MATLAB EXPO

MATLAB 환경에서 레이다 및 안테나 시스템의 설계 및 운용에 대한 최적화 기법

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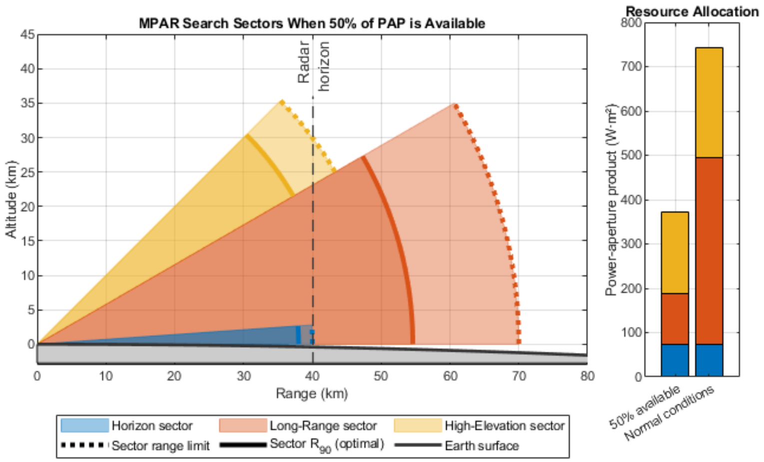
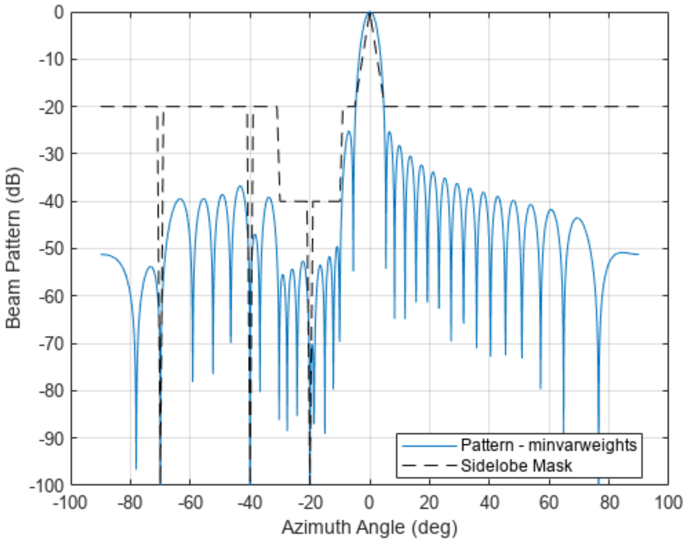
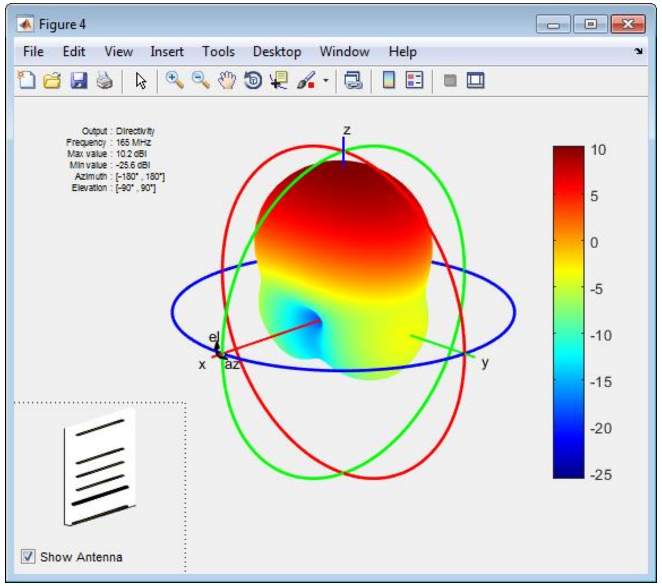
Apply design optimization to key radar and antenna design challenges





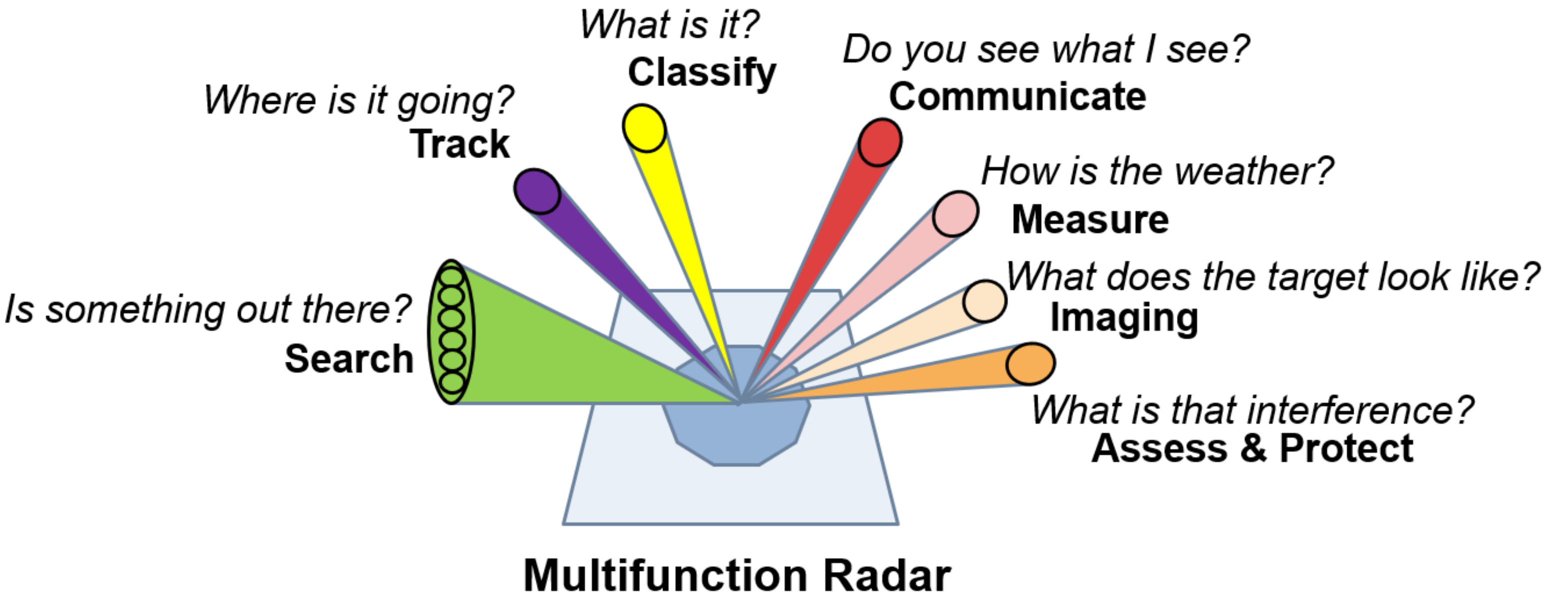


Radar resource management
-. QoS based Approach

Array pattern synthesis
-. Convex Optimization

Antenna design
-. Surrogate Optimizer

Multifunction Phased Array Radar (MPAR)



Capabilities

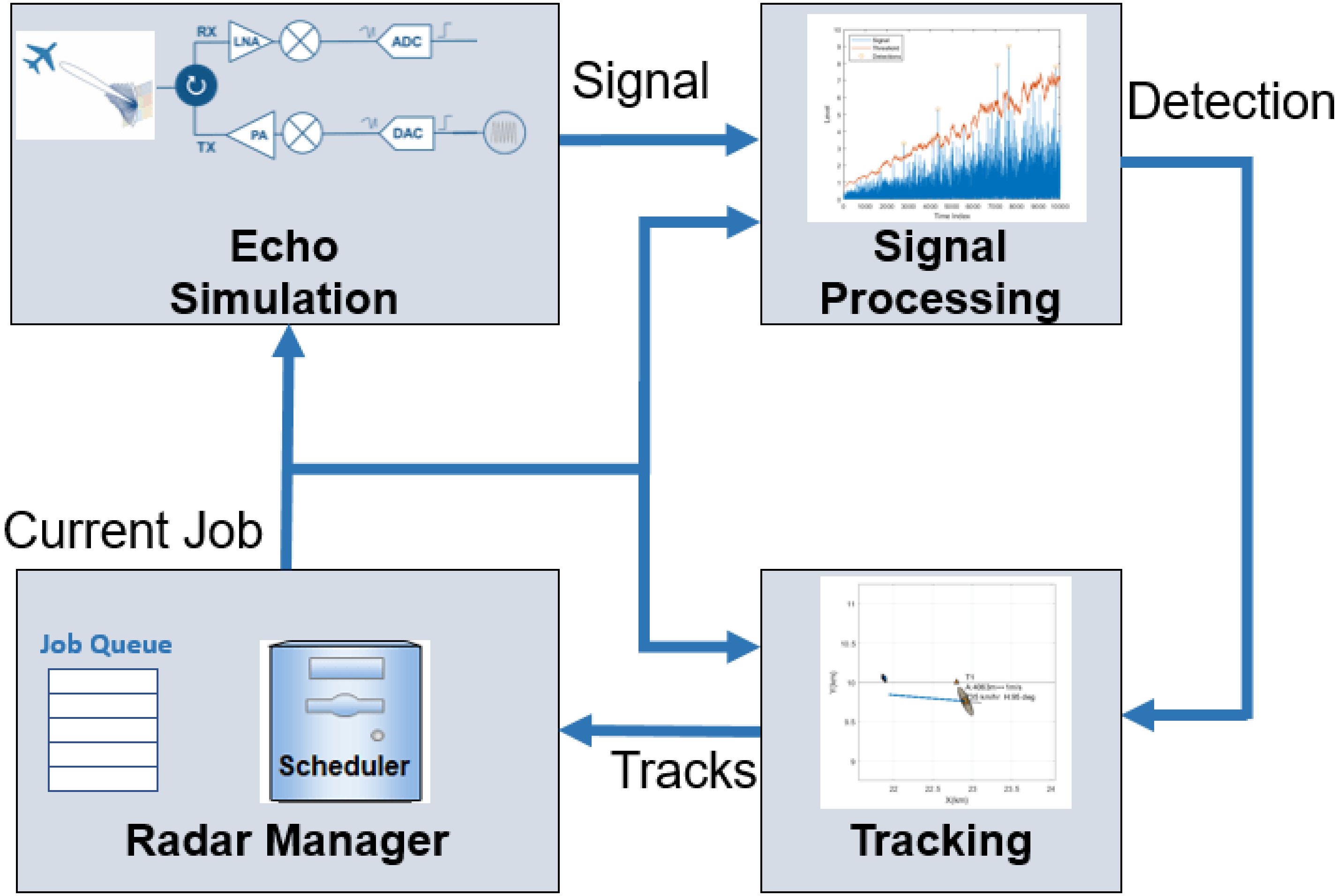
- Electronically steered phased array enables an ***agile*** beam and dynamic time/energy resource allocation
- Control parameters can be ***varied*** nearly ***instantaneously***
- ***Many tasks*** supporting ***different functions*** can be multiplexed in time and angle

Resource constraints

- Transmit energy/time budget
- Bandwidth
- Computation
- Emission reduction

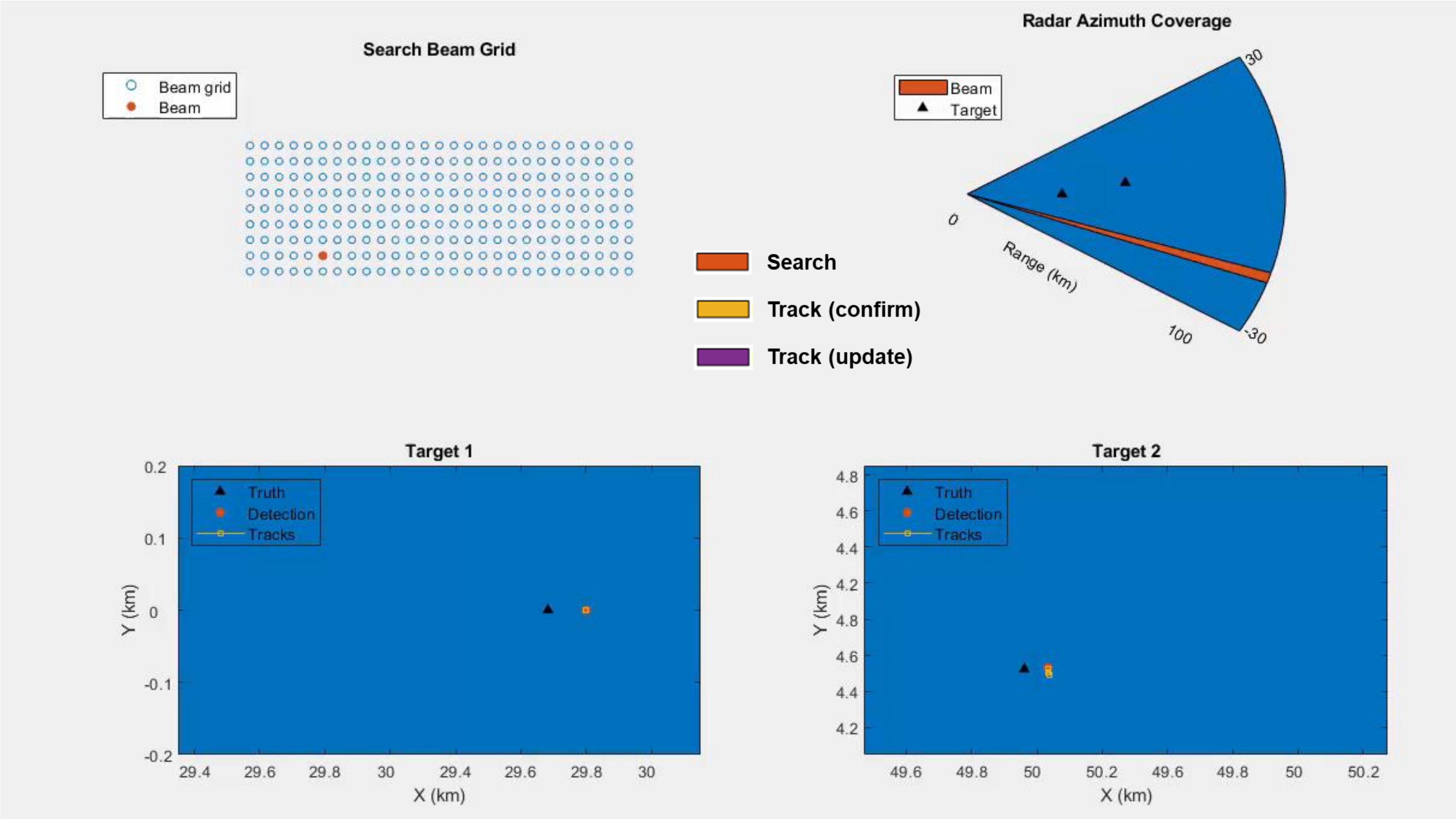
Close the data processing loop with resource management

Link to example

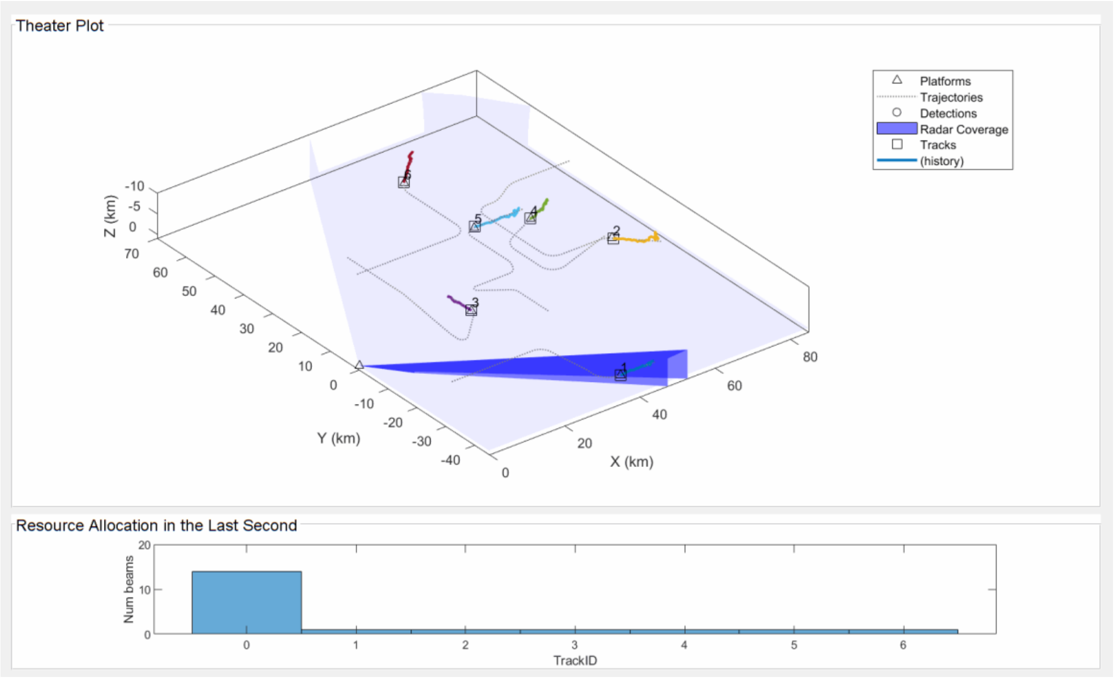


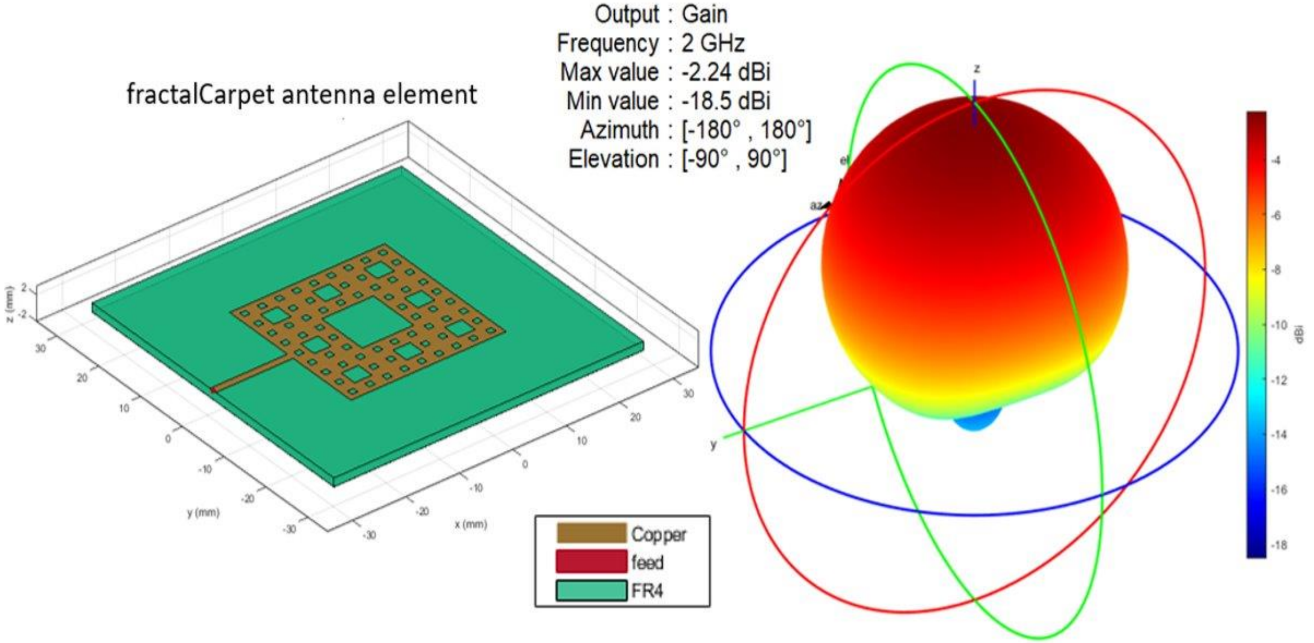
Detect, confirm, and track targets with multifunction phased array radar system

[1:02]



Operational and physical resources are limited





Higher frequency operation increases the interference challenges

Aviation Today

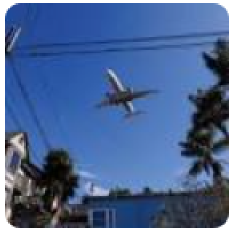
FAA Issues New Radar Altimeter 5G C-Band Risk Assessment ...

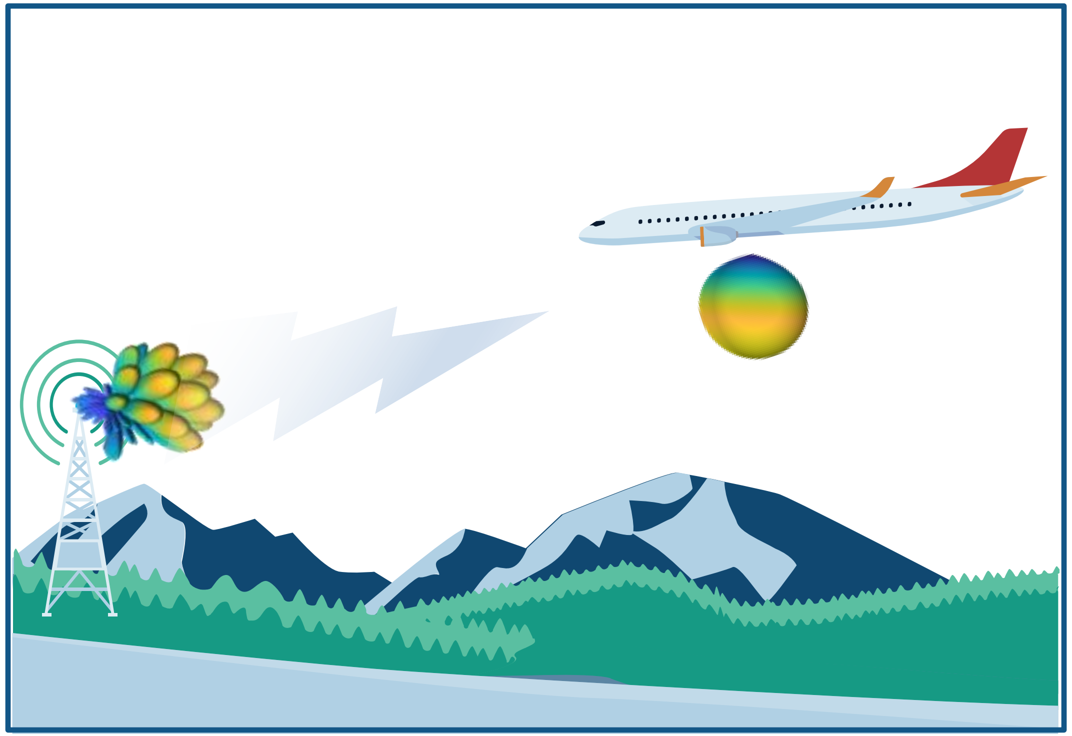
As the FAA indicated in its Dec. 7 AD, while it has heard concerns from airlines, the FAA, and aircraft OEMs over the potential interference...

Reuters

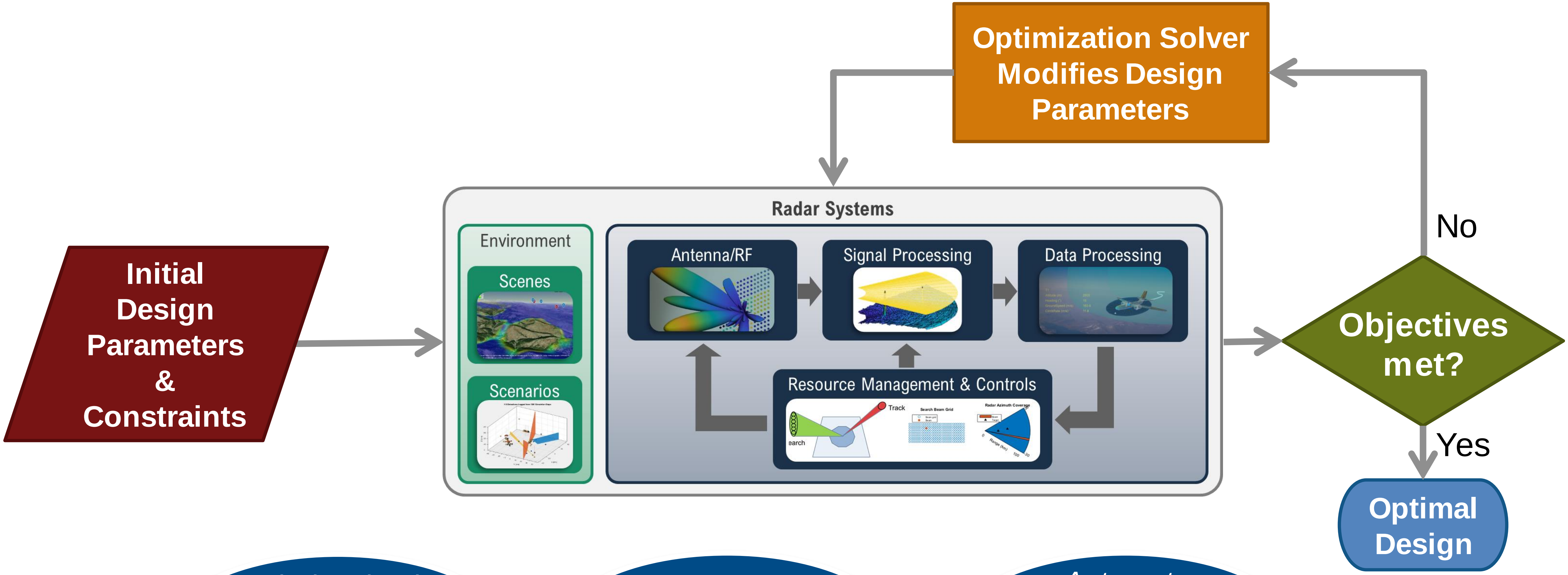
FAA wants U.S. airlines to retrofit, replace radio altimeters

... a push to retrofit and ultimately replace some airplane radio altimeters that could face interference from C-Band 5G wireless service.





Address the design challenges with optimization workflows

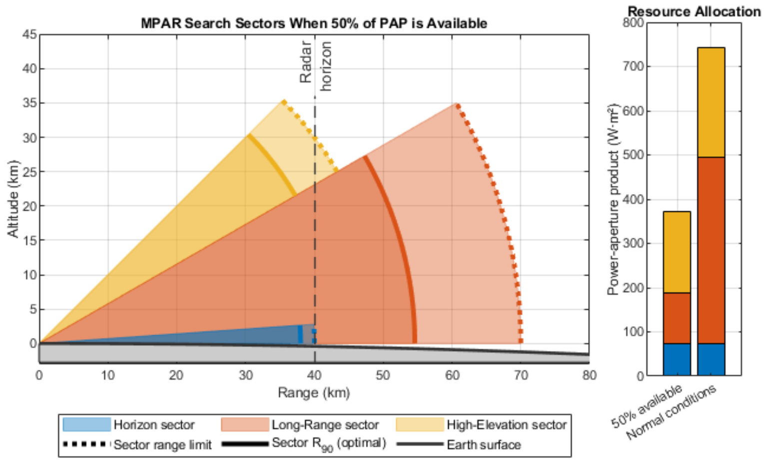


Find optimal designs while satisfying requirements

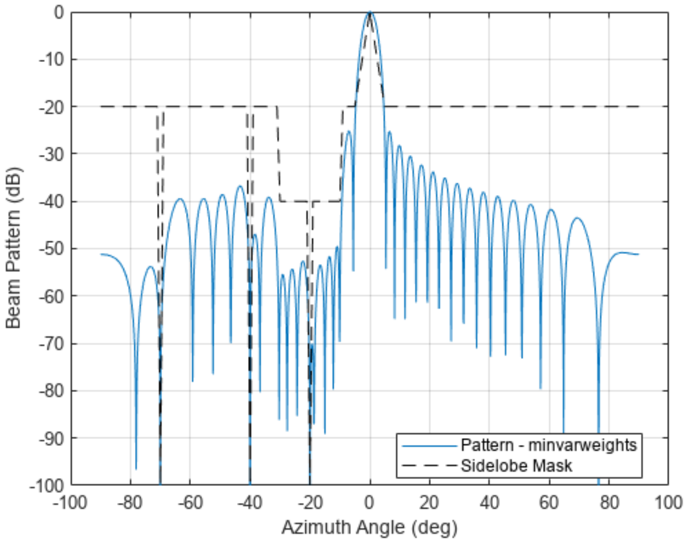
Reduce time of design iterations

Automate operational decision-making

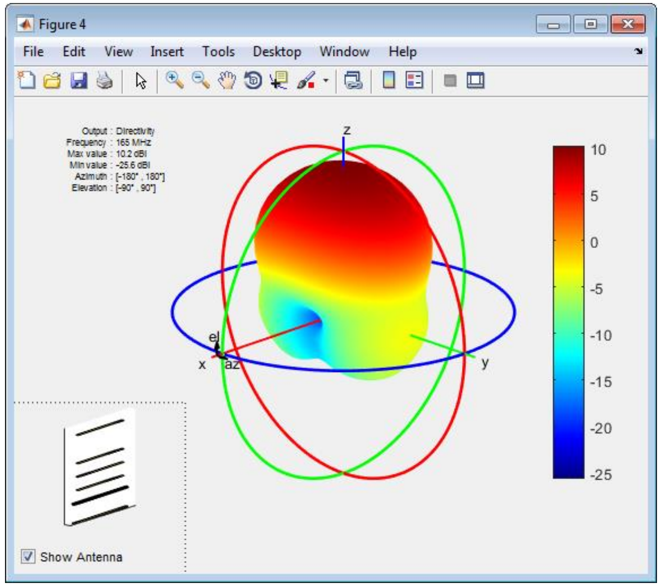
Apply design optimization to key radar and antenna design challenges



Radar resource management
-. QoS based Approach



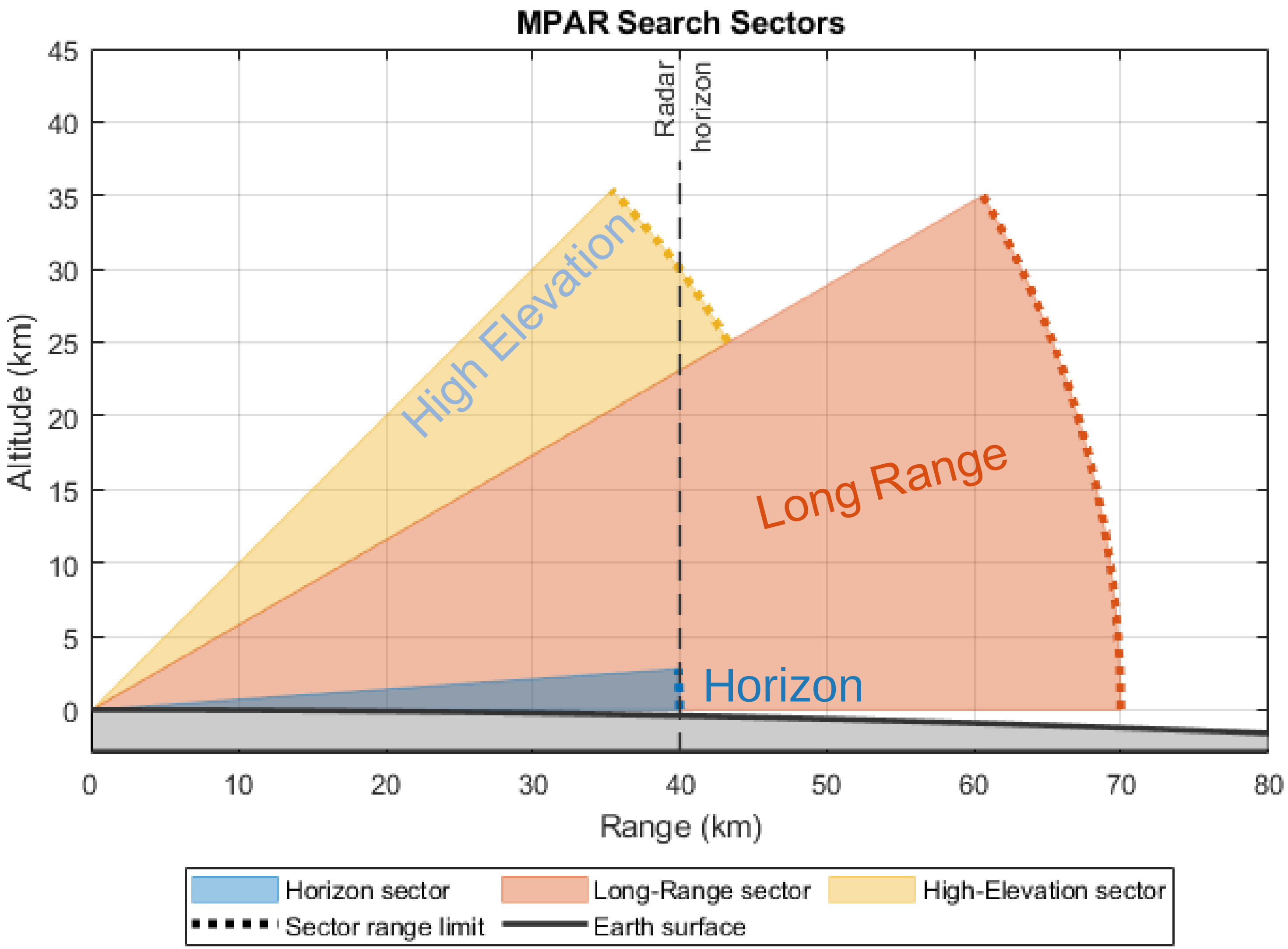
Array pattern synthesis



Antenna design

Manage radar resources between three search sectors

Link to example



[Link to example]

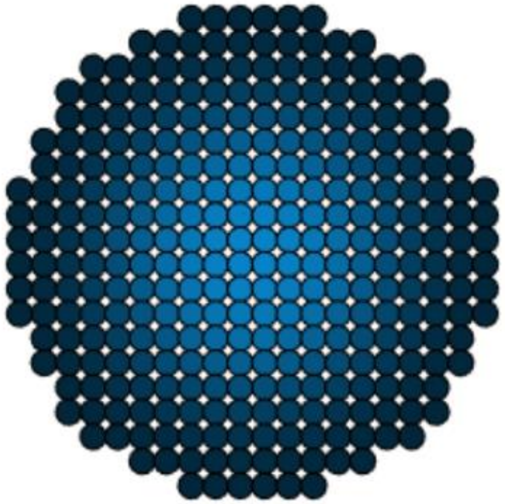
Successful completion of a search task depends on power aperture product (PAP)

Cumulative Probability of Detection (P_c)

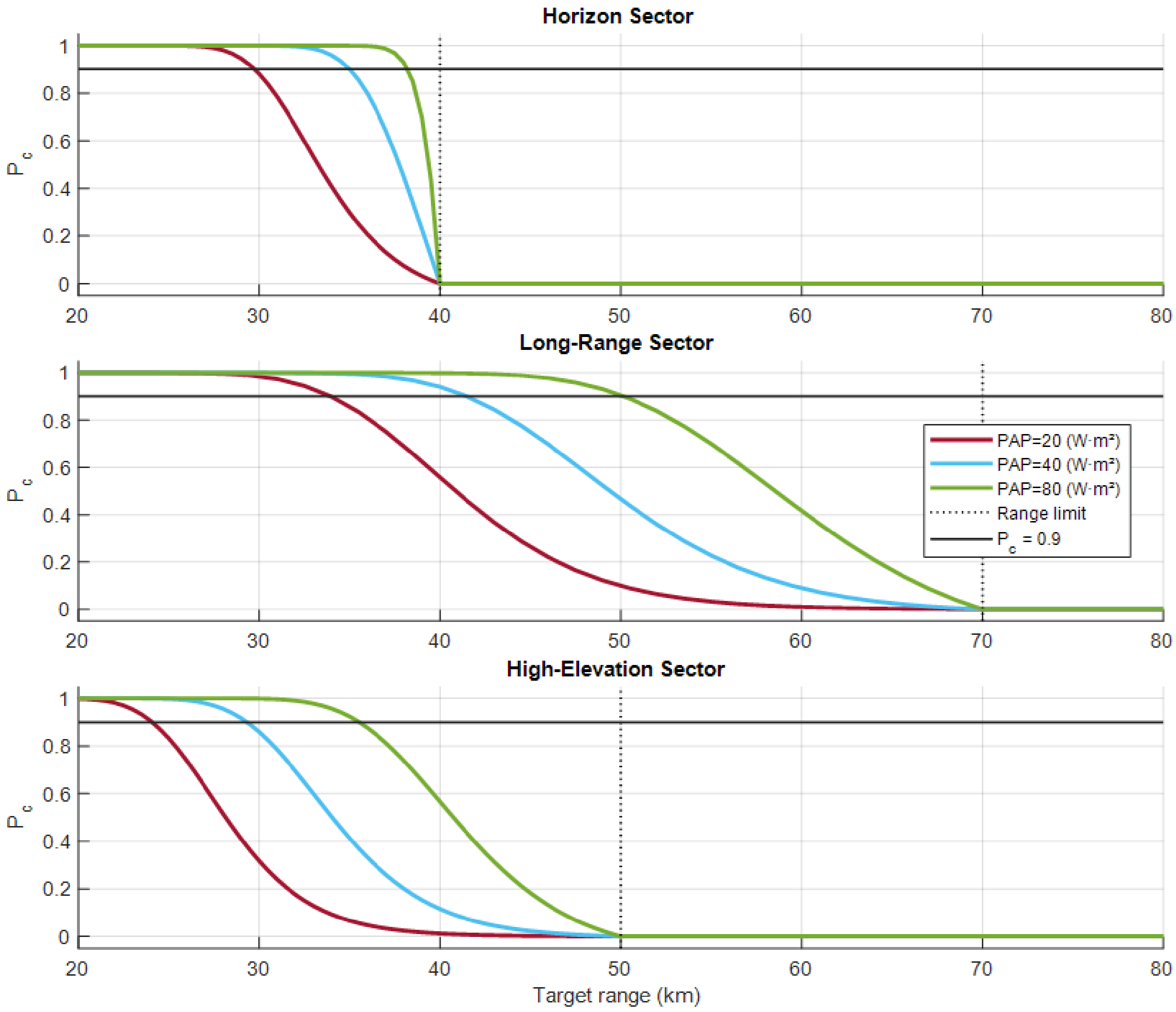
$$P_c(R) = E_\Delta\{1 - \prod_{n=0}^{N}[1 - P_d(R_m - \Delta \cdot dR - n \cdot dR)]\}$$

where

$$P_d(R) = P_{fa}^{\frac{1}{1+SNR_m\left(\frac{R_m}{R}\right)^4}} \qquad SNR_m = PAP \cdot \frac{\sigma}{4\pi k T_s R_m^4 L} \cdot \frac{t_f}{\Omega}$$



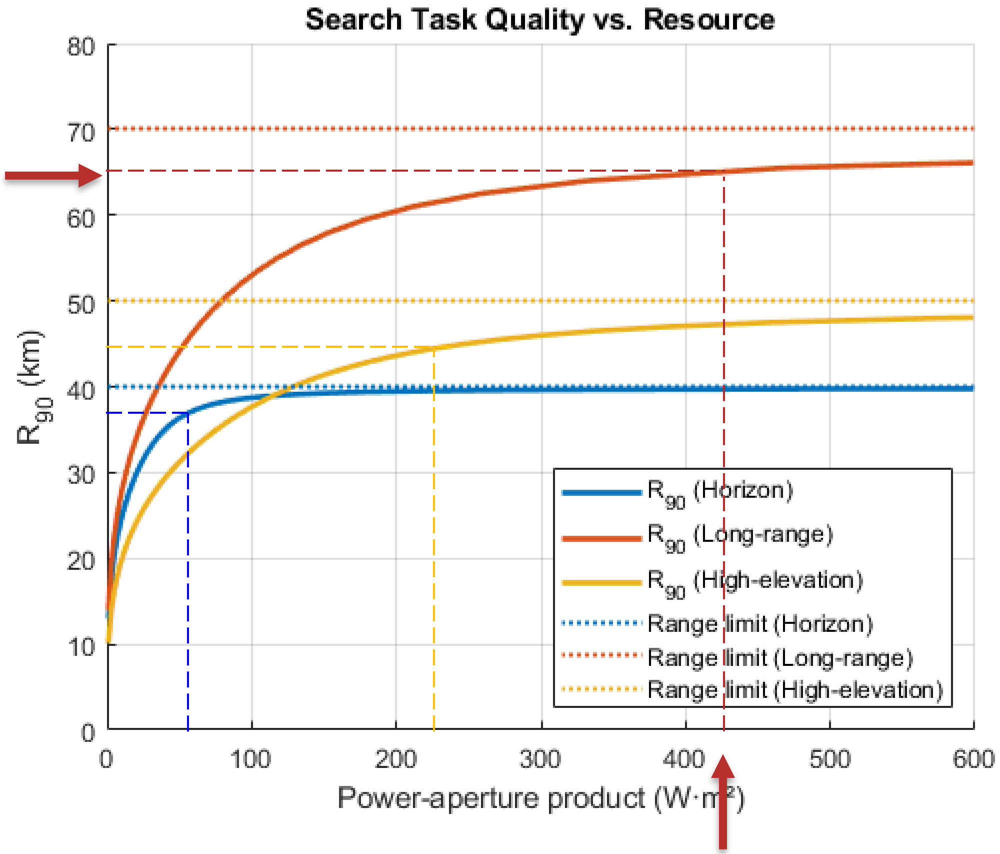
Circular Planar Array



R_m: range limit, Ω: search volume, T_s: system noise temperature, L: system loss

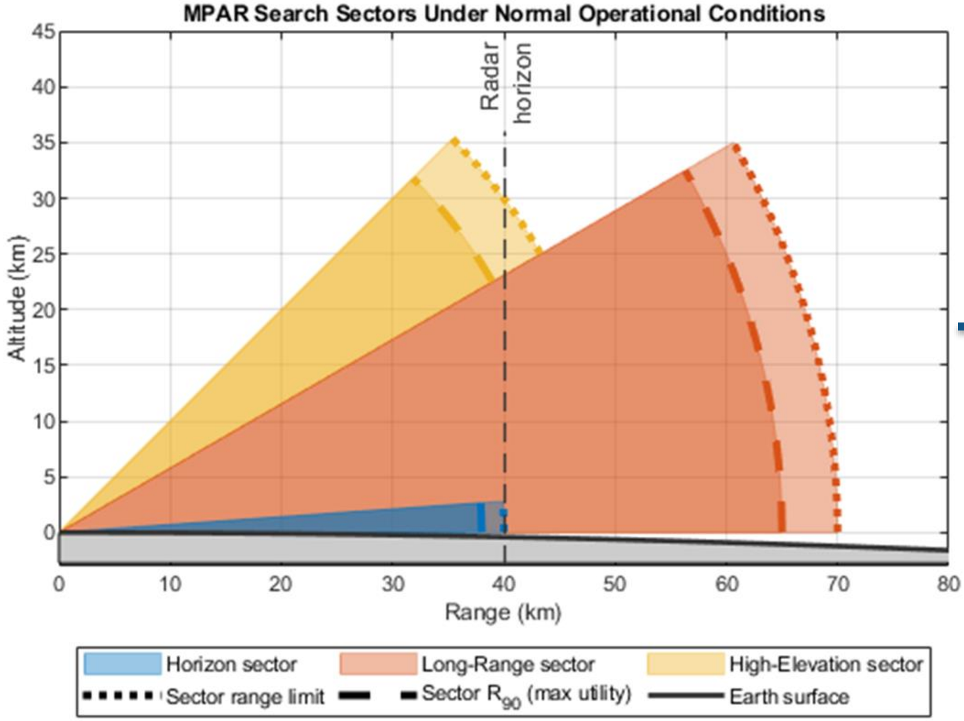
Resource allocation under normal operational conditions

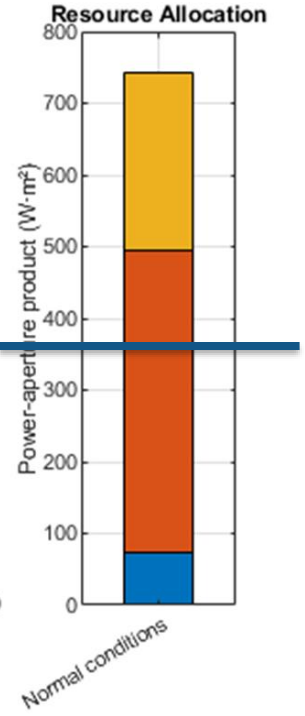
65km



74 W·m² 247 W·m² 422 W·m²

743 W·m²





What if we only have access to half of the required PAP?

Optimize search quality across all sectors with QoS

Quality metric

Resource

# of search sectors

$$\max_{PAP} u(PAP) = \sum_{i=1}^{M} w_i \cdot u_i(q_i(PAP_i;\theta_i))$$

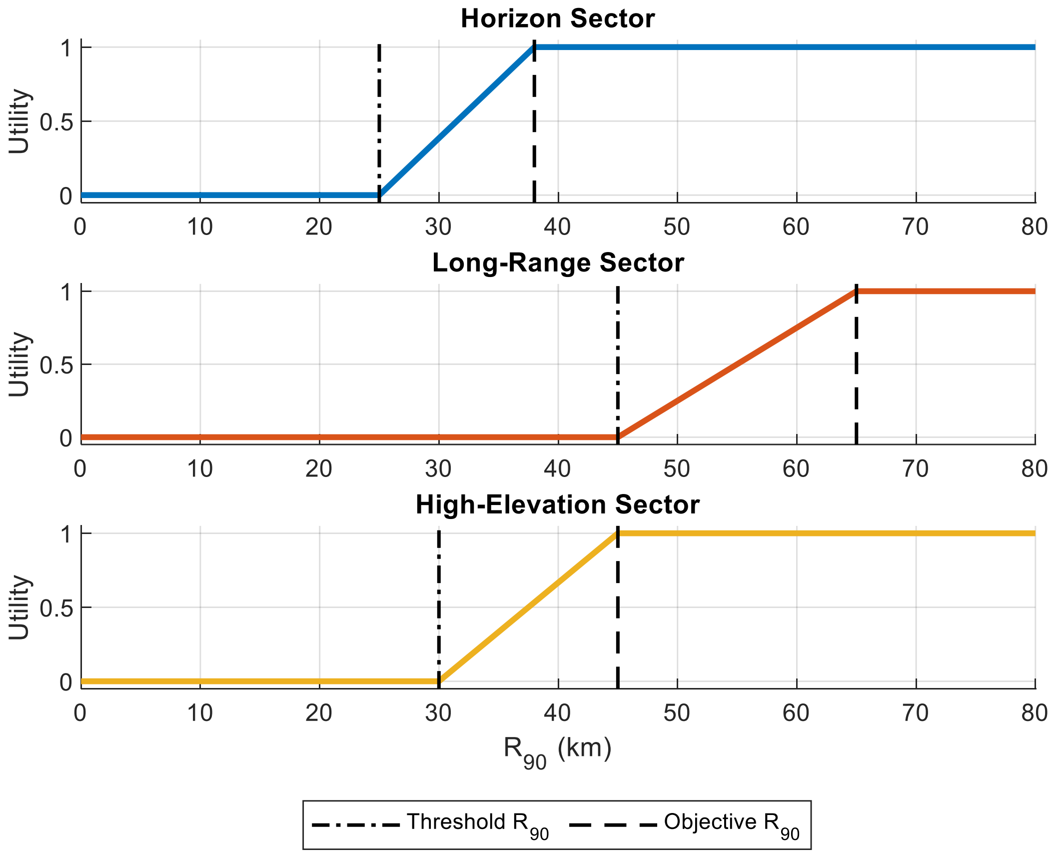
Weights

Utility function

such that $$\sum_{i=1}^{M} PAP_i \leq PAP_{search}$$

where

$$u_i(R_{90}) = \begin{cases} 0, & R_{90} < R_{t_i} \\ \frac{R_{90} - R_{t_i}}{R_{o_i} - R_{t_i}}, & R_{t_i} \leq R_{90} \leq R_{o_i} \\ 1, & R_{90} > R_{o_i} \end{cases}$$

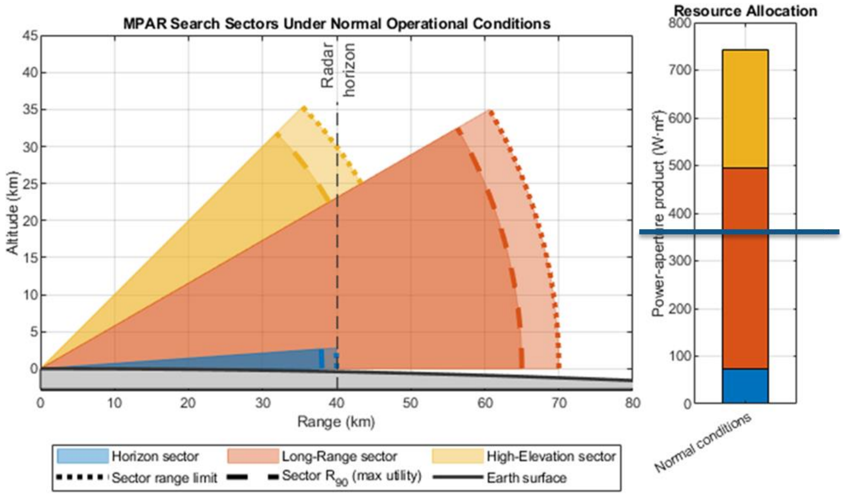


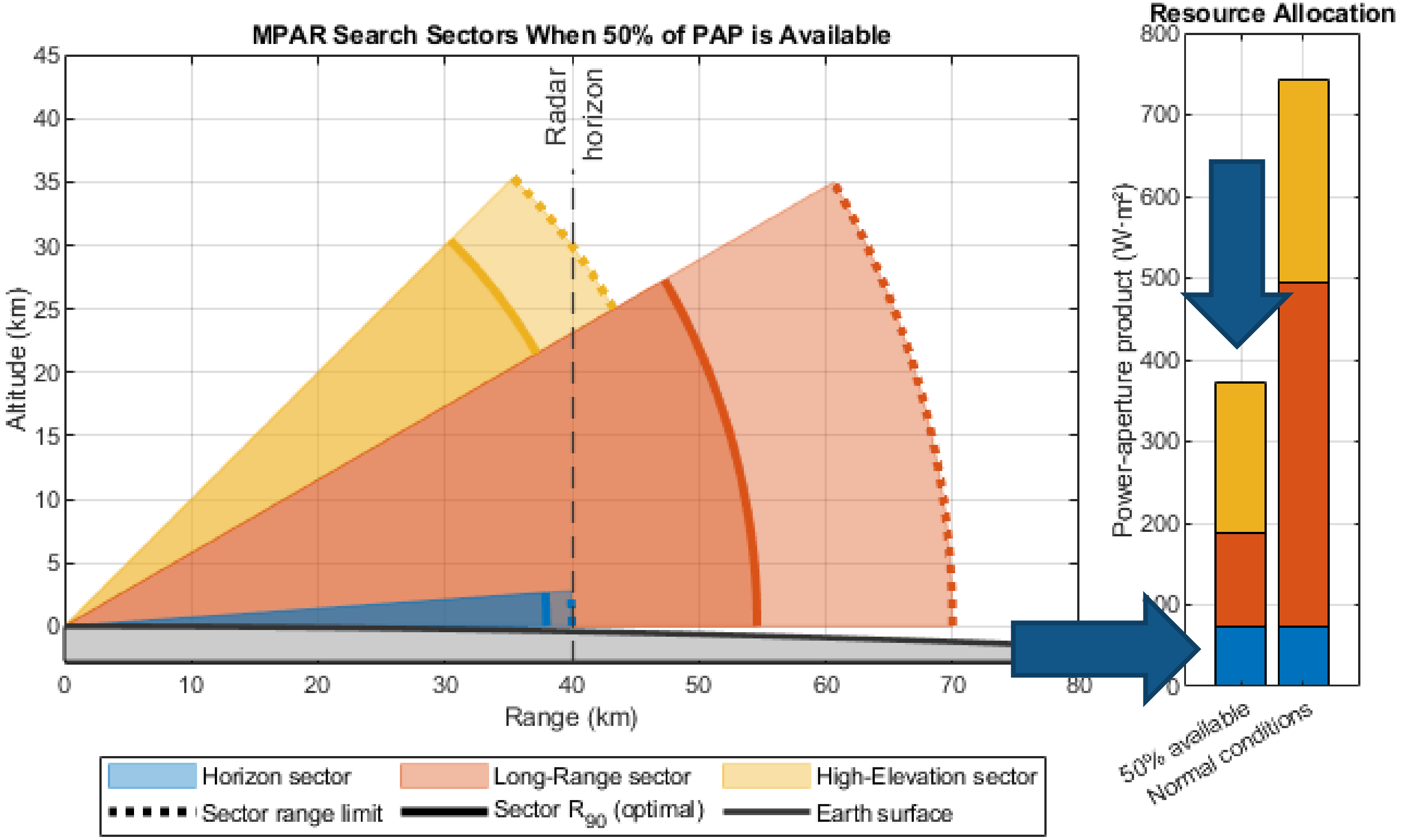
$$PAP = [PAP_1, PAP_2, \ldots, PAP_M]$$

Find optimal resource allocation under constrained operating conditions

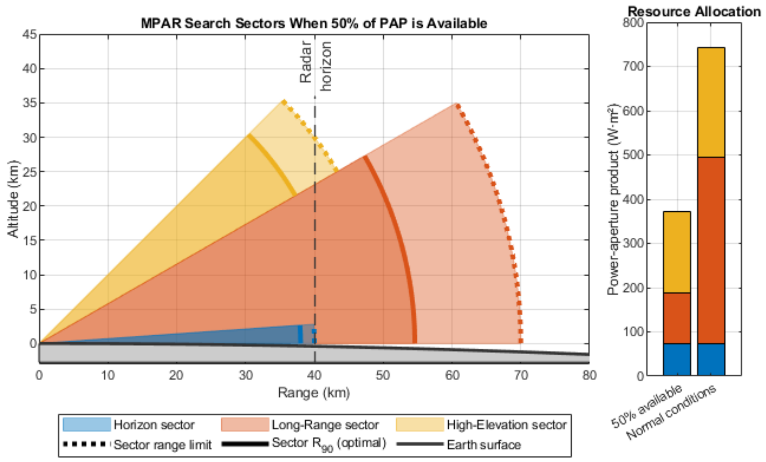
Search Sector	Priority Weights (w_i)
Horizon	0.55
High Elevation	0.3
Long Range	0.15

```
% Objective function
fobj = @(x)helperQoSObjective(x, searchSectorParams, w);
% Constraint
fcon = @(x)helperQoSConstraint(x, searchPAP);
…
papAllocation = fmincon(fobj, startPAP, [], [], [], [], LB,
UB, fcon, options);
```

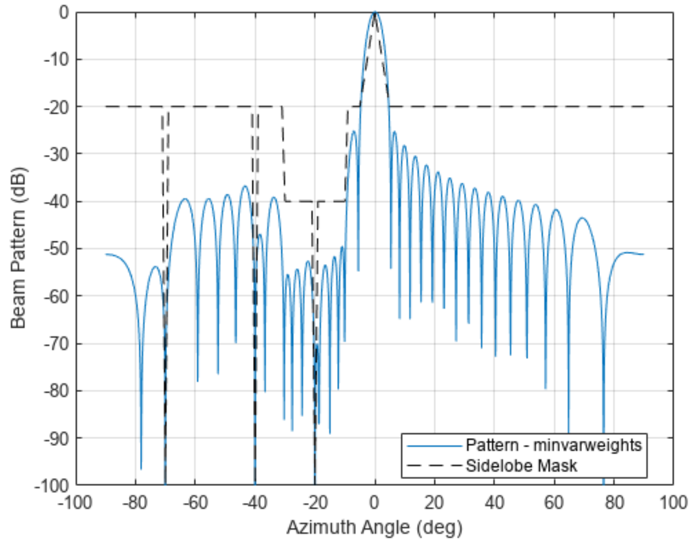




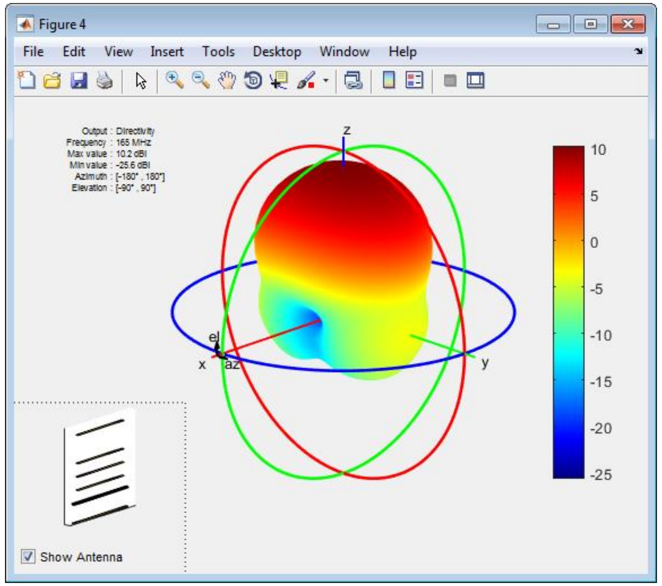
Apply design optimization to key radar and antenna design challenges



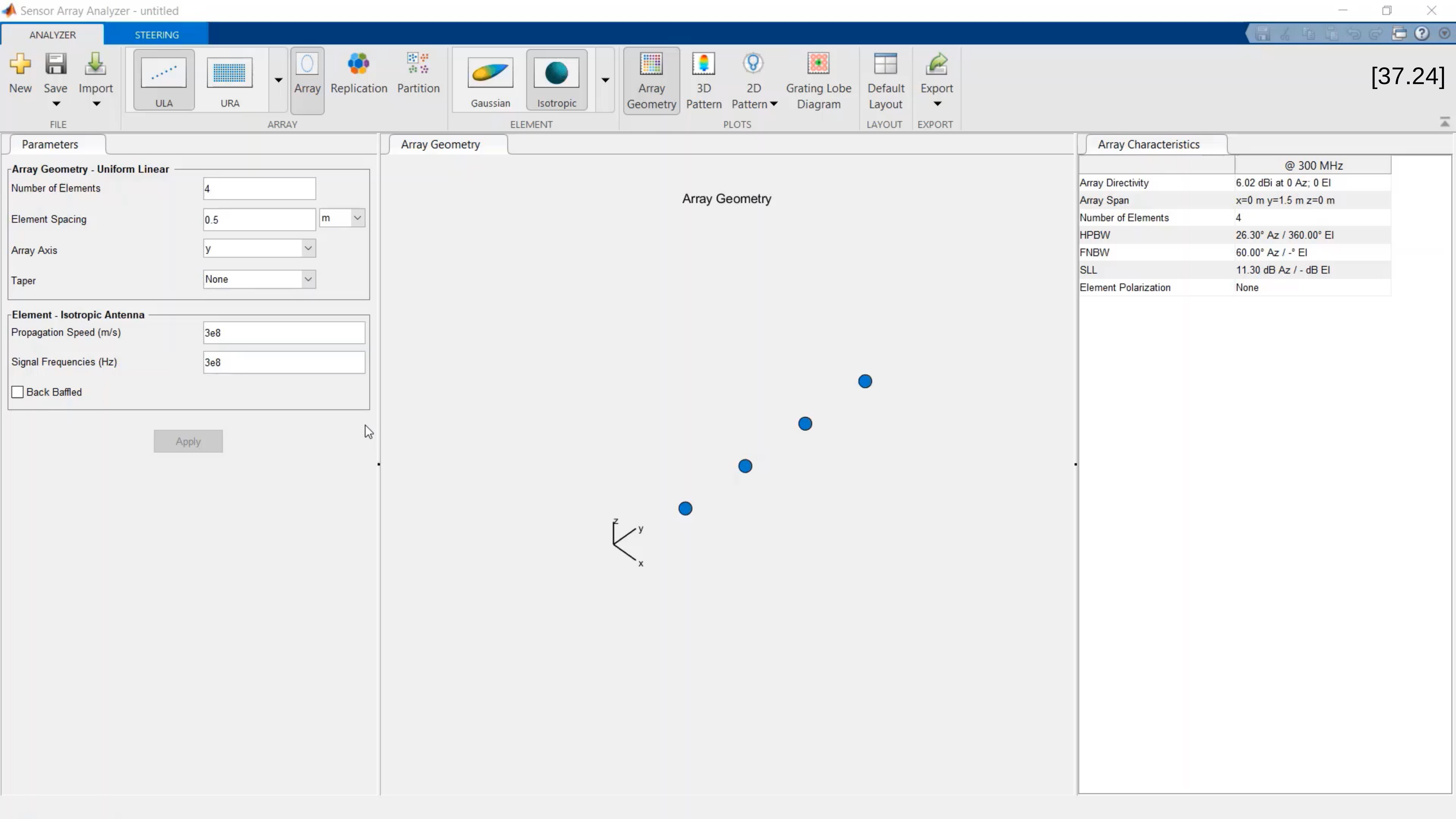
Radar resource management



Array pattern synthesis
-. Convex Optimization

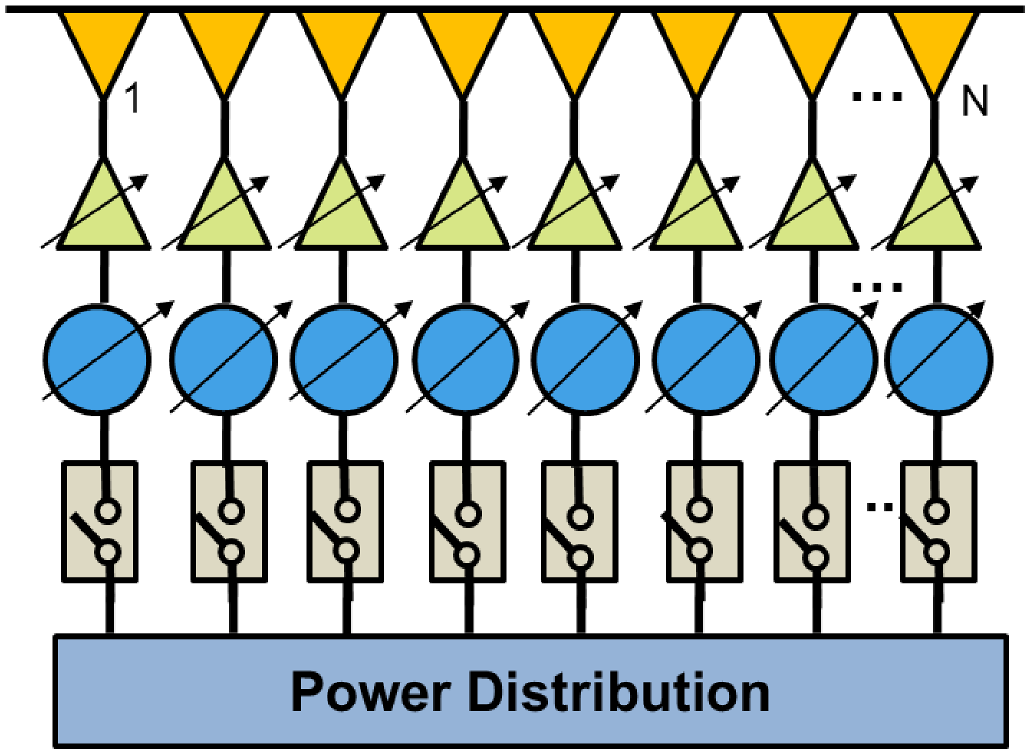


Antenna design

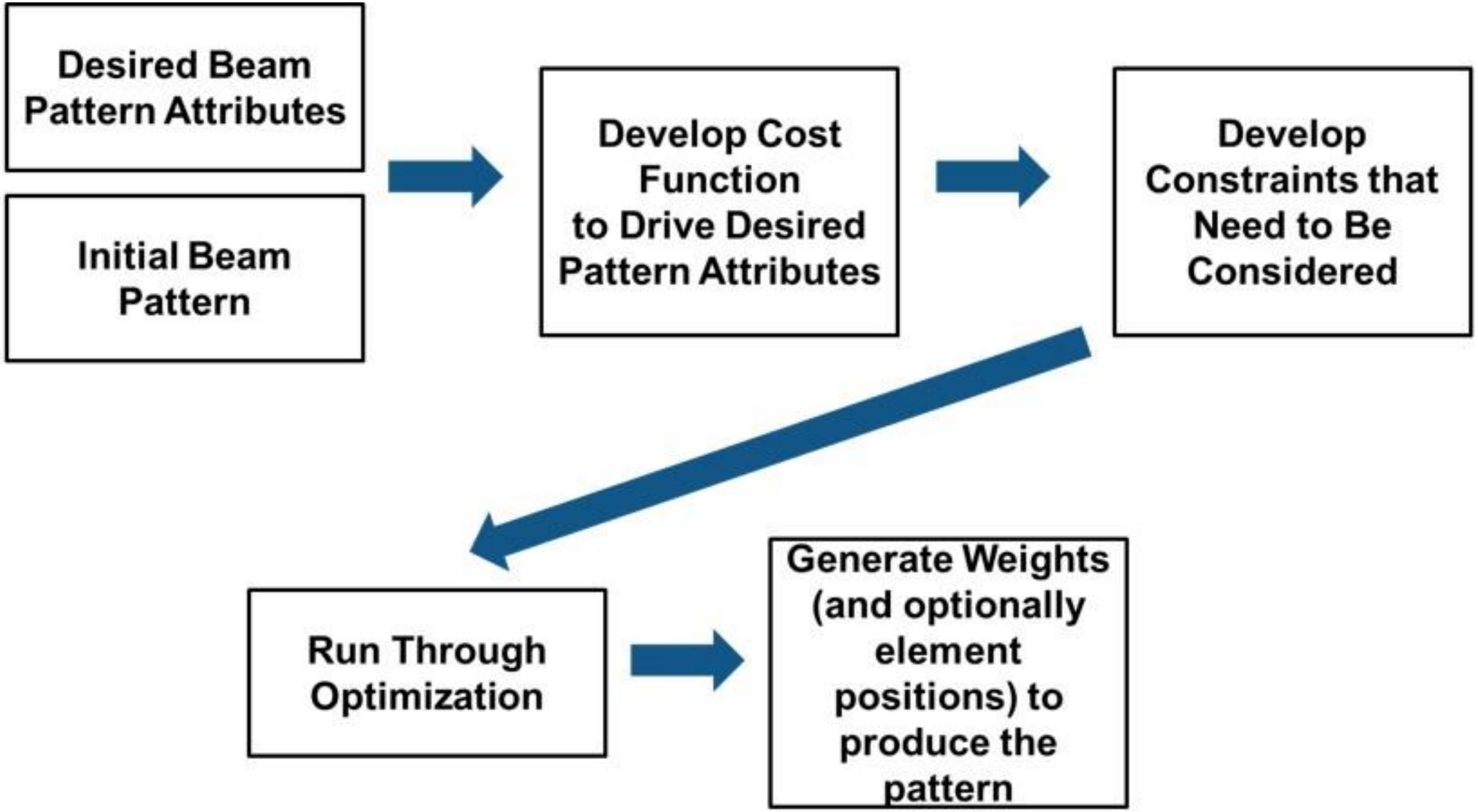

Sensor Array Analyzer - untitled
ANALYZER
STEERING
New
Save
Import
FILE
ULA
URA
Array
Replication
Partition
ARRAY
Gaussian
Isotropic
ELEMENT
Array Geometry
3D Pattern
2D Pattern
Grating Lobe Diagram
PLOTS
Default Layout
LAYOUT
Export
EXPORT
[37.24]
Parameters
Array Geometry - Uniform Linear
Number of Elements 4
Element Spacing 0.5 m
Array Axis y
Taper None
Element - Isotropic Antenna
Propagation Speed (m/s) 3e8
Signal Frequencies (Hz) 3e8
Back Baffled
Apply
Array Geometry
Array Geometry
z
y
x
Array Characteristics
@ 300 MHz
Array Directivity 6.02 dBi at 0 Az; 0 El
Array Span x=0 m y=1.5 m z=0 m
Number of Elements 4
HPBW 26.30° Az / 360.00° El
FNBW 60.00° Az / -° El
SLL 11.30 dB Az / - dB El
Element Polarization None

How can I obtain a pattern that meets my requirements?

- Traditional process very tedious
- Trial and error with array geometry, parameters, spacing, weighting, etc.

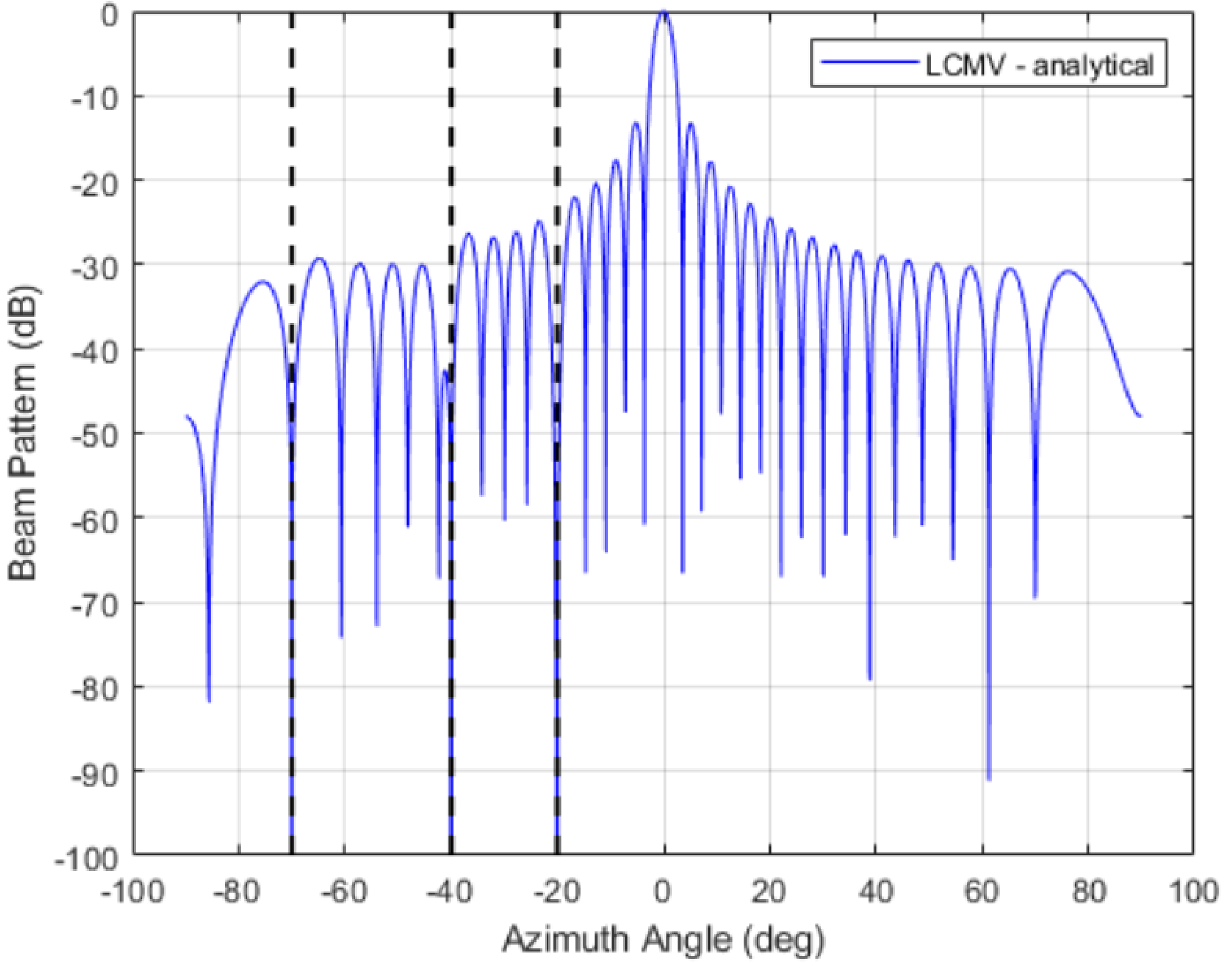


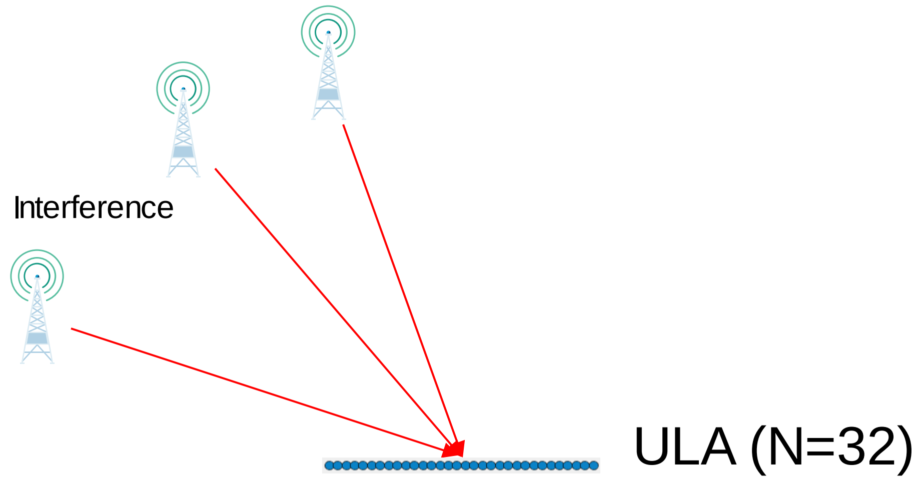
You can perform array synthesis using optimization to drive pattern attributes



Example: Linear Constraints Minimum Variance (LCMV) Beamforming

Link to example





Signal of interest at 0° azimuth
Interference at -70°, -40°, and -20° degrees azimuth

$$w_o = \min_w w^H R\, w$$

$$\text{s.t. } B(\theta_0, w) = 1$$

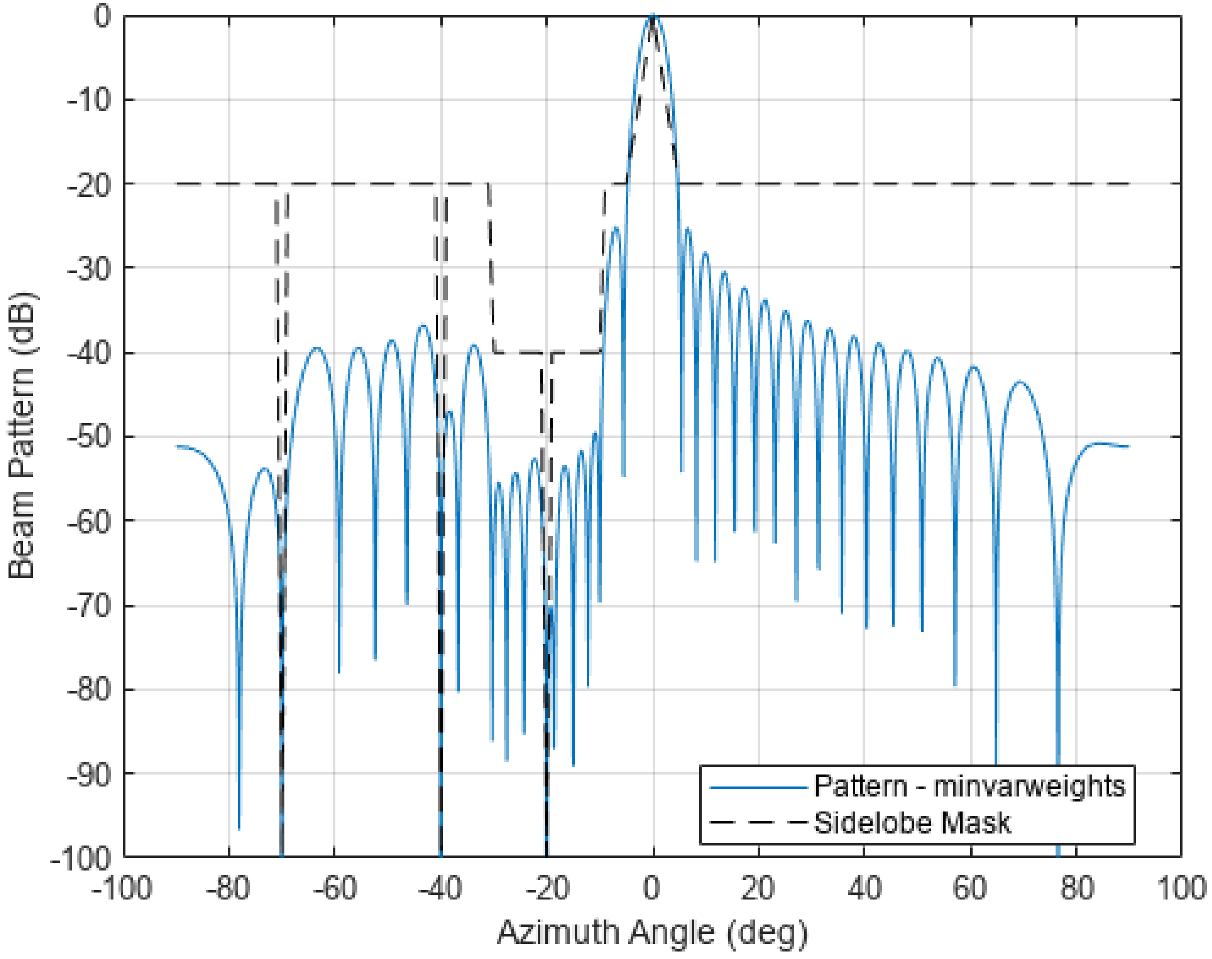
$$B(\theta_k, w) = 0$$

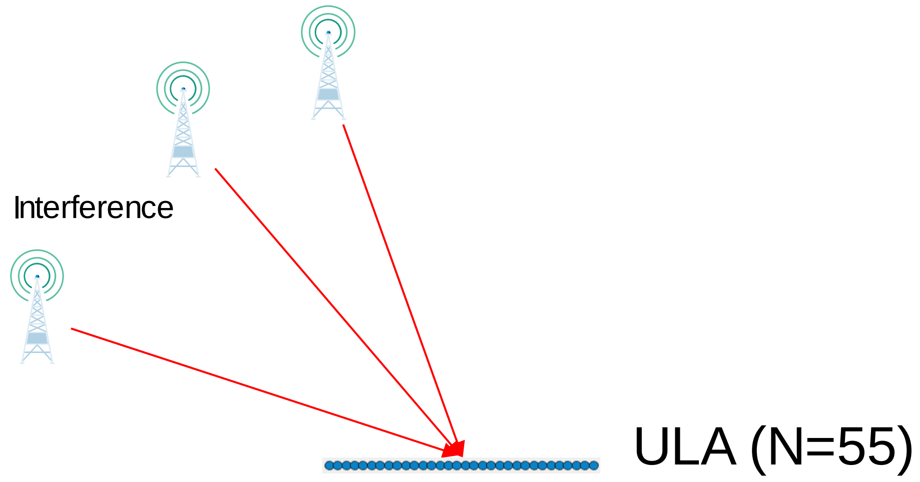
$$k = 1, 2, \ldots, K$$

```
w_lcmv = lcmvweights(sv_c, r_c, Rn); % LCMV weights
```

Example: Minimum Variance Beamforming

[Link to example](#)





Signal of interest at 0° azimuth
Interference at -70°, -40°, and -20° degrees azimuth

Sidelobes < −40 dB between −30 and −10 degrees
Sidelobes < −20 dB everywhere outside mainlobe

Beamformer weights → `wts`

Beamforming directions → `ang`

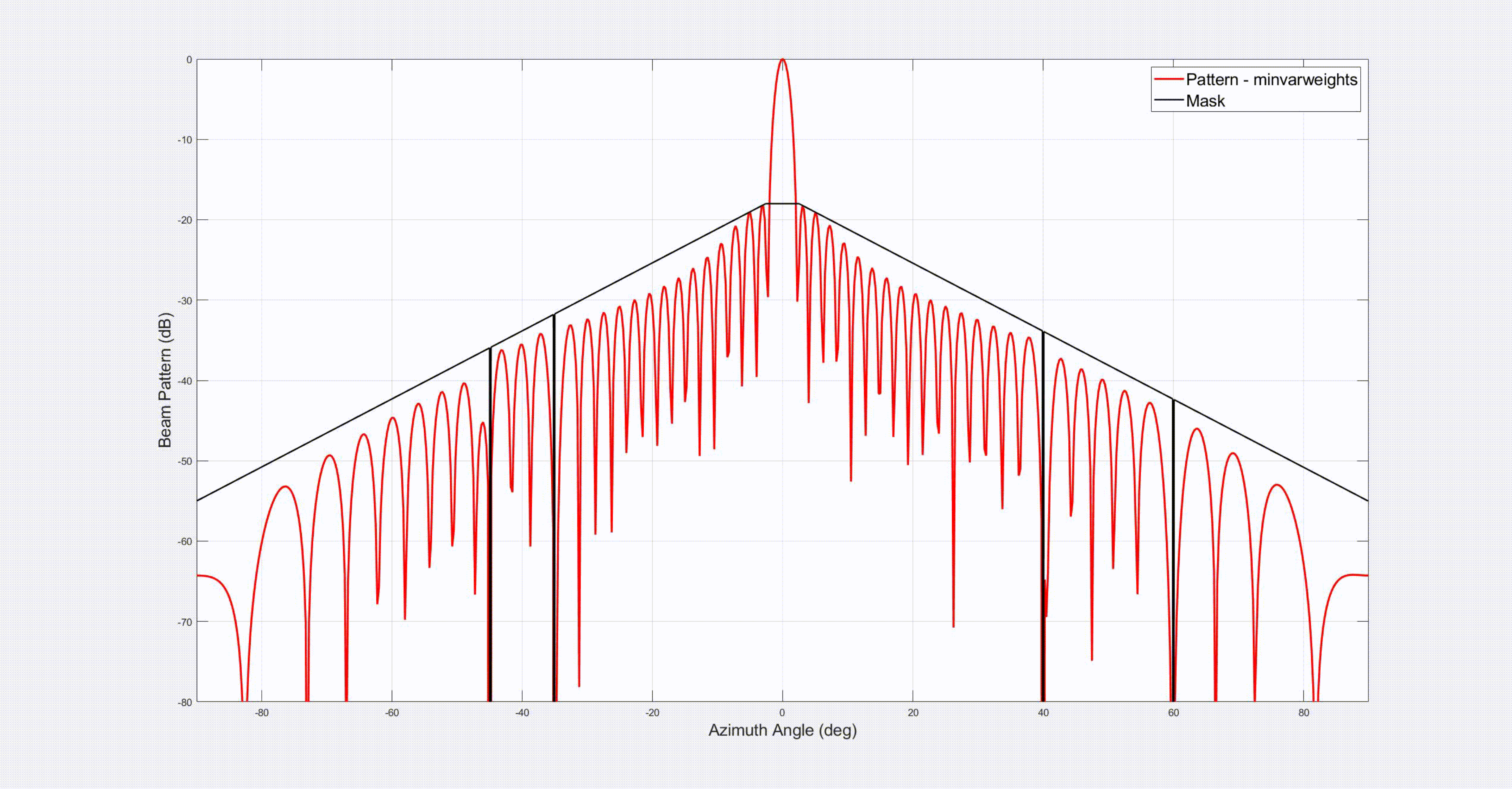
```
wts = minvarweights(pos,ang)
```

Element positions → `pos`

Example: Minimum Variance Beamforming

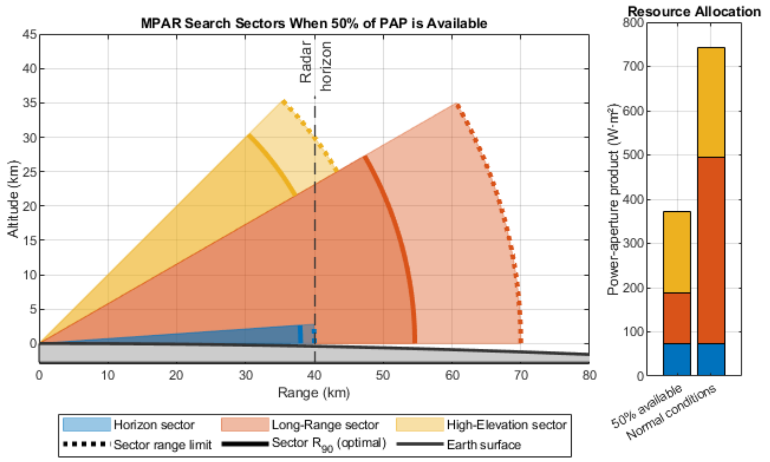
Link to example

Tapered sidelobe mask decreasing linearly from -18 dB to -55 dB
Nulls at -45, -35, 40, and 60 degrees azimuth
Sweep beam from -35 to 35 degrees

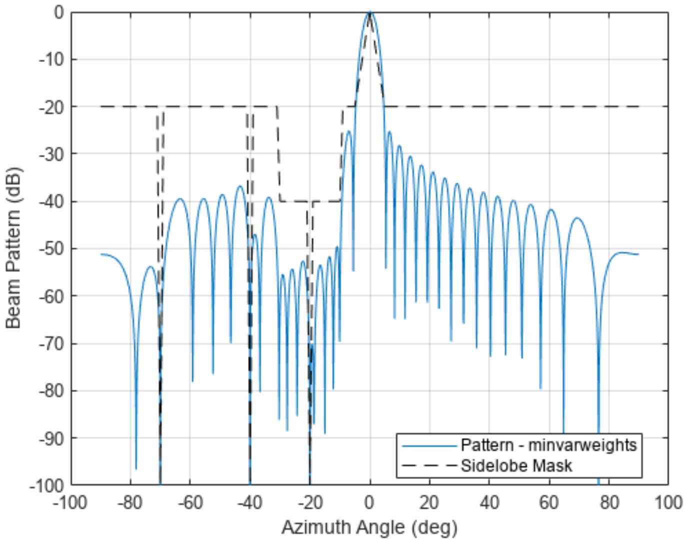


*. Lebret, Hervé, and Stephen Boyd. "Antenna Array Pattern Synthesis via Convex Optimization." *IEEE Transactions on Signal Processing,* Vol. 45, No. 3 (March 1997), pp. 526–532

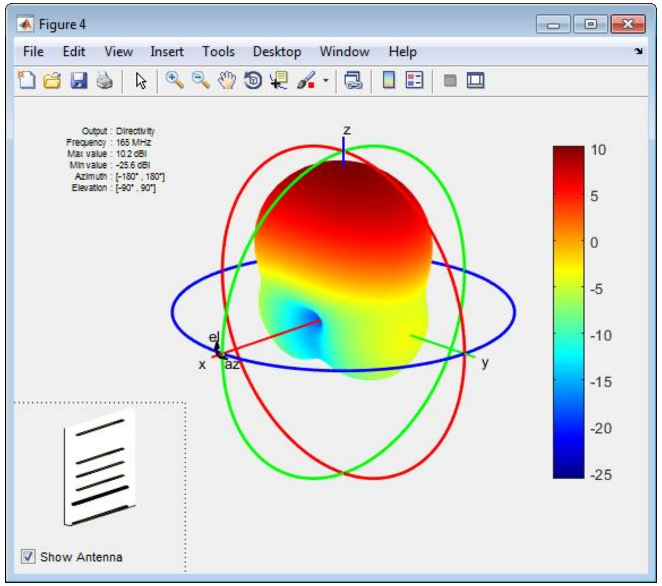
Apply design optimization to key radar and antenna design challenges



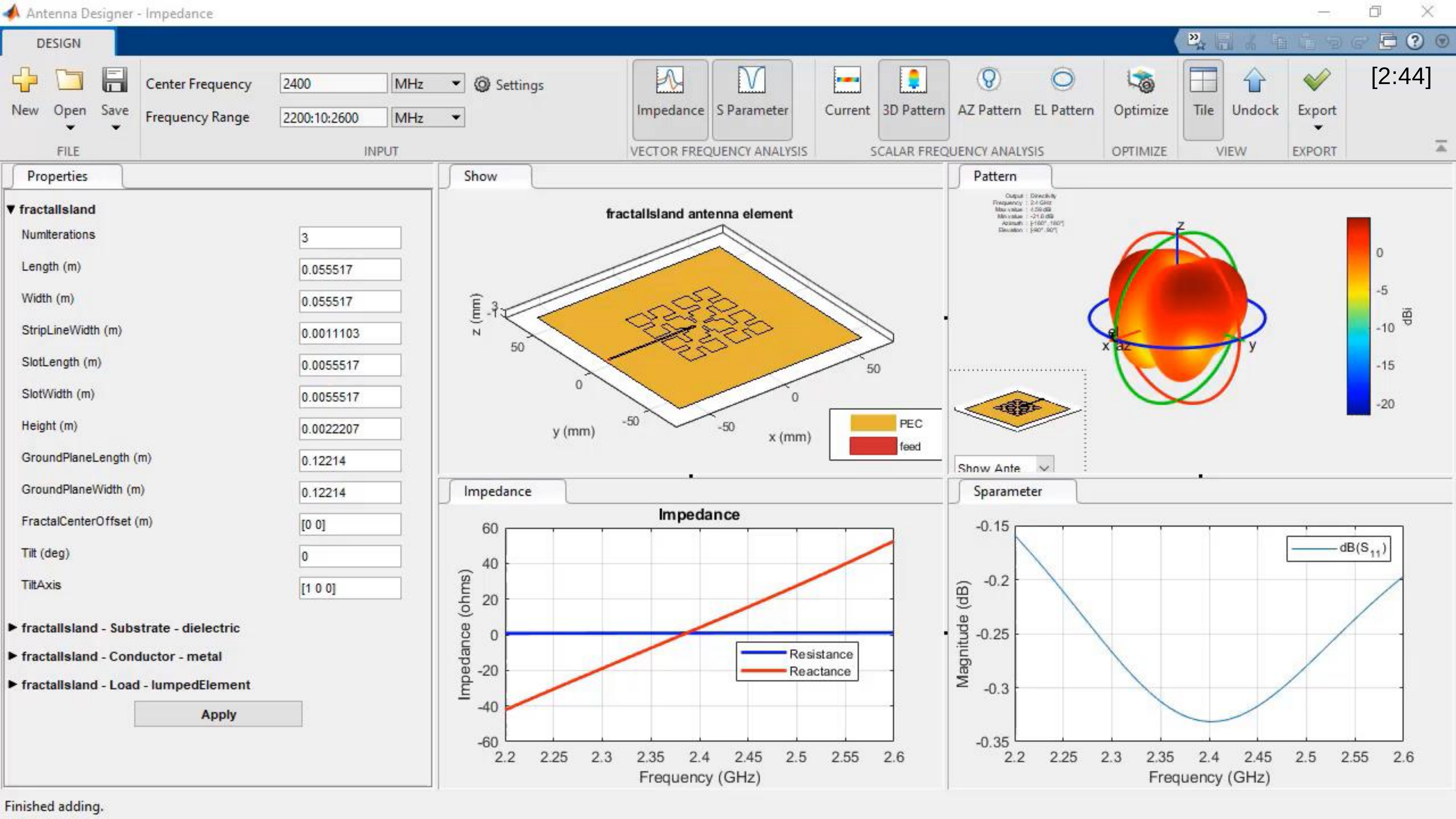
Radar resource management



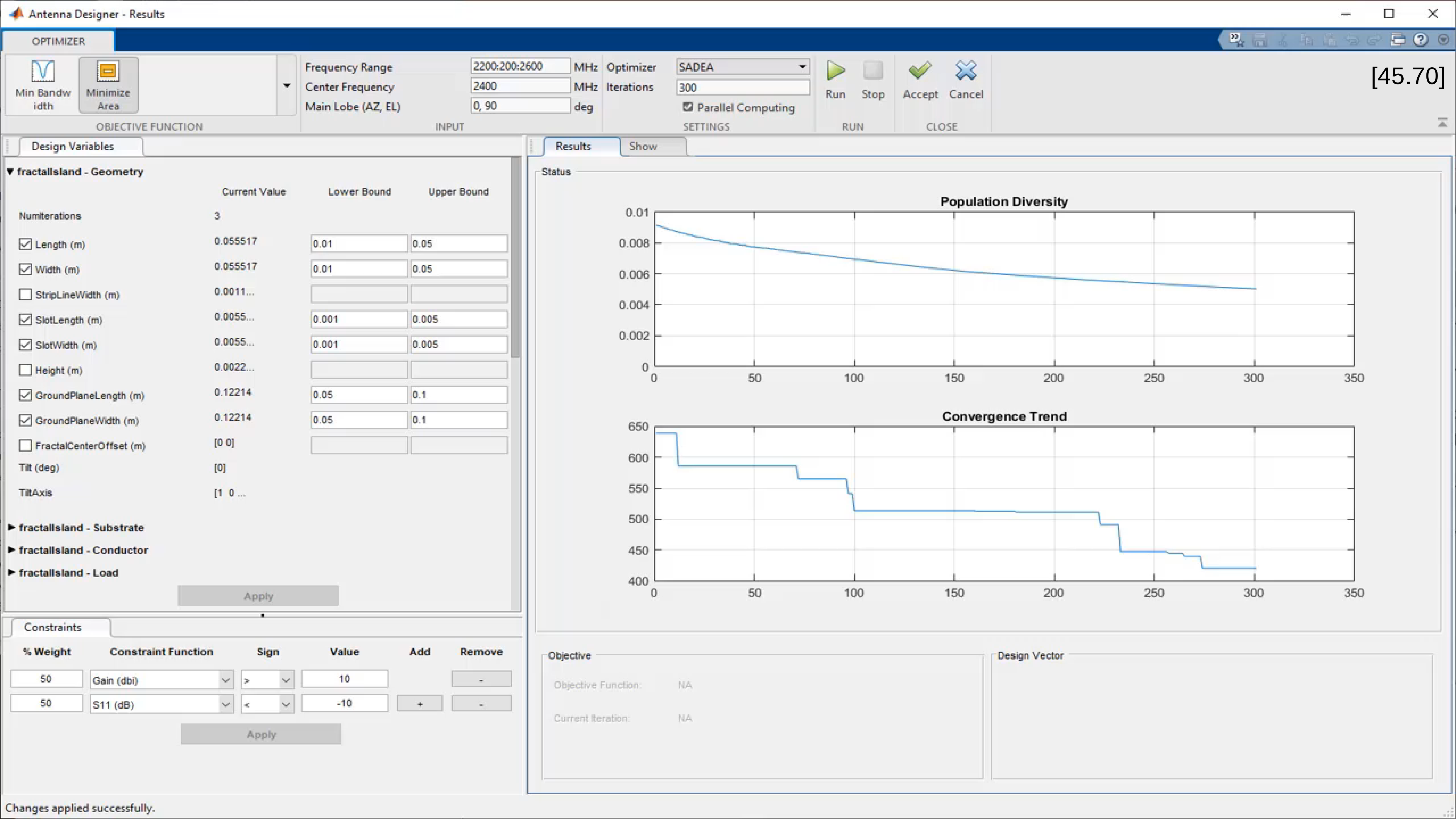
Array pattern synthesis



Antenna design
-. Surrogate Optimizer

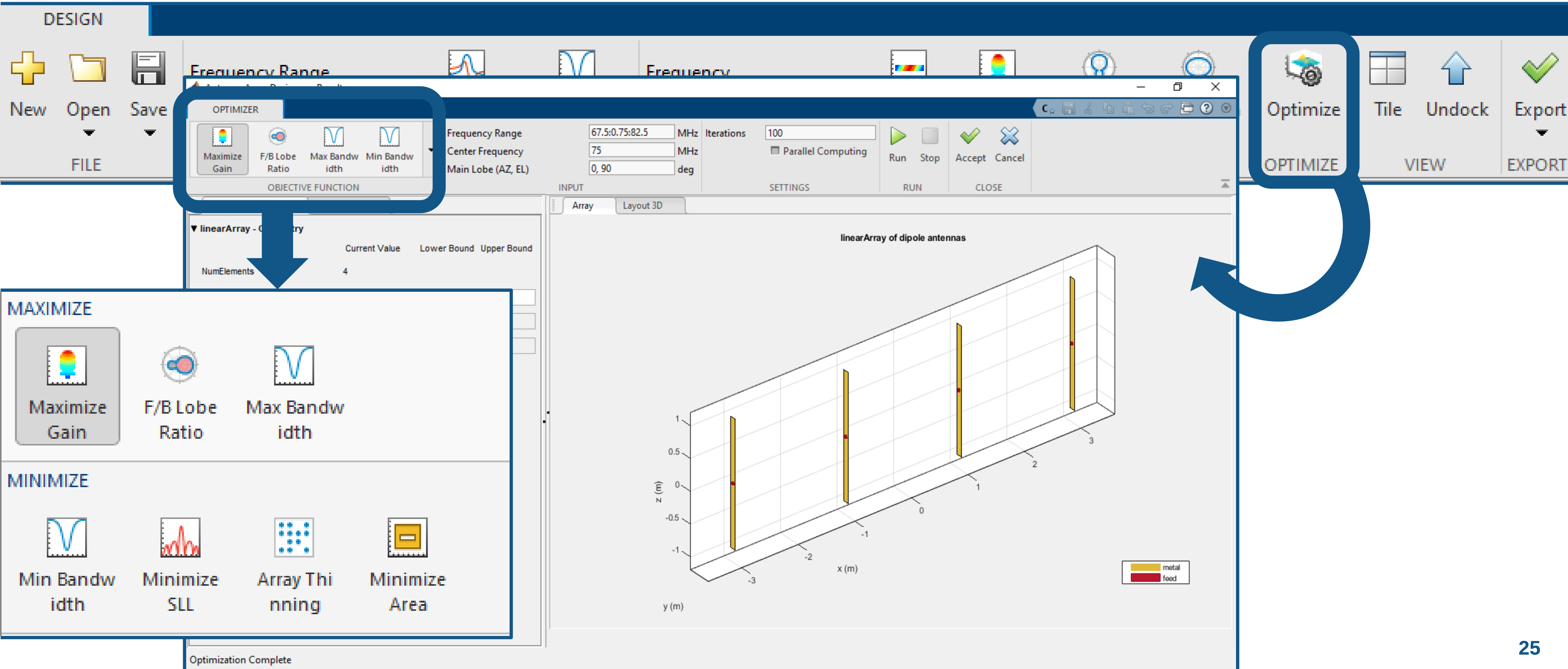


Antenna Designer - Impedance
DESIGN
New
Open
Save
FILE
Center Frequency
2400
MHz
Settings
Frequency Range
2200:10:2600
MHz
INPUT
Impedance
S Parameter
VECTOR FREQUENCY ANALYSIS
Current
3D Pattern
AZ Pattern
EL Pattern
SCALAR FREQUENCY ANALYSIS
Optimize
OPTIMIZE
Tile
Undock
VIEW
Export
EXPORT
[2:44]
Properties
fractalIsland
NumIterations 3
Length (m) 0.055517
Width (m) 0.055517
StripLineWidth (m) 0.0011103
SlotLength (m) 0.0055517
SlotWidth (m) 0.0055517
Height (m) 0.0022207
GroundPlaneLength (m) 0.12214
GroundPlaneWidth (m) 0.12214
FractalCenterOffset (m) [0 0]
Tilt (deg) 0
TiltAxis [1 0 0]
fractalIsland - Substrate - dielectric
fractalIsland - Conductor - metal
fractalIsland - Load - lumpedElement
Apply
Show
fractalIsland antenna element
z (mm)
y (mm)
x (mm)
PEC
feed
Pattern
z
x
y
az
el
dBi
0
-5
-10
-15
-20
Show Ante
Impedance
Impedance
Impedance (ohms)
Frequency (GHz)
Resistance
Reactance
Sparameter
Magnitude (dB)
Frequency (GHz)
dB(S11)
Finished adding.


Antenna Designer - Results
OPTIMIZER
Min Bandwidth
Minimize Area
OBJECTIVE FUNCTION
Frequency Range 2200:200:2600 MHz
Center Frequency 2400 MHz
Main Lobe (AZ, EL) 0, 90 deg
INPUT
Optimizer SADEA
Iterations 300
Parallel Computing
SETTINGS
Run
Stop
RUN
Accept
Cancel
CLOSE
[45.70]
Design Variables
fractalIsland - Geometry
Current Value
Lower Bound
Upper Bound
NumIterations 3
Length (m) 0.055517 0.01 0.05
Width (m) 0.055517 0.01 0.05
StripLineWidth (m) 0.0011...
SlotLength (m) 0.0055... 0.001 0.005
SlotWidth (m) 0.0055... 0.001 0.005
Height (m) 0.0022...
GroundPlaneLength (m) 0.12214 0.05 0.1
GroundPlaneWidth (m) 0.12214 0.05 0.1
FractalCenterOffset (m) [0 0]
Tilt (deg) [0]
TiltAxis [1 0 ...
fractalIsland - Substrate
fractalIsland - Conductor
fractalIsland - Load
Apply
Constraints
% Weight
Constraint Function
Sign
Value
Add
Remove
50 Gain (dbi) > 10 -
50 S11 (dB) < -10 + -
Apply
Results
Show
Status
Population Diversity
0.01
0.008
0.006
0.004
0.002
0
0 50 100 150 200 250 300 350
Convergence Trend
650
600
550
500
450
400
0 50 100 150 200 250 300 350
Objective
Objective Function: NA
Current Iteration: NA
Design Vector
Changes applied successfully.

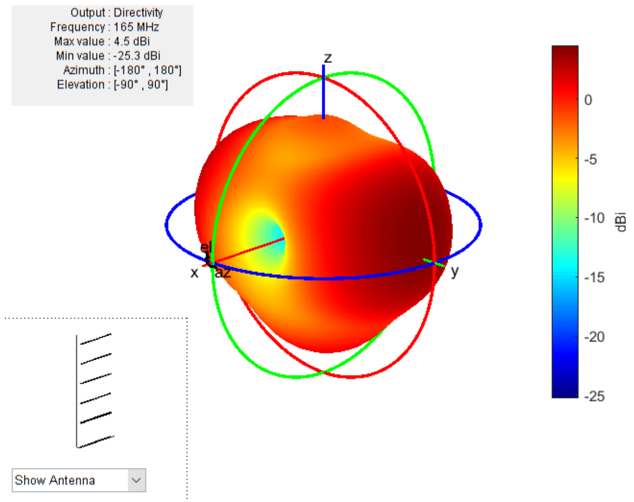
Also Optimize Arrays and PCB Antennas

Antenna Array Designer | Antenna Designer | PCB Antenna Designer

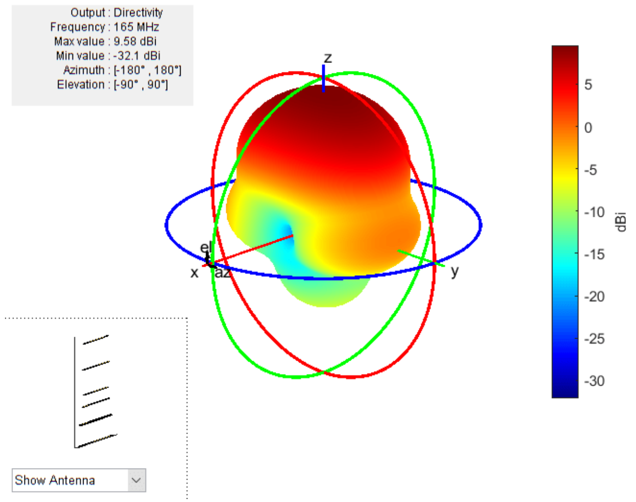


Define Customized Optimization Workflows in MATLAB

- Define the objective and constraint function using MATLAB functions
- Use global or local optimization methods applied to antenna design
- Use parallel computing to speed up computation



Poor directivity



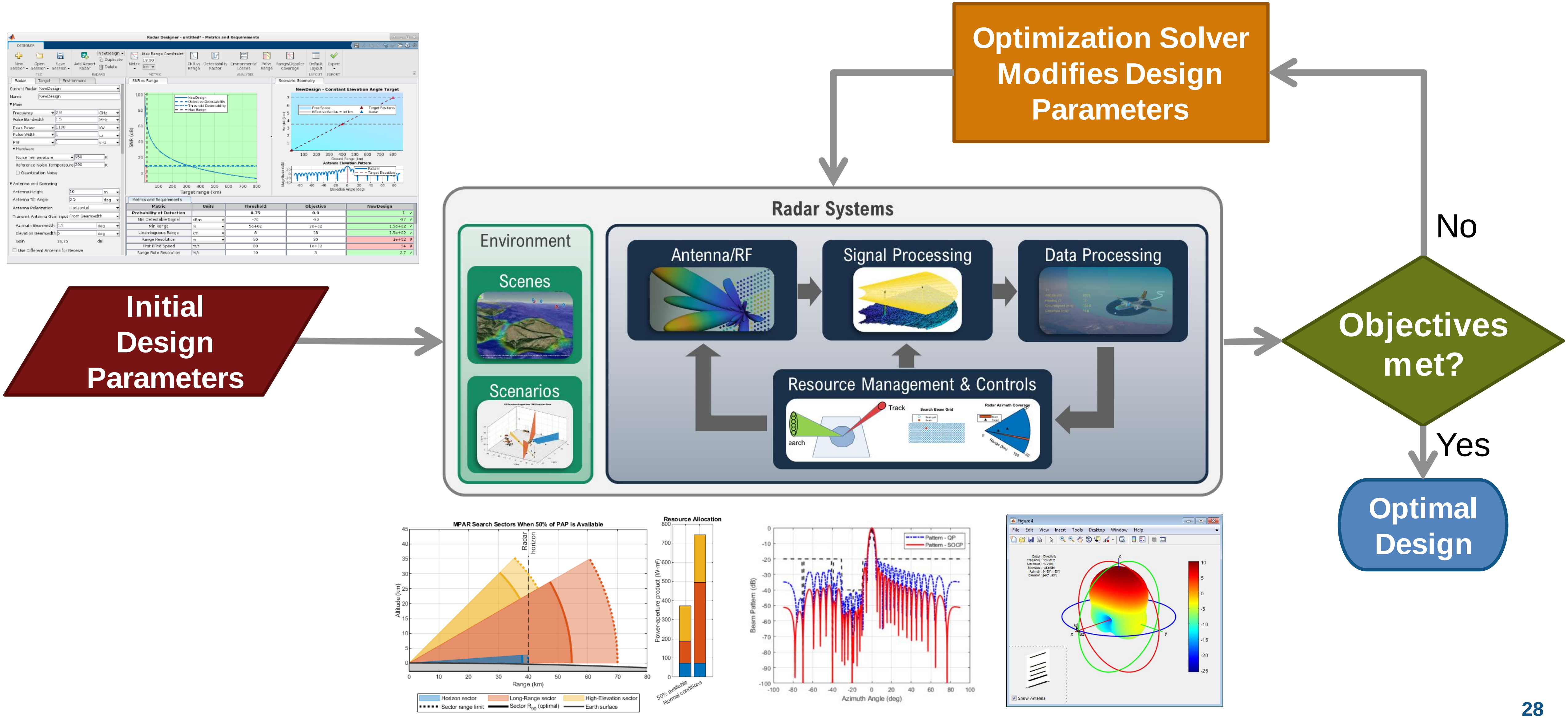
Optimized pattern

```
% Optimizer options
optimizerparams = optimoptions(@patternsearch);
optimizerparams.UseCompletePoll = true;
optimizerparams.PlotFcns = @psplotbestf;
optimizerparams.UseParallel = true;
optimizerparams.Cache = 'on';
optimizerparams.MaxIter = 100;
optimizerparams.FunctionTolerance = 1e-2;

% Antenna design parameters
designparams.Antenna = yagidesign;
designparams.Bounds = parameterBounds;

% Analysis parameters
analysisparams.CenterFrequency = fc;
analysisparams.Bandwidth = BW;
analysisparams.ReferenceImpedance = Z0;
analysisparams.MainLobeDirection = ang(:,1);
analysisparams.BackLobeDirection = ang(:,2);

% Set constraints
constraints.S11min = -10;
constraints.Gmin = 10.5;
constraints.Gdeviation = 0.1;
constraints.FBmin = 15;
constraints.Penalty = 50;
optimdesign = optimizeAntennaDirect(designparams,analysisparams,constraints,optimizerparams);
```

Example: Design Optimization of Six-Element Yagi-Uda Antenna

Summary and Resources

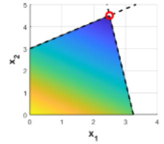
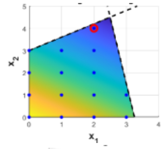
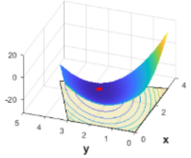
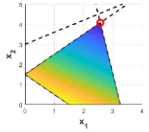
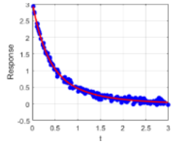
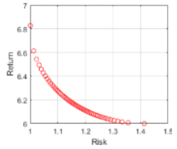
Apply design optimization to key radar and antenna design challenges



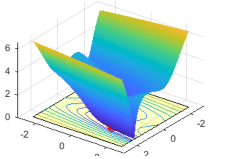
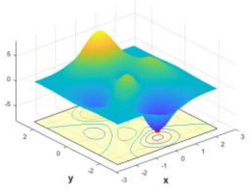
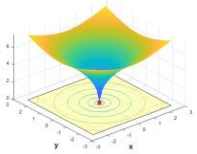
Solving: Problem Types and Algorithms

Optimization Toolbox

Global Optimization Toolbox

- Linear programming
  - Simplex and interior-point
- Mixed-integer linear programming
  - Branch-and-cut
- Quadratic programming
  - Interior-point, active-set, trust-region
- Second-order cone programming
  - Interior-point
- Least-squares and nonlinear equations
  - Interior-point, trust-region, Levenberg-Marquardt
- Multiobjective optimization
  - Weighted and goal-attainment
  - *Genetic algorithm*
  - *Paretosearch*

- Nonlinear optimization
  - Nelder-Mead simplex
  - Interior-point, SQP, trust-region
  - *MultiStart & GlobalSearch*
  - *Pattern (direct) search*
  - *Genetic algorithm*
  - *Simulated annealing*
  - *Particle swarm*
  - *Surrogate optimization*
- Mixed-integer nonlinear optimization
  - *Genetic algorithm*
  - *Surrogate optimization*

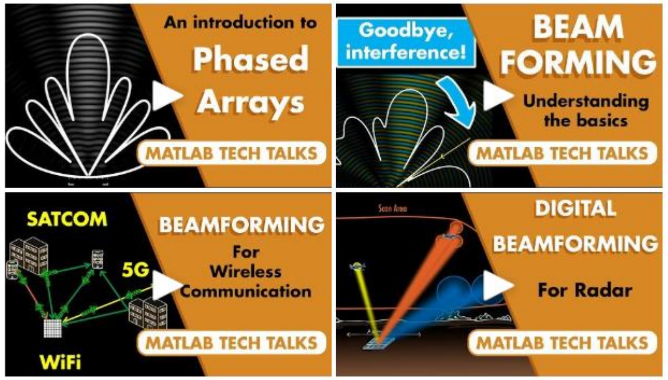
Optimization Decision Table

Global Solver Characteristics

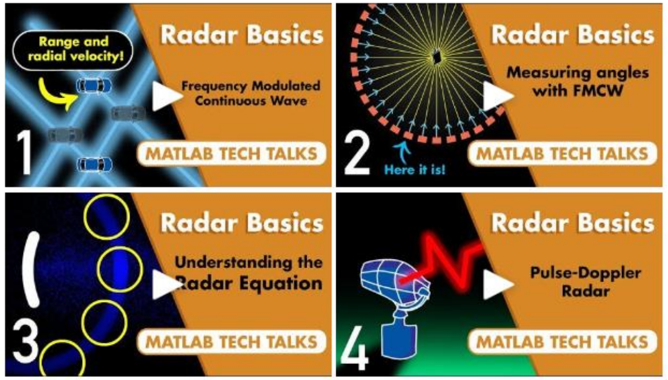
Learn more about designing and optimizing radar and antenna systems in MATLAB

Videos

Phased Array



Radar



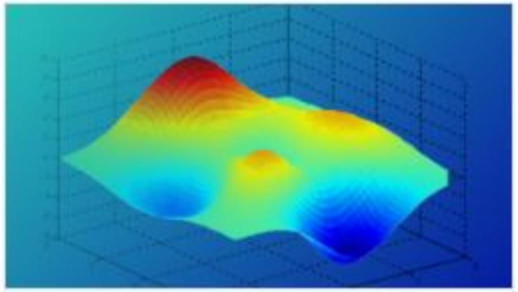
Training

Optimization Onramp

100%

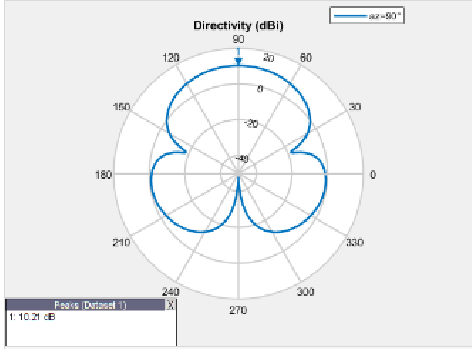
5 modules | 1 hour | Languages

Modeling Radar Systems with MATLAB

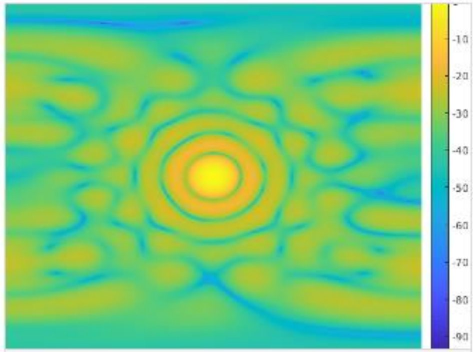


Optimization Techniques in MATLAB

Examples



Surrogate Optimization of Six-Element Yagi-Uda Antenna



Array Pattern Synthesis Part III: Deep Learning

MATLAB EXPO

Thank you

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