



# Antenna Synthesis for IoT and Wireless Applications

International IoT Seminar

Building Next Generation IoT & Wireless Devices and Solutions

**August 24, 2017**

# Outline

- Introduction to Antenna Synthesis
- AntSyn System Description
- Examples

# Antenna Design Challenges

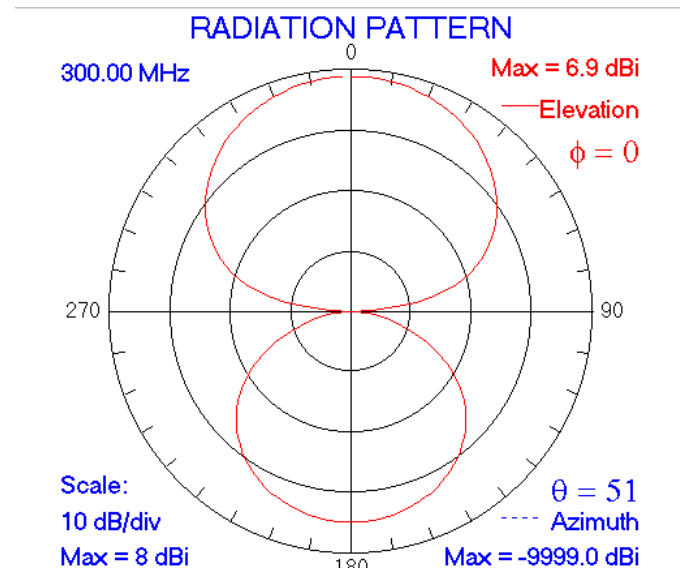
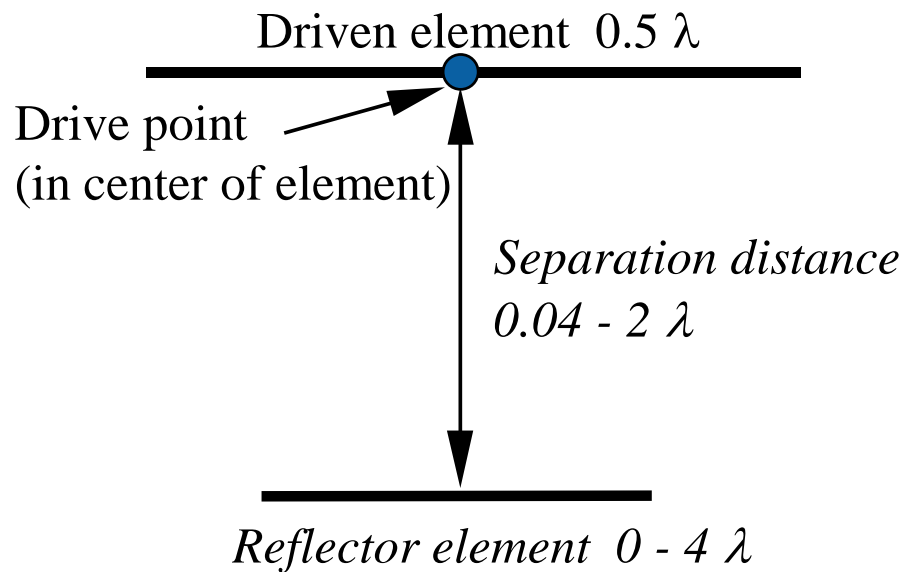
- Challenging size, cost & performance goals
- Shortage of experienced designers
- Time and budget are under pressure
- Productivity difficult when wrestling with physics

# Difficult to Design?

- Enormous range of possible solutions for even the simplest antennas
- Limitless number of antenna shapes to choose from
- Optimum design is often non-intuitive and difficult to find
- EM simulation is very expensive for “blind” optimization

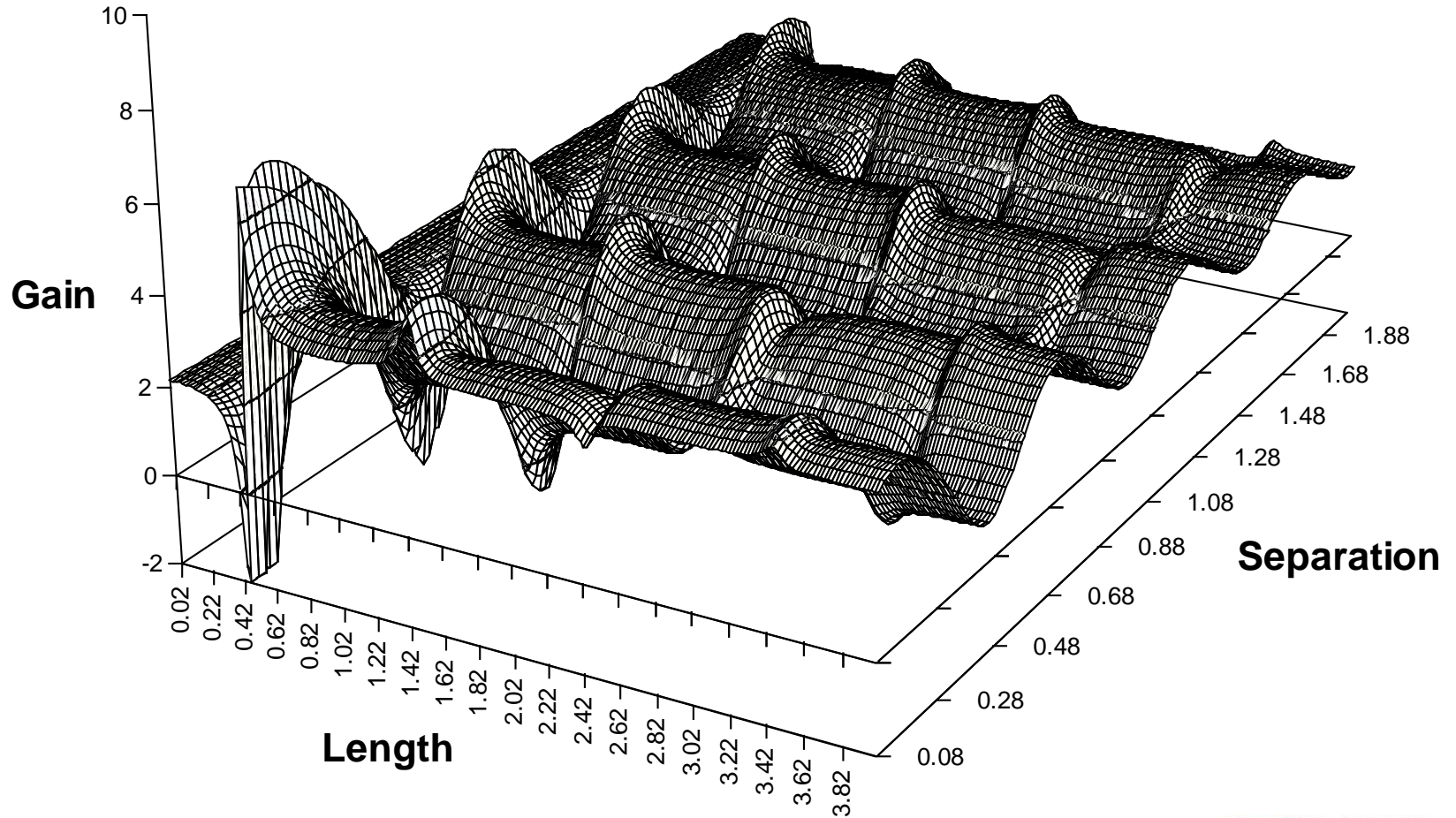
# How Difficult is Antenna Design?

## A Simple Wire Antenna Example



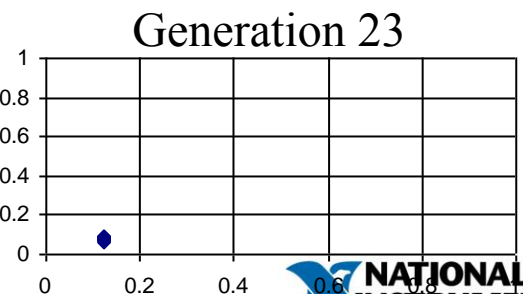
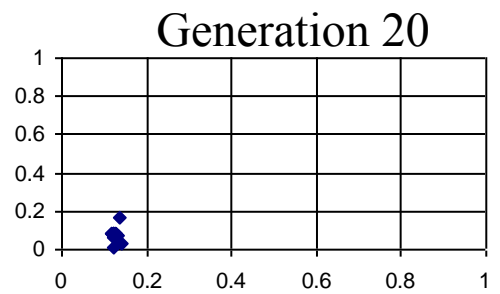
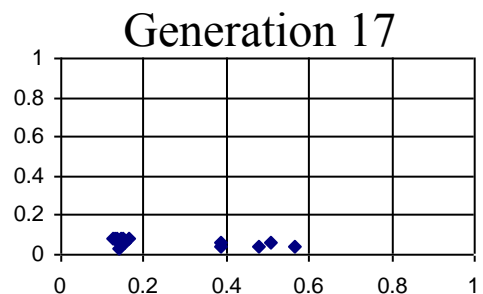
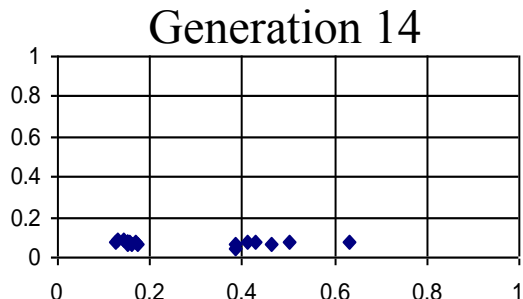
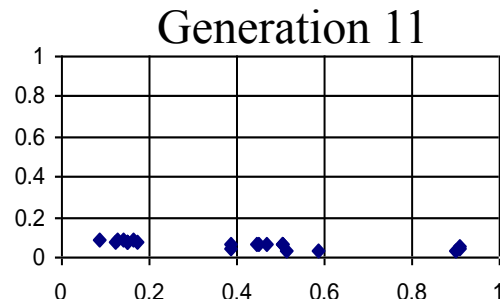
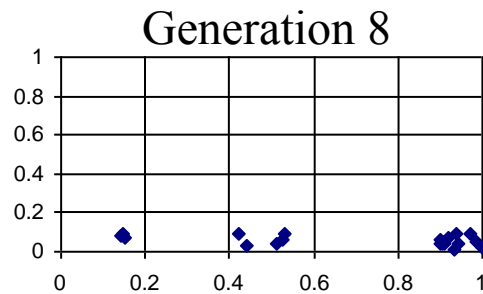
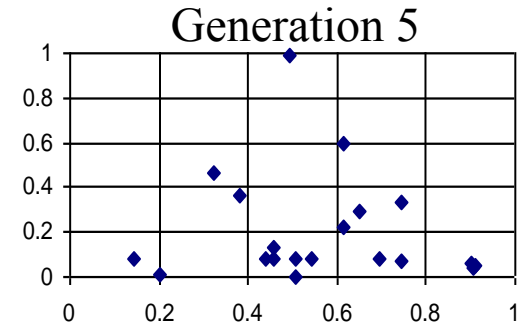
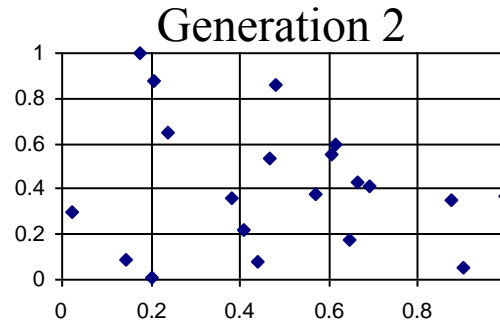
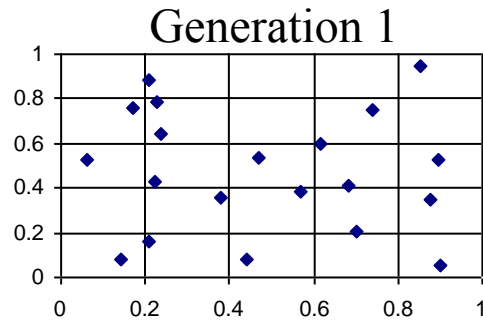
Linden, 1997

# How Difficult is Antenna Design?



# Genetic Algorithm Optimization

A Genetic Algorithm can focus in on most useful areas of search space





# What is Antenna Synthesis?

- Imagine a system that automates the antenna design process for both Systems/RF Engineers and Antenna Experts
- Requires:
  - Expert system for antenna selection, fitness scoring, representation, etc.
  - Antenna optimization engine



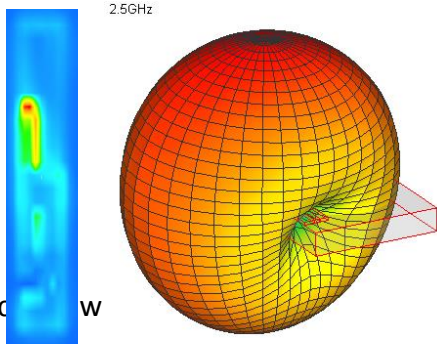
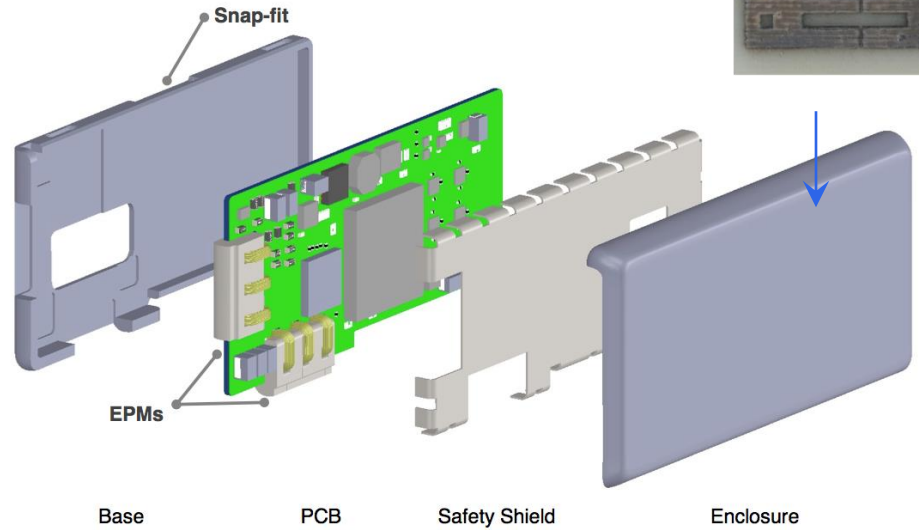
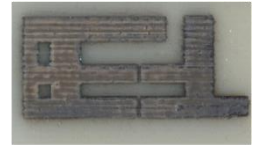
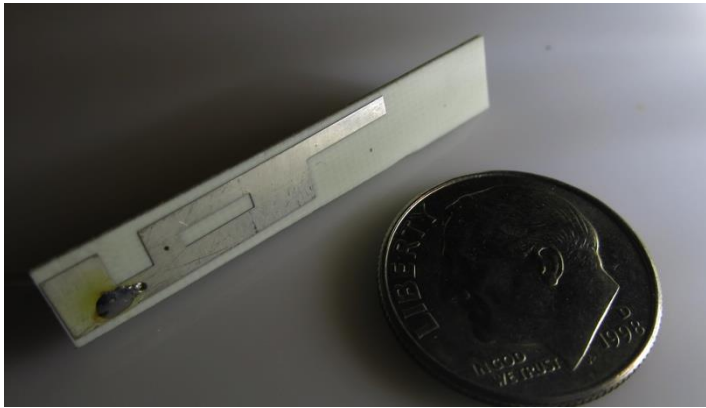
# How It Works

- Antenna performance requirements are defined by the user - not the model
- Advanced algorithm performs smart optimization, eliminating weaker solutions with each iteration
- EM solver used to provide accurate evaluation of candidate antennas

Design by Requirements: What you want is what you get



# Google's Project Ara Smartphone



# Antenna Synthesis Benefits

- All levels of engineer can develop optimum antennas
  - Senior engineers rapidly gain more insight
  - Less experienced designers can produce excellent designs
- Explore more design space with smart optimization while reducing local EM simulation loading
- Scalable with compute power
- Increases reliability of finding a solution quickly
  - Reduces risk, rework, and failed projects
- Easy to use and intuitive

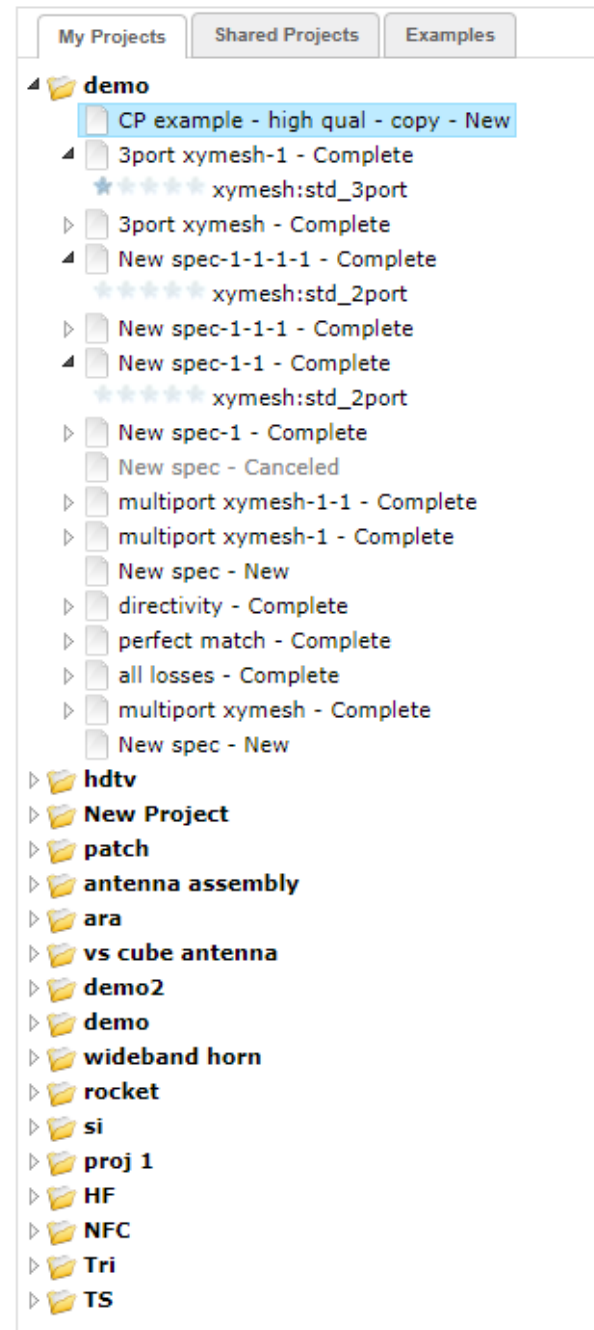
# Spec Sheet Overview

- Spec sheets are used to collect antenna requirements
  - Band
    - Pattern
    - Input impedance and reflection
  - Geometry
    - Bounding box/cylinder
    - Separate ground specifications
    - Infinite ground
    - Mast/standoff
  - Antenna Library
  - Advanced: arrays, matching, etc.
  - Run controls

The screenshot displays the AntSyn: Antenna Synthesis Module software interface. The main window is titled "New Sheet (Antenna Synthesis)" and shows a "Frequency" panel with a plot of gain versus frequency. The plot shows a peak gain of approximately 10 dB at 100 MHz. The "Band" panel is highlighted in blue, showing a frequency range of 100 to 1000 MHz. The "Geometry" panel is highlighted in green, showing a 3D model of the antenna and its geometry. The "Antenna Library" panel is highlighted in orange, showing a list of antenna types. The "Antenna Arrays, Matching, Multiport" panel is highlighted in orange, showing a list of antenna arrays. The "Run Controls" panel is highlighted in red, showing a "Run" button and a "Run Controls" section.

# The AntSyn Spec Sheet

- Spec sheets are grouped into project folders



# Bands, Frequencies, Input Impedance

SpecSheet (demo>CP example - high qual - copy) Text View

+ Band 1 ×

### Frequency

Band Start   Stop  GHz  Num Freqs   [Learn more](#) ▼

### Input

:1 Connected to Load Impedance: Z real  Ohms Z imag  Ohms *Note: Antenna will be optimized to the conjugate of the load impedance.* [Learn more](#) ▼

Elevation: 0 to +180  Azimuth: -180 to +180

# Pattern

Gain Pattern
[Learn more](#)

Elevation: 0 to +180

Azimuth: -180 to +180

Gain vs Elevation Angle  
 Gain vs Azimuth Angle  
 Gain and Beamwidth (Elevation)  
 Gain and Beamwidth (Azimuth)

At this elevation:

deg	≥	≤	Gain should be: dBi
<input type="checkbox"/> 0	<input checked="" type="radio"/>	<input type="radio"/>	<input type="text" value="5"/> <input type="button" value="OK"/>
<input type="checkbox"/> 45	<input type="radio"/>	<input type="radio"/>	<input type="text" value="3"/> <input type="button" value="OK"/>
<input type="checkbox"/> 90	<input type="radio"/>	<input type="radio"/>	<input type="text" value="0"/> <input type="button" value="OK"/>
<input type="checkbox"/> 135	<input type="radio"/>	<input type="radio"/>	<input type="text" value="-10"/> <input type="button" value="OK"/>
<input type="checkbox"/> 180	<input type="radio"/>	<input type="radio"/>	<input type="text" value="-10"/> <input type="button" value="OK"/>
<input type="checkbox"/> <input type="text" value=""/>	<input type="radio"/>	<input type="radio"/>	<input type="text" value=""/> <input type="button" value="OK"/>
<input type="checkbox"/> <input type="text" value=""/>	<input type="radio"/>	<input type="radio"/>	<input type="text" value=""/> <input type="button" value="OK"/>

**Coverage in Azimuth**

Rotationally symmetric around the Z axis

This spec covers  to  deg in **Azimuth**

(Allowed range: -180 to +180)

Includes all losses  
 Includes dielectric loss (perfect match)  
 No loss (directivity)

**Pattern Efficiency: 100.4% (0.016 dB)**  
**Realizability: Not physically possible**

**3D gain angle visualization**  
 Gain: ■ greater ■ equal ■ less

Polarization:

[Learn more](#)

Sidelobe level vs max gain:  dB angles covered

Backlobe level vs max gain:  dB angles covered

Axial Ratio  dB angles covered

Cross-polarization  dB angles covered

Max coupling to active ports: (for arrays & phased ports)  dB

Max coupling to inactive ports: (multi-port antennas only)  dB

Planar Array Scan Angle: Elevation  Azimuth

Dielectric properties for this band:
 

- Dielectric constant  Loss tangent
- Dielectric constant  Loss tangent

Overall Efficiency  dB

[Learn more](#)



# Geometry

## Geometry and Environment

[Learn more](#) ▼

Antenna axis points toward  X  Z

Dimension units:

Constrain Antenna Geometry  
(Applies to full antenna unless separate constraints are applied to Built-in Ground)

Max Shape:  X  Y  Z  cm

Apply Separate Constraints to Built-in Ground

Built-in Ground Size Max

Shape:  X  Y  Z  cm

Built-in Ground Size Min

Shape:  X  Y  Z  cm [auto](#)

Location on Ground (if applicable):

Ground Type (advanced):

Infinite Ground

Mast/Standoff Min  Max  cm

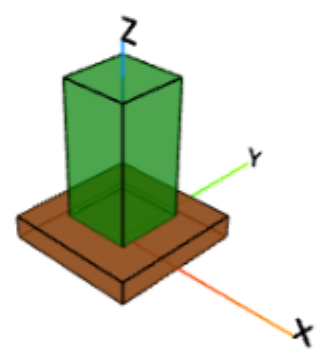
Use dielectric, if applicable

Dielectric constant:  Loss tangent:

Only design antennas that use a dielectric substrate

Geometry Constraints

Antenna  Built-in Ground  Infinite Ground



View Max Built-in Ground Size  View Min Built-in Ground Size

View Max Mast/Standoff  View Min Mast/Standoff




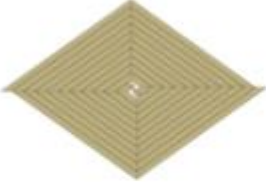

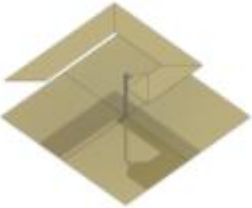
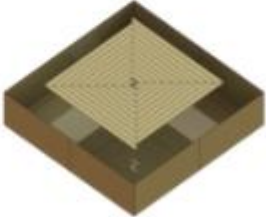

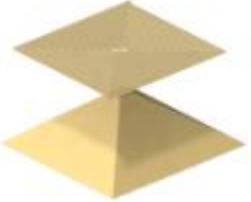

# Antenna Library

**Antenna Library** ▲

Note: All antenna library images show the antenna axis oriented toward the Z axis. [Learn more](#) ▼

View by Type  View All  View Best for Spec

3d enviro horn multiport patch planar wire Select all planar antennas

 <input type="checkbox"/> edgeslot.std Parameters	 <input type="checkbox"/> lpa.genetic Parameters	 <input type="checkbox"/> lpa.std Parameters	 <input type="checkbox"/> spiral:archsquarestr Parameters	 <input type="checkbox"/> spiral:archsquarestr Parameters
 <input type="checkbox"/> spiral:archsquarestr Parameters	 <input type="checkbox"/> spiral:archsquarestr Parameters	 <input type="checkbox"/> spiral:archsquarestr Parameters	 <input type="checkbox"/> spiral:archsquarestr Parameters	 <input type="checkbox"/> spiral:archsquarewir Parameters

# Antenna Library

## • 189 Antenna Styles and Growing

- Wideband 3d Dipoles
- Horns (circular, square)
- Multi-port antennas (e.g., crossed dipoles)
- Patch antennas
- Edge-slot antenna
- LPAs (wire and planar)
- Wire collinear-dipole arrays
- Crooked-wire genetic antennas (CWGAs)
- Helices & quadrifilar helices
- Wire mesh antennas
- Branching or multi-wire CWGAs (monopoles & quadrifilars)
- Quad antennas
- Yagi antennas
- Planar mesh antennas (e.g., PIFA-like internal antennas)
- Vivaldi-style antipodal antenna
- UWB planar dipoles and monopoles
- Square spirals (wire and planar)



# Advanced: multi-port, matching, arrays

**Multi-port Band Assignment ▲**

Multi-port antenna(s) must be selected to enable this feature [Learn more ▼](#)

Antenna	Port#	Band 1
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**Matching Network ▲**

Use matching network     Match each band separately [Learn more ▼](#)

# Elements  min  max

L  min  max nH    C  min  max pF

**Arrays ▲**

Use Arrays [Learn more ▼](#)

Type  ▼    Element Uniformity  ▼

Element Spacing ⓘ    # of Elements    min    max

X    mm ▼

Y

**Advanced Controls ▼**

**Run**

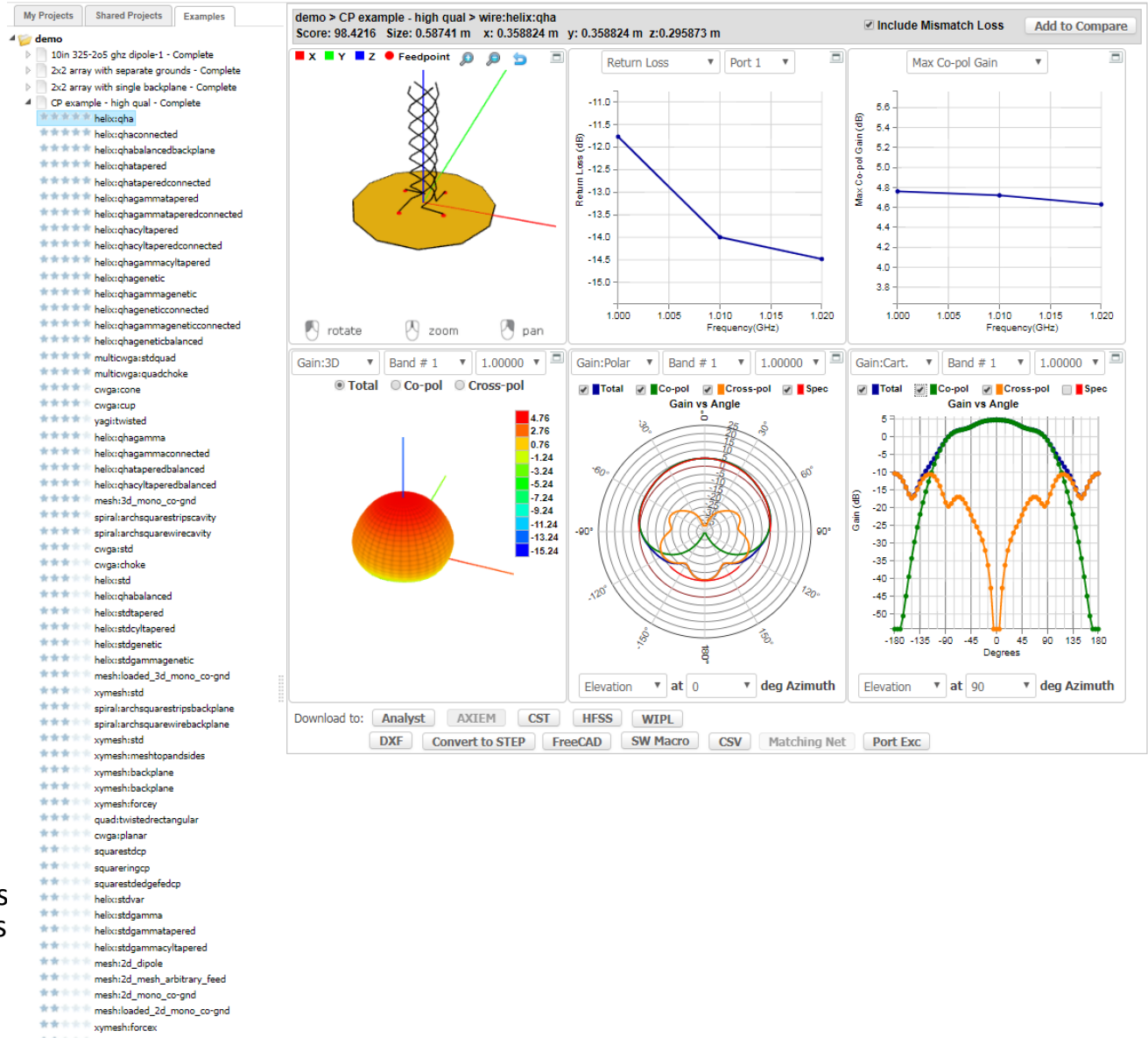
Send Email when complete     Generate full report for intermediate results ⓘ [Learn more ▼](#)

Run Quality:    Low    Medium    High

            ⓘ

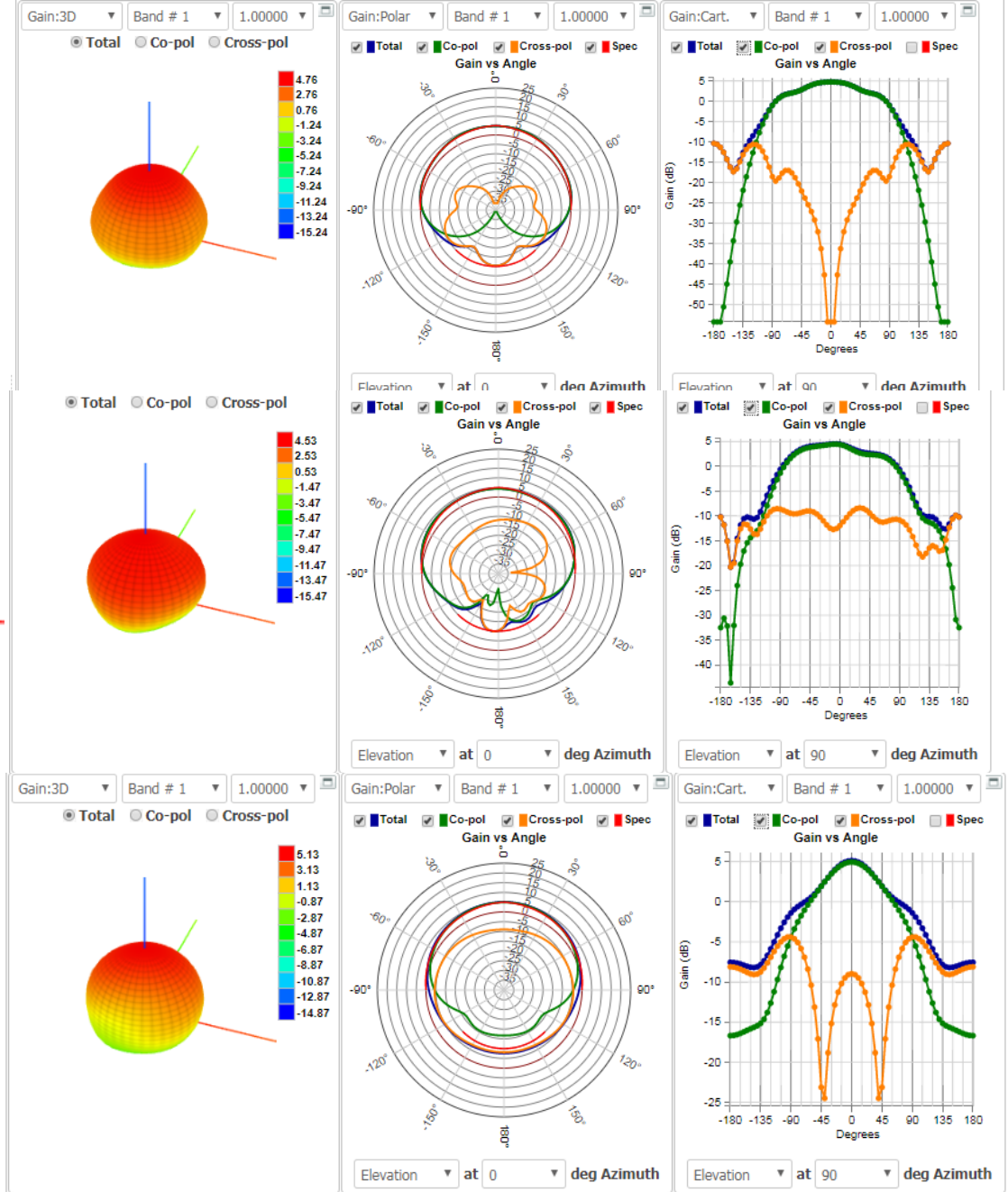
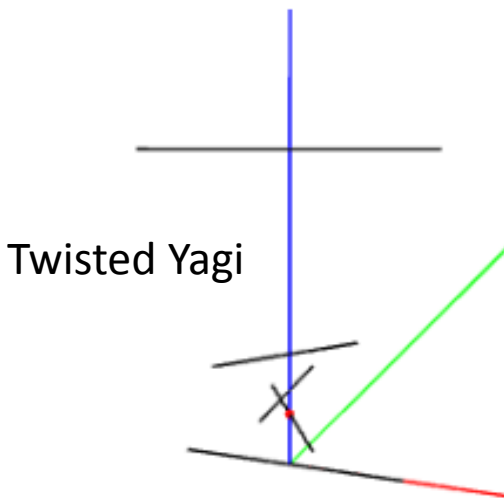
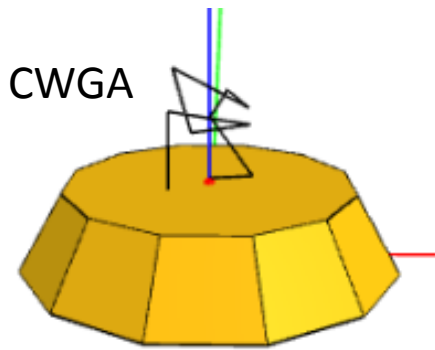
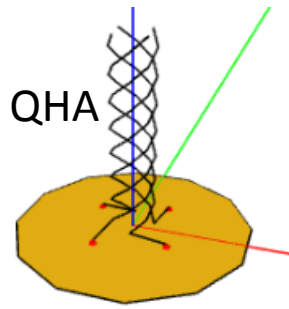
# Results

- When spec sheet is run, AntSyn returns one or more optimized antenna designs
- Star ratings give qualitative measure of performance vs specs for quick overview of performance
- Results are viewed using a customizable dashboard allows rapid evaluation
  - 3D rough model
  - Input performance vs freq in several formats, including:
    - VSWR
    - Return loss (dB)
    - Z real, Z imaginary
    - Smith chart
  - Max gain vs freq
  - Pattern cuts
    - 3 panels, user settable
    - Total, Co-pol, Cross-pol in any combination
  - Qualitative star-rating helps to identify good performers quickly
- Download to many simulator and CAD formats available



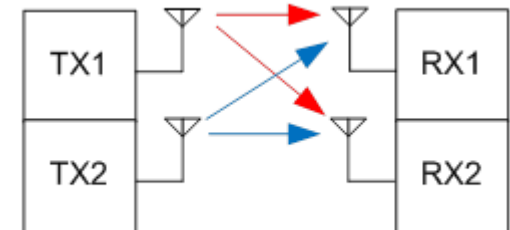
# Results

- These three antennas came from 1 run, along with 68 others



# IoT Example

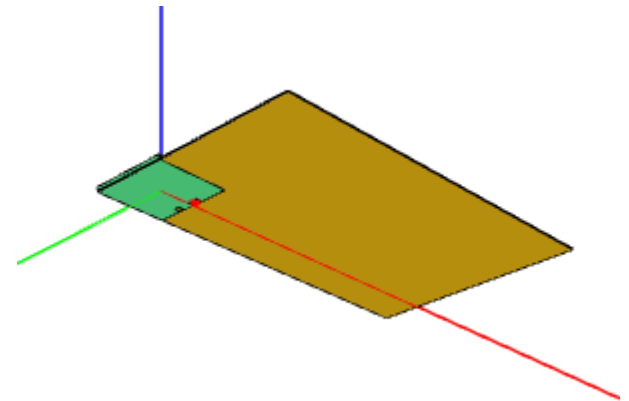
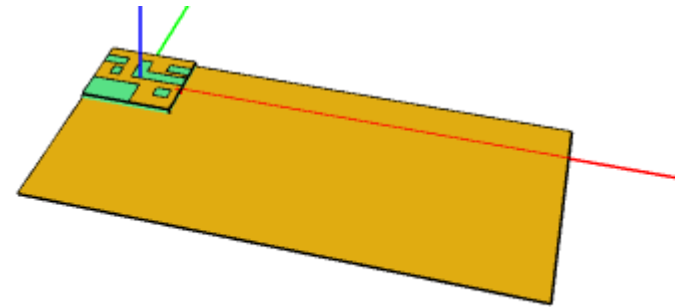
- Dual-band WiFi
  - 2.4 and 5 GHz bands
- IoT device package
  - Compact, planar geometry
  - Approx. size of standard business card, 90mm x 50mm
  - Antenna integrated with electronics
  - Antennas placed along long edge
- Multiple-input Multiple-output (MIMO)
  - 2+ ports/antennas for transmit and receive on each device
  - Needs isolation between ports to create decoupled channels



MIMO = MULTIPLE INPUT, MULTIPLE OUTPUT

# Iteration 1: Single-port antenna on dielectric

- Dielectric
  - Tends to constrain fields for better isolation
  - Allows more miniaturization
  - Usually decreases efficiency
- Synthesize single-port antenna on dielectric, add 2 to a single substrate & calculate coupling
- Generic mesh antenna type used
  - PIFA-style, with short and feed
  - Ground is cut back underneath to give radiator access to free space
  - 50-ohm antenna: no matching needed





# Single-port Antenna Specification

- VSWR & efficiency
- “planar:xymesh” antenna, 30 x 10 mm x 1.5mm, corner of ground

Band 1 Band 2

Frequency

Band Start 2.4 GHz Stop 2.5 GHz WiFi 2.4G Num Freqs Auto Auto

Input

VSWR 2 :1 Connected to Load Impedance: Z real 50 Ohms Z imag 0 Ohms

Band 1 Band 2

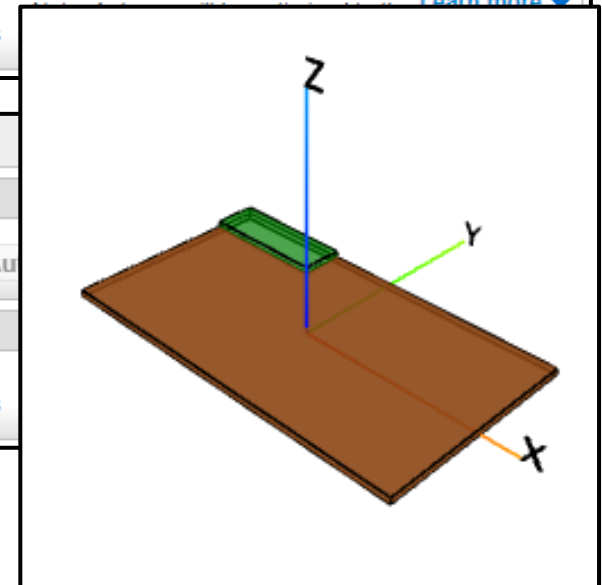
Frequency

Band Start 5.2 GHz Stop 5.9 GHz WiFi 5G Num Freqs Auto Au

Input

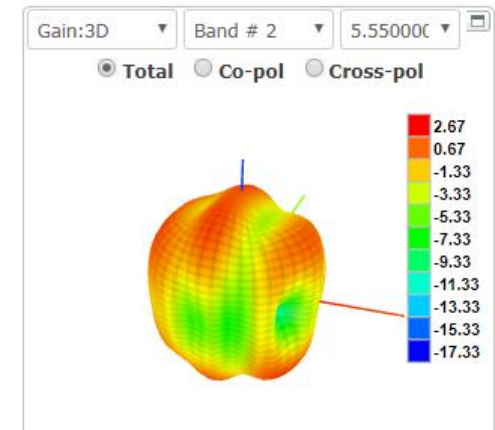
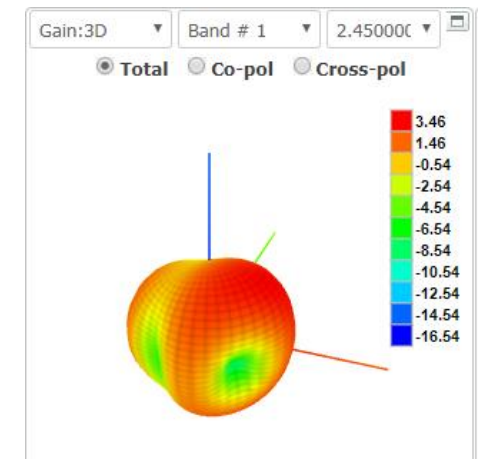
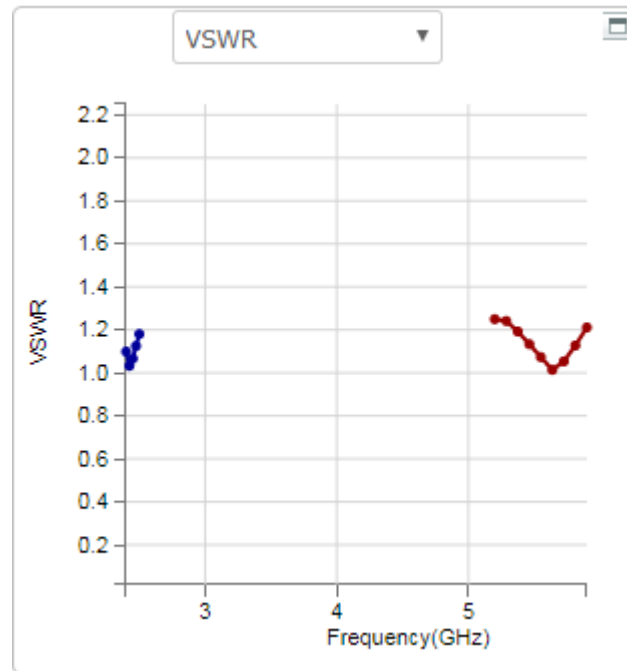
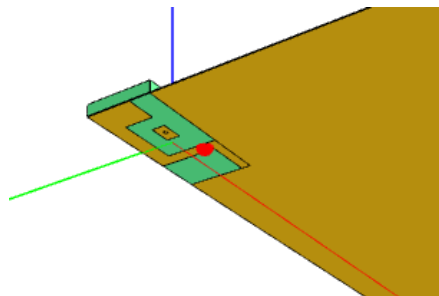
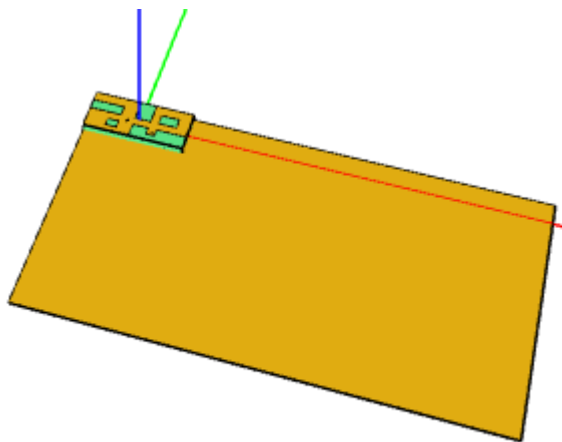
VSWR 2 :1 Connected to Load Impedance: Z real 50 Ohms Z imag 0 Ohms

Overall Efficiency -2 dB



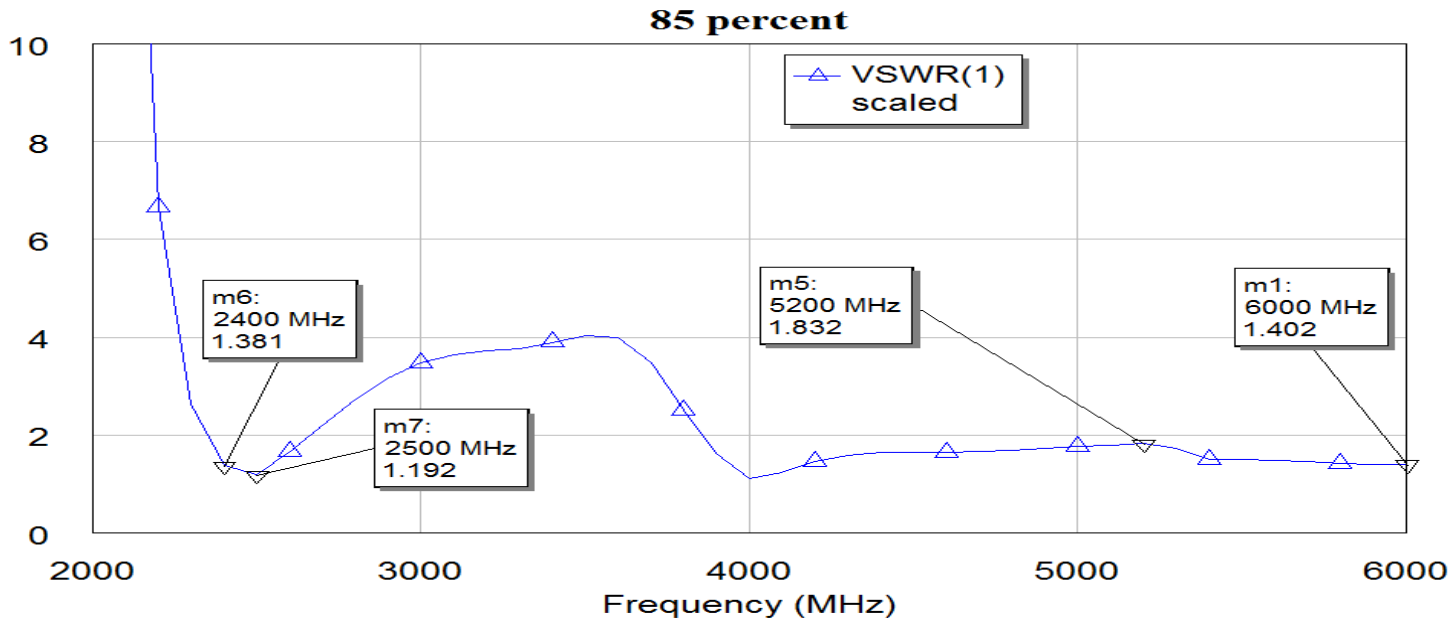
# Single-port Antenna Results

- Overall envelope: 90 x 50 mm, 1.5mm thick
- Antenna is 20 X 8.5 mm, 1.5 mm thick, efficiency: -0.2 dB



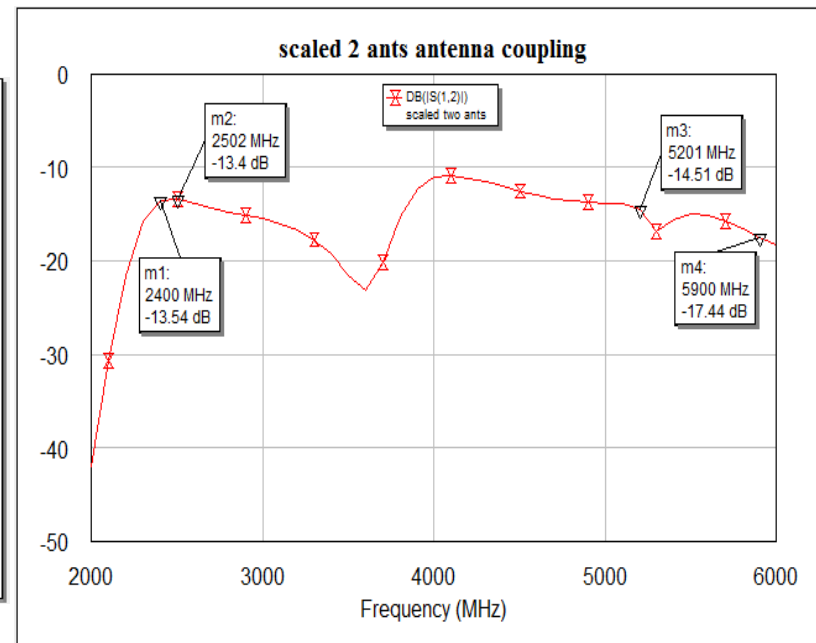
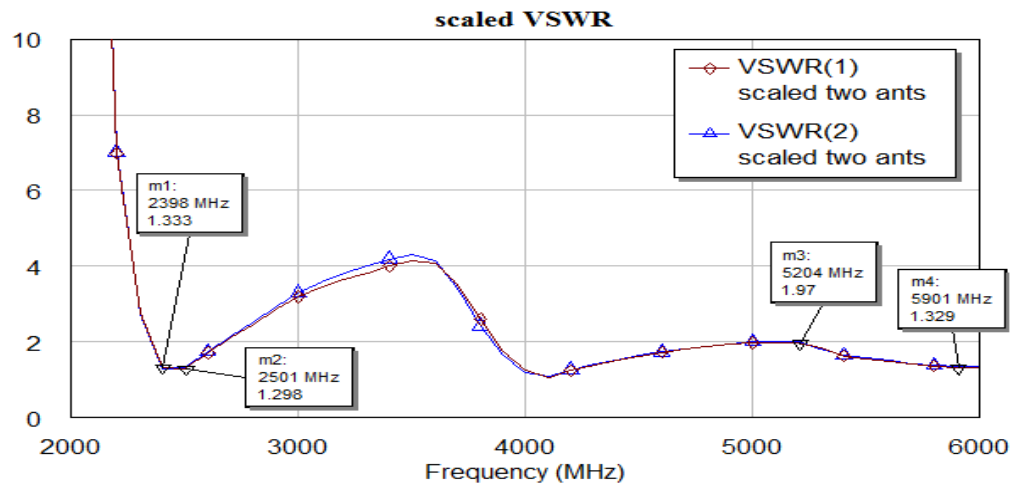
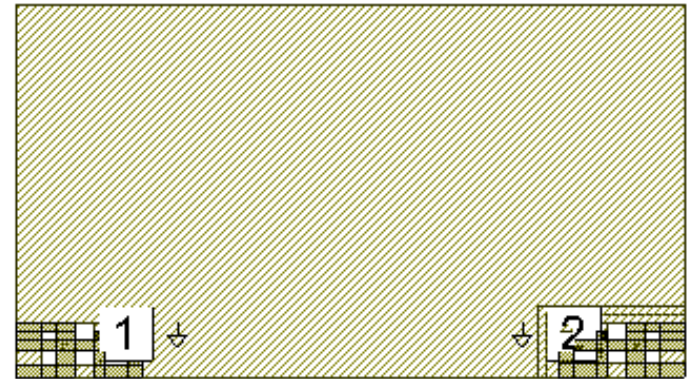
# Single-port Antenna Analysis

- Imported into Microwave Office, resimulated in AXIEM (2.5D EM simulator)
  - Infinite sheet of dielectric vs AntSyn's finite sheet,
  - Reduced the antenna resonant frequencies
- Antenna re-tuned
  - Scaled 15% smaller, 17 x 7.2mm
  - Thinner substrate (0.9 mm)



# Single-port Antenna Analysis

- Two of these antennas on same long edge have good VSWR and coupling level
- This antenna does not work in center of the edge

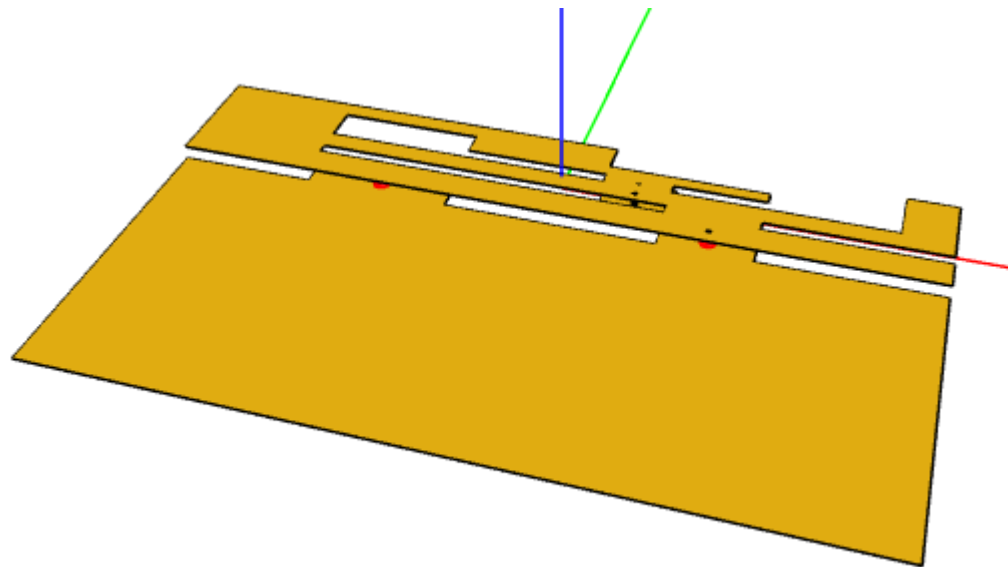


# Single-port Antenna Analysis

- This approach worked for 2 antennas
- New design needed for a third port in center of edge
- Would rather optimize a complete design directly, versus hope it works once multiple antennas are integrated

## Iteration 2: 2-port antenna, no dielectric

- Direct design of 2-port antenna before attempting 3-port design
- No dielectric: increases bandwidth, efficiency, packaging usage, simulation speed
- 50-ohm ports



# 2-port Antenna: Specification

- AntSyn spec: multiport antenna used, so more “bands” used
  - Band 1: 2.4GHz WiFi, port 1 active
  - Band 2: 2.4 GHz WiFi, port 2 active
  - Band 3: 5 GHz WiFi, port 1 active
  - Band 4: 5 GHz WiFi, port 2 active

The screenshot displays the AntSyn software interface for a multi-port antenna. The main window is titled "SpecSheet (xymesh demo>dual band mimo array 2port 3 shorts)" and includes a "Text View" button. Below the title bar, there are four tabs labeled "Band 1", "Band 2", "Band 3", and "Band 4". The "Frequency" section shows "Band Start" at 2.4 GHz and "Stop" at 2.5 GHz, with a "WiFi 2.4G" band type and "Num Freqs" set to "Auto". The "Input" section shows "VSWR" set to 2 and "Connected to Load". A "Max coupling to inactive ports: (multi-port antennas only)" setting is shown as -15 dB. A "Multi-port Band Assignment" dialog box is open, displaying a table with the following data:

Antenna	Port#	Band 1	Band 2	Band 3	Band 4
multiport:xymesh:coplanarmonopole_2port	1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	2	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

# 2-port Antenna: Specification

### Geometry and Environment [Learn more](#) ▼

Antenna axis points toward  X  Z

Dimension units:  [?](#)

Constrain Antenna Geometry  
(Applies to full antenna unless separate constraints are applied to Built-in Ground)

Max Shape:  X  Y  Z  mm

Apply Separate Constraints to Built-in Ground

Built-in Ground Size Max  
Shape:  X  Y  Z  mm

Built-in Ground Size Min  
Shape:  X  Y  Z  mm [auto](#)

Location on Ground (if applicable):  [?](#)

Ground Type (advanced):

Infinite Ground

Mast/Standoff Min  Max  mm

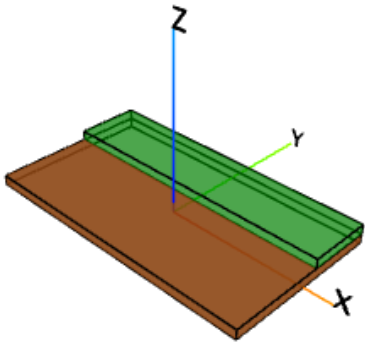
Use dielectric, if applicable

Dielectric constant:  Loss tangent:

Only design antennas that use a dielectric substrate

#### Geometry Constraints

■ Antenna ■ Built-in Ground ■ Infinite Ground



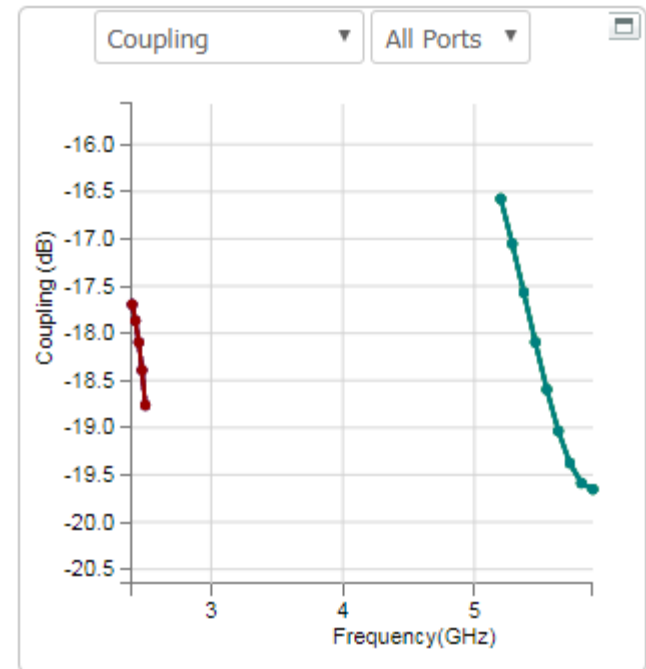
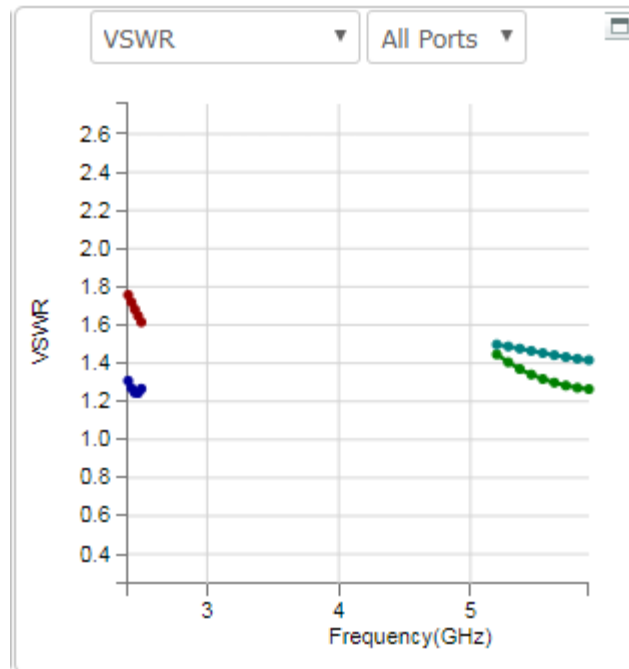
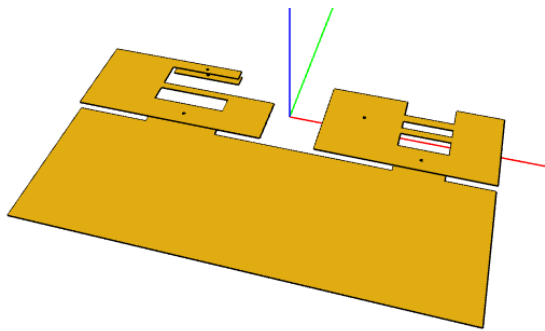
View Max Built-in Ground Size  View Min Built-in Ground Size

View Max Mast/Standoff  View Min Mast/Standoff



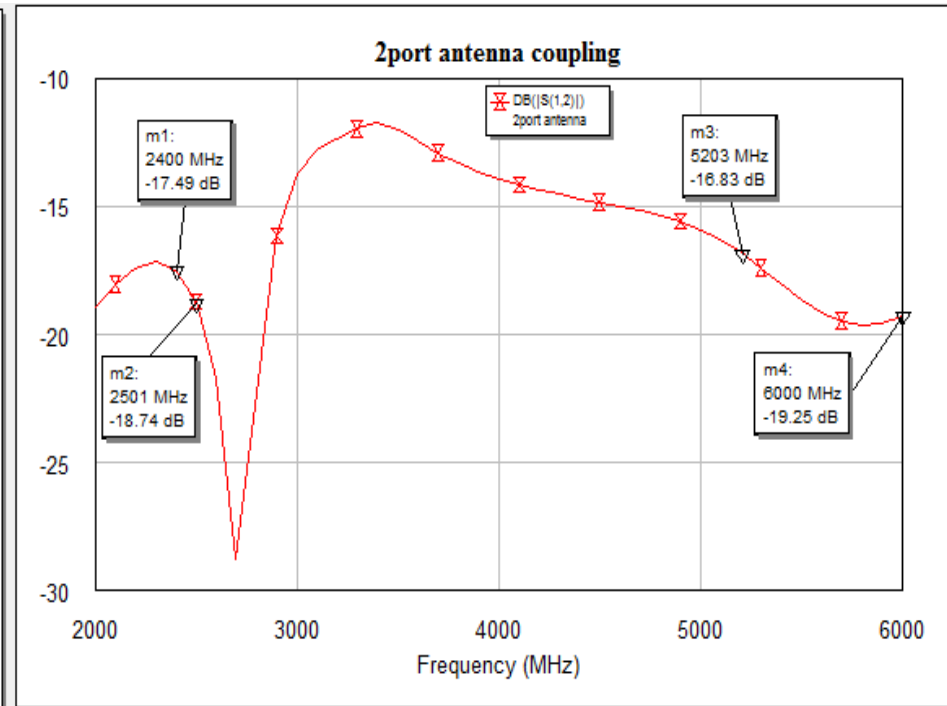
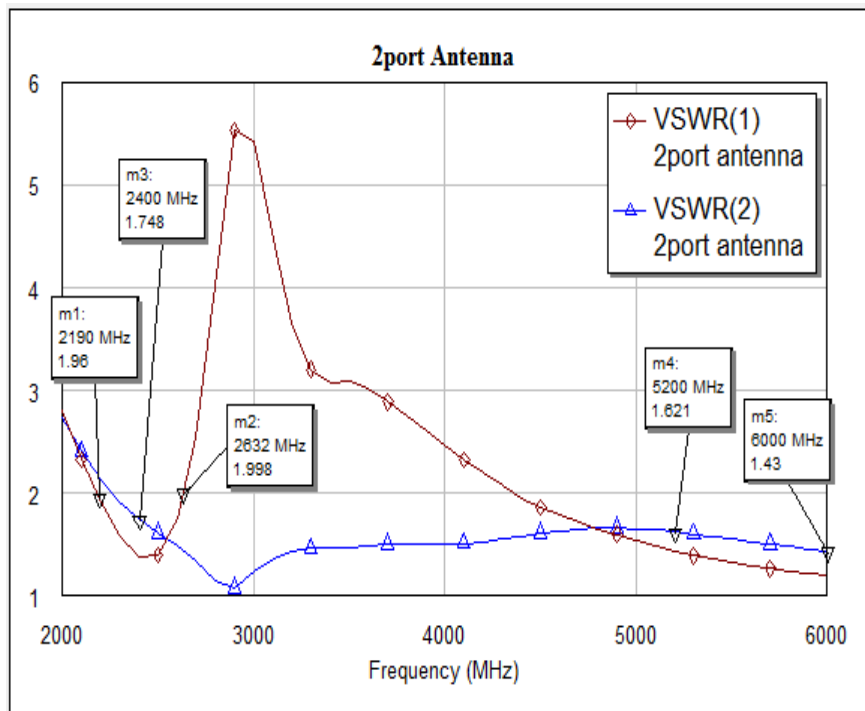
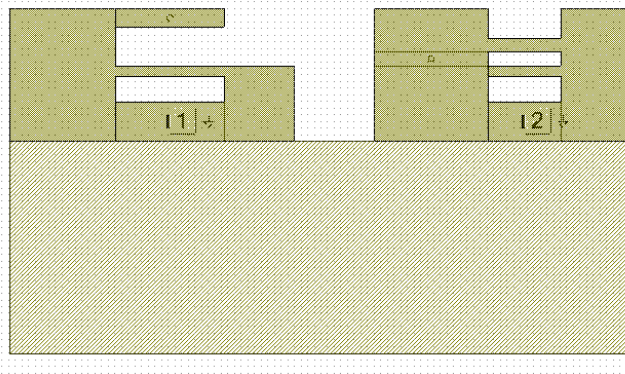
# 2-port Antenna: Results

- Good VSWR and coupling results
- Though optimized as a single 2-port antenna, AntSyn removed connections between ports



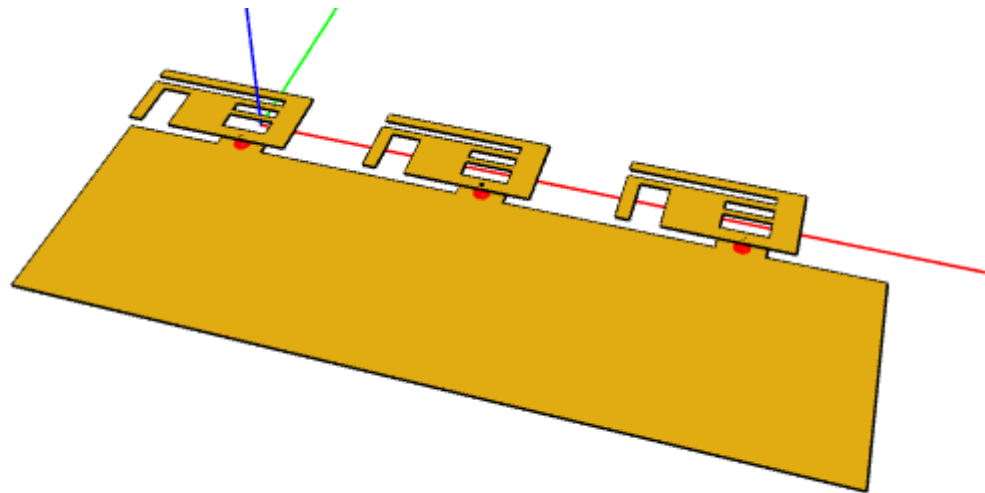
# 2-port Antenna: Analysis

- AXIEM simulation of VSWR and Coupling match well with AntSyn



## Iteration 3: 3-port antenna array

- 3-port single antenna is harder to optimize due to increased degrees of freedom
- 2-port antenna looks a lot like an array of two elements, what if we design a 3-element array?



# 3-port Array: Specification

### Geometry and Environment

Antenna axis points toward  X  Z

Dimension units: mm [?](#)

Constrain Antenna Geometry  
(Applies to full antenna unless separate constraints are applied to Built-in Ground)

Max Shape: Box X 30 Y 20 Z 4 mm

Apply Separate Constraints to Built-in Ground

Built-in Ground Size Max  
Shape: Box X 30 Y 50 Z 1 mm

Built-in Ground Size Min  
Shape: Box X 30 Y 50 Z 1 mm [auto](#)

Location on Ground (if applicable): top\_center (0, +Y) [?](#)

Ground Type (advanced): auto

Infinite Ground

[Learn more](#) ▼

#### Geometry Constraints

■ Antenna ■ Built-in Ground ■ Infinite Ground

### Arrays ▲

Use Arrays

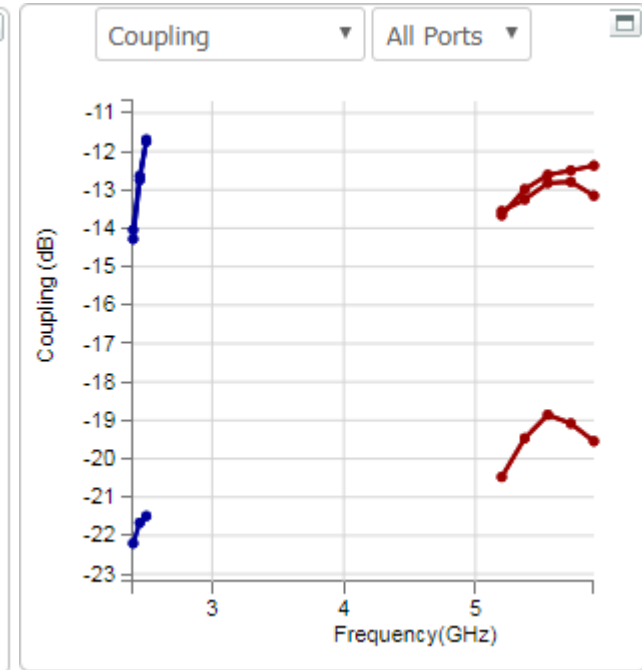
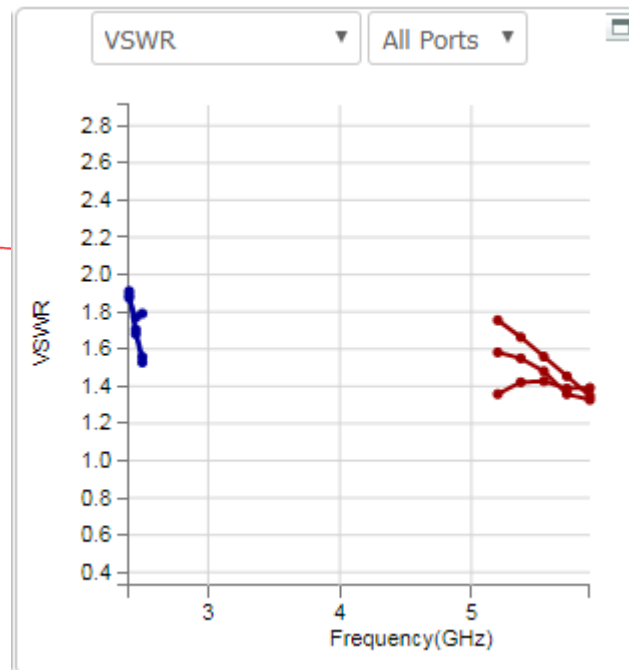
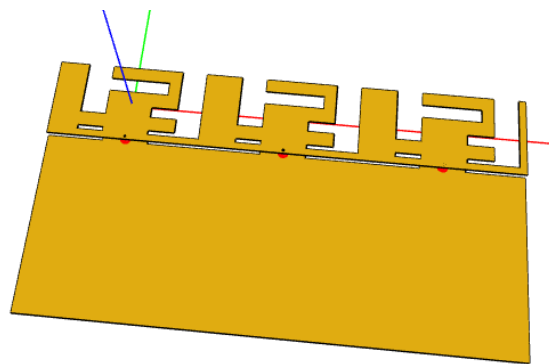
Type Planar Element Uniformity Uniform  Single Backplane

Element Spacing	# of Elements	min	max	
X	3	30	30	mm
Y	1	50	50	

Max coupling to active ports:  
(for arrays & phased ports) -12 dB

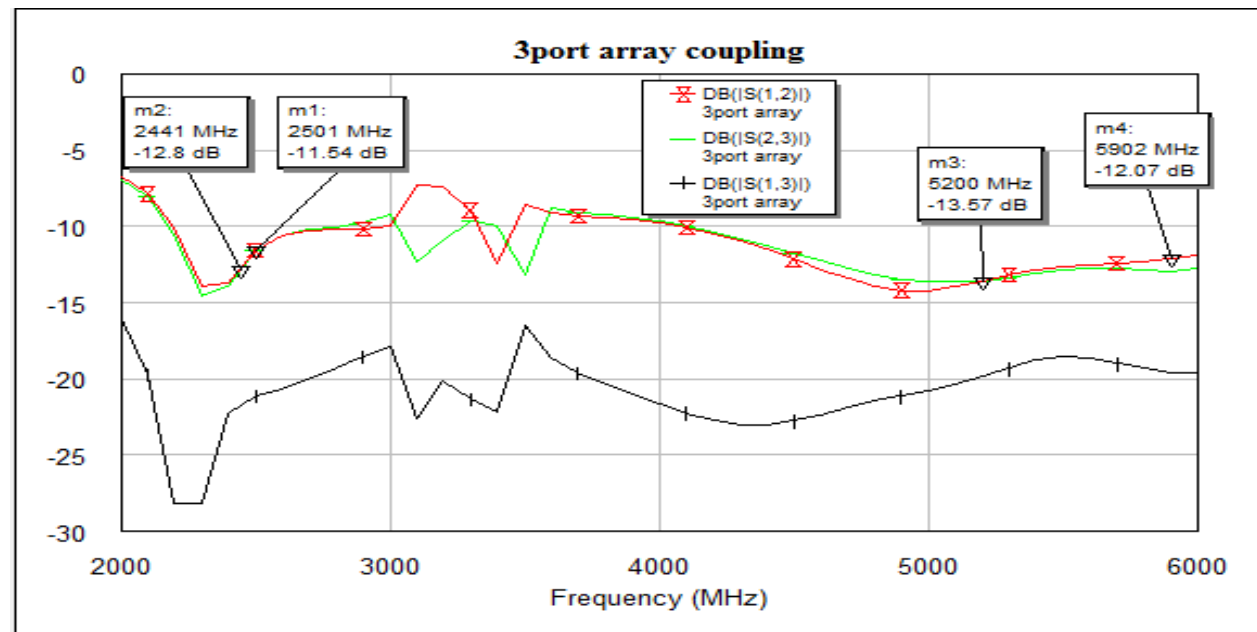
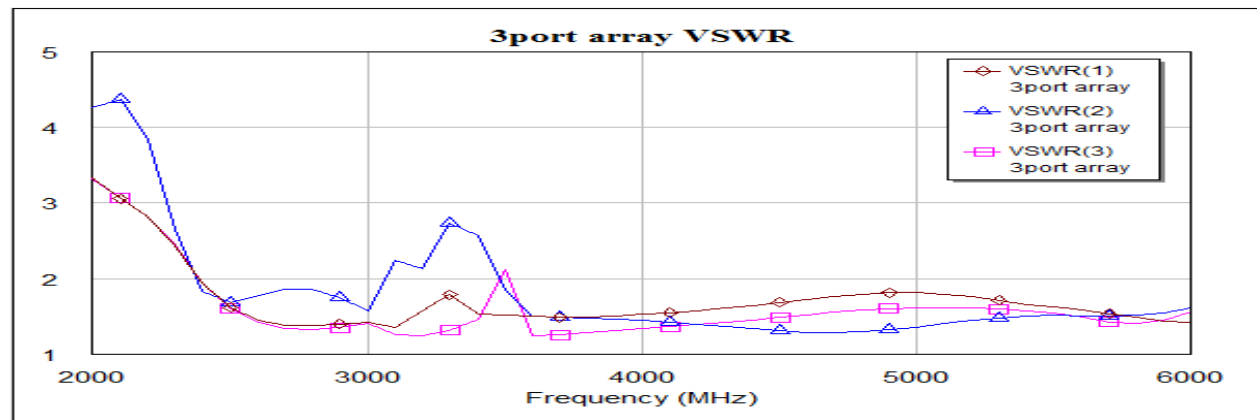
# 3-port Array: Results

- Overall envelope is 90 mm x 50 mm x 1.3 mm
- Elements are 30 mm x 15.3 mm x 1.3 mm thick
- Elements are actually connected across all the feedpoints, though their isolation is good



# 3-port Array: Analysis

- AXIEM, results match well with AntSyn
- Antennas are reasonably broadband
  - Center antenna has slightly worse VSWR between bands, still  $< 3$
- Coupling is below  $-11.5$  dB across bands of interest

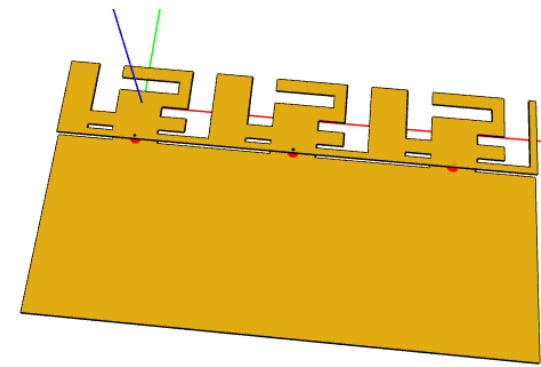
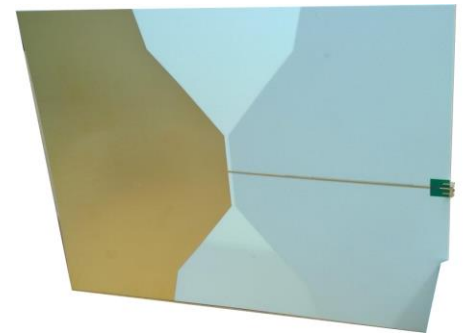


# IoT Example - Conclusions

- Good results from each approach
- Results from AntSyn match well with AXIEM
- Next steps
  - Miniaturization
    - How small can the antennas be, with and without dielectric?
    - What is the quantitative tradeoff for using dielectric?
    - What is the tradeoff between size and isolation?
  - Adding more ports/antennas
    - How many ports are feasible in a given space?
    - What is the best geometric configuration? Antenna type?
    - Which is better: an N-port antenna or an array?

# Antenna Synthesis Summary

- Quickly create high-performance designs with multiple competing criteria
  - Increased performance and/or efficiency can be achieved in many cases
  - Higher confidence in achieving superior result
  - Automated discovery of design principles from which insight can be gained
  - Supports a wide (and growing) range of specifications & applications
- Significantly faster and lower-cost design process
  - Less time needed to begin new design efforts
  - Ability to rapidly run what-if design scenarios and trade studies
  - Greater agility and responsiveness to new requirements
  - All of the above lead to cost savings as well





# Thank You for Your Attention