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Synthetic Aperture Radar Modeling using MATLAB and Simulink

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Agenda

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- What is Synthetic Aperture Radar?
  - SAR Imaging Process
- Challenges in Design and Simulation
- Modeling in MATLAB
- System Block Diagram
- Algorithm Flow
- Modeling in Simulink
  - Key modules involved
- Conversion Simulink-HDL
  - Major modules involved
- SimRF Model for Raw Data Generation
- Results and Discussions
  - Simulator GUI Snapshots
  - Other Results

What is Synthetic Aperture Radar? (Contd.)

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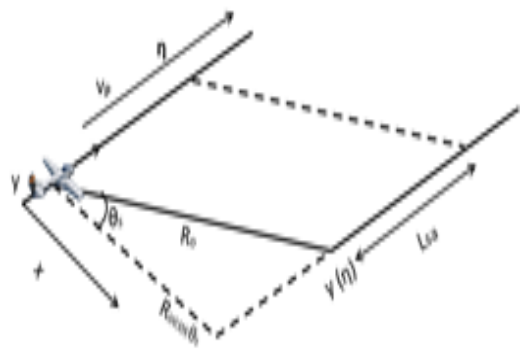
- Synthetic Aperture Radar (SAR) is application of RADAR system to generate a ‘Synthetic Aperture’



- Generating High Resolution Images out of Radar data.
- Exploiting the capabilities of Radar Ranging by moving the platform orthogonal to antenna radiation direction.
  - Radio-waves transmitted by the antenna are scattered, received back, recorded, and processed to generate images of the ground terrain-objects.
  - Two-dimensional data is collected by using such a geometry.
- Range/Fast-time direction and Azimuth/slow-time direction.
  - Azimuth direction data arises out of inter-pulse Doppler generated due to platform motion with respect to ground target.
  - Doppler is also referred to as Phase history.

What is Synthetic Aperture Radar? (Contd.)

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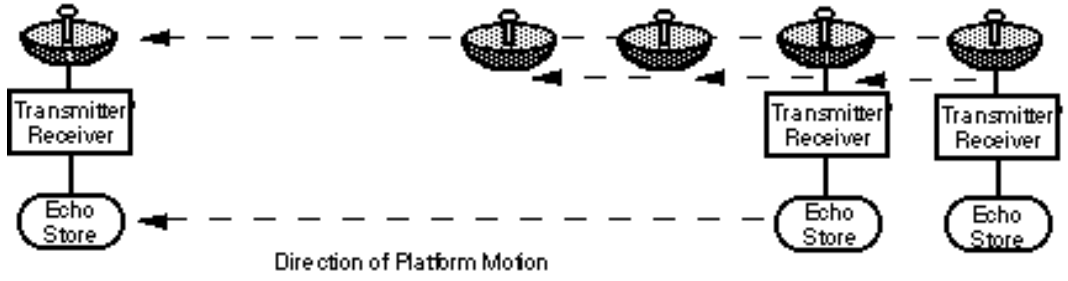
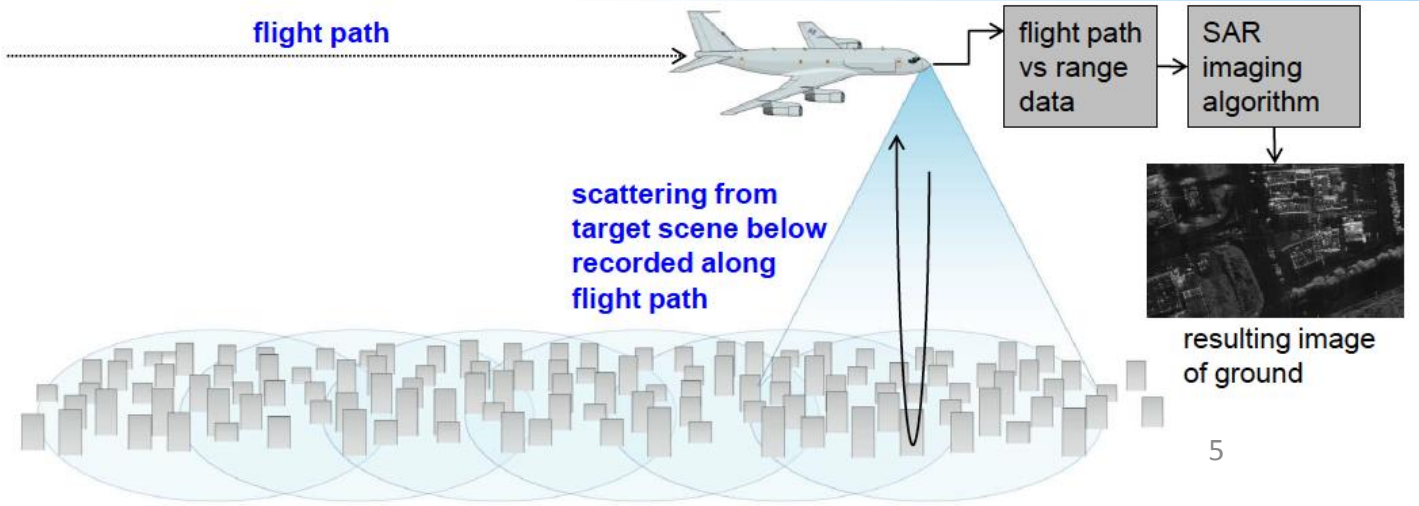
- Range and azimuth data are processed to generate SAR image
- Advantages of Synthetic Aperture Radar
  - Key advantage being an active sensor system.
  - All-Weather Performance, Independent of atmospheric conditions (day, night, fog, rain etc.).
  - Foliage Penetration for certain operating Frequencies.
  - Long range operation (~200 meters up to few hundred kilometers).
  - High resolution imaging (1 meter at orbital altitude of ~500Kms).

SAR Imaging Process

- Ensemble of 2D reflections, each being a reflection from an individual scatterer in the scene
- Small antenna illuminates large swaths on ground
- Phase encoded (either Linear Frequency Modulated-LFM compression or digitally encoded) pulses are transmitted and echoes received
- SAR algorithm processes raw data into an image
  - Synthesizing an aperture as large as the flight path
  - Narrow synthesized beam width, high resolution, high gain
- Best algorithm for each application depends on: geometry and radar parameters, accuracy required, efficiency required



Courtesy: Japan Aerospace Exploration Agency



Challenges in Design and Simulation

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- The problem is primarily a System development problem
- The problem includes
  - Proof of Concept development
    - Signal Processing Algorithm development
    - Hardware(RF + Baseband Processing)
- Most of the solutions focus on specific targets either RF or Baseband
- The fundamental advantage MATLAB provides is an end-to-end simulation and design of the system.
- Looking at fundamental implementation level, a simple example can be datatype.

Challenges in Design and Simulation

- The ease MATLAB provides in including equations, generating data pertaining to the equations helps ease the entire chain.
- The typical chain of any prototype development has simulation as its very prominent component.
- Especially, in design of radar systems where the cost of hardware implementation is very high.
- MATLAB provides a platform wherein the entire simulation can be performed in short time.

Modeling in MATLAB

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- Entire development can be summarized into 2 parts
  - Simulator Development to generate SAR Raw Data
  - Processing Algorithm Development to process the Raw Data generated from the Simulator
- Simulator development involves:
  - Transmit waveform design and description
  - Platform trajectory description
  - Target description
  - Platform motion and echo return capturing
- Processing Algorithm Development
  - Involves carrier removal
  - Range Processing
  - Motion compensation(optional/depending on requirement)
  - Squint Angle Correction(optional/depending on requirement)
  - Azimuth Processing

System Block Diagram

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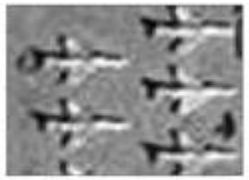


Input Image (2D Intensity Matrix)

Raw Data Generator (Squint/ Broad-side)

Processing

Pre-Processing

Range Frequency Transform

Range Compression

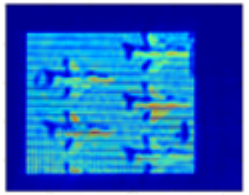
Range Walk Compensation

Azimuth Frequency Transform

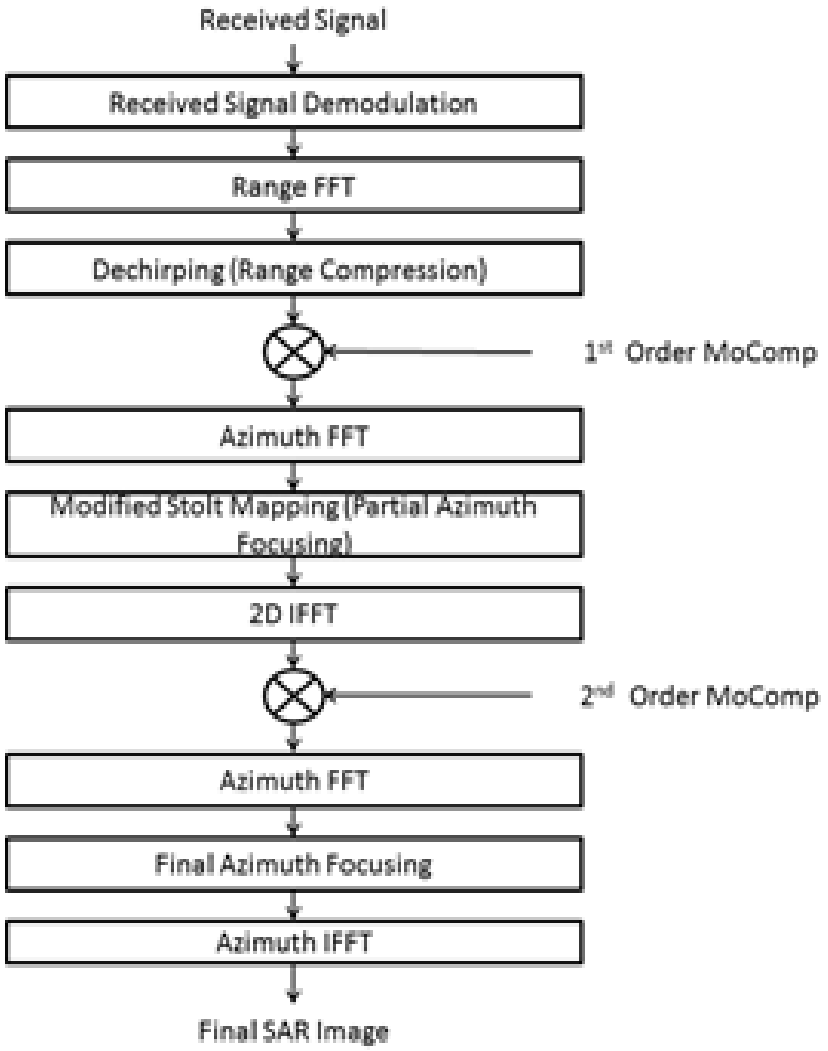
Modified Omega-K

Image De-skew for Squinted Data + Inverse transformation

Output Image (2D Intensity Matrix)

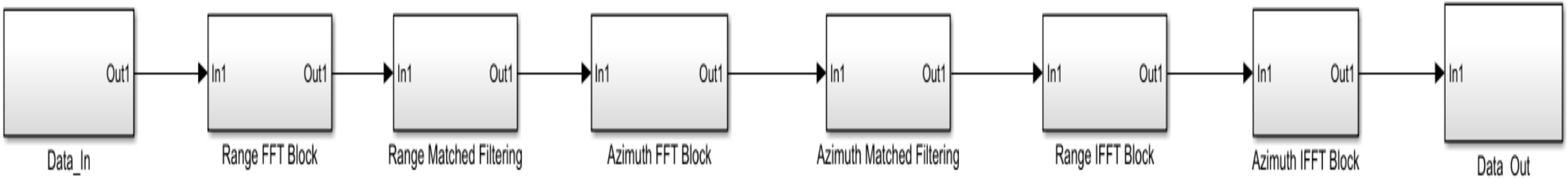


Algorithm Flow



Reference: Mishra N. and Swarup S.,"Extended Omega-K Algorithm for High Squint Mode Airborne SAR Imaging with Motion Compensation", IEEE International Microwave and RF Conference 2014

Modeling in Simulink



Modify Simulation Parameters

Key Modules Involved

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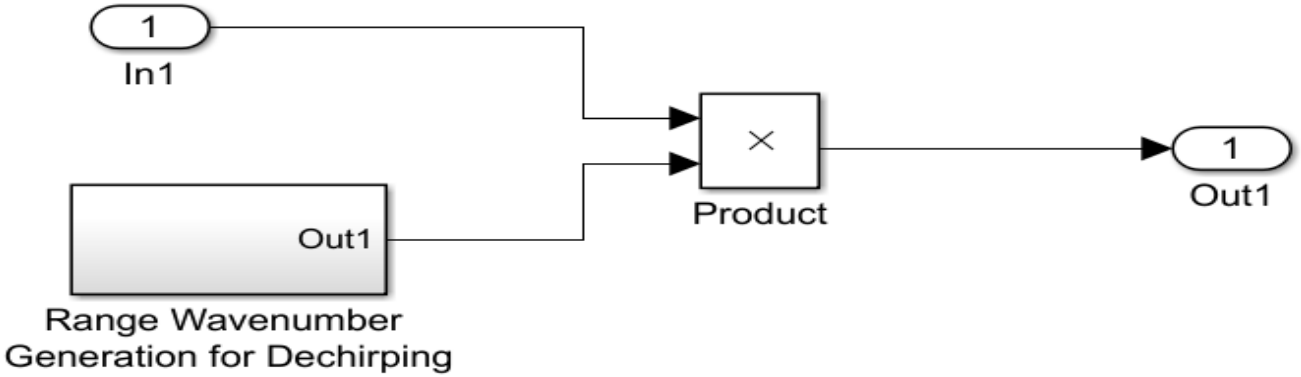
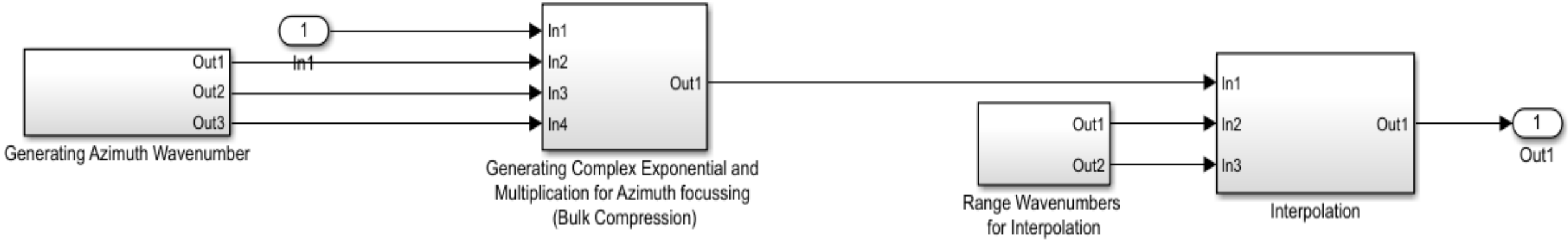
Range Matched Filtering



Azimuth Matched Filtering



Conversion Simulink-HDL

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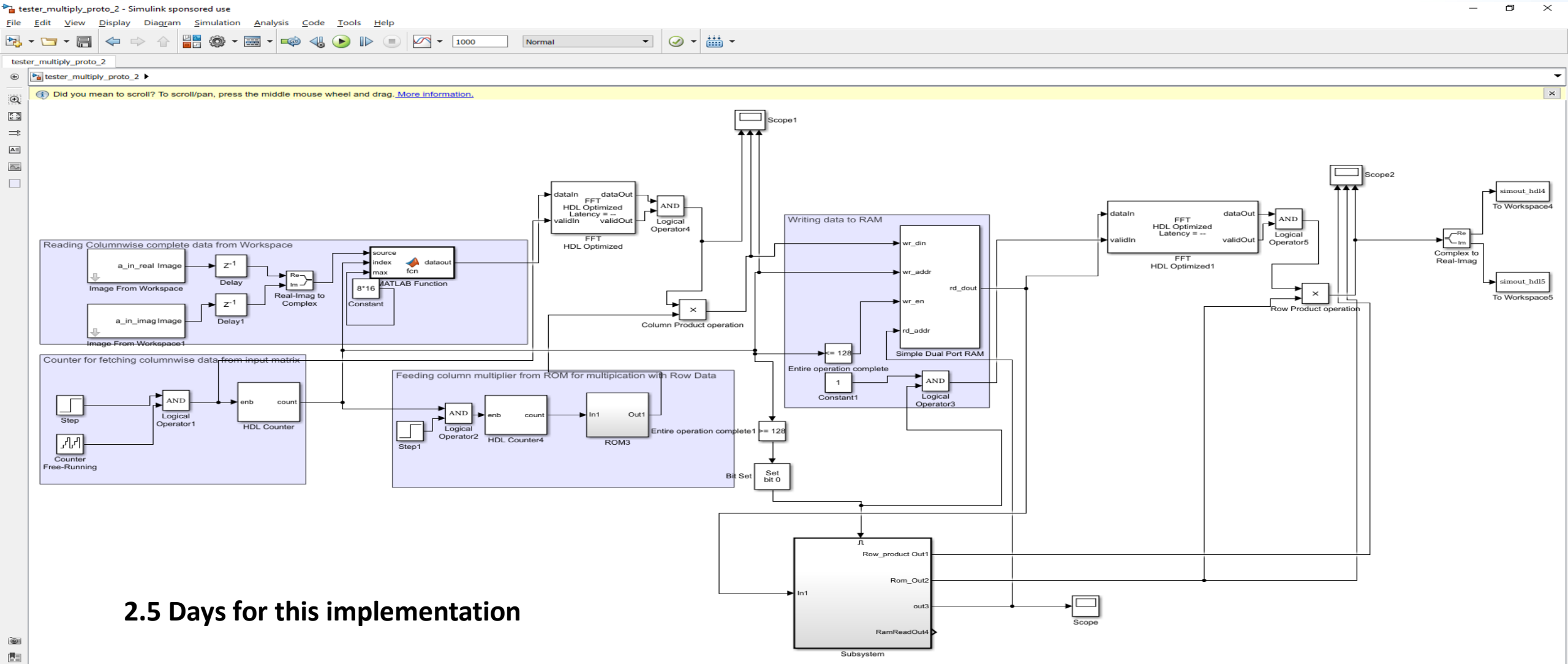
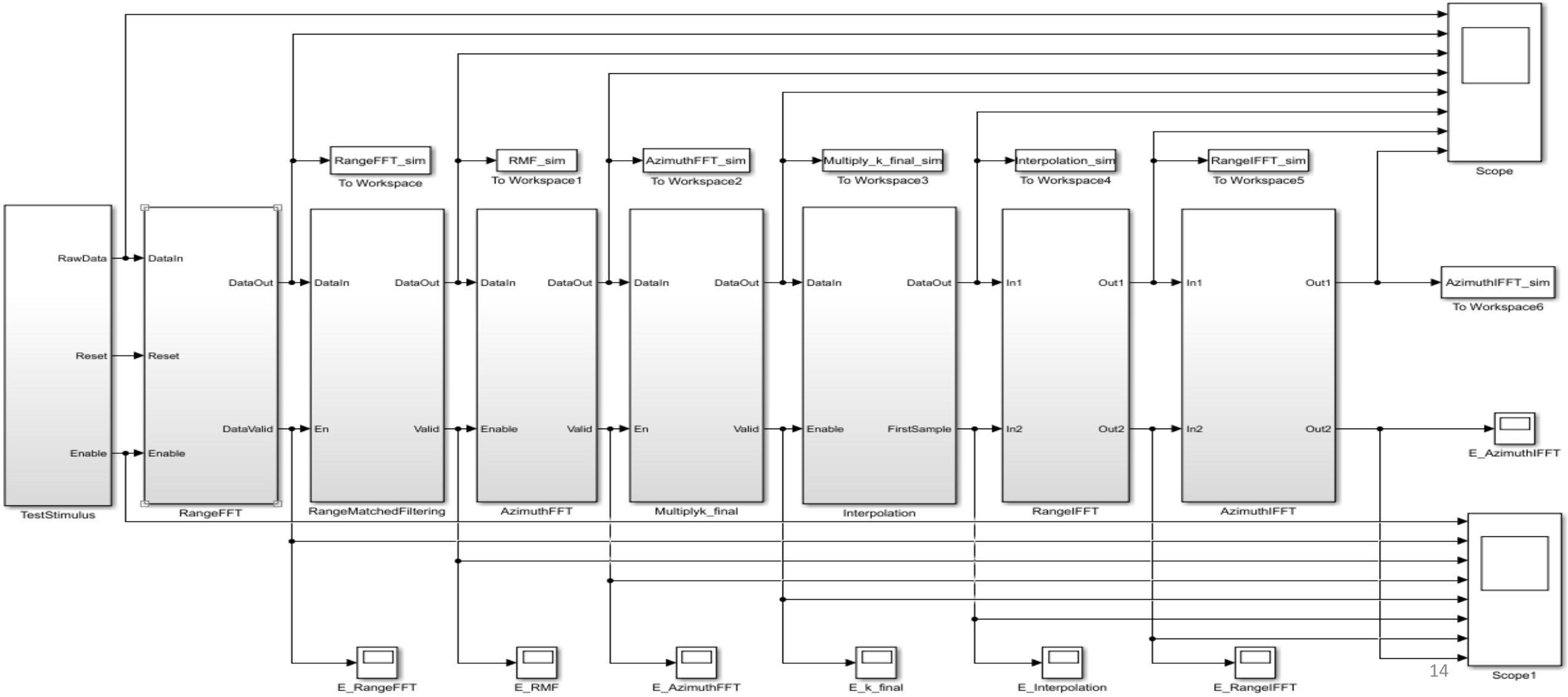
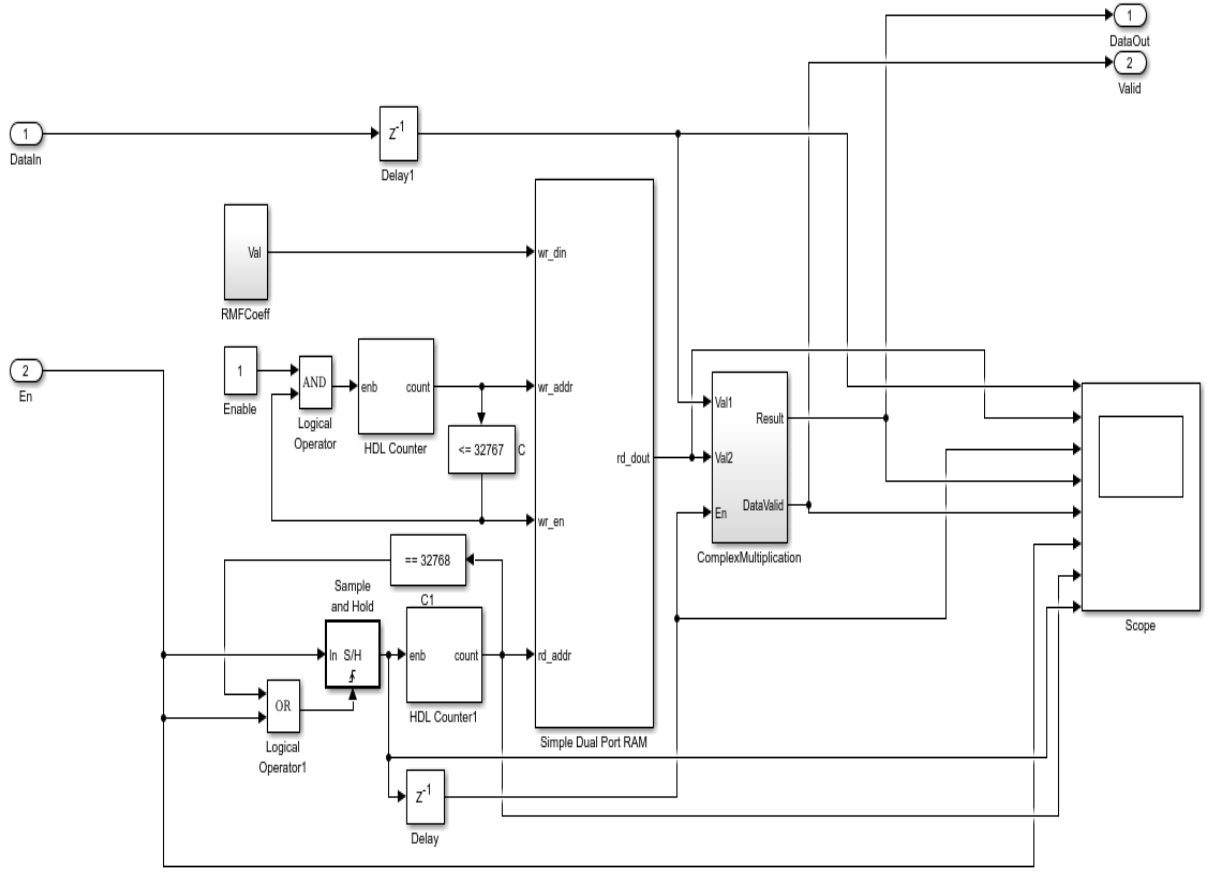


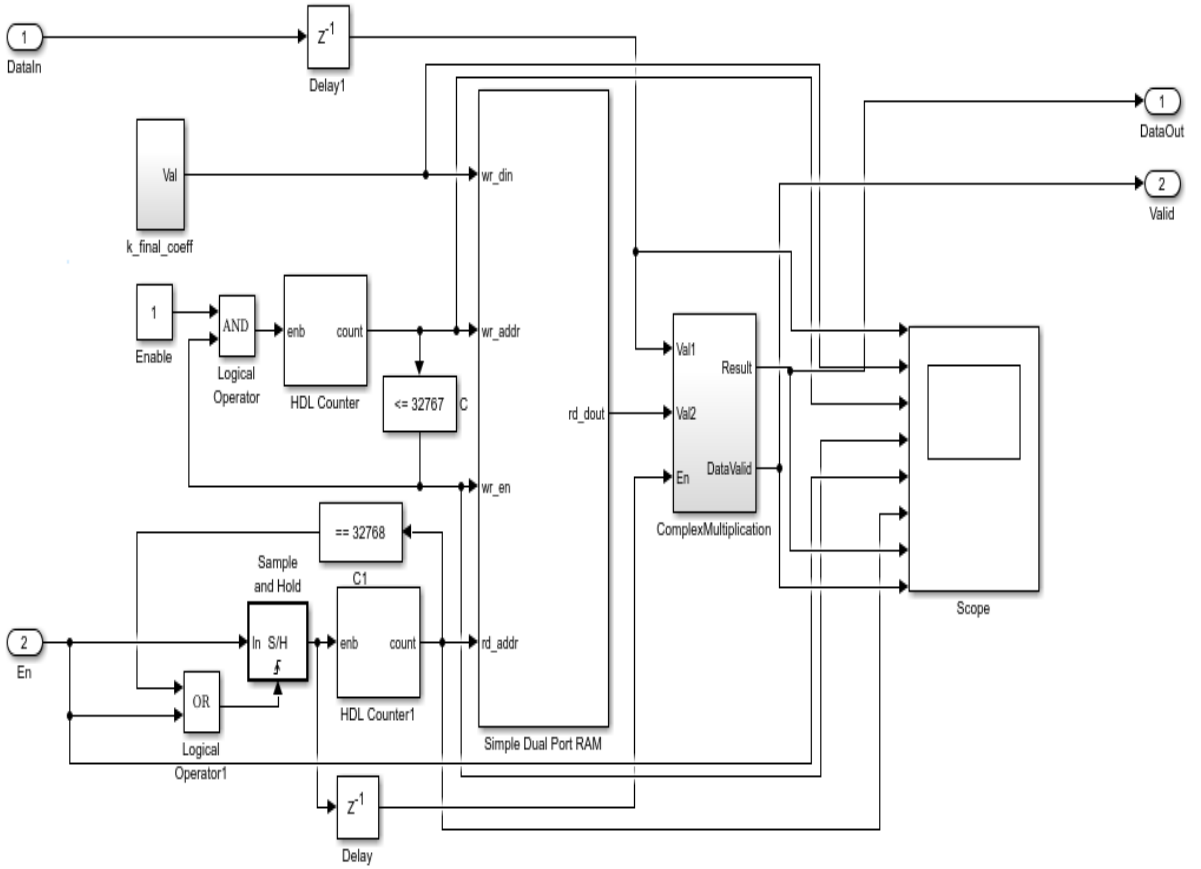
2.5 Days for this implementation

Conversion Simulink-HDL(Contd.)



Major Modules Involved

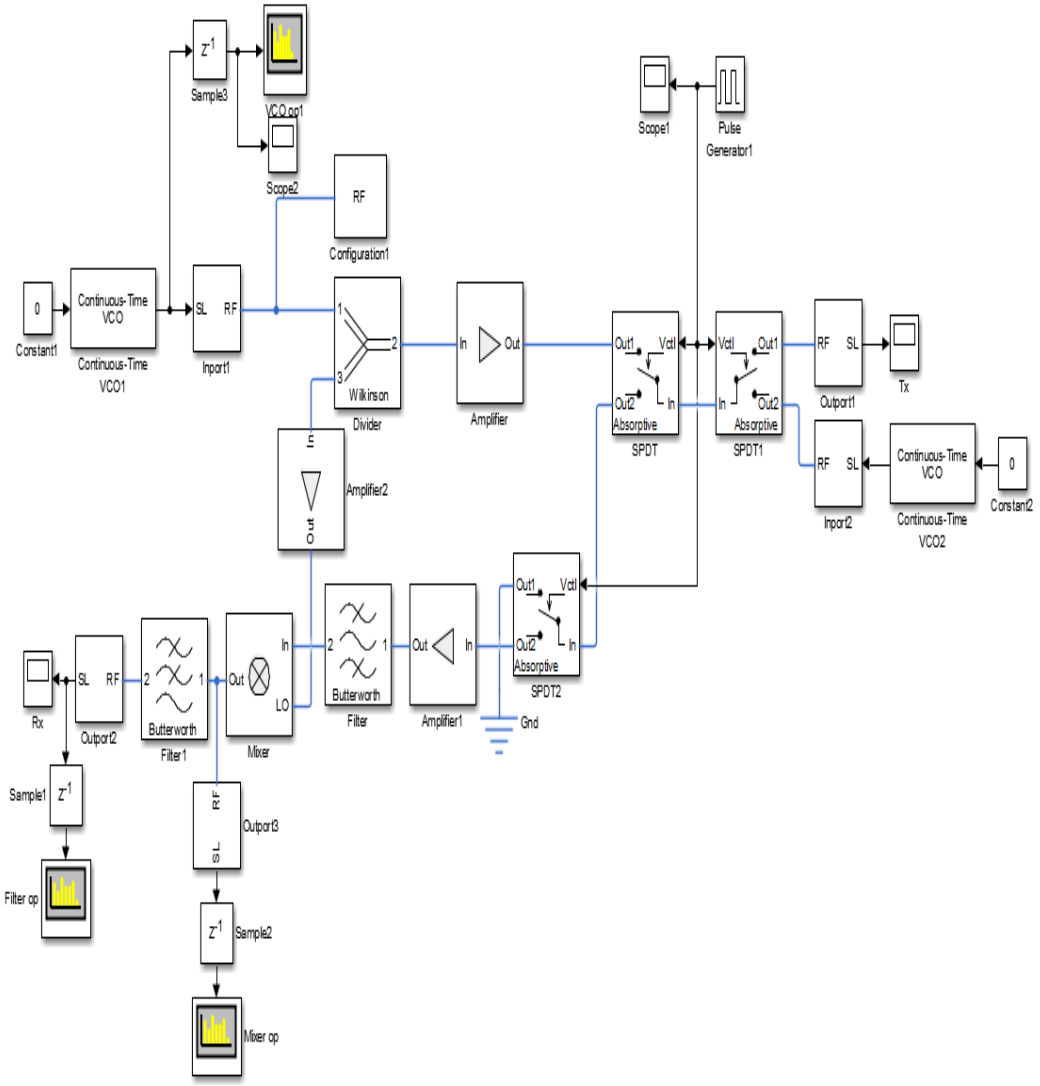




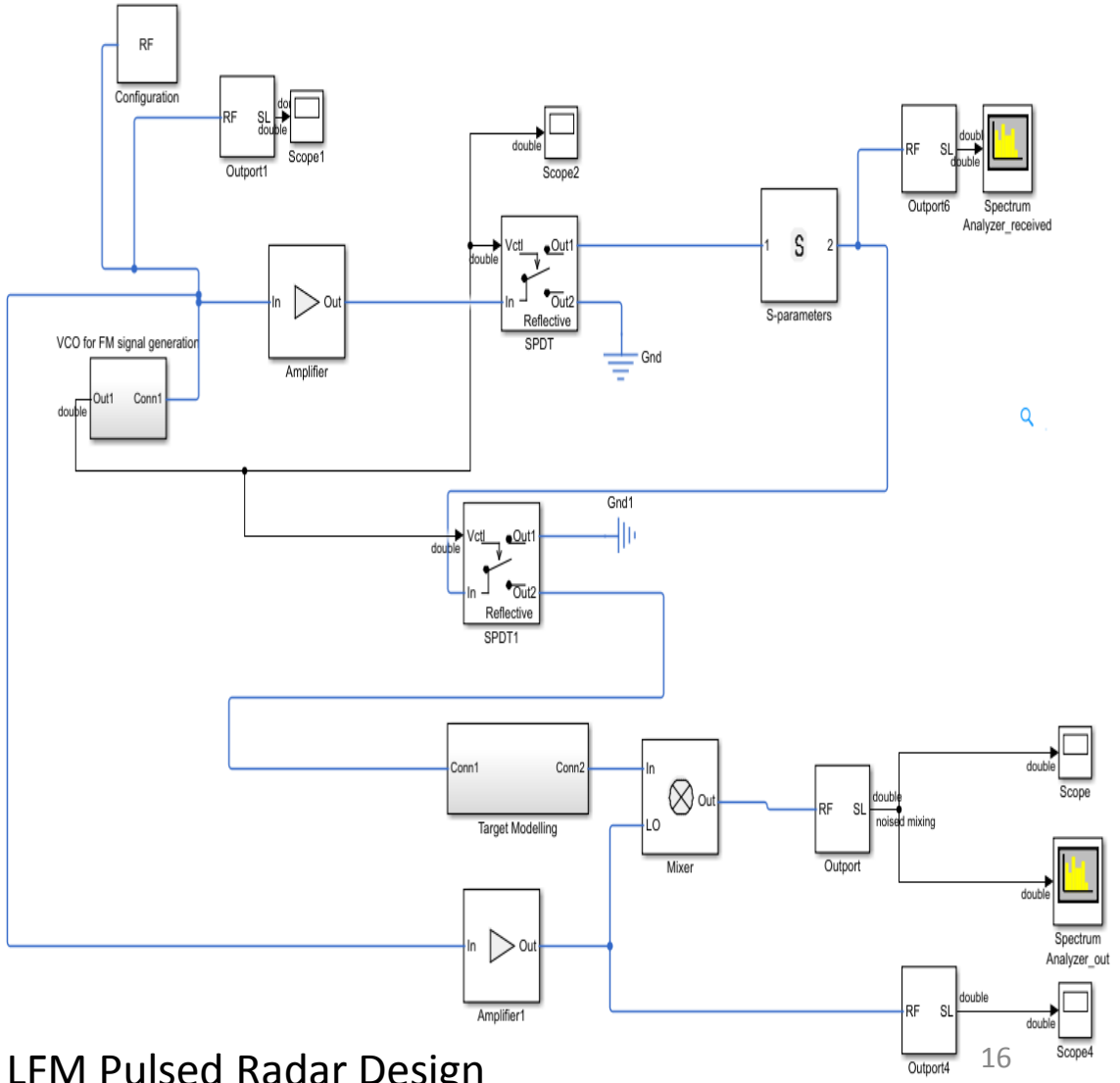
Range Matched Filtering

Azimuth Matched Filtering

SimRF Model for Raw Data Generation



Simple Pulsed Radar Design



LFM Pulsed Radar Design

SAR Simulator GUI Snapshots

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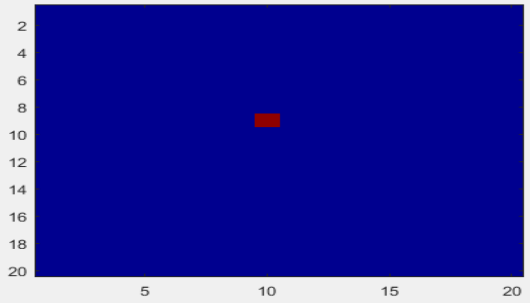
Simulator GUI With antenna Side-lobes

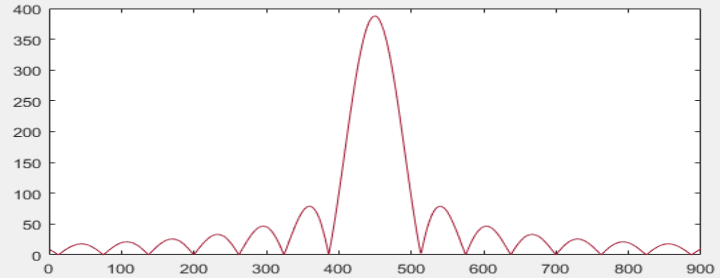
simulator_gui

SAR Simulator

Target Image Location



Antenna Beam Pattern



Carrier Frequency: 4500e6

Bandwidth: 100e6

Squint Angle From Frontside (in Degrees): 90

Pulse Repitition Frequency: 300

Flight Velocity: 200

Flight Duration: 3

Approx. Distance to Target: (•) >10 Kilometers ( ) <10 kilometers

Include Antenna Side-Lobes?: (•) Yes ( ) No

Resulting SNR: 29.2689

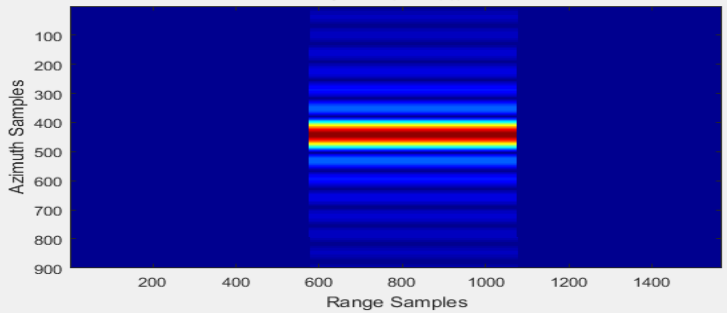
Show Antenna Pattern

RDA

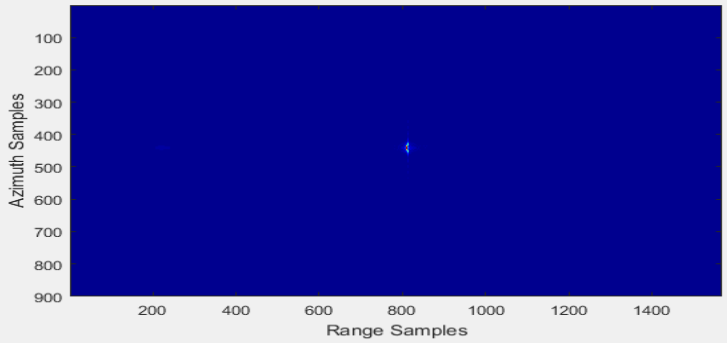
Generate Raw Data

WKA

SAR Raw Data



w-k focused data



Ask me anything

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4/17/2017

SAR Simulator GUI Snapshots

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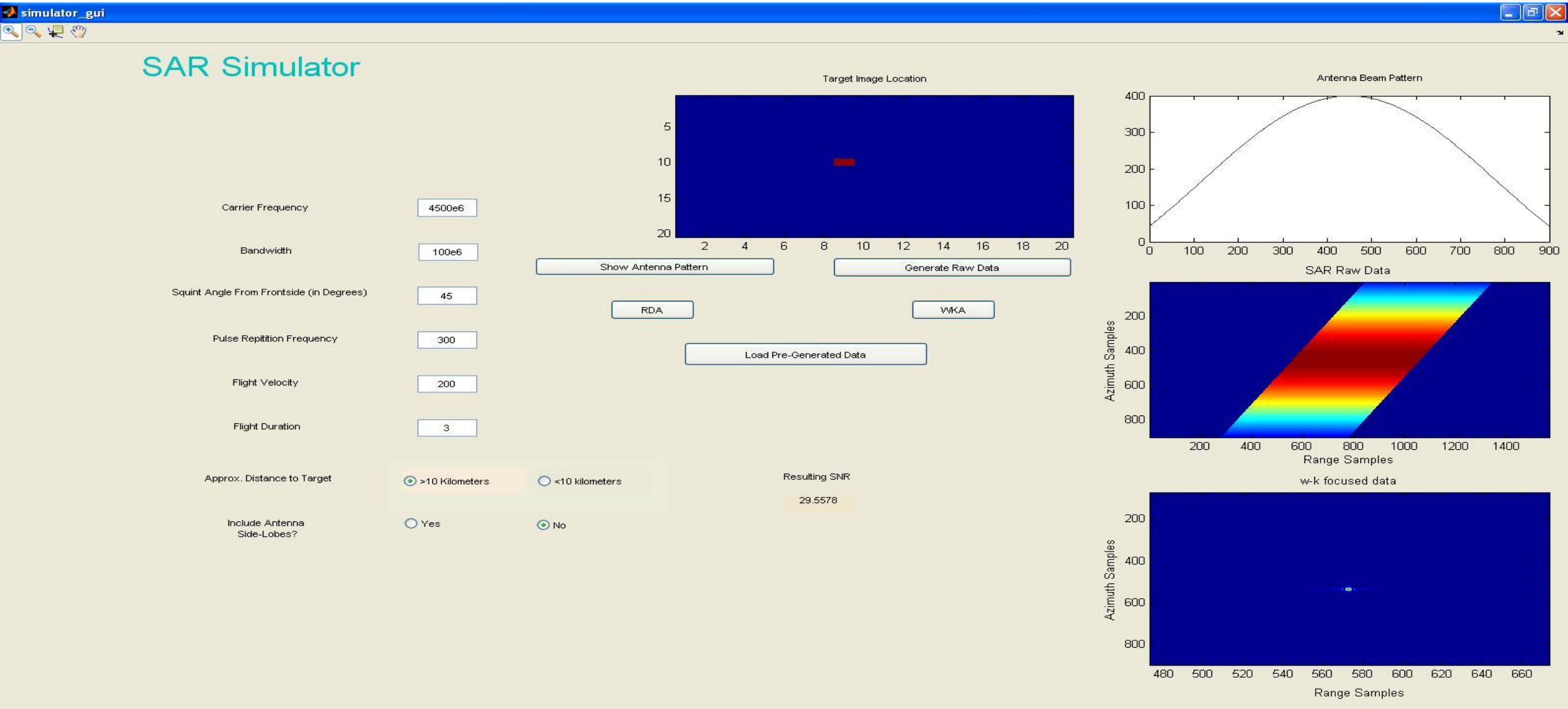
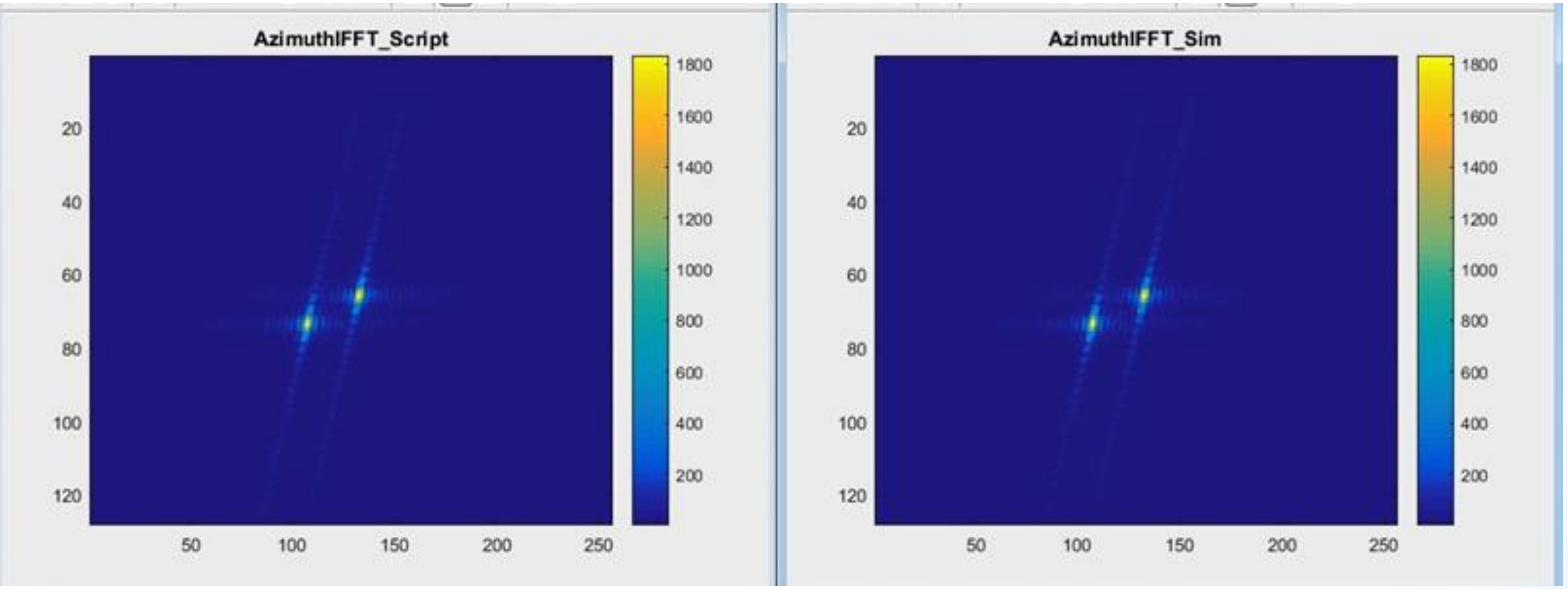
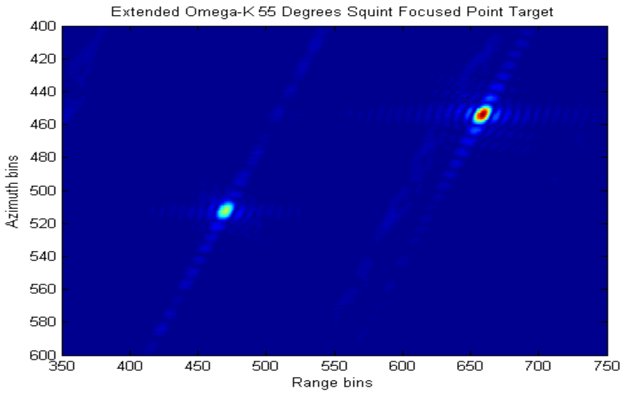
Simulator GUI without antenna Side Lobes at 45° Squint from Direction of Flight Path



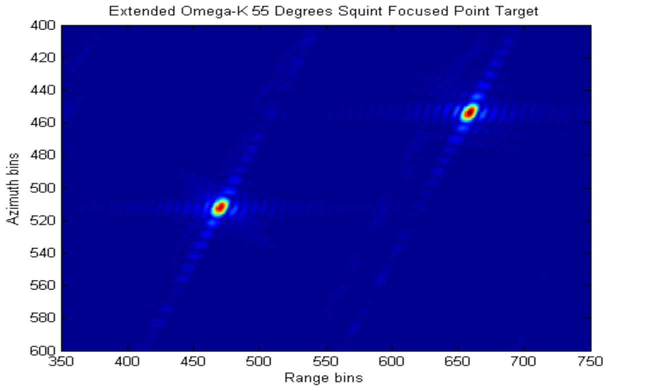
Results



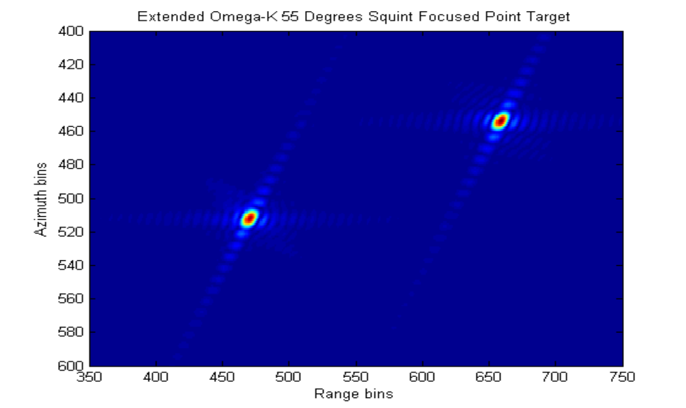
AzimuthIFFT_Script
AzimuthIFFT_Sim



Extended Omega-K 55 Degrees Squint Focused Point Target
Azimuth bins
Range bins



Extended Omega-K 55 Degrees Squint Focused Point Target
Azimuth bins
Range bins



Extended Omega-K 55 Degrees Squint Focused Point Target
Azimuth bins
Range bins

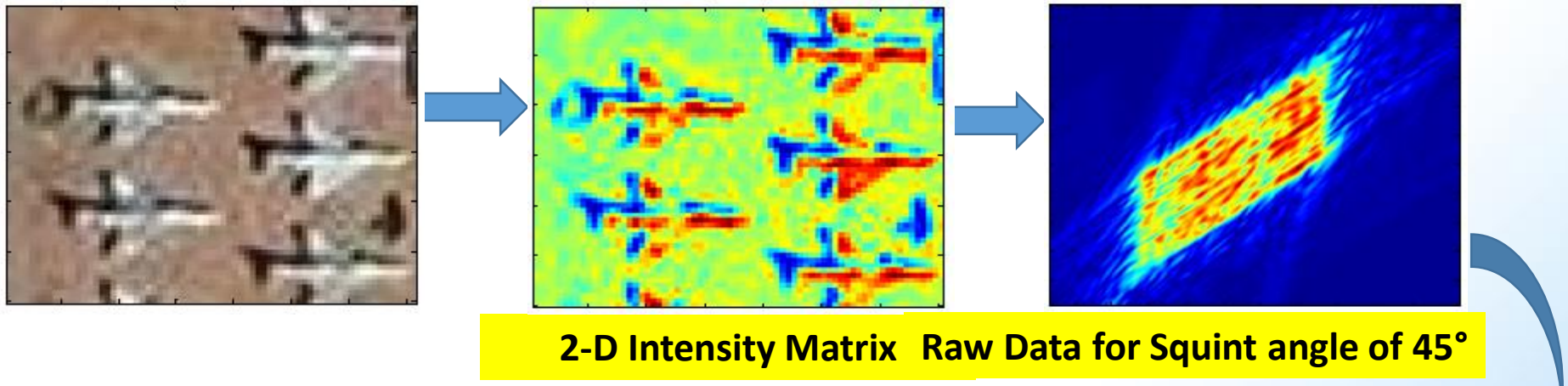
Results (Contd.)

Our Processed

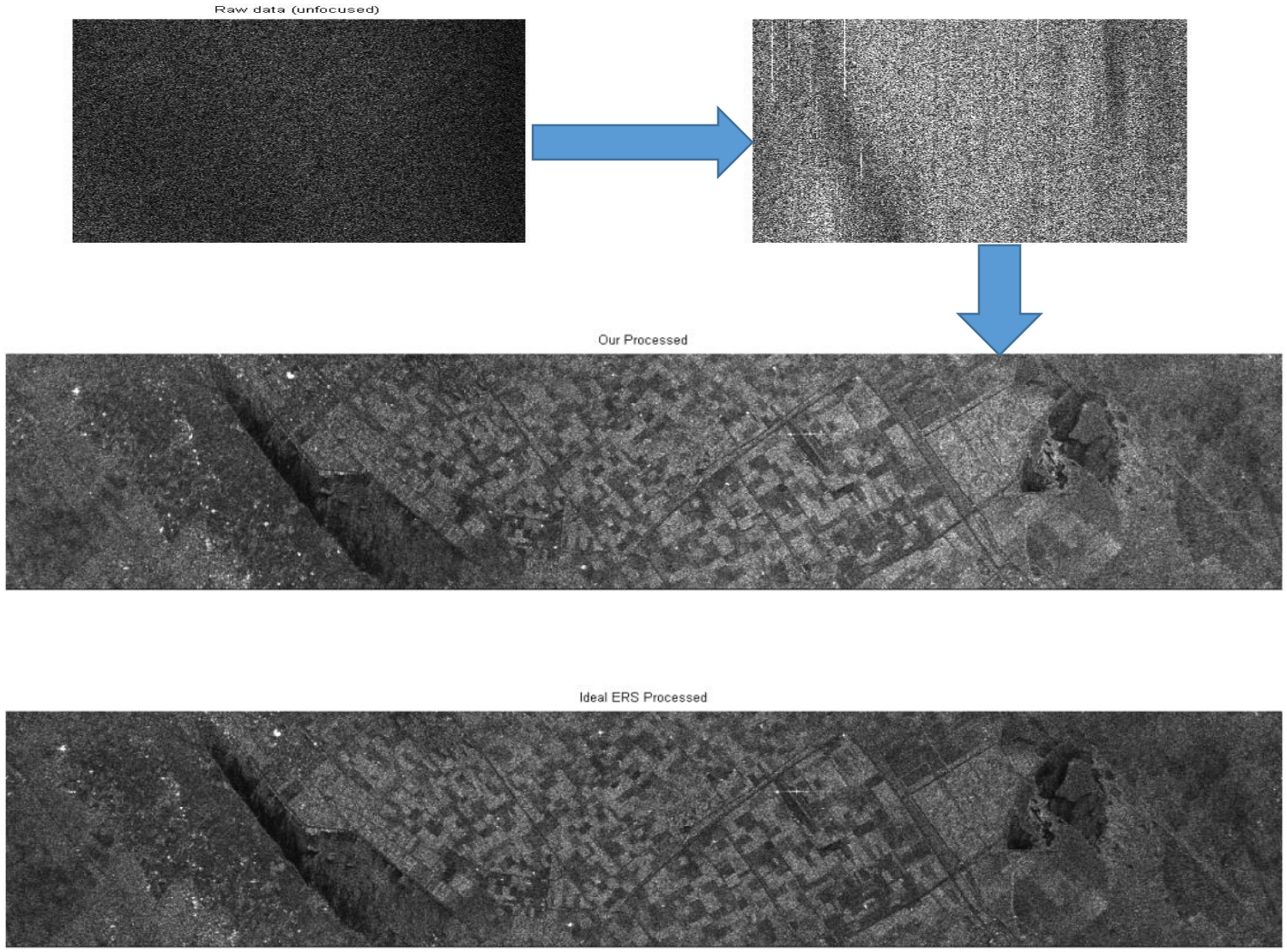
Ideal ERS Processed

Courtesy: SAR Remote Sensing Initiative (DLR Germany)

Results (Contd.)



Results (Contd.)



Courtesy: SAR Remote Sensing Initiative (DLR Germany)
SAR Imaging on Open-Source Raw Data set, improved resolution with high contrast.

Results (Contd.)

SAR Imaging on Radarsat-1 Raw Data set

References

- Mishra N. and Swarup S.,“Extended Omega-K Algorithm for High Squint Mode Airborne SAR Imaging with Motion Compensation”, IEEE International Microwave and RF Conference 2014
- Vandewal M. et.al., “Efficient and Precise Processing for Squinted Spotlight SAR through a Modified Stolt Mapping”, EURASIP Journal on Advances in Signal Processing 2007.
- Nguyen M.P., “Second Order Motion Compensation for Squinted Spotlight Synthetic Aperture Radar”, Asia-Pacific Conference on Synthetic Aperture Radar 2013(APSAR).
- Cumming I.G., Wong F.H.,“Digital Processing of Synthetic Aperture Radar Data: Algorithms and Implementation”,Artech House, 2004.
- MATLAB-Simulink Documentation