Waveform Generation and Analysis of Complex Radar EW Systems

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Agenda

- Radar EW System Test Concept
  - Test Challenges
  - Proposed Test platform
- Basic Waveform Generation
- Environments
- Form Complex Waveforms
- EW Key Models and Supported Systems
- Test System Issues
- Summary

Radar EW Test Challenges

Complex Test Signals

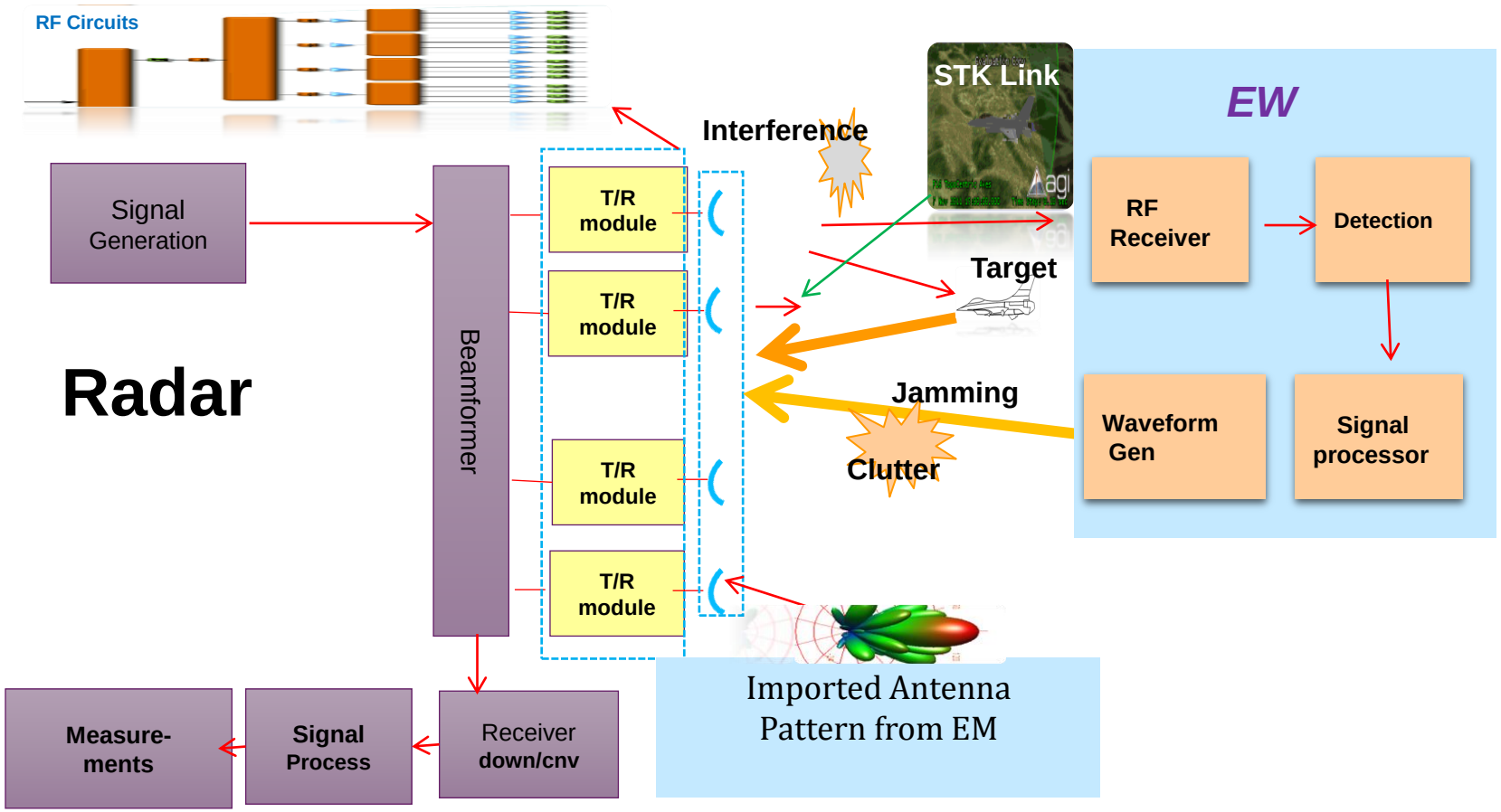
- **Signal types**
  - Radar Transmitter – Waveforms of different Radars EW Systems with Array Antennas, Beamforming.
  - Radar Receiver – Target Emulation: Target Returned with RCS Plus Clutter, Interference and Jamming
  - EW Emulation: Transmission Waveforms Plus Interference
- **Requirements**
  - Multi-emitter
  - Dynamic Pulse
  - Long sequence
  - Wideband

Analysis for different test cases

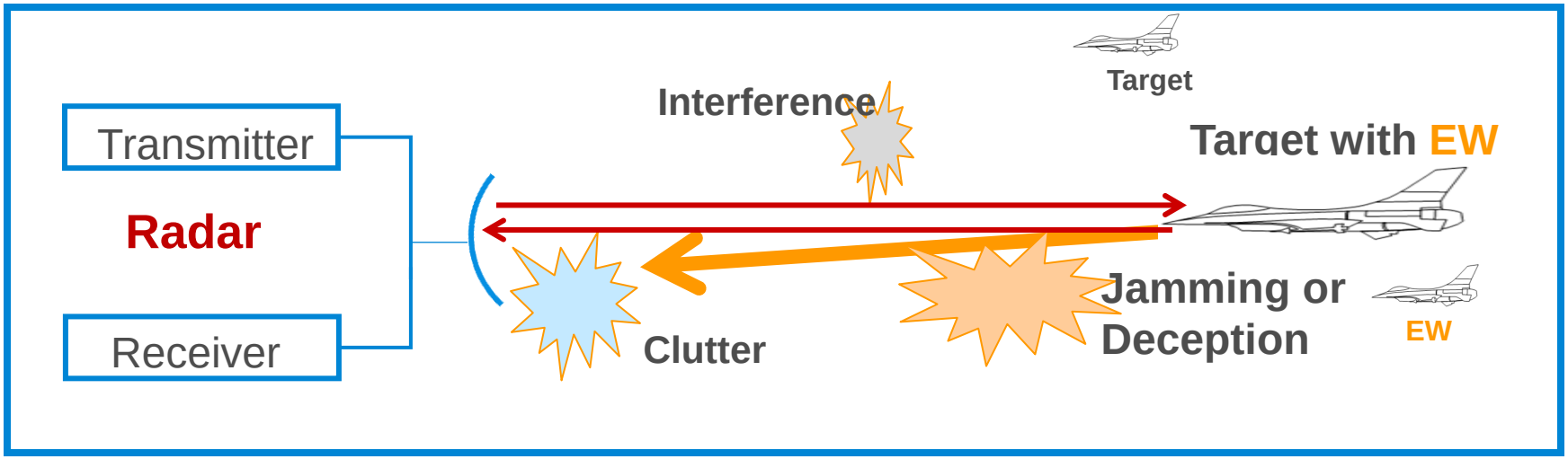
- **Performance Measurement Challenge**
  - Antenna pattern measurements: 2D and 3D
  - Environments include clutters, Interference,
  - noise, multipath
  - Tx measurements: ACLR and EVM
  - Rx measurements: Detection rate, false
  - alarm rate measurements
- **Tool requirements**
  - Integration capability for auto-test purpose
  - Support Co-Sim with MATLAB, Circuits and EM
  - Flexible and Integration capability

New for Radar EW System Solutions

Typical Radar EW application in SystemVue to support cross-domain, cosimulation with RF as well as EM to include real world environments such as Interference, target RCS, clutter, jamming, and STK link for flight test



Electronic Warfare (EW) Concept



- **Electronic Warfare (EW)**

  It is military action using electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy.

- **EW includes**
  - electronic attack (EA or ECM)
  - electronic protection (EP)
  - electronic warfare support (ES)

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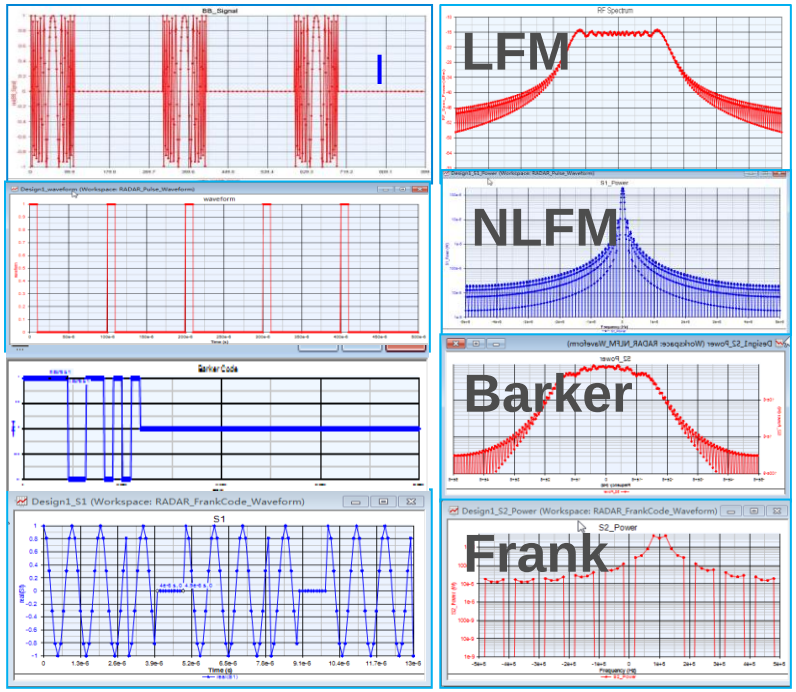
Basic Waveform Generation – Models

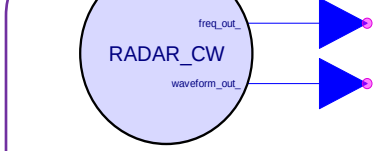
	Basic	Advanced
Source	1. CW Pulse, LFM, NLFM and FMCW 2. Binary phase coded (Barker) 3. Poly phase coded (ZCCode, Frank), 4. Poly Time 5. FSK HP 6. Arbitrary PRN	DDS UWB, SFR SAR Phased Array MIMO

Source Models

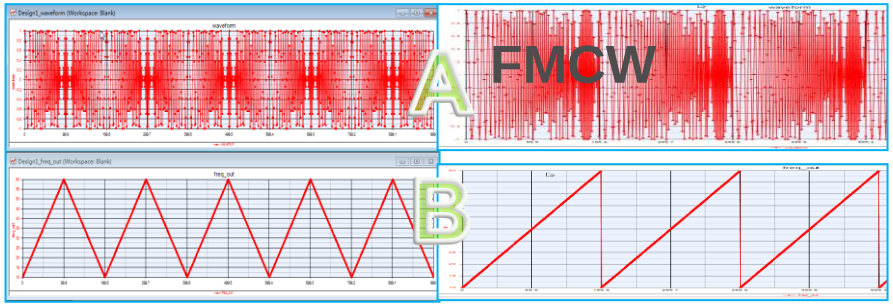
- Pulse signal generator
- Linear FM pulse waveform (LFM)
- Nonlinear FM waveform (NLFM)
- Binary phase coded waveform (Barker)
- Poly phase coded waveform (Frank, P-Code, ZC)



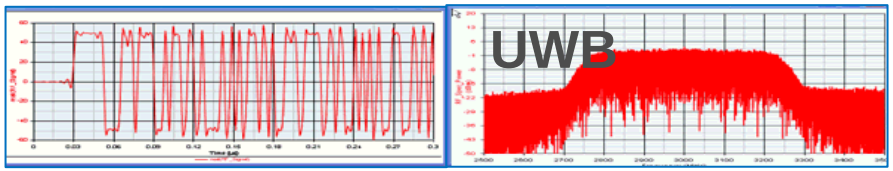
- Continue Waveform (CW)
- FMCW
- Ultra Wideband (UWB)
- Step Frequency Source
- SAR Source



R1 {RADAR_CW@RADAR Models}
Waveform_type=Sawtooth
Amplitude=1V
Period=1s
Lower_freq=10Hz
Delta_f=50Hz
Sample_rate=200Hz



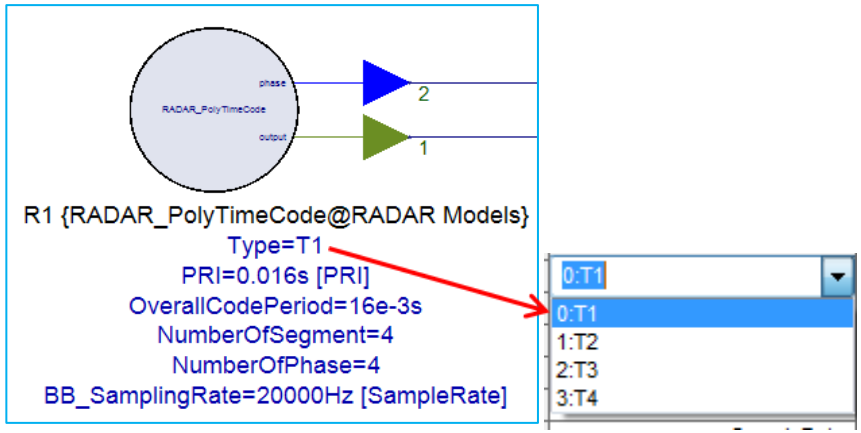
FMCW Signals: **A**. Waveforms **B**. Frequency vs Time

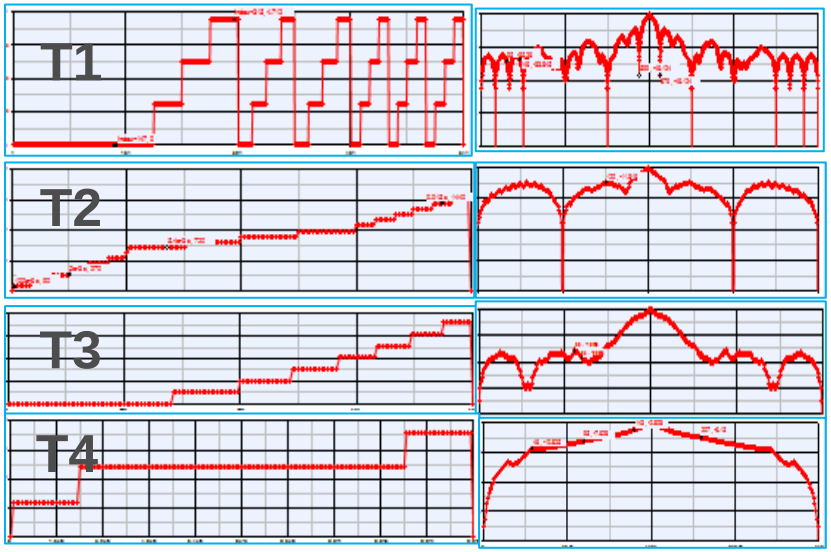


UWB Signal: Waveform and Spectrum

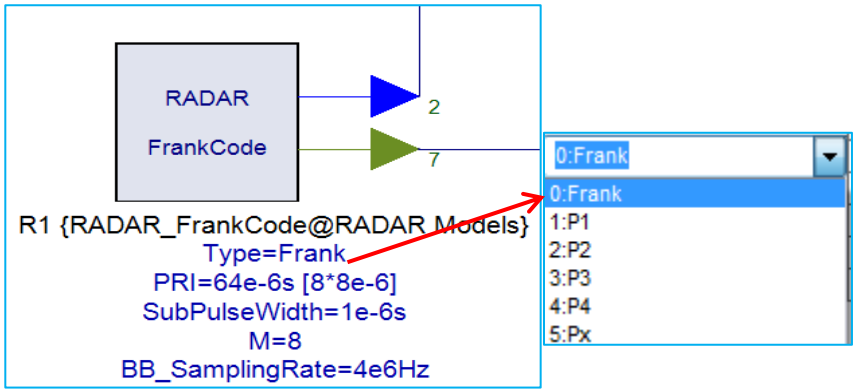
Source Models

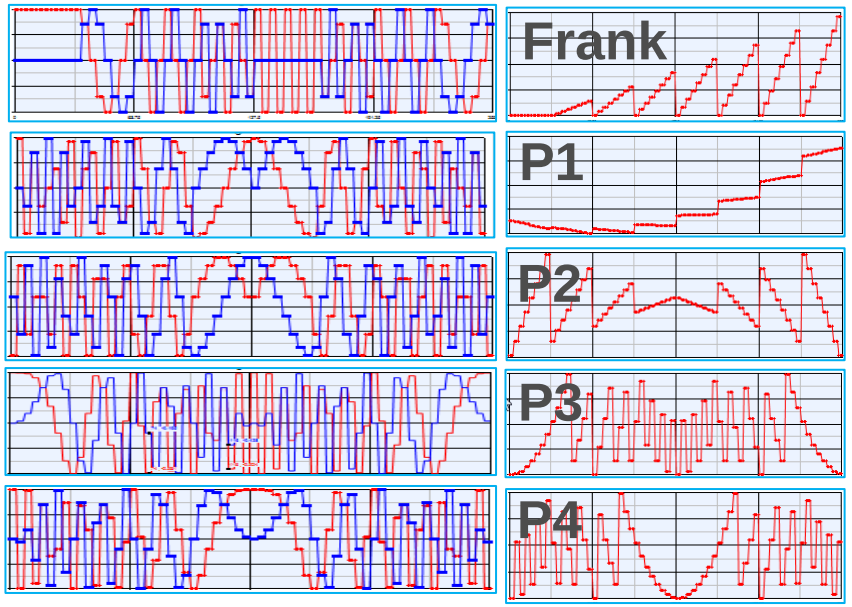
PolyTime Coded Source





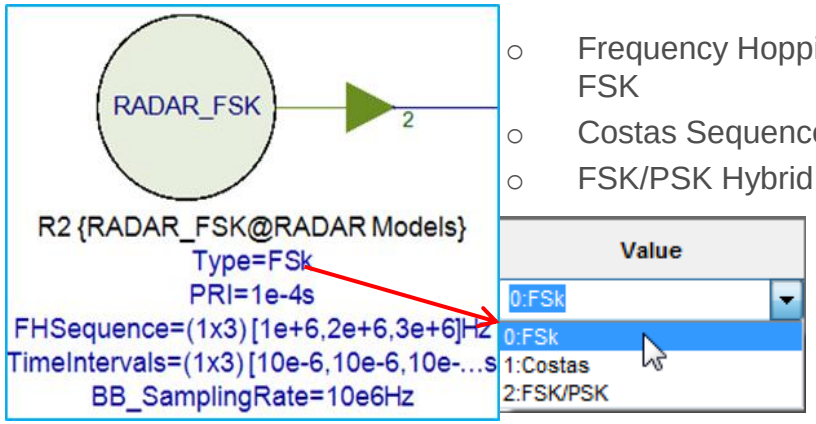
PolyPhase Coded Source



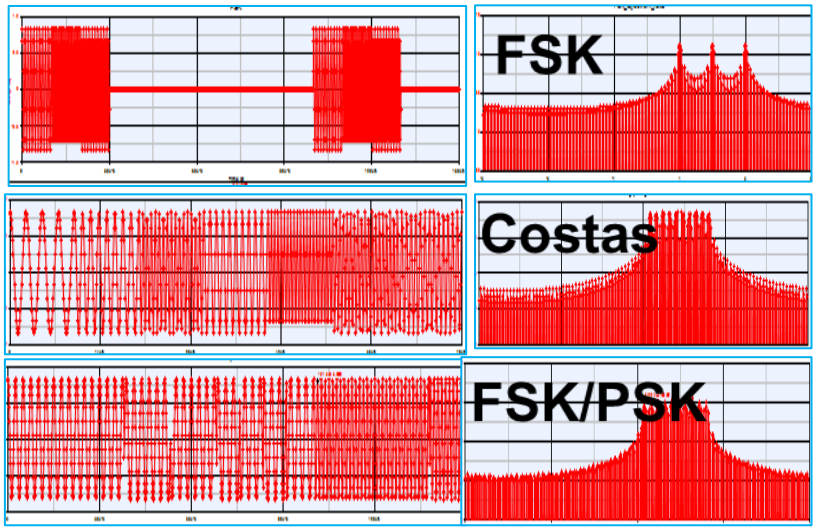


Source Models

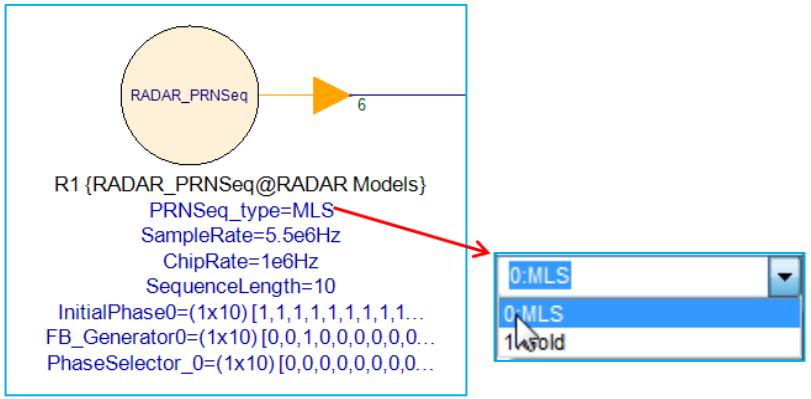
Frequency Hopping Source

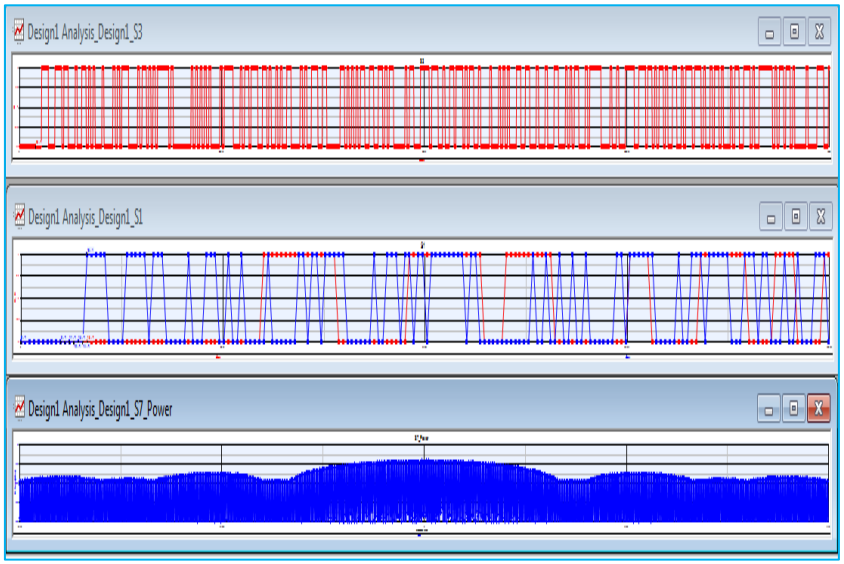


- Frequency Hopping FSK
- Costas Sequence
- FSK/PSK Hybrid



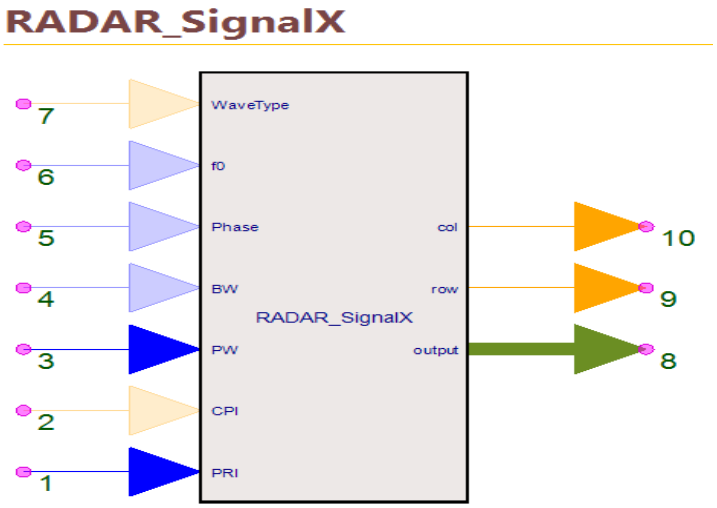
Pseudo Random Source

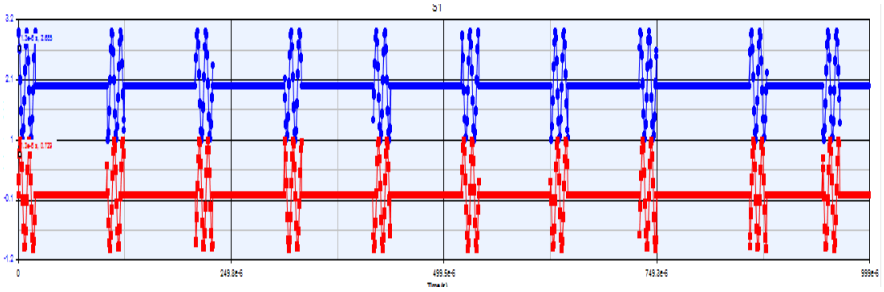




Dynamic Signal Generation Model

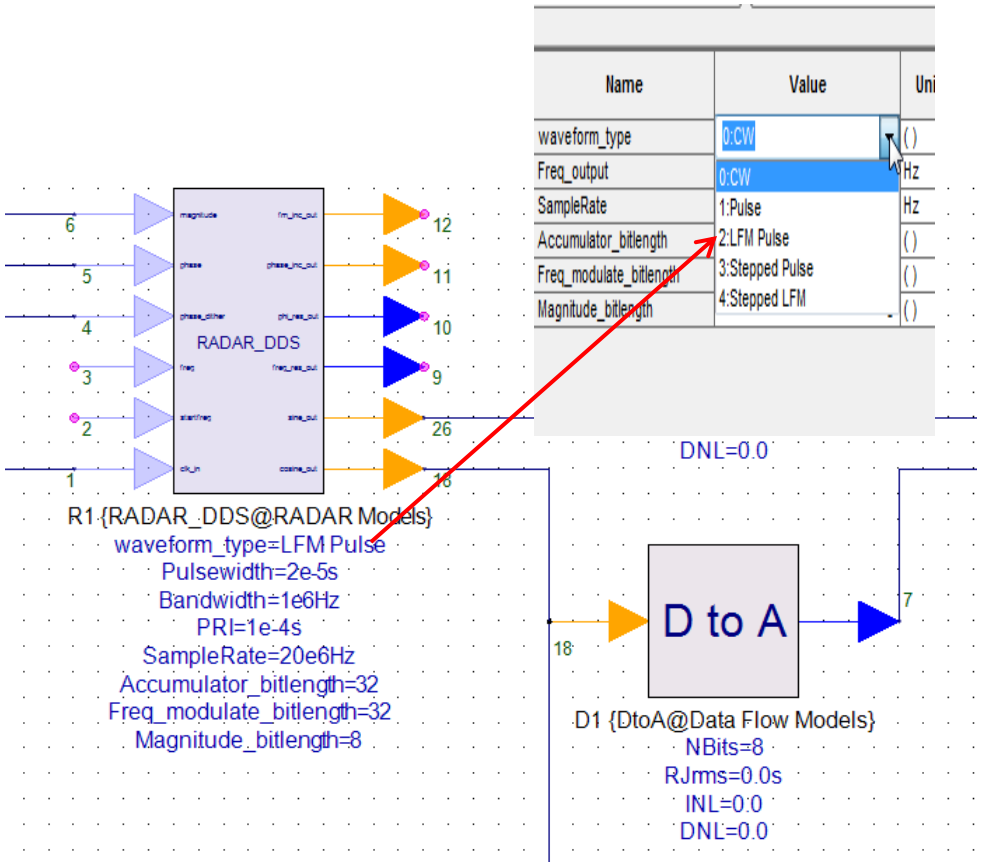
- This model can be used for generating pulse waveforms with dynamic parameters for waveform type , PRI, carrier frequency, pulsewidth, bandwidth, phase and the number of pulses in one CPI.
- This model is useful for the jitter PRI and stagger PRI cases.
- Built for Radar EW customers based on their request

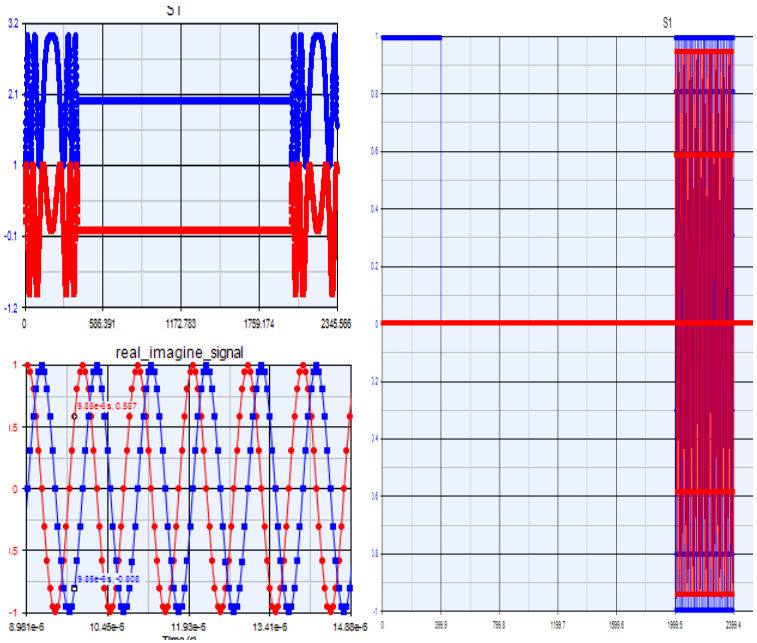




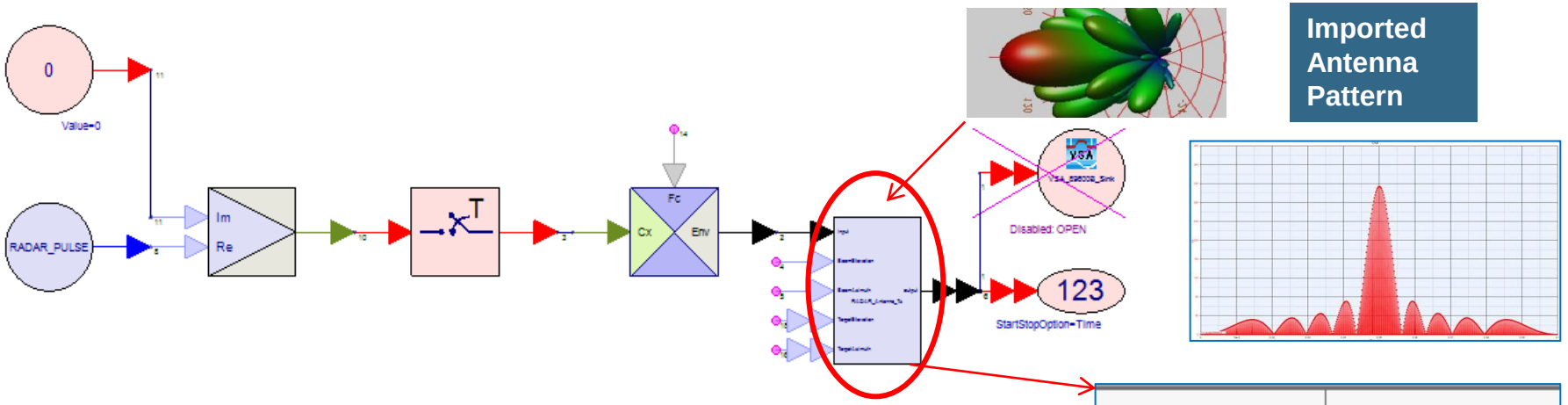
Source Models

Direct Digital Synthesis (DDS) Model





Signal Generation with Antenna Model



Name	Value
RadarWorkMode	1:Search
Pattern	0:UserDefinedPattern
AntennaPatternArray	[ones(361*181, 1)]
ThetaAngleStart	0
ThetaAngleEnd	180
PhiAngleStart	0
PhiAngleEnd	360
AngleStep	1
AntennaScanPattern	0:Circular
ScanRate	
ElevationAngle	
TargetAzimuthAngle	
TargetElevationAngle	
BeamAzimuthAngle	
BeamElevationAngle	0

0:Circular
1:Bidirectional Sector
2:Unidirectional Sector
3:Bidirectional Raster
4:Unidirectional Raster

- Support Two working modes: ***search*** and ***tracking***.
- Antenna pattern:
  - For user defined, AntennaPatternArray parameter is used for importing from other SW such as EmPro,
  - Besides User Defined Pattern, the other patterns are Uniform, Cosine, Parabolic, Triangle, Circular, CosineSquarePedestal, and Taylor.
- Antenna Scan Pattern
  - Circular, Bi-directional Sector scan , Uni-directional Sector Scan, Bi-directional raster, Uni-directional Raster.
- Moving target scenario

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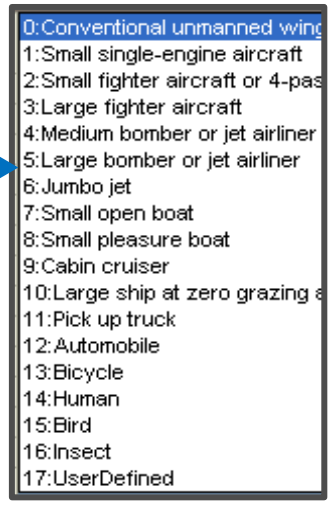
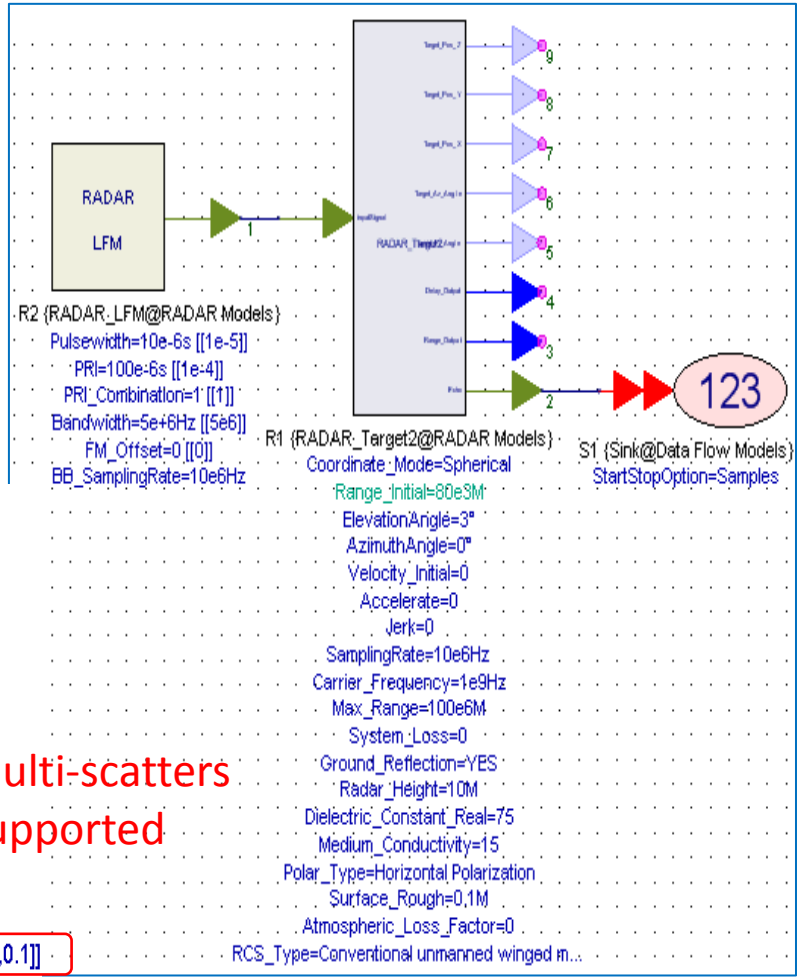
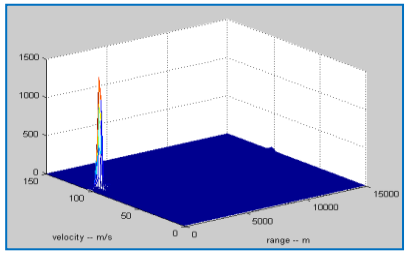
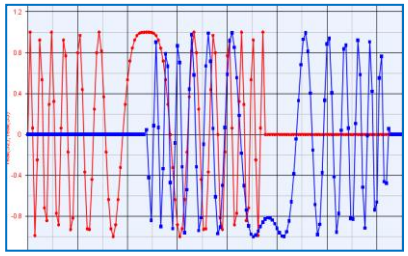
Upgrade Moving Target Model

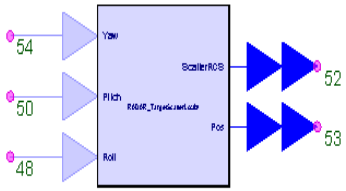
- Earth effect
  - Atmospheric Loss
  - More RCS Types
  - System_Loss
  - Ground Reflection
  - Polarization
  - Dielectric Effection
  - Trajectory









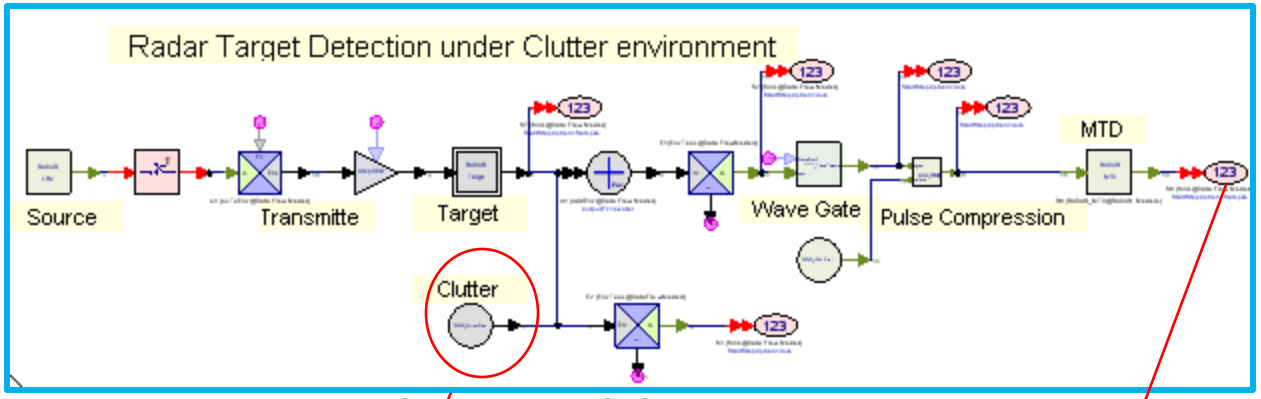


Trajectory_Mode=Cartesian
NumberOfTargetScatter=5
ScatterLoc=(1x3) [0,0,0]M [[0 0 0]]
Position_Initial=(1x3) [0,0,0]
Velocity_Initial=0
Accelerate_Initial=0
IsRandomError=0 [false]
RCS=(1x5) [0.2,0.1,0.3,0.5,0.1] [[0.2,0.1,0.3,0.5,0.1]]
IsRCSRandom=0 [false]
TimeStep=1e-9s

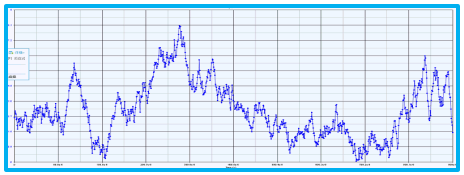
Multi-scatters Supported

Clutter Model with K Clutter

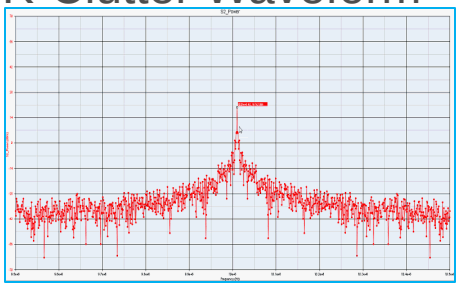
- Clutter model generates coherent or non-coherent correlated clutter.
- This model supports Rayleigh, Log Normal and Weibull and K PDF
- Gaussian, Cauchy and All Pole PSD supported
- The moving-target echo is covered by strong K clutter in the example



Clutter Model



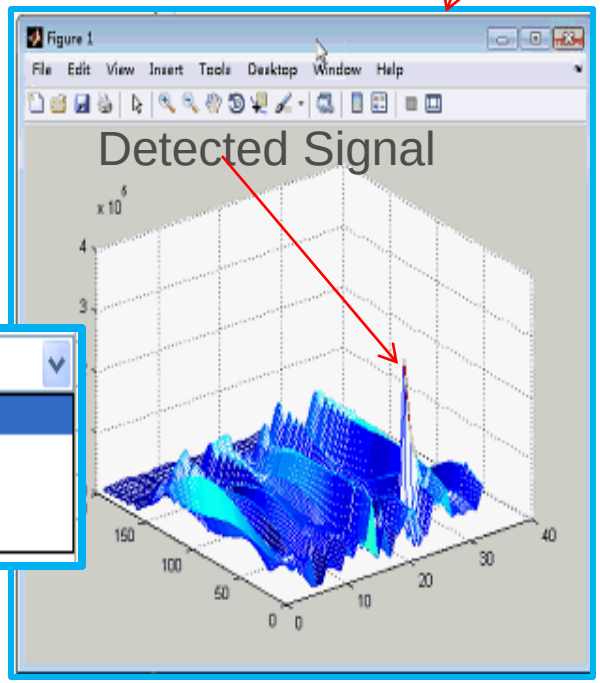
K-Clutter Waveform



K-Clutter Spectrum

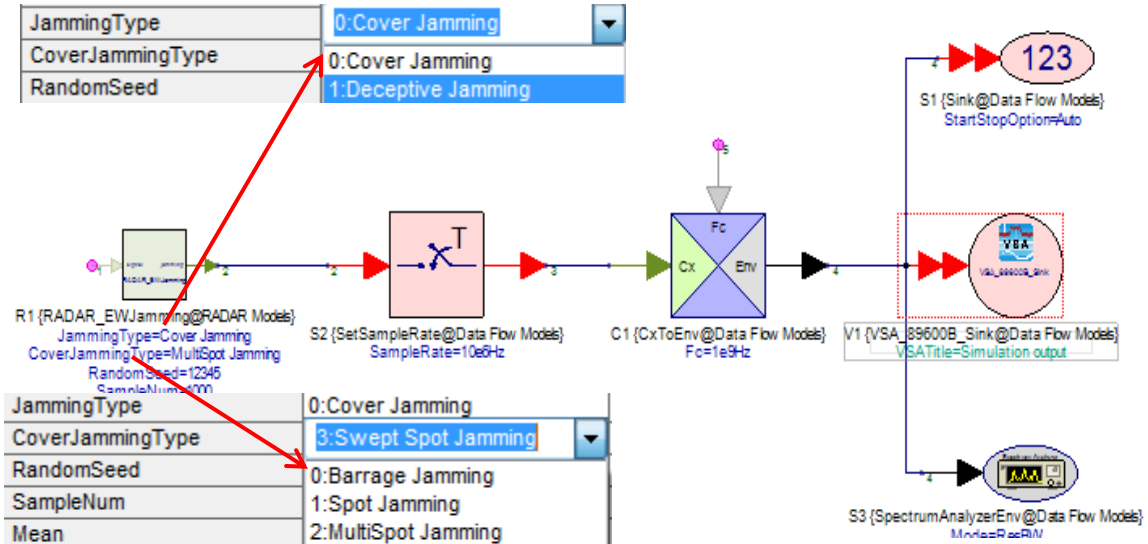
Name	Value	Units
RF_Freq	10e9	Hz
SampleRate	10e6	Hz
PRF	10e3	Hz
PDF	0:Rayleigh PDF	
Variance		
PSD	0:Gaussian PSD	
Fd		
PSDVariance		
FilterLen		
Seed	1234567	( )
IsCoherent	1:Coherent	( )

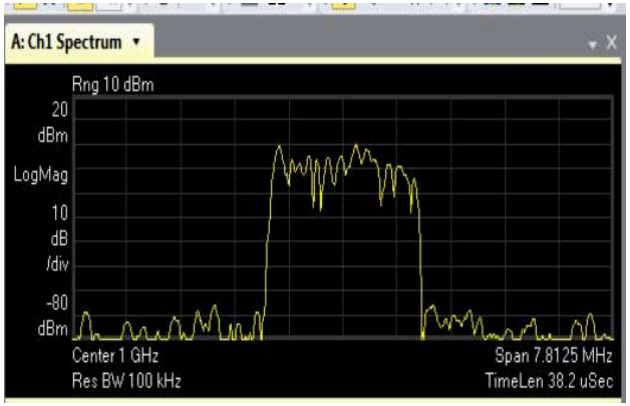
0:Rayleigh PDF
0:Rayleigh PDF
1:LogNormal PDF
2:Weibull PDF
3:K PDF

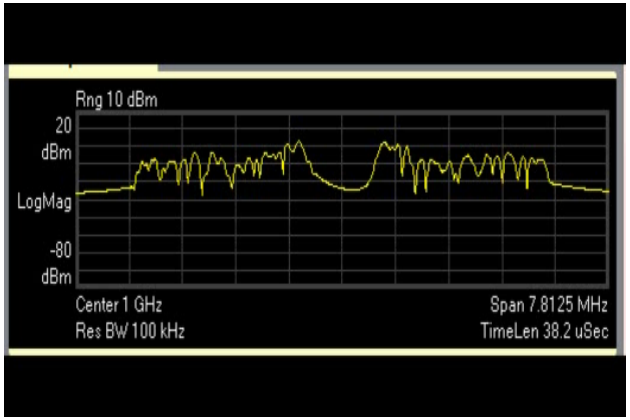


Jamming Source

- Jamming Type: Jamming, Deception
- Jamming Cover Type: Barrage, Spot, Multi-Spot, Swept







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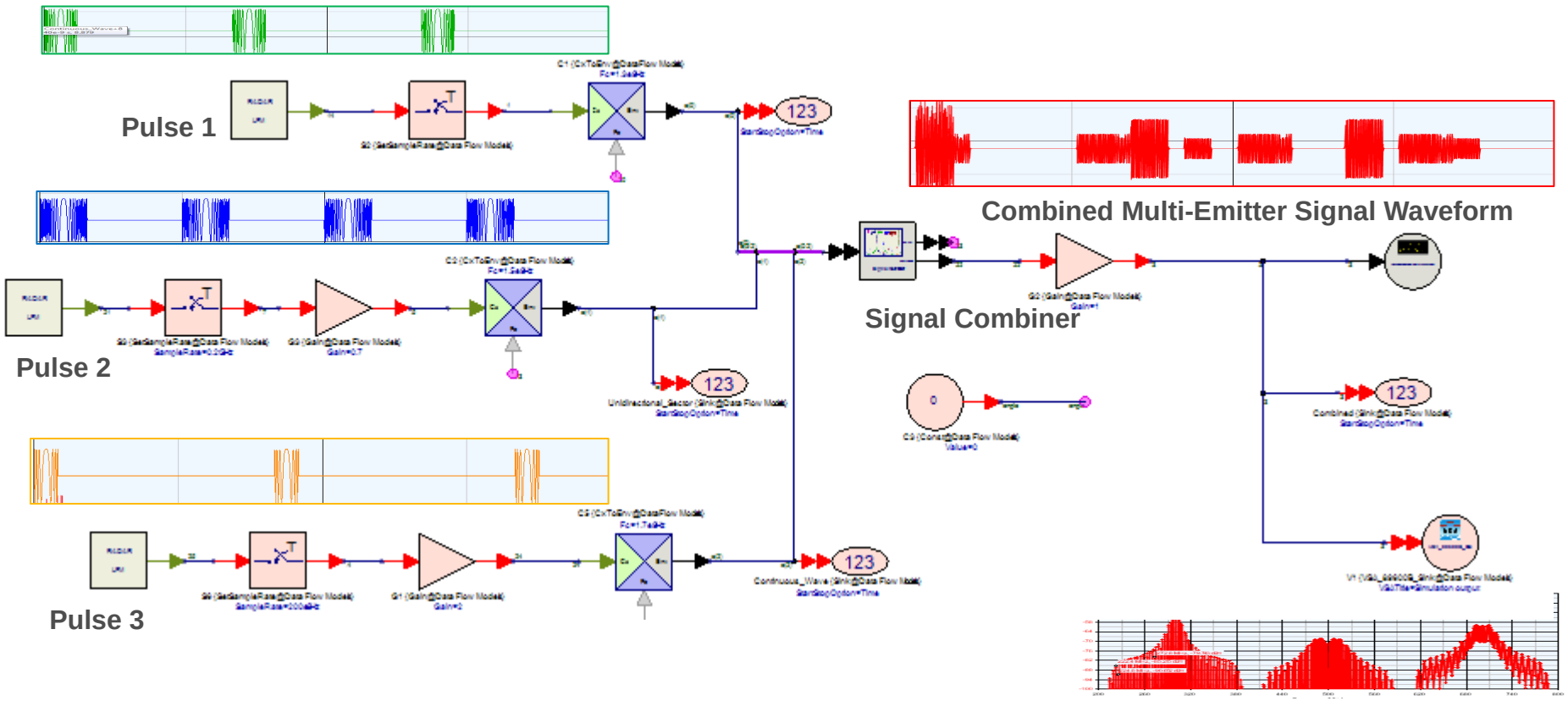
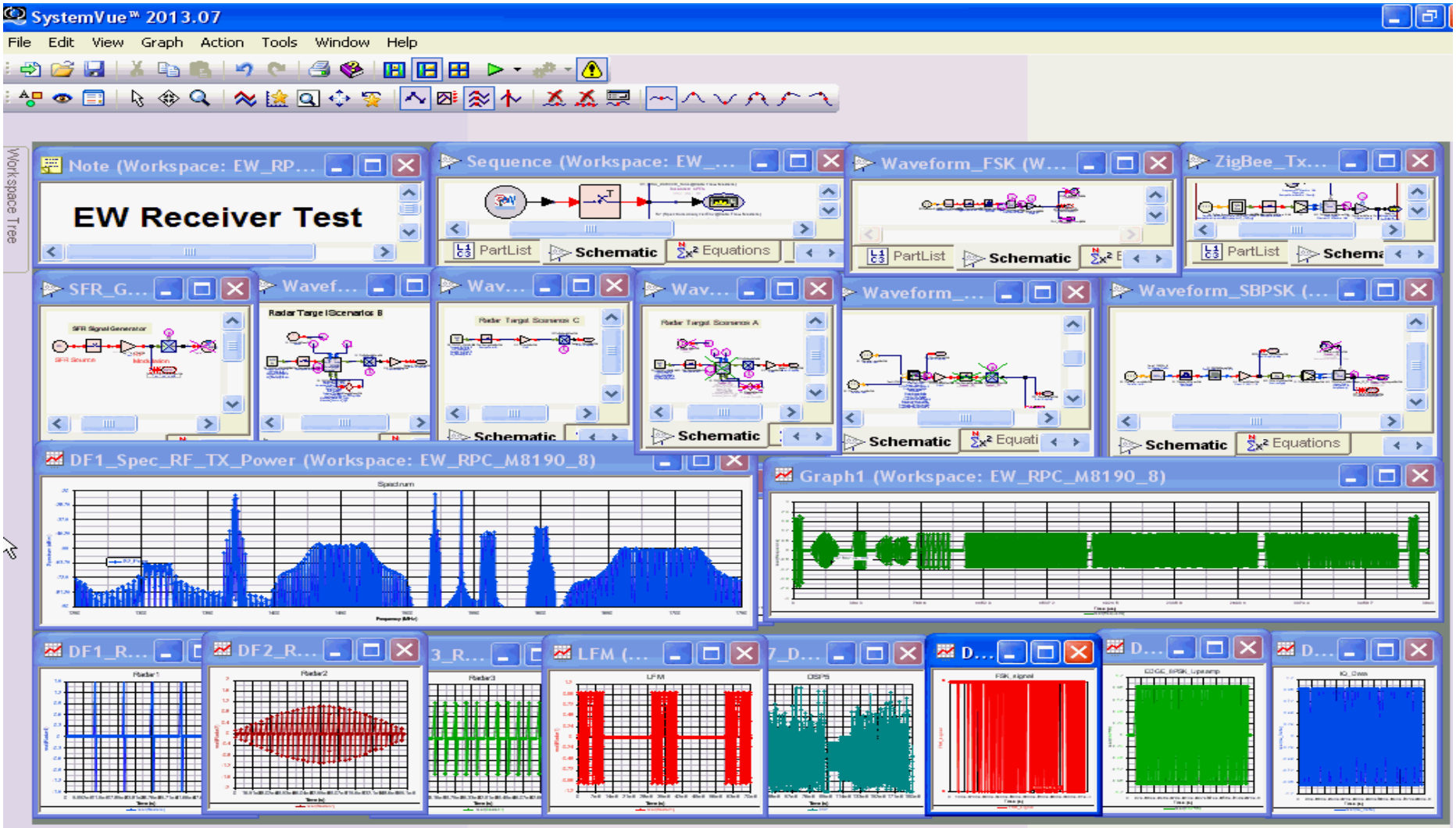
Signal Combiner



Download to AWG/VSG

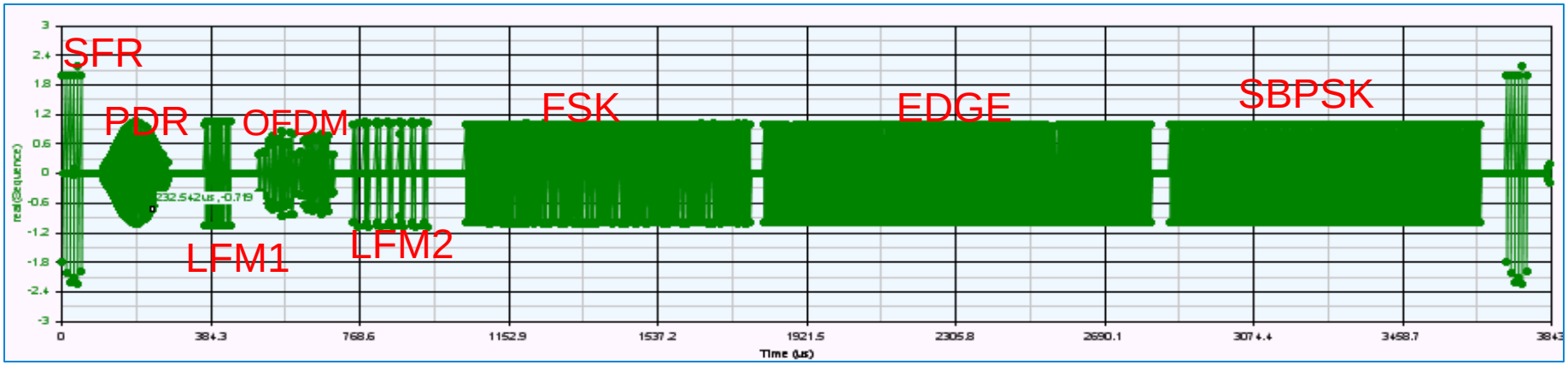
Waveform Sequence Composer example

Electronic Warfare Environments Scenario from Interferences

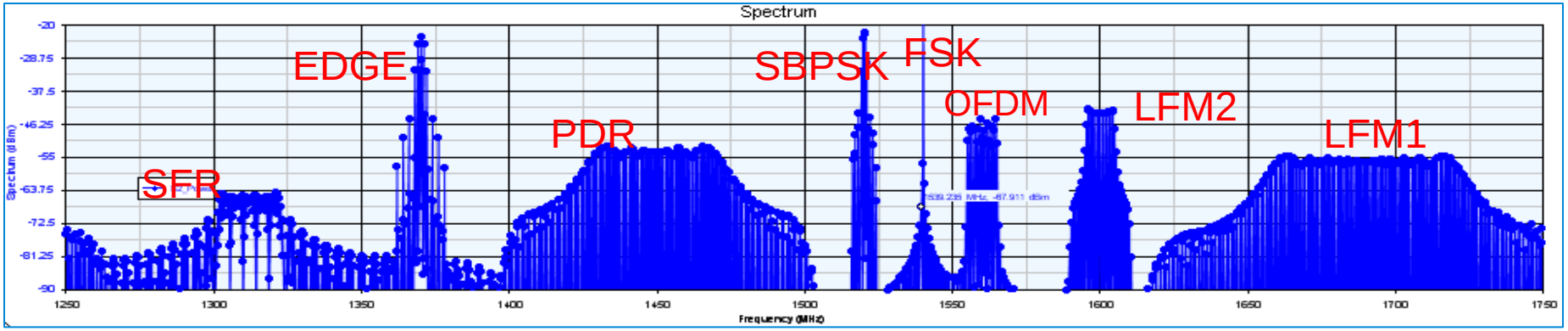


Waveform Sequence Composer example

Generated EW System Test signals waveform to emulate the Scenario



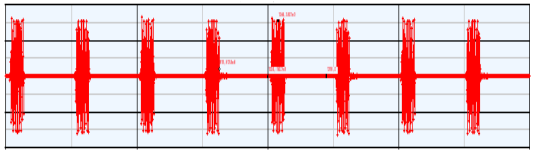
Generated EW System Test signals spectrum to emulate the Scenario

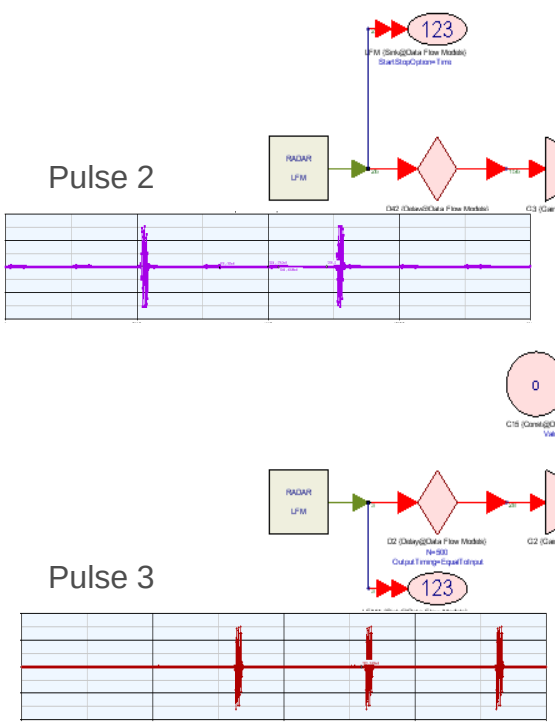


Examples/Instruments/Radar/Waveform Sequencing/EW_8_Emitters.wsv

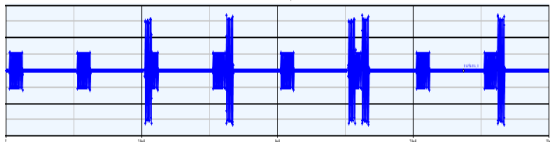
Signal Generation based on Channelization

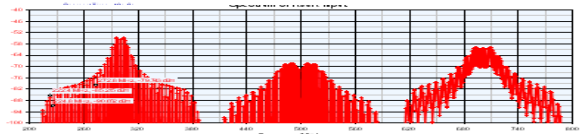
Pulse 1





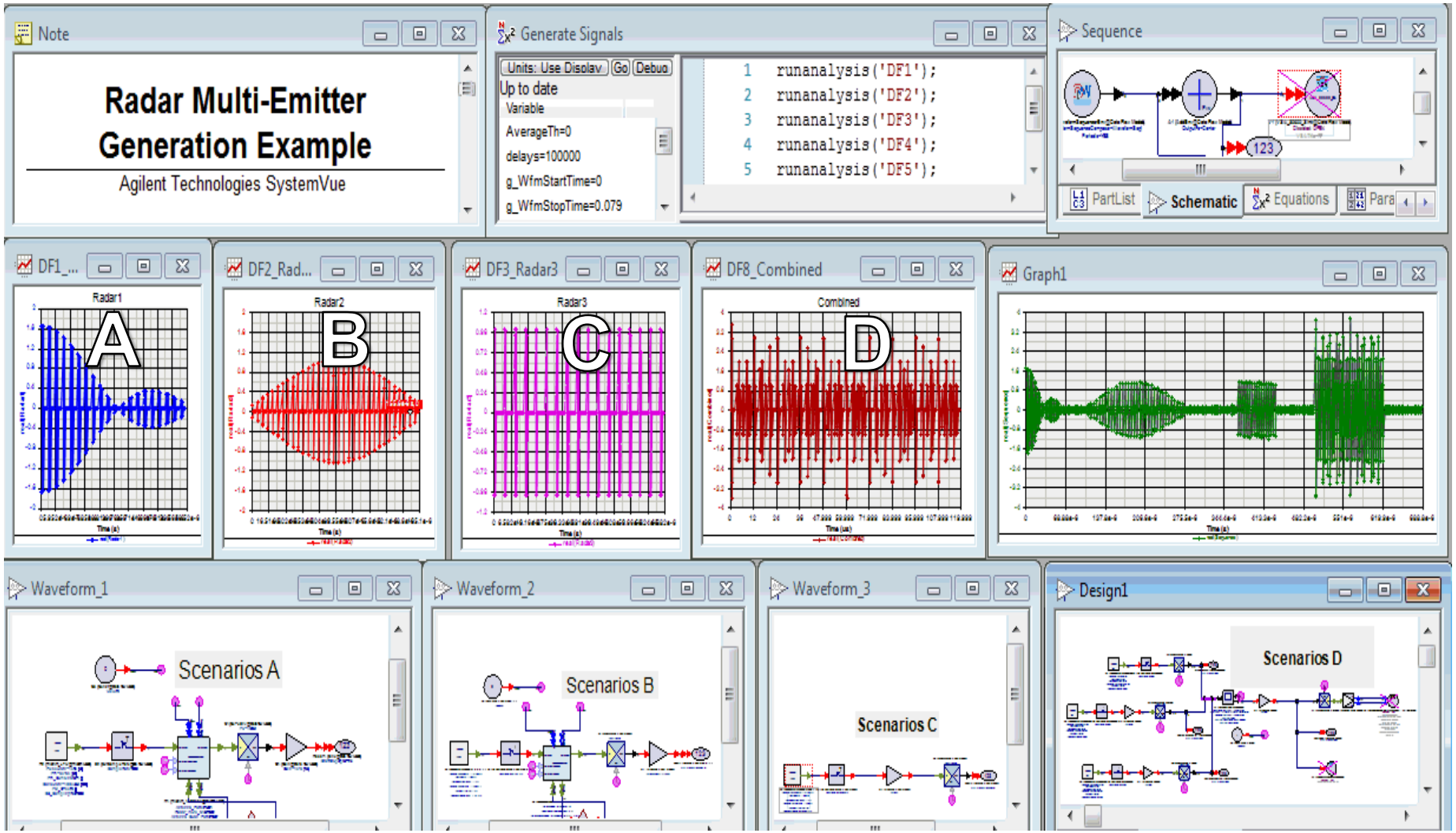
Multi-Emitter Signal Waveform





Multi-Emitter Signal Spectrum

Signal Generation based on WFC + Combiner



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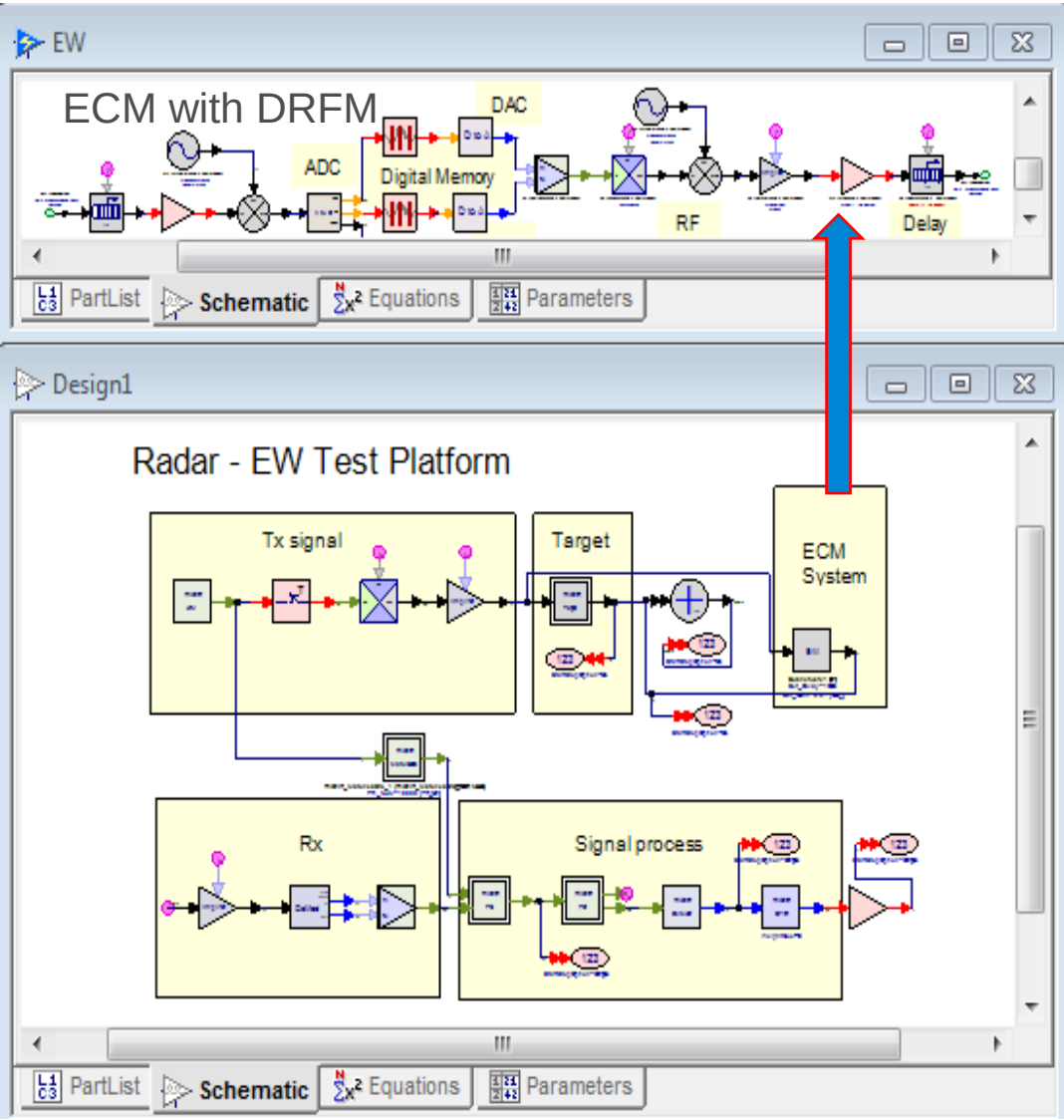
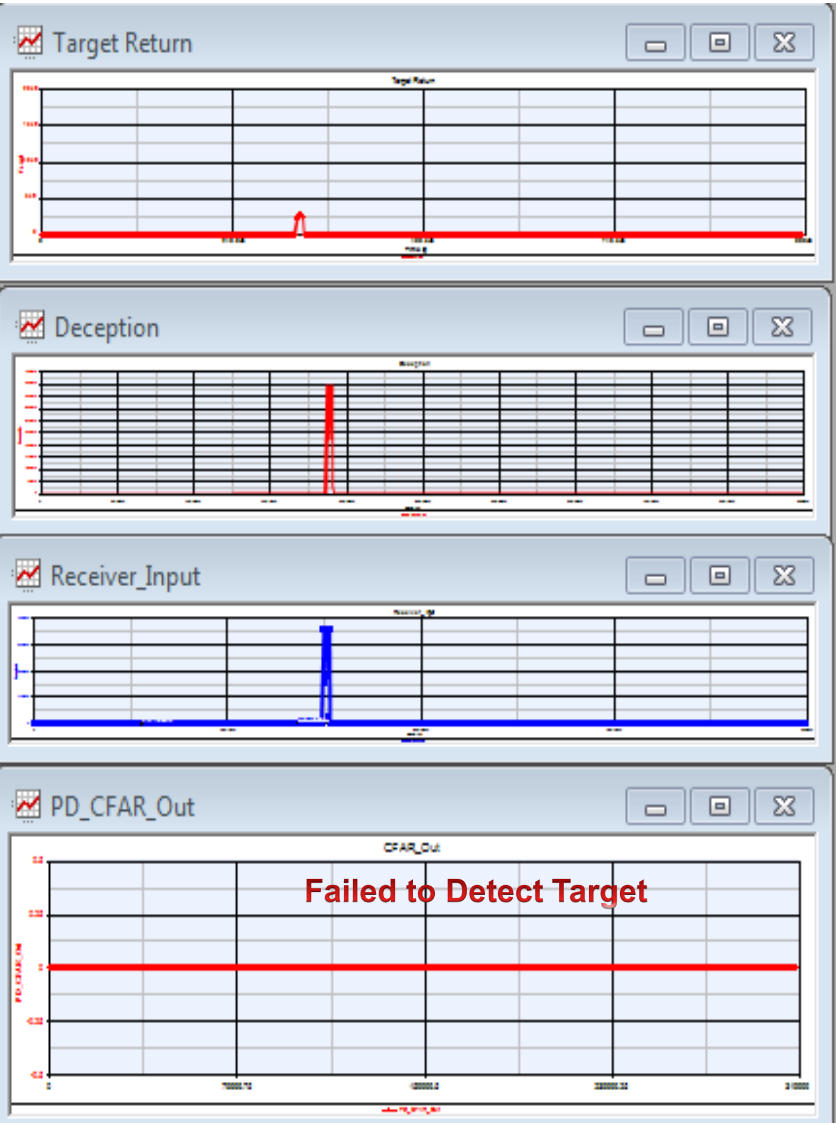
EA (Electronic Counter Measures ECM) based on DRFM





Electronic Attack (EA) Setup

Nonresponsive Jammer

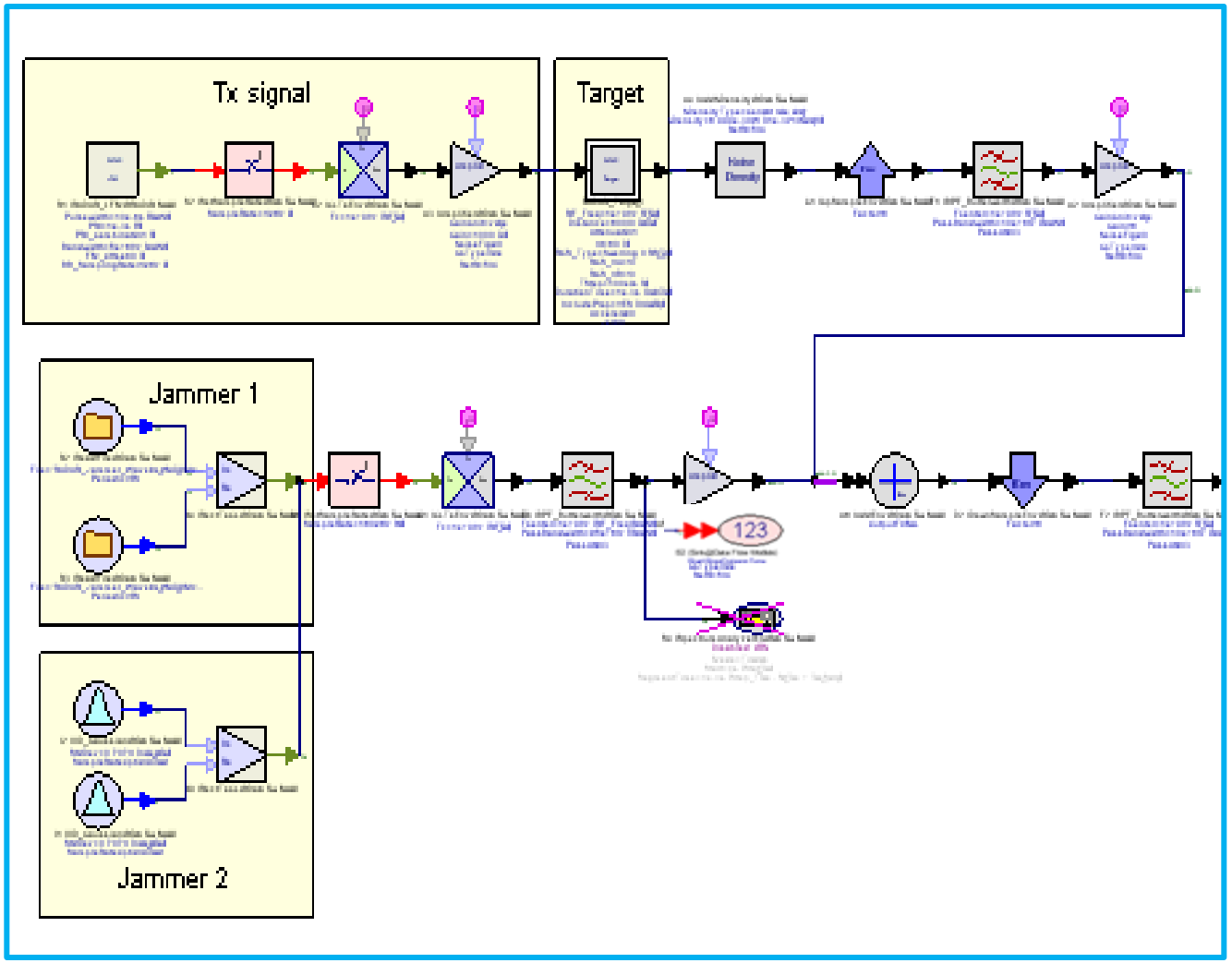
- Masking

Responsive Jammer

- Masking

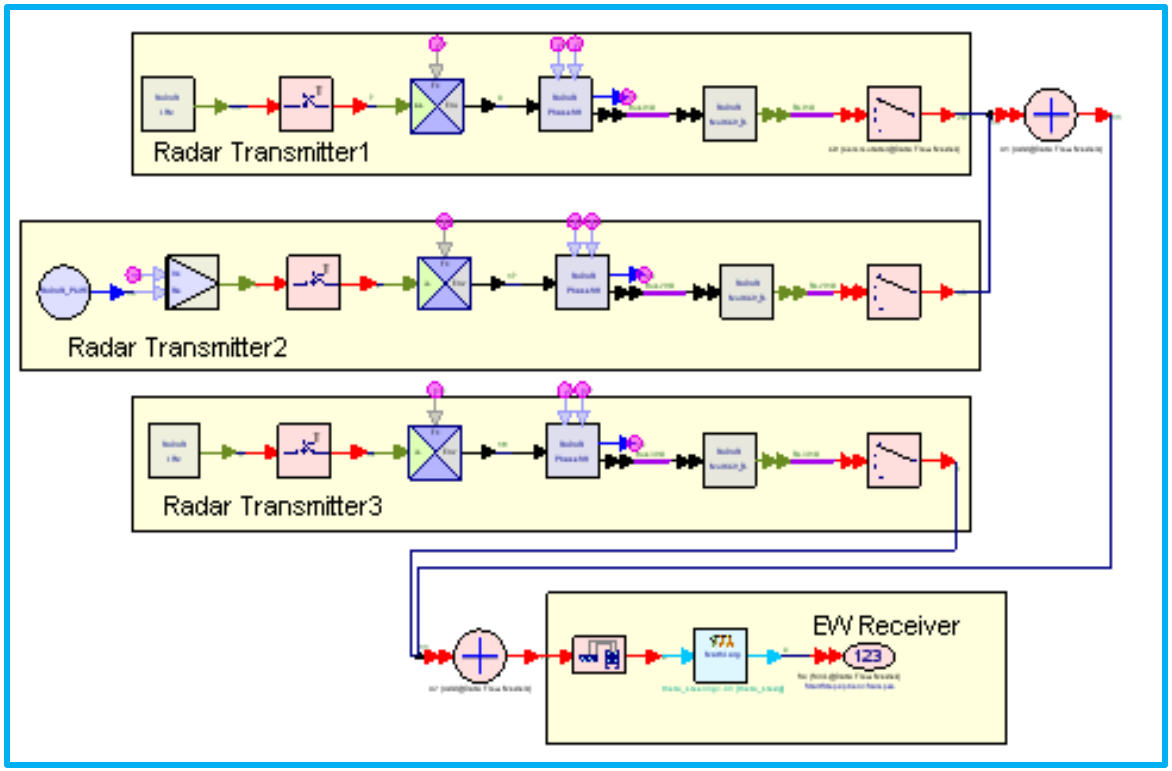
Coherent Jammer (Repeater)

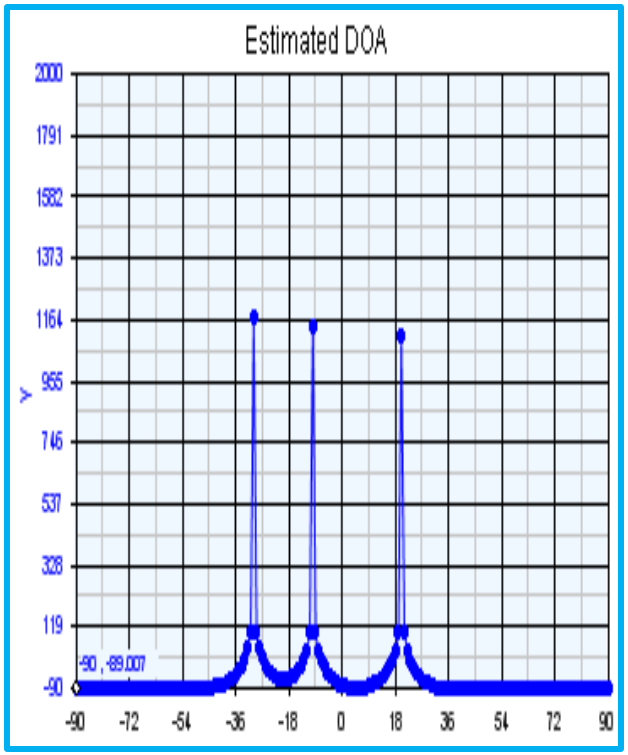
- Masking
- Deception



Electronic Protection (EP) Receiver for Estimating DOA

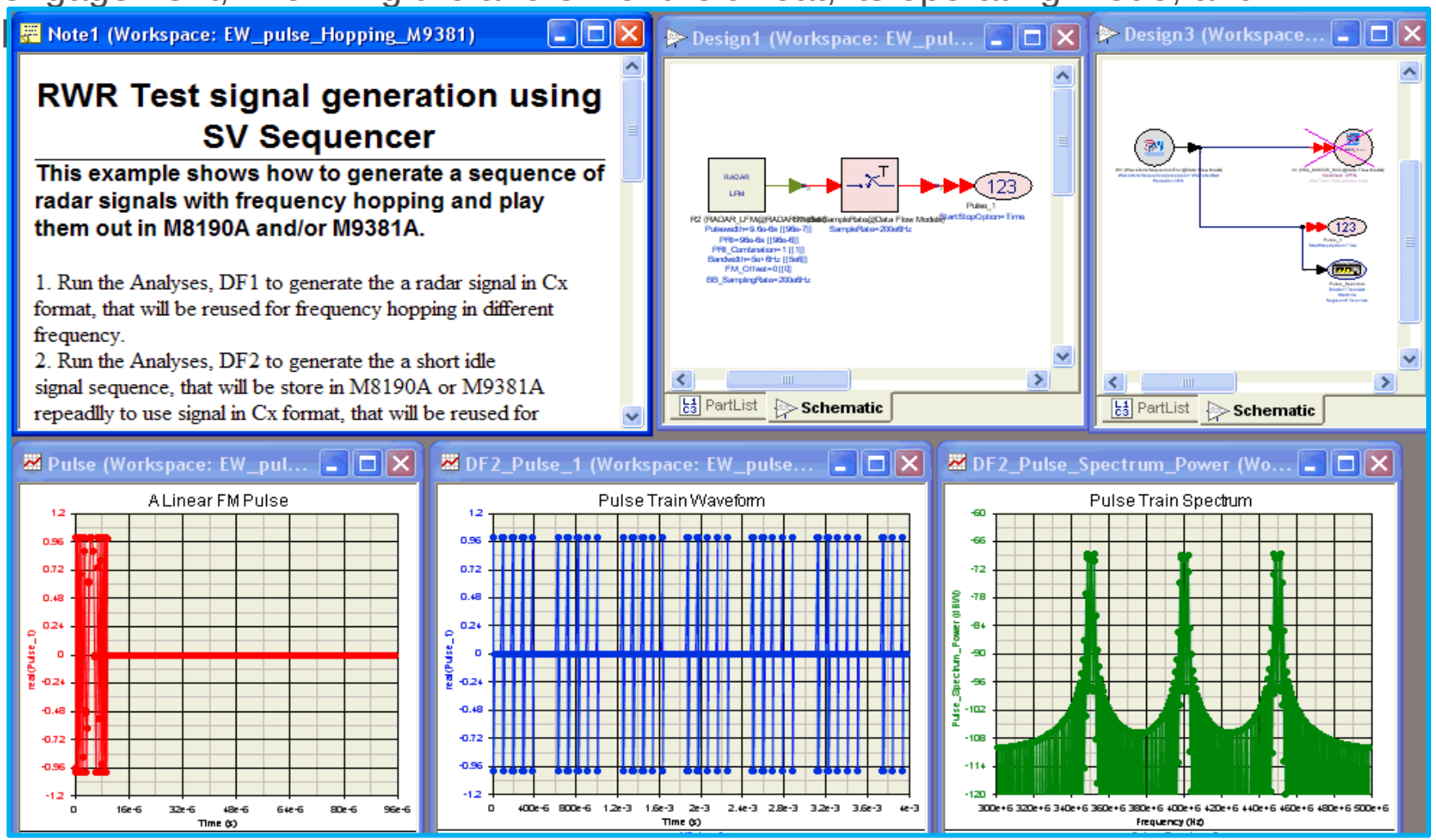
- EW receivers estimate Direction of Arrival (DOA) of received signals
- Two Algorithms include MUSIC and ESPRIT



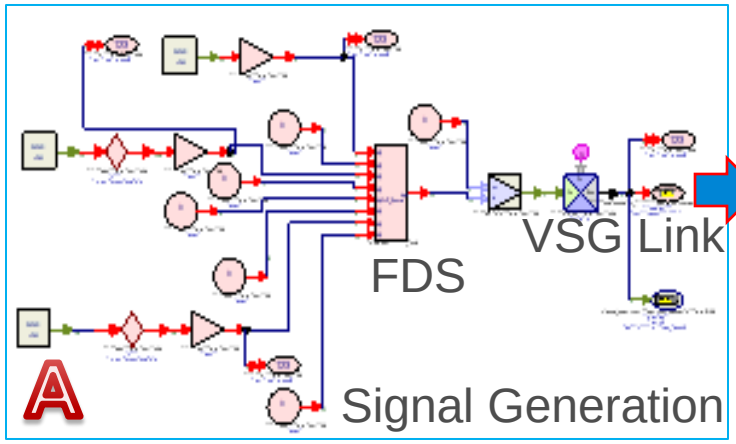


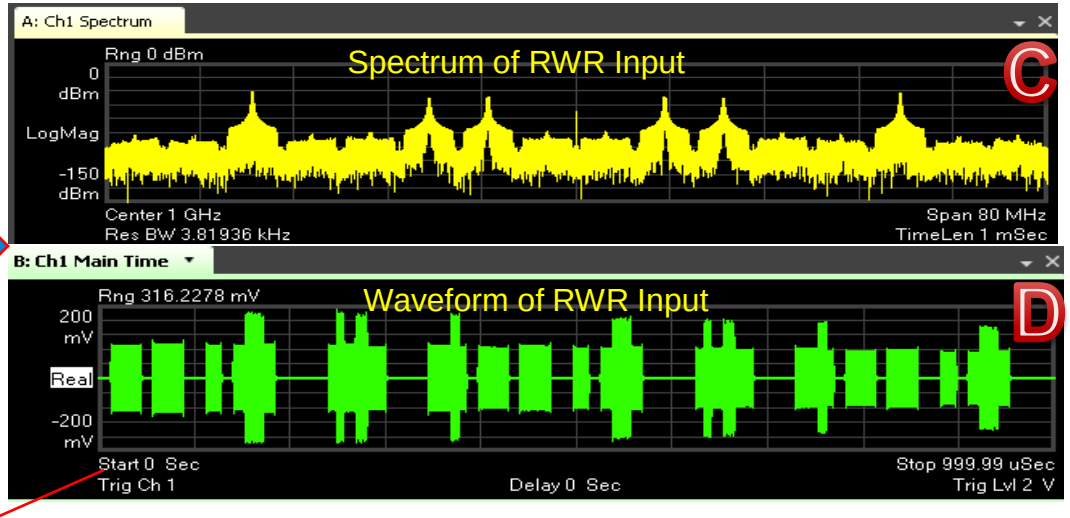
ES Signal Generation for testing RWR

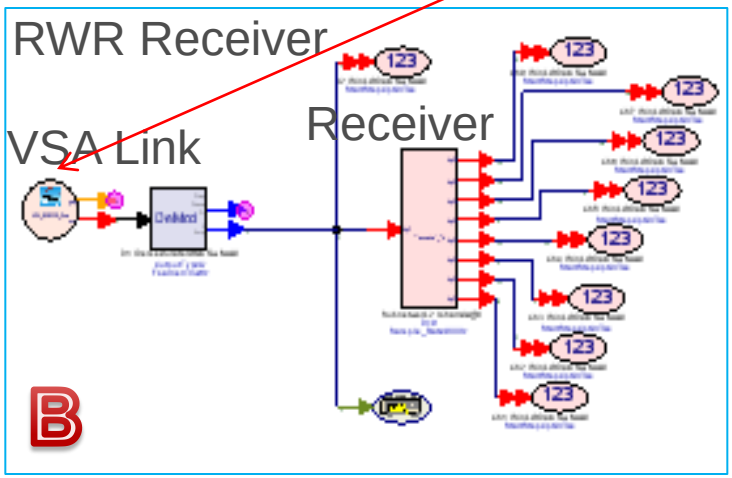
Radar Warning Receiver (RWR) may play a critical role in a one on-one engagement, informing the aircrew of the threat, its operating mode, and



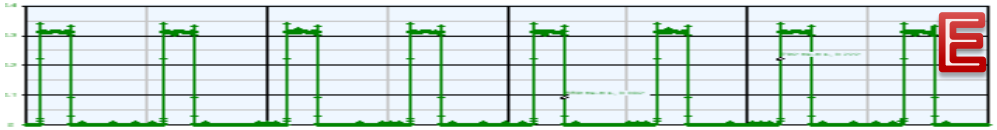
ES:RWR Test



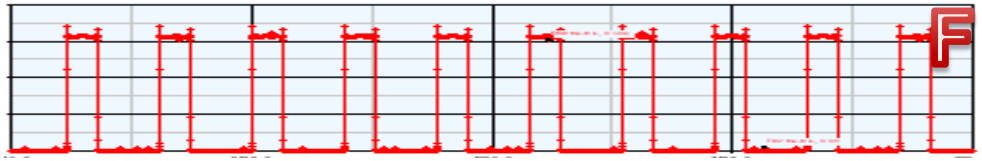




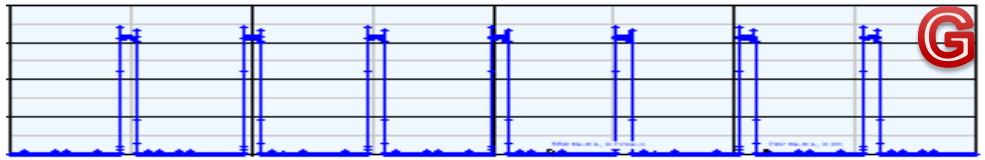
RPI 1 – Separated Emitters by RWR Receiver



RPI 2 – Separated Emitters by RWR Receiver



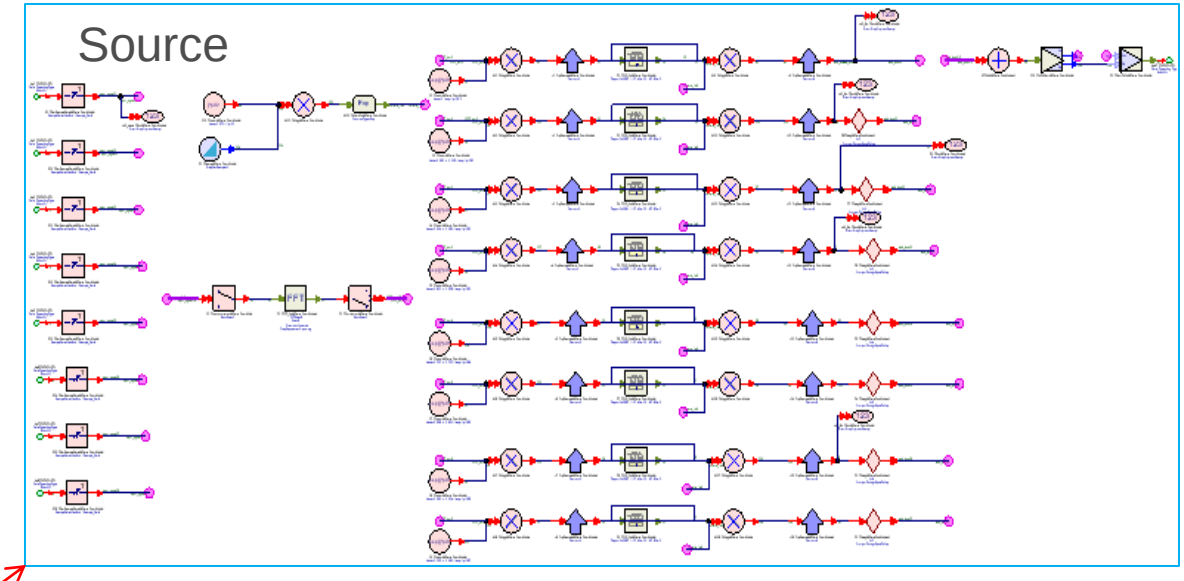
RPI 3 – Separated Emitters by RWR Receiver



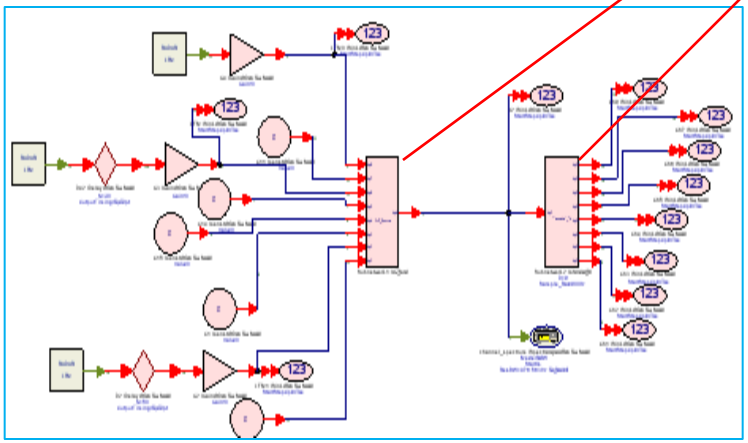
ES: RWR based on Frequency band(s)

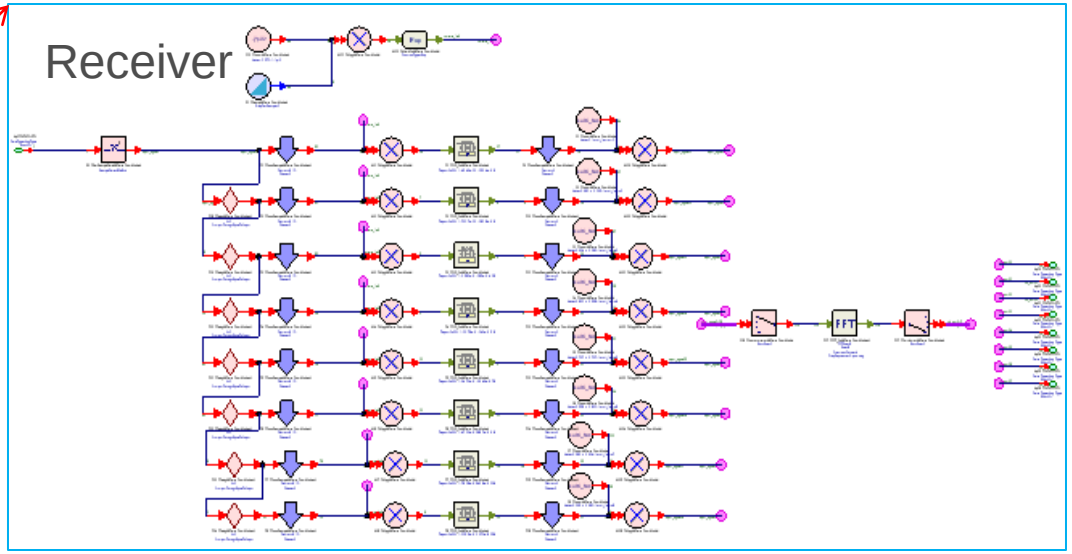
Considerations for RWR modeling:

- Frequency band(s)
- Direction Finding (DF) methods
- Pulse interleaving and resolution
- Emitter identification



RWR Receiver Test Setup

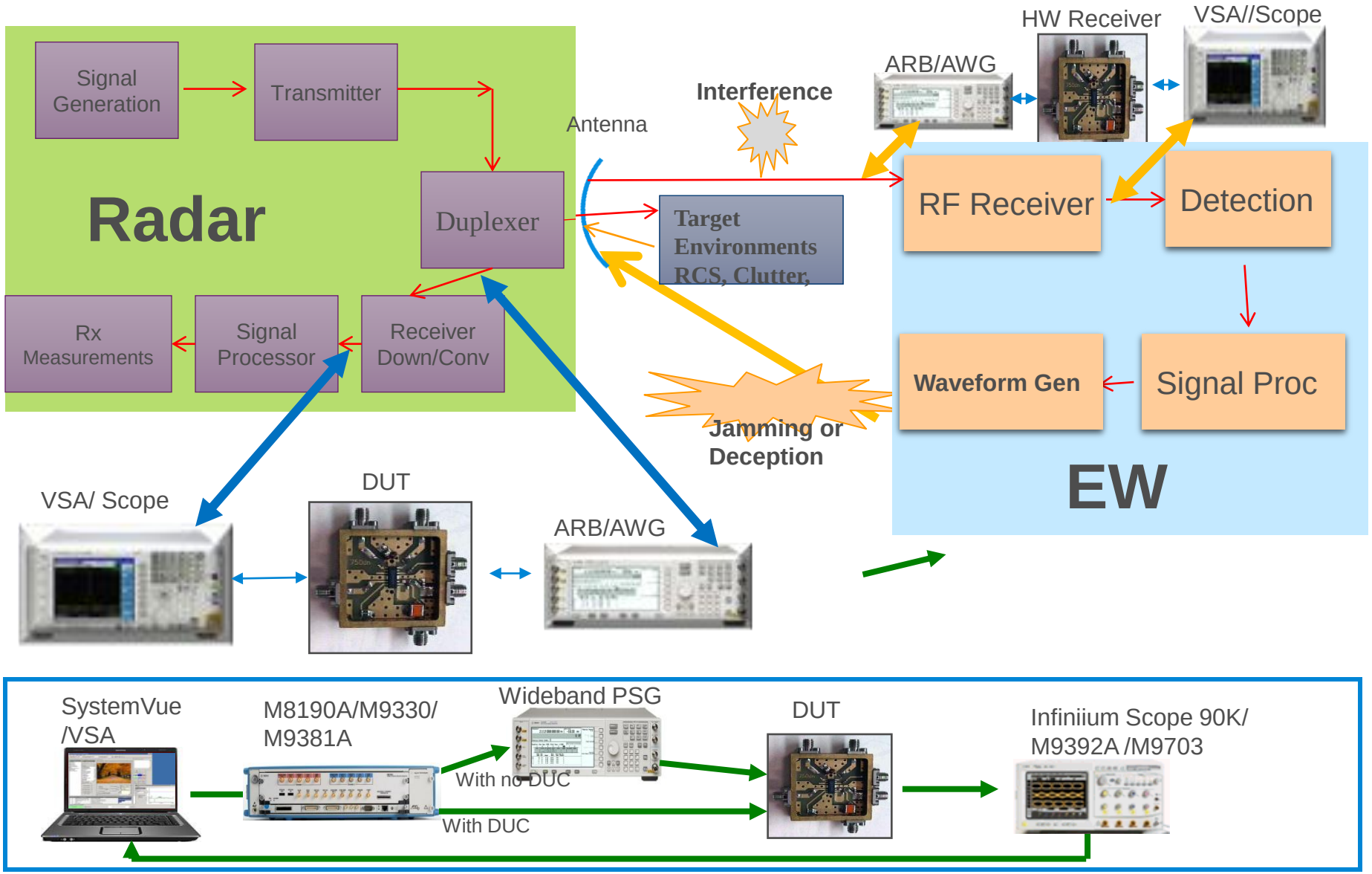




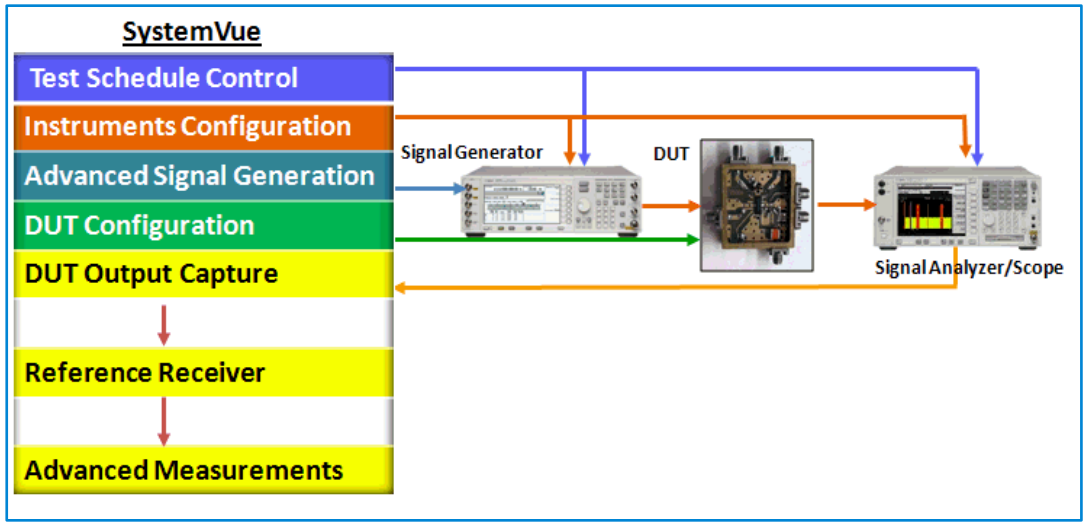
Agenda

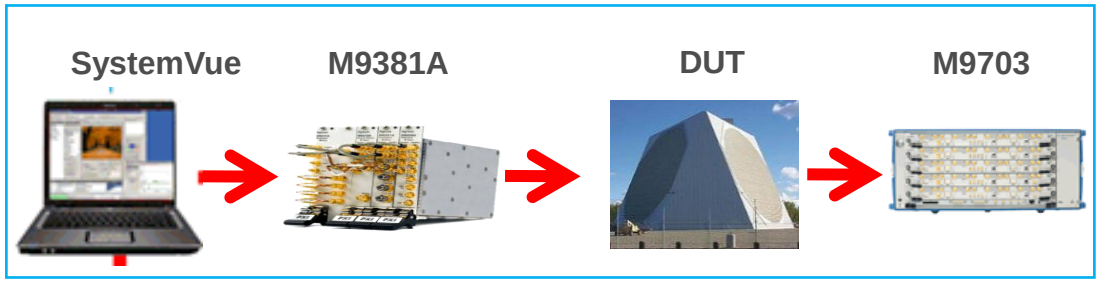
- Radar EW System Test Concept
  - Test Challenges
  - Proposed Test platform
- Basic Waveform Generation
- Environments
- Form Complex Waveforms
  - Signal Combiner
  - Waveform Sequencer
  - Channelization
- EW Key Models and Supported Systems
- Test System Issues
- Summary

Radar EW – Test Platform



Integrated Test System Control





System Test Requirements:

Integrated environment :

Measurements, FPGAs, HDL, Jammers, Clutters

RF Architecture Considerations

- Power Amp w. Nonlinearity
- System Linearization, DPD

Complex Waveforms

- Radar , EW, Interference
- MilCom, SatCom, Commercial

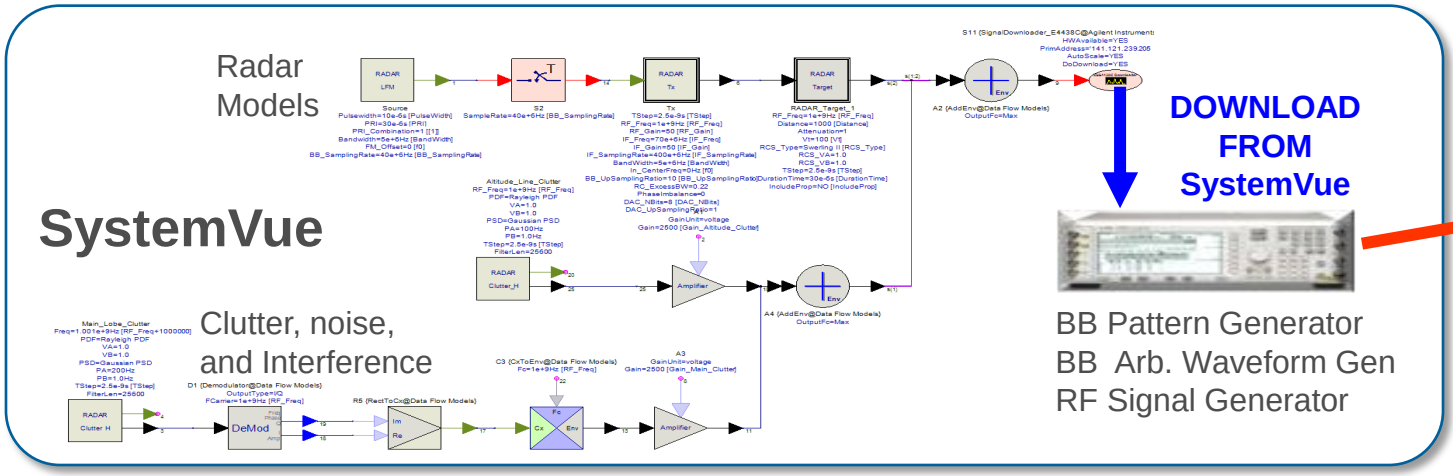
System performance measurements

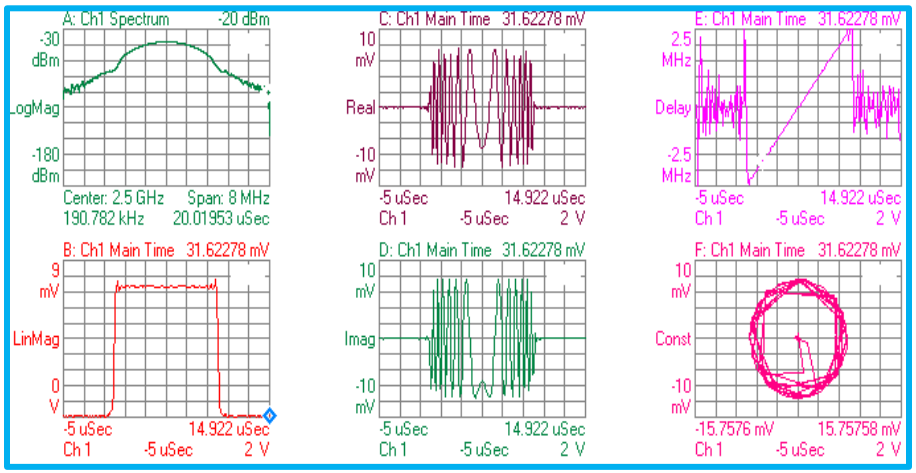
- Sensitivity, selectivity, Dynamic range
- CFAR, Detection Rate
- Imaging Quality

System Test –

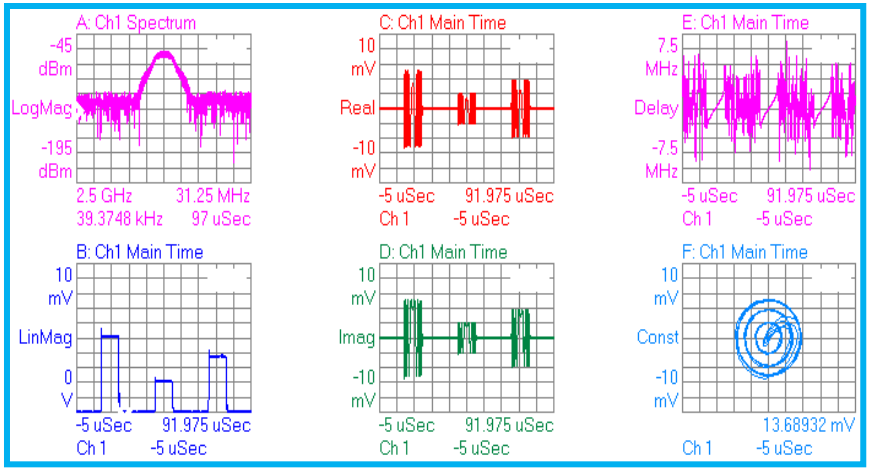
Custom Waveforms + Advanced Measurements + Automated Test

Basic Waveform Generation – Target Return signals



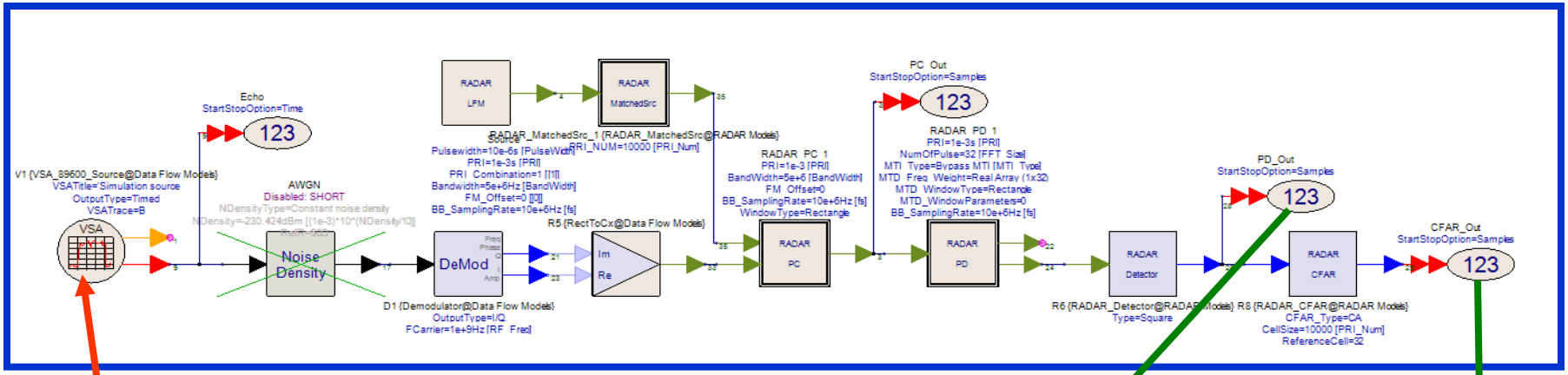


LFM Transmission Signal

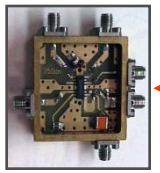


Received Target Return Signal

Advanced Measurements – Receiver Test

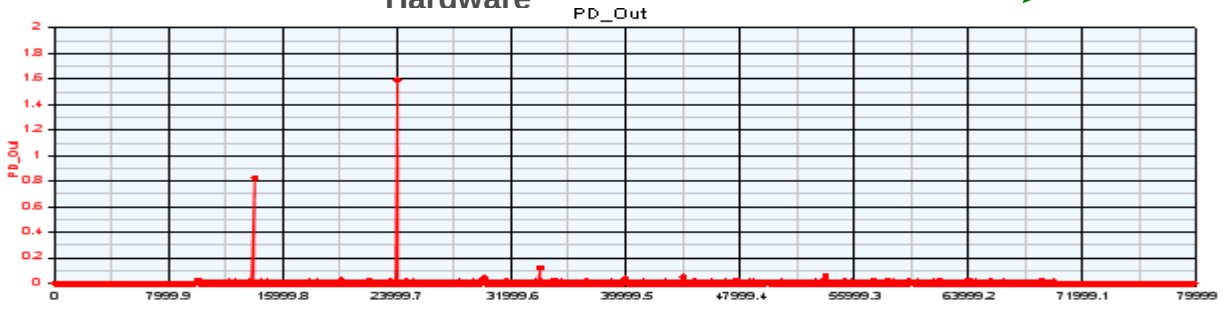


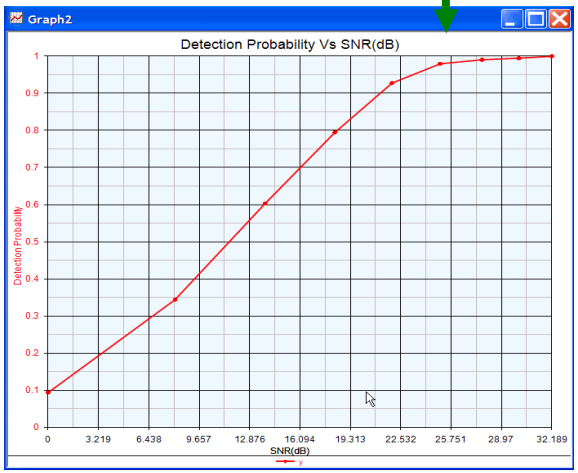
LA, Scope
PSA/MXA/VSA/PXA



Signal Processor
Hardware

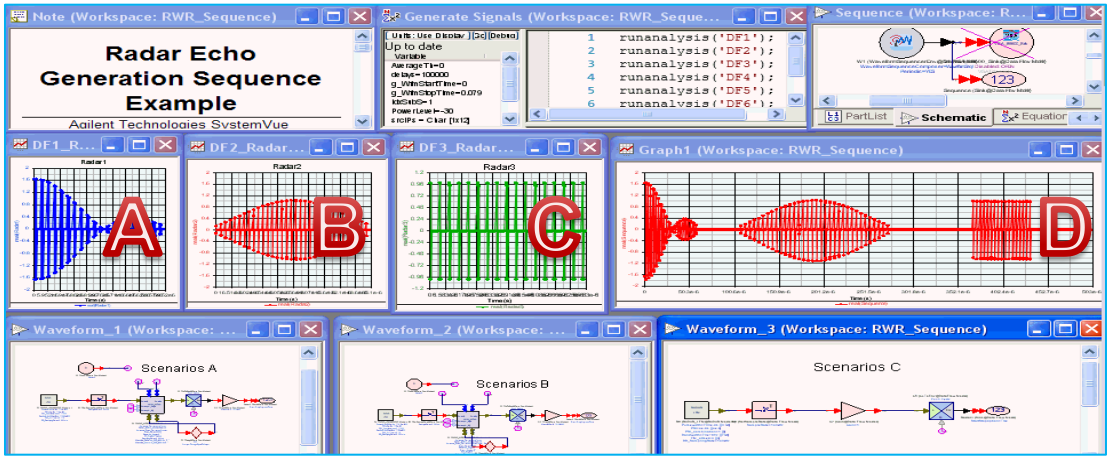
ESG/PSG/MXG/PXB



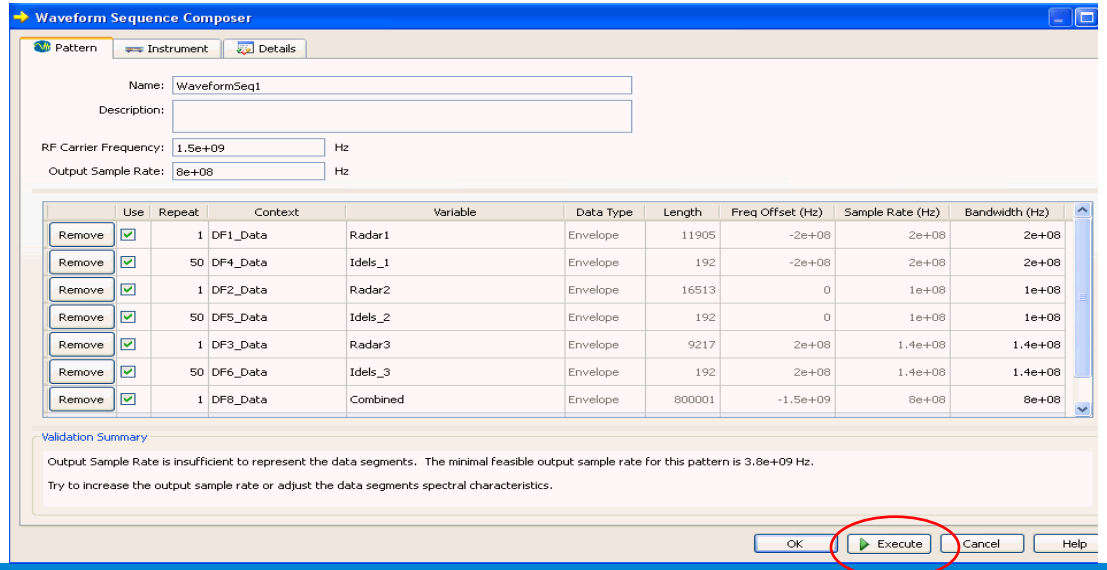


Waveform Sequence Composer

Collect datasets & files with pre-calculated waveform data (→ “segments”)



Assemble segments into a composite waveform using the UI



Then, download!

Signal Combiner

Support for PXI/modular M9381A VSG

What is M9381A? High-performance RF vector signal generator

- Frequency coverage from 1 MHz to 3 GHz / 6 GHz
- RF modulation bandwidth up to 160 MHz (± 0.3 dB flatness)
- Deep waveform memory (1 Gsamples)

M9381A VSG

SystemVue supports

- "Signal_Downloader" simulation sink
- Waveform Sequence Composer

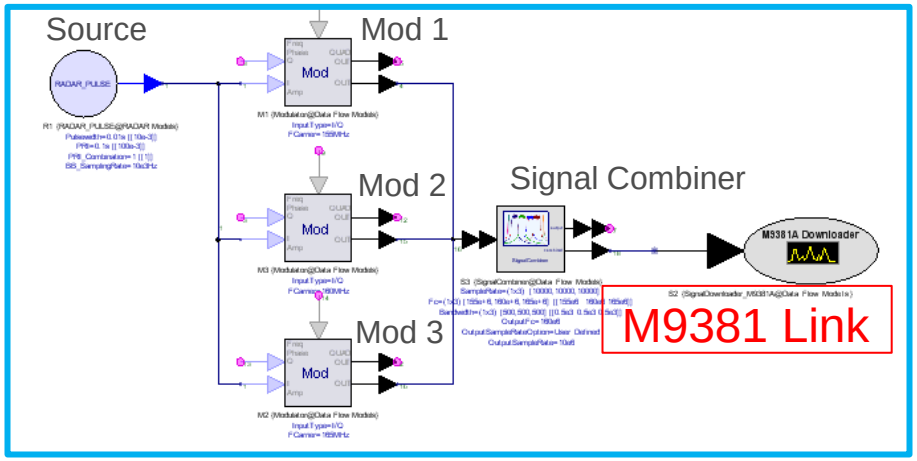


Fig. 1. Download 3 radar Tx Signals to M9381A

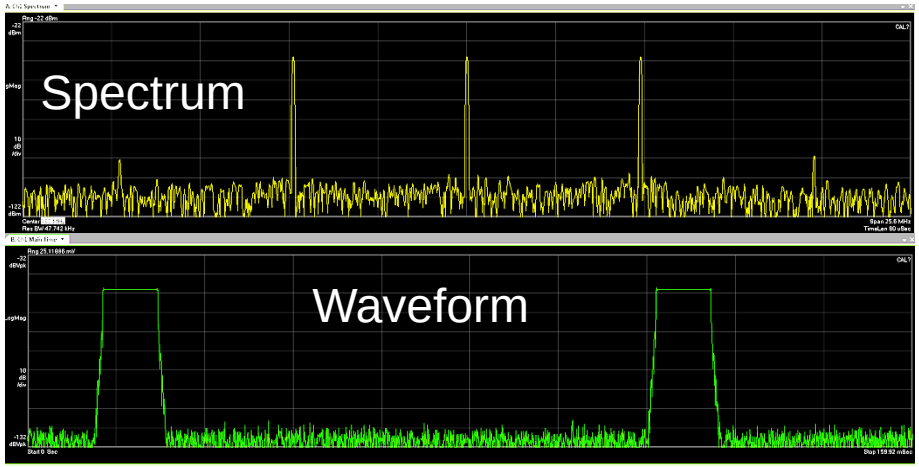
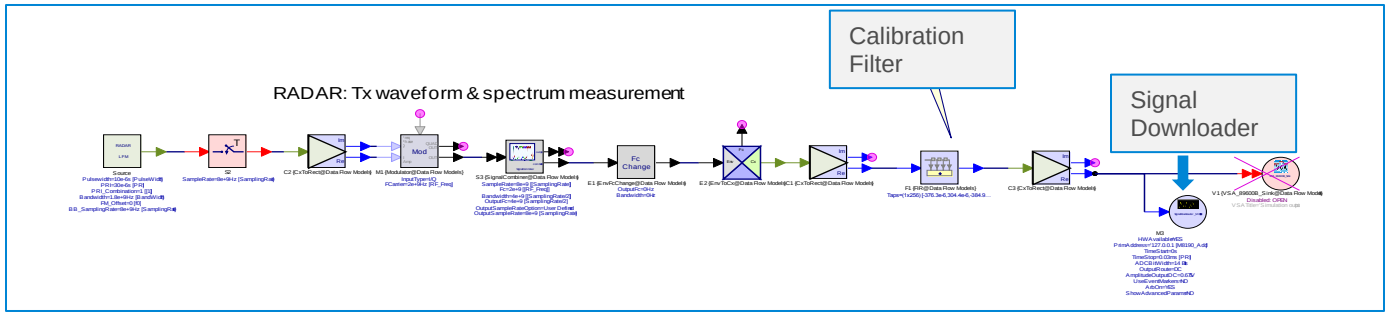
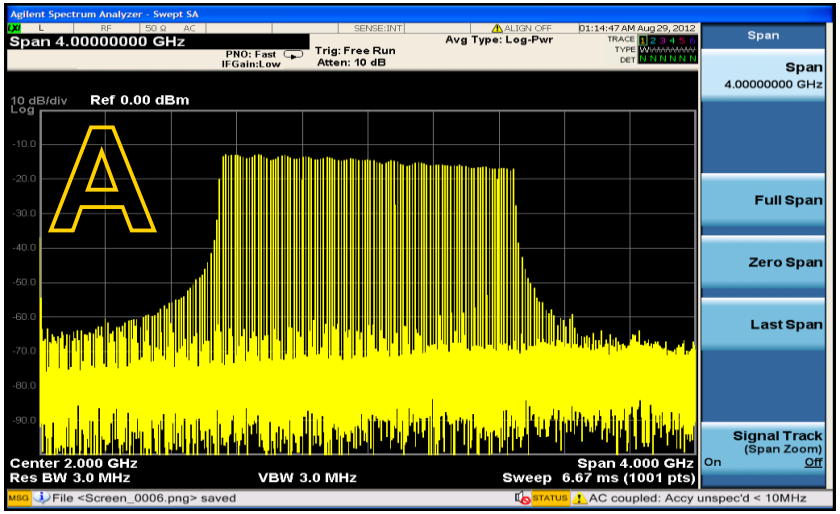


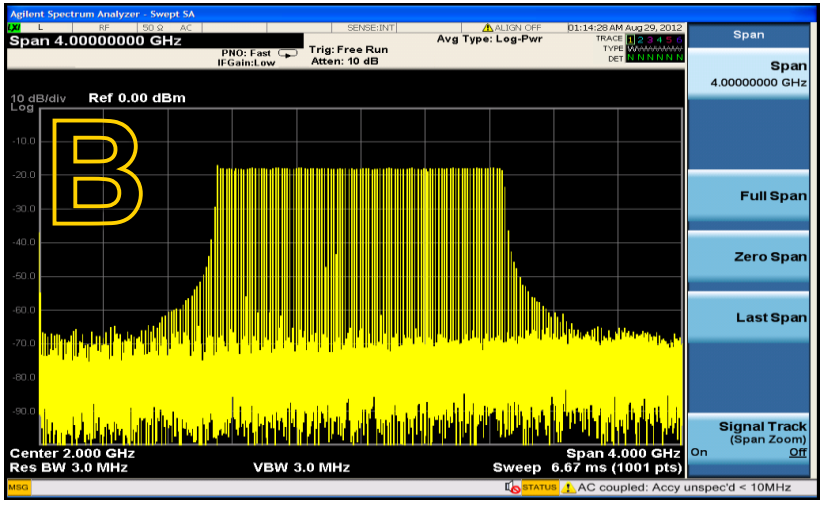
Fig. 2. Downloaded RF signal measured by VSA

UWB Radar Signal Generation with Calibration



UWB Radar Signal Generation with Calibration Filtering for Vector Signals

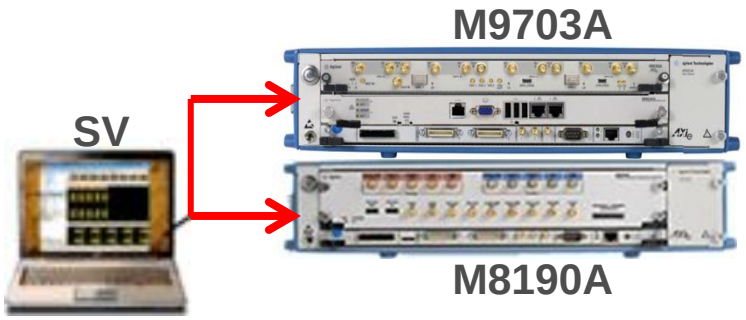


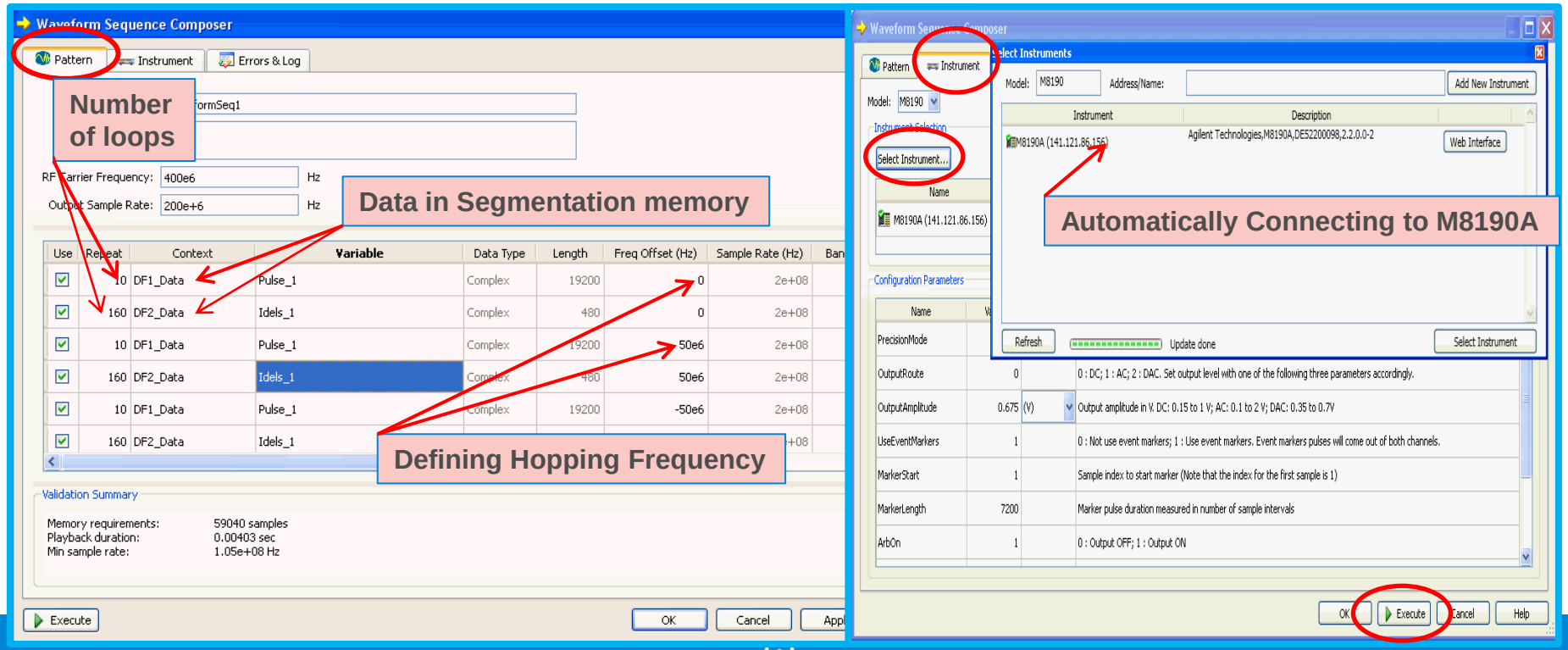


Spectrum of UWB radar with 1.8 GHz bandwidth at 2 GHz carrier frequency
A. Without Calibration. B. With Calibration.

Sequencer supported for generating long sequences

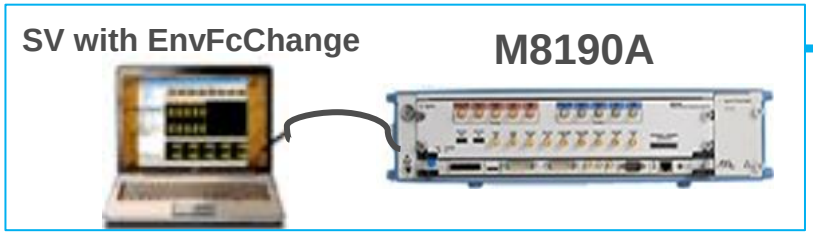
- **Take Advantages of Sequencer, supported by SV Waveform Sequence Composer (WSC)**
  - Avoid to save '0's to HW memory
  - Repeatedly use data segments to save memory
  - User Friendly UI and easy to use
  - No need to write code by users
  - Multi-Emitter signals with frequency hopping for up to 50 seconds of playtime, supported by hundreds of Radar & Comm signals with flexible parameter settings

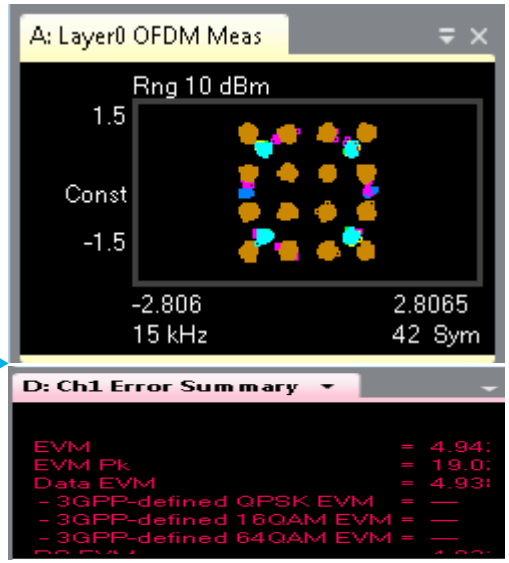




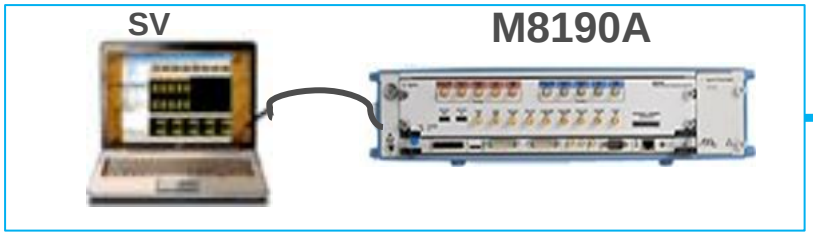
Digital Up Conversion (DUC) Supported in SV

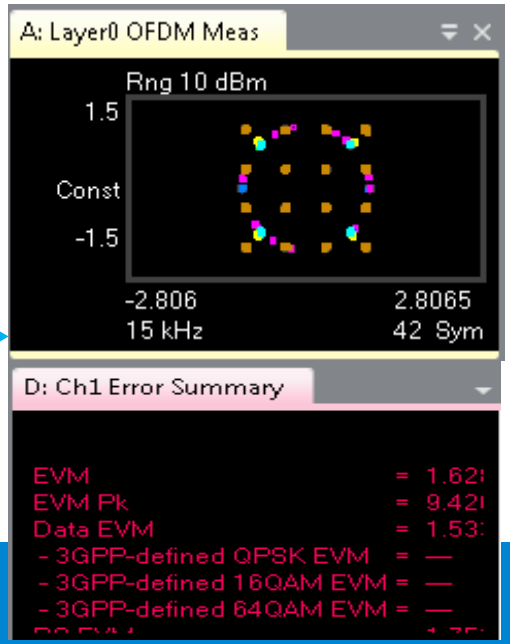
- **Advantages:** Better RF Signal quality as well as better frequency resolution, reduced cost and more efficient memory utilization (support variable sampling rate start from 20.833 MHz to 2.4 GHz).
- **Upgrade Signal Downloader** - Supports DUC SignalDownloader_M8190Env_@Agilent Instruments or SignalDownloader_M8190Env_1CH@Agilent Instruments
- **Upgrade WSC –** Support DUC





Multi-Emitter Generation with no DUC

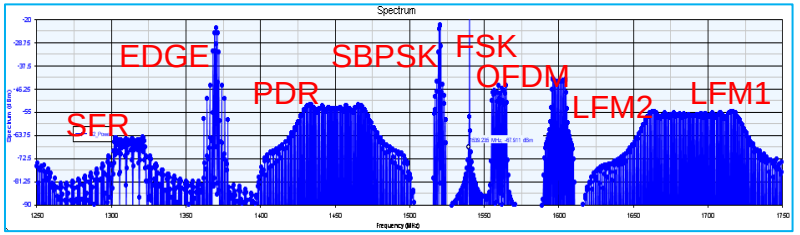


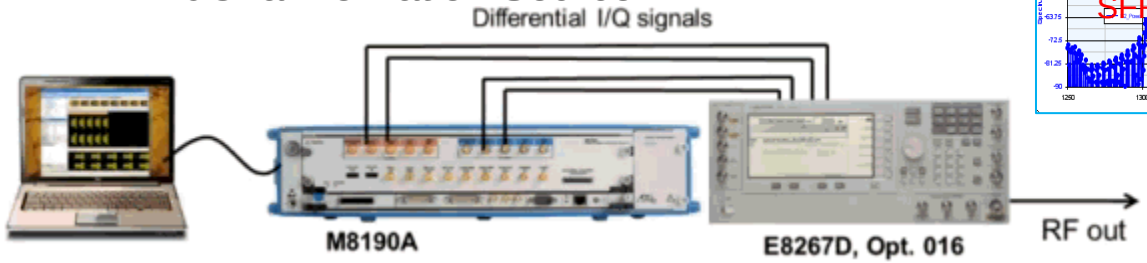


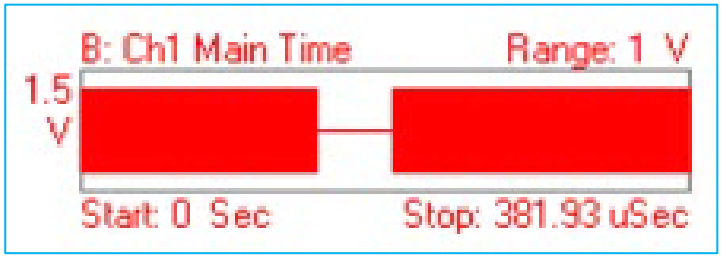
Multi-Emitter Generation with DUC

EW Test Platform

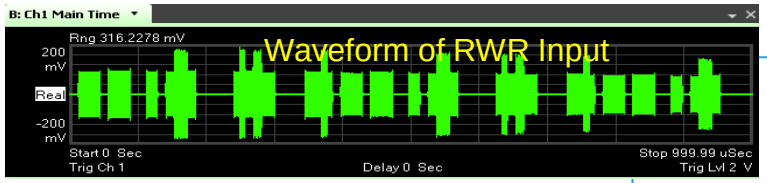
- **Supporting:** EA, EP, ES
- **Multi-Tools for generating EW test signals**
  - Waveform Sequence Composer
  - Signal Combiner
  - Channelization Source

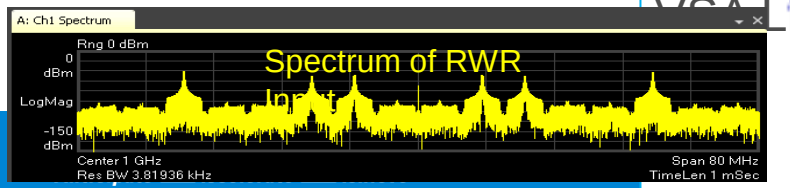


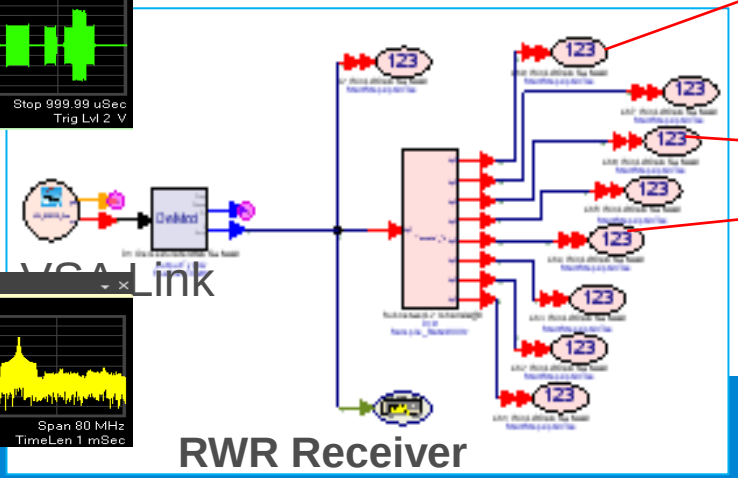


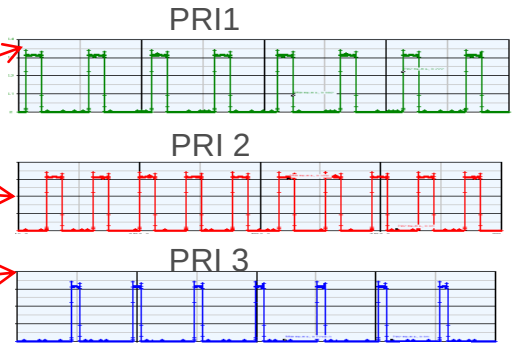


- **EW Signal Processing:** RWR, AOD,DRFM









Example: Generating Long Sequence Using WFS + DUC

Assuming: A LFM transmitter Waveform with Bandwidth=400MHz, PRI = 100 us, Pulse Width = 4us, the Max Samples for M8190A=2 G

The Memory savings can be calculated as below:

- Without WFS the Max Sequence length:

  Max Samples/ (2*Bandwidth)/2 = 2e9/8e8/2 = 1.25 Sec

- With WFS, we only need to save one PRI wave and repeatedly use it,

  so the Max Sequence length:

  Max Samples/(PRI*(2*Bandwidth))/2 = 1.25/1e-4=1250 sec

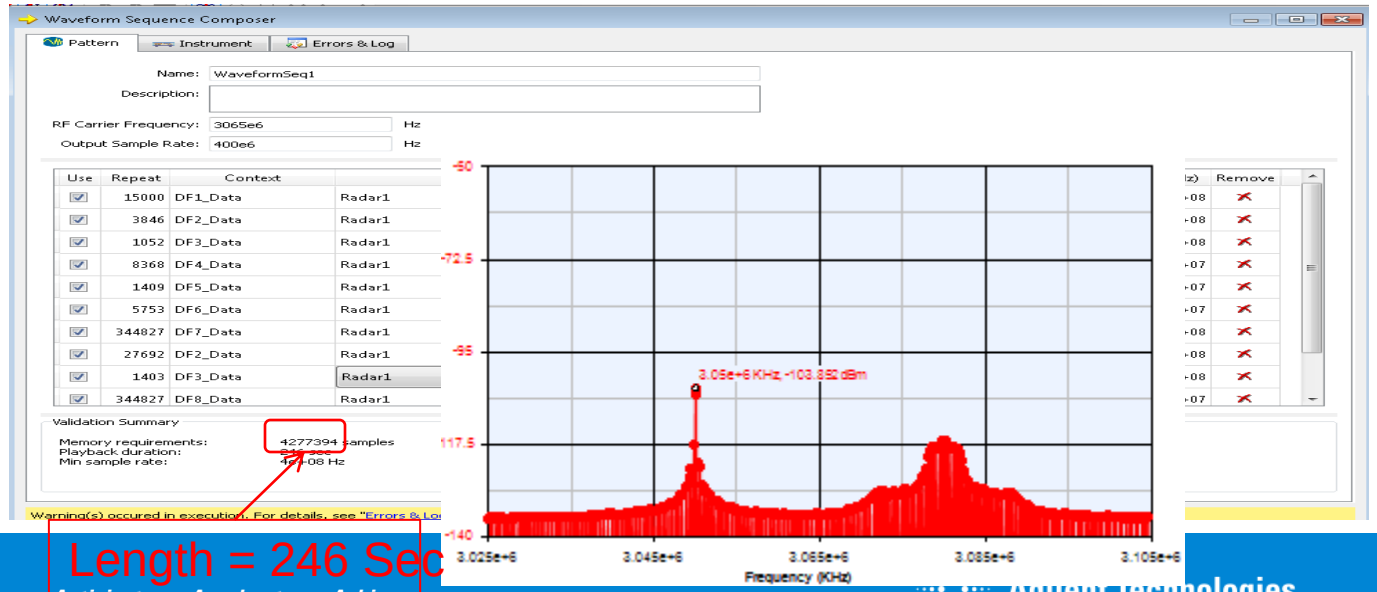
- Memory savings = 10e4

Mode	PRI(uSec)	PW(uSec)	RF(MHz)	Chirp (Mhz/PW)
A1	1000	4.1	3050	0
A2	650	3.2	3050	50
A3	2850	12.2	3050	185
T1	478	1.8	3080	20
T2	1064	1.8	3080	44
T3	478/586	1.8	3080	22
T4	87	0.6	3080	0

Mode	Time in Mode (Sec)
A1	15
A2	2.5
A3	3
T1	4
T2	1.5
T3	2.75
T4	30
A2	18
A3	4
T4	30

Example: Generate Complex Signals defined by the Tables

Configured ComplexSignals In SV UI



Length = 246 Sec

Summary

- Some of the challenges encountered for Radar EW test have been discussed

- Proposed solution has the following advantages
  - **Generate Complex Waveforms for transmitters, receivers and EW system test**
  - **Radar EW environments are considered including Clutter, Interference, Jamming/Deception**
  - **Advanced measurements for System performance evaluation are provided including Sensitivity, Dynamic range, False alarm, Detection Rate, Imaging Quality and also Radar parameter estimation are provided.**
  - **System automatically Test can be setup with the configuration of Custom Waveforms + Advanced Measurements + Automated Test**
  - **Strong integration capability has been shown. The SW can integrates Signal source in SW or HW, HW instruments, Custom FPGA and RF Device together for test and verification purpose.**
  - **Lower product risks, Reduce cost, Higher system performance.**
  - **Customization and flexibility and easy to use**