Reducing MIMO and AESA Radar Design Risks with Earlier System Design Validation

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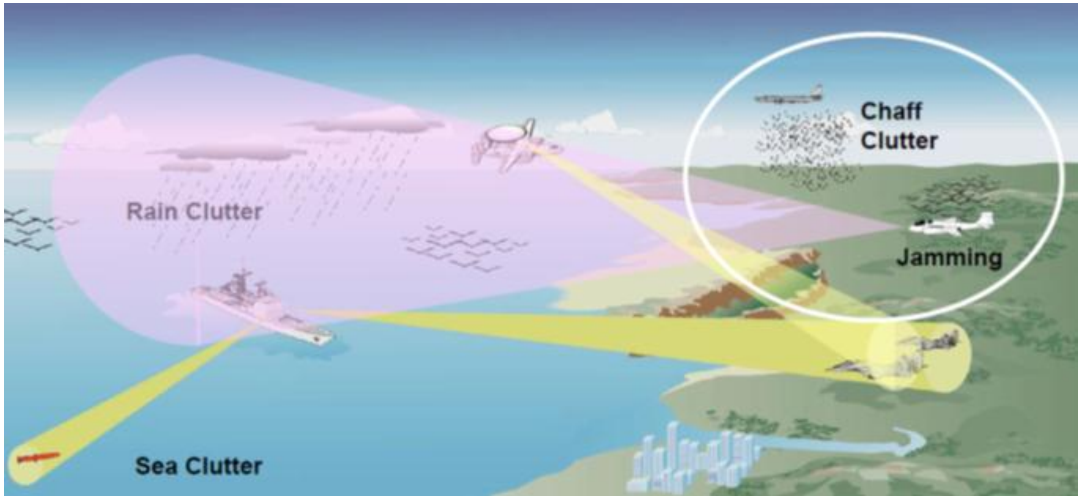
Agilent Technologies, Inc.

Agenda:

- Challenges in designing Multi-Antenna Systems
- Proposed Design Solutions – Introduce Generic Framework
- Phased Array Radar Simulation
- MIMO Radar Simulation

Challenges for Multi-Antenna Radar Engineers

- Moving Platform
- Moving Volume Target
- Cross-Domain Architectures
- Complex Environments



Proposed Solution to Addresses Design Challenges

1. Moving Platform
2. Detecting moving Target
3. Complex Architectures
4. Complex Environments

Advanced

Radar EW System

Design Tool

SystemVue
Electronic System-Level Design

Reduce Risks

Lower Cost

Faster Development

Higher performance

Easy to use

Radar Scenario Simulation Framework : 3 Layers

3. Platform Setup
(Trajectory Layer)

- Tx Moving Platform – 1:N
- Moving Target With Multi-Scatters : 1:K
- Rx Moving Platform- 1:M

2. Antenna Setup
(Antenna Layer)

(Trajectory Layer)

- Tx Antenna Location- 1:N
- Rx Antenna Location- 1:M

1. Data Flow Setup
(signaling layer)

Source → Beamformer → T/R, T/R, T/R, T/R

Moving Target
Interference
Clutter
Jamming

T/R, T/R, T/R, T/R → Beamformer → Receiver → Display/ Measurements

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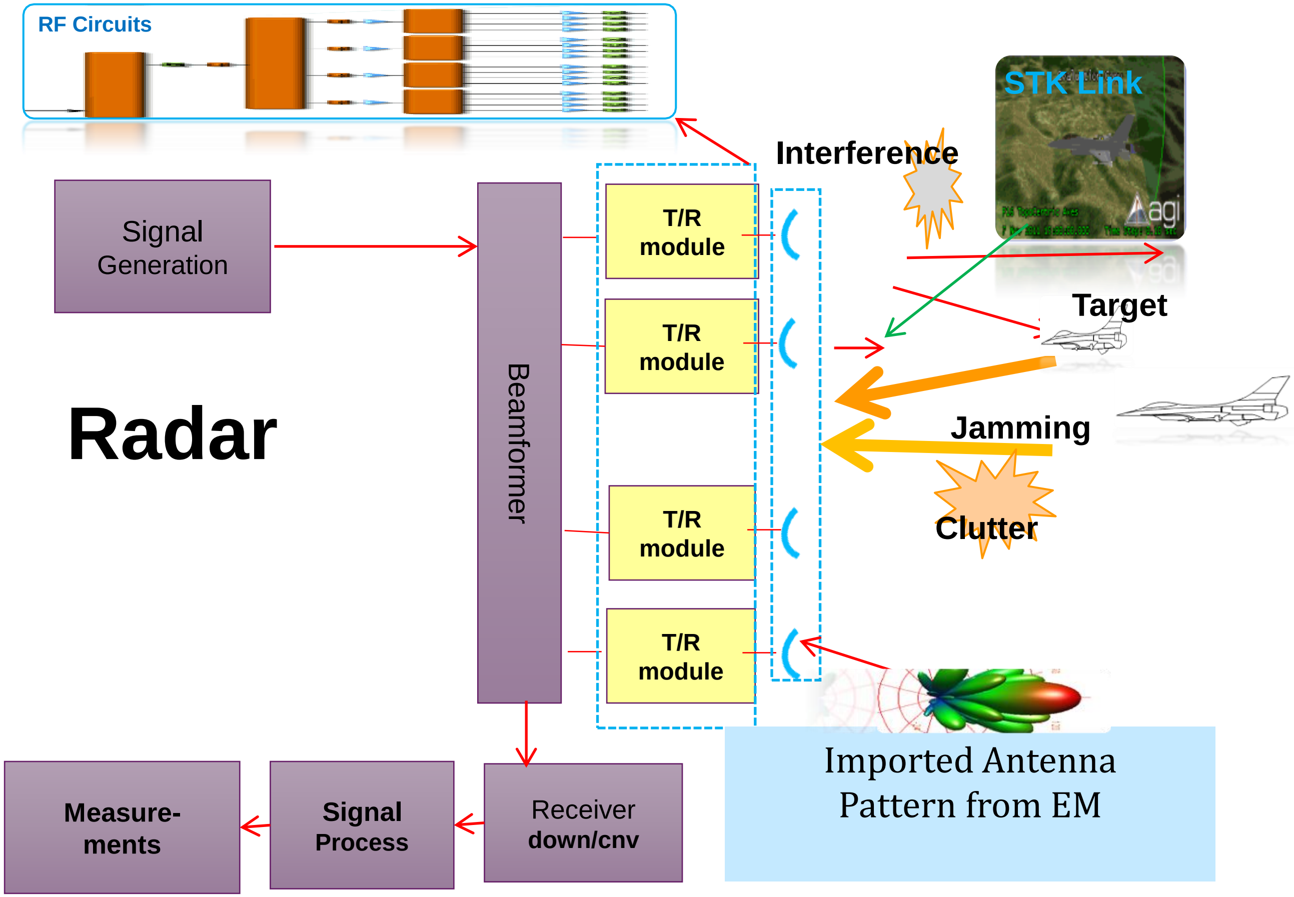
1. Signal Layer Designs

Challenges

1. ***Support DSP, Cosimulation with RF as well as EM***
2. ***Include real world environments such as Interference, target RCS, Clutter, Jamming, and STK link for flight test***

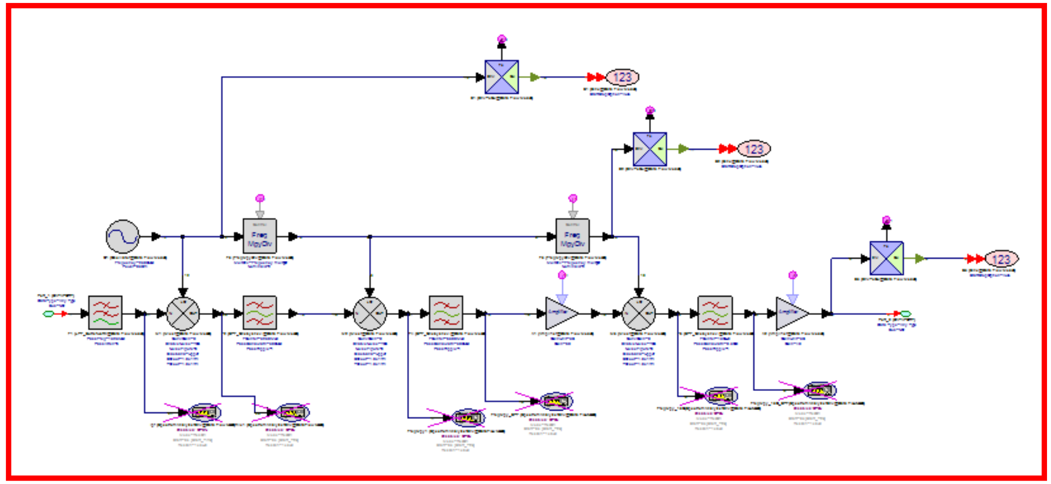


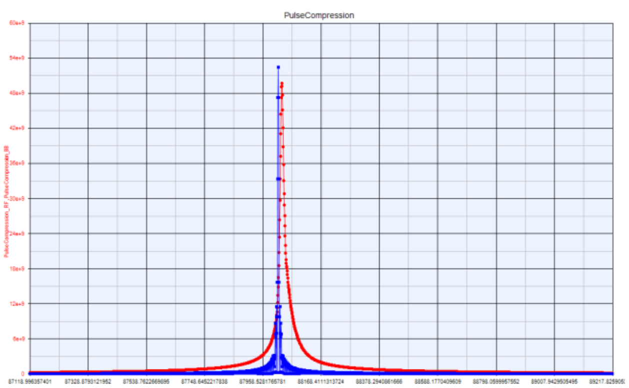
Algorithm Design in Signal Layer

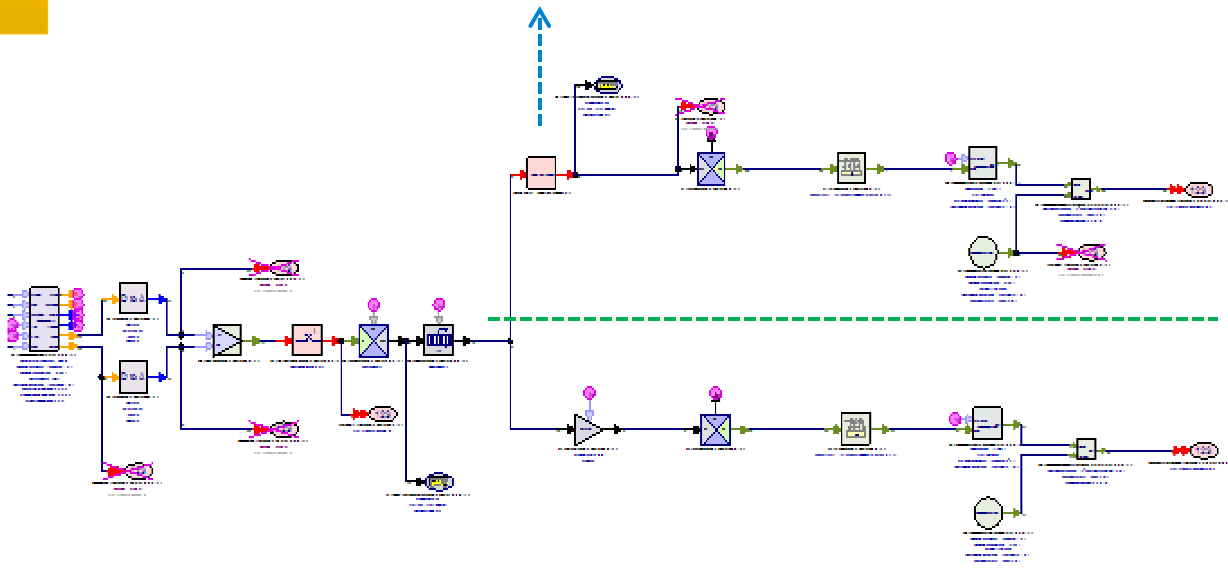
Algorithms Simulation and Verification

↓

Algorithms & RF mixed signal Simulation and Verification



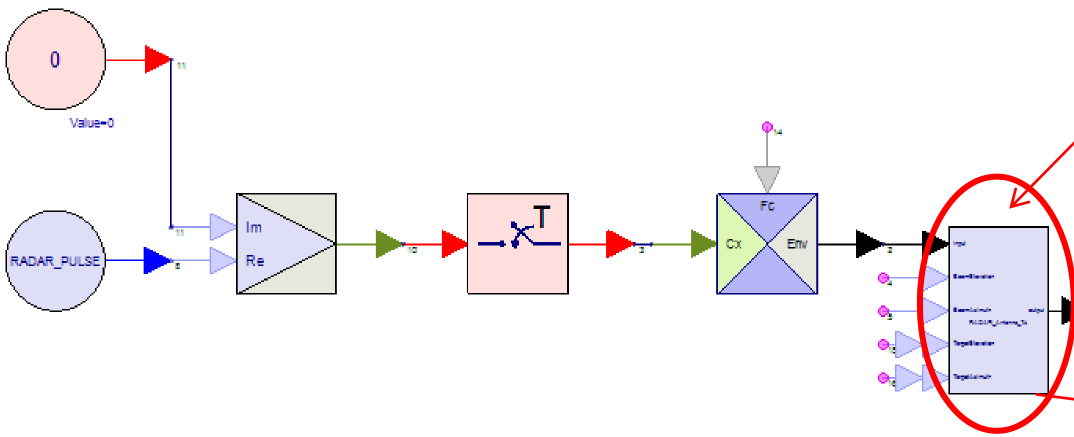


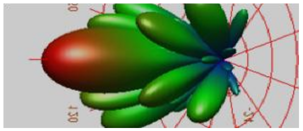


Models to support Radar EW Design Layer

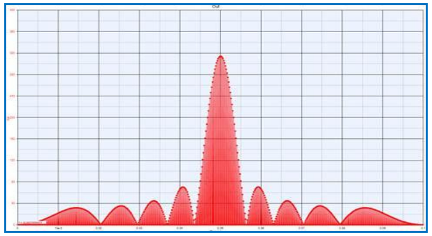
	Basic	Advanced
Source	CW Pulse, LFM, NLFM, FMCW, Binary phase coded (Barker), Poly phase coded (ZCCode, Frank), PolyTime, FSK HP, Arbitrary PRN	DDS, UWB, SFR, SAR, Phased Array, MIMO
RF Behavior	Tx and Rx Front-end, PA, LNA, Filters	DUC, DDC, ADC, DAC, T/R Modules
Antenna	Antenna Tx & Rx	Phased Array Antenna, Tx & Rx
Environments	Clutters, Jamming, Interference	Moving target, Multi Scattering RCS, STK-Link
EW	Detection, EP, ES, EA	Receiver, DOA, Dynamic Signal generation, DRFM
Signal Processing	Pulse Compression, Detection & Tracking, CFAR, MTI, MTD	STAP, SF Processing, Beam forming, Adaptive Phased Array Receiving
Measurements	Waveform, Spectrum, Group Delay	Imaging Display, Detection Rate, False Alarm Rate, Range & Velocity Estimation, Antenna Pattern 2D&3D
Moving Platform		Moving Platform Tx & Rx
Systems	CW Pulse, Pulse Doppler, UWB FMCW, SFR, SAR	Phased Array MIMO

Antenna Model





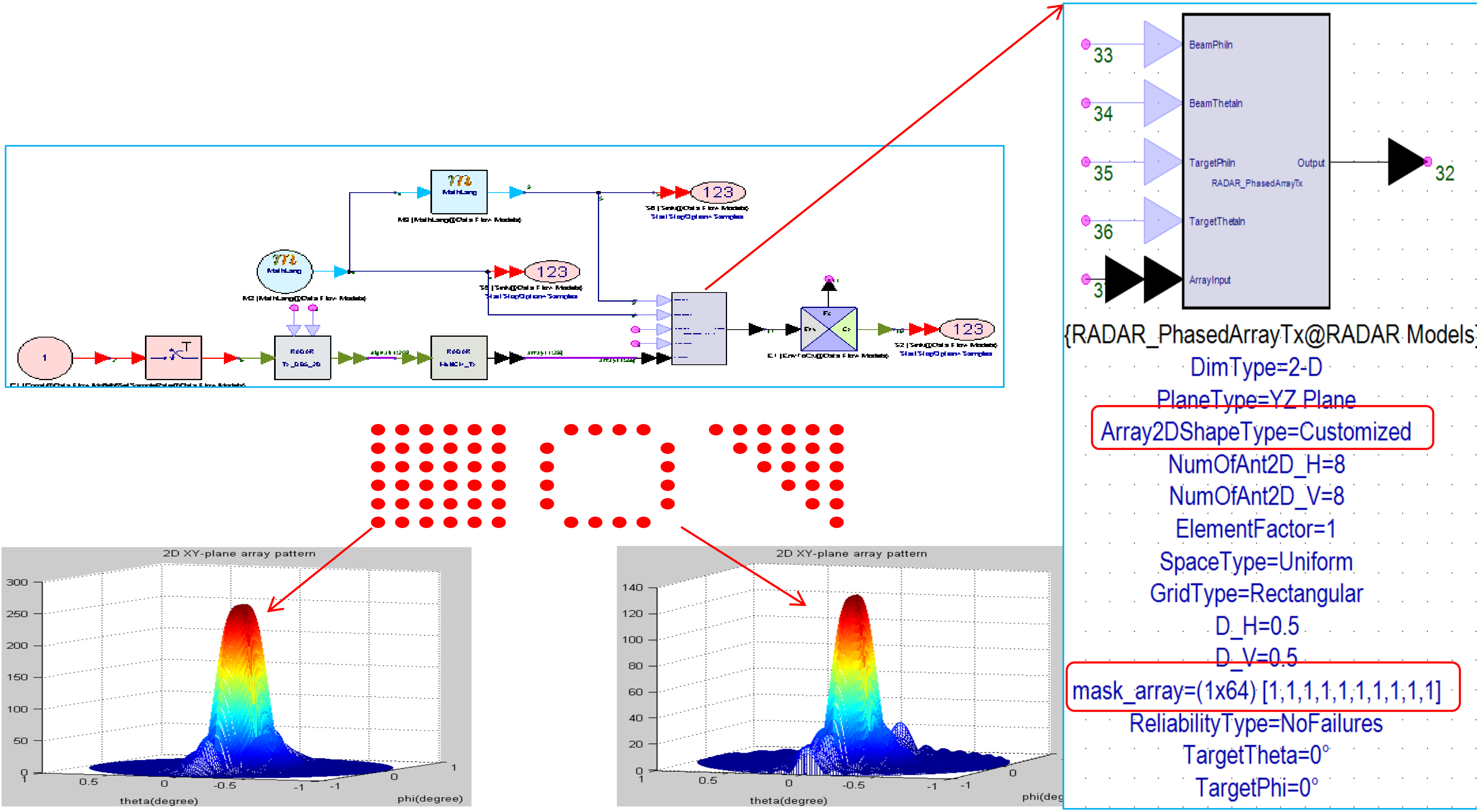
Imported Antenna Pattern



- 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, Bidirectional Sector scan , Unidirectional Sector scan, Bidirectional raster, Unidirectional raster.
- Moving target scenario

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	0:Circular
ElevationAngle	1:Bidirectional Sector
TargetAzimuthAngle	2:Unidirectional Sector
TargetElevationAngle	3:Bidirectional Raster
BeamAzimuthAngle	4:Unidirectional Raster
BeamElevationAngle	0

Phased Array Antenna Model



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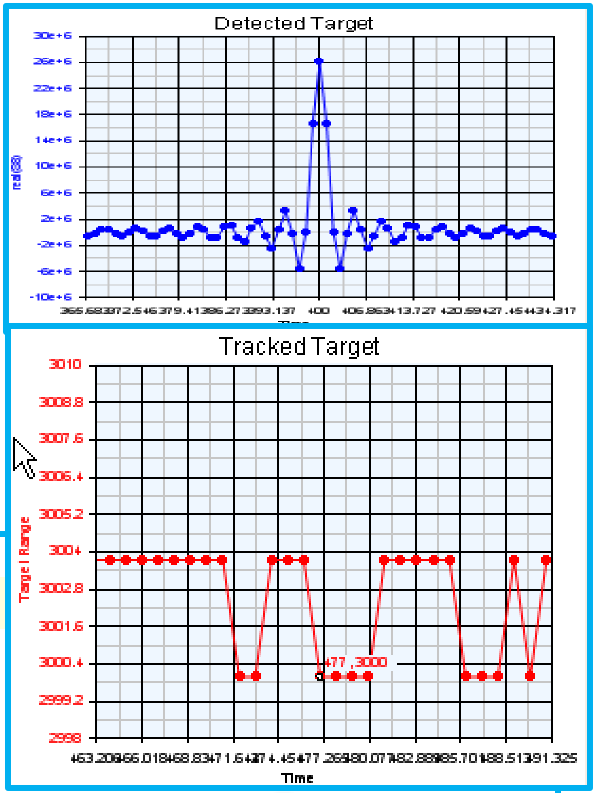
Wavegate and update Pulse Compression

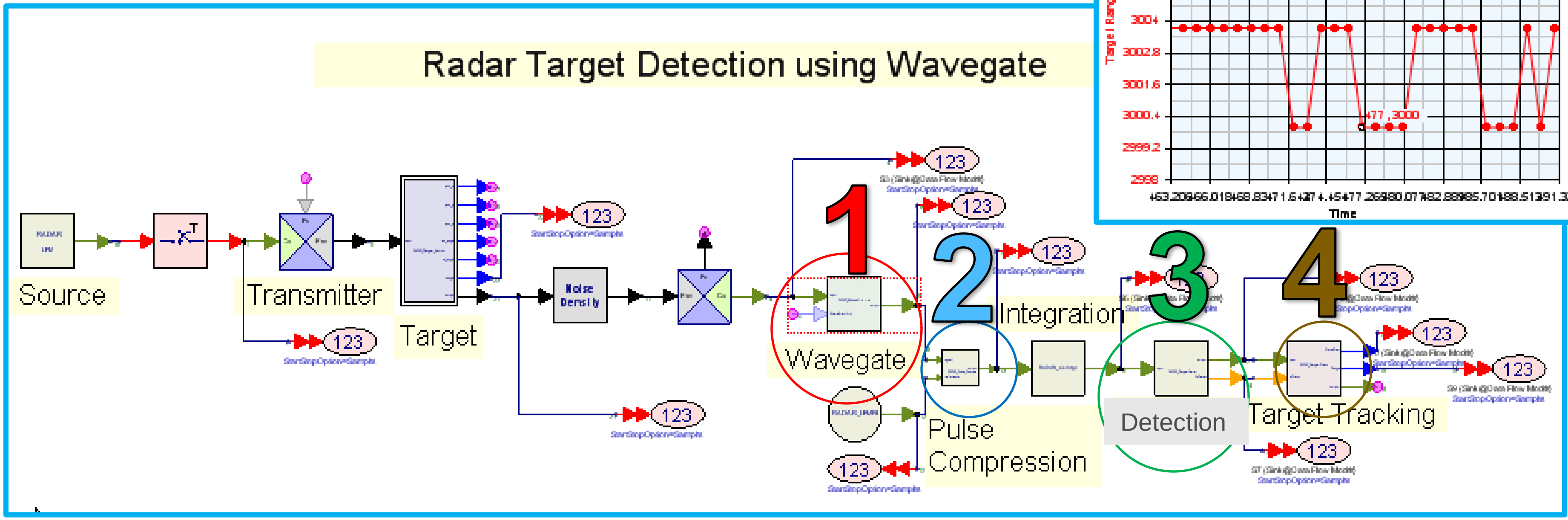
1. Unique Wavegate model: The wavegate refers to a fraction of time window in one PRI for efficient simulation.

2. Update Pulse Compression model: It is implemented in Frequency domain with a pulse compression algorithm which is widely used in the radar system.

3. Radar Detector: This model is used to detect the target in the noise environment based on improved Bernoulli algorithm.

4. Target Tracking: This model is used to track the target and measure the target range when the target is detected.

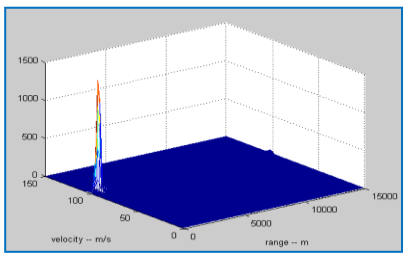


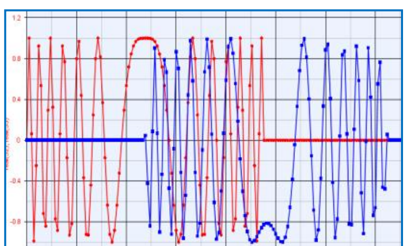


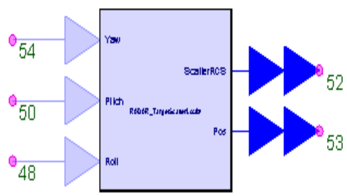
Moving Target Model

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

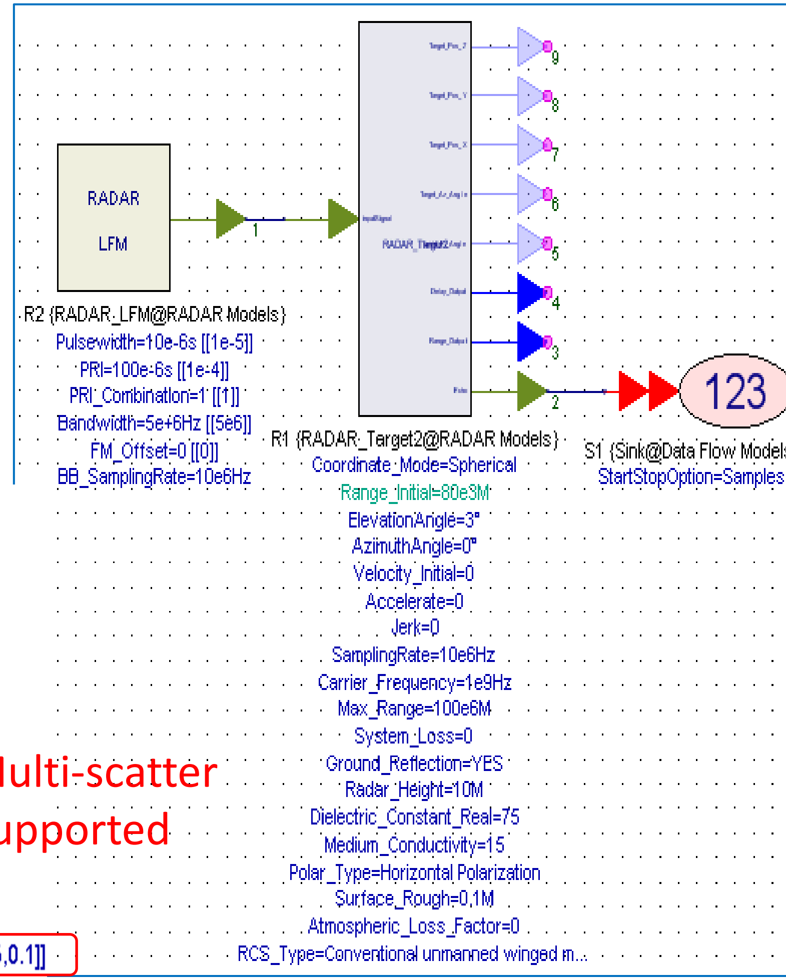
0:Conventional unmanned wing
1:Small single-engine aircraft
2:Small fighter aircraft or 4-pas
3:Large fighter aircraft
4:Medium bomber or jet airliner
5:Large bomber or jet airliner
6:Jumbo jet
7:Small open boat
8:Small pleasure boat
9:Cabin cruiser
10:Large ship at zero grazing a
11:Pick up truck
12:Automobile
13:Bicycle
14:Human
15:Bird
16:Insect
17:UserDefined





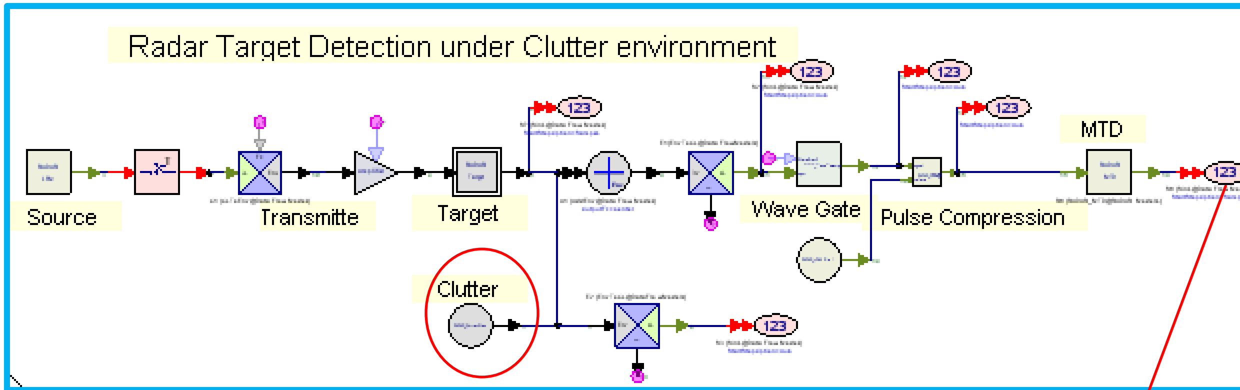


Multi-scatter Supported



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

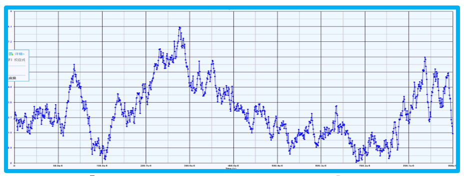


Clutter Model

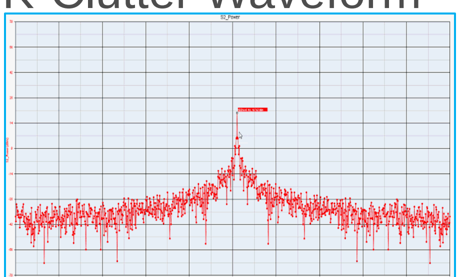
Name	Value	Units
RF_Freq	10e9	Hz
SampleRate	10e6	Hz
PRF	10e3	Hz
PDF	0:Rayleigh PDF	
Variance		
PSD	0:Gaussian PSD	
Fd		
PSDVariance		
FilterLen		
Seed	1234567	( )
IsCoherent	1:Coherent	( )

0:Rayleigh PDF

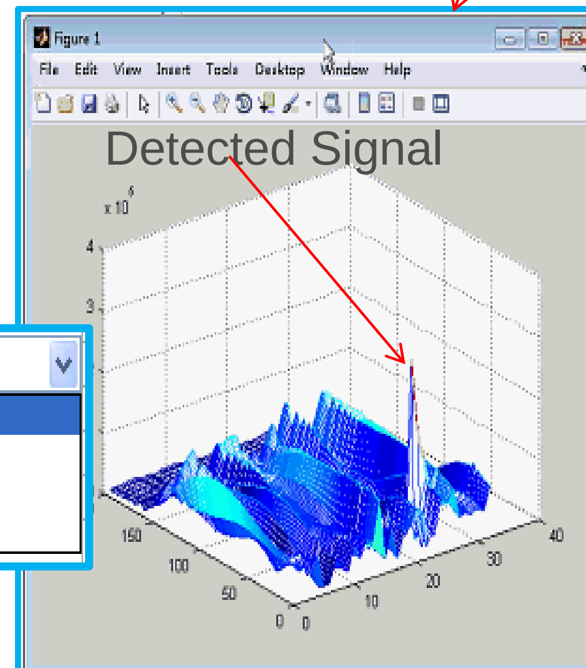
- 0:Rayleigh PDF
- 1:LogNormal PDF
- 2:Weibull PDF
- 3:K PDF



K-Clutter Waveform

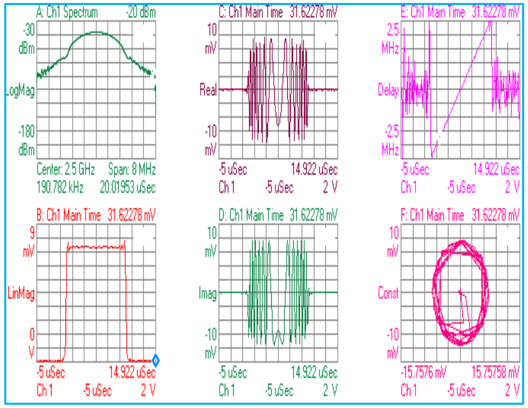


K-Clutter Spectrum

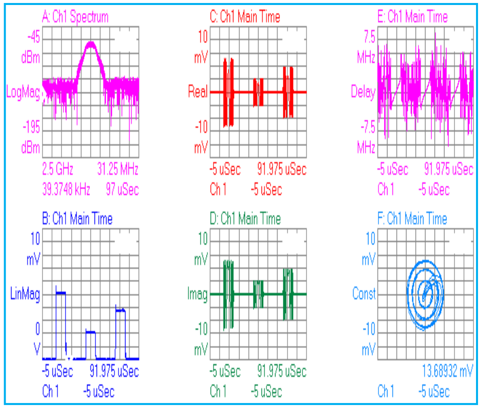


Radar Measurements

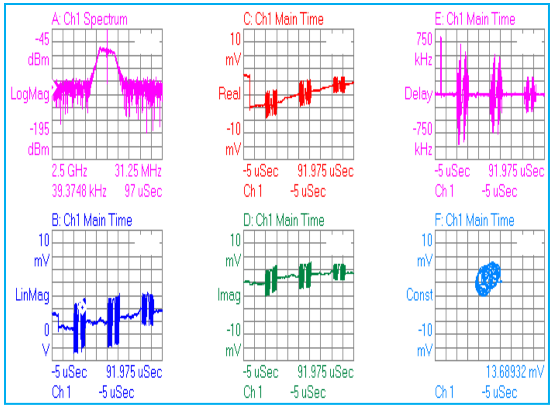
Radar Measurements: Basic measurements: Waveform, Spectrum, and SNR. Advanced measurements Detection probability, False Alarm probability, Parameter Estimation and Antenna Pattern Measurements



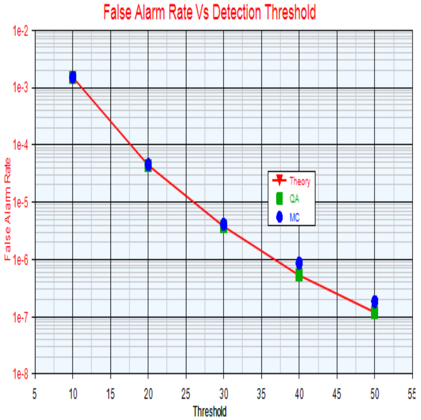
Transmission signal



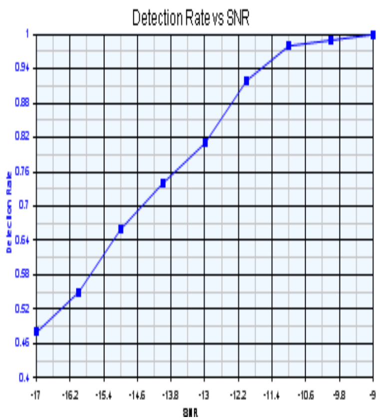
Target return signal



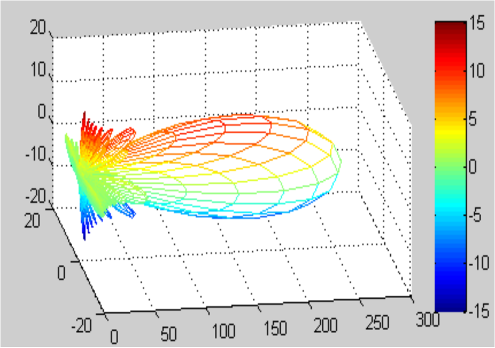
Target return signal with clutter



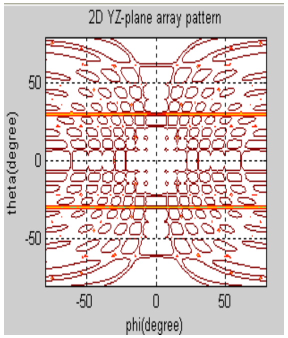
False Alarm Rate



Prob. Detection vs. S/N



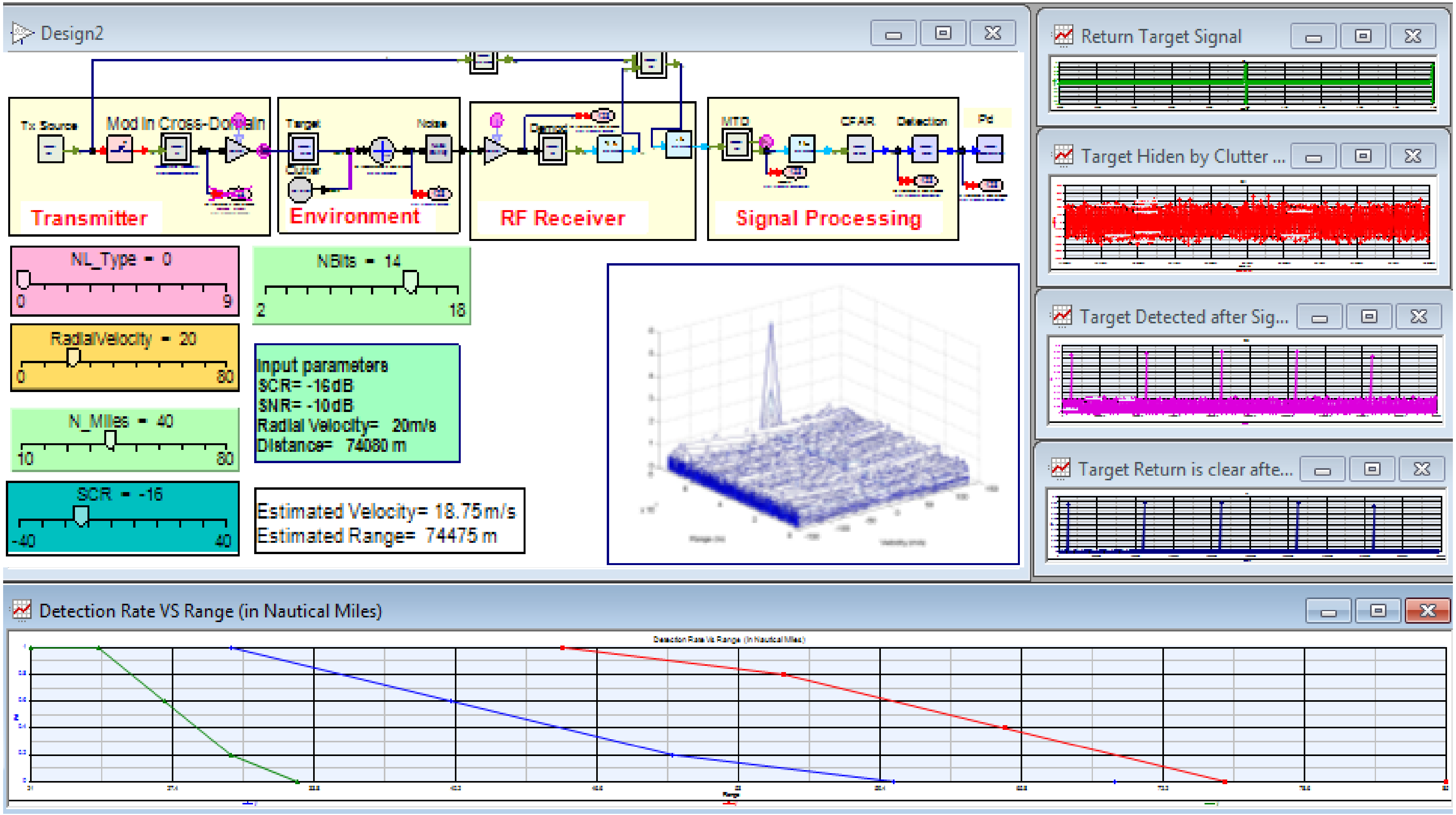
3D Antenna Pattern



2D Antenna Pattern

Template for Pulse Doppler Radar

To do a better job for winning new business by quickly putting together proposals and plans



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How to use the template

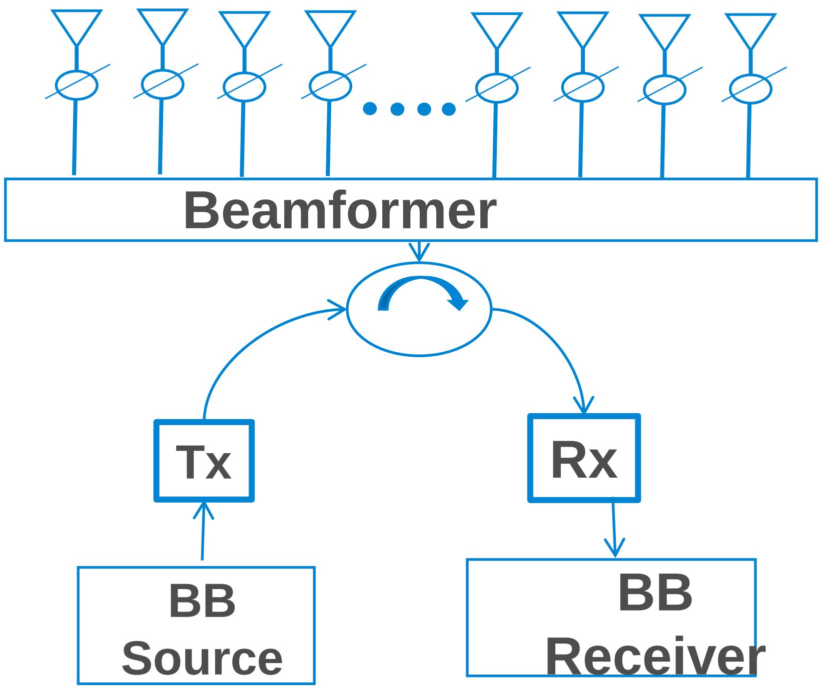
- **Allow the user to quickly put together a PD system for algorithm design, with**
    - Complete PD system with advanced signal processing and No-need to start from scratch
    - Cross-domain architecture supported
    - Complex environment
    - Advanced measurements
    - Allow inserting custom algorithm for designing and validation and re-use user-IP
- **Easy to use**
    - Design, main measurements and estimated parameters are shown in top level
    - Key parameters specified are easy to modified by using sliders
    - One click to get all results, including 3D plot, measurements and parameter estimations

Phased Array Radar

- Why Phased Array Radar?
  - Achieving high dynamic range to allow the use of **a** large PA
  - Achieving rapid volume searches while using **an** aperture with an inherently narrow beam width
  - Maintaining robust wideband imaging performance, even in the presence of strong land-based jammers.
- Passive Antenna System (PAS) vs. Active Antenna System (AAS)
- Phased Array Radar application
  - Digital Array (DAR)
  - Array Adaptive Processing

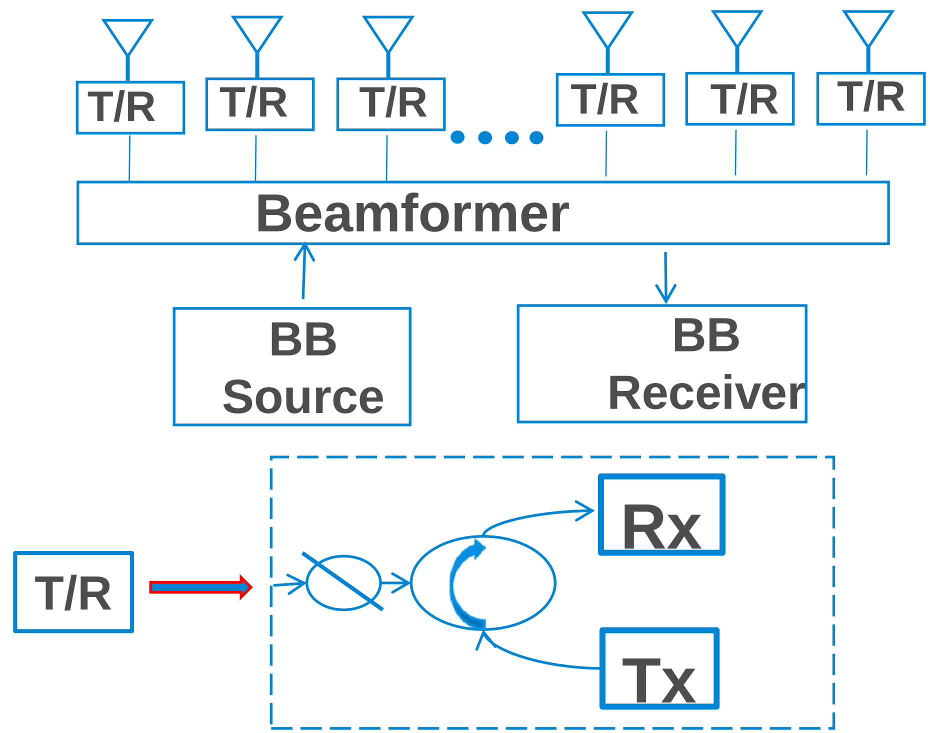
PESA vs. AESA

Passive Antenna System



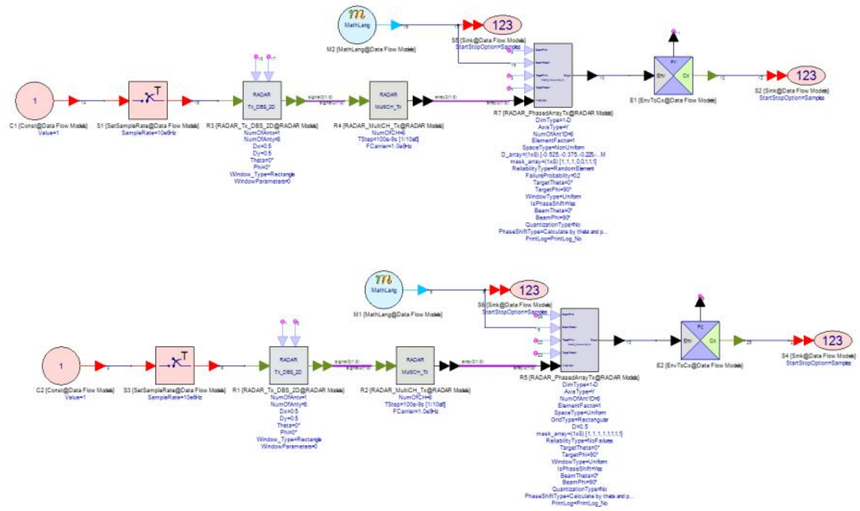
- Array Antenna driven by single large transmitter HPA
- First receive LNA after beam is formed
- Large signal loss between radiating element and transmitter/LNA
- Antenna connects to transmitter and receiver

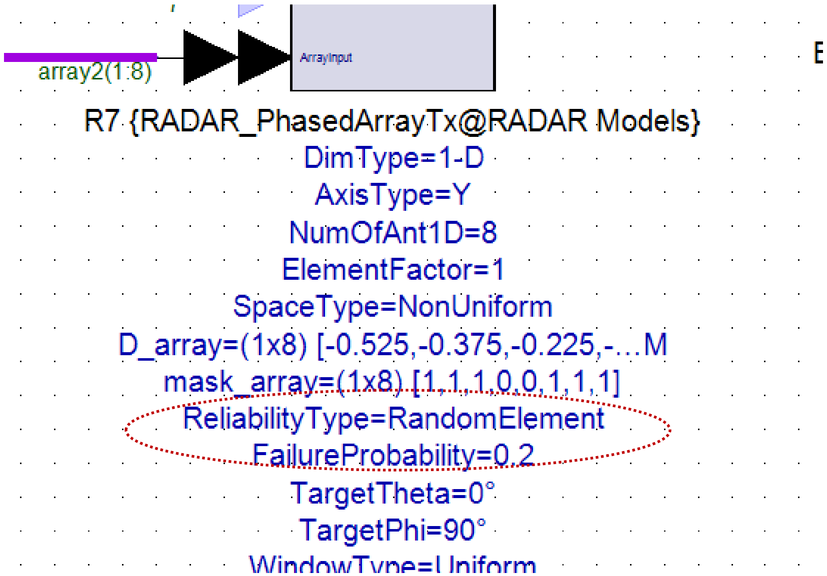
Active Antenna System

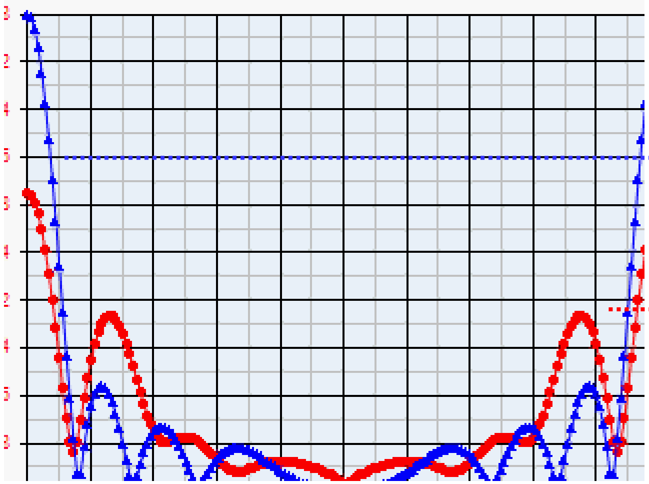


- T/R Module behind each radiating element
- Transmitter distributed through antenna in many small HPAs
- First receiver distributed through antenna in many small LNAs
- Small signal loss between HPA/LNA and radiating element

Reliability Test





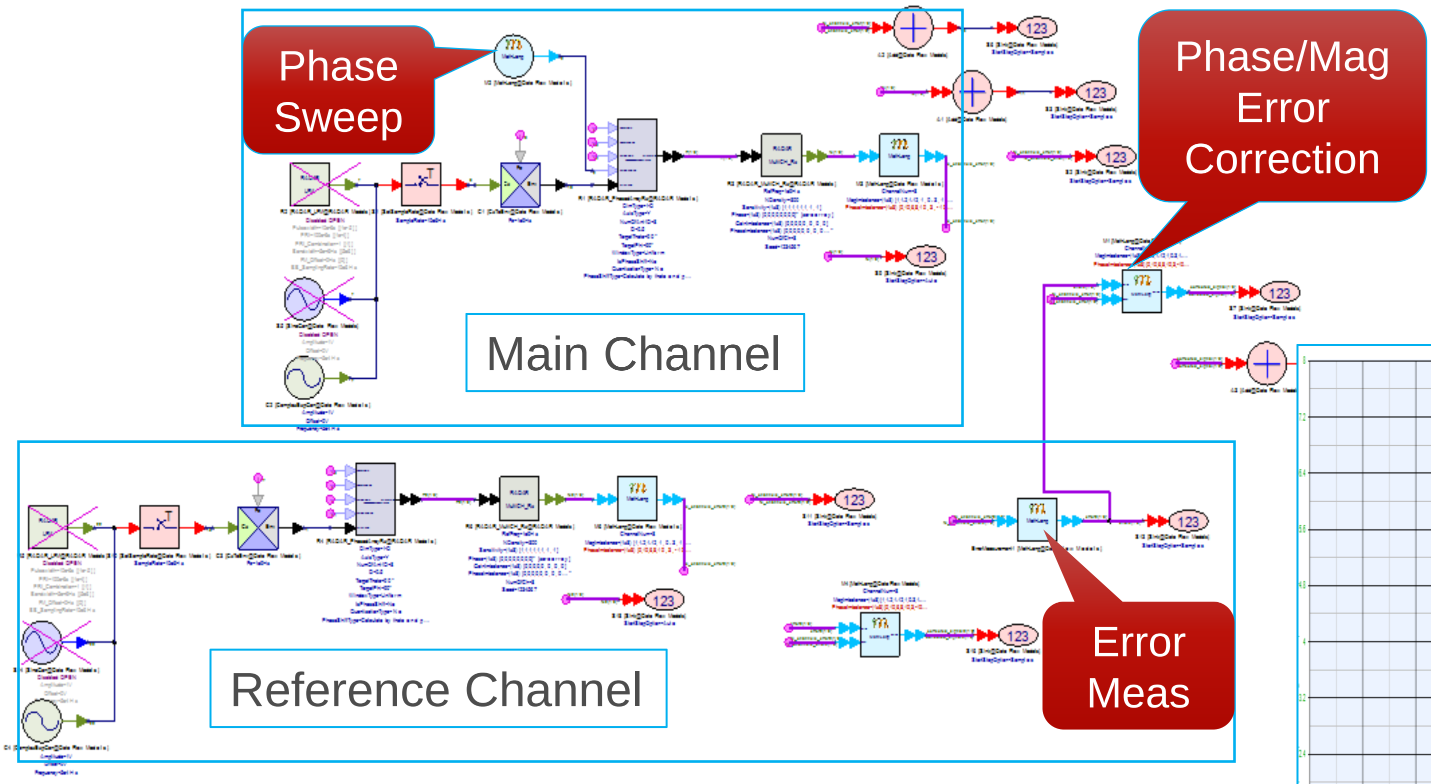


No disabled array elements

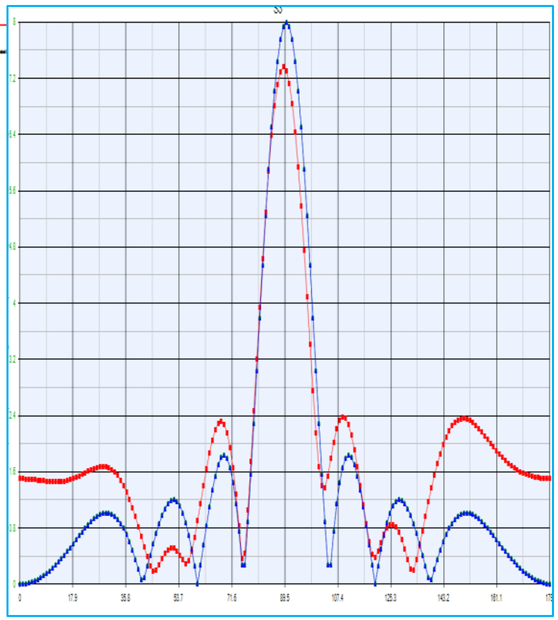
With 20% elements failing

Phased Array Radar Simulation in SystemVue

Magnitude and phase error correction simulation in SystemVue

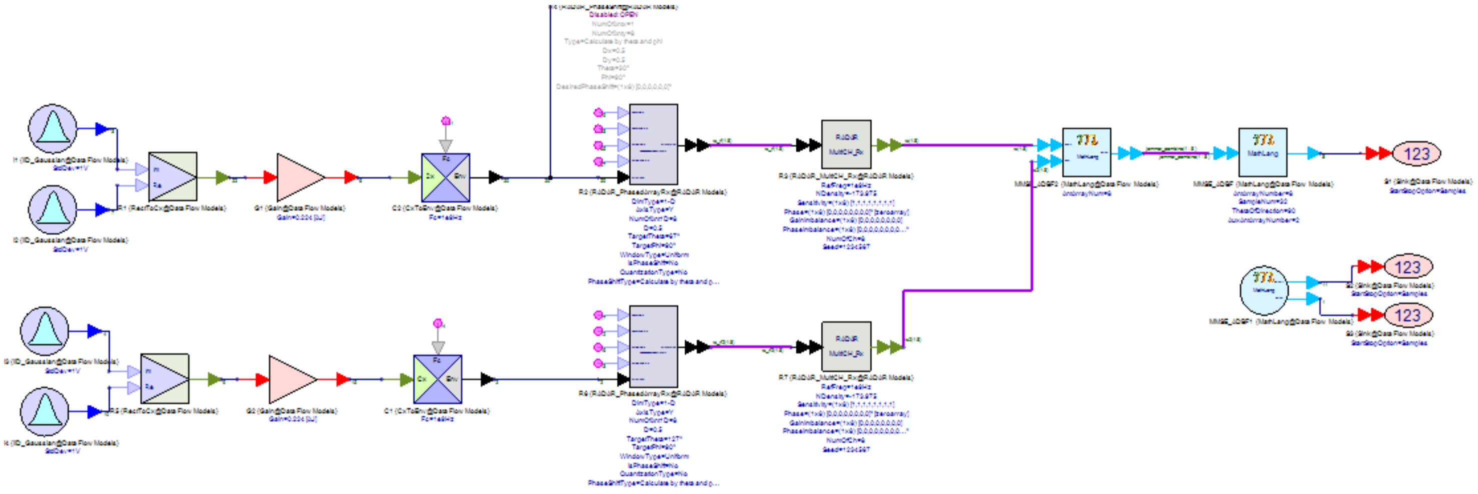


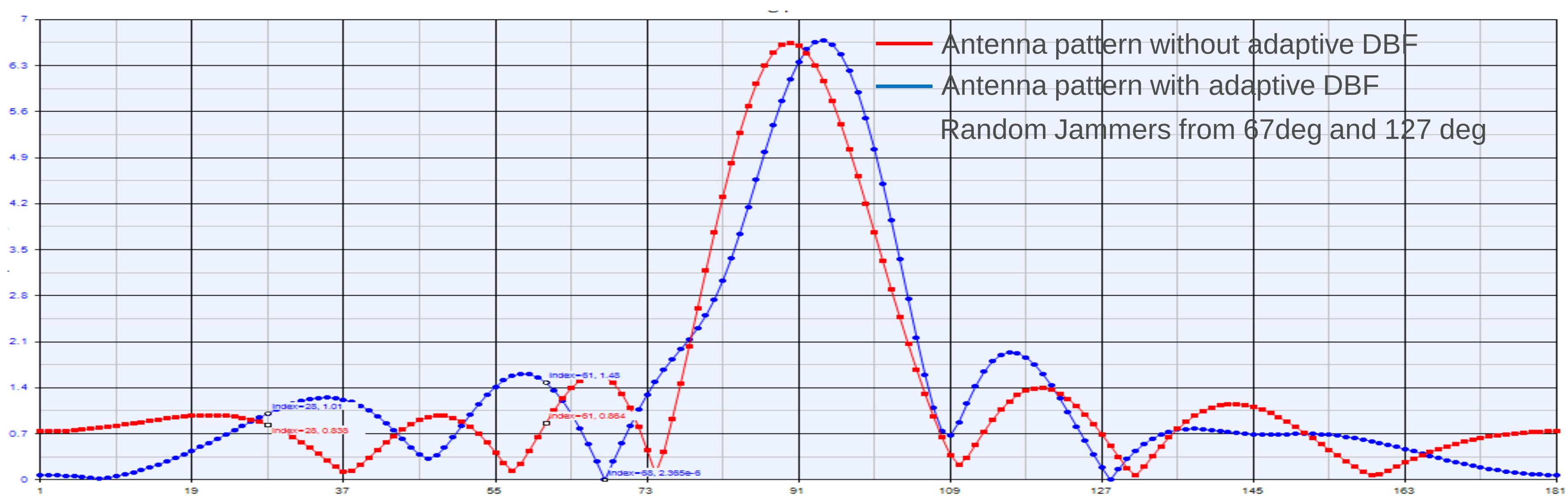
Red line - pattern with magnitude and phase error
Blue line - pattern after error correction



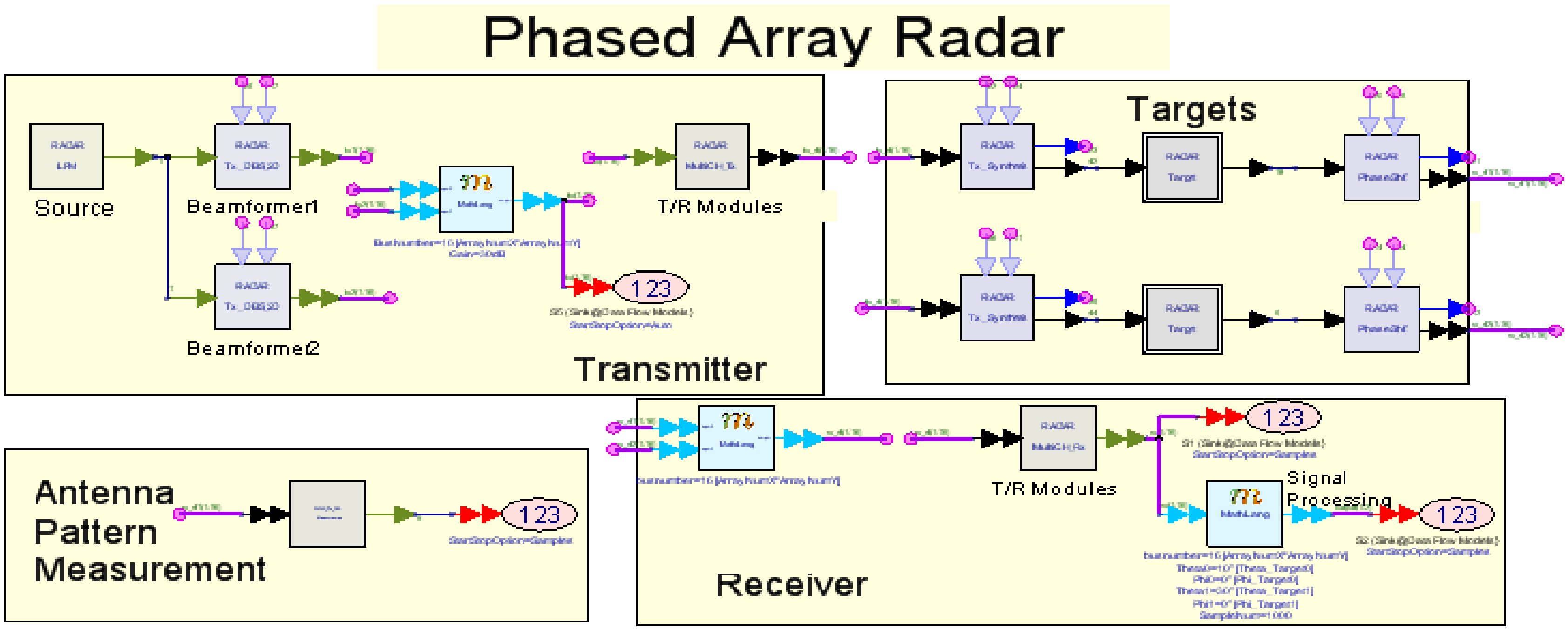
Phased Array Radar Simulation in SystemVue

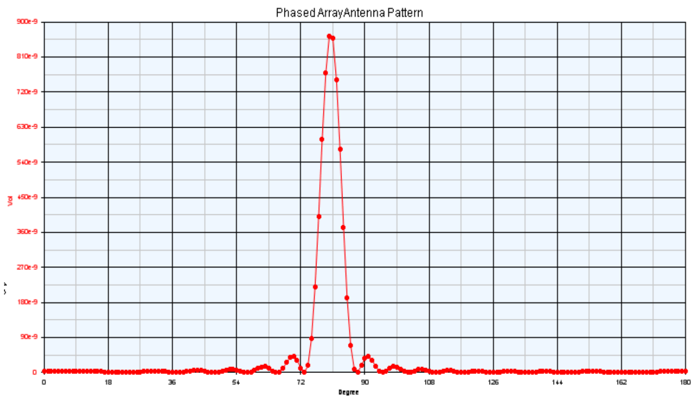
Adaptive DBF (MMSE algorithm) in SystemVue

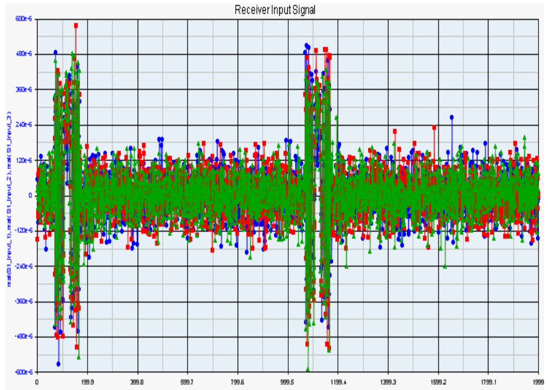


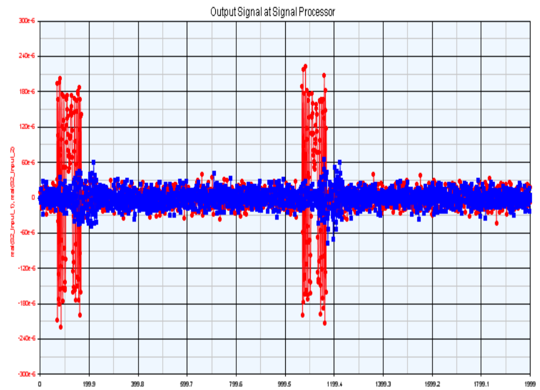


Adaptive Processing for Phased Array Radar



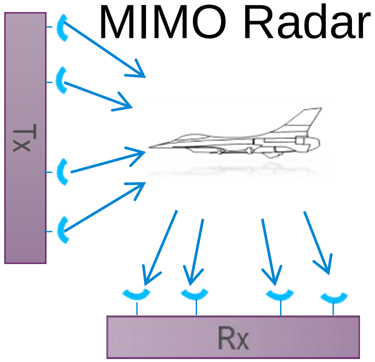






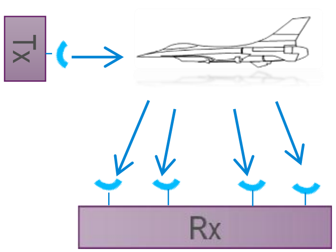
Introduction to MIMO Radar

MIMO Radar



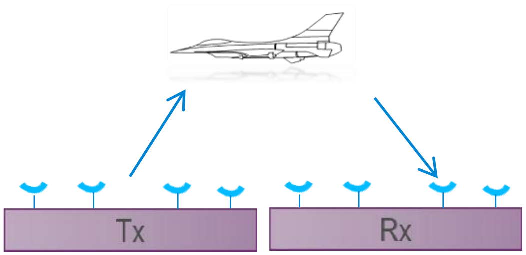
- Diversity of Waveforms
- Centralization of Processing for target detection and localization

Multi-Static Radar



- Single illuminator and receivers that work as independent radar

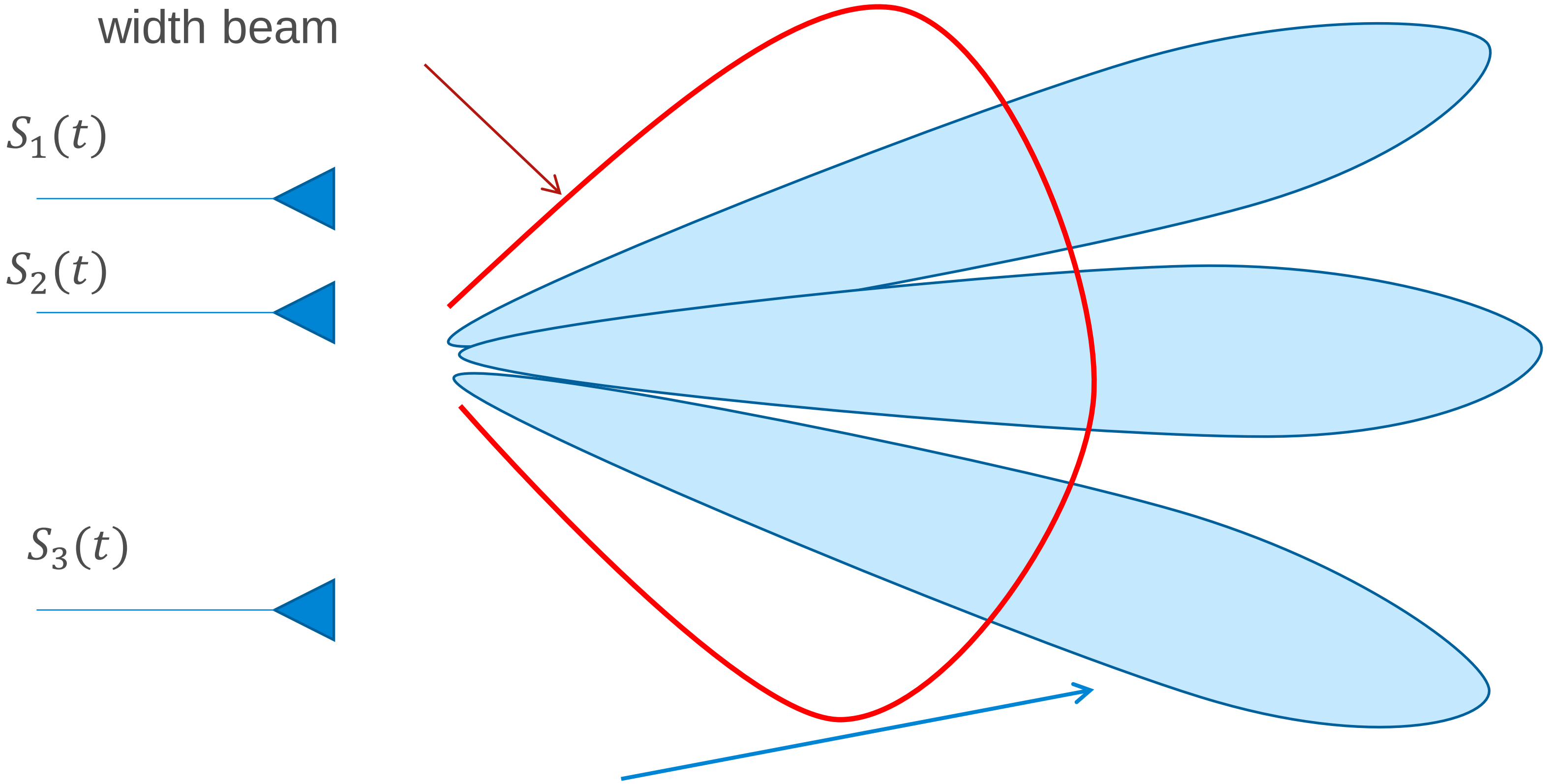
Phased Array Radar



- Single Waveform
- Centralization of Processing for received signals

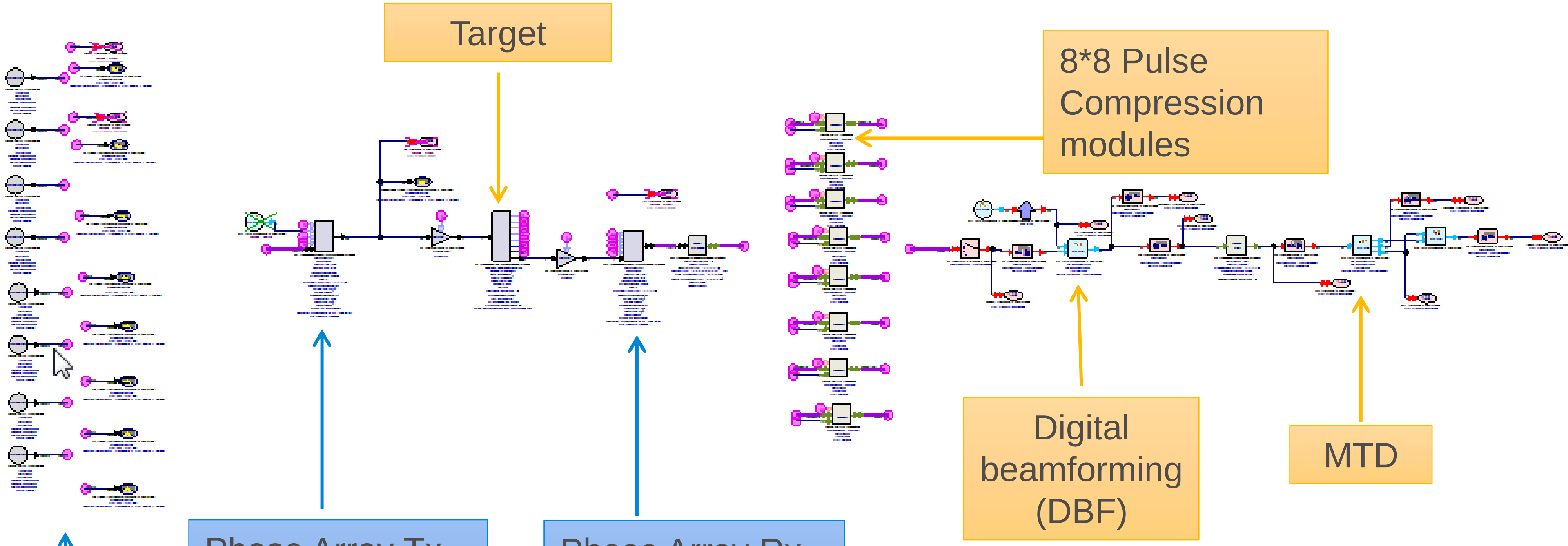
MIMO Basic

Transmit low-gain& wide beam-width beam



Receive high-gain& beam forming multiple narrow beam-width beam

MIMO Radar Signal Processing in SystemVue

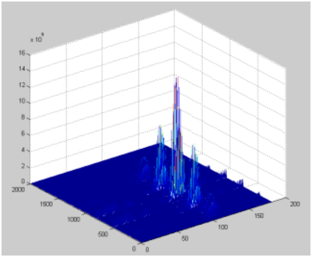


Phase Array Tx (8 subarrays/ elements)

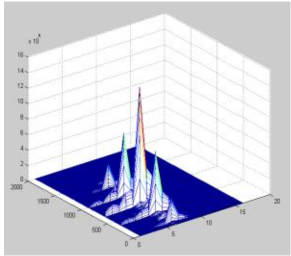
Phase Array Rx (8 subarrays /elements)

8 OFDM-LFM

8*8 virtual array



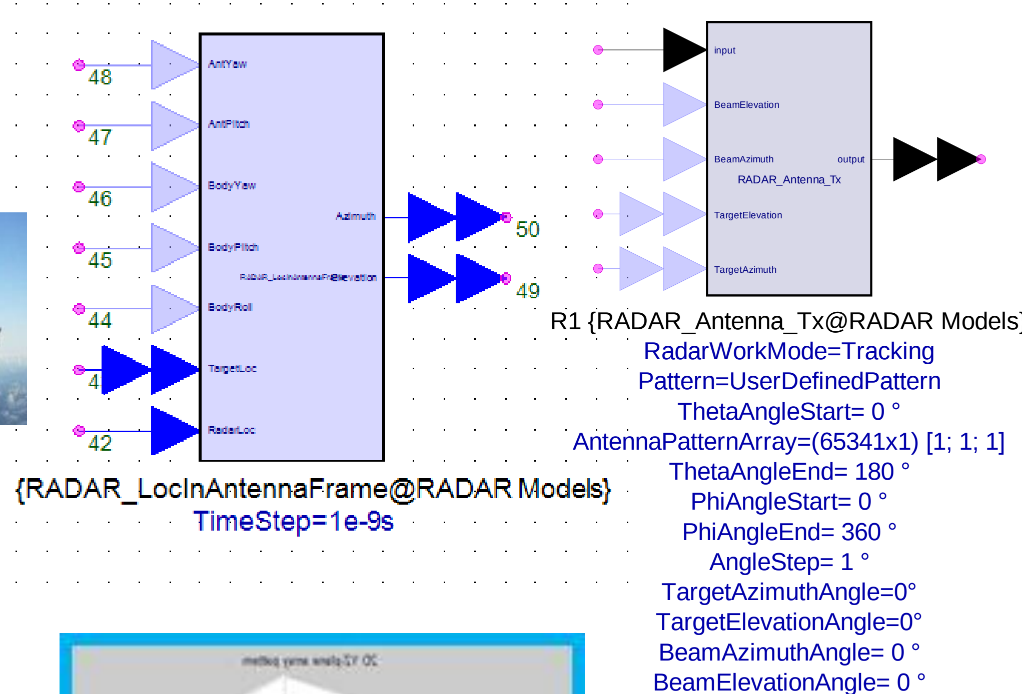
Result of DBF

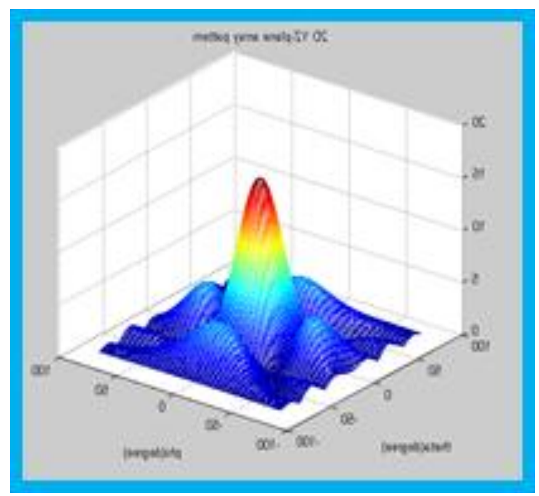


R-D Matrix

Velocity: 5.625m/s
Range: 49925m
Angle: 10 degree

2. Antenna Layer

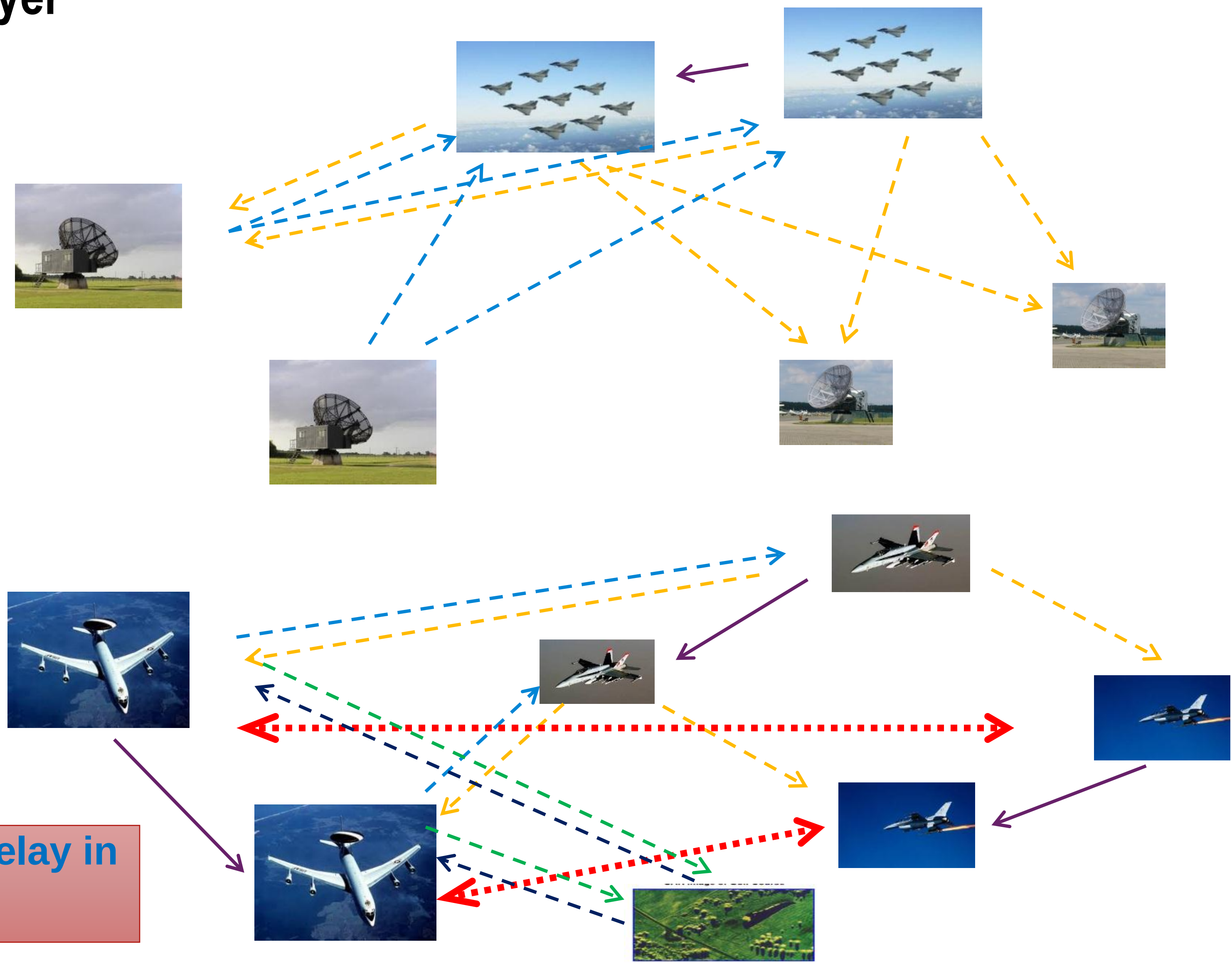




3. Trajectory Layer

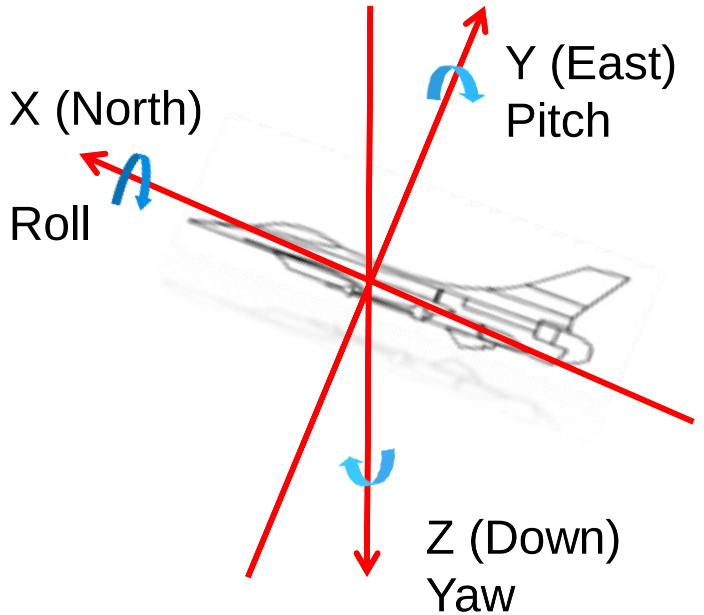
Ground Based

Airborne
Space-borne
Ship-based



To compute the **Delay in ECI frame**

Trajectory Layer



LLA Frame

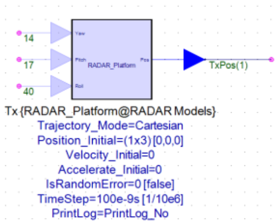
ECEF Frame

ECI Frame

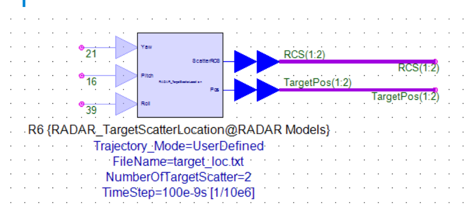
ENU Frame

NED Frame

Body Frame



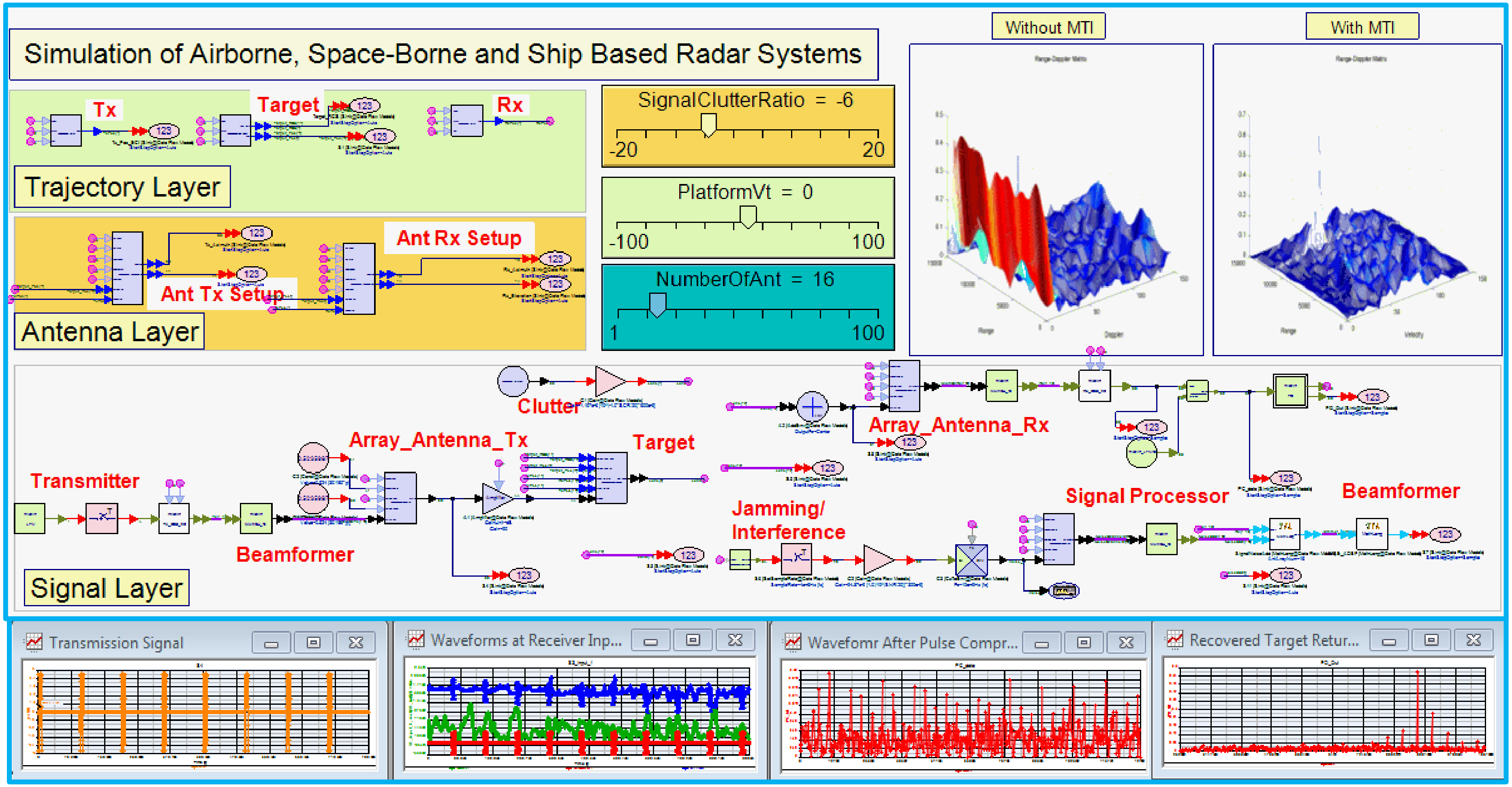
Velocity Frame



Maneuver radar platform and target modeling with Euler angles and velocity, accelerate, jerk

Example: Unique Template for Airborne, Space-Borne and Ship-Based Radar

To put together a new system proposal quickly to win business



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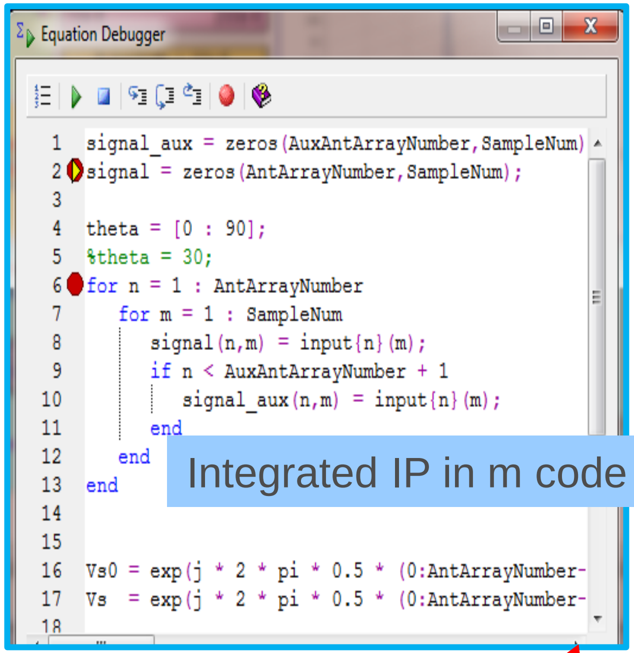
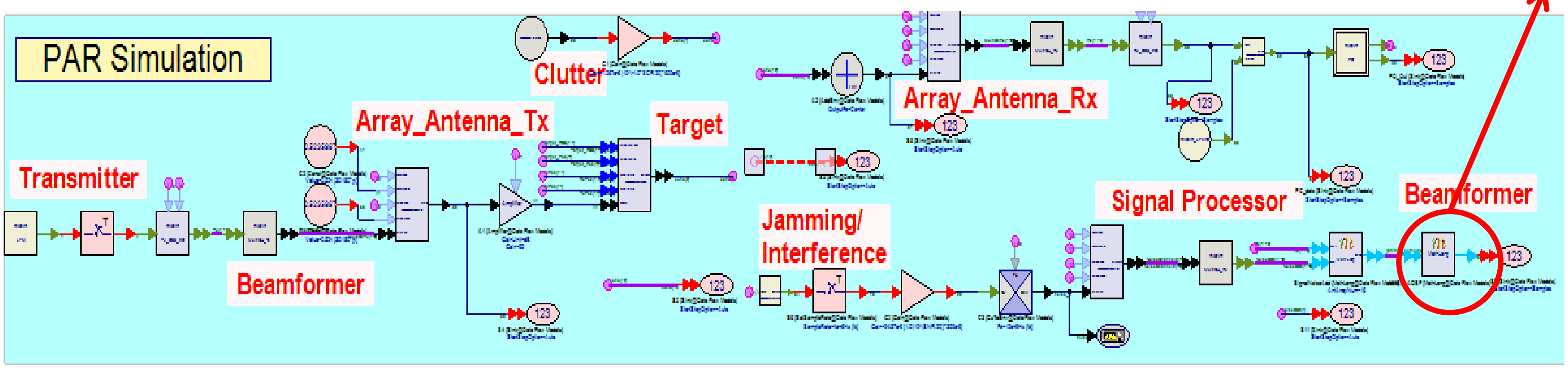
Example: Unique Template for Airborne, Space-Borne and Ship-Based Radar

For Best Model-Based platform for IP Integration of Advanced Radar EW Systems

For Easiest way to create complex Radar EW scenarios





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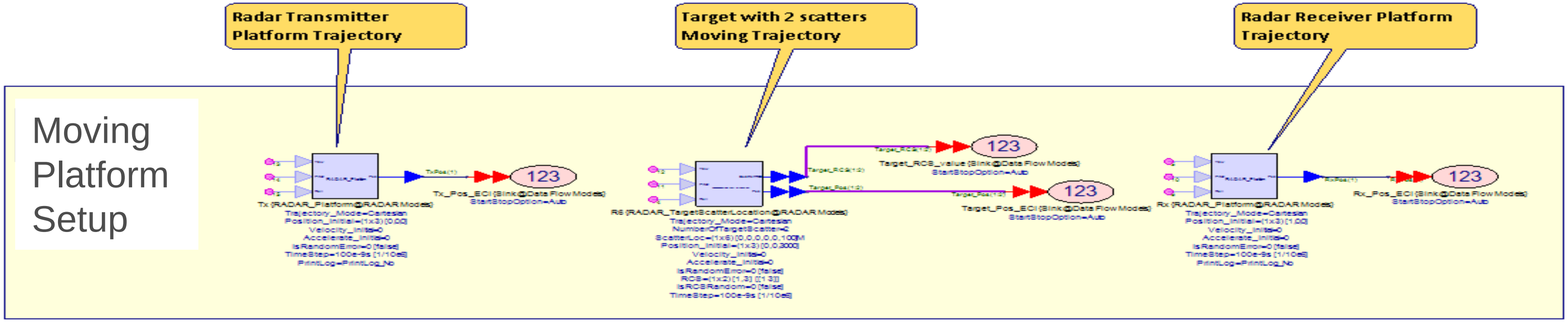
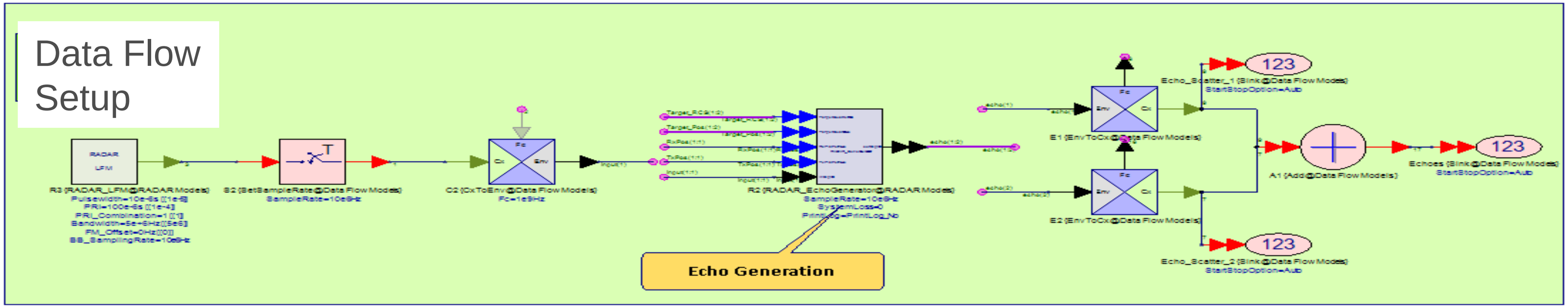
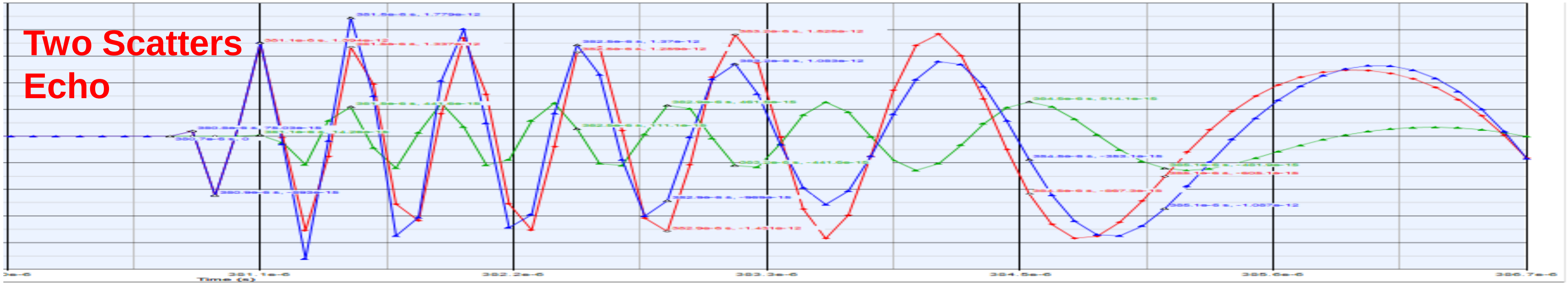
Example: Two Scatters with Moving Target

Using the Radar Scenario Simulation Framework







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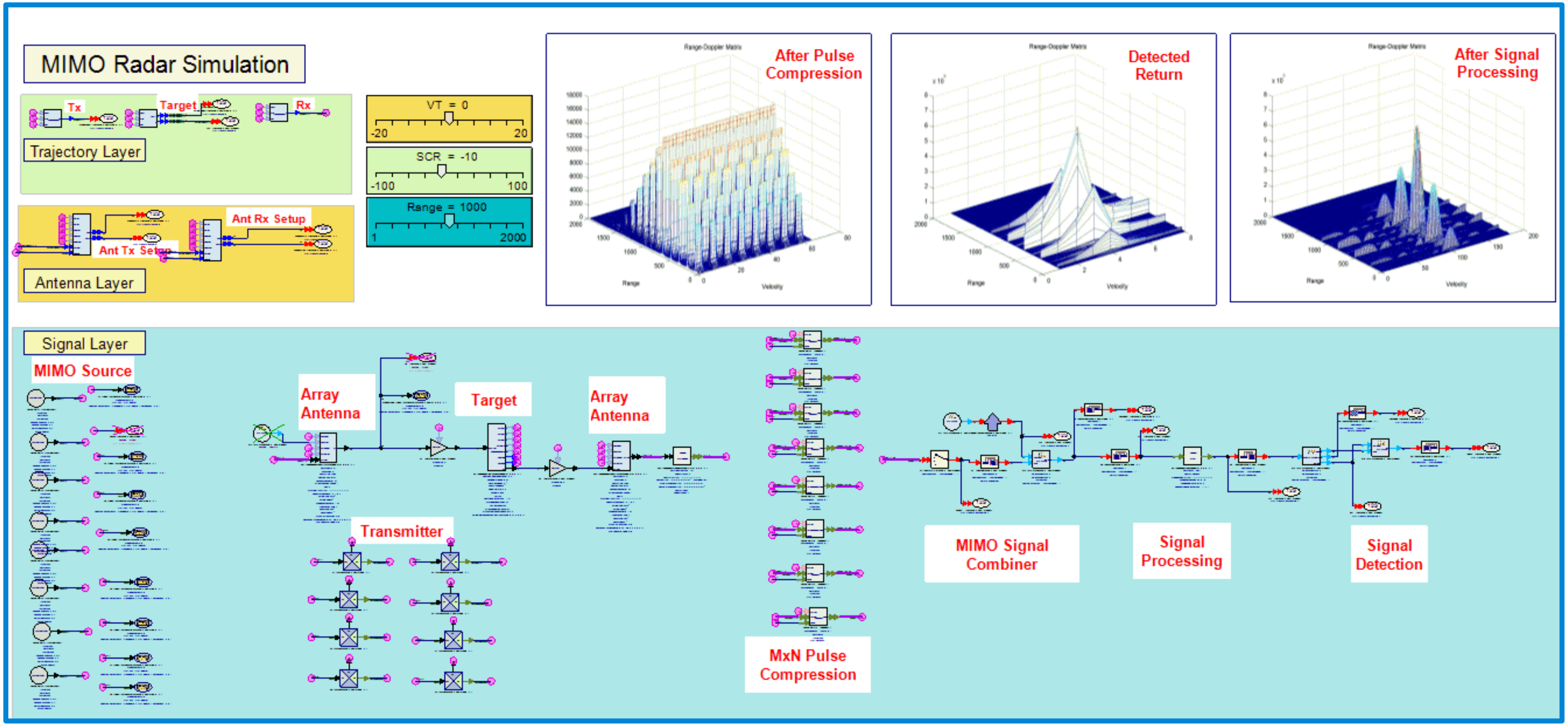
Example: Unique Template for MIMO Simulation

For Reduced Risks, Lower Costs and Higher Performance
To put together a new system proposal quickly to win business



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Summary

- Overcome design challenges and reduce design risks
- As seen, the proposed solution has the following advantages:
  - **Earliest Possibly Integration of RF & DSP for Architecture design to win. Develop proposal with higher confidence**
    - Modeling and analysis of complex Radar EW systems
    - Cross-Domain simulation including RF and DSP
    - Save months for developing systems to meet aggressive schedule
  - **Best model-based platform for IP Integration of Radar EW Systems**
    - Verify models developed by different engineers using different languages such as C++, MATLAB, HDL, ADS, etc in system level .
    - Reuse legacy Intellectual Property (IP)
    - Build virtual models of existing hardware through measurement
    - Integrate modeling & design using test equipment to verify and test system performances
  - **Easiest way to create complex Radar EW scenarios**
    - Verify systems with environment scenarios, such as clutter, jamming/deception, interference, RCS to meet complex system specs.
    - Perform virtual flight test to reduce costly field test.