MATLAB EXPO 2018

Designing and Integrating Antenna Arrays with Multi-Function Radar Systems

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Agenda

- Design challenges of multi function radar systems
- Simulation frame work
- Antenna and Antenna array design
- Integrating Antenna and RF chain for improved fidelity of the system
- Multi Function Radar Design

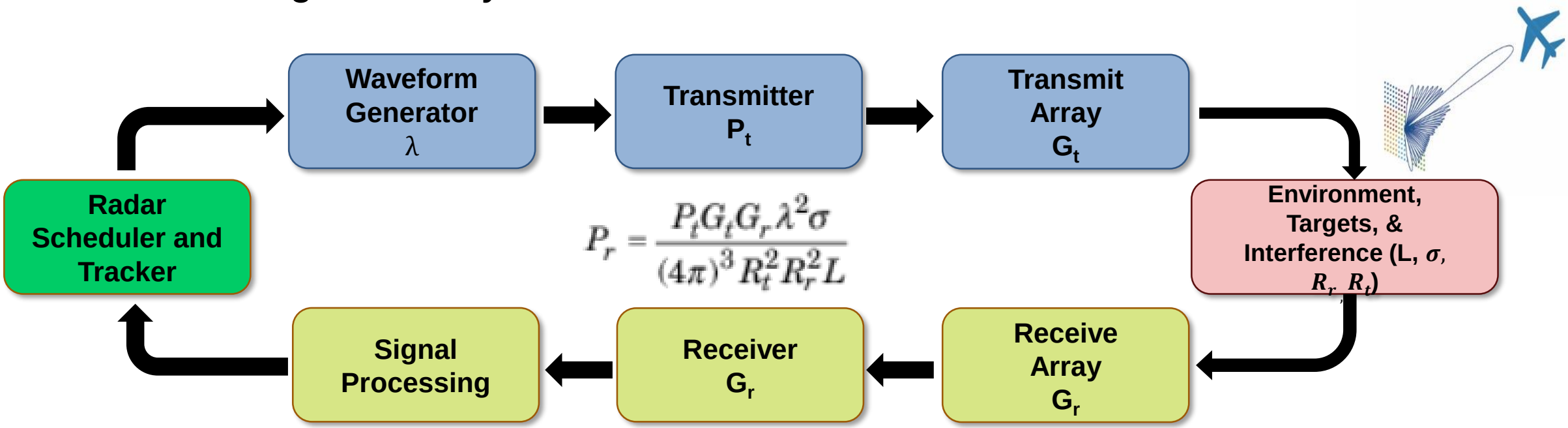
Challenges with Radar System Design

- Technical
  - Waveform modelling
  - Antenna modelling
  - Channel modelling
  - Development of sophisticated algorithms
  - Complexity involved in multi function radar scenarios

- Project Management
  - Radar Design requires multi domain expertise and collaboration
  - Lack of reuse between requirements, development and implementation
  - Lack of reuse between customer/developer and across projects

Radar and EW Simulation Framework Overview

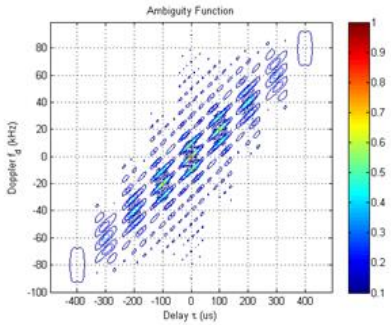
- Extensible modeling tools for radar design
- Multi-domain system modeling for radar systems
- Path to higher fidelity and customization



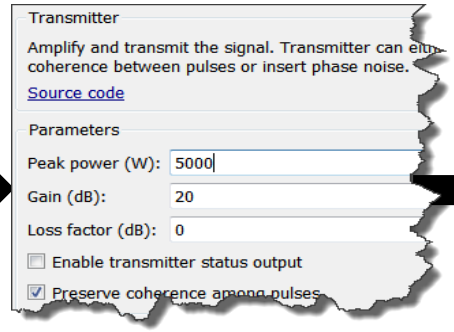
Phased Array System Toolbox for Radar System design

- ✓ Functions for calculations and analysis
- ✓ Apps for common workflows
- ✓ Parameterized components for system modeling

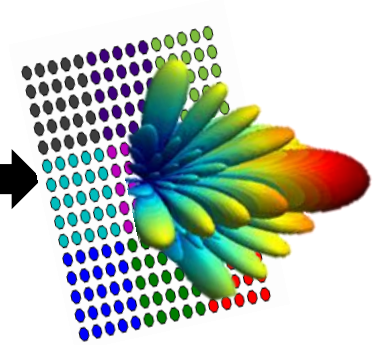
Waveforms:
Pulse, LFM, FMCW, etc.

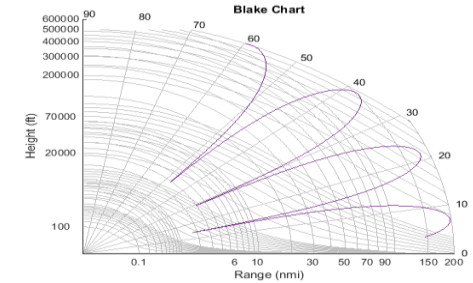


Transmitter:
Monostatic and Bistatic



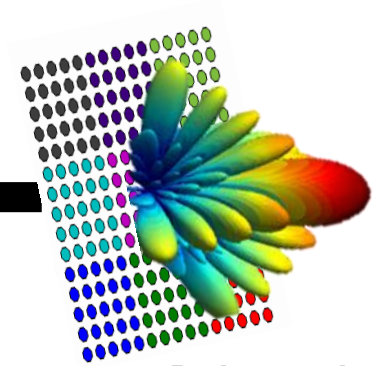
Tx Antenna Arrays:
ULA, URA, UCA, etc.



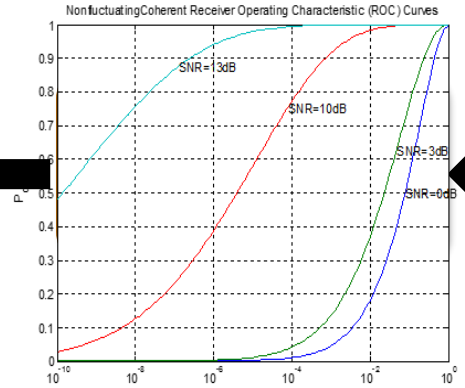


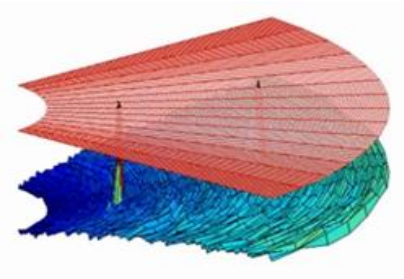
Channel:
Environmental effects, target models,
impairments, interferences

Rx Antenna Arrays:
ULA, URA, UCA, etc.



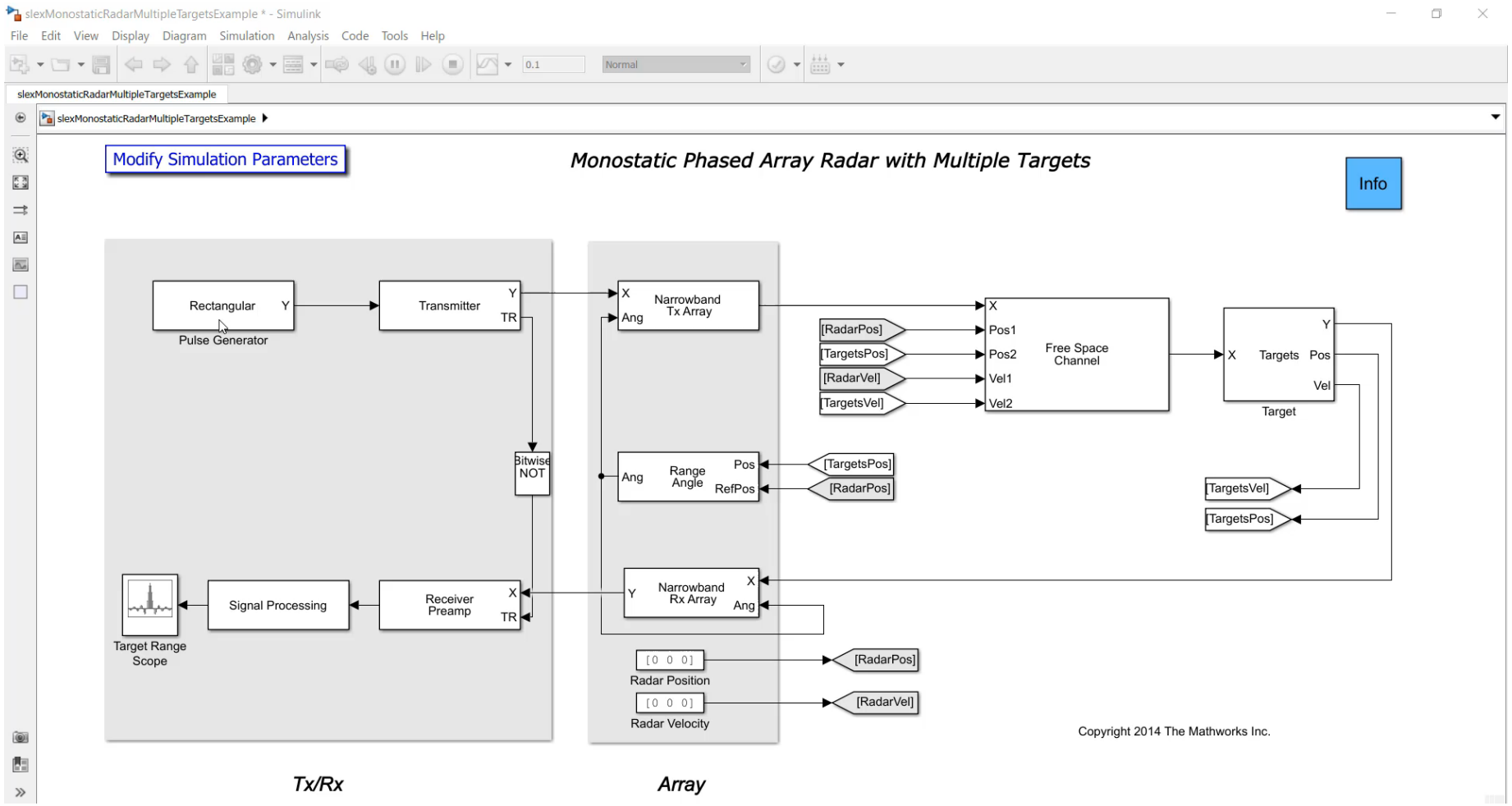
Receiver:
Monostatic and Bistatic





Beamforming, Matched Filtering,
Detection, CFAR, STAP, etc.

Radar Modelling Challenges/ More Fidel Systems

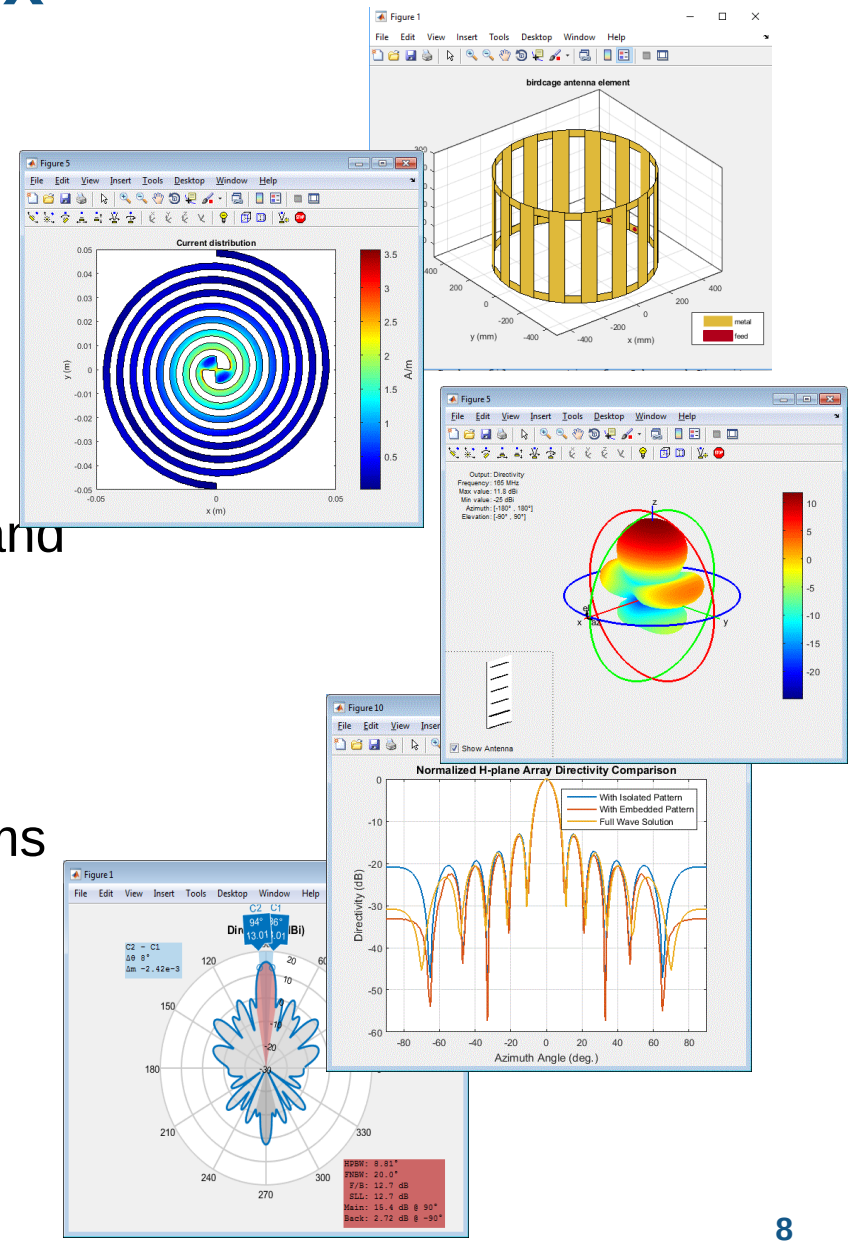


Agenda

- ✓ Design challenges of multi function radar systems
- ✓ Simulation frame work
- Antenna and Antenna array design
- Integrating Antenna and RF chain for improved fidelity of the system
- Multi Function Radar Capabilities

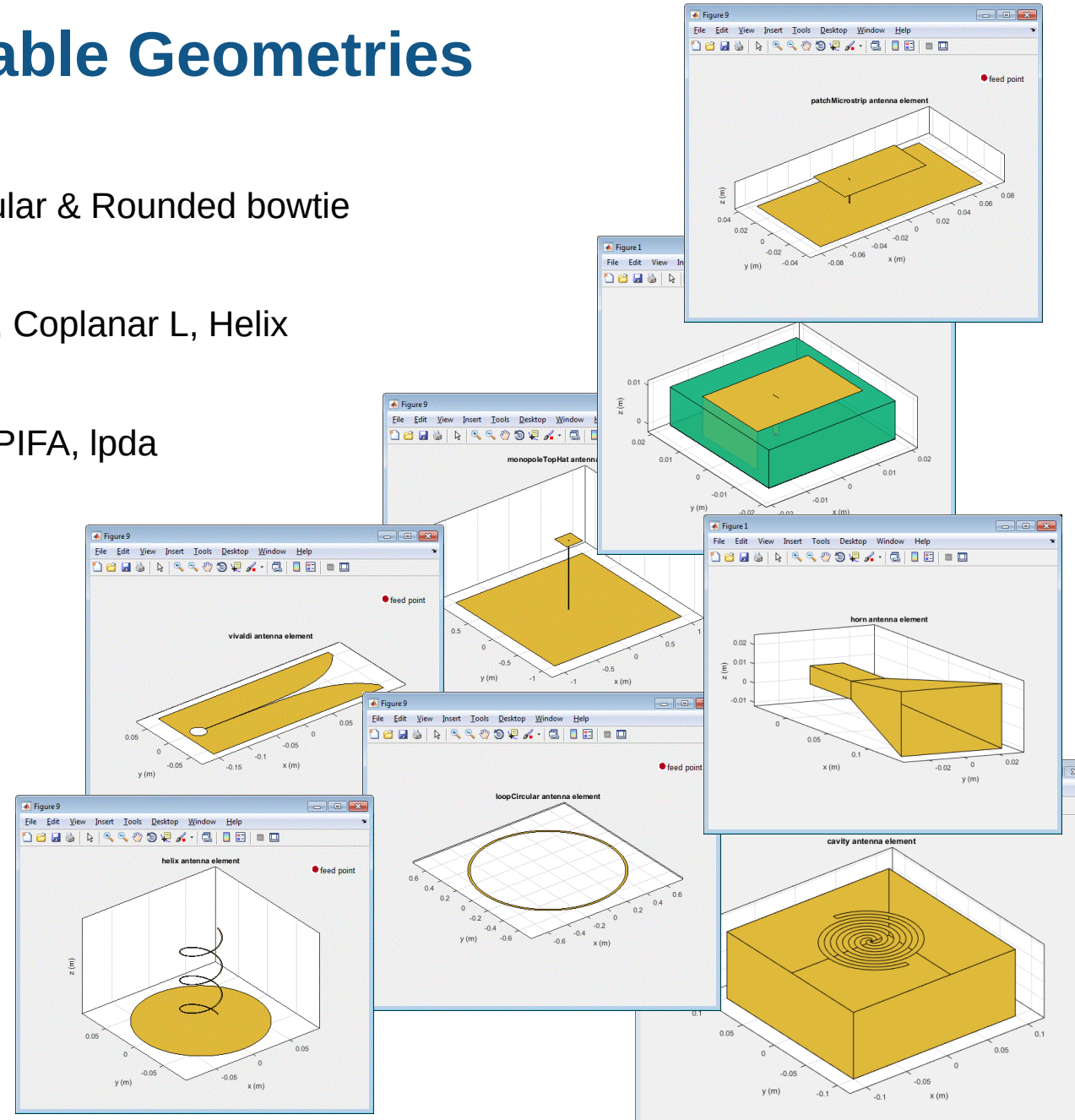
Easier Antenna Design with Antenna Toolbox

- Design is easy and natural
  - Library of parameterized antenna elements
  - Functionality for the design of antenna arrays
  - CAD description streamlined
- Rapid simulation setup
  - Full Methods of Moments solver employed for ports, fields and surface analysis
  - No need to be an EM expert
- Seamless integration
  - Model the antenna together with signal processing algorithms
  - Rapid iteration of different antenna scenarios for radar and communication systems design
  - Antenna fabrication with Gerber file generation

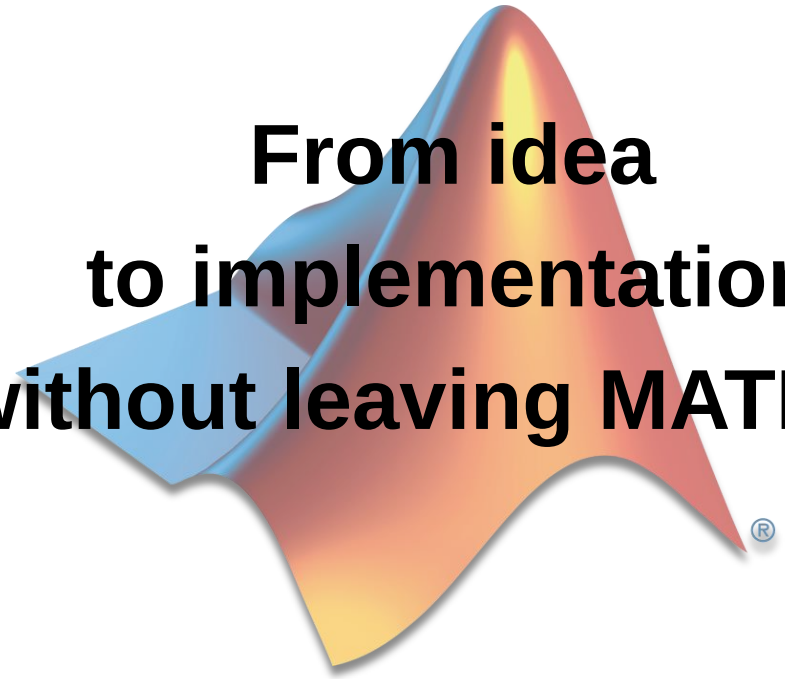


Antenna Catalog: Readily Available Geometries

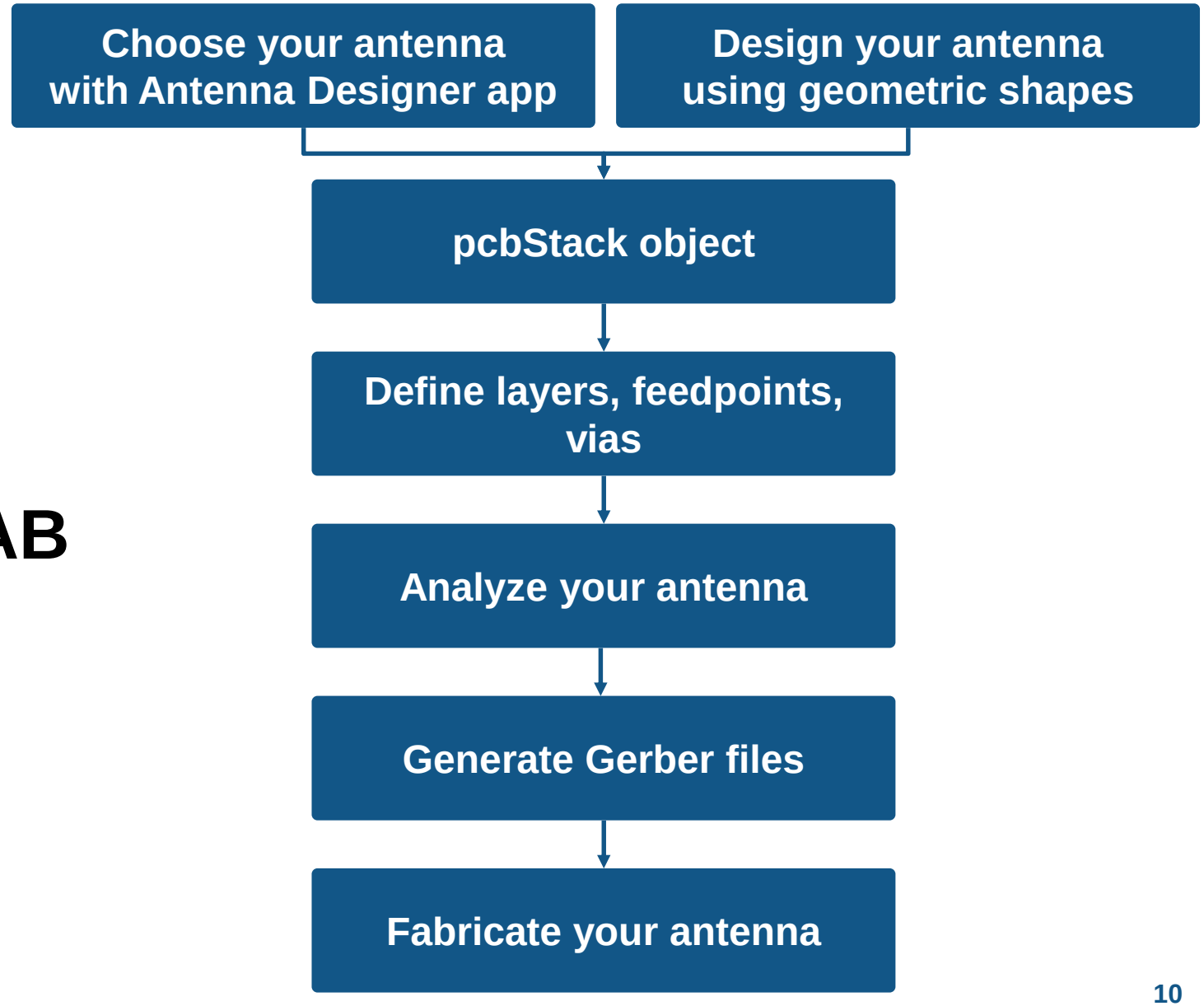
- Dipole antennas
  - Dipole, Vee, Folded, Meander, Blade, Cycloid, Triangular & Rounded bowtie
- Monopole antennas
  - Monopole, Top hat, Inverted-F, inverted-L, Coplanar F, Coplanar L, Helix
- Patch antennas
  - Rectangular, circular, triangular, E-shaped, Inset-fed, PIFA, lpda
- Spirals and loops
  - Equiangular, Archimedean spiral
  - Circular, Rectangular loop
- Backing structures
  - circular, rectangular & corner Reflector
  - circular & rectangular Cavity
- Aperture
  - Horn, waveguides
- Other common antennas
  - Yagi-Uda, Vivaldi, Biquad, Slot, Birdcage, Cloverleaf



Printed Antenna Design – NEW WORKFLOW!

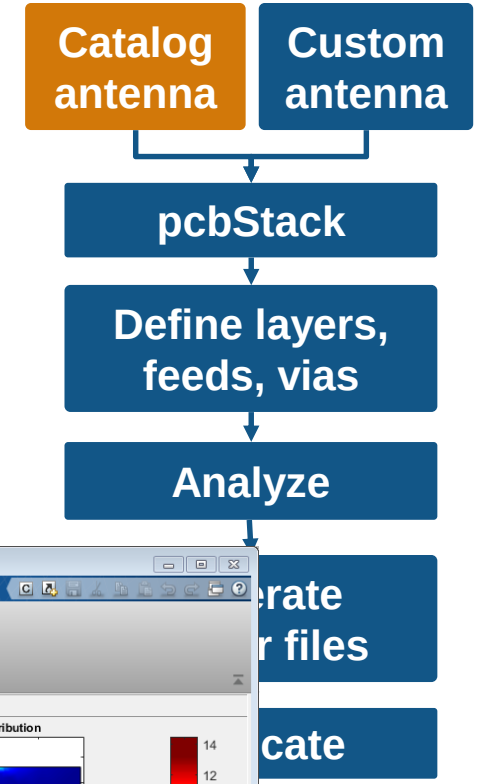


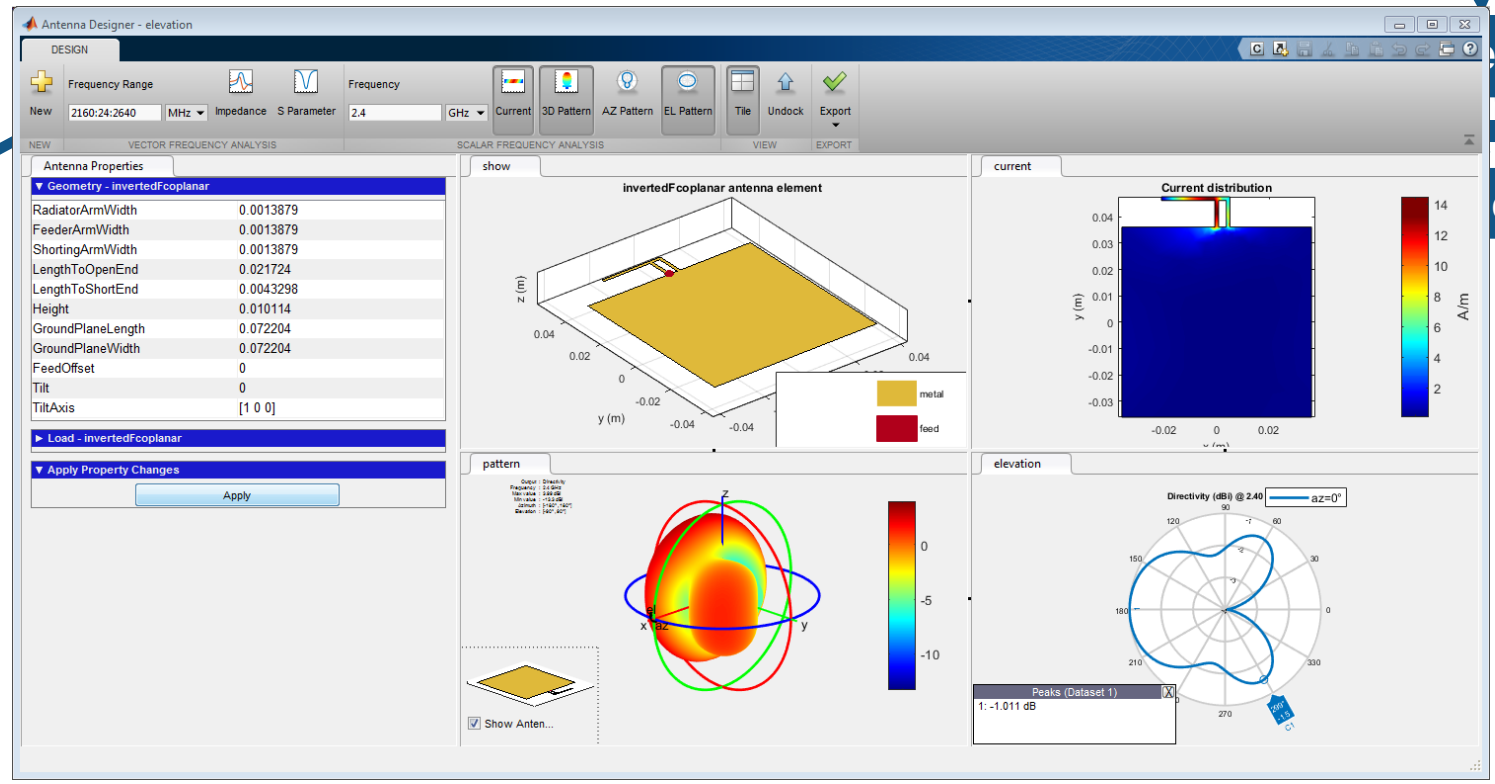
From idea
to implementation
without leaving MATLAB



Antenna Designer App

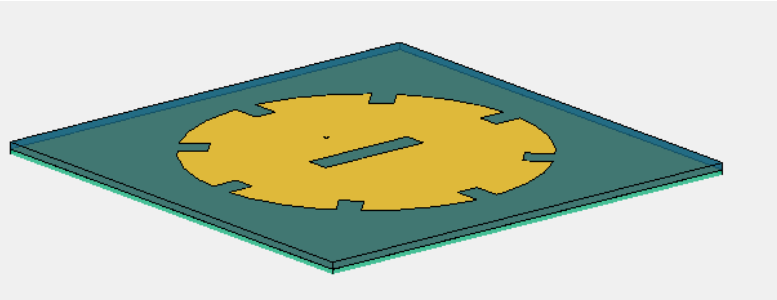
- Pick an antenna using high level specifications
- Add dielectric
- Design an antenna at the desired operating frequency
- Visualize results and iterate on antenna geometrical properties
- Generate MATLAB scripts for automation

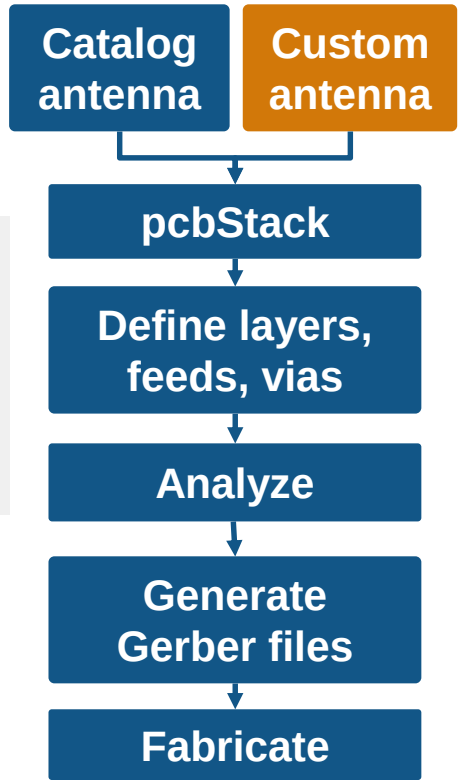




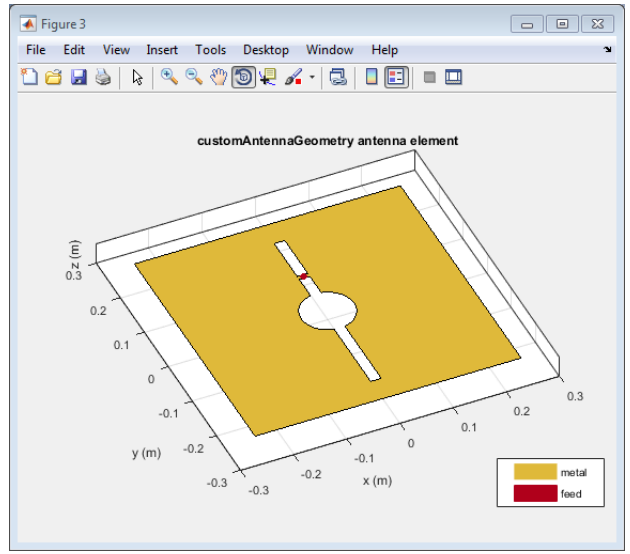
Create a custom antenna using geometric shapes

- Define the boundaries of the metal layers
  - Rectangle, Circle, Polygon
- Use Boolean operations on boundaries
  - Subtract , Add, Intersect
- Define the feeding point (inset or probe)
- Integrate your custom antenna
  - Add backing structure
  - Add dielectric





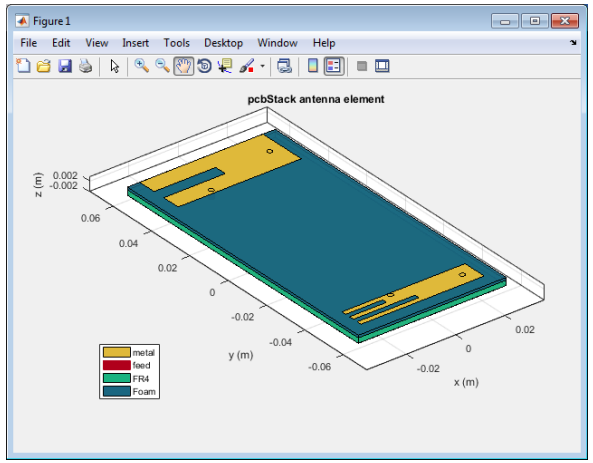

```
% Use arbitrary geometric structures
plate  = antenna.Rectangle('Length',0.18,'Width',0.18);
notch1 = antenna.Circle('Center',[0,0],'Radius',.06);
notch2 = antenna.Rectangle('Length',0.15,'Width',.01);
b      = plate-notch1-notch2;
show(b);
```



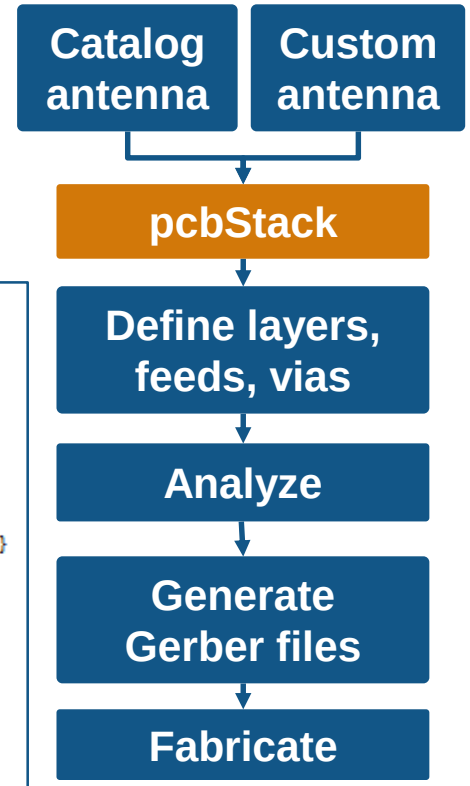
Import your antenna in pcbStack

- Arbitrary number of metal and dielectric layers
- Rectangular board shape

```
% Use an antenna catalog element
P = pcbStack(catalogAntenna);

% Use arbitrary geometric structures
P = pcbStack;
P.Layers = {ant,d1,d2,b};
```

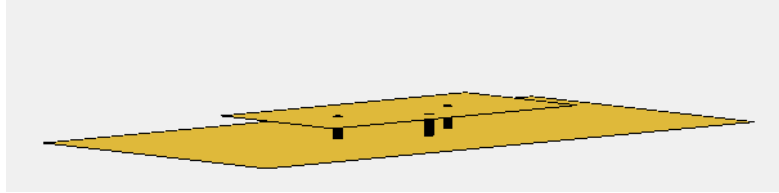



```
pcbStack with properties:

           Name: 'MyPCB'
       Revision: 'v1.0'
     BoardShape: [1×1 antenna.Rectangle]
  BoardThickness: 0.0100
         Layers: {[1×1 antenna.Rectangle]  [1×1 antenna.Rectangle]}
  FeedLocations: [-0.0187 0 1 2]
   FeedDiameter: 1.0000e-03
   ViaLocations: []
    ViaDiameter: []
    FeedVoltage: 1
      FeedPhase: 0
           Tilt: 0
       TiltAxis: [1 0 0]
           Load: [1×1 lumpedElement]
```



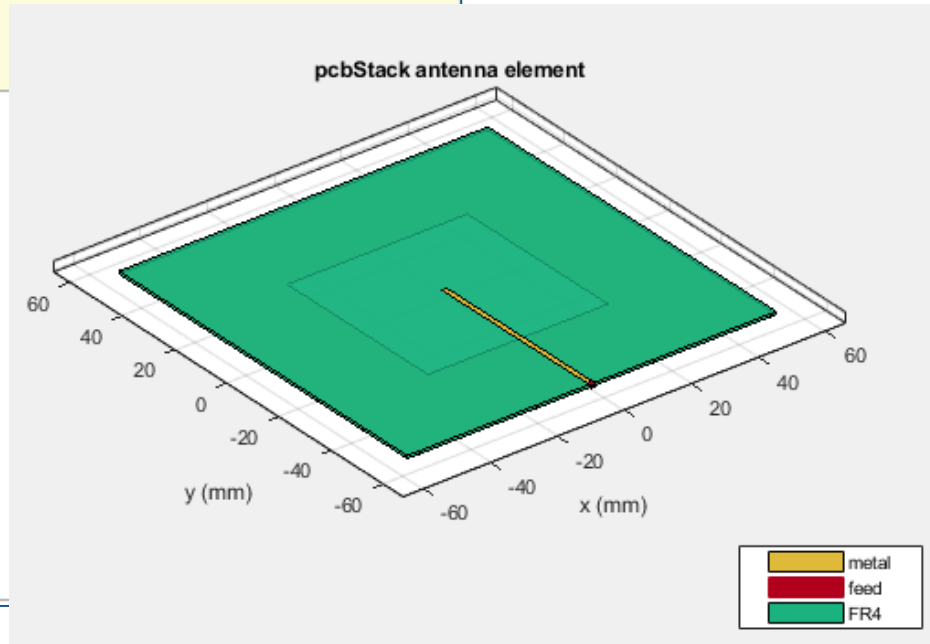
Define layers, feed and vias

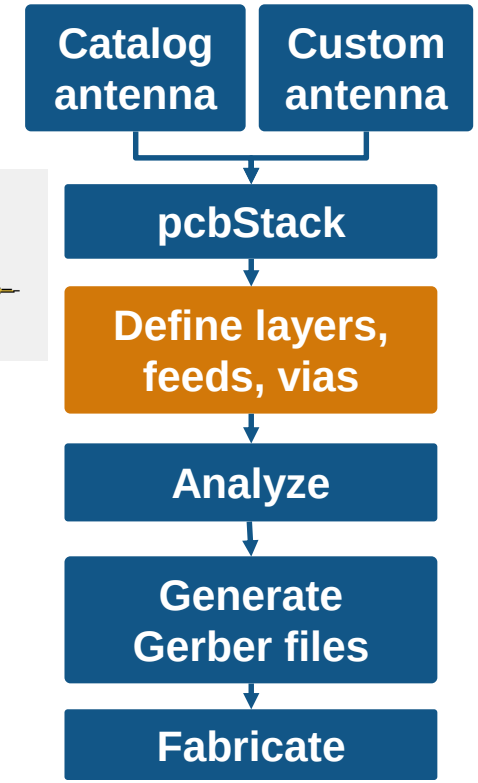
- Feed point can be probe-fed or edge-fed
- Define multiple feed points
- Define multiple vias between metal layers



```
%% Create layer shapes
feedline = antenna.Rectangle('Length',pcbTraceWidth,                    ...
    'Width',pcbTraceLength, 'Center',[0, -gndWidth/2+pcbTraceLength/2]);
gnd      = antenna.Rectangle('Length',gndLength,'Width',gndWidth);
gndslot  = antenna.Rectangle('Length',slotLength,'Width',slotWidth);
gndPlane = gnd - gndslot;
figure
show(gndPlane)
```

```
%% Create stack
d = dielectric(pcbMaterial);
d.EpsilonR = pcbEpsilonR;
d.LossTangent = 0;
d.Thickness = pcbThickness;
p = pcbStack;
p.Name = 'Strip-fed slot';
p.BoardShape = gnd;
p.BoardThickness = pcbThickness;
p.Layers = {feedline,d,gndPlane};
p.FeedLocations = [0,-gndWidth/2,1,3];
p.FeedDiameter = pcbTraceWidth/2;
figure
show(p)
```





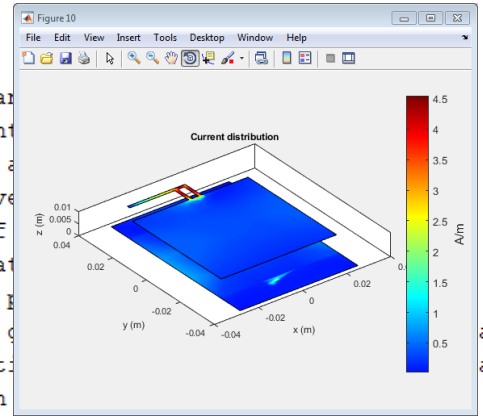
Analyze the antenna

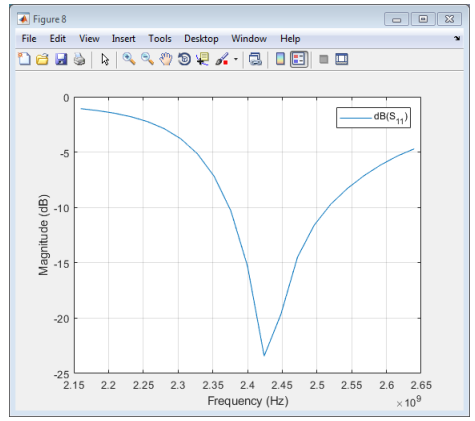
```
Analysis and visualization for antenna and arrays
-------------------------
   show              - Visualize the antenna or array structure
   design            - Design an antenna
   impedance         - Calculate and/or plot the input impedance of ar
   returnLoss        - Calculate and/or plot the return loss of an ant
   sparameters       - Calculate the S-parameters for the antenna or a
   vswr              - Calculate and/or plot the voltage standing wave
   pattern           - Calculate and/or plot the radiation pattern of
   patternAzimuth    - Calculate and/or plot the azimuth radiation pat
   patternElevation  - Calculate and/or plot the elevation radiation p
   axialRatio        - Calculate the axial ratio in dB of an antenna c
   beamwidth         - Calculate the width of the main beam in a parti
   current           - Calculate and/or plot the current distribution
   feedCurrent       - Calculate the current at the antenna or array feed
   charge            - Calculate and/or plot the charge distribution c
   EHfields          - Calculate and/or plot the Electric and Magnetic
   mesh              - Change or display the mesh properties for the a
   meshconfig        - Change the mesh mode for the structure being ar
   info              - Display information about antenna/array
   gerberWrite       - Write Gerber files from pcbStack antenna/array
   exportGeometry    - Export geometry of pcbStack antenna/array

Analysis and visualization for arrays
-------------------------
   layout            - Visualize the array layout on the X-Y plane
   correlation       - Calculate the correlation coefficients between
   arrayFactor       - Calculate and/or plot the array factor in dB
   patternMultiply   - Calculate and/or plot the radiation pattern of the array using pattern multiplication (without the effect of mutual coupling)
```

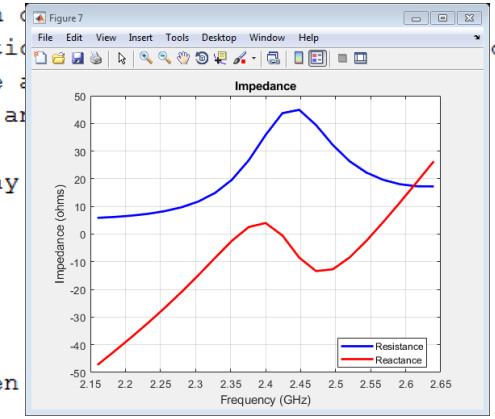
azimuth and elevation

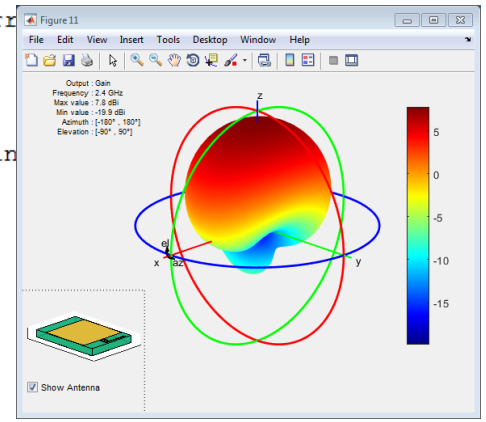
arr

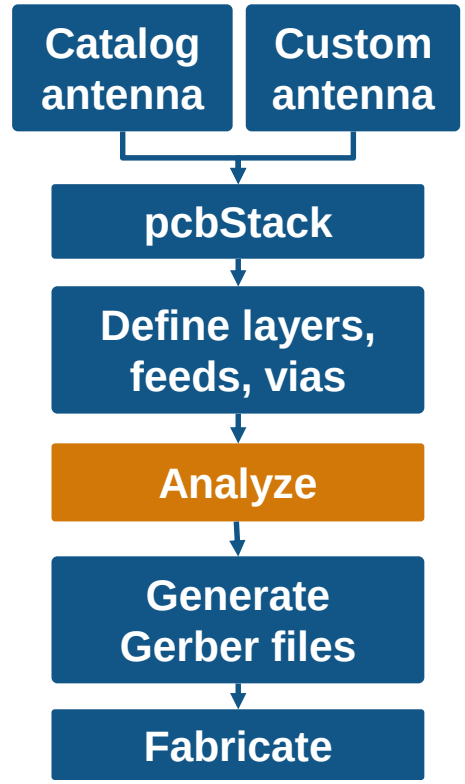
oin









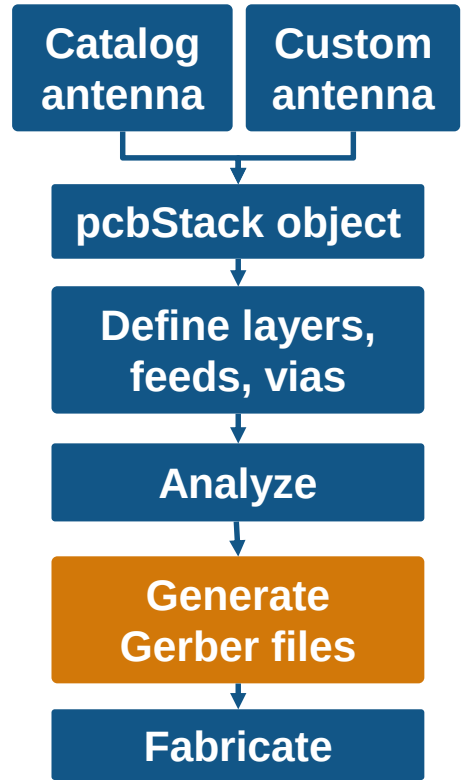


Gerber file generation

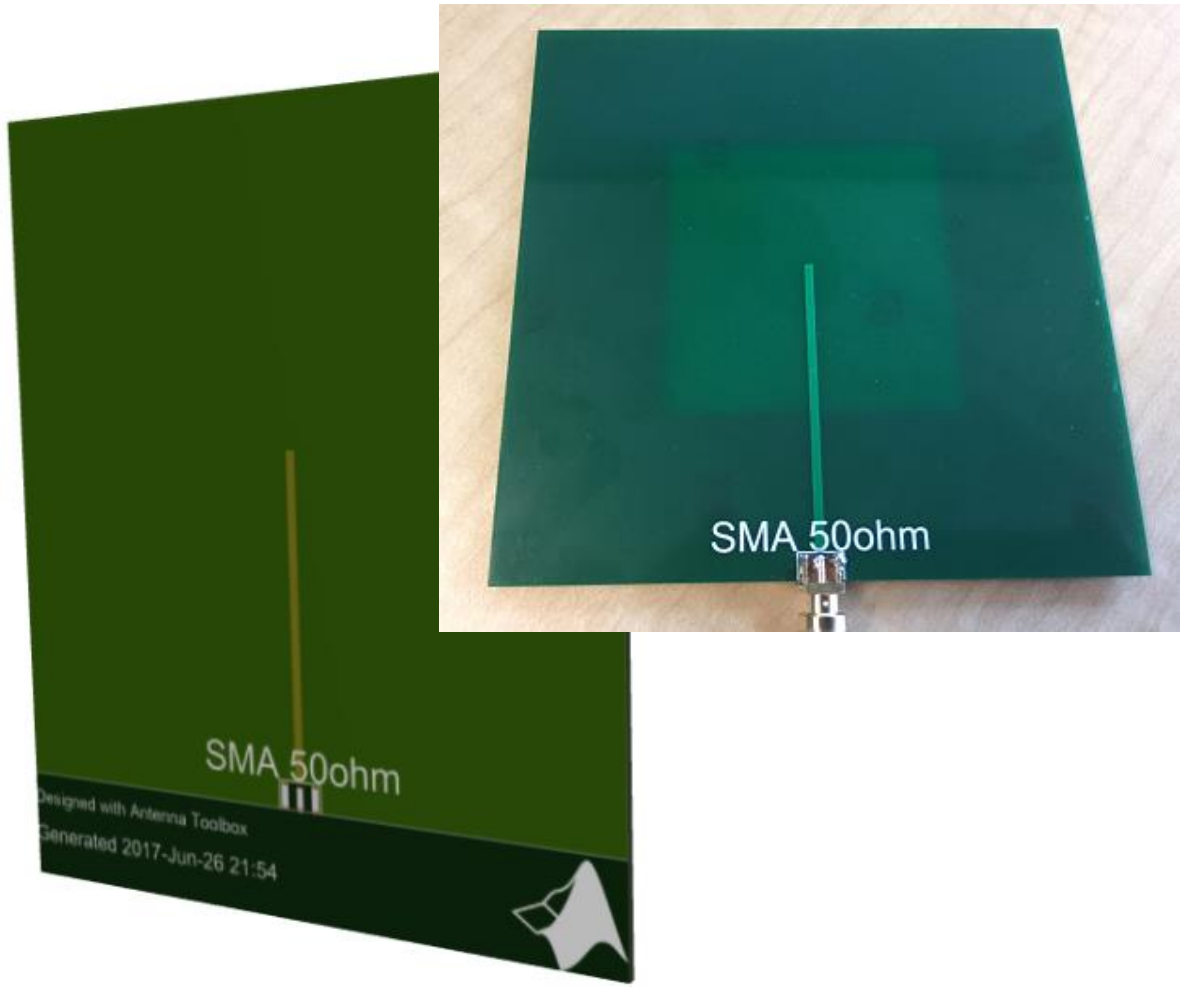
- Choose the manufacturing service
  - Gerber file viewer
- Choose the connector type
  - Define your own, if not in the library
  - Position on the board if edge-fed
- Generate Gerber files
  - ASCII files for geometric properties
  - BOM for antenna manufacturing

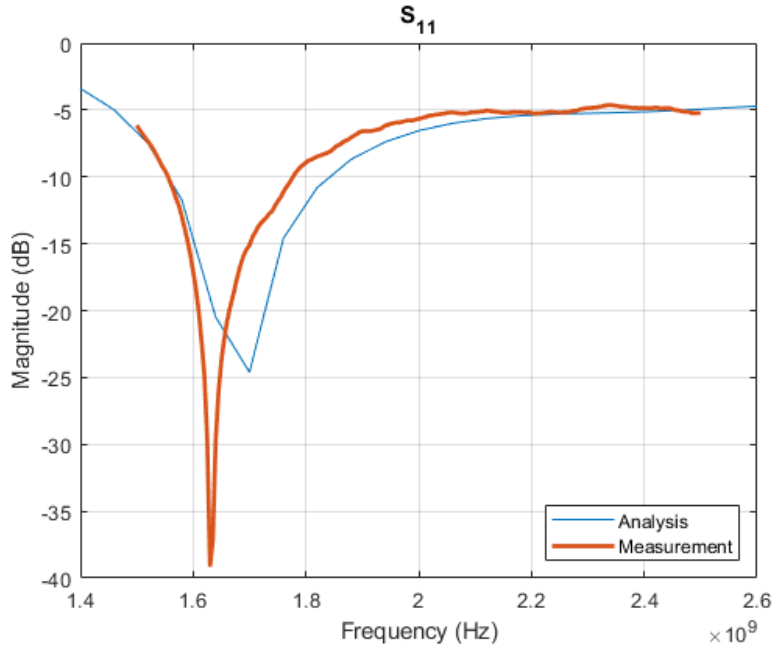
```
%% Gerber generation
% Create the Connector and Writer
W = PCBServices.MayhewWriter;
C = PCBConnectors.SMAEdge_Samtec;
C.EdgeLocation = 'south';
C.ExtendBoardProfile = false;
%%
W.Filename = 'Microstrip-fed slot patch';
A = PCBWriter(p,W,C);
gerberWrite(A)
```

Name	Type	Size
Microstrip_fedSlotPatch.dri	DRI File	1 KB
Microstrip_fedSlotPatch.gbl	GBL File	1 KB
Microstrip_fedSlotPatch.gbo	GBO File	237 KB
Microstrip_fedSlotPatch.gbp	GBP File	1 KB
Microstrip_fedSlotPatch.gbs	GBS File	1 KB
Microstrip_fedSlotPatch.gpi	GPI File	2 KB
Microstrip_fedSlotPatch.gtl	GTL File	2 KB
Microstrip_fedSlotPatch.gto	GTO File	315 KB
Microstrip_fedSlotPatch.gtp	GTP File	1 KB
Microstrip_fedSlotPatch.gts	GTS File	1 KB
Microstrip_fedSlotPatch.ipc	IPC File	1 KB
Microstrip_fedSlotPatch	Text Docu...	1 KB



Fabricate the antenna





Catalog antenna

Custom antenna

pcbStack object

Define layers, feeds, vias

Analyze

Generate Gerber files

Fabricate

Full-Wave Antenna Analysis from a Photo

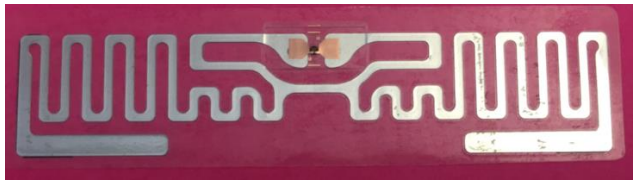
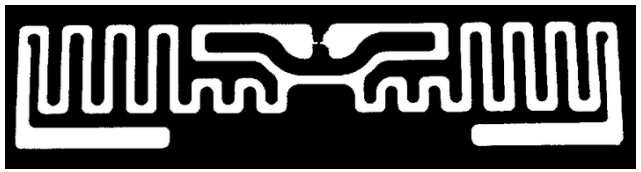
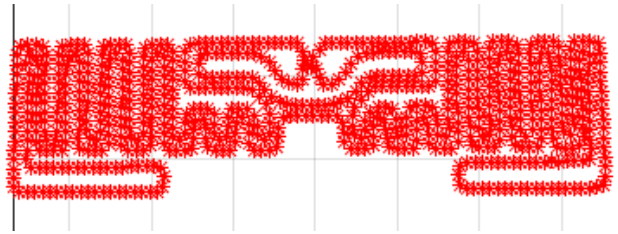


Photo Import



Segmentation

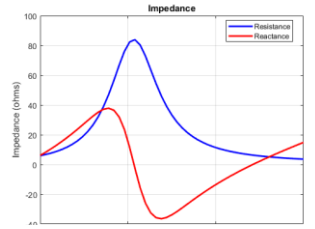


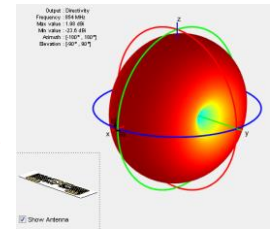
Extract Boundary

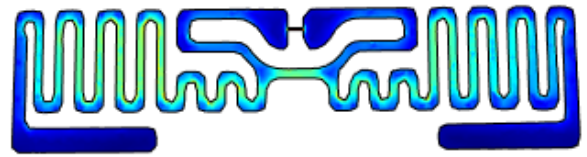
Clean up Geometry

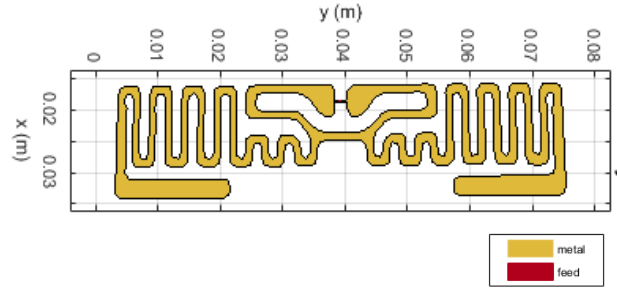
Define Feed

Analyze









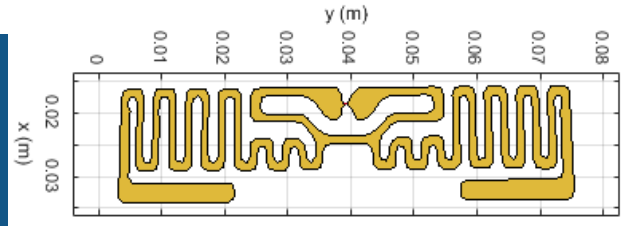


Image Processing Toolbox

Antenna Toolbox

Increasing the Efficiency of the Antenna Design Workflow

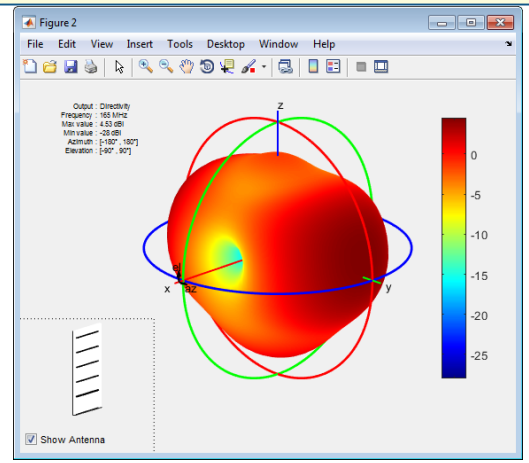
- Use global and local optimization routines for antenna design
- Use parallel computing to speed up design space exploration

```
%%
patternoptions = psoptimset(@patternsearch);
patternoptions.PlotFcns = @psplotbestf;
patternoptions.MaxIter = 25;
optimdesign = patternsearch(@(x) yagi_objective_function(yagidesign,x,freq,elang),...
                            parasitic_values,[],[],[],[],LB,UB,[],patternoptions);
```

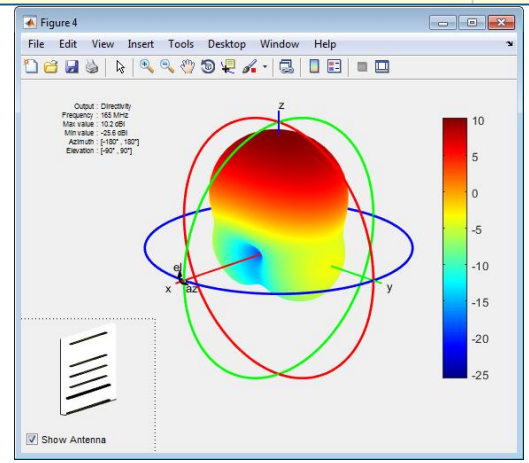
```
parfor m = 1:numel(freq)
    RLparfor(m) = returnLoss(sp, freq(m));
end
```

	time	numWorkers
Without Parallel Computing	113.3	1
With Parallel Computing	23.597	12

```
Speed-up due to parallel computing = 4.80134
```



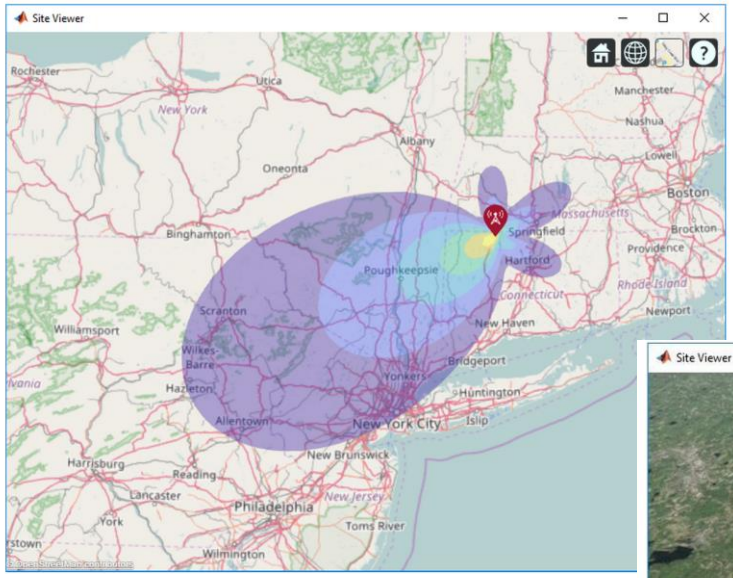
Poor directivity

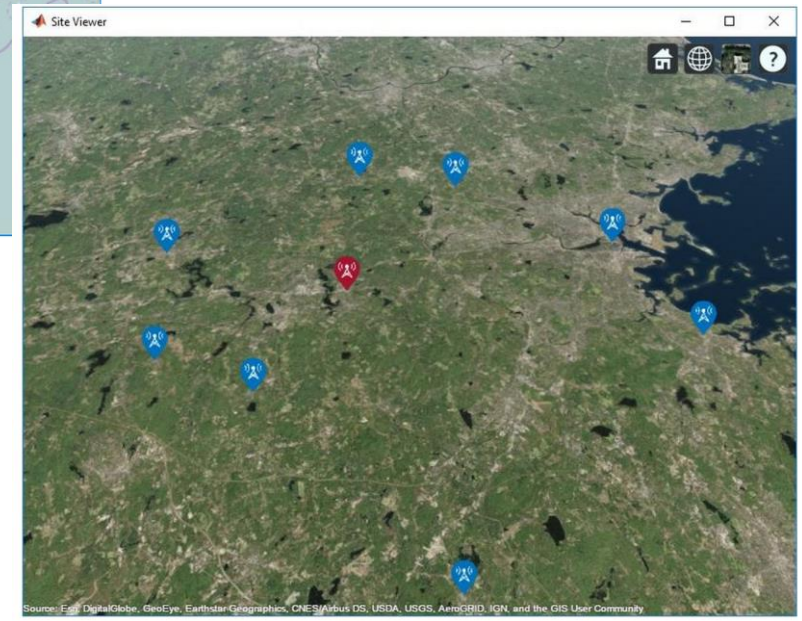


Optimized pattern

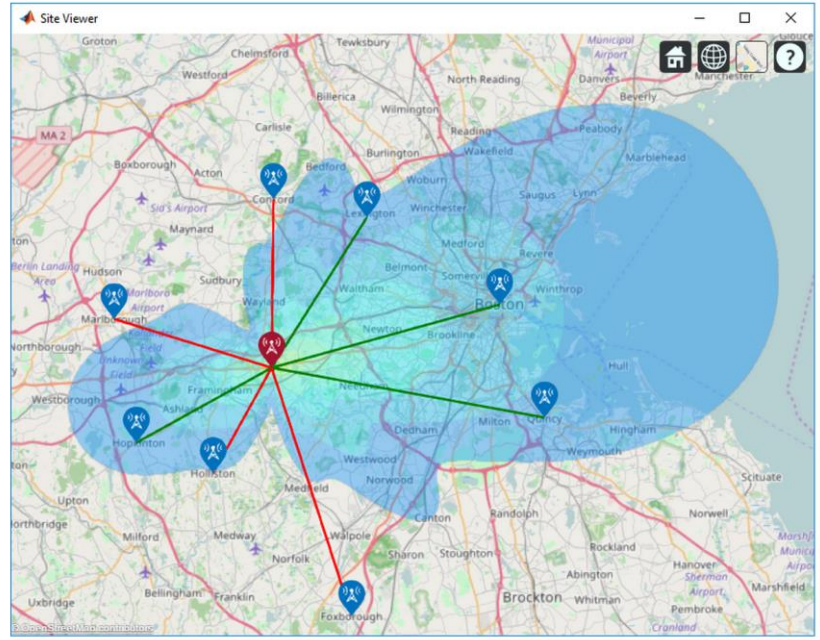
Coverage and Field Strength Visualization on Map

- Compute antenna pattern and visualize field strength projected on flat earth map





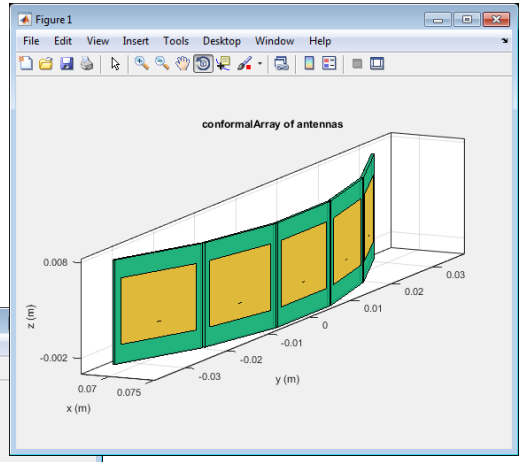
- Visualize antenna coverage on flat earth map and communication links
  - Define transmitter and receiver
  - Antenna design, frequency, power, and sensitivity
  - Effect of rain, wind, snow

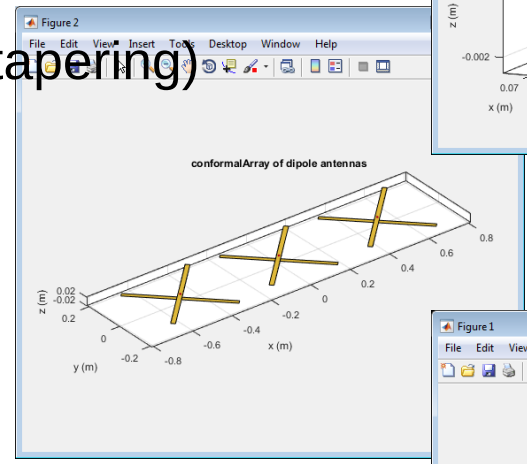


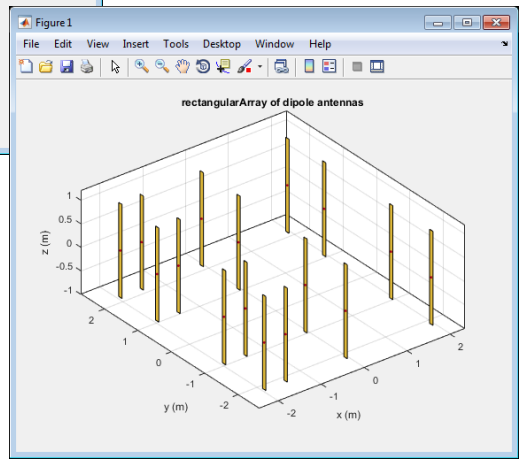
Antenna Array Design

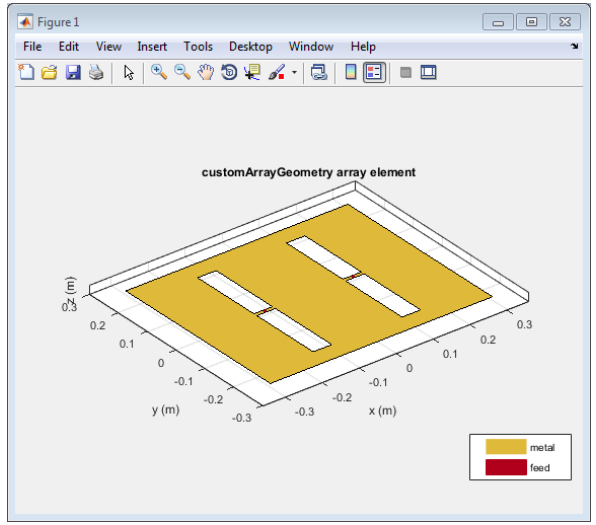
- Regular arrays
  - Linear, Rectangular, Circular array
  - Change individual elements properties (rotation, size, tapering)
- Conformal arrays (arbitrary position of the elements)
- Heterogeneous arrays (different element types)
- Arbitrary shape planar arrays
  - Define arbitrary geometry

```
arr = conformalArray;
d = dipole;
b = bowtieTriangular;
arr.Element = {d, b};
arr.ElementPosition(1,:) = [0 0 0];
arr.ElementPosition(2,:) = [0 0.5 0];
show(arr)
```



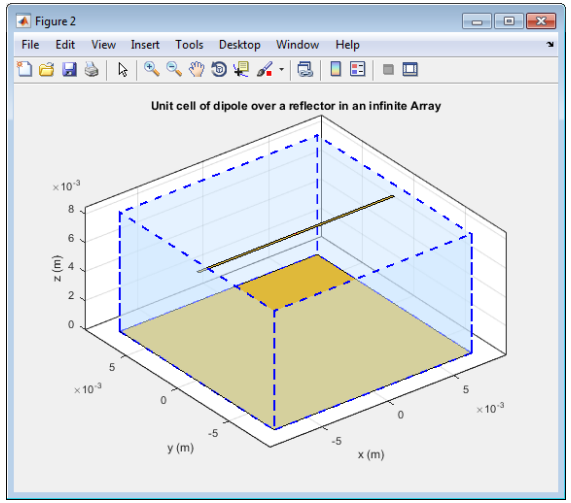






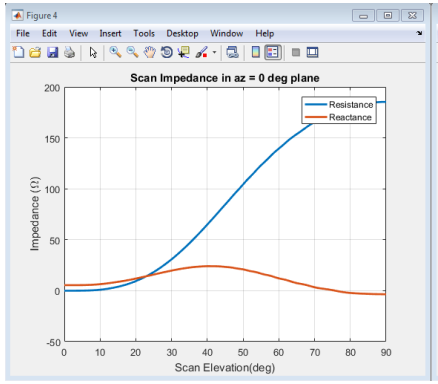
What if my Array is Really Large?

- Infinite Array Analysis
  - Repeat unit cell infinitely
  - Impedance and pattern become function of frequency and scan angle
  - Ignore edge effects
  - Captures mutual coupling
- Validate with full wave simulation on smaller arrays

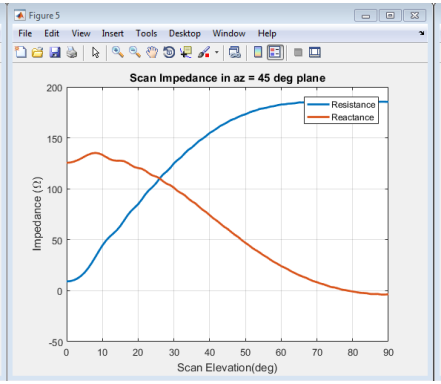


Scan Impedance @10GHz

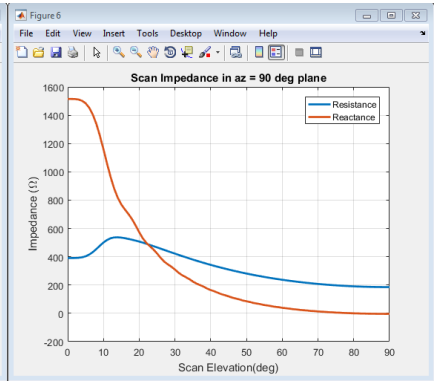
0deg Azimuth



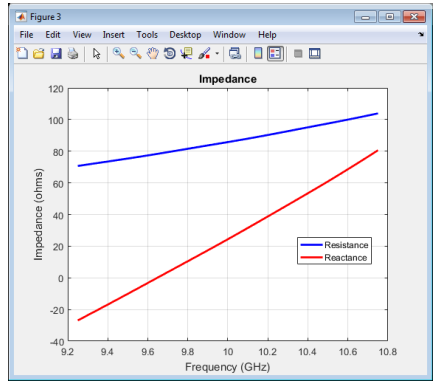
45deg Azimuth



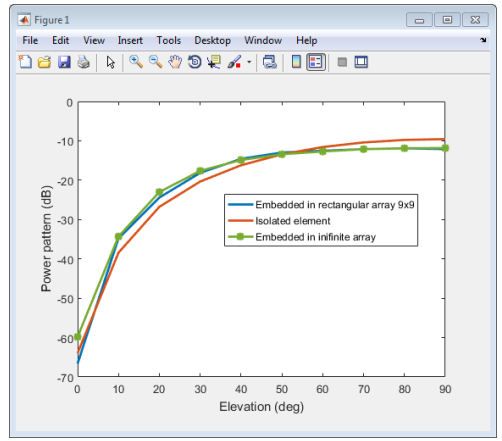
90deg Azimuth



Scan Impedance
0deg Azimuth
45deg Elevation

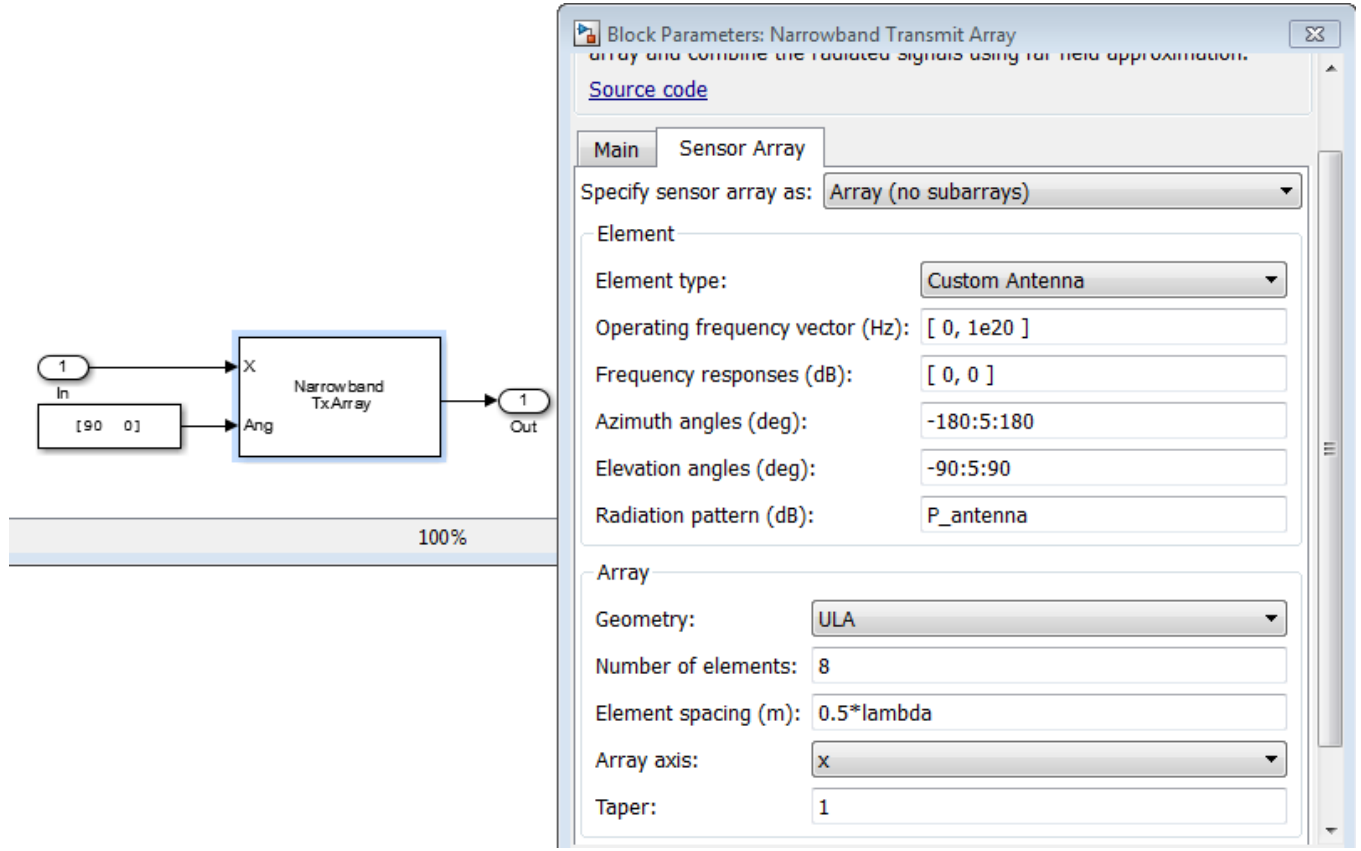


Power Pattern



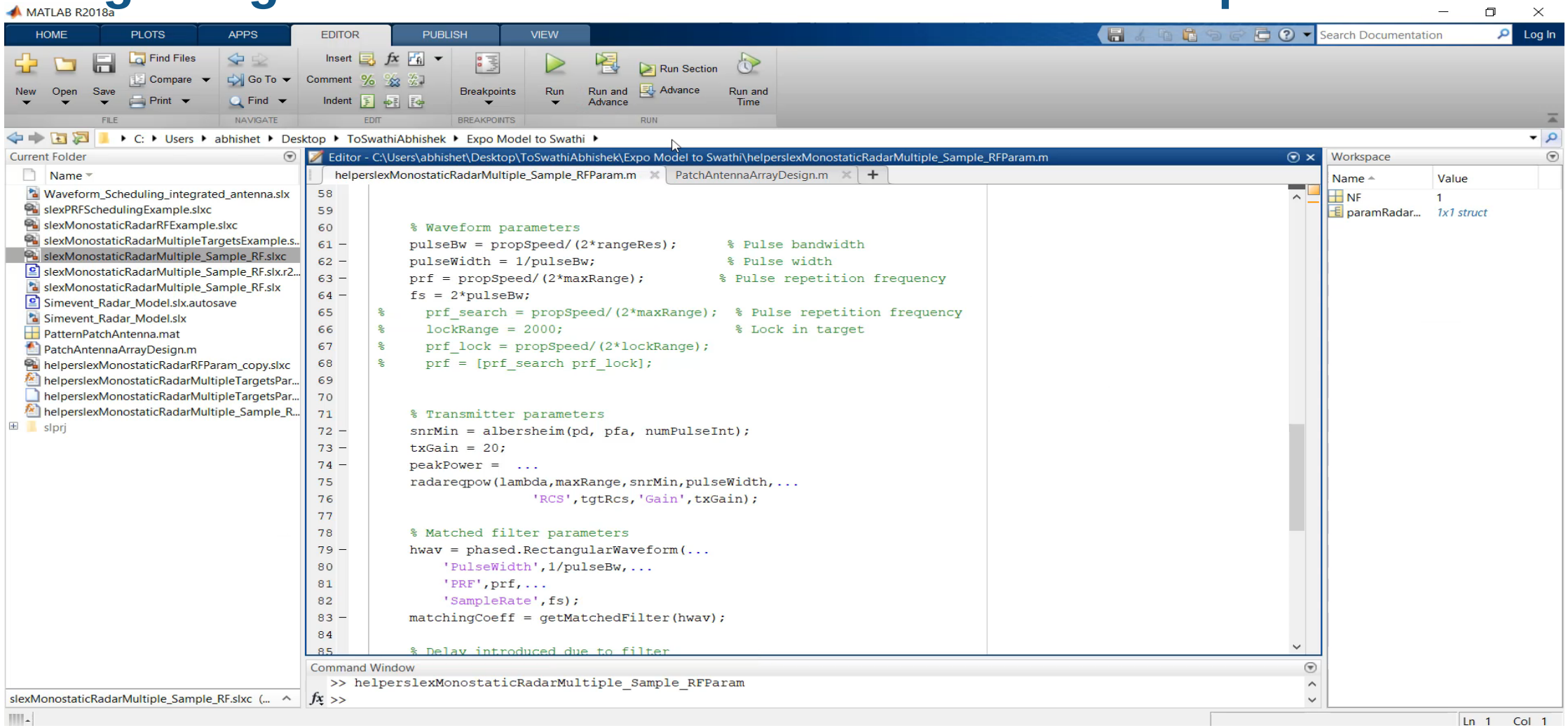
Combine Antenna Design and Phased Array Algorithms

- You can integrate your antenna in Phased Array System Toolbox (PST) array objects
  - Use the accurate far field (complex) radiation pattern of the antenna
- PST provides algorithms and tools to design, simulate, and analyze phased array signal processing systems
  - Beamforming, Estimation of Direction of Arrival
- Uses pattern superposition to compute the array pattern

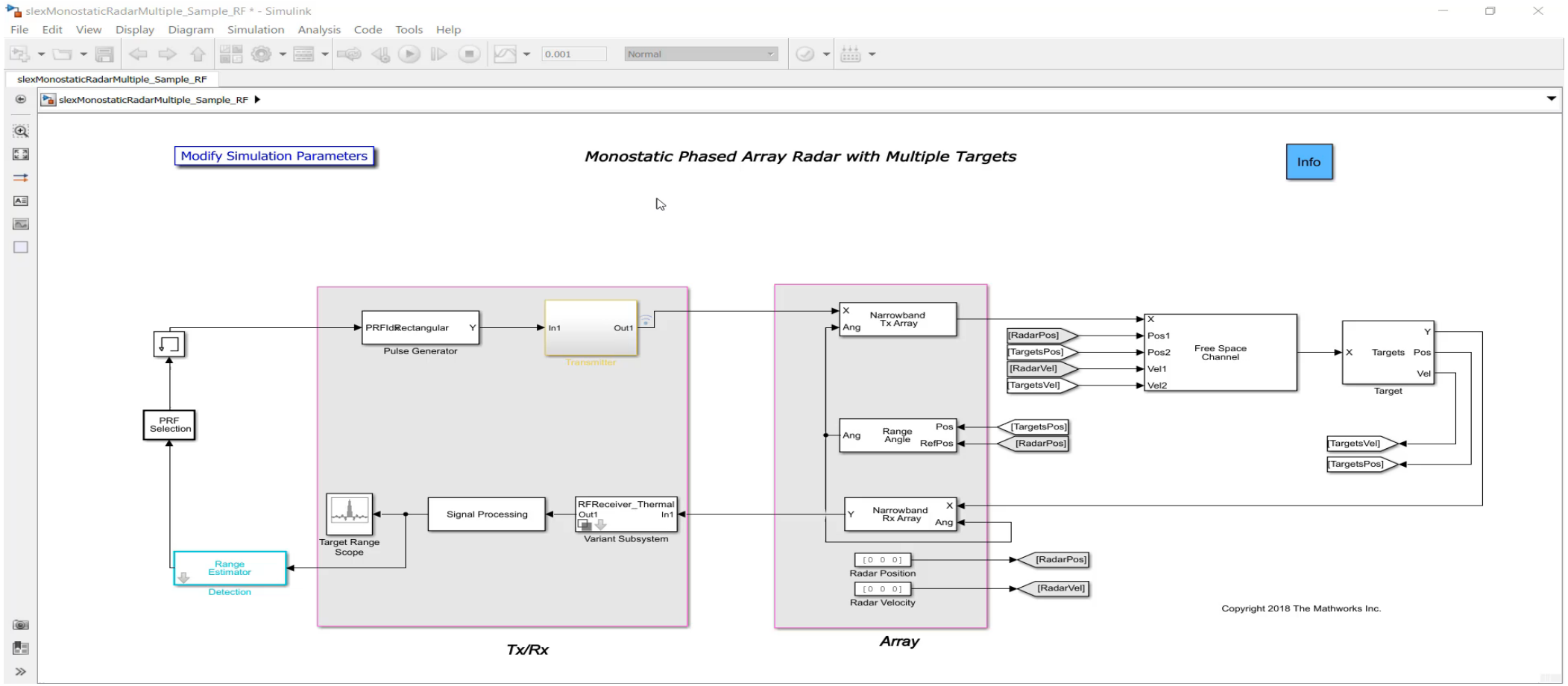



```
% Import antenna element in PST
myantenna = dipole;
myURA = phased.URA;
myURA.Element = myantenna;
```

Integrating Antenna Radiation Pattern & RF Components



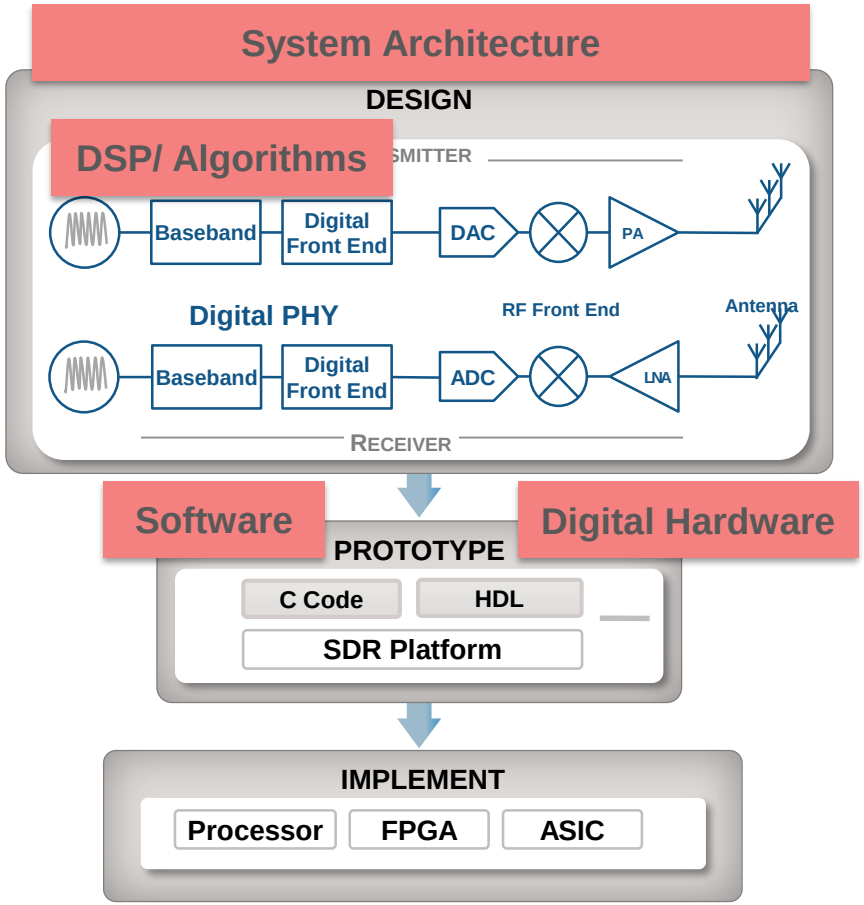
Integrating Antenna Radiation Pattern & RF Components



MATLAB & Simulink: Unified Design Platform

for algorithm developers, system architects, HW and SW developers

MathWorks R2018a

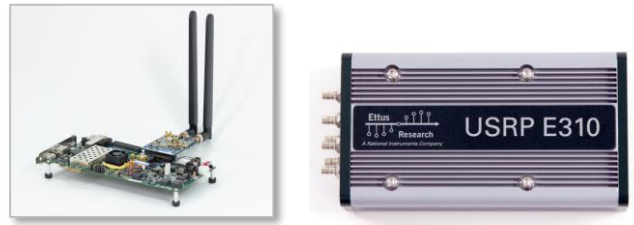


HDL and C code generation

Instrument Control Toolbox

RF Test Instruments

SDR Support Packages
Communications System Toolbox



Software-Defined Radio

Fixed-Point Designer
HDL Coder
Embedded Coder
LTE HDL Toolbox

Multi-vendor hardware support

XILINX

intel FPGA

Microsemi

Radar System: Antenna to Algorithms

Antenna, Antenna arrays
type of element, # elements, configuration

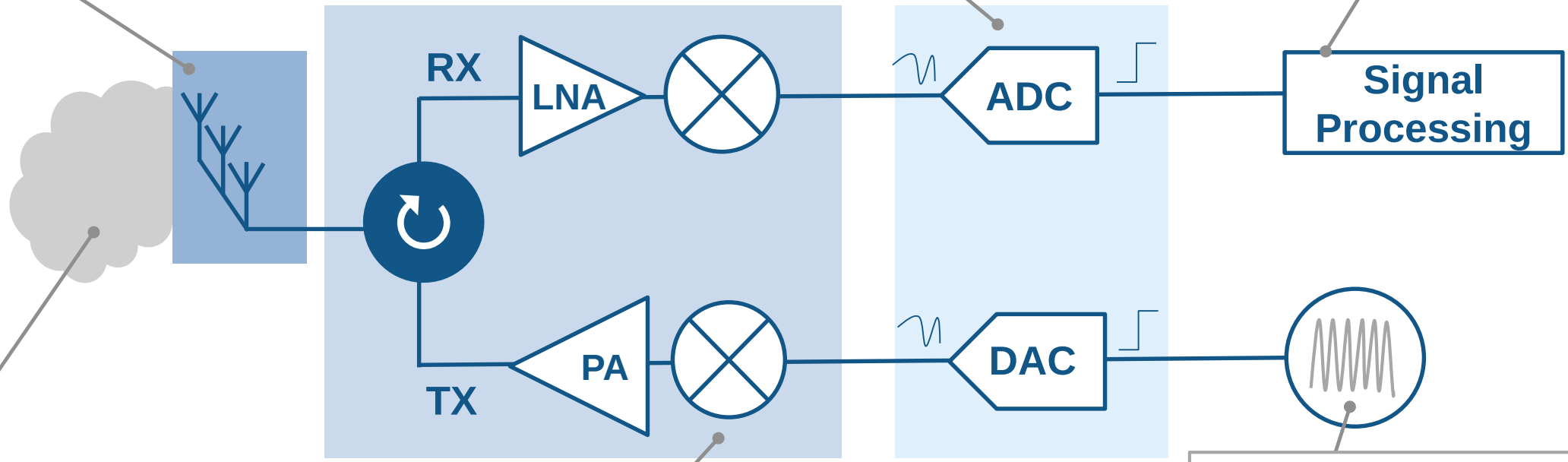
- Antenna Toolbox
- Phased Array System Toolbox

Mixed-Signal
Continuous & discrete time

- Simulink
- DSP System Toolbox
- Control System Toolbox

Algorithms
beamforming, beamsteering, MIMO

- Phased Array System Toolbox
- Communications System Toolbox
- DSP System Toolbox



- Communications System Toolbox
- Phased Array System Toolbox

Channel - *interference, clutter, noise*

- RF Blockset
- RF Toolbox

RF Impairments
frequency dependency, non-linearity, noise, mismatches

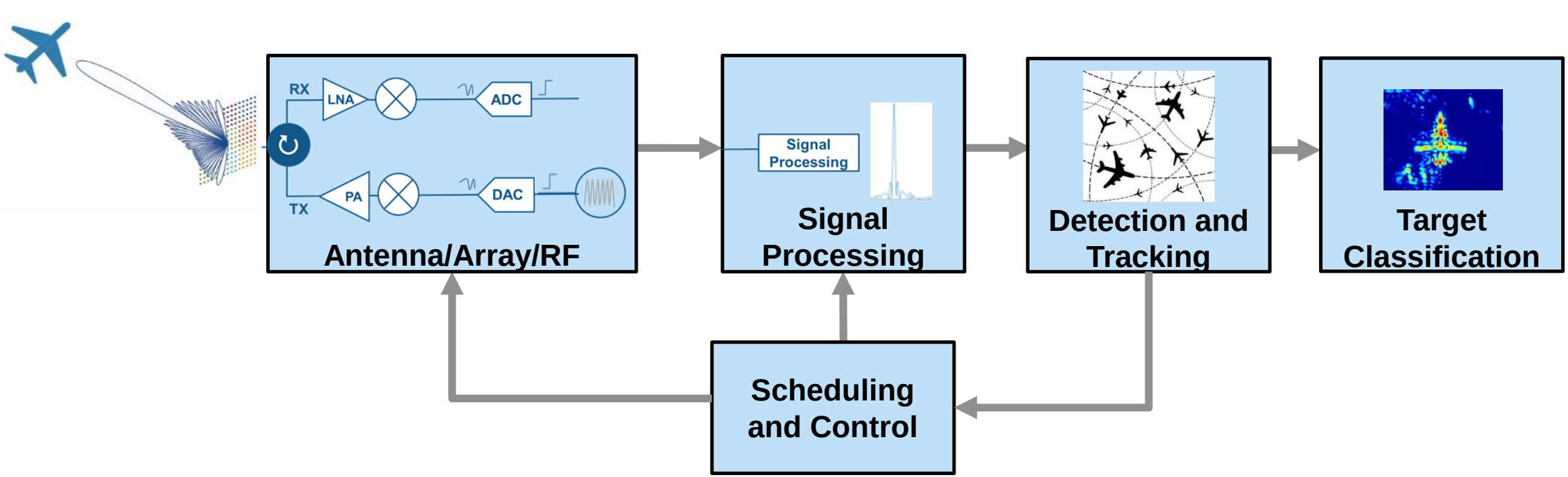
- Phased Array System Toolbox
- Signal Processing Toolbox
- SimEvents
- Instrument Control Toolbox

Waveforms & Resource Scheduling

Agenda

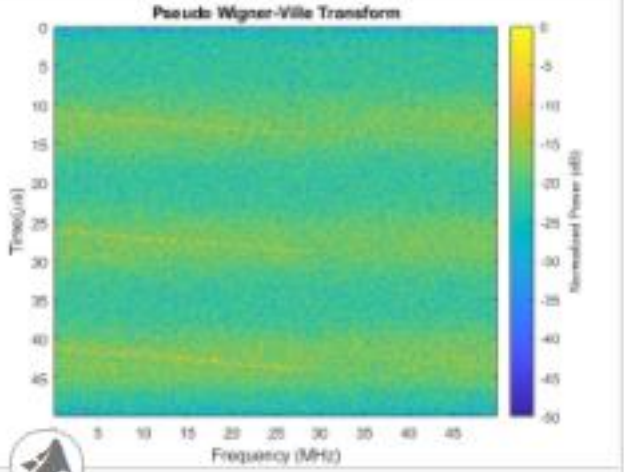
- ✓ Design challenges of multi function radar systems
- ✓ Simulation frame work
- ✓ Antenna and Antenna array design
- ✓ Integrating Antenna and RF chain for improved fidelity of the system
- ▪ Multi Function Radar Capabilities

Typical Multi Function Radar System



Modeling and Simulating Radar and EW Functions

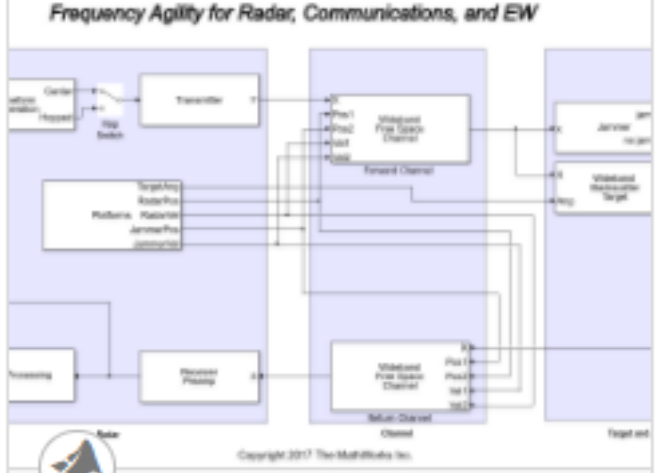
R2018a



Signal Parameter Estimation in a Radar Warning Receiver

Modern aircraft often carry a radar warning receiver (RWR) with them. The RWR detects the radar emission and warns the pilot when

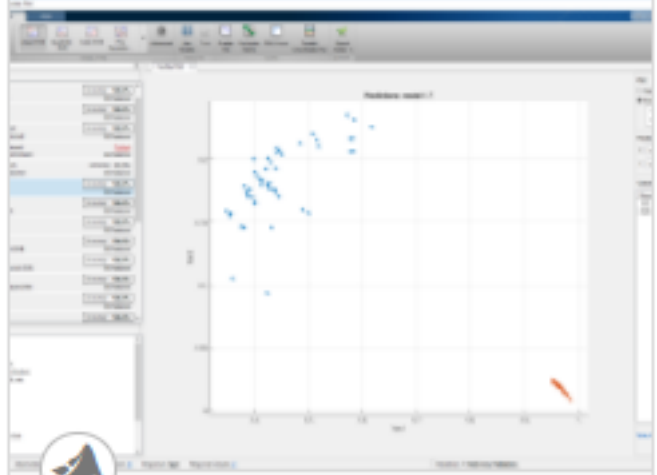
Open Live Script



Interference Mitigation Using Frequency Agility Techniques

Model frequency agility techniques to counter the effects of interference in radar, communications, and EW systems. Using Simulink, a scenario

Open Model



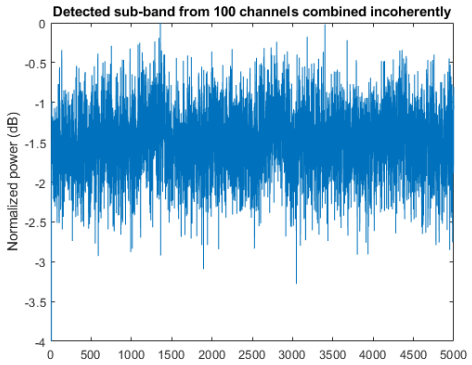
Radar Target Classification Using Machine Learning

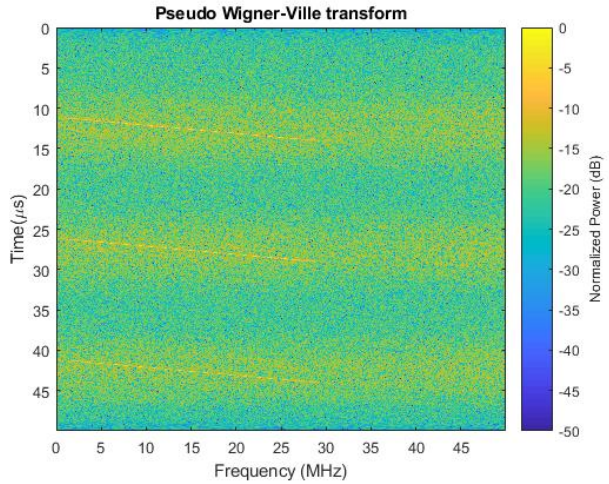
Use machine learning to perform target classification. The example synthesizes the echos from a cylinder and a cone and uses

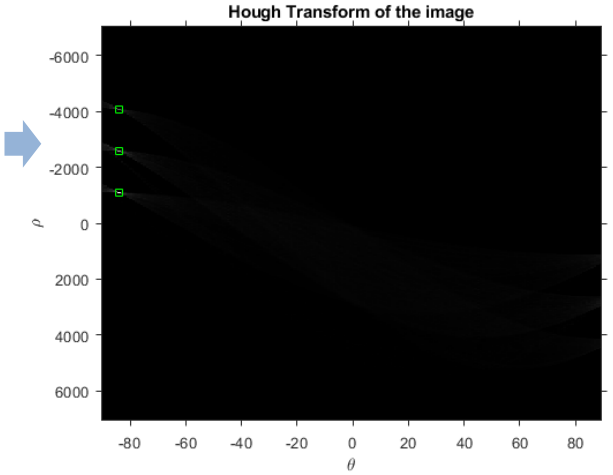
Open Script

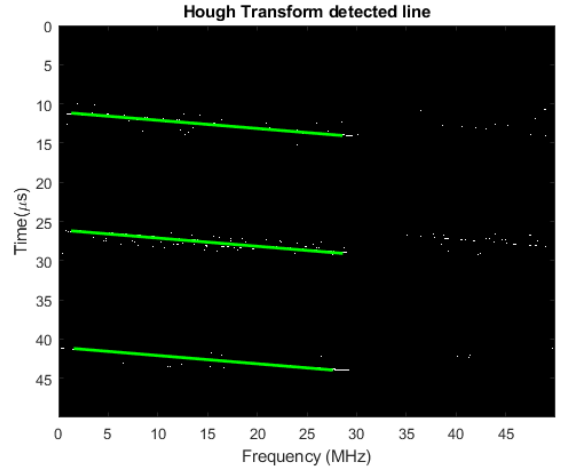
Radar Signal Characterization Example

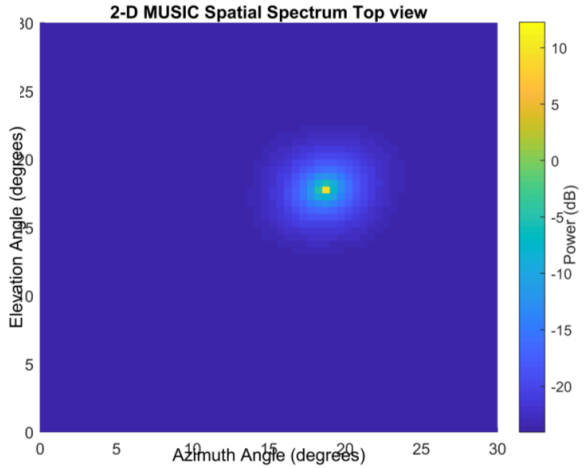
R2018a







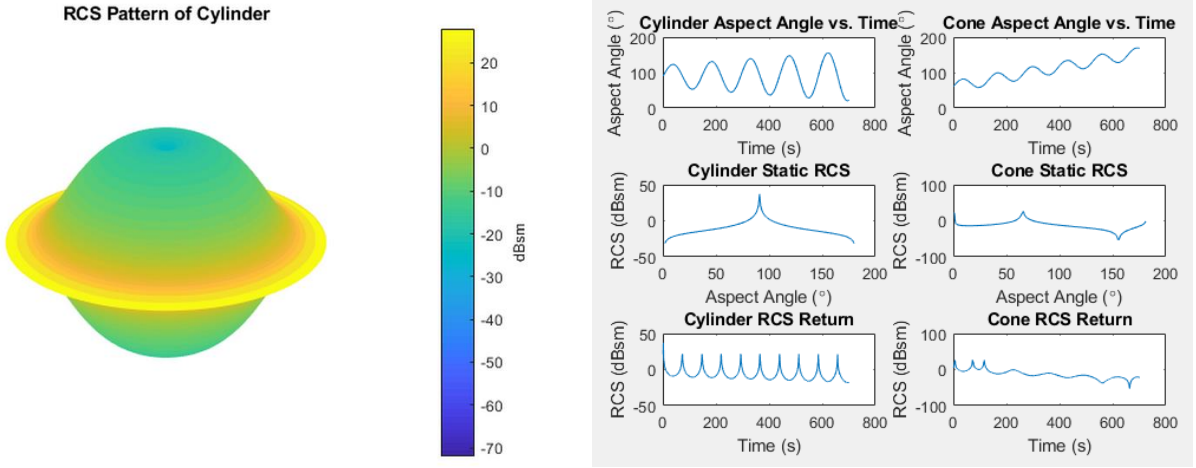




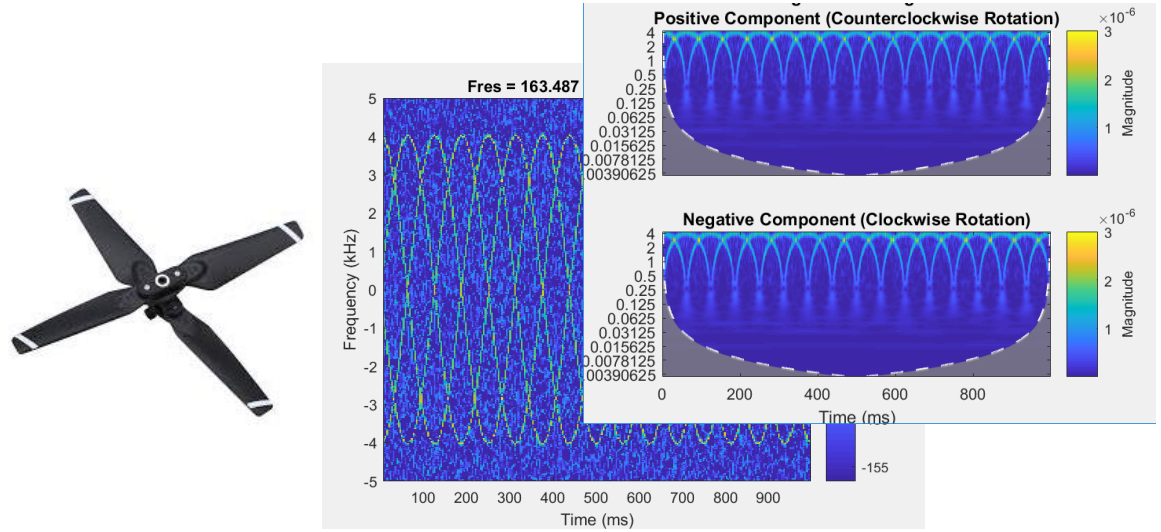
Pulse Repetition Interval = 15 us
Pulse Duration = 2.97 us
Pulse bandwidth = 28.31 MHz
Center frequency = 4.5286 GHz
Azimuth angle of arrival = 18.5 degrees
Elevation angle of arrival = 17.5 degrees
Emitter location is 3325.5 m from the RWR

https://www.mathworks.com/help/phased/examples/signal-parameter-estimations-in-a-radar-warning-receiver.html

Machine Learning for Radar Examples

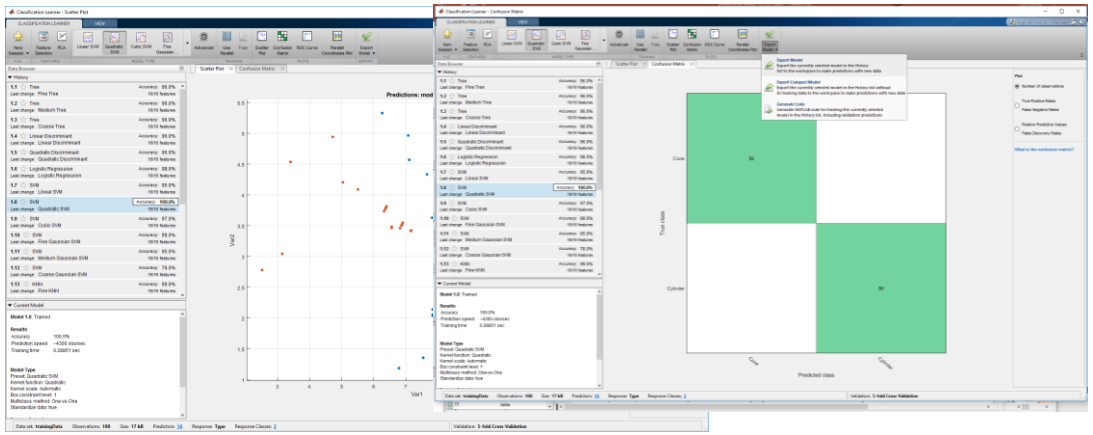


Synthesize returns (radar cross section)



Synthesize micro-Doppler (Time-frequency)

Signals
Features
Time-frequency
Etc.



Statistics and Machine Learning Toolbox

Classification

Reutech Radar Systems Develops Naval Air and Sea Surveillance Radar with Model-Based Design

Challenge

Develop the core signal processing subsystem for a naval air and sea surveillance radar system

Solution

Use Model-Based Design with MATLAB and Simulink to develop algorithms, model key components, perform system-level simulations, and generate HDL code

Results

- Development time cut by two engineer years
- Signal processing designs reused
- Reliable firmware delivered

The RSR 210N multipurpose 2D radar system.

"Completing this project on time without Model-Based Design would have been very difficult. The ability to generate code with HDL Coder and to separate signal processing algorithm design from detailed hardware implementation helped us reduce effort on the project by two engineer-years."

- Kevin Williams, Reutech Radar Systems

Link to user story

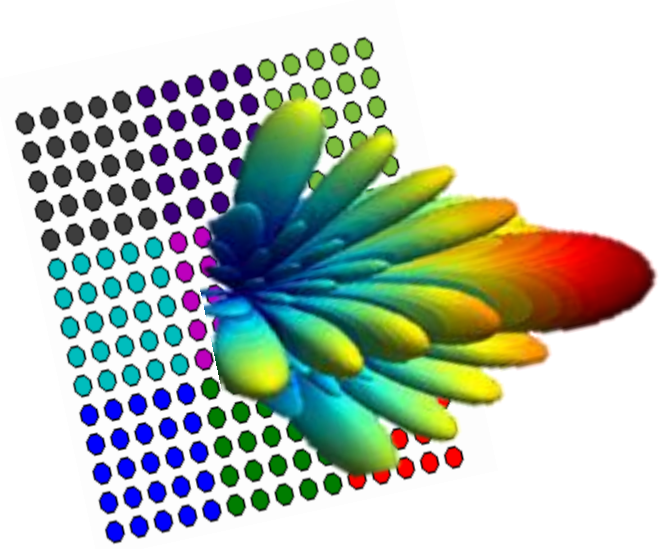
MathWorks® | Training Services

Phased Array System Toolbox Fundamentals

This one-day course provides a comprehensive introduction to the Phased Array System Toolbox™. Themes including radar characterization and analysis, radar design and modeling and radar signal processing are explored throughout the course.

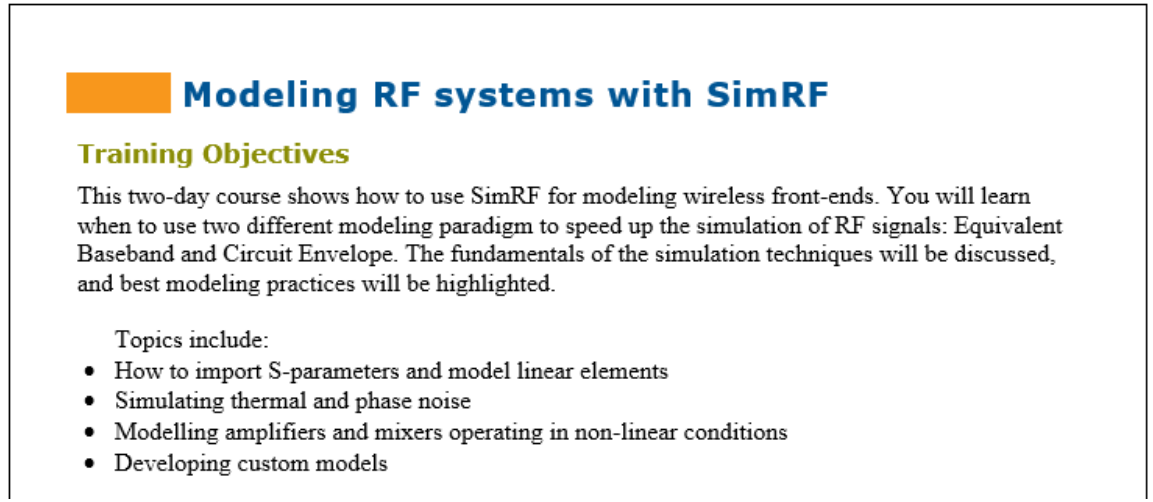
Topics include:

- Review of a Monostatic End-to-End Radar Model
- Characterize and analyze radar components and systems
- Design and model components of a radar system
- Implement a range of radar signal processing algorithms



Modeling RF Systems

- Introduction to RF simulation using MathWorks tools
- How do I model my RF system with RF Blockset?
- Importing S-Parameters and modeling linear operation
- Fundamentals of noise simulation
- Modeling non-linear devices
- Developing custom models



Modeling RF systems with SimRF

Training Objectives

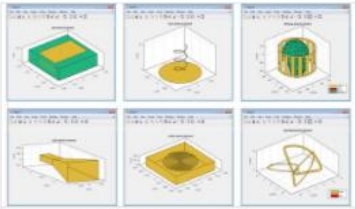
This two-day course shows how to use SimRF for modeling wireless front-ends. You will learn when to use two different modeling paradigm to speed up the simulation of RF signals: Equivalent Baseband and Circuit Envelope. The fundamentals of the simulation techniques will be discussed, and best modeling practices will be highlighted.

Topics include:

- How to import S-parameters and model linear elements
- Simulating thermal and phase noise
- Modelling amplifiers and mixers operating in non-linear conditions
- Developing custom models

Antenna Toolbox

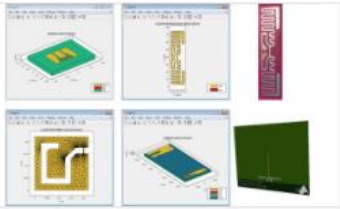
Capabilities



Antenna Catalog

Use parameterized antennas for rapid design and visualization.

» Learn more

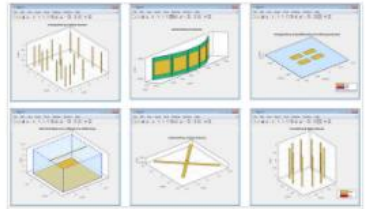


Custom Geometry and Fabrication

Design antennas with arbitrary planar geometry, and manufacture PCB antennas.

» Learn more

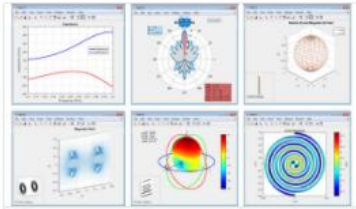
Watch video 2:39



Antenna Arrays

Design linear, rectangular, circular, and conformal antenna arrays.

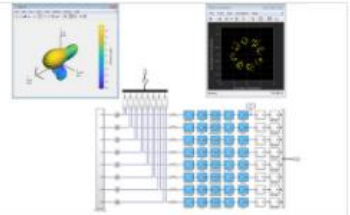
» Learn more



Analysis, Design, and Tuning

Analyze antenna elements and antenna arrays with the method of moments.

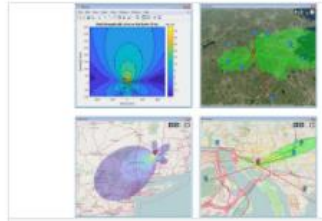
» Learn more



System Integration and Simulation

Integrate antennas and arrays for the design and simulation of radar and communications systems.

» Learn more

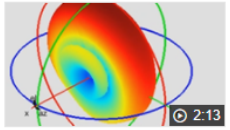


RF Propagation

Use map-based visualization of antenna sites, signal strength coverage, and communication links.

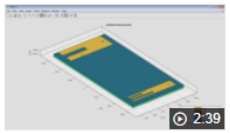
» Learn more

Videos



Antenna Toolbox Overview

Design, analyze, and visualize antenna elements and antenna arrays using Antenna Toolbox.



PCB Antenna Design, Simulation, and Fabrication with MATLAB

Design and rapidly prototype custom printed circuit board (PCB) antennas. Iterate on your design, solve the PCB structure, and generate Gerber files for antenna fabrication in just a few lines of...

Explore, Pick, Iterate: Three Steps for Antenna Design

Starting from your specifications, choose, solve, and design an antenna in just a few steps using the Antenna Designer App. Visualize the simulation results and iterate on the antenna properties to meet the design requirements.

Summary

- Building Multi function radar systems is easier with MathWorks tools
  - Phased Array System Toolbox
  - Antenna Toolbox
  - RF Blockset
- Target Hardware support
- Many examples to get started with

Explore these examples and more online:

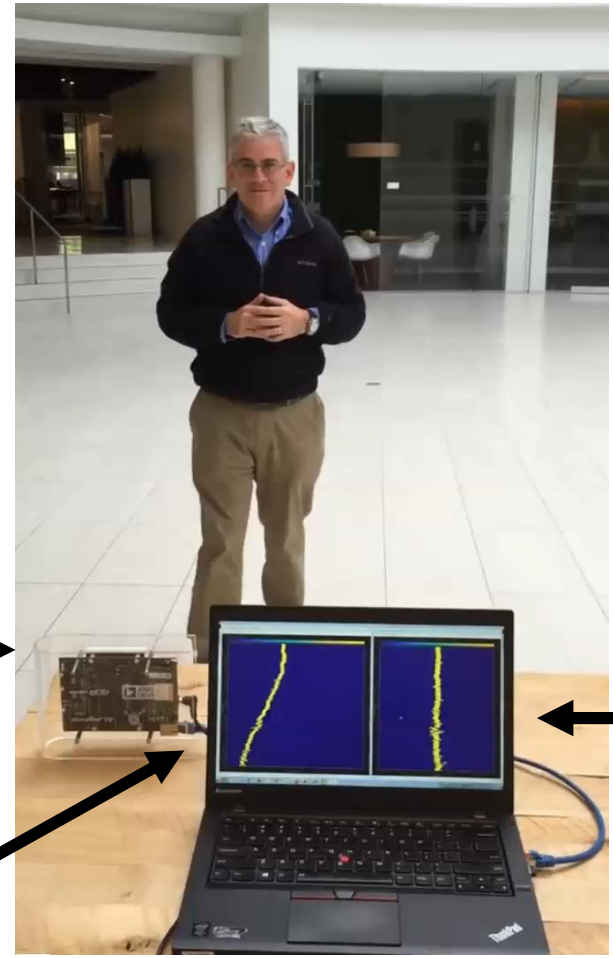
mathworks.com/phased-array-examples

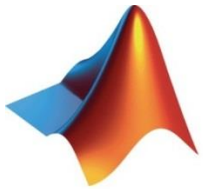
- *Antenna Array Analysis with Custom Radiation Pattern*
- *Array Pattern Synthesis*
- *Mutual Coupling in Large Arrays*
- *Space-Time Adaptive Processing*
- *Designing a Monostatic Pulse Radar*
- *Ground Clutter Mitigation with MTI Radar*
- *Simulating a Bistatic Polarimetric Radar*

Radar System Design: *mathworks.com/radar*

Demonstration at Demo booth

- **Real Time Range Doppler Mapping with Radar Hardware.**
- **Simulink Model to Demonstrate Fidelity with RF components**
- **Antenna Pattern Generation**





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Swathi.Balki@mathworks.in

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Email: info@mathworks.in

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