

2010

Aerospace and Defense Symposium



Uncovering the Hidden Impairments in Advanced RADAR Systems

*Dingqing Lu
David Leiss*



Agilent Technologies

Agenda

- SystemVue Overview
- Radar System Design Challenges
- Signal Processing Algorithm Creation
- Examples
 - Pulsed Doppler (PD) Radar
- Wrap up
- Questions and Answers

2010

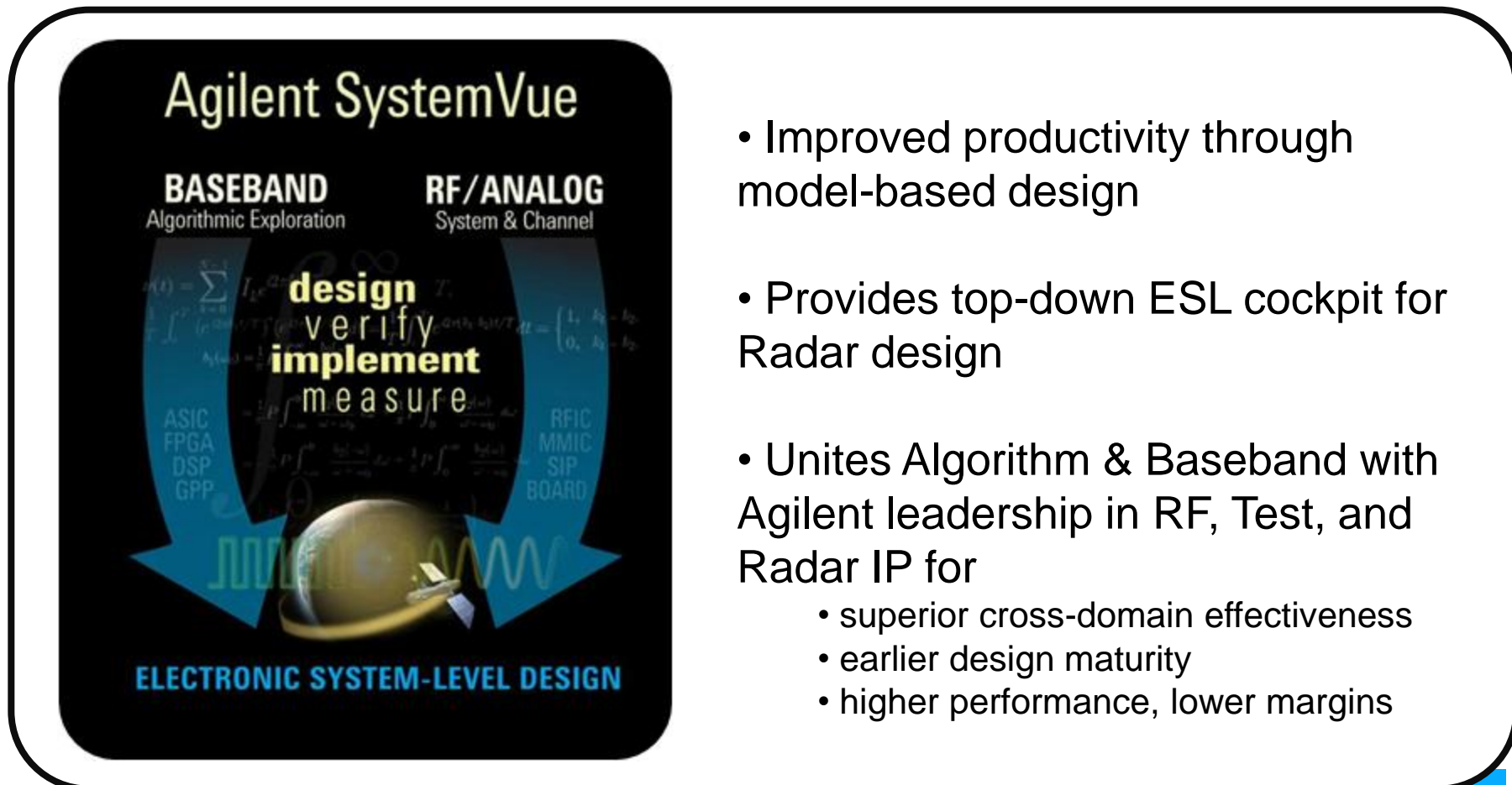


Agilent Technologies



Agilent SystemVue

For Radar System Architects and Algorithm Developers



- Improved productivity through model-based design
- Provides top-down ESL cockpit for Radar design
- Unites Algorithm & Baseband with Agilent leadership in RF, Test, and Radar IP for
 - superior cross-domain effectiveness
 - earlier design maturity
 - higher performance, lower margins

2010

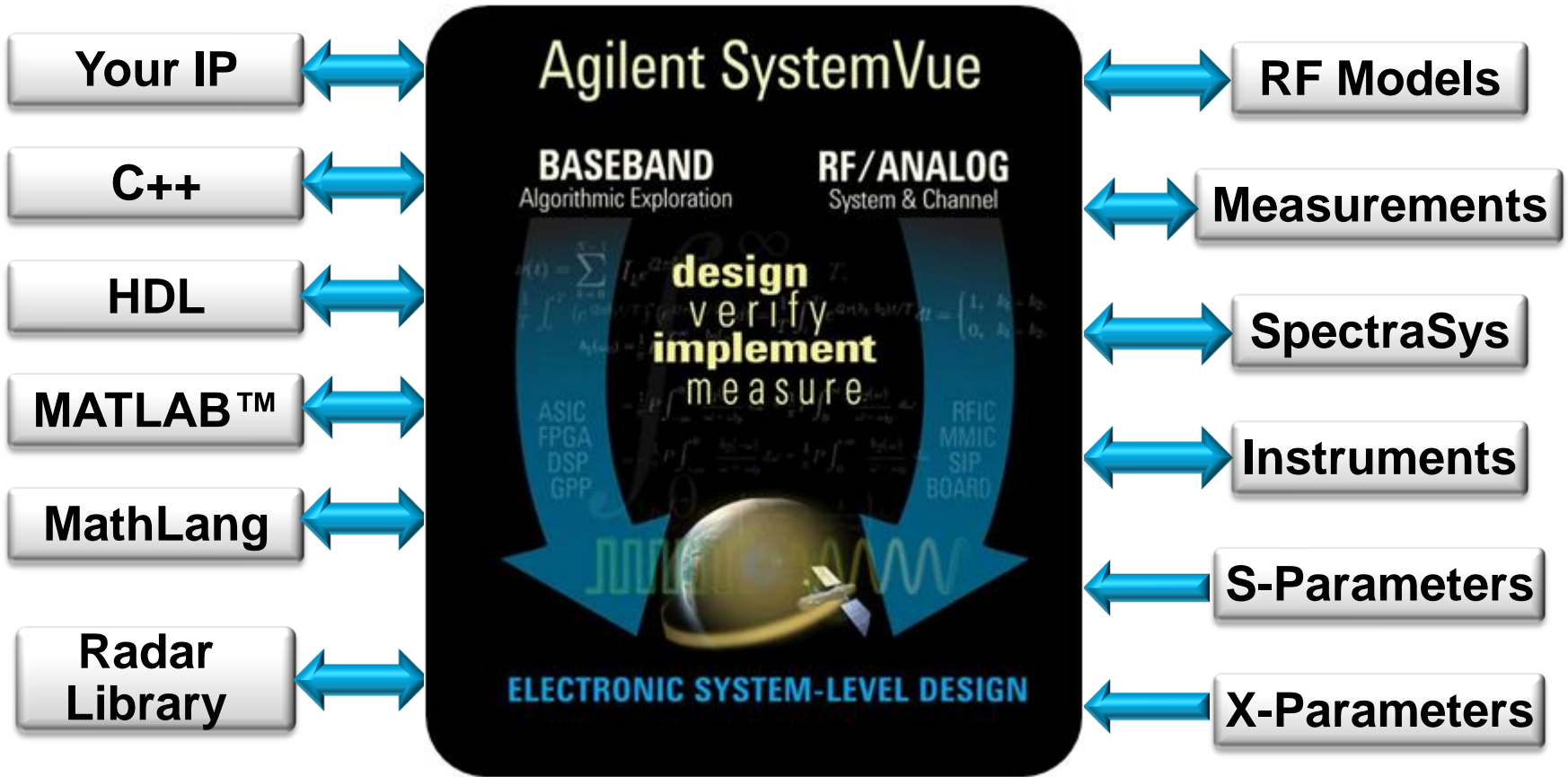


Agilent Technologies



Agilent SystemVue

Integrates with Your Existing IP



Results : Faster Development Time & Identification of Hidden Impairments

2010



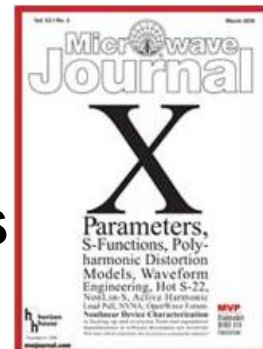
Agilent Technologies

Uncovering the Hidden Impairments in Advanced RADAR Systems

April 14, 2010

SystemVue - *Enabling Capabilities for Radar Design*

- **Convenient, polymorphic** algorithm modeling and debugging model-based design using native MathLang¹, MATLAB™ CoSim, C++, HDL
- **Superior RF models and simulators**
unites RF & Baseband approaches, reduces excess design margins for both
- **Built-in Radar Library³**
prototype radar sources, channel models and measurements
- **Path to rapid prototyping**
C++ and VHDL Code Generation paths to your existing design flow infrastructure
- **Built for easy verification**
links to Test Equipment and Hardware in the Loop (HIL) co-simulation allows easy verification at both the block-level and circuit-level
- **Embed measured S-parameters and X-parameters**
Frequency dependent linear and non-linear modeling



2010



Agilent Technologies



5

System Design Challenges

- Advanced radar systems require very high levels of complexity in order to fulfill their assigned missions
- They are based on radar signal processing algorithms
- Algorithm creation requires a platform for simulation and verification
- Models for Radar waveform signal generation, transmission, antennas, T/R switching, clutter, noise, jamming, receiving, signal processing and measurements are needed to create these advanced algorithm

2010



Agilent Technologies



6

Signal Processing Algorithm Creation

- System Platform is needed for both design and verification
- The Platform can provide
 - User-friendly algorithm modeling & debug environment supporting variety of languages such as C++ or m-code*
 - Algorithm design/verification environment for signal generation and performance measurements
 - Interface to test equipment to verify the implemented hardware (compared to the original pure algorithm)
 - Test sources include radar signal generation with RCS, Clutter, Jamming, Doppler frequency offset
 - Measurements include waveforms, spectra, detection rate, false alarm rate (FAR)
 - Estimation of speed, distance and angles for the detected target

2010

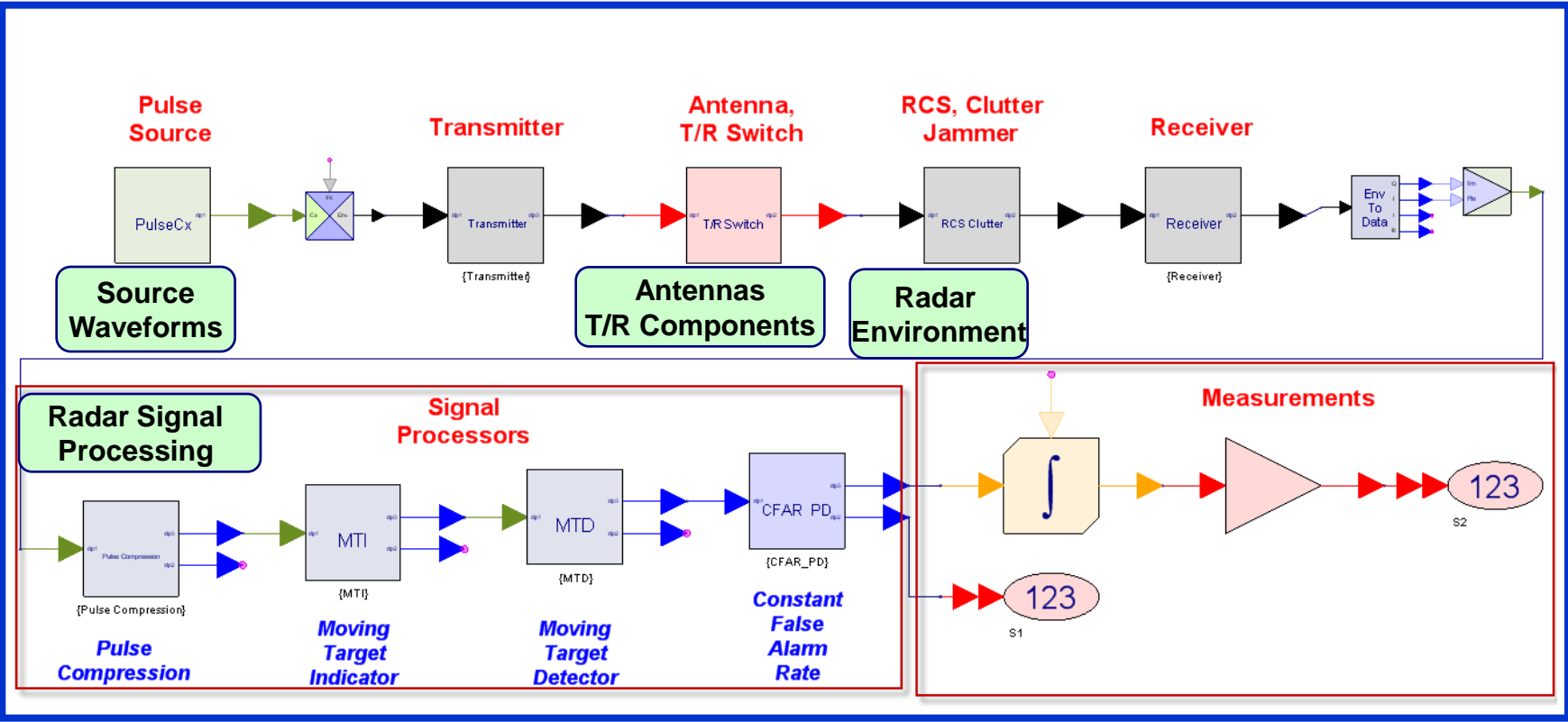


Agilent Technologies



Platform for Simulation

Top-Level Radar System Level Model

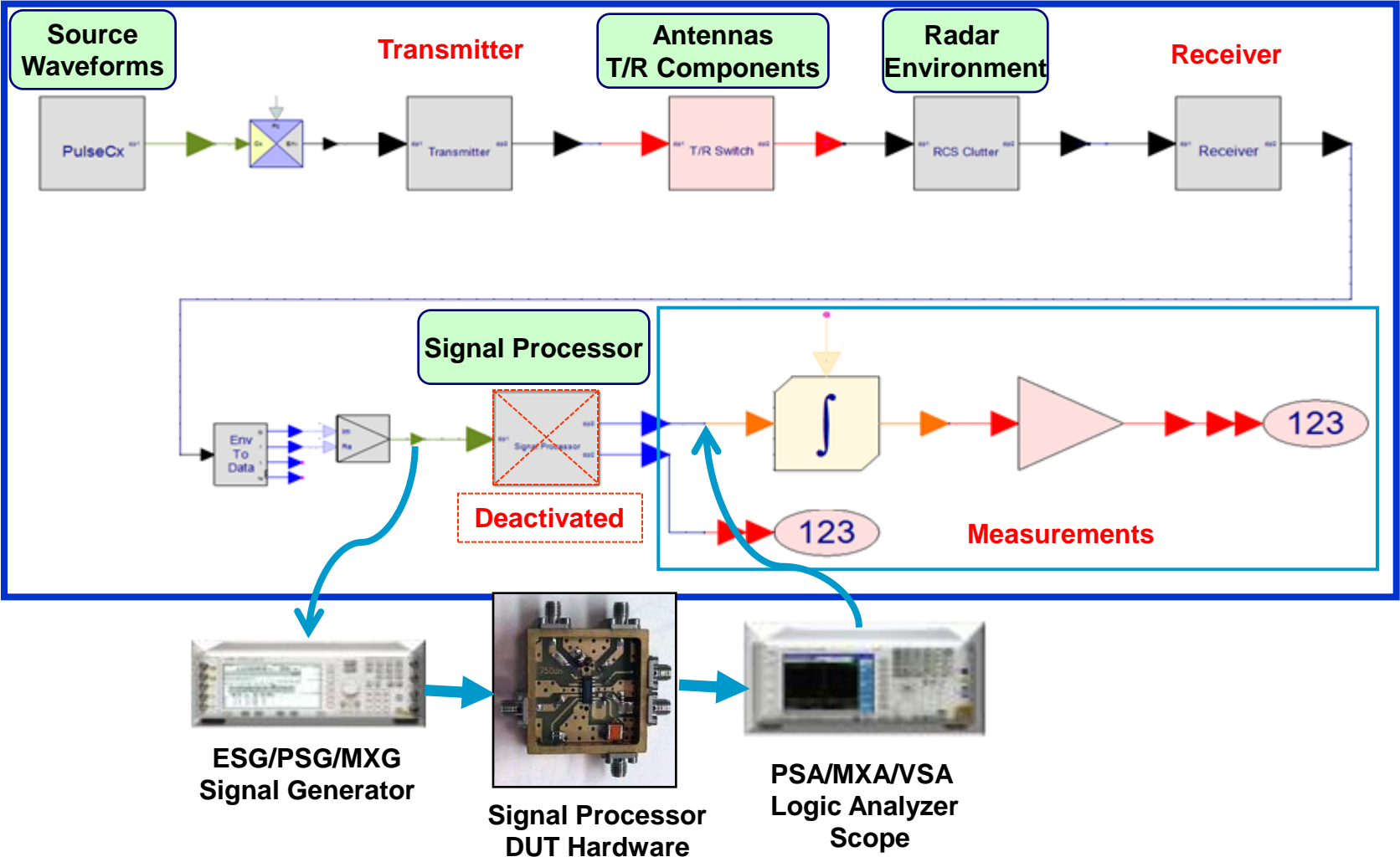


Radar Library Components

2010



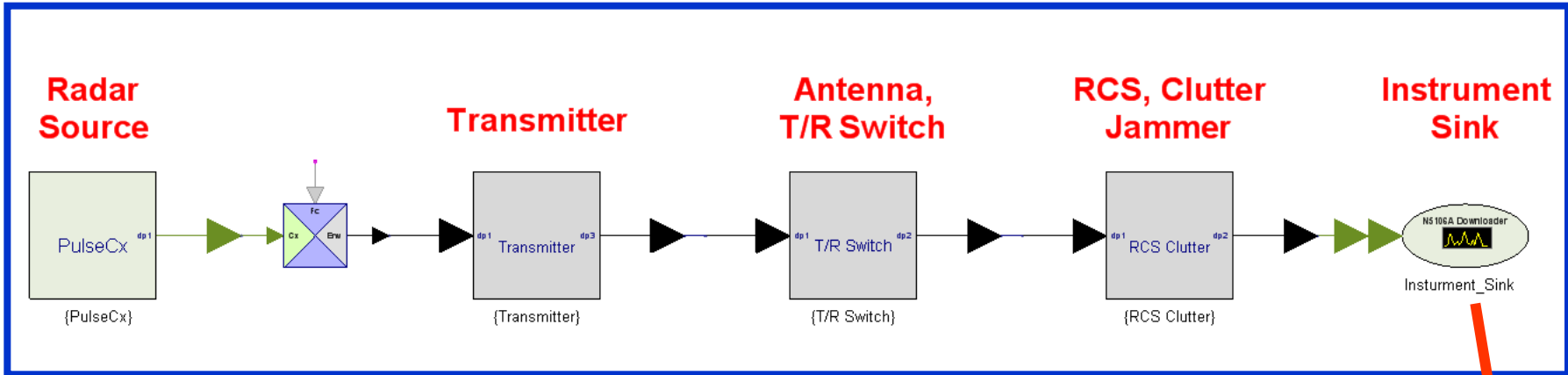
Platform for Test and Verification



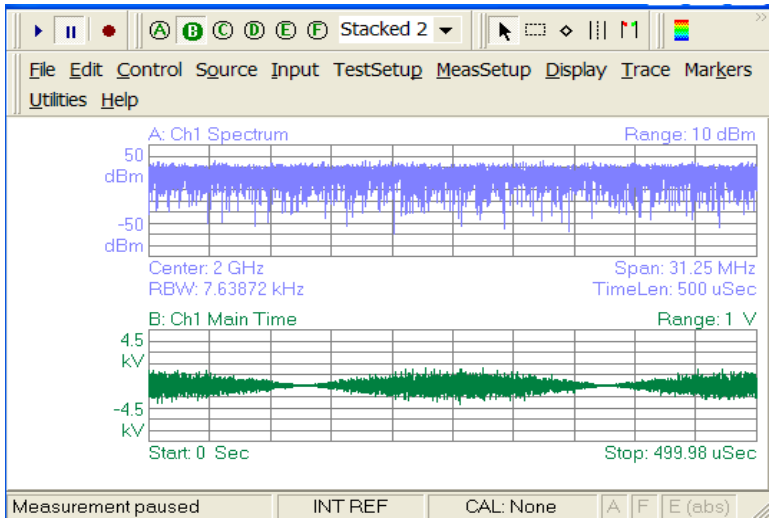
2010



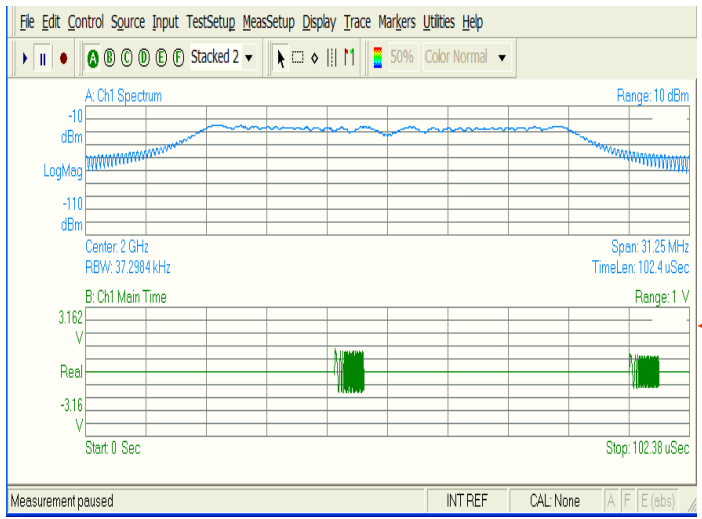
Platform - Generate test signals



Signal with Clutter



Signal without Clutter



Signal Generator



DUT



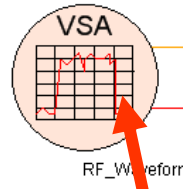
Signal Analyzers
Logic Analyzers,
Scopes

2010

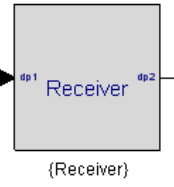


Platform - Expand measurements

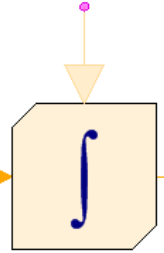
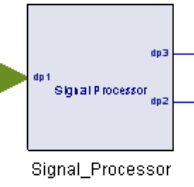
Vector
Spectrum
Analyzer
Link



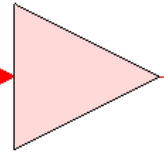
Receiver



Signal
Processor



Measurements



123

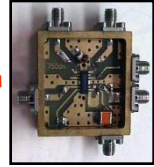
Probability
of Detection

123
PD_Results

2D PD
Processing
Results



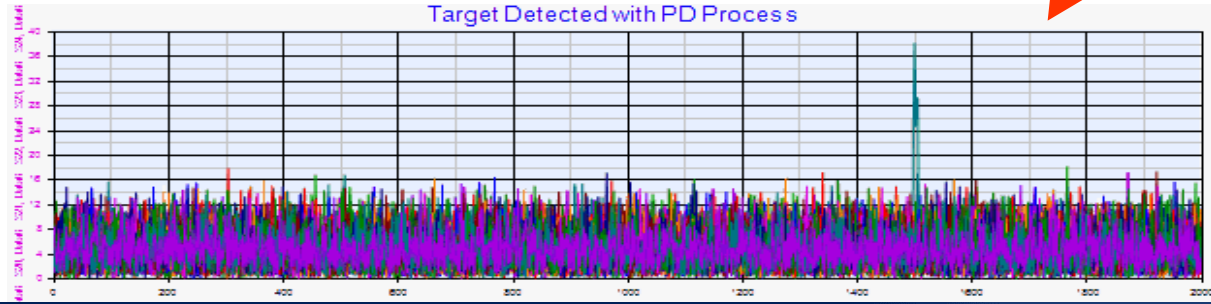
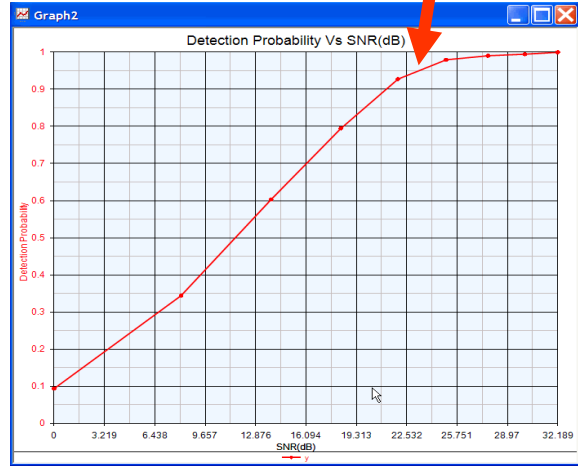
PSA/MXA/VSA
LogAna, Scope



Signal Processing
Hardware



ESG/PSG/MXG

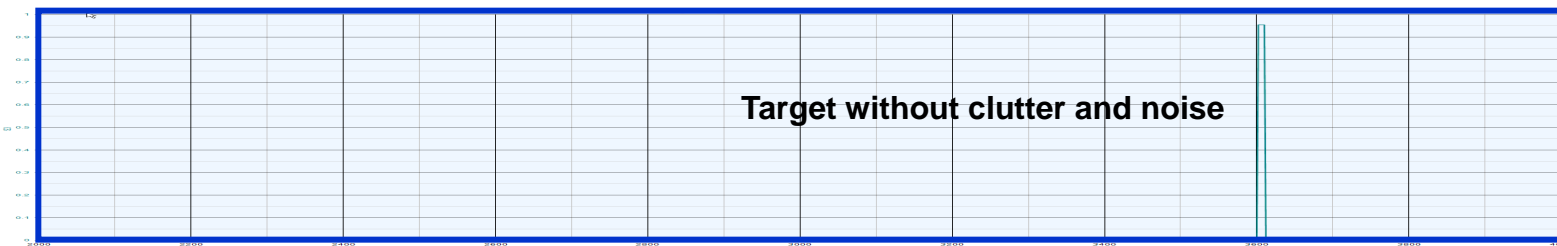


2010



Pulsed Doppler Radar System

- PD radars are extremely valuable for finding small moving targets hidden by heavily cluttered environments
- Unlike the continuous waveform (CW) radar, the PD radar has ability to detect angle, distance, *and also velocity*
- Typical examples : low-flying aircraft and anti-ship missiles, weather
- PD radars are used for many military and commercial applications



2010



Agilent Technologies



PD Radar System – In Principle

- The Radar Transmission signal and Returned signal [1,2] are given by

Ideal Transmitted Waveform: $S(t) = A(t)\text{Cos}(2\pi f_c t)$

- Where: $A(t)$ = *The waveform complex envelope*
 f_c = *Carrier frequency*

$$S(t - \tau) = A(t)\text{Cos}(2\pi(f_c + f_d)t - \tau) + N_C(t) + N_n(t) + N_j(t)$$

- Where: f_d = *The Doppler Frequency Shift*
 τ = *Path Delay*
 N_C = *Clutter*
 N_n = *Thermal Noise*
 N_j = *Jamming*



PD Radar System – In Principle

$$S(t - \tau) = A(t)\text{Cos}(2\pi(f_c + f_d)t - \tau) + N_c(t) + N_n(t) + N_j(t)$$

- Cannot detect the target in time domain because small moving targets are hidden by heavily cluttered environments
- Must detect the signal in frequency domain using the Doppler frequency analysis
- We must collect return data and process in both range and frequency domain for estimating $\hat{\tau}$ and f_d .
- 2-dimensional signal processing is required for a moving target indicator (MTI) and moving target detection (MTD).
- Constant false alarm rate (CFAR) processing is needed for auto-detection in PD process. Without CFAR, auto-detection will fail.

2010

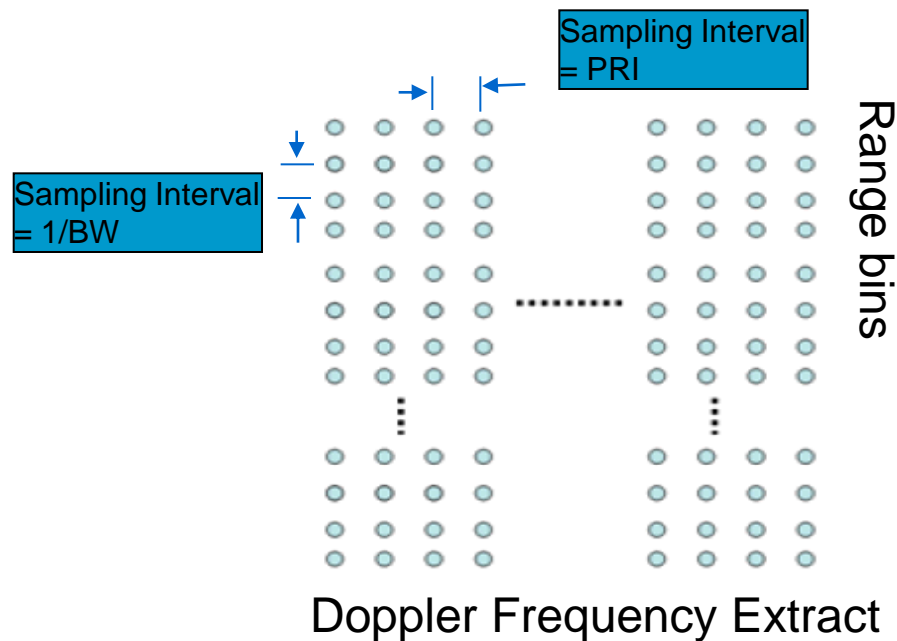


Agilent Technologies



PD Radar System – In Principle

- 2-D data matrix of coherent, baseband returns for M pulses
 - Fast time sample rate is 10^5 to 10^8 samples/sec
 - Slow time sample rate is the PRF, 10^3 to 10^5 samples/sec
 - Collected using the pulse burst waveform



2010

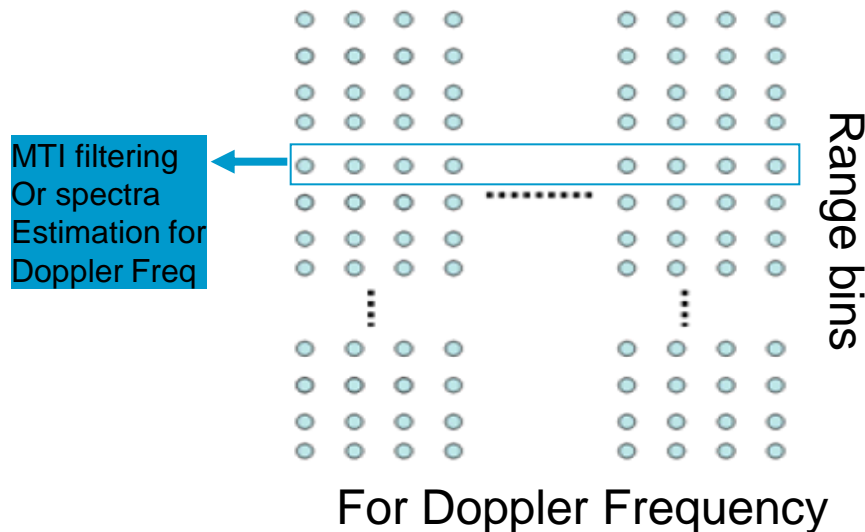


Agilent Technologies



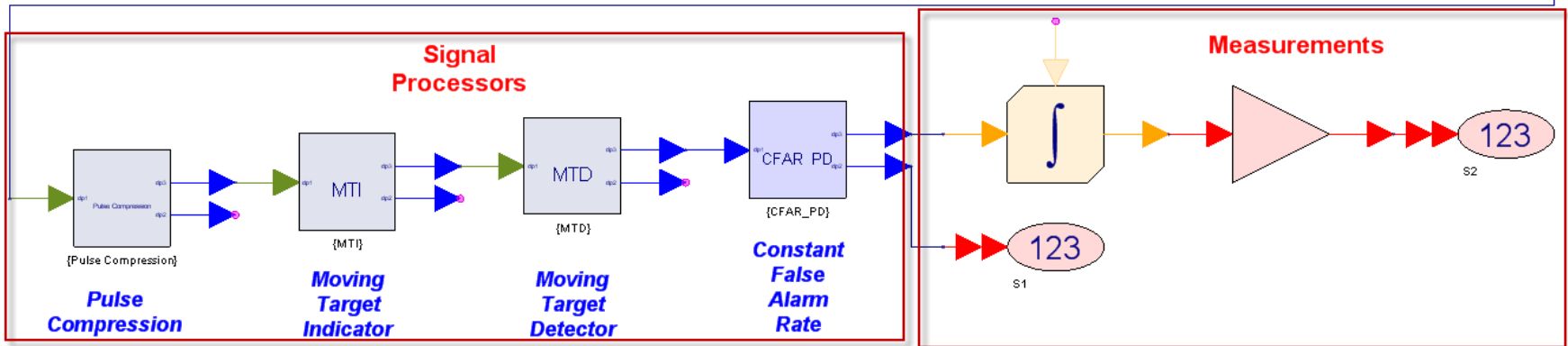
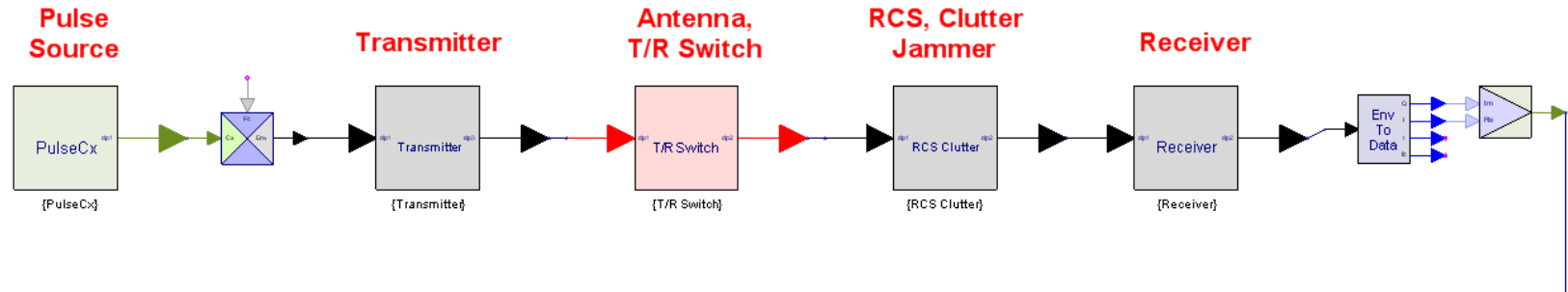
PD Radar System – In Principle

- To estimate the Doppler frequency and the target delay 2D signal processing is needed
 - Doppler processing operates on each row of this Matrix
- Two major processing
- MTI applies a linear filter to each row
 - PD applies a spectrum estimation to each row



PD Radar System Structure

Pulse Doppler Signal Processing Implementation



Pulse Doppler Signal Processor

2010



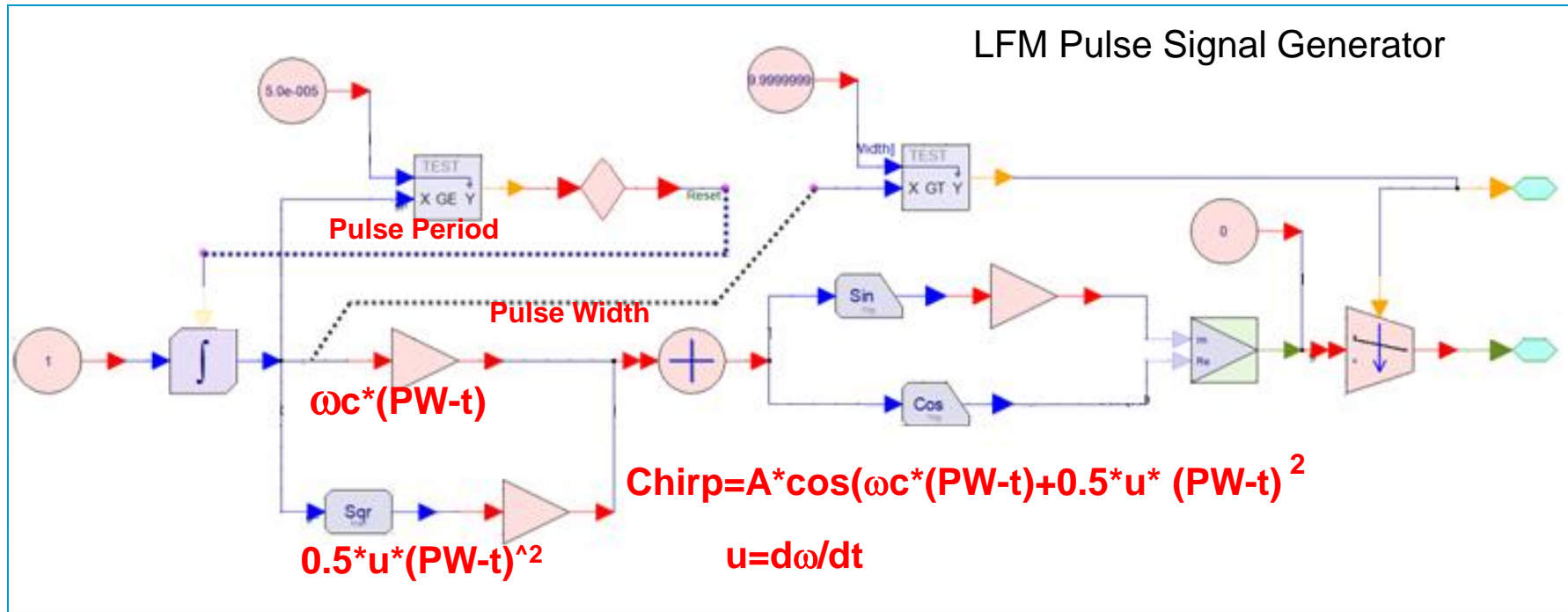
Agilent Technologies



PD Radar System – Signal Source Models

Radar LFM Pulsed Source - Behavioral Model

Based on the mathematical definition of an LFM Signal



PD Radar System – Signal Source Models

Radar LFM Pulsed Source – C++ Code Generation

C++ Code Generation Options

Name: Cpp1 ★ Save as Favorite...

Description: LFM Chirp 🏭 Factory Defaults

Select 1 or More Parts and/or Subnetworks for Code Generation

Top Level Design: Radar_Chirp

Selected Items:

Part	Model	Generated Class Name
ChripVA1	Add@Data Flow Models	Add
ChripVD1	Delay@Data Flow Models	Delay
ChripVG1	Gain@Data Flow Models	Gain1
ChripVG2	Gain@Data Flow Models	Gain2
ChripVG3	Gain@Data Flow Models	Gain3
ChripW1	Math@Data Flow Models	Math

Add Delete

Visual Studio Solution Directory

Use default directory

Output Directory: C:\Documents and Settings\dleiss\My Documents\Webcast\Radar_chirp

Shell Configuration

Shell Type: SystemVue Model

- SystemVue Model
- Win32 Standalone DLL
- ADS Ptolemy Model

2010



Agilent Technologies



PD Radar System – Signal Source Models

Radar LFM Pulsed Source - MathLang Model



MathLang_LFM_Source

PP=50 μ s [PP]

Tstep=0.01 μ s [Tstep]

FM_Low=-10MHz [FM_Low]

FM_High=10MHz [FM_High]

PW=1 μ s [PW]

**Alternative Method:
MATLAB™ CoSim.**



{MATLAB_Cosim@Data Flow Models}

```
Equations I/O Custom Parameters
1 % LFM Chirp Equations
2 npoints = PP/Tstep;
3 N = PW/Tstep;
4 % Compute alpha
5 mu = 2. * pi * (FM_High-FM_Low) / PW;
6 wc= 2. * pi * FM_Low;
7 LFM=zeros(1,npoints);
8 for t=1:N;
9 T=(t-1)*Tstep;
10 % Compute the complex LFM representation
11 X = wc * T;
12 Q = cos(X + mu*T^2 / 2); % Imaginary part
13 I = -sin(X + mu*T^2 / 2); % Real Part
14 LFM(1,t) = I + i * Q; % complex sigma
15 end
```

2010



Agilent Technologies



PD Radar System – Target return model

Target return model

- Including RCS, Doppler effect, Delay and Attenuation
- Fluctuant RCS types: Swirling 0, I , II , III , IV linear FM pulse signal generator

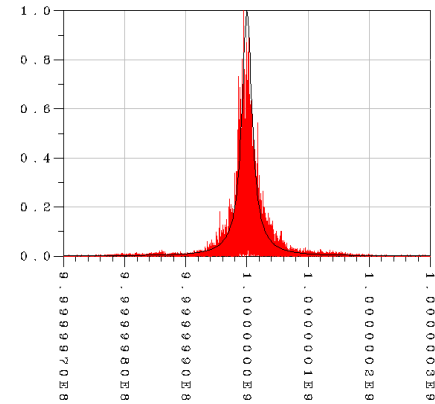
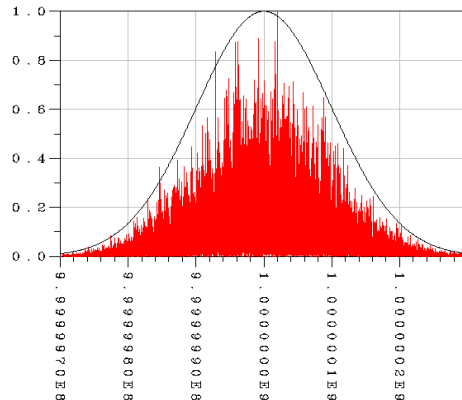
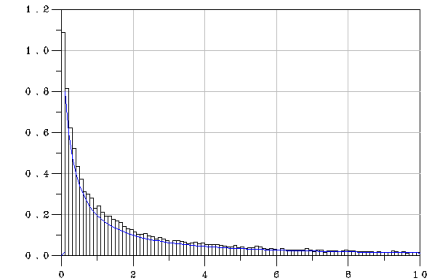
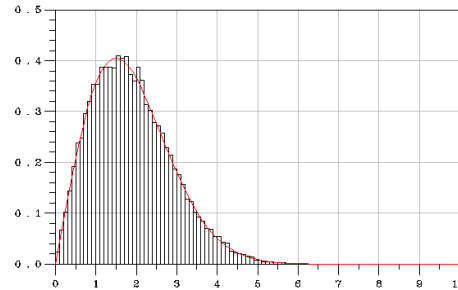
$$s_r(t - t_r) = kA(t - t_r) \cos[2\pi(f_0 \mp f_d)t - 4\pi R_0 / \lambda + \varphi] \cdot U(t - t_r)$$



PD Radar System – Clutter

Choice of 4 amplitude probability distribution functions (PDF) and 3 power spectrum density (PSD) functions

- PDF
 - Rayleigh
 - Log-Normal
 - Weibull
 - K – Distribution
- PSD
 - Gaussian
 - Cauchy
 - All Pole

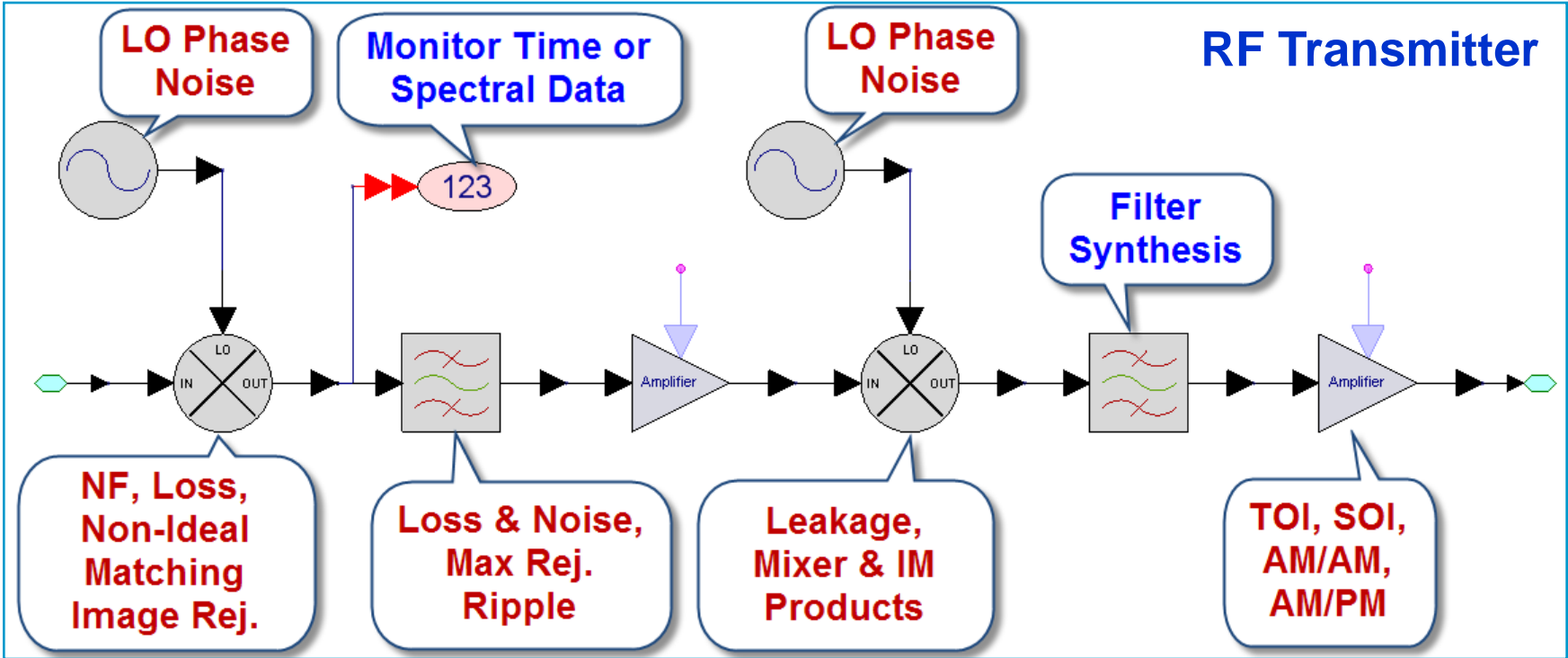


2010



PD Radar System – Transmitter model

The RF transmitter includes oscillators, mixers, amplifiers and filters



(Note Model Impairments)

2010

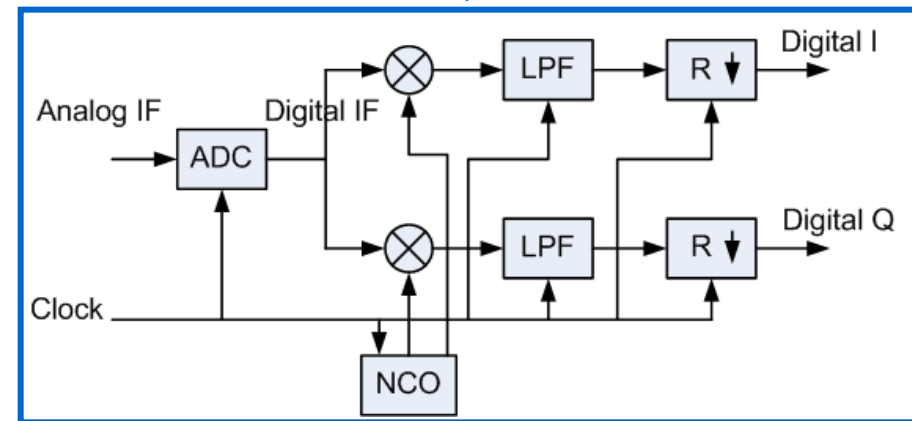
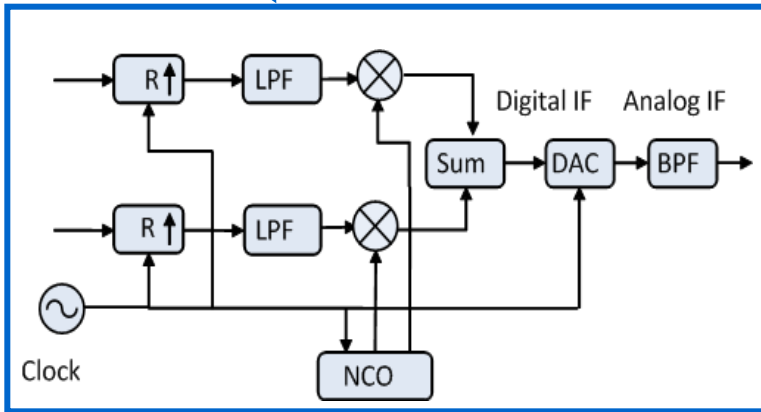
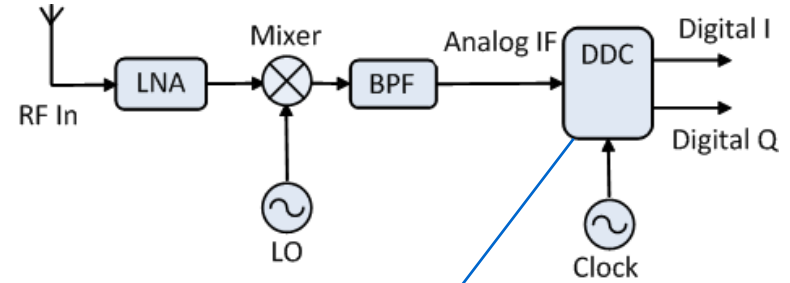
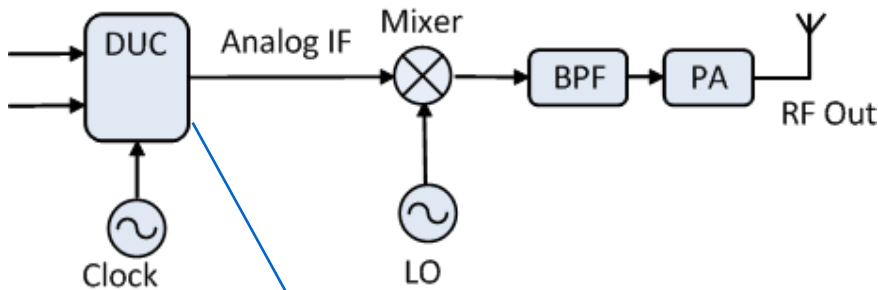


Agilent Technologies



PD Radar System – Digital Up Converters

- Digital Up/Down converter (DUC/DDC) for digital IF

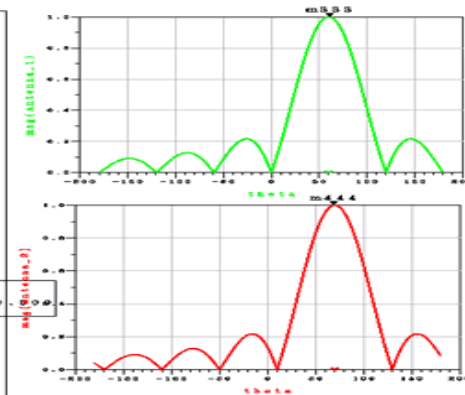
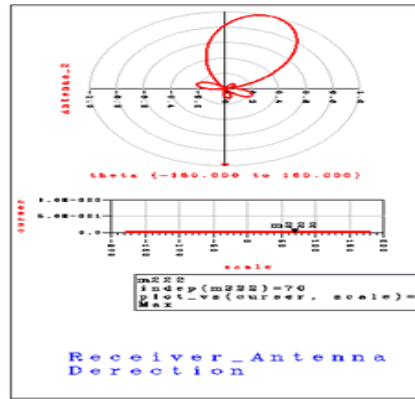
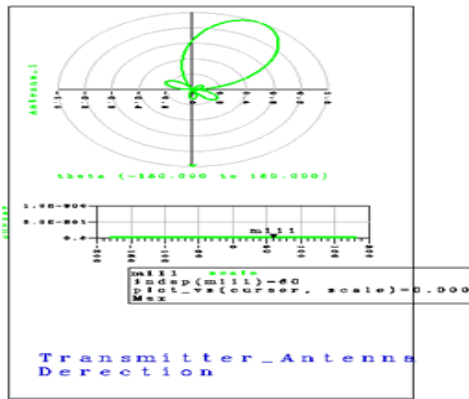
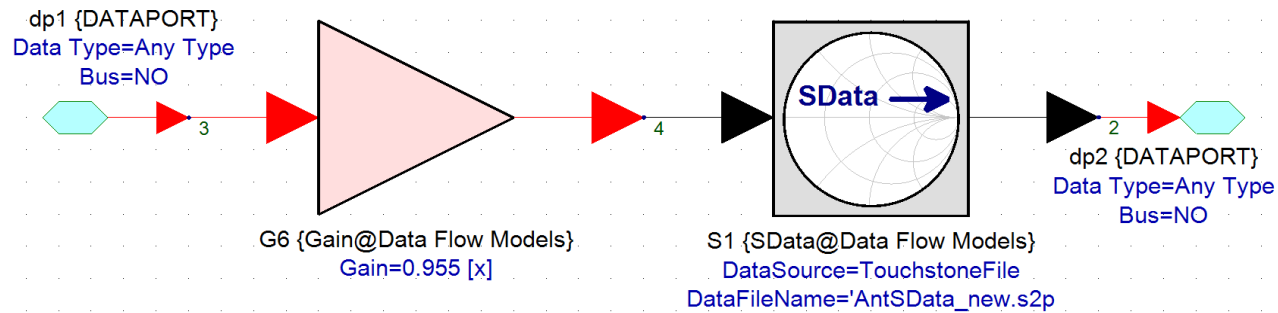


2010



PD Radar System – Antenna

- S-parameters based
- Antenna rotation pattern is considered
- Leverage EM simulation tools antenna analysis result



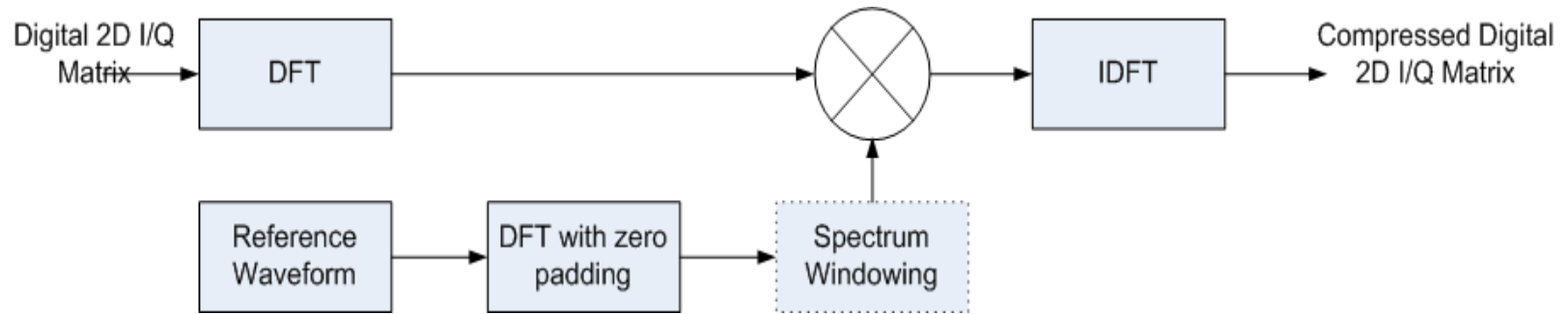
2010



Agilent Technologies



PD Radar System – Pulse Compression



2010



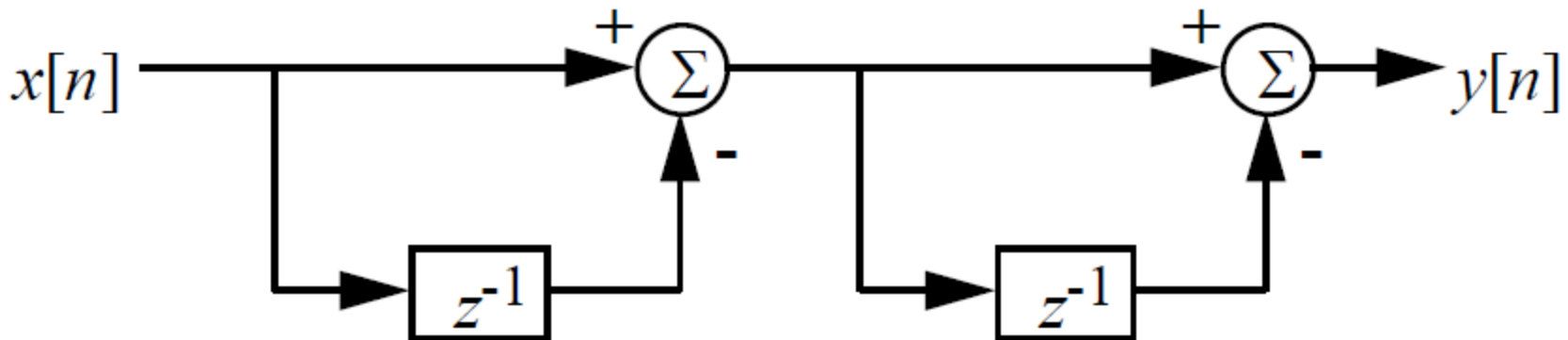
Agilent Technologies



PD Radar System – Moving Target Indicator

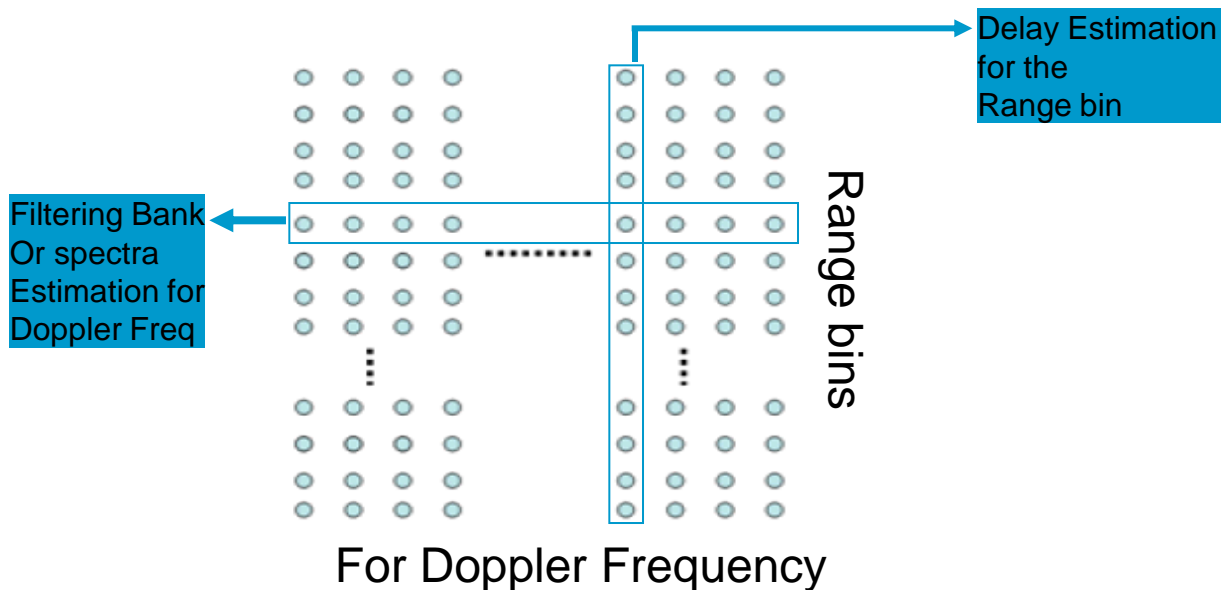
- The basic idea for the moving target indicator (MTI) is to filter the clutter at DC or very near DC but keep the other spectrum region remaining flat
- A three-pulse (double, second-order) canceller can be formed by cascading two first-order sections
- Transfer function

$$H(z) = 1 - 2z^{-1} + z^{-2}$$



PD Radar System – Moving Target Detection

- A bank of Doppler filters or FFT operators cover all possible expected target Doppler shifts.
- The input data is collected in a repetition period by using a data bank and then data points within the same range are correlated and processed by using FFT until all data in the data bank is processed.



PD Radar System – MTD Model

– The MTD model created using Math Language

The image displays three windows from the SystemVue 2009 software:

- SystemVue - [MTD]:** Shows the 'Open Model' of the MTD block. It features a central 'MathLang' block with three data ports: 'dp1 (DATAPORT)', 'dp2 (DATAPORT)', and 'dp3 (DATAPORT)'. The block is connected to a schematic diagram on the left.
- 'M1' Properties:** Shows the configuration for the 'M1' block. The 'Equations' tab is active, displaying the following code:

```
1 % function [MTD_Out, MTD_Max] = SV_MTD(Input)
2 % Boundary Check
3 -if (m_N < 1)
4     error('m_N should be greater than 0');
5     m_N = 1;
6 end;
7 -if (m_M < 1)
8     error('m_M should be greater than 0');
9     m_M = 1;
10 end;
11 MTD_Out = zeros(1, m_N*m_M);
12 tmp_out = zeros(m_N, m_M);
13 MTD_Max = zeros(1, m_N);
14 %R_Input = reshape(Input, m_N, m_M);
15 R_Input = zeros(m_N, m_M);
16
```
- Data5\M1_Eqn:** Shows the MATLAB code for the MTD model. The code includes error checks for m_N and m_M , and a loop for calculating the output. A red box labeled 'Debug Code' highlights the MATLAB code. The output window shows the following results:

```
>> R_Input
ans =
-1.76777e-006 + 9.21692e-007j    0    0    0    0
-1.94112e-006 + 5.88707e-007j    0    0    0    0
-5.41401e-006 - 3.80097e-007j    0    0    0    0
3.43429e-006 + 4.25052e-006j    0    0    0    0
2.47072e-006 - 7.00665e-007j    0    0    0    0
```

2010



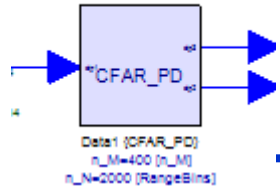
PD Radar System – CA CFAR

- – **Test cell:** the detected cell
- – **Guard or gap cell:** value not to be included in the interference estimate due to possible target contamination
- – **Reference cell:** values assumed to be interference only, thus used to estimate interference parameters

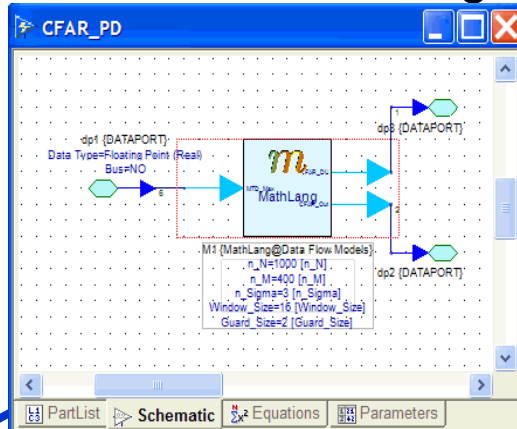


PD Radar System – CFAR Model

– The CFAR model created using Math Language



Open Model



Open Code

```

Units Use MKS Go
Up to date
Variable
ans=1606
CFAR_DU=0
CFAR_Out = Real [1x2000]
K=1606
M_State = struct [1x1]
MTD_M = Complex [1x2000]
MTD_Max = Complex [2000x1]
margin=0
nargout=0
Y=4.41489 - 30.9227j

1 % function [CFAR_Out,DU]= ADS_CFar(MTD_Max)
2 -if (n_N < 1)
3     error('n_N should be greater than 0');
4     N = 1;
5 end
6 -if (n_M < 1)
7     error('n_M should be greater than 0');
8     M = 1;
9 end
10 -if ((n_Sigma < 0.0 ))
11     error('Sigma should be greater than 0');
12     n_Sigma = 0.01;
13 end
14 -if (Window_Size < 1)
15     error('CFAR Window Size should be greater than 0');
16     Window_Size = 1;
17 end
18 -if (Guard_Size < 1)
19     error('CFAR Guard Size should be greater than 0');
20     Guard_Size = 1;
21 end
22
23 CFAR_Out = zeros(1, n_N);
24 CFAR_DU = zeros(1, 1);
25 MTD_M=MTD_Max';
26 [Y, K] = max(MTD_M);
27 startW=n_M+Guard_Size+1;
28 stopW=startW+Window_Size;

```

```

>> Y
ans =
    4.41489 - 30.9227j
>> K
ans =
    1606
>> |

```

Debug Code

```

25 MTD_M=MTD_Max';
26 [Y, K] = max(MTD_M);
27 startW=n_M+Guard_Size+1;
28 stopW=startW+Window_Size;
29 startW_1=n_M-Guard_Size-Window_Size-1;
30 stopW_1=startW_1+Window_Size;
31 nnn=n_Sigma*sqrt(2)/pi*(mean(MTD_M(1,startW:stopW)))+mean(MT
32 -if abs(MTD_M(1,K))>abs(nnn)
33     CFAR_Out(1,K)=1;
34 -else
35     CFAR_Out(1,K)=0;
36 end
37 %
38 CFAR_DU(1,1) = CFAR_Out(1,K);
39 % CFAR_DU(1,2) = K;

```



PD Radar System – Measurements

- Basic measurements
 - Waveform
 - Spectrum
 - Signal Noise Ratio
- Advanced measurements
 - Estimation of Distances and Speed
 - Detection probability

$P_d = \text{Number of Successful detection} / \text{Total number of Tests}$

- False Alarm probability

$P_f = \text{Number of False Error} / \text{Total Number of Tests}$

Importance sampling and Quasi-Analytical method will be used to speed up the P_f simulation [4-5].

2010



Agilent Technologies



PD Radar System – Simulation Setup

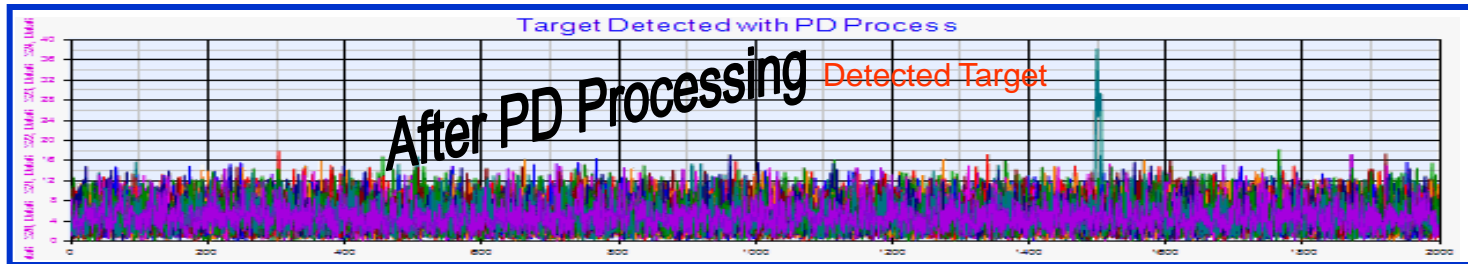
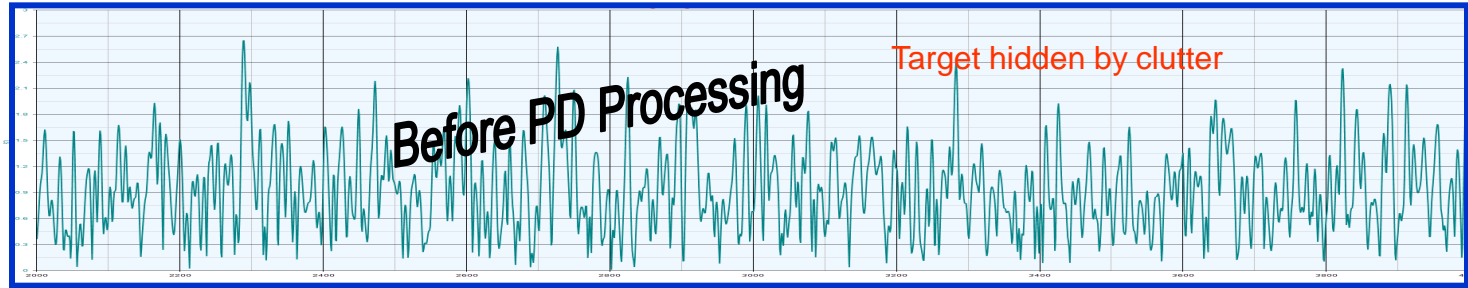
- All key parameters can be set at the Parameter table defined for the PD simulation system as seen as below. Use can very easily edit, add or delete any parameter.

Name	Description	Default Value	Units	Tune	Show	Initially Use Default
PulseWidth	Pulse Width	500e-9	s	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
PRF	Pulse Repeat Frequency	10000	Hz	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Fd	Doppler Frequency	8125	Hz	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Range	Target Range	12000	M	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
RF_Freq	RF Frequency	10e9	Hz	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
IF_Freq	IF Frequency	2.9e9	Hz	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
BB_Freq	Baseband Frequency	60e6	Hz	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Bandwidth	Band Width	47e6	Hz	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
SamplingFreq	Simulation Sampling Frequency	20e6	Hz	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
FFTSize	FFT Size	32	()	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
n_M	Detection Cell	400	()	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Window_Size	CFAR Window Size	32	()	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Guard_Size	CFAR Guard Size	6	()	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Sigma	Clutter Standard Diviation	2.5	()	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
C_BW	Clutter Bandwidth	1e6	Hz	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
RotationAngle	Antenna Rotation Angle	60	deg	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Theta	Antenna Angle	90	deg	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
n_Sigma	Noise Standard Diviation	3	()	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
n_Detection	Number of statistics for the detec	1	()	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>



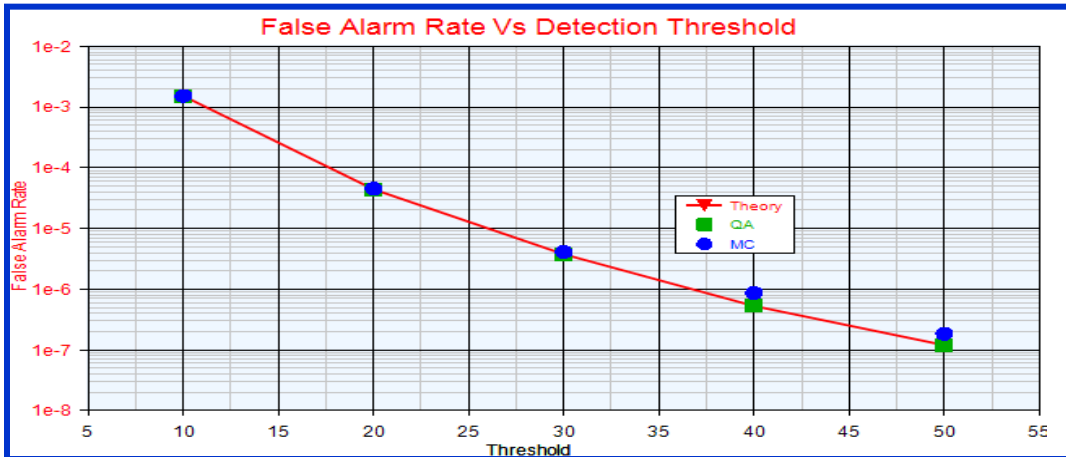
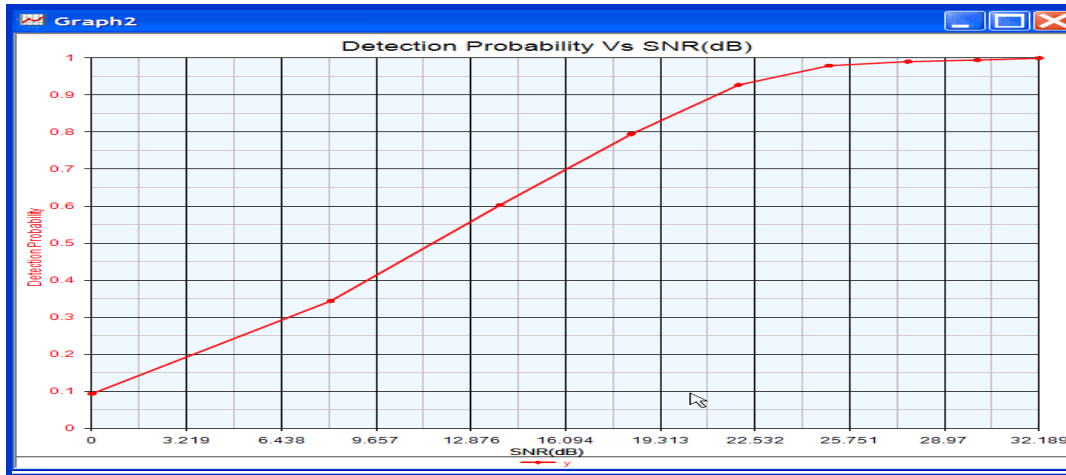
PD Radar System – Simulation Results

- PD radar extremely valuable in situations involving small moving targets hidden by heavily cluttered environments



PD Radar System – Performance

- Detection Probability
- Estimation of Target Distance and Speed



Simulation Results window showing parameters and a 'Go' button. The window title is 'Simulation_Results'. Below the title bar, there is a 'Units: Use Display' button and a 'Go' button. The main area contains the text 'Up to date' and a list of simulation parameters.

```
C=300e+6
Carrier=10e+9
DelayTime=80.3e-6
DetectorProbability=1
DopplerFrequency=8125
FFT_Size=32
PRF=10000
SamplingRate=20e+6
TargetDistance=12045
TargetSpeed=243.75
```

2010



Agilent Technologies



Summary

- Algorithms are critical for high-performing advanced radars
- A unified approach using Agilent SystemVue was demonstrated
 - Provides a user friendly environment for algorithm development
 - Integrates software and hardware to verify algorithms
- A development example for PD radar key algorithms was shown
- SystemVue can also be used to develop algorithms for Digital Array Radar plus Space-time adaptive processing (STAP) and MIMO Radar

2010



Agilent Technologies



36

THANK YOU

For more information

www.agilent.com/find/eesof-systemvue

www.agilent.com/find/eesof-systemvue-videos

www.agilent.com/find/eesof-systemvue-evaluation

Or, contact your regional Agilent resource

- www.agilent.com/find/eesof-contact

2010



References

1. www.ntia.doc.gov/osmhome/reports/ntia00-40/ntia00-40.pdf
2. I. Skolnik, Radar Handbook, 2nd ed. McGraw-Hill, Inc. 1990
3. D. Curtis Schleher, MTI and Pulse Doppler Radar, Artech House, Inc. 1991
4. Dingqing Lu and Kong Yao "Importance Sampling Simulation Techniques Applied to Estimating False Alarm Probabilities," Proc. IEEE ISCAS, 1989, pp.598-601
5. Dingqing Lu "Quasi-Analytical Method For Estimating low False Alarm Rate," accepted by EuRAD 2010.



SystemVue – *Supplemental Slides*

- *Enabling Capabilities for Radar Design*

2010

Copyright © 2010 Agilent Technologies



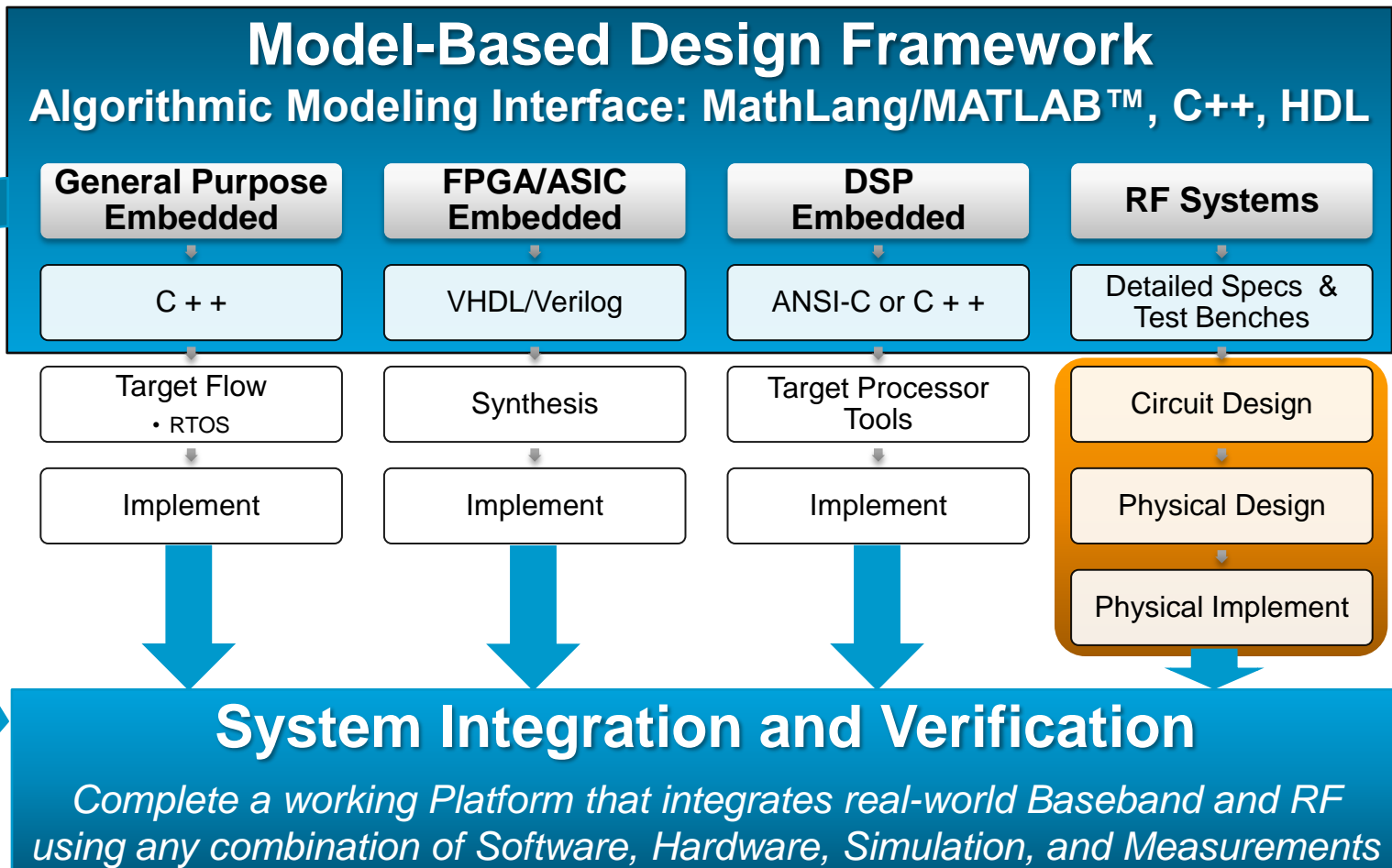
Agilent Technologies

Uncovering the Hidden Impairments in Advanced RADAR Systems



April 14, 2010

SystemVue - Enabling Capabilities for Radar Design



2010



Agilent Technologies



40