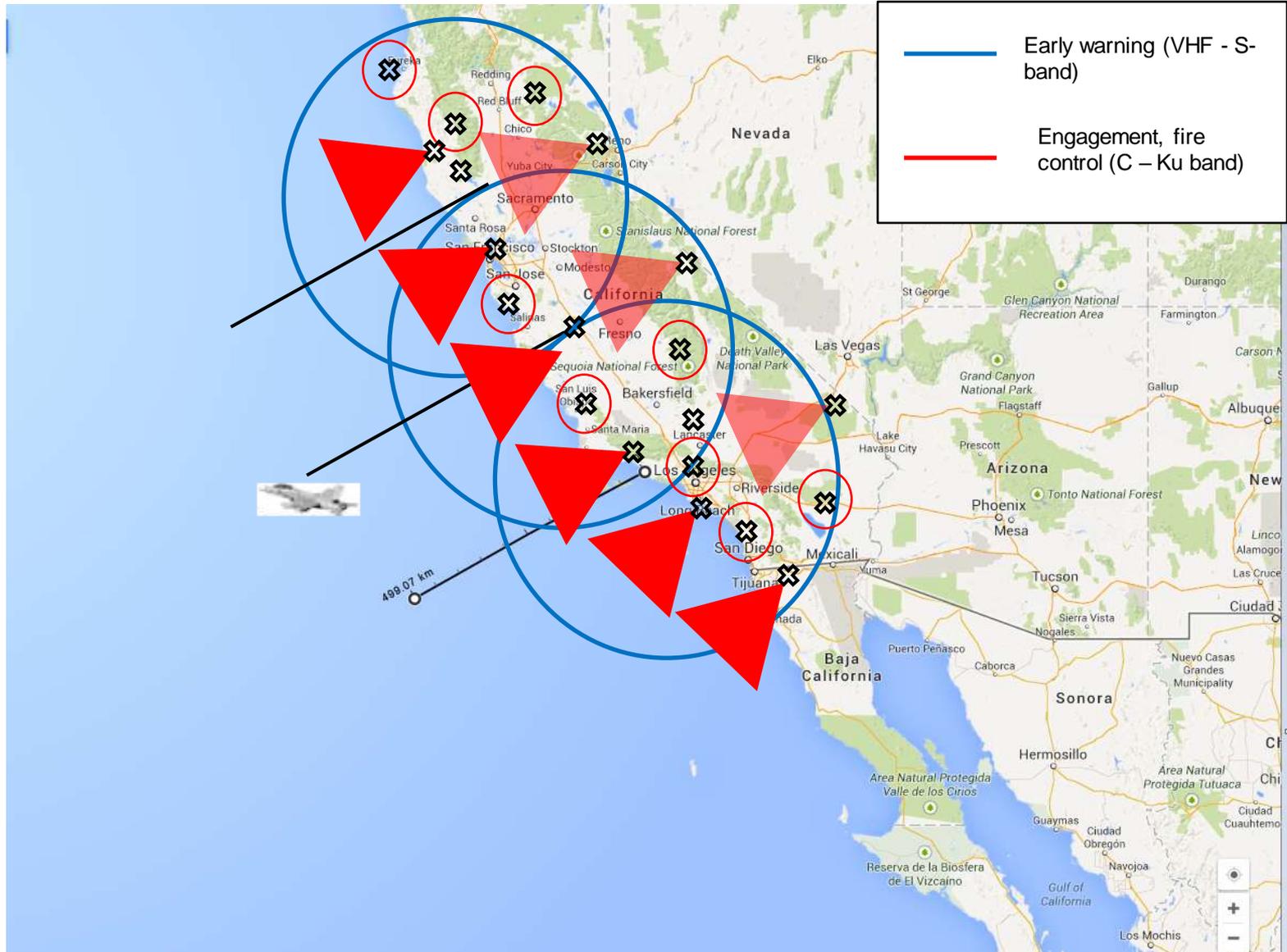
Walt Schulte
Applications engineer
Keysight Technologies



Agenda

- ➔ • Basic EW
- EW test
- Multi-emitter simulation
- Closed-loop adaptive simulation

The threat environment

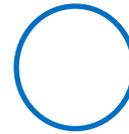


What are the threats?

The SA-20 battery



<http://www.ausairpower.net/sams-iads.html>



“Big Bird” search/acquisition radar

Frequencies < 3 GHz

Range: 300-400 km

Peak power: 100s of kW to MW

PRFs: 100 – 1000 pps

Mechanical Scan rates ~ 10 - 20 s

Multiple elevation beams where PRF changes with beam



Grave Stone tracking/fire control radars

Frequencies 8 – 18 GHz

Range: 50 – 150 km

Peak power: 10s to 100s of kW

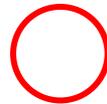
PRFs: 10k – 500k pps

Electronically-scanned in 60-120 sectors.

Transporter Erector Launchers (TELARS) containing missiles. Multiple can be fired and controlled at a time. Usually semi-active guidance

What are the threats?

Point defenses

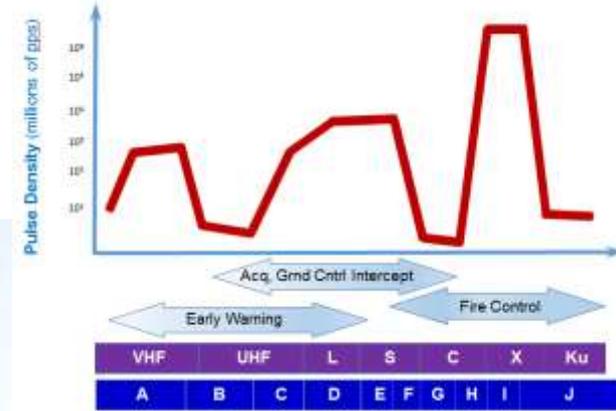


Mobile short-medium range mobile systems like the SA-11, SA-15, SA-17, etc with 30-50 km range used to plug gaps in air defenses and confuse order-of-battle with 'shoot and scoot' capability

American MIM 104 Patriot battery

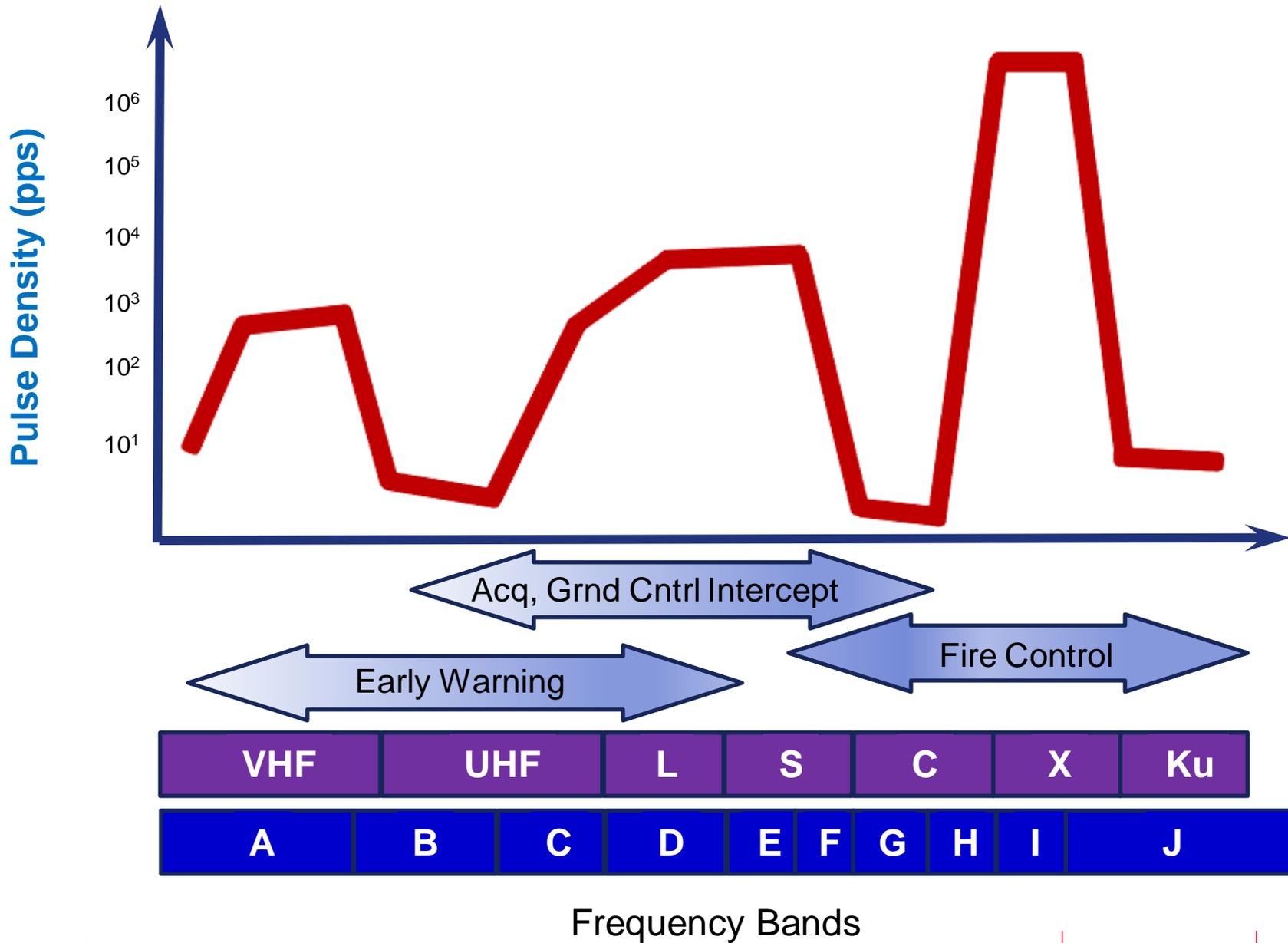
AN/MPQ-53
radar (C-band)

Missile is Ka
band active
seeker



radar

Seeker (between
26 – 40 GHz)



Sorting/deinterleaving threats

$$PDW_i = [AoA_i, f_i, PW_i, TOA_i, Amp_i]$$

AoA is calculated with a variety of techniques:

- Amplitude comparison
- Interferometry
- TDOA
- Differential Doppler

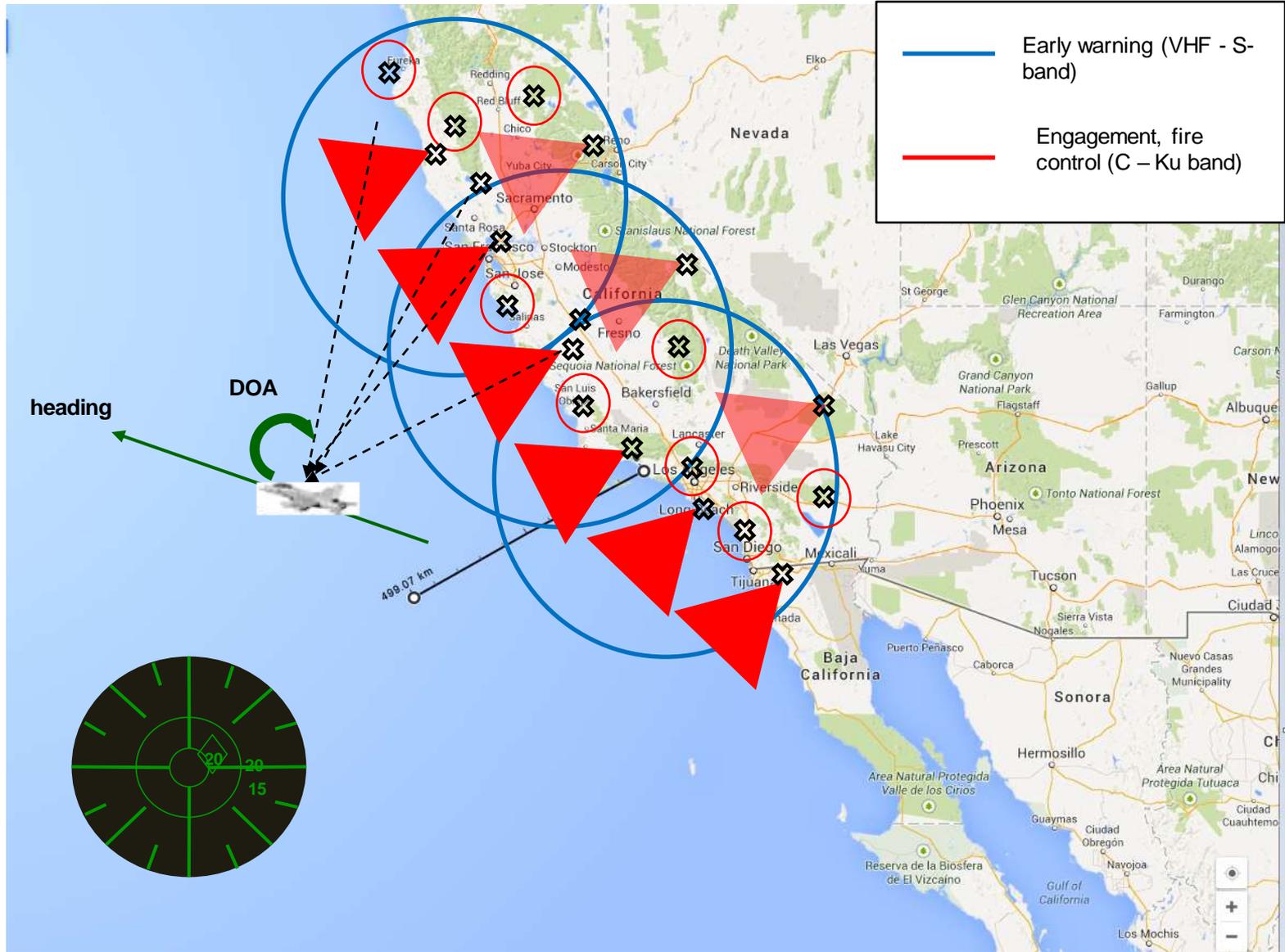
heading

3.

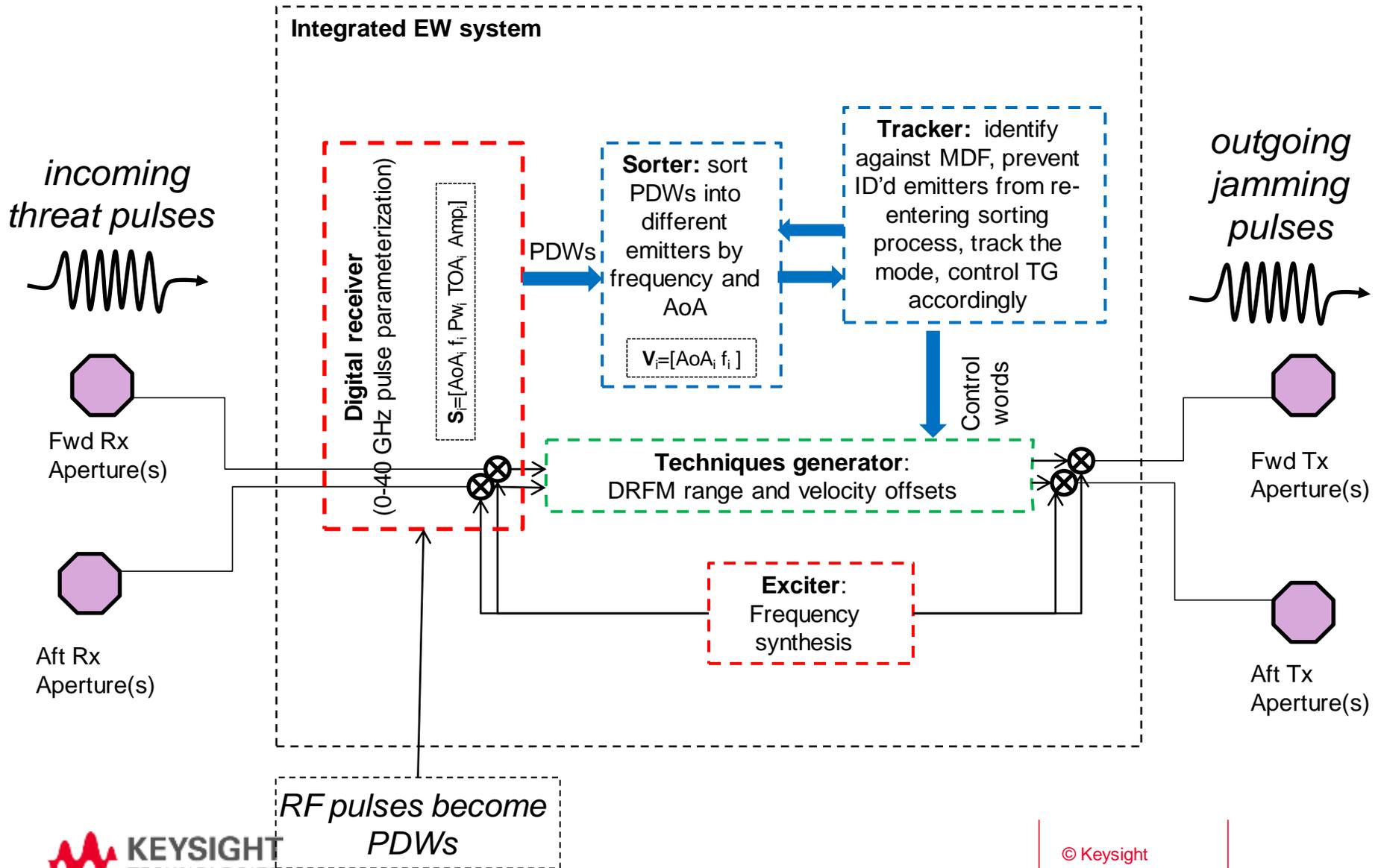
2.

1.

The threat environment



Jammer Block Diagram



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High-level RF/uWave test requirements

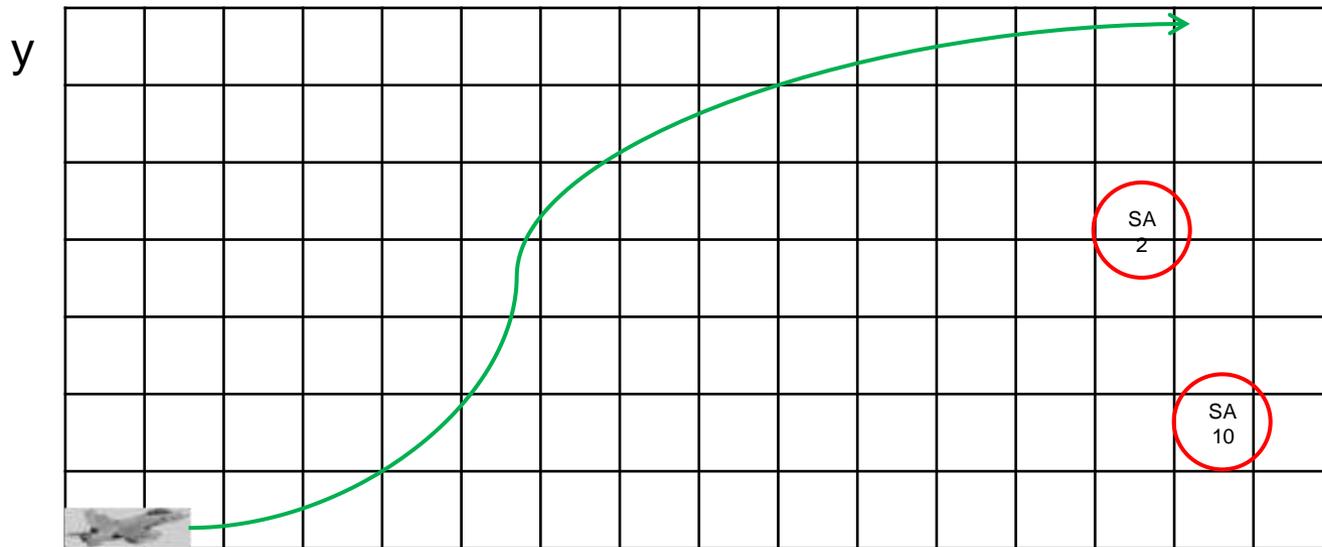
- 1 to 10 million pulses-per-second
- Agile amplitude range
- Agile frequency switching
- AoA
- Interferers
- Hours-long scenarios simulating EOB
- Adaptivity: change the threats in response to positive tracking and/or jamming from the EW system under test

Mathematical simulation considerations

- Gaming area: 2D? 3D? Duration? Number of players? Terrain? Atmospheric?
- What simulation granularity/resolution to use?
 - *Worded differently, what Δt should be used in the simulation?*
- For each Δt , how many pulses to be streamed depends on EW receiver sensitivity, PW, PRI, and number of emitters
- For each Δt , will our interface to simulation assets keep up with the desired pulse density? Do PDWs need to be duplicated with AoA shifts?

A simple 2D gaming area with 3 players

- Δt is chosen so that our computer(s) can keep up with the computation of the simulation parameters for each player and the streaming of PDWs to available signal sources
- For each Δt , we compute $\Delta x, \Delta y$ of all players and then their range and bearing.
- For each player, we scale power according to range, ERP, and gain and compute the PDWs based on PRI, PW, bearing, and amplitude
- Combine PDWs and stream to agile sources with triggers

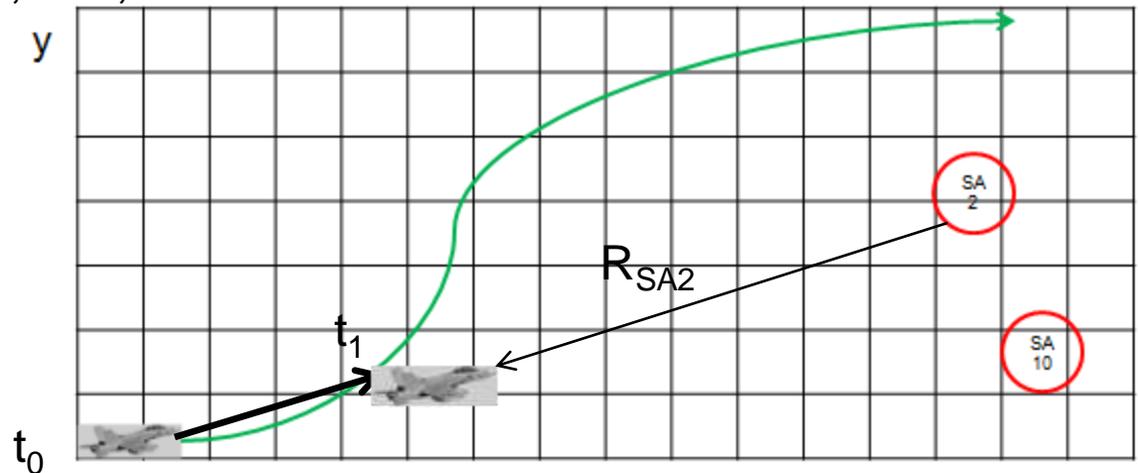
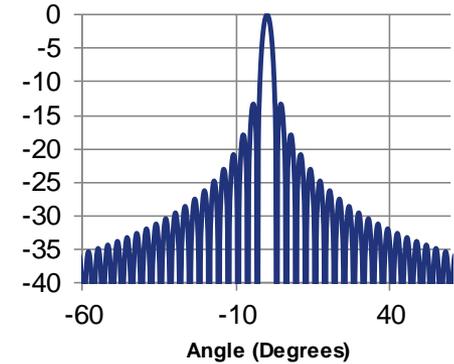


$$P_{Sut} = \frac{P_t G_t G_{sut} \lambda^2}{(4\pi)^3 R^2}$$

An example set of calculations in a 2D gaming area

- When the player carrying the DUT moves on the interval $t_0 \rightarrow t_1$, we must re-calculate the range equation on the right as follows.
- First we calculate the 2D range and bearing from the SA2 to the DUT.
- Then we determine the gains of both the DUT and SA2.
- Enter the gain, range, wavelength, and transmitted power for the SA2 into the range equation to get the power to the SUT
- calculate PDWs based on PRI, PW, and above
- Repeat for remaining threats

$$P_{Sut} = \frac{P_t G_t G_{sut} \lambda^2}{(4\pi)^3 R^2}$$



EW test requirements for signal generators

Requirement

- **Plays PDWs streams**
- **Power:** precisely controlling 1-way range equation to EW SUT (polarization, range, kinematics, threat Tx, EW SUT Rx)
- **Modulation:** simulating the threat's output waveforms
- **SPURS, harmonics, images:** the EW receiver will try classify all spurious content from 2-18 GHz

Example

- Create scenarios lasting hours or longer
- $$P_{Sut} = \frac{P_t G_t G_{sut} \lambda^2}{(4\pi)^3 R^2}$$
- chirp deviation, Barker chip width
- Less than -70 dBc

EW test requirements for signal generators

Requirement

- **Timing resolution:** Creating precise pulse widths, PRFs, and DTOA is very important.
- **Switching speed:** creating maximum pulse density with the minimum number of signal generators
- **Create Angle of Arrival (AoA)**

Example

- ~2 ns timing resolution for adjusting PRI and pulse width
- Switching speeds of ~ 200 ns
- Multi-source synchronization for <10 ps DTOA, <1° phase, <.1 dB amplitude

UXG Agile Signal Generator

20 and 40 GHz Options

For high-speed, low phase noise, multi-port applications



- **200 ns update rate**
- Phase repeatable or phase continuous frequency switching
- Two Amplitude Ranges
 - 10 dBm LO
 - -120 to 0 dBm (90 dB agile)
- 10-25% Linear Chirp Widths
 - Arbitrary Chirp Profiles
- Pulse ~6 nS Rise/ Fall Pulses, 90 dB on/off
- -70 dBc spurious @18 GHz
- Industry leading phase noise -126 dBc @10 kHz @10 GHz
- Multiple Instrument Coherence

Lower cost of ownership

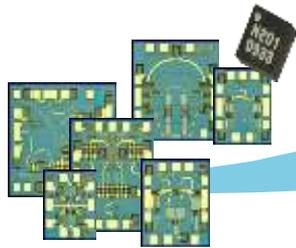
- Industry's best reliability with a target MTBF of 75k hours.

Frequency Range	0.01 to 20/40 GHz
Output Power	+ 10 dBm
Agile Amplitude Switching Range	80 dB < 0 dBm 20 GHz Model Only
Agile Amplitude Switching Range	10 dB > 0 dBm
Phase Noise (10 GHz @ 20 kHz offset (typical))	-126 dBc/Hz
Non-harmonic Spurious	-70 dBc
Digital word control	Frequency, FM/PM
Compatibility mode	Comstron
Pulse On/Off	90 db
Minimum Pulse Width	5nS
Size	3U

UXG - Enabling Technologies



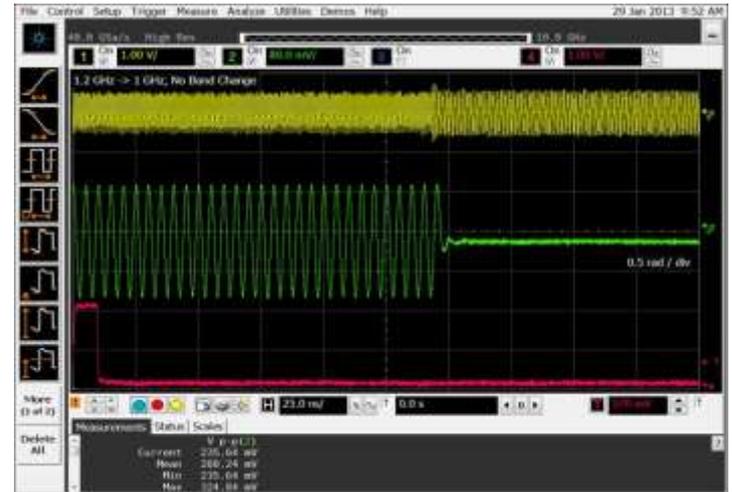
UXG Agile Signal Generator



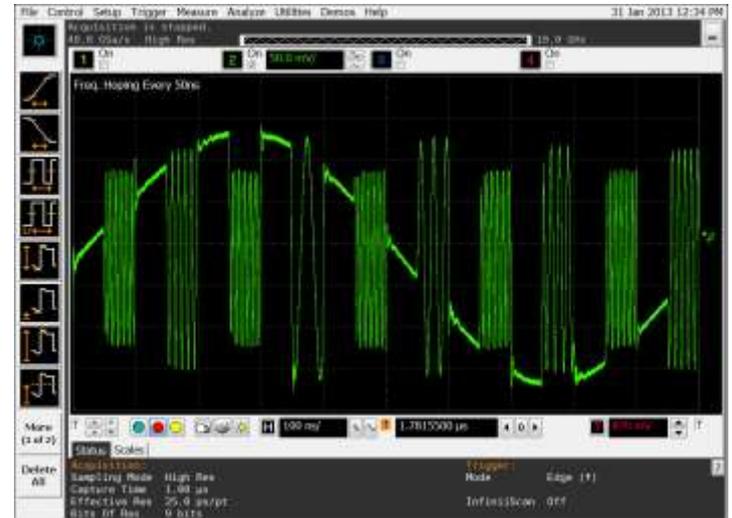
**nanoFET MMIC
Switches & Attenuators**



Proprietary DAC

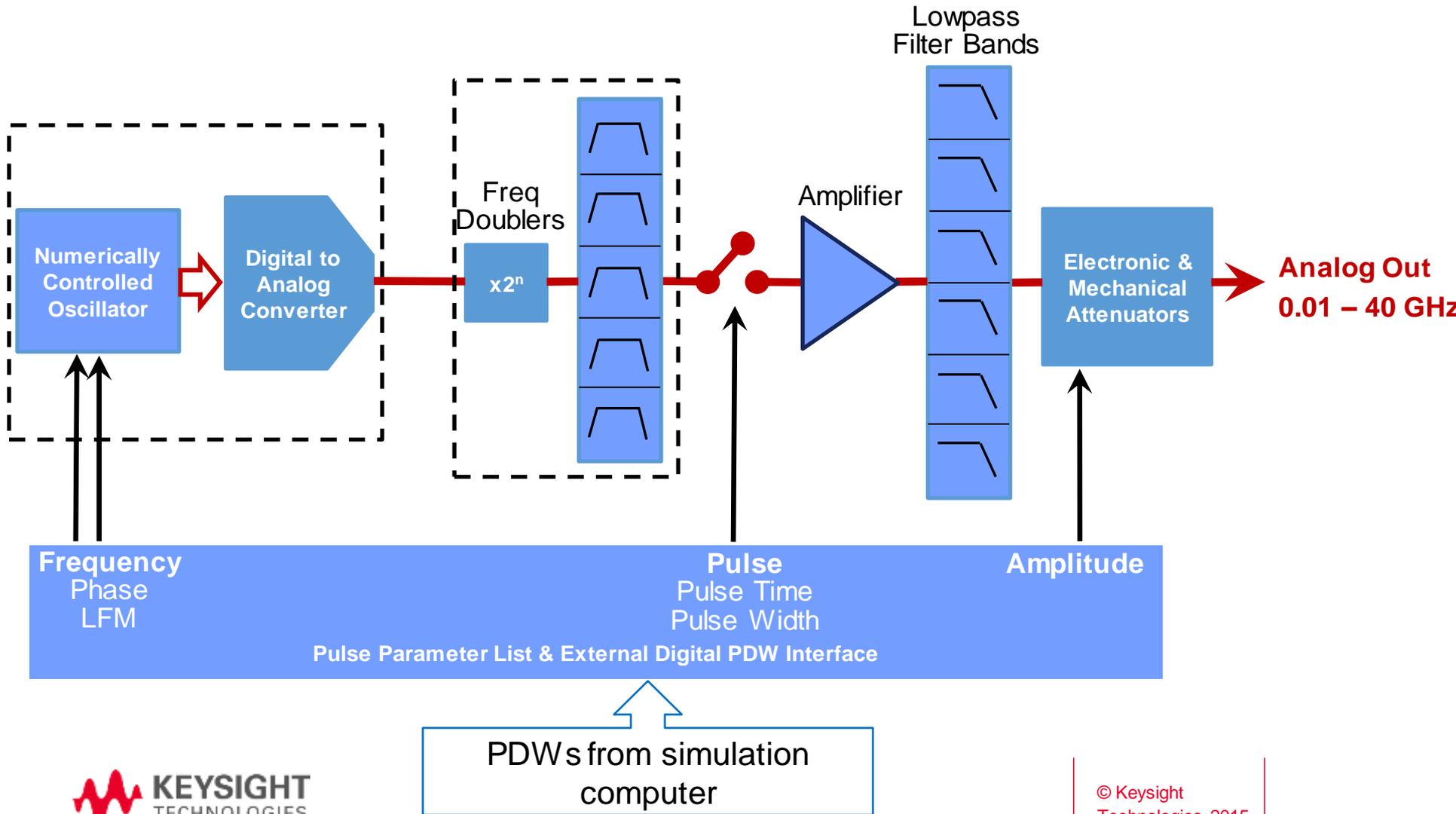


200 ns Update Rate

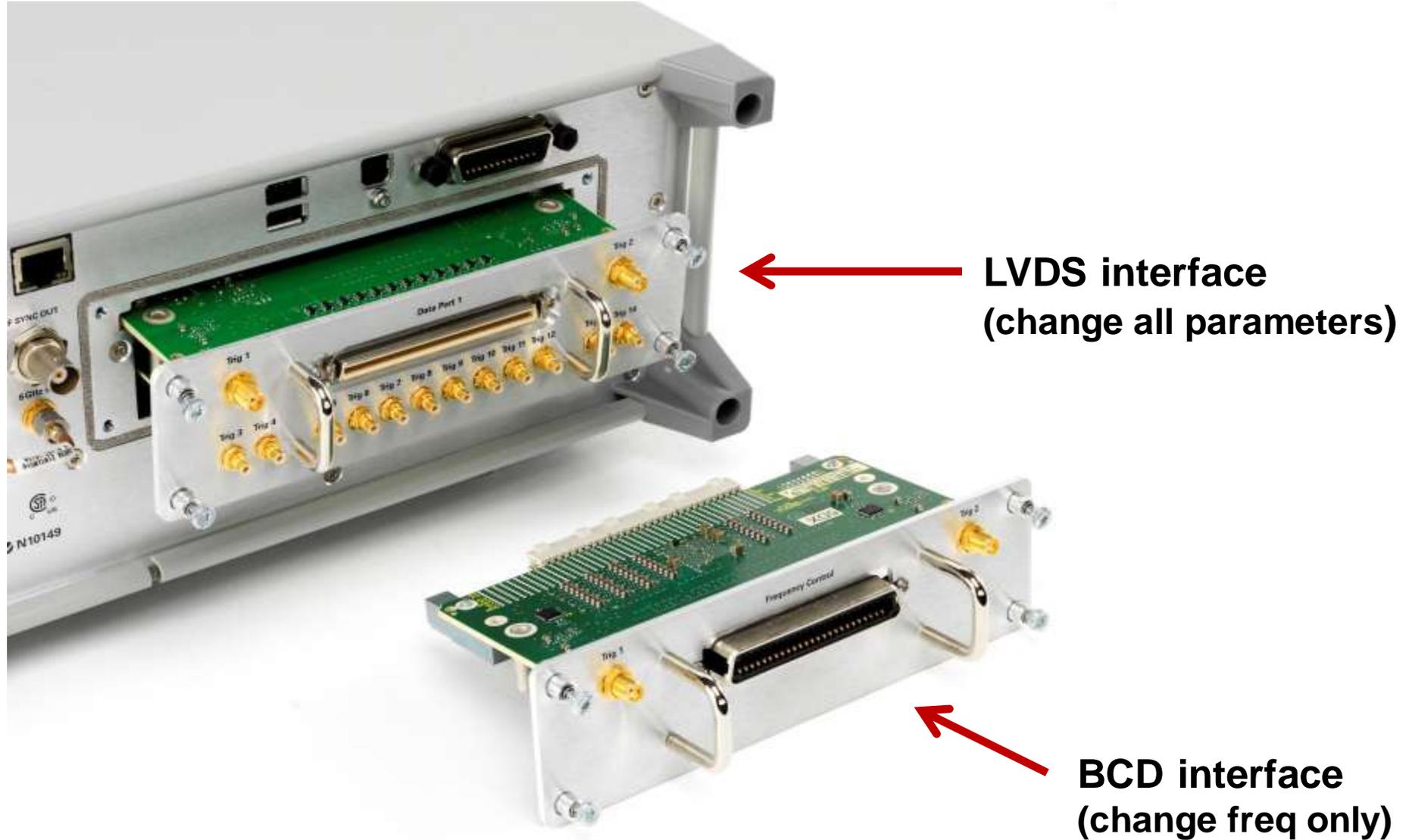


Phase Coherent Switching

N5193A UXG agile signal generator

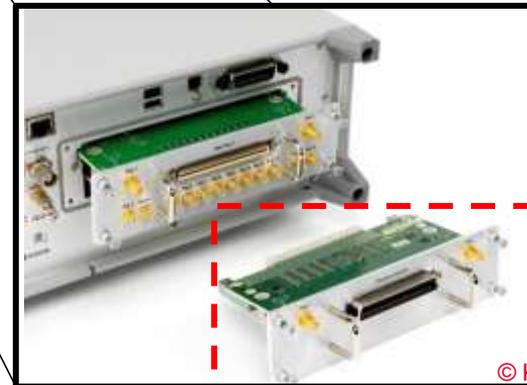
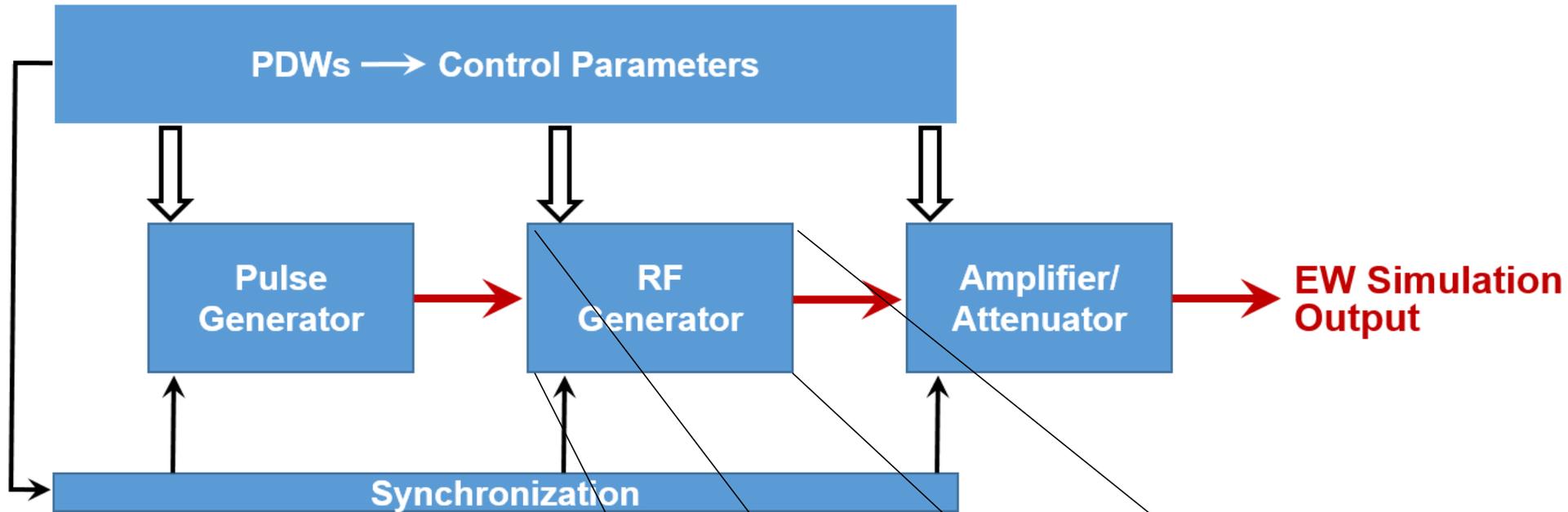


Rear Panel LVDS or BCD I/O Control Port



Legacy threat simulators

A look at 1 channel out of many



**BCD interface
(change freq only)**

Threat simulation today

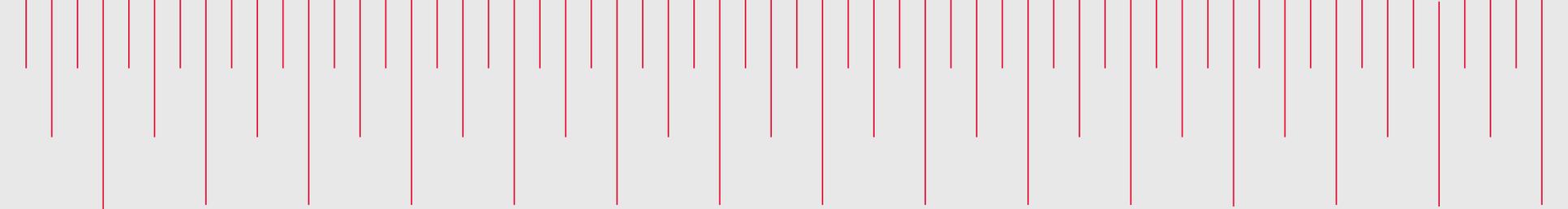
A look at 1 channel out of many

**LVDS interface
(send PDWs, source replaces all other simulation elements)**

Threat simulation
computer

PDWs



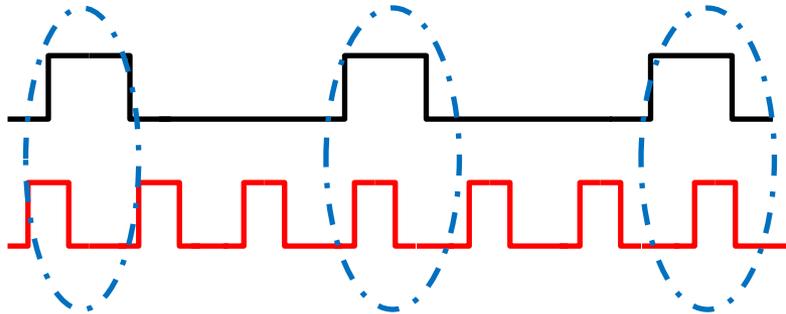


Agenda

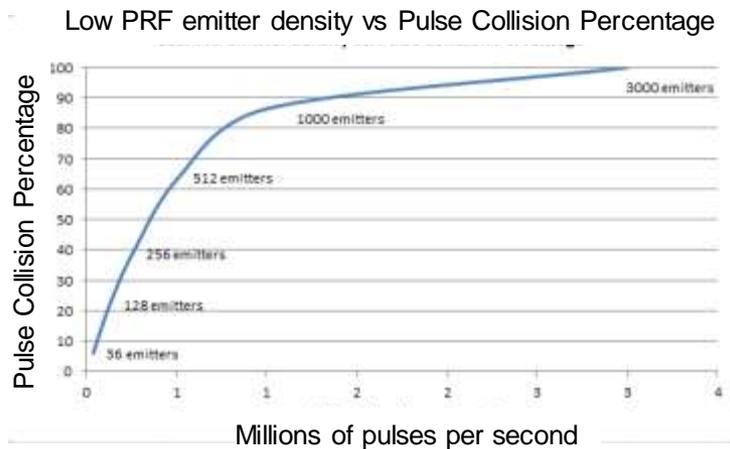
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Creating pulse density

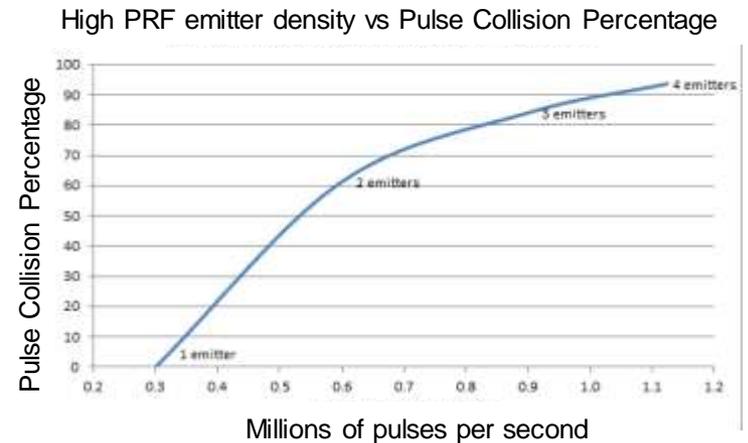
– What is pulse-on-pulse?



– Pulse collisions depend not only on number of emitters but also their PRFs, PWs and therefore duty cycles.



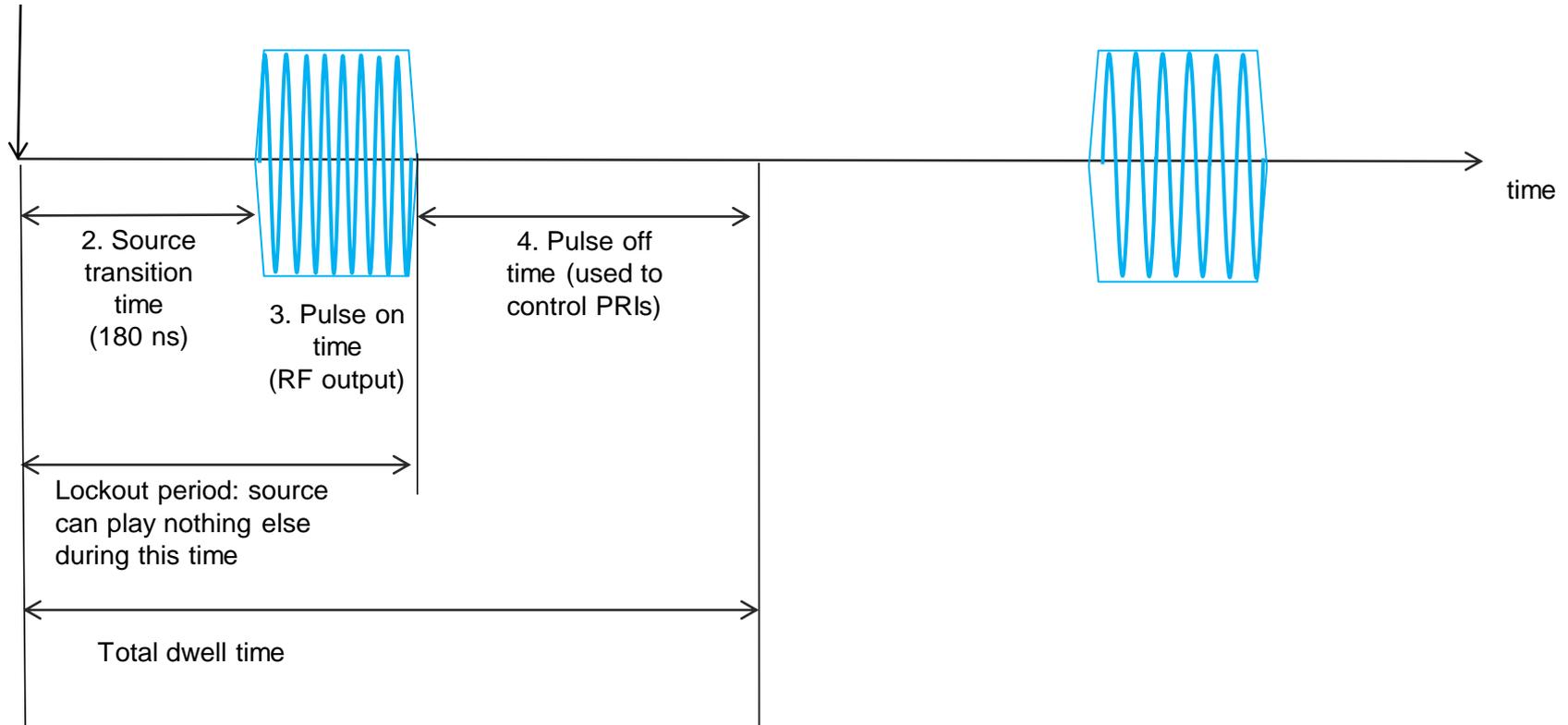
VS



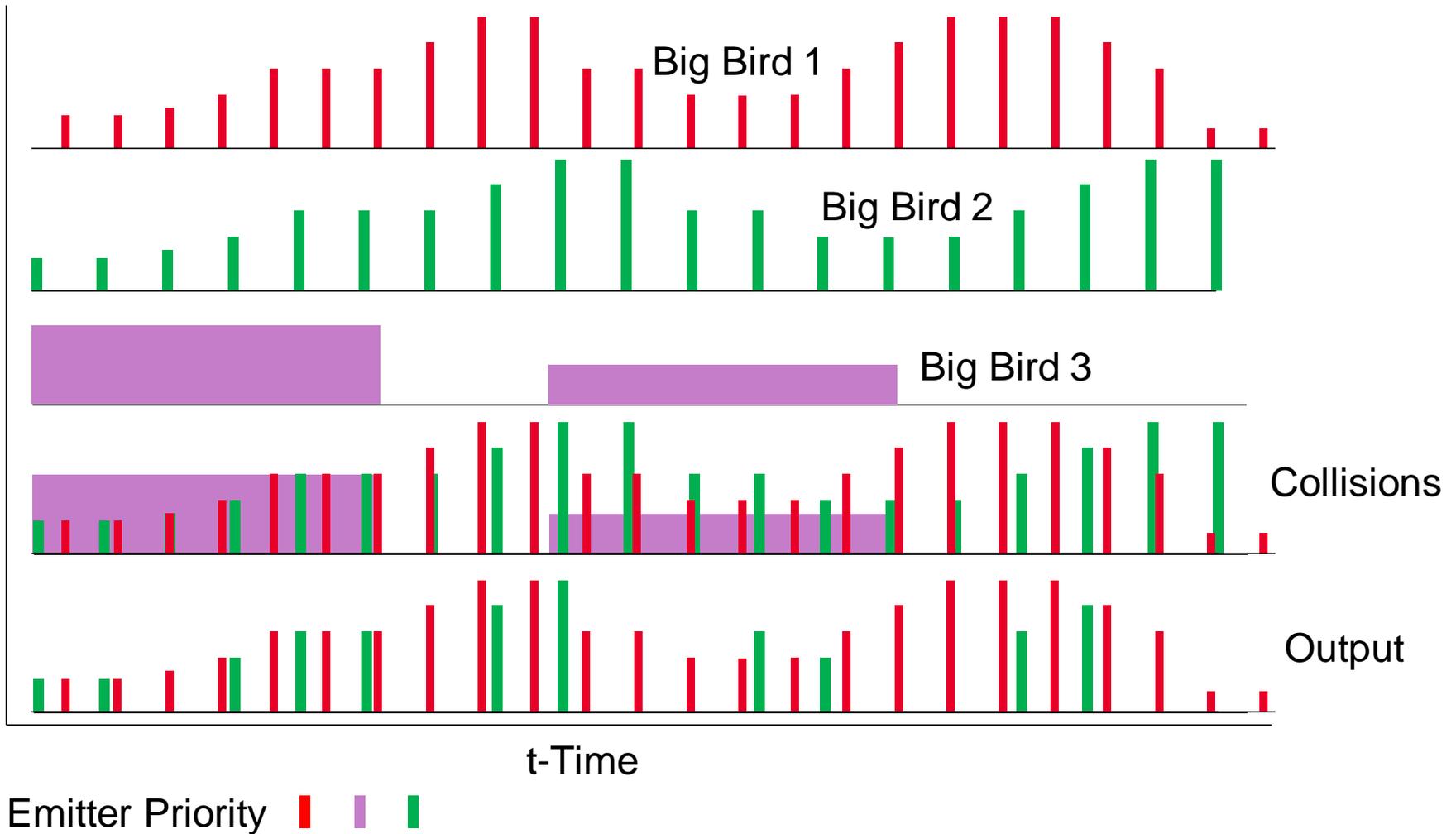
Agile source output

Why transition time matters to pulse density

1. Start playing PDW
(which includes off time)

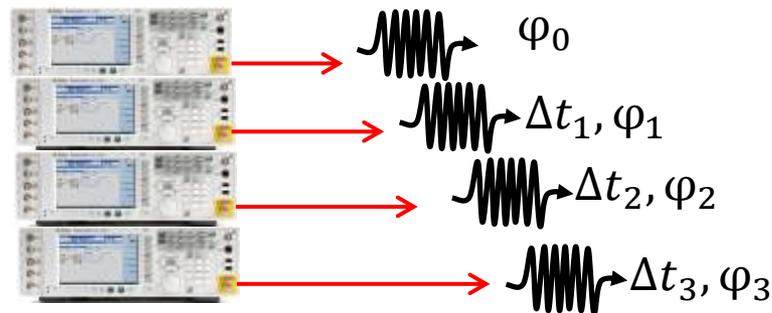
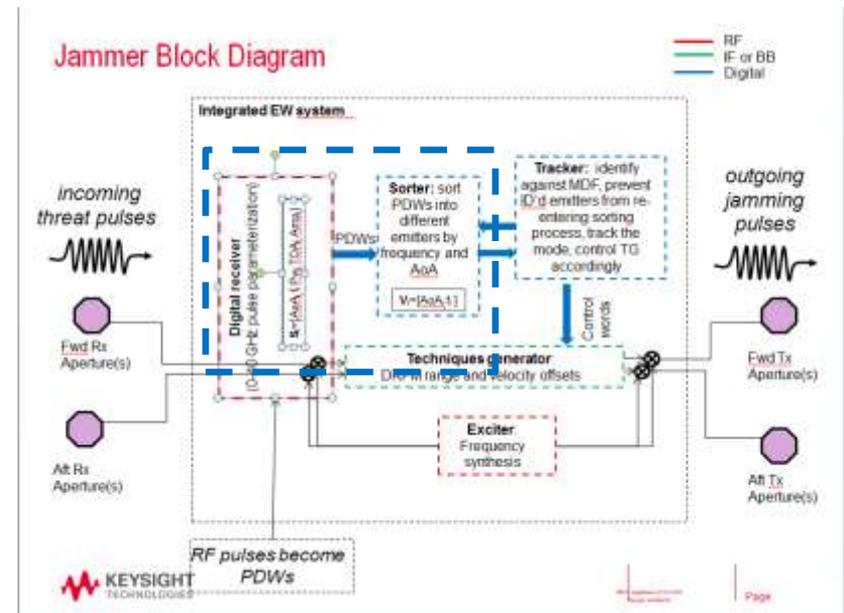


Pulse Interleaving



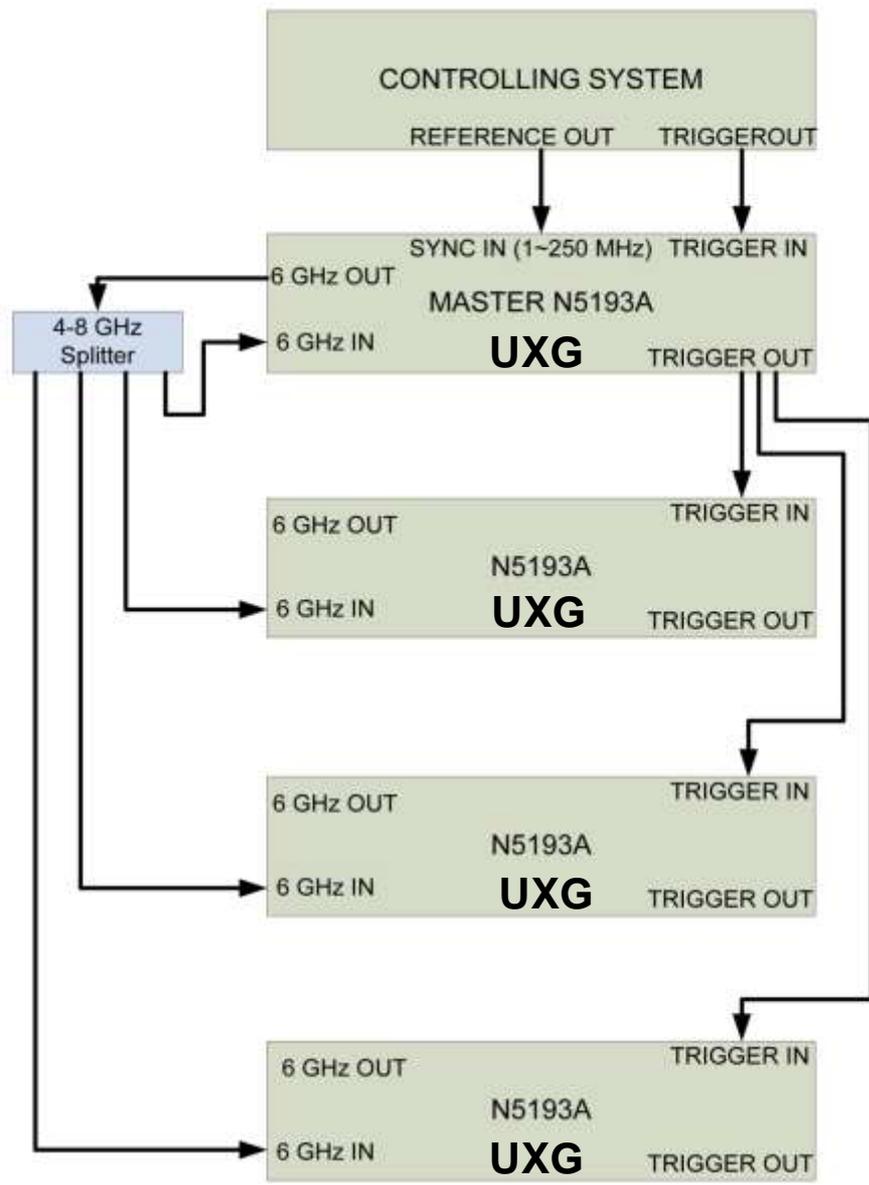
Creating AoA to test sorting

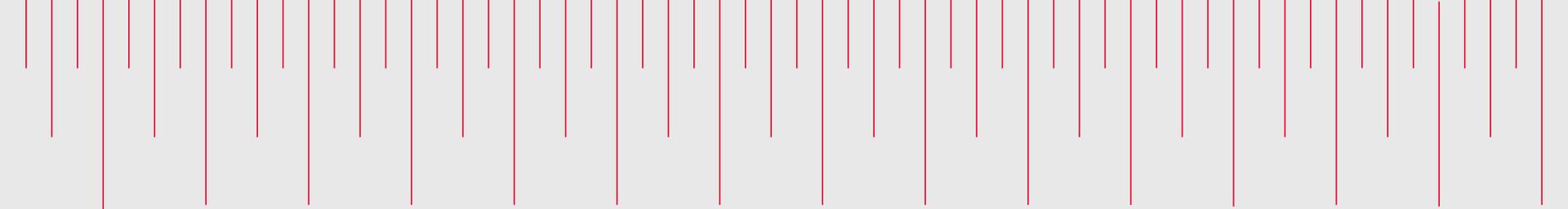
- The digital receiver parameterizes the RF pulse into a PDW
- Each PDW is [AoA_i , f_i , PW_i , TOA_i , Amp_i]
- AoA and frequency are primary sorting parameters
- Simulation must create AoA at RF!



Multiple Instrument Synchronization

- Simulate AoA
- Exercise direction finding receivers
- Play any pulse out of any emitter on any channel to increase pulse density





Agenda

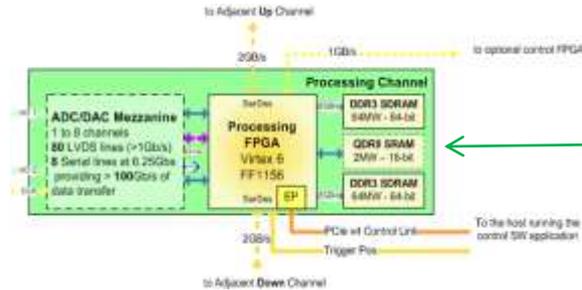
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How to make the simulation adaptive

█ RF
█ IF or BB
█ Digital
uW Downconverter

Threat simulation computer

PDWs

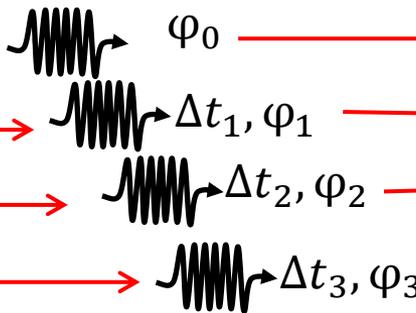
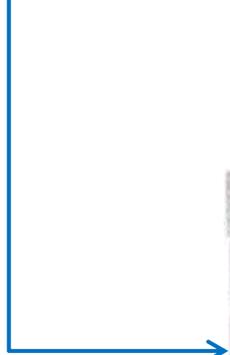


Digitizers

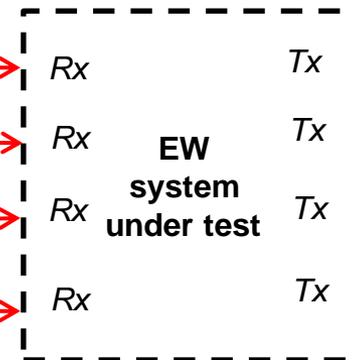


Jamming pulses

PDWs



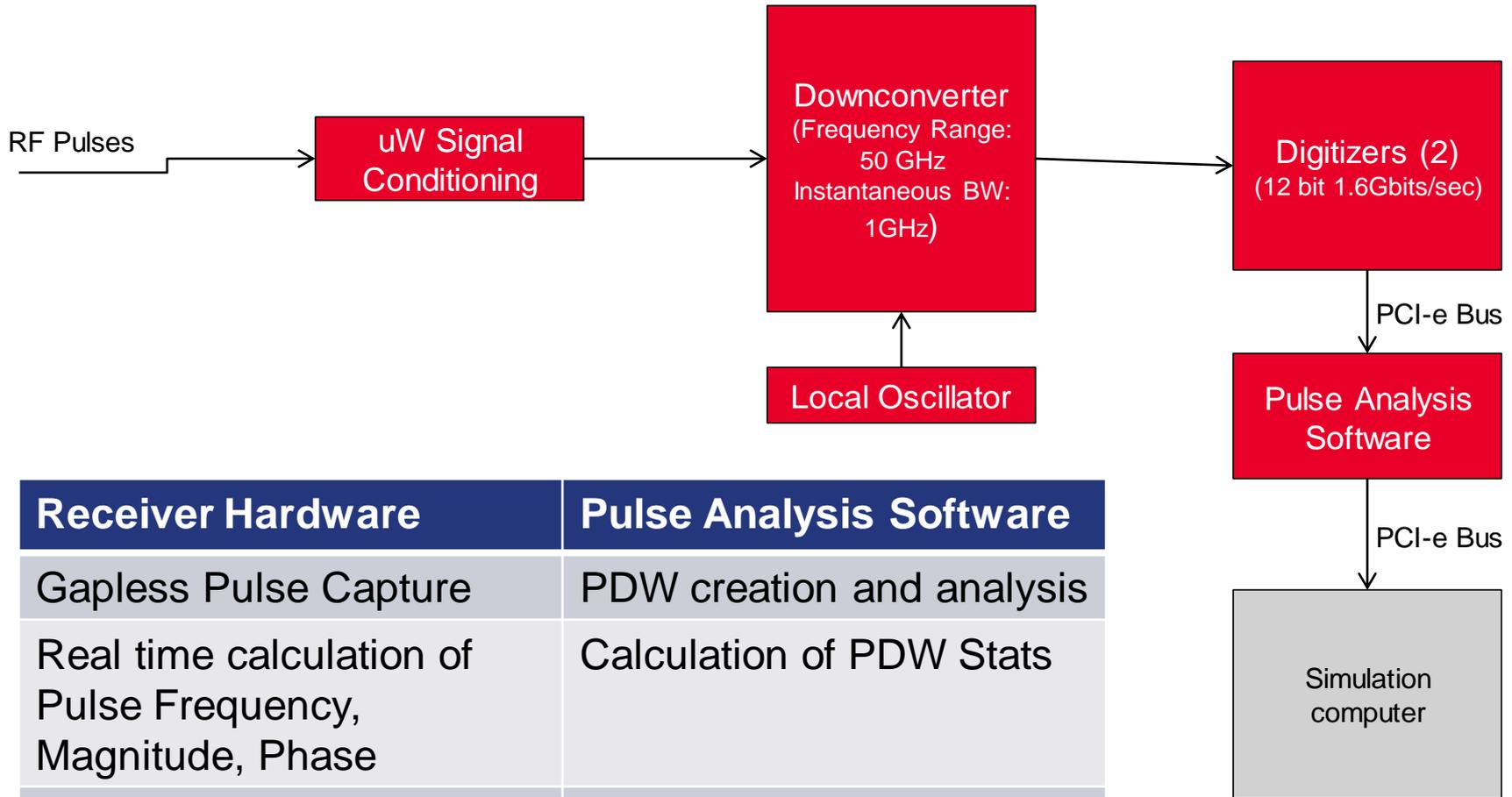
RF pulses become PDWs



Measurement requirements to enable closed-loop simulation

- Signal conditioning: SFDR, noise floor and sensitivity, TOI, low pass filtering for the digitizer
- Digitizer: ADC with sufficient sample rate and on-board signal processing resources such as an FPGA to parameterize baseband pulses
- Which interface from digitizer?

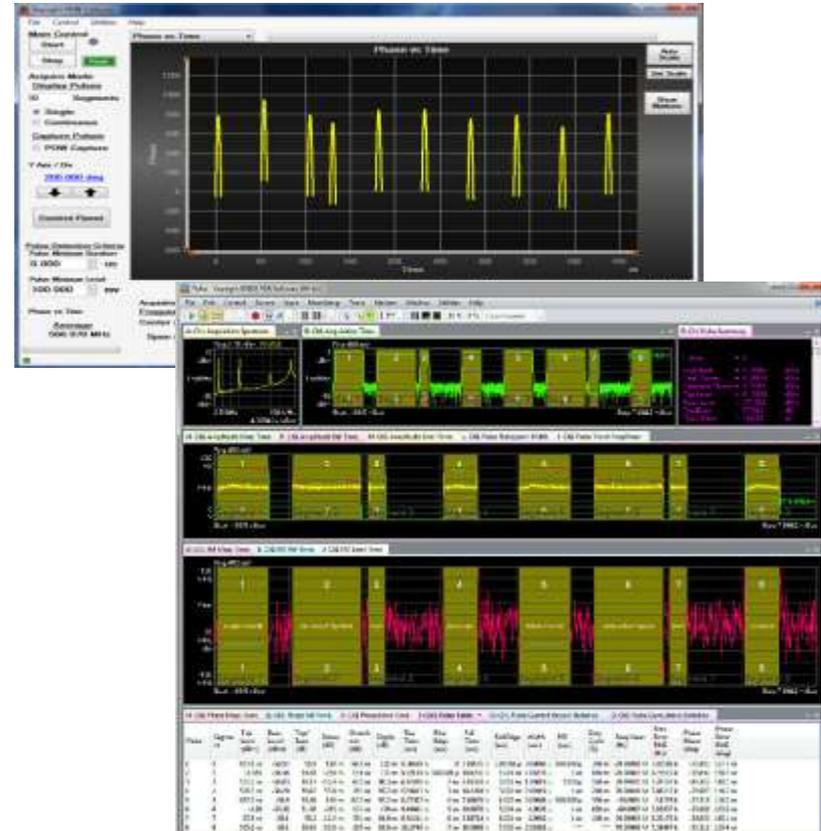
The PDW-creation architecture – an intermediate solution



Receiver Hardware	Pulse Analysis Software
Gapless Pulse Capture	PDW creation and analysis
Real time calculation of Pulse Frequency, Magnitude, Phase	Calculation of PDW Stats
Segmented Memory/Data Decimation	
Digital Down Converter	

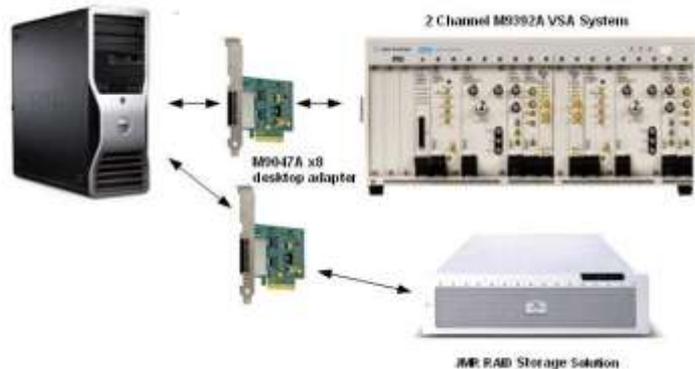
Software for PDW creation

- Convert segments + parameters from digitizer(s) into full PDW and PRI
- Long term goal is to eliminate the need for this intermediate layer
 - Digitizer should compute full PDW.
 - PRI should be computed by simulation computer



Data transfer from the digitizer

Cabled PCIe option for this application:



- challenge is getting the data from the digitizer to the simulation computer
- PCIe digitizer can be placed directly in the simulation computer or cabled using PCI cable
- Data rate must support expected pulse density and size of PDWs!

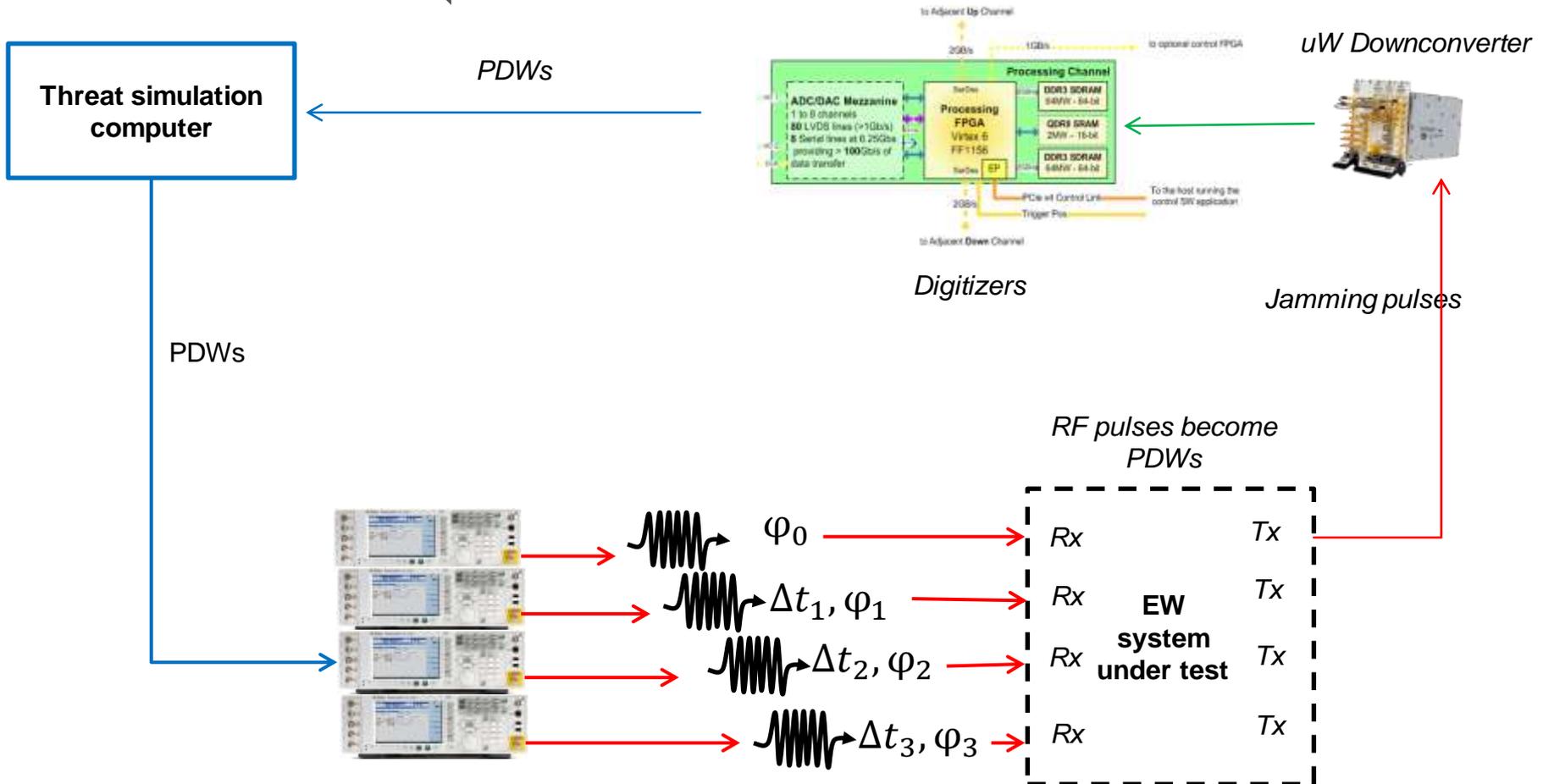
U5303A digitizer is PCIe Gen 2

PCIe Per lane:
v1.x: 250 MB/s
v2.x: 500 MB/s
v3.0: 985 MB/s

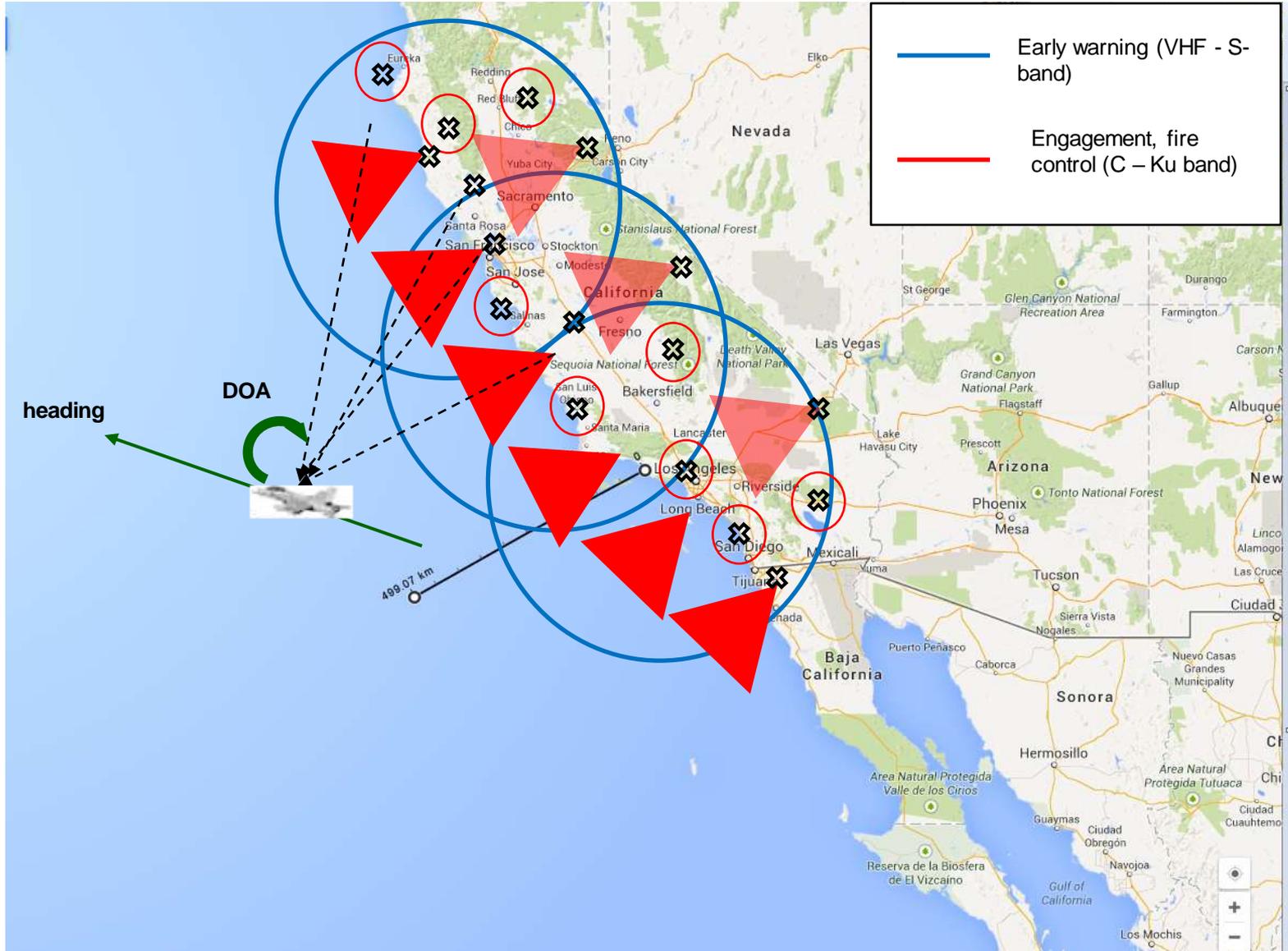
A final look at our adaptive simulation

- █ RF
- █ IF or BB
- █ Digital

Do we have low-enough latency through the analysis chain to meet requirements?



Conclusion



Resources

- N5193A UXG agile signal generator: www.keysight.com/find/uxg
- N7660B MESHG: www.keysight.com/find/N7660B
- “Electronic warfare signal generation: technologies and methods”
 - <http://literature.cdn.keysight.com/litweb/pdf/5992-0094EN.pdf>

backup