

ELEN716 Phase II: Coplanar Waveguide Bowtie Antenna

By Troy Pandhumsoporn

Introduction

[2]

- A coplanar waveguide antenna is a broad-bandwidth antenna made of two sets of conical conductors, triangular elements
- Simple Geometry, more directive antenna, easy integration with microwave components
- Emphasis on angles rather than lengths (produced wide bandwidth)

Main Objective: Investigate 4-element array radiation characteristics, Phase I
comparison

Table 8-2 Elements for Array Antennas

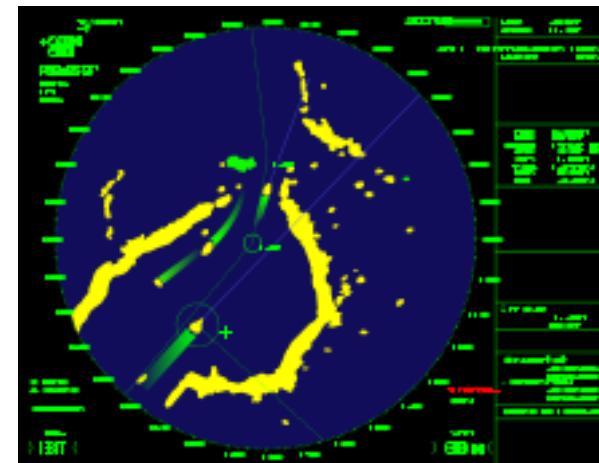
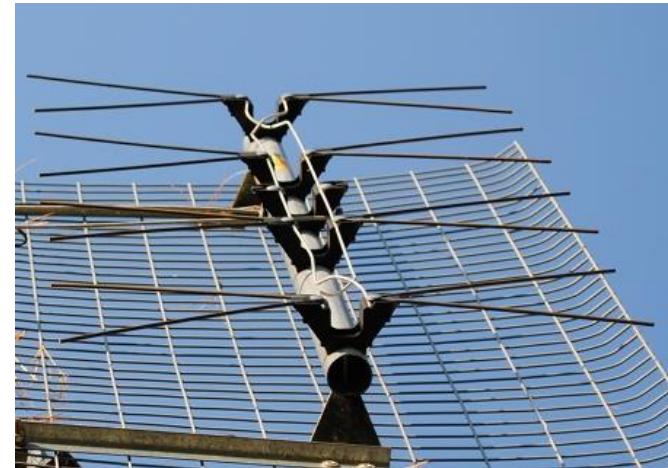
Element	Examples	Advantages; Disadvantages
<i>Dipole-based elements, backed by a ground plane</i>		
Dipole	Fig. 3-20 Fig. 8-35a	Wide beam, simple structure; narrow band
Bow-tie	Fig. 7-32	Wide beam, simple structure, broadband
<i>Microstrip elements</i>	Sec. 11.2	Wide beam, low-profile; narrow band in basic form
<i>Slot elements</i>	Fig. 8-35b Fig. 8-34b	High-power applications; many are narrow band
<i>Aperture elements</i>		
Open-ended waveguide	Fig. 9-9	Compact, moderate bandwidth; bulky structure
Horn antenna	Fig. 9-11	Moderate bandwidth, fewer array elements; limited scan due to wide spacing
<i>Tapered slot antennas</i>	Fig. 8-35c and d	Wide beam, broadband; not low-profile
<i>Low-profile, broadband elements</i>		
	Fig. 8-38 Sec. 8-11	Broadband, low-profile



Applications

[3]

- Wireless Communications
 - Wearable Electronics
 - WLAN, WiMAX
- Phased Arrays
- UHF Television Reception
- EMI Testing (immunity, emissions)
 - Ham Radio (Foxhunting, General Radio Band Reception)
- **Radar Applications (this antenna)**
 - Navy & Military



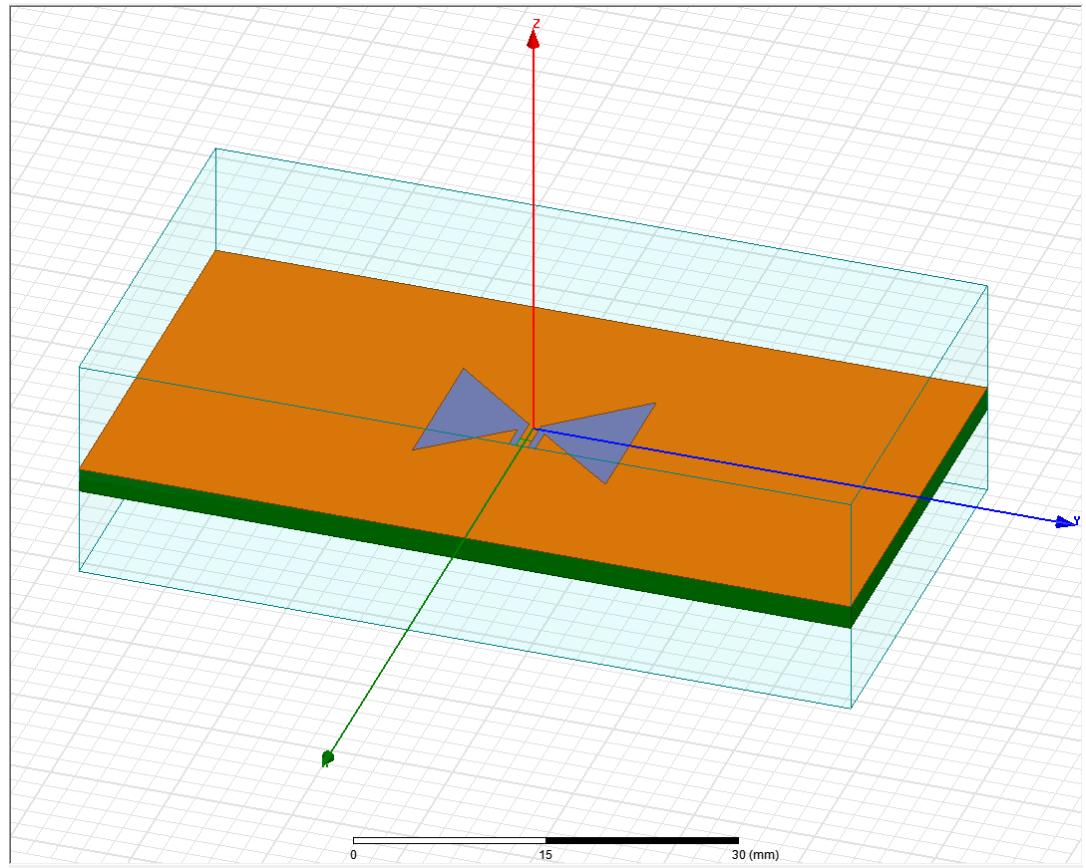
[5]

Main Outline

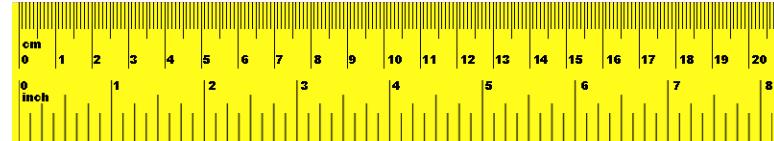
- 4-Element Array (Radiation Characteristics:
HPBW, SLL, S-parameters, coupling)
 - Array Arrangement/Spacing ($\lambda/2$, λ in +x direction)
 - Changing port excitations (4x1 in +x direction)
 - Shorting a port, monitoring impact
 - 2D or 1D beam scanning with excitation scheme
(uniform/non-uniform) (may include 2x2 array)
 - Discuss/Compare with Phase I
 - Optional Add-Ons

Modified Design

- Feed Length: 13 mm → 3.27 mm
- Aperture Dimensions (one triangle) (Height = 21 mm, Base = 12.7 mm) reduced to (Height = 8 mm, Base = 12.7 mm)
- Needed to be able to expand with respect to normal λ range for the Y-direction and 2x2 array.
- Optimized to remain at its solution frequency of 10 GHZ, at the cost of higher bandwidth.
- Aperture Antenna Angle remains the same.



Still can measure
with a ruler!



Old Design

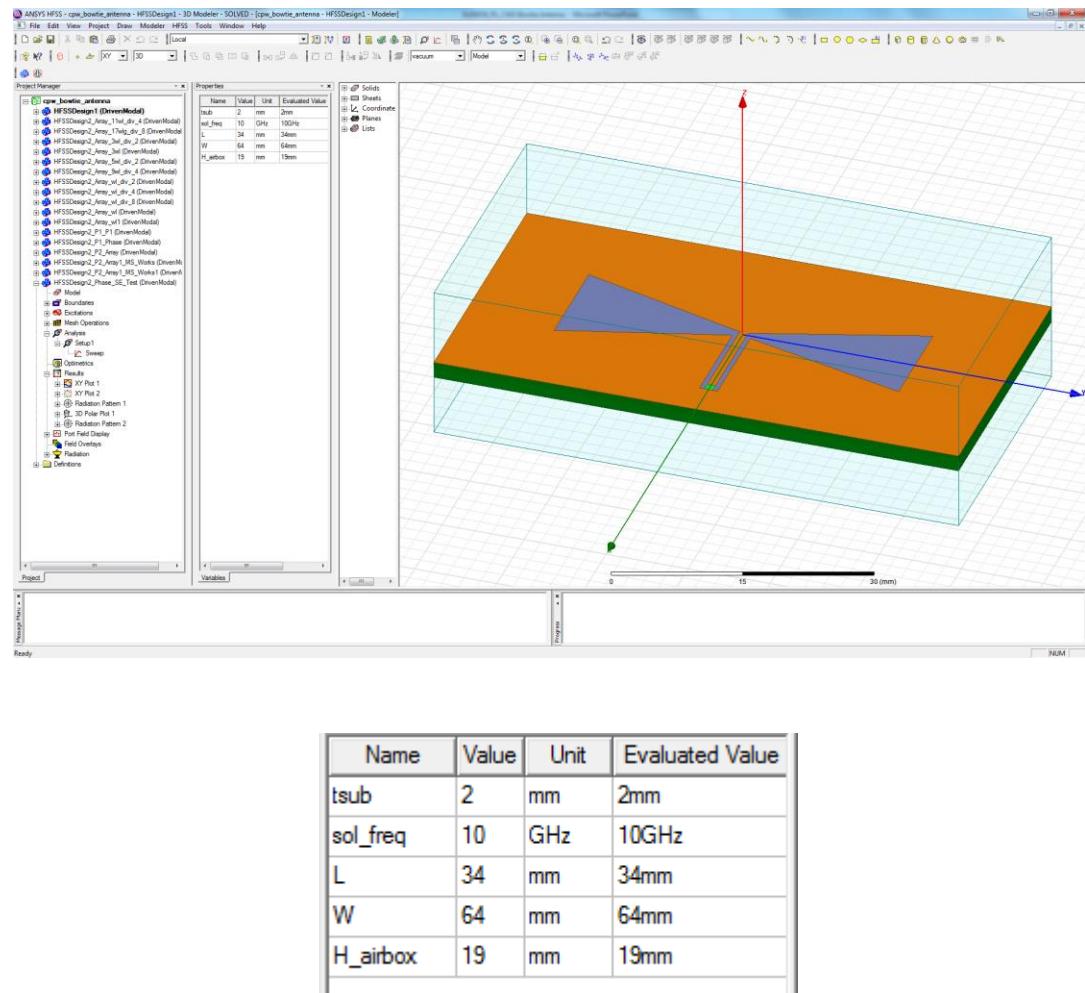
- 50 Ω Lumped Port Excitation for CPW feed (1mm x 1mm)

- Copper Cladding with Cutout (serves as ground and antenna shape etched)
- Simulated in 8 – 12 GHz range as used in the paper.

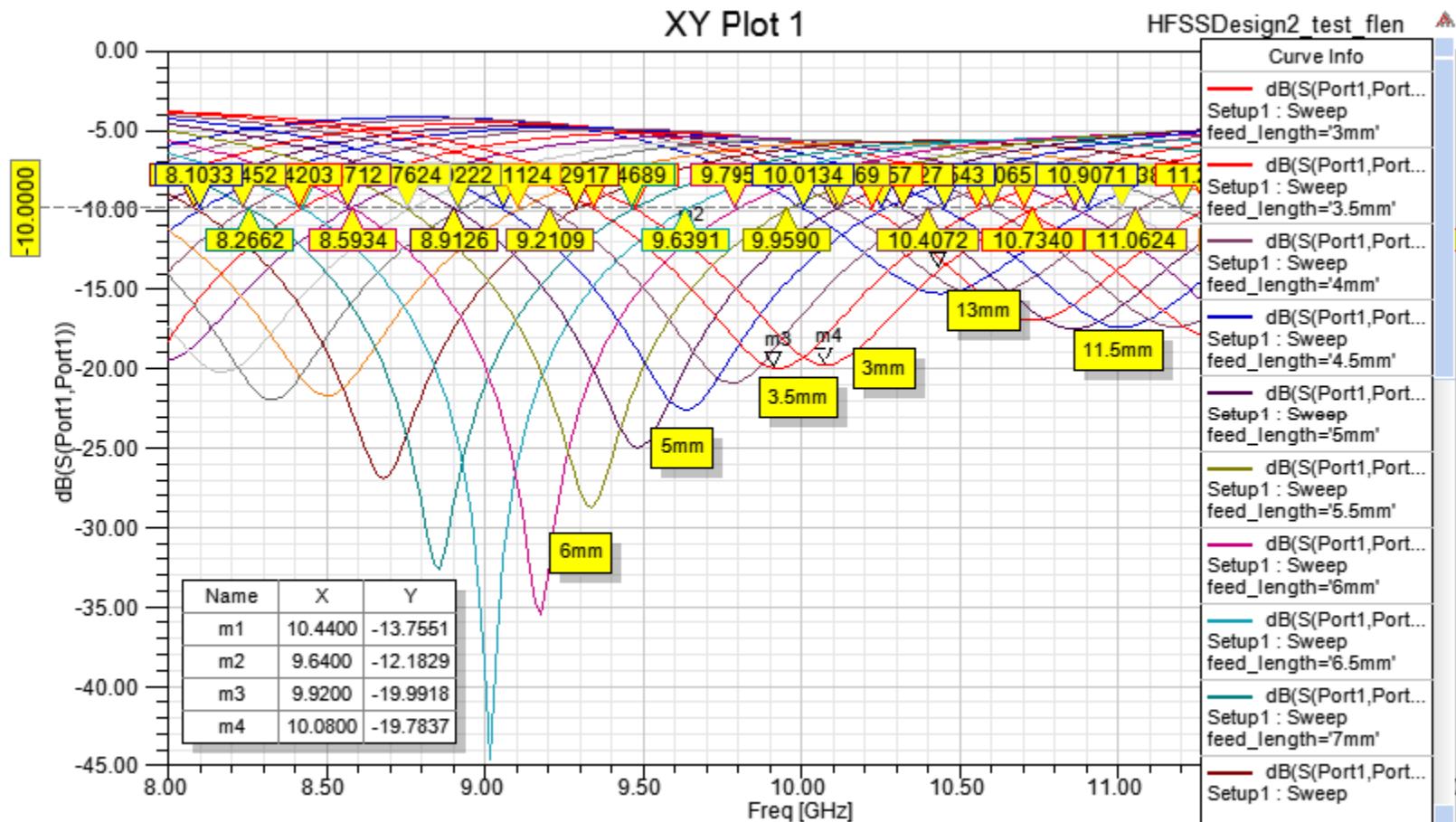
- Polyline Draw Tool and Arlon Cu Clad 217(tm) chosen ($\epsilon_r = 2.17$)

- Height = 21 mm, Base = 12.7 mm (triangle dimensions)

From the paper, 1 GHz BW, -18 dB return loss antenna

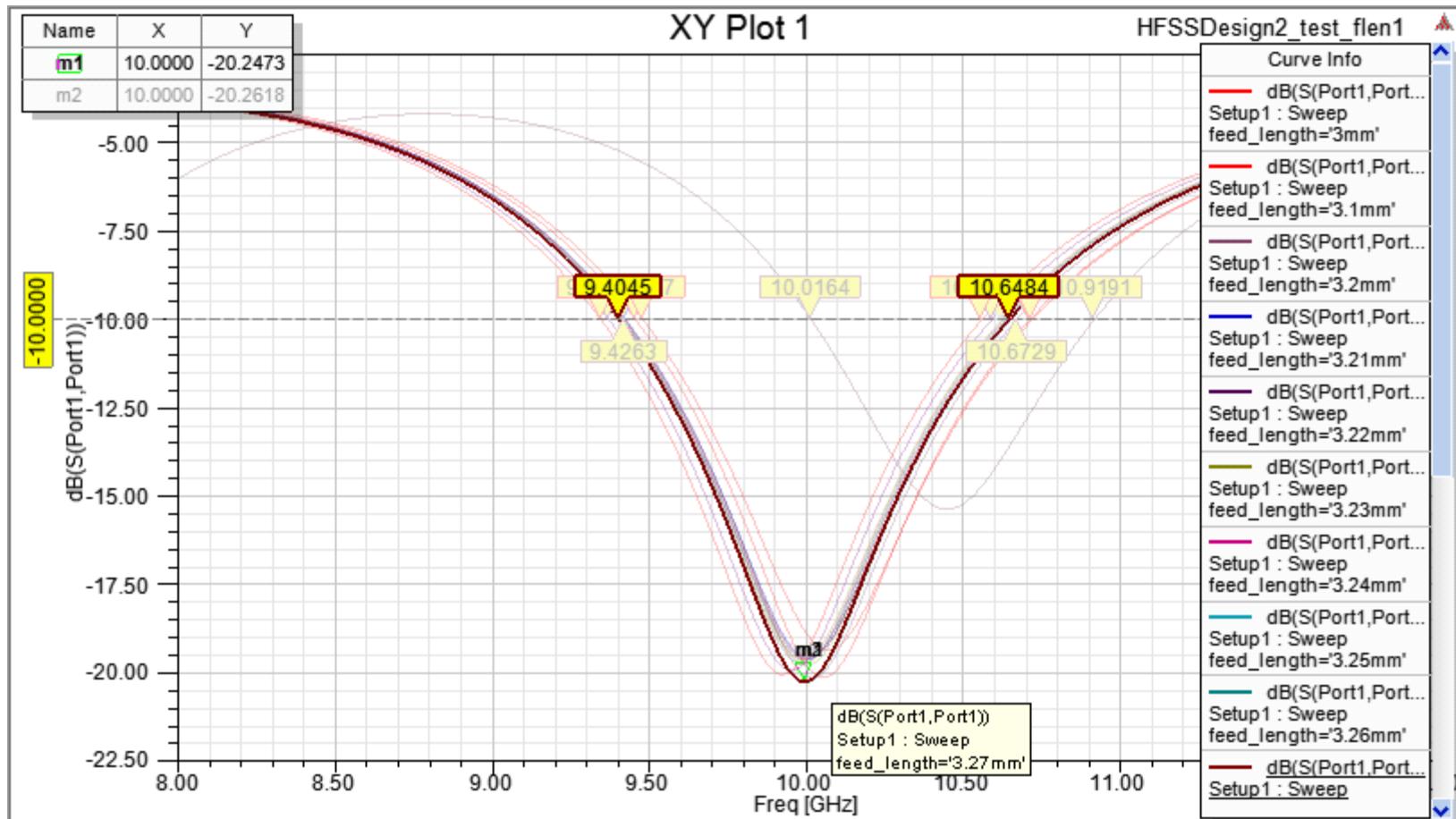


Parametric Analysis (optimal feed length)



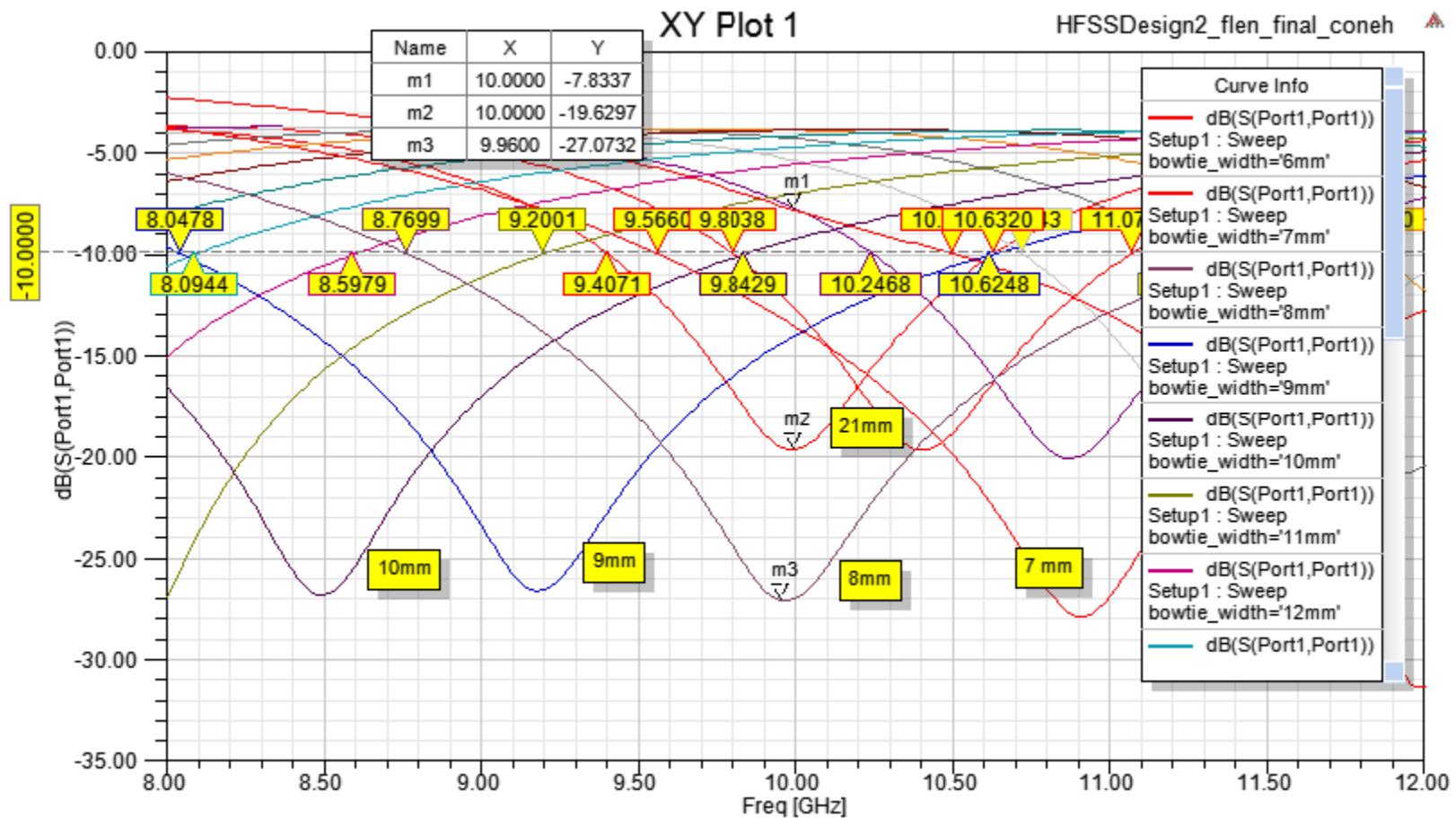
From 3mm to 13 mm, 1mm step increments. Somewhere between 3-3.5 mm.

Parametric Analysis (optimal feed length) (continued)



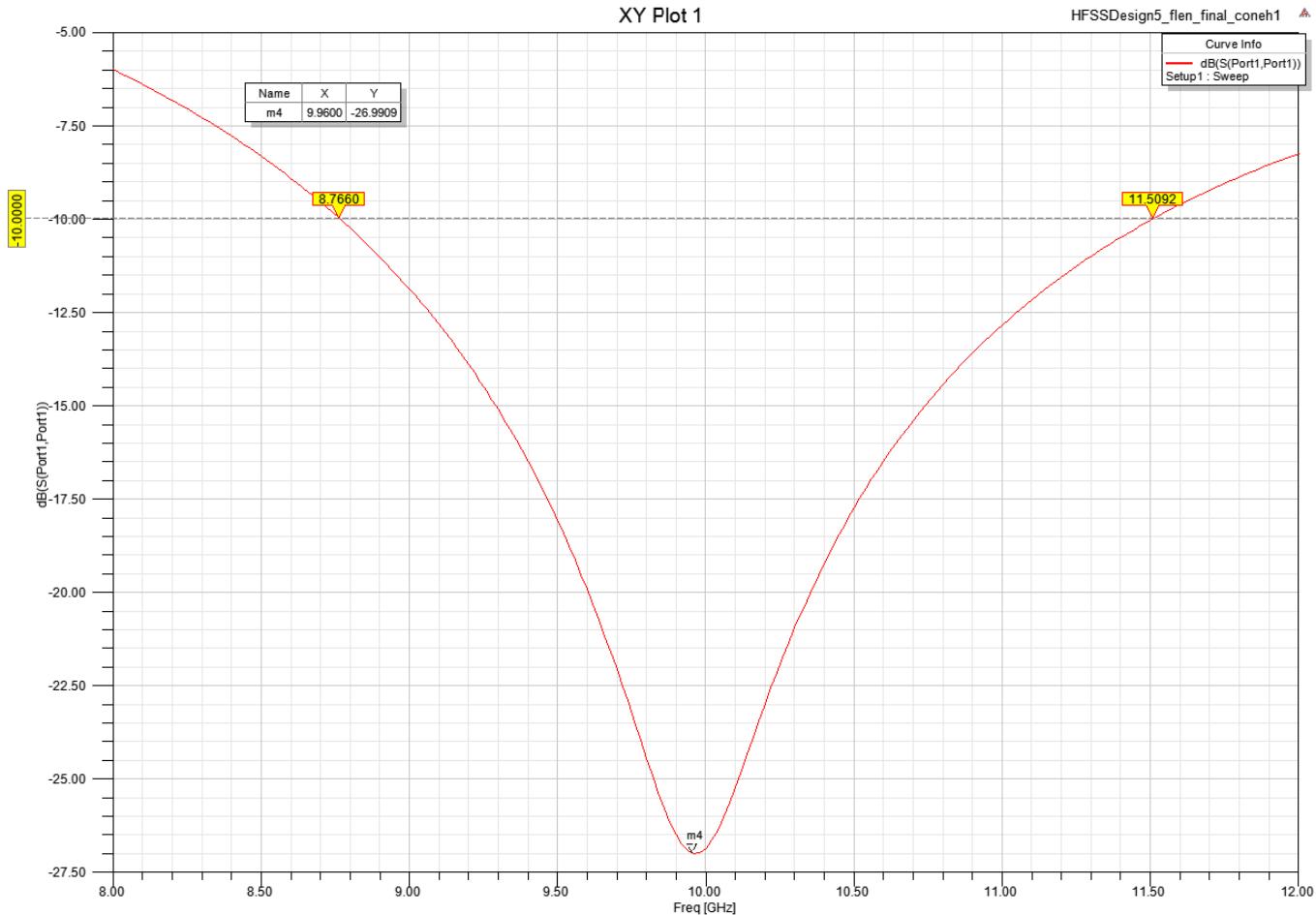
From 3.2 mm to 3.3 mm, 0.01 mm increments
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Aperture Base (with optimized feed length)



From 6mm to 21 mm, 1 mm step increments. m3 is close enough

Final Antenna Element S11 plot



$S_{11} = -26.9909 \text{ dB}$, $\sim 2.75 \text{ GHz BW}$ (trade-off for array characteristics)

Center-To-Center Spacing

d	Calculated distance d	Intersect ?
$d = \lambda/8$	3.75 mm	Yes
$d = \lambda/4$	7.5 mm	Yes
$d = \lambda/2$	15 mm	No (Yes for y-direction)
$d = 3\lambda/4$	22.5 mm	No
$d = \lambda$	30 mm	No

$$\beta d = \frac{2\pi}{\lambda} x \lambda = 2\pi$$

$$\alpha - \beta d < \psi \text{ (visible region)} < \alpha + \beta d$$

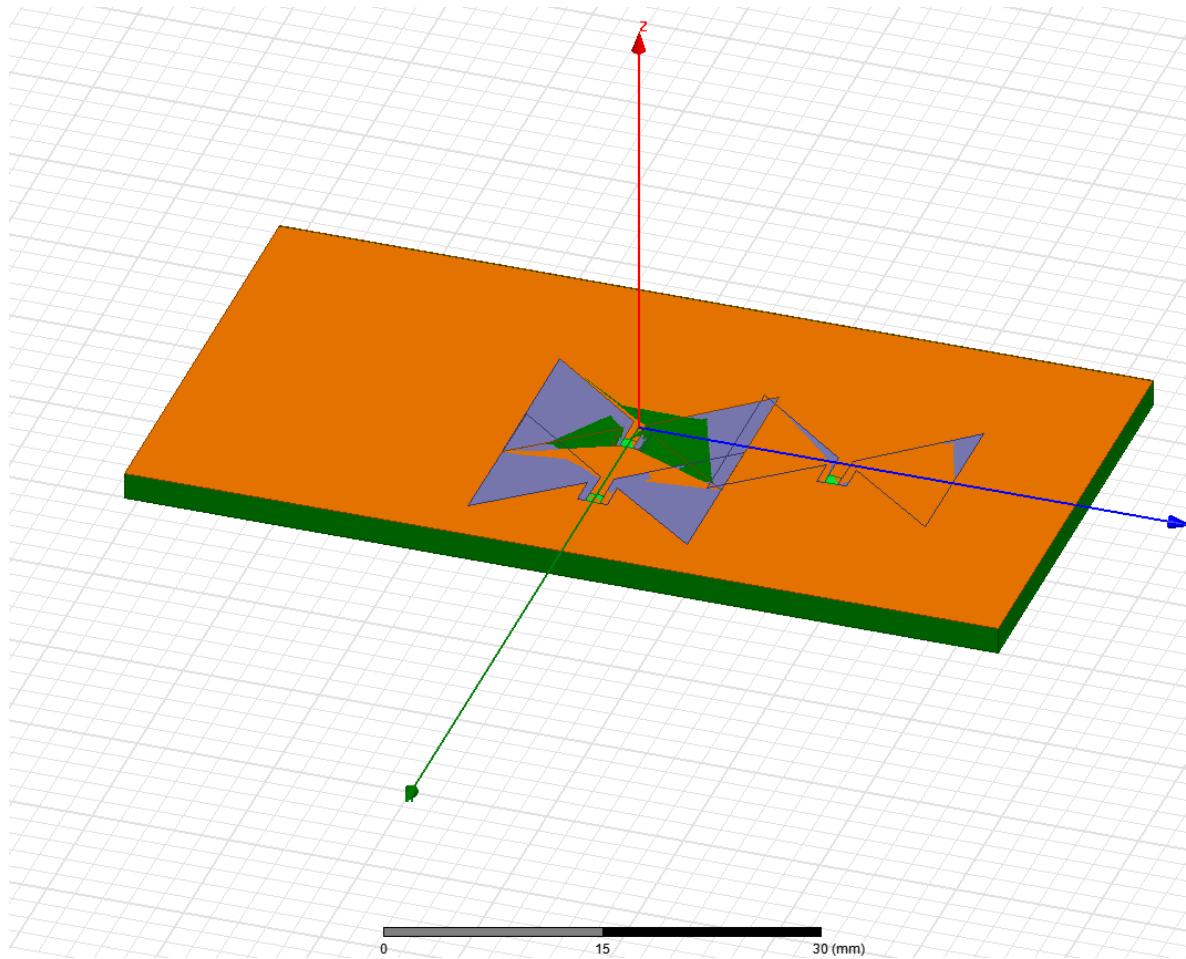
The pattern should repeat every λ spacing (array factor is 2π periodic)

Phase + $2\pi N$ = Equivalent Phase

The dimensions of antenna are $W \times L = 64 \text{ mm} \times \underline{34 \text{ mm}}$, width (expanding y, -y direction) and length (expanding x, -x direction). Best array created along the +x direction.

$d = (c/f_o)/N = \lambda_o/N$ In the x direction, intersection at $d = \lambda/4$; in the y-direction, $d = \lambda/2$.

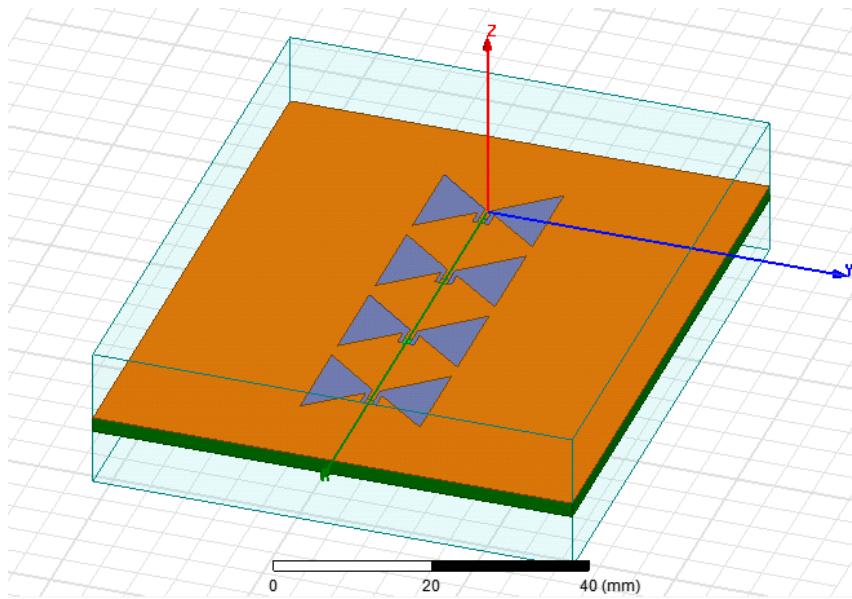
Bottlenecked Center-to Center Spacing



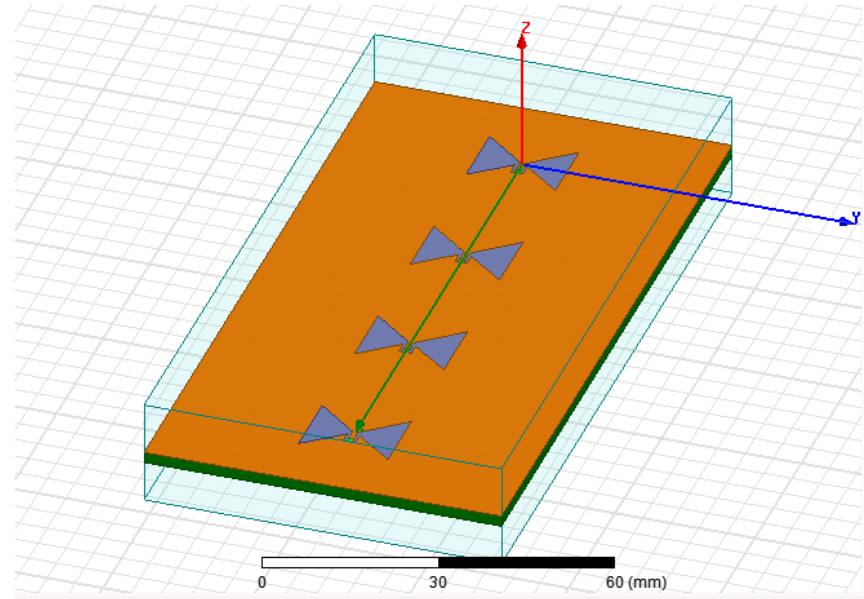
Therefore, Min Spacing +X-axis is $d > \lambda/4$, Min-spacing +Y-axis for $d > \lambda/2$
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4x1 array (+x direction) layout [best way]

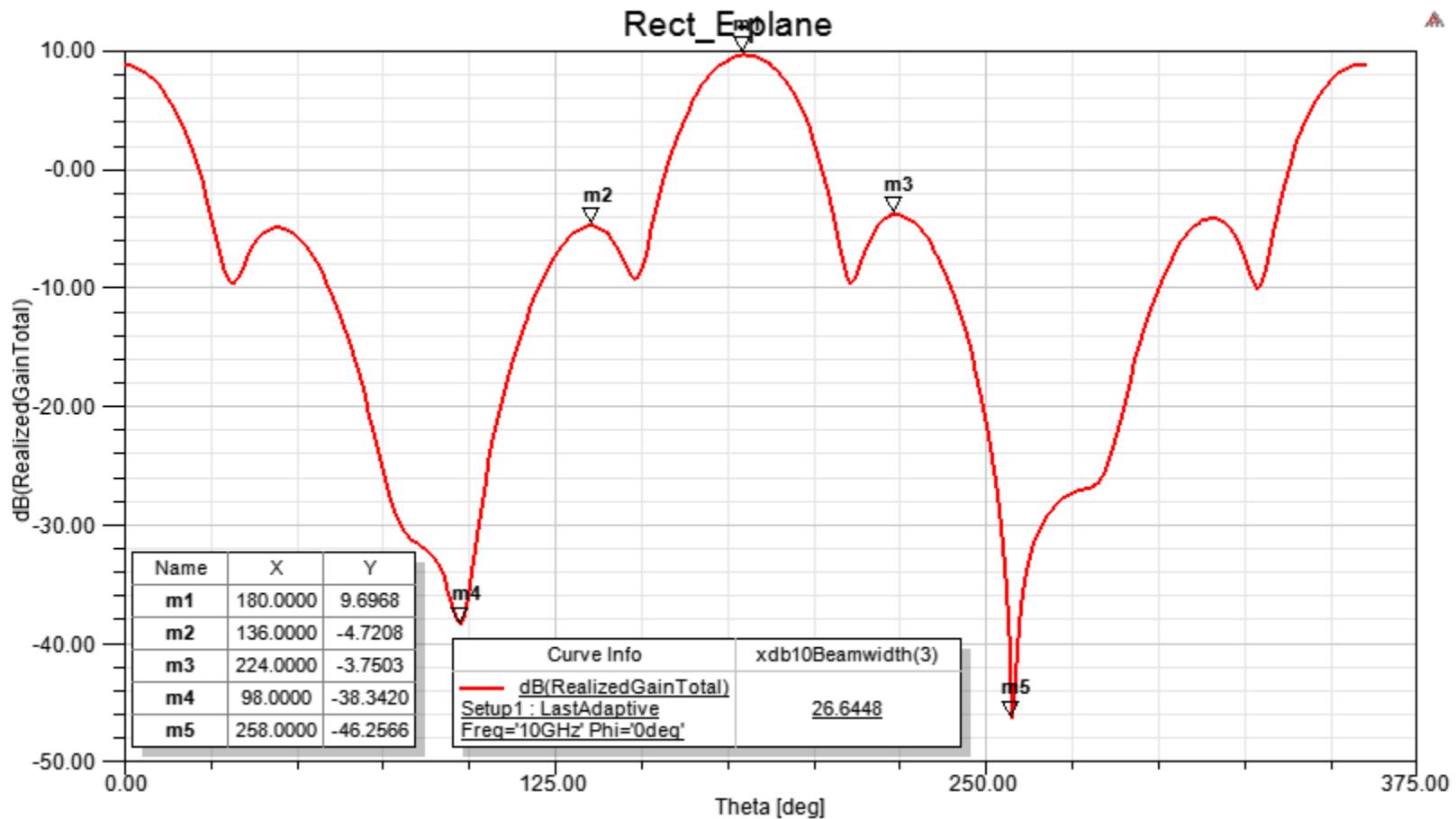
$\frac{\lambda}{2}$ *spacing*



λ *spacing*

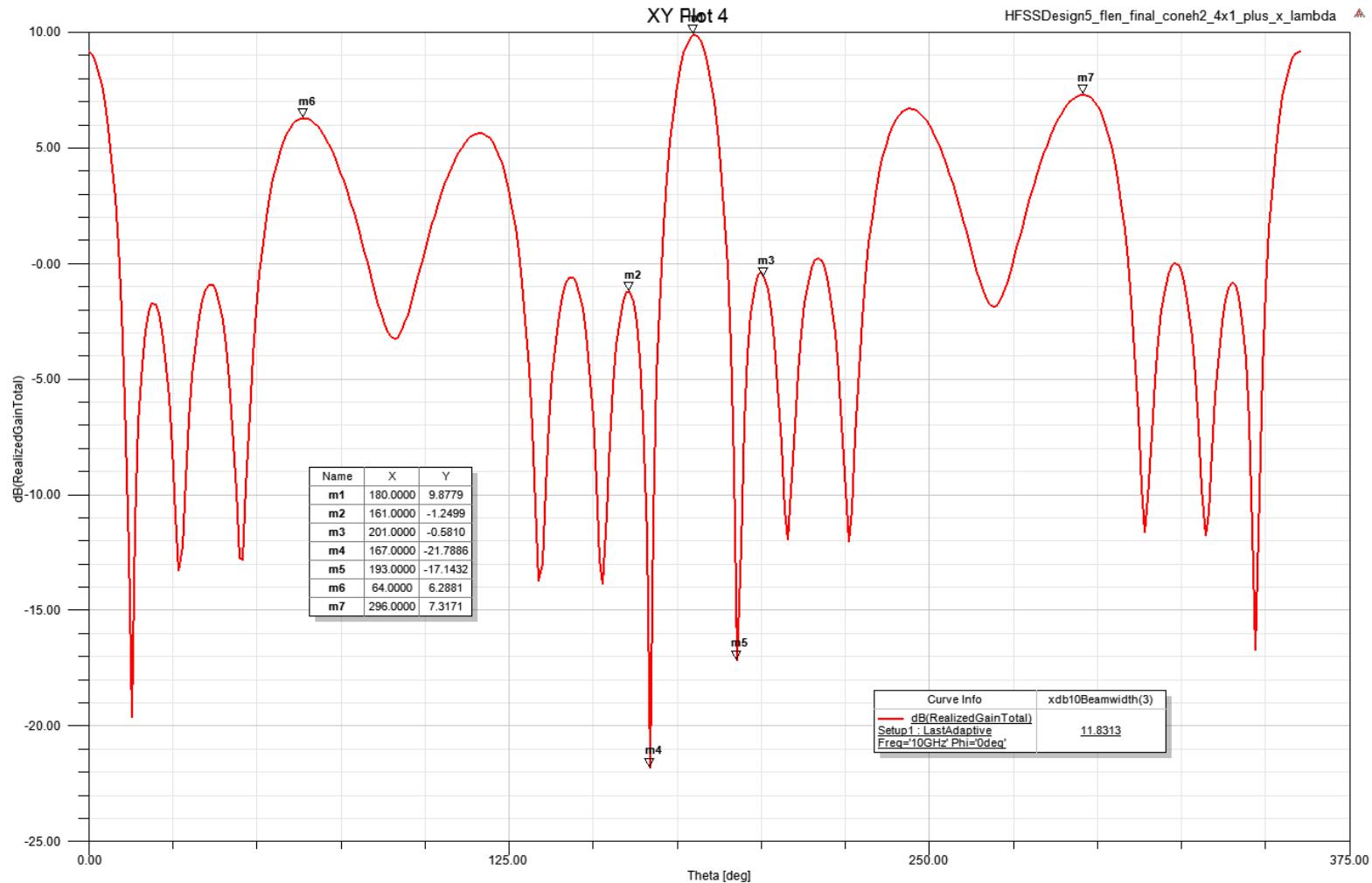


4x1 array (+x direction), $\lambda/2$ spacing



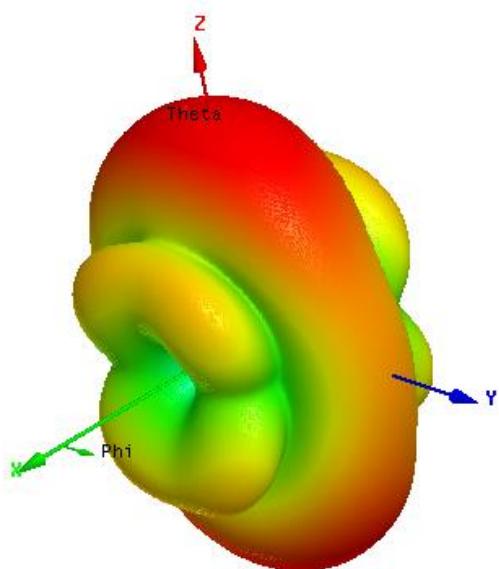
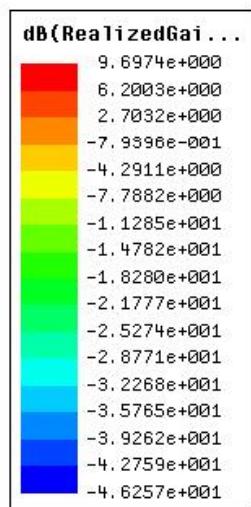
HPBW = 26.6448° (highest), SLL = -5.9465 dB, BWFN = 160°

4x1 array (+x direction), λ spacing

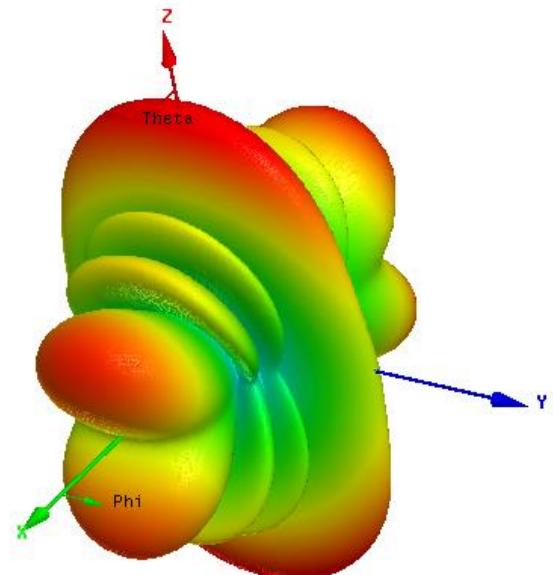
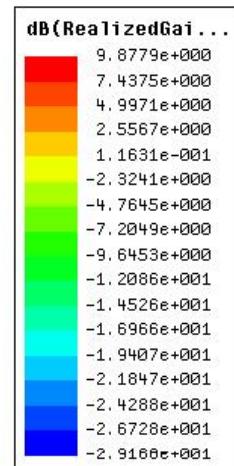


4x1 array (+x direction): 3D Polar Plots

$\lambda/2$ spacing



λ spacing



The λ spacing has slightly higher gain.

General Trends of Mutual Coupling [3, pg. 306-308]

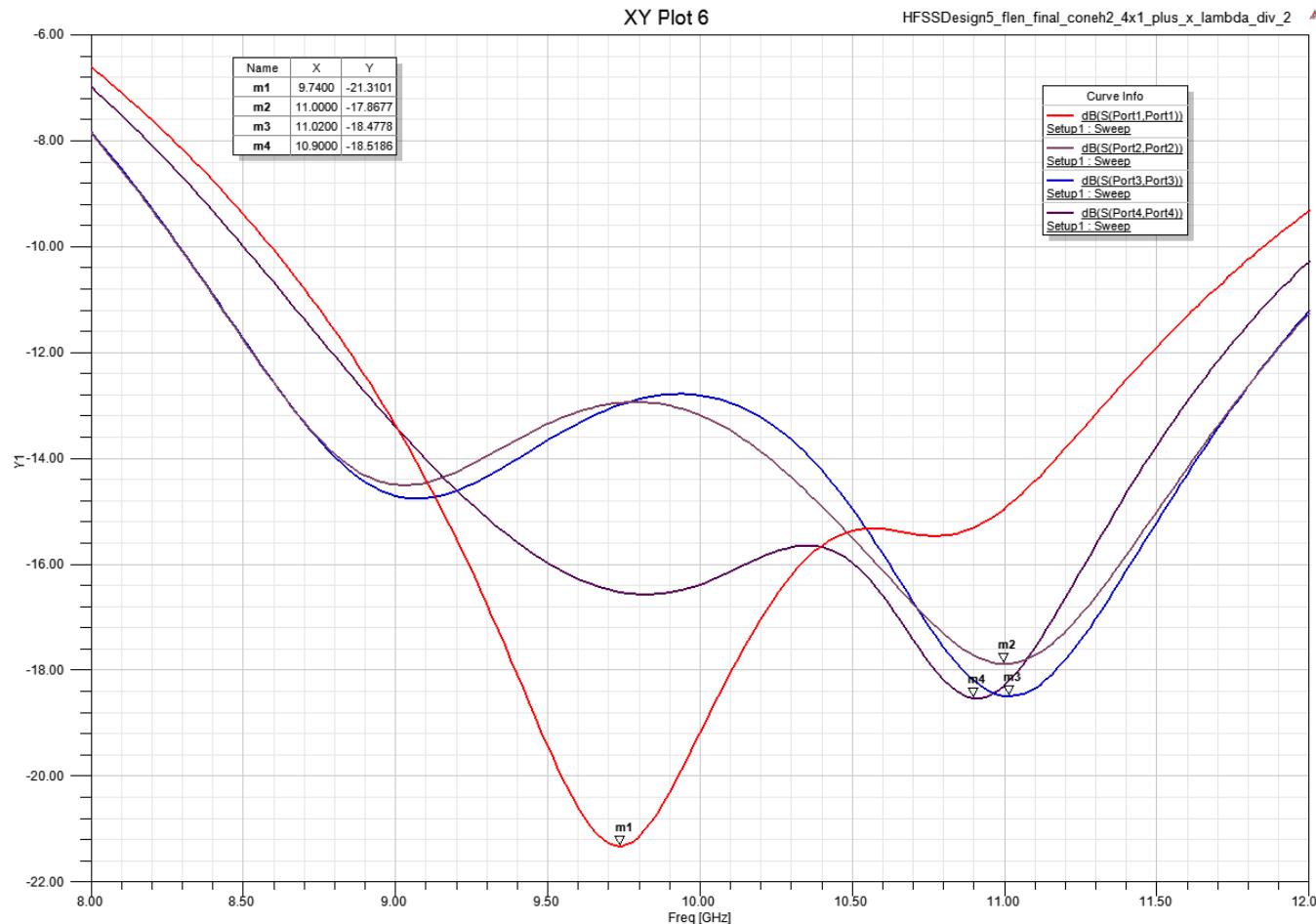
- a. The magnitude of mutual impedance decreases with spacing distance d , in many cases decaying as $1/d^2$ [H.8.2: Hansen, "Phased Array Antennas," 2nd ed., p. 225].
- b. The far field pattern is an indicator of coupling between elements, although the coupling mechanism is a near-field, not far-field, effect. Coupling is proportional to the element pattern level in the array plane (or surface). And, elements with a narrow pattern will have lower coupling than elements with a broad beam.
- c. Elements with polarizations (i.e., electric field orientations) that are parallel couple more than when collinear.
- d. Larger elements have smaller coupling.

Just as with the impedance matrix, the scattering matrix is symmetric for a reciprocal device and $S_{nm} = S_{mn}$. The off-diagonal entries represent the coupling between ports. So the coupling between ports m and n in dB, C_{mn} , is

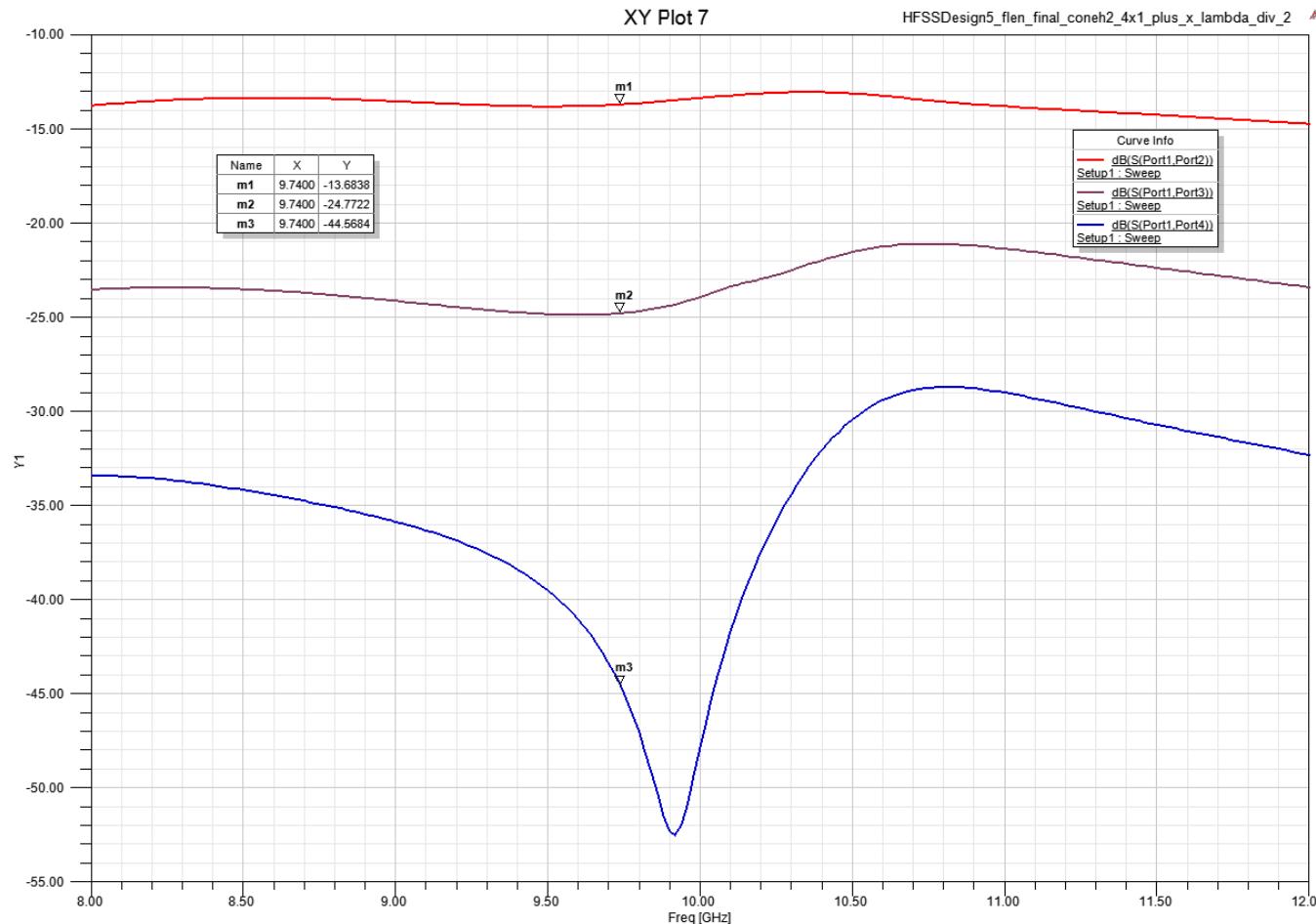
$$C_{mn} = 20 \log |S_{mn}| \quad [\text{dB}] \quad (8-96)$$

The scattering parameter method is the easier way of quantifying coupled arrays, used in RF circuit analysis.

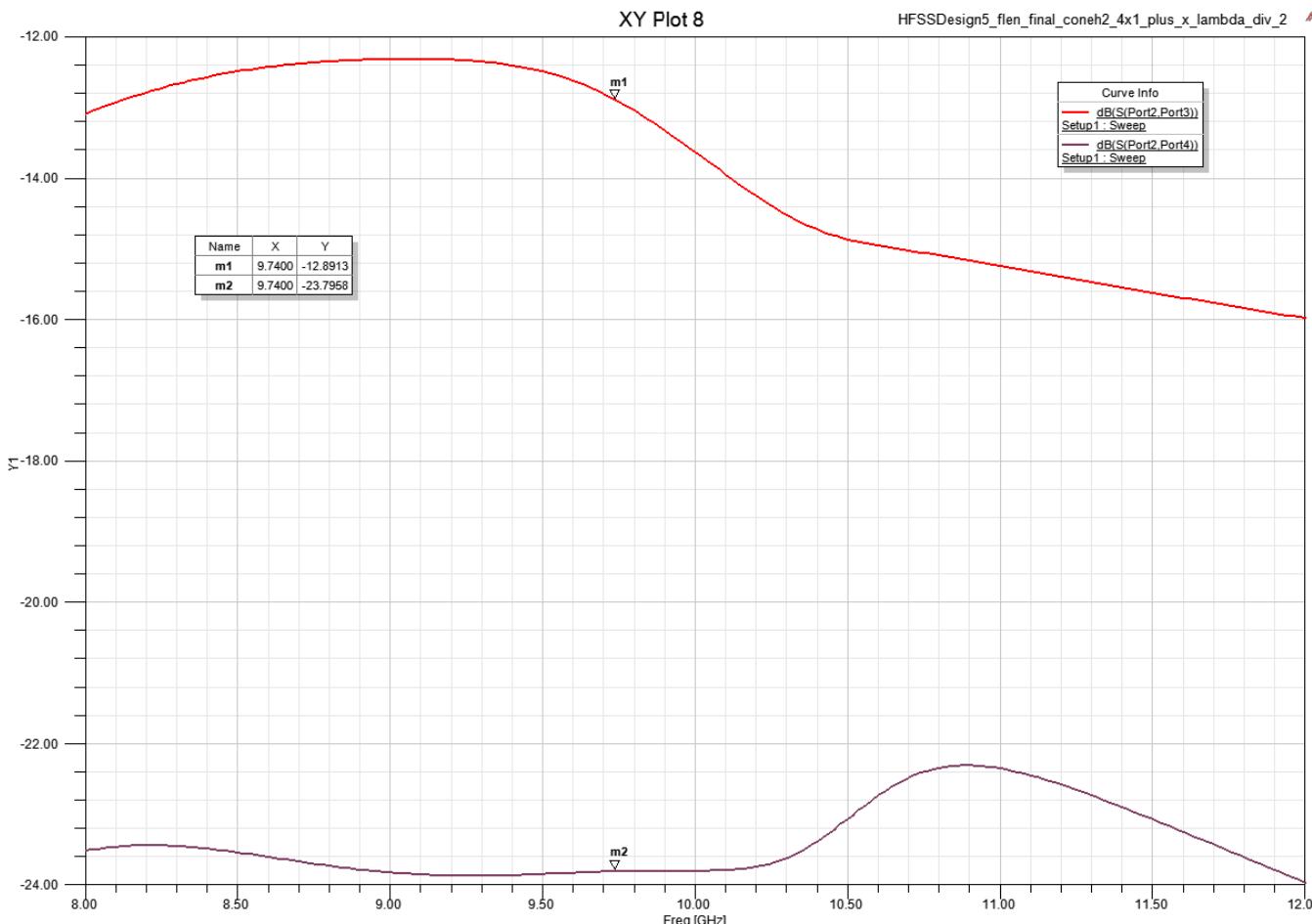
4x1 array (+x direction): S11, S22, S33, S44 parameters, $\lambda/2$ spacing



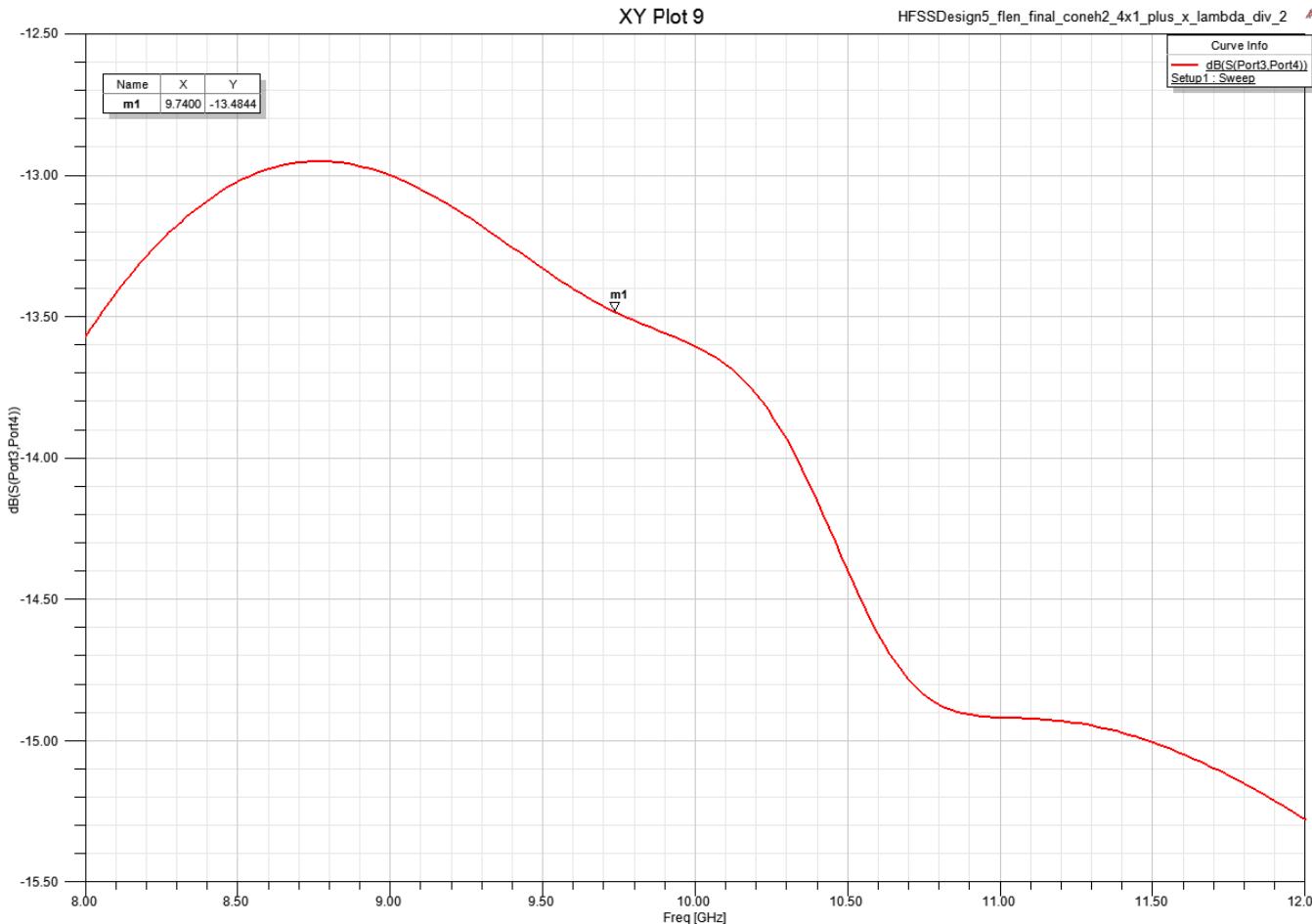
4x1 array (+x direction): S12, S13, S14, parameters, $\lambda/2$ spacing



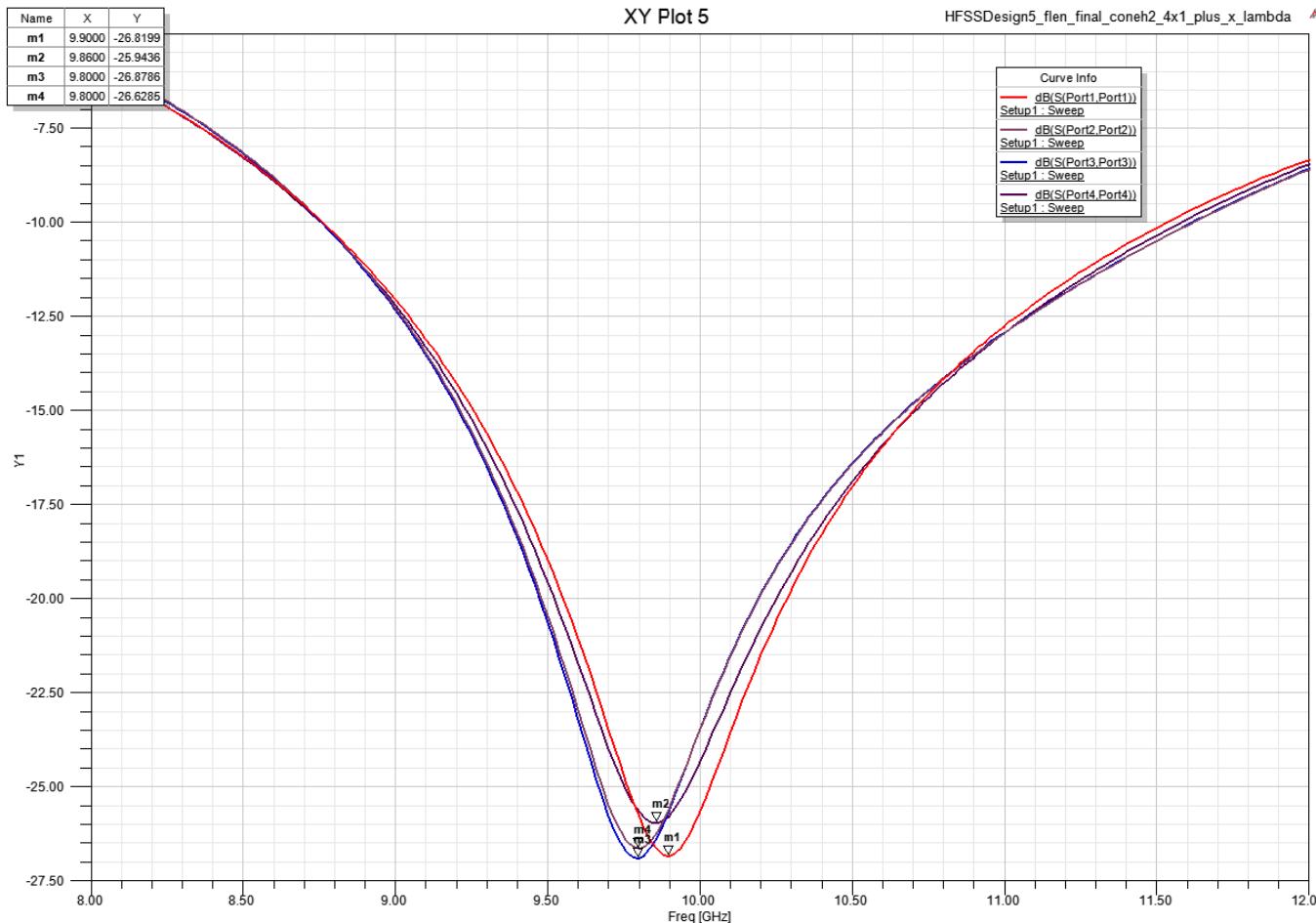
4x1 array (+x direction): S23, S24, parameters, $\lambda/2$ spacing



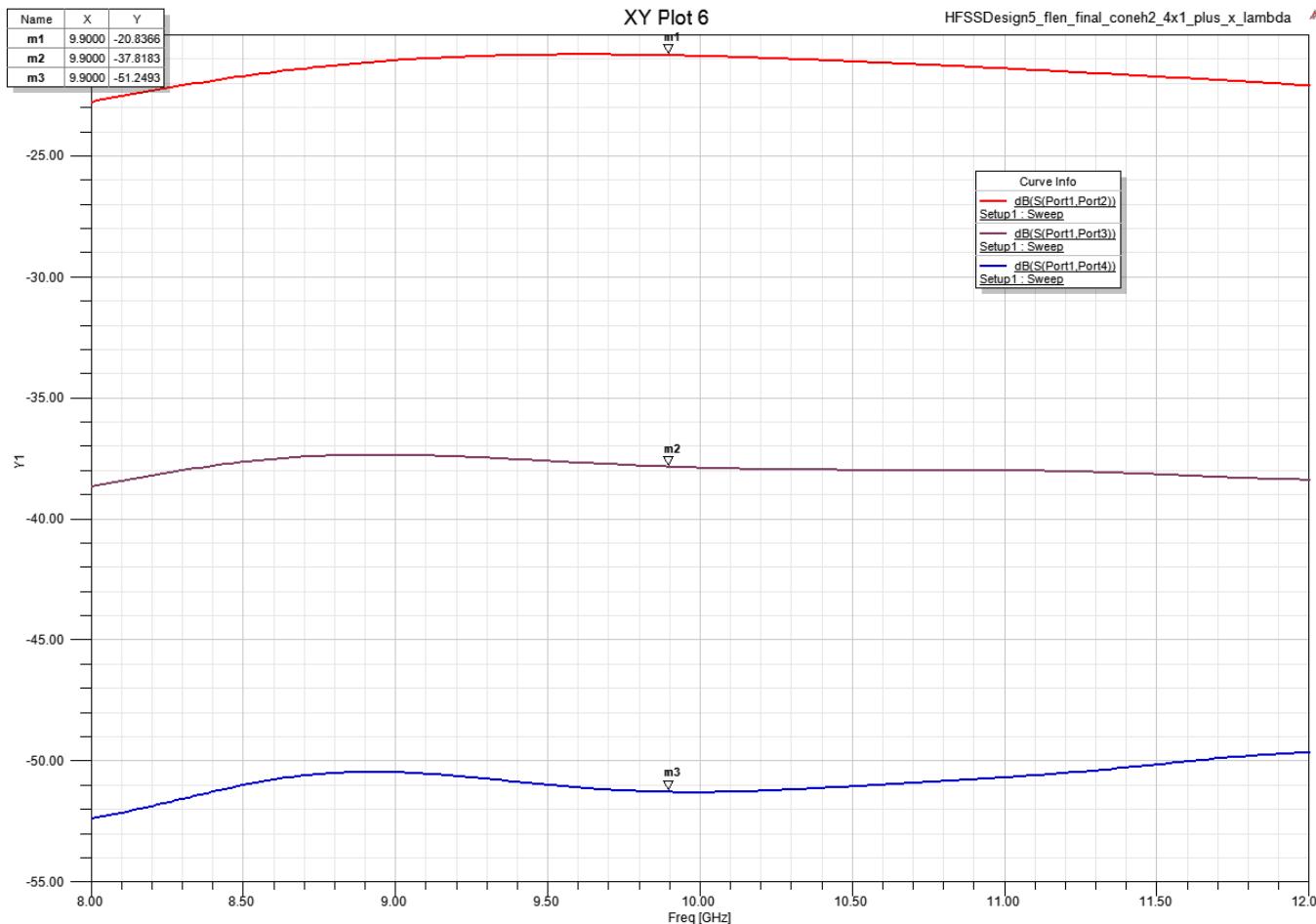
4x1 array (+x direction): S34, parameters, $\lambda/2$ spacing



4x1 array (+x direction): S11, S22, S33, S44 parameters, λ spacing

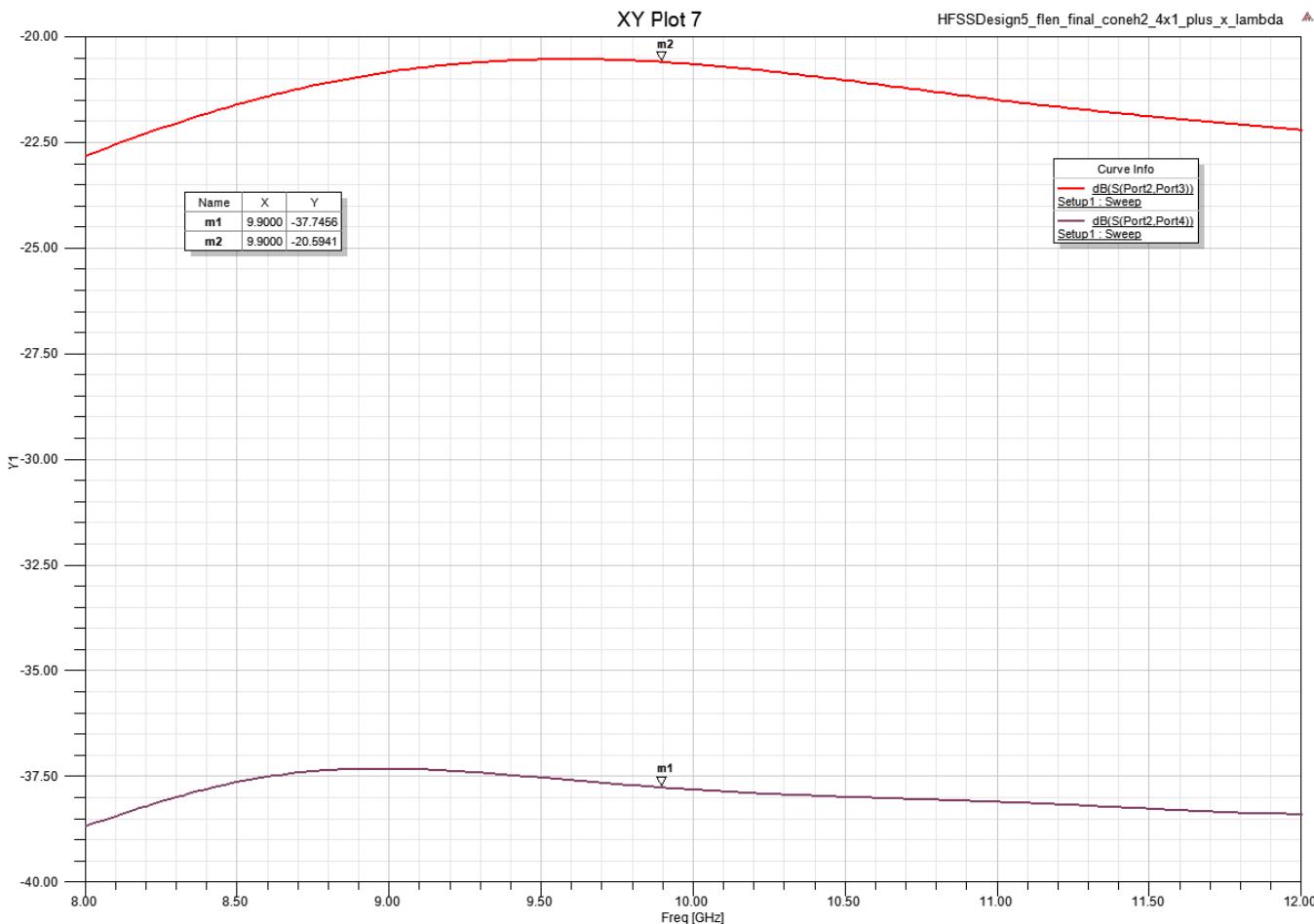


4x1 array (+x direction): S12, S13, S14, parameters, λ spacing



Expected coupling by arrangement by distance between each element
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4x1 array (+x direction): S23, S24,
parameters, λ spacing



4x1 array (+x direction): S34, parameters, λ spacing

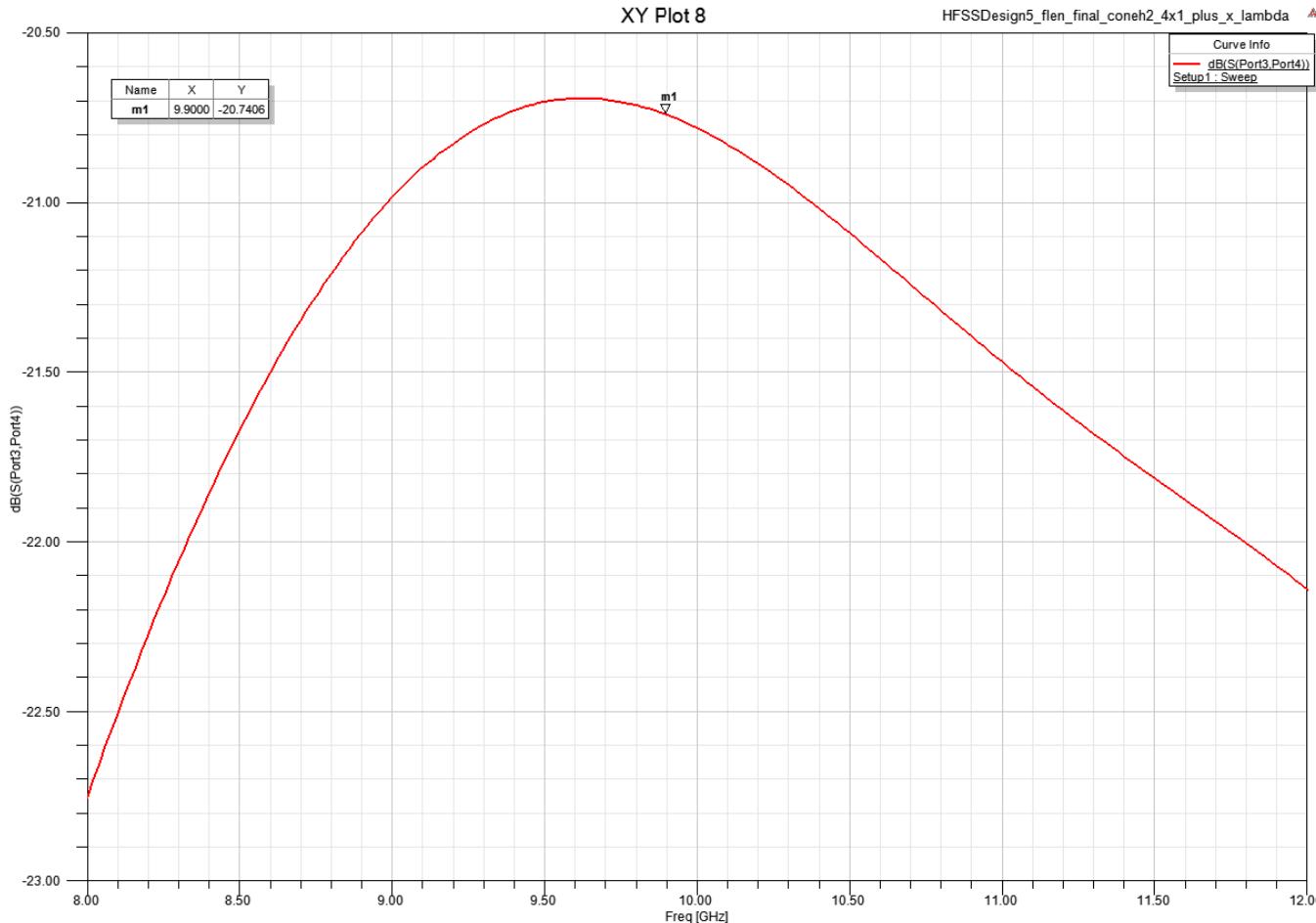


Table Summary

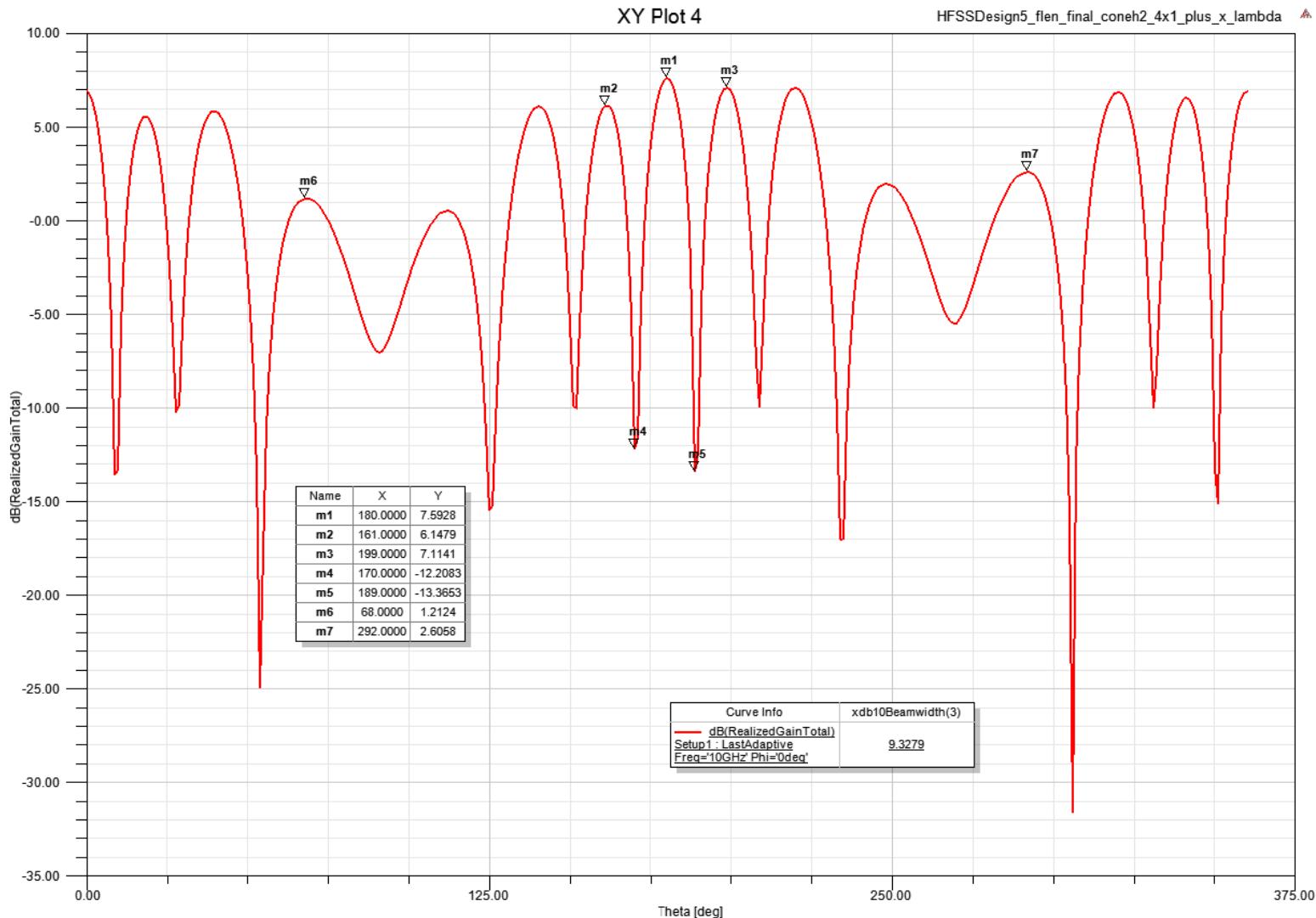
	Original λ spacing	Original $\lambda/2$ spacing
S11	-26.8199 dB	-21.3101 dB
S22	-26.6285 dB	-17.8677 dB
S33	-26.8786 dB	-18.4778 dB
S44	-25.9436 dB	-18.5186 dB
S12	-20.8366 dB	-13.6838 dB
S13	-37.8183 dB	-24.7722 dB
S14	-51.2493 dB	-44.5684 dB
S23	-37.7456 dB	-12.8913 dB
S24	-37.7456 dB	-23.7958 dB
S34	-13.4844 dB	-13.4844 dB

Overall, the λ spacing has better coupling than $\lambda/2$ spacing since it has a higher negative decibel value.

Changing Port Excitation, λ spacing

- From the difference between $\lambda/2$ and λ spacing, we can see from the S-parameter plots, the smaller spacing increases the coupling between elements.
- Lower variations of return loss plots for λ spacing .
- Respective (similar) reflection/transmission coefficients are better for λ (little deviation of plot characteristic)
- The overall coupling between elements is still good even for the worst S-parameter transmission coefficient.

Port 2 and 3 Shorted: Rect. E-field



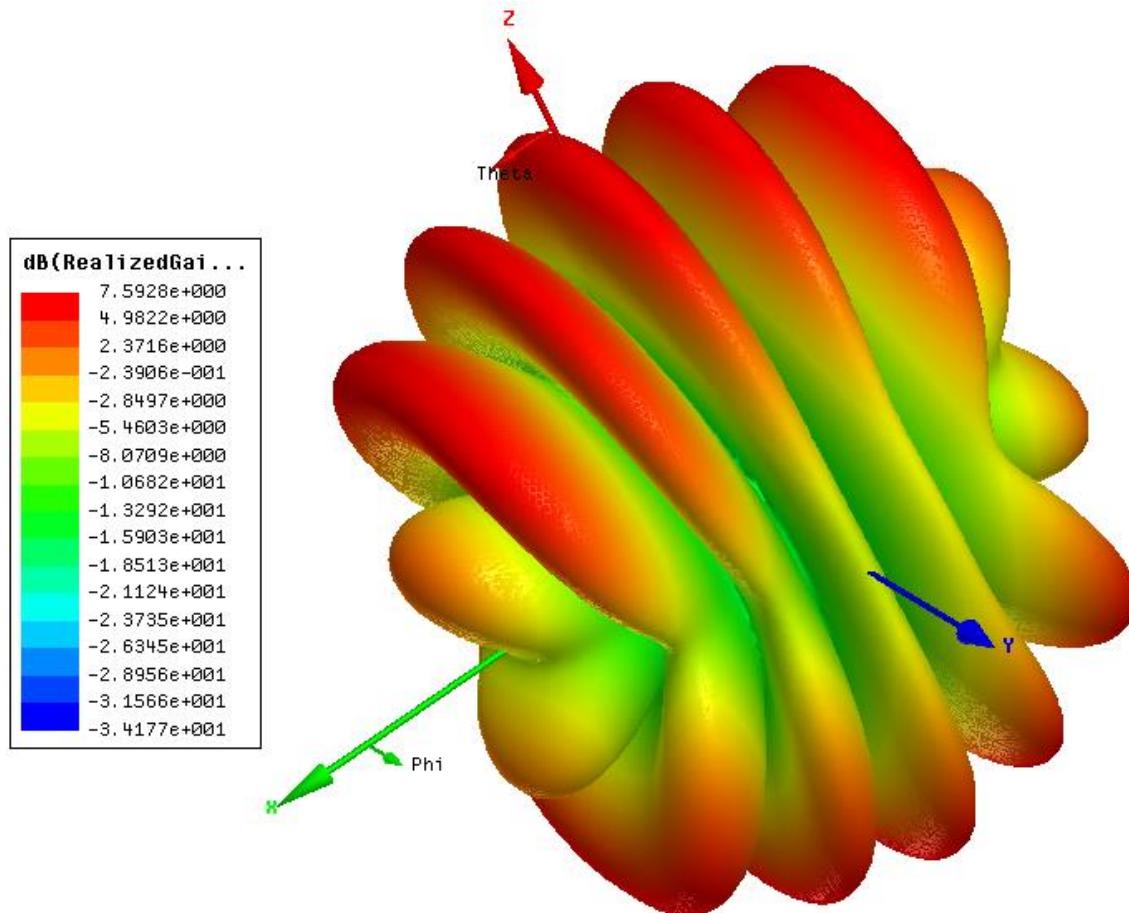
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HPBW = 9.3279° (smaller), SLL = -0.4787 dB , BWFN = 29°

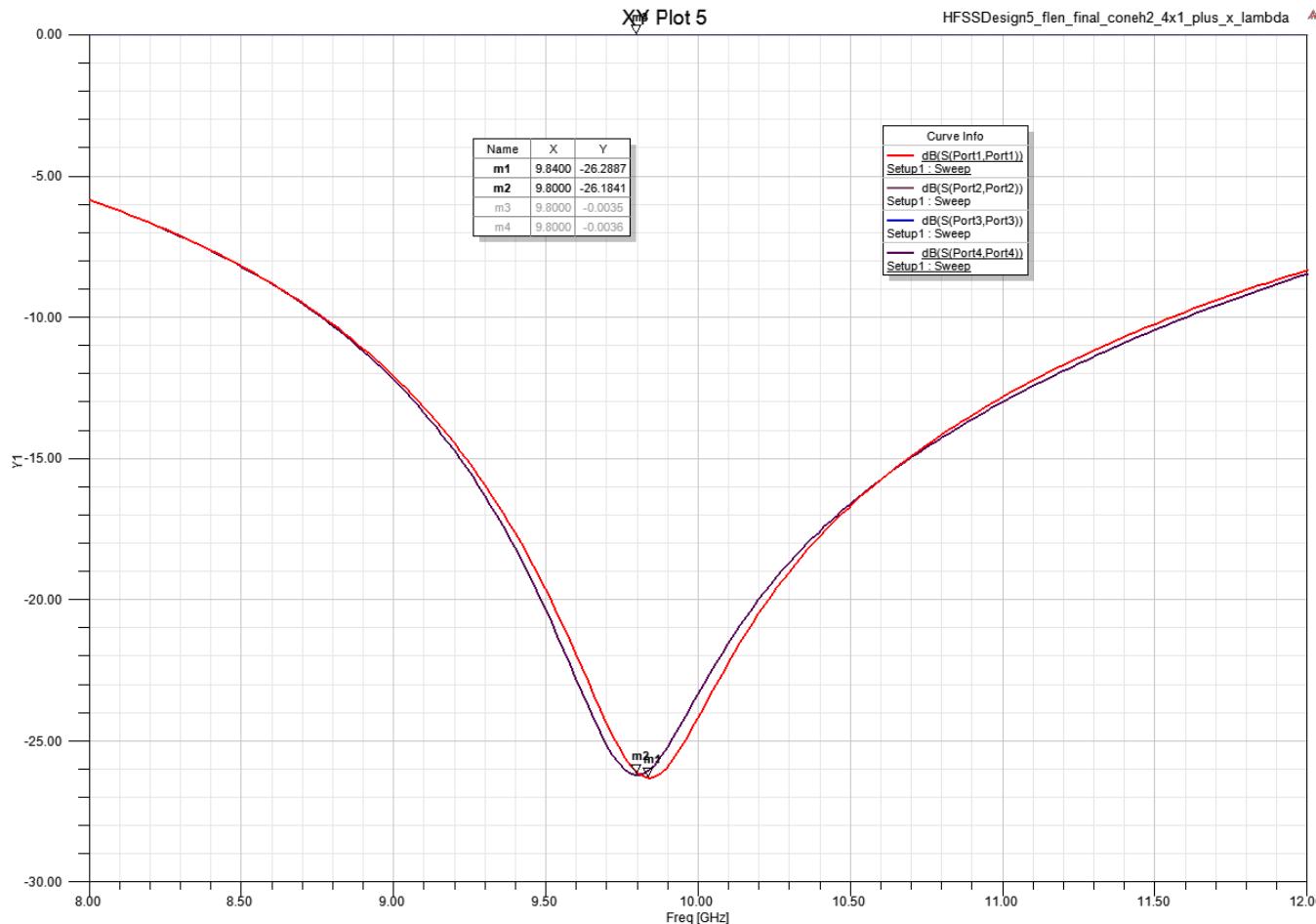
28

Port 2 and 3 Shorted: 3D Polar Plot

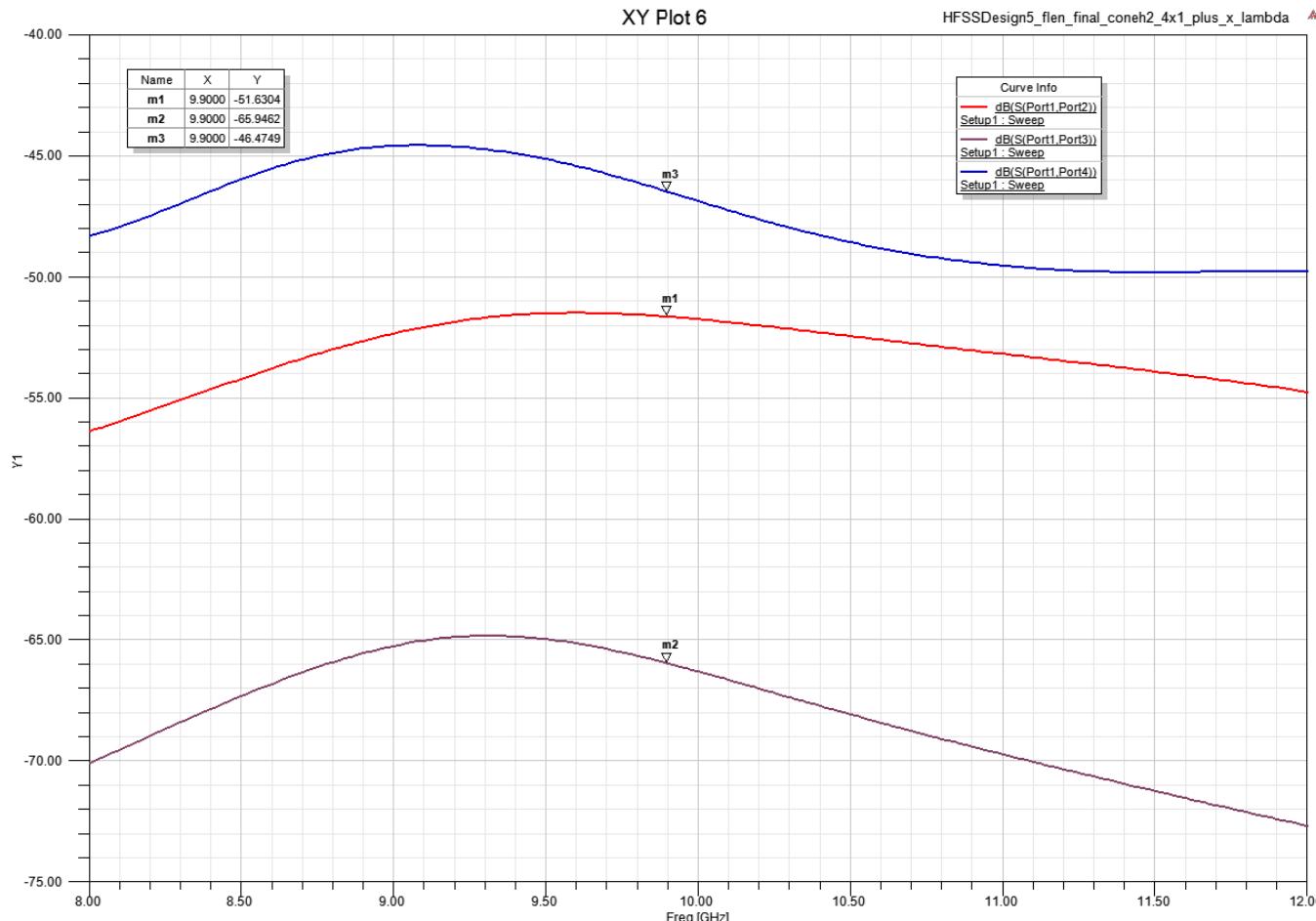
Gain at
7.5928 dB vs.
Gain at
9.7889 dB
(original)



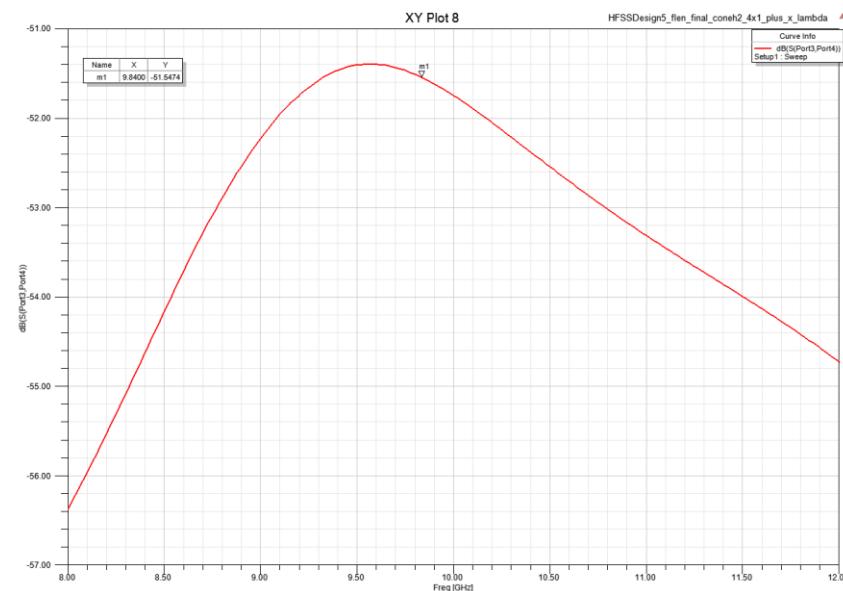
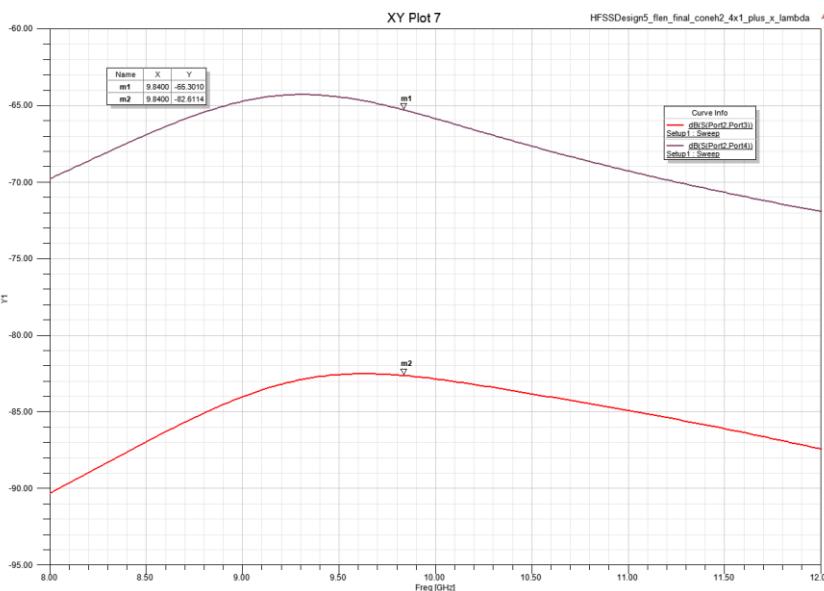
Port 2 and 3 Shorted: S11, S22, S33, S44 parameters, λ spacing



Port 2 and 3 Shorted: S12, S13, S14, parameters, λ spacing



Port 2 and 3 Shorted: S23, S24, S34 parameters, λ spacing

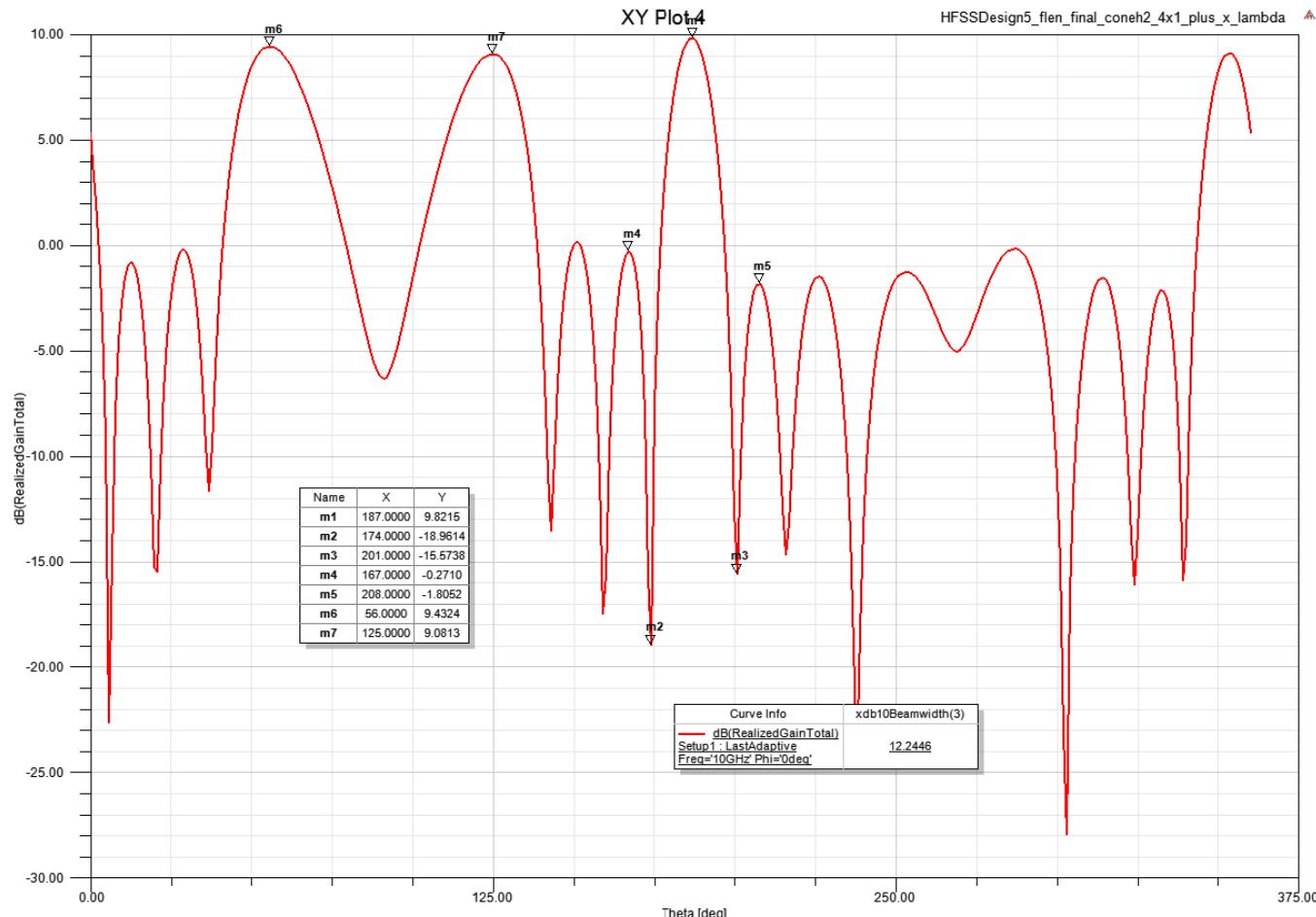


Shorted Port Changes

	Original	Port 2 and Port 3 Shorted
S11	-26.8199 dB	-26.2887 dB
S22	-26.6285 dB	N/A
S33	-26.8786 dB	N/A
S44	-25.9436 dB	-26.1841 dB
S12	-20.8366 dB	-31.5304 dB
S13	-37.8183 dB	-65.9462 dB
S14	-51.2493 dB	-45.4749 dB
S23	-37.7456 dB	-52.6114 dB
S24	-37.7456 dB	-55.3010 dB
S34	-13.4844 dB	-45.4749 dB

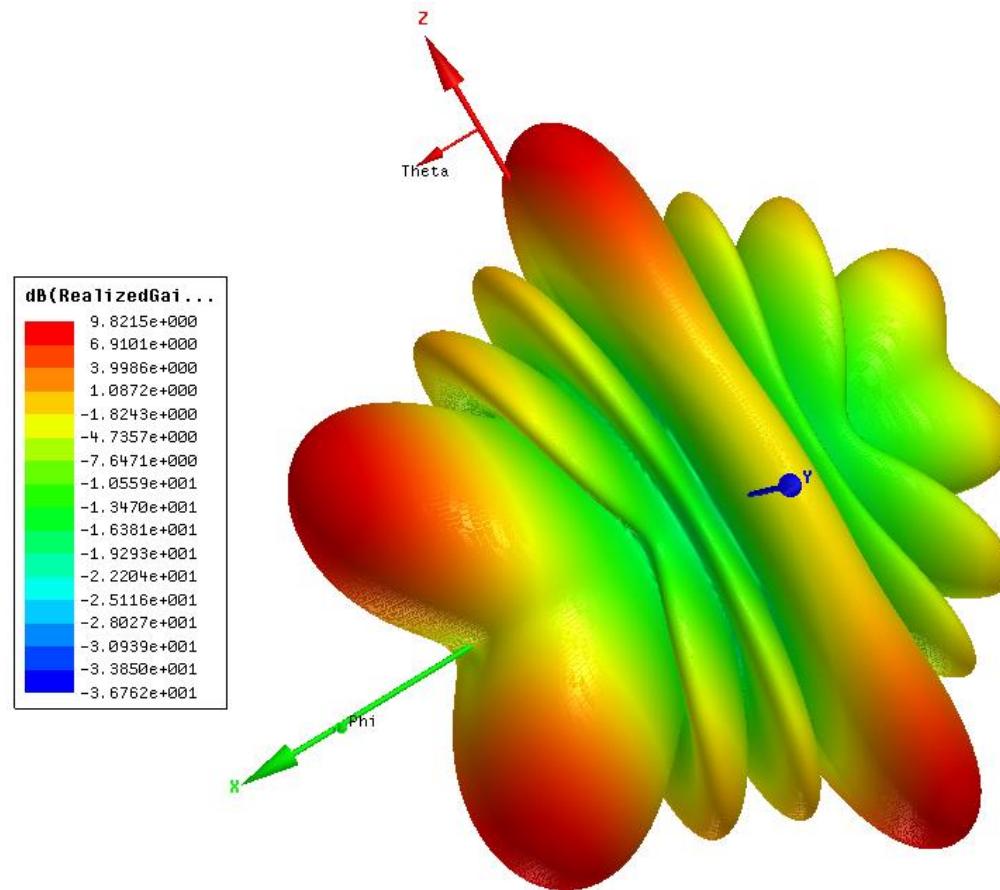
The effect of shorting port 2 and 3 affects the S-parameters having a greater - dB value, which minimizes the mutual coupling between elements. (Assume that it is the case for other combinations)

1D beam, Uniform Beam Scanning, $d = \lambda$ spacing.



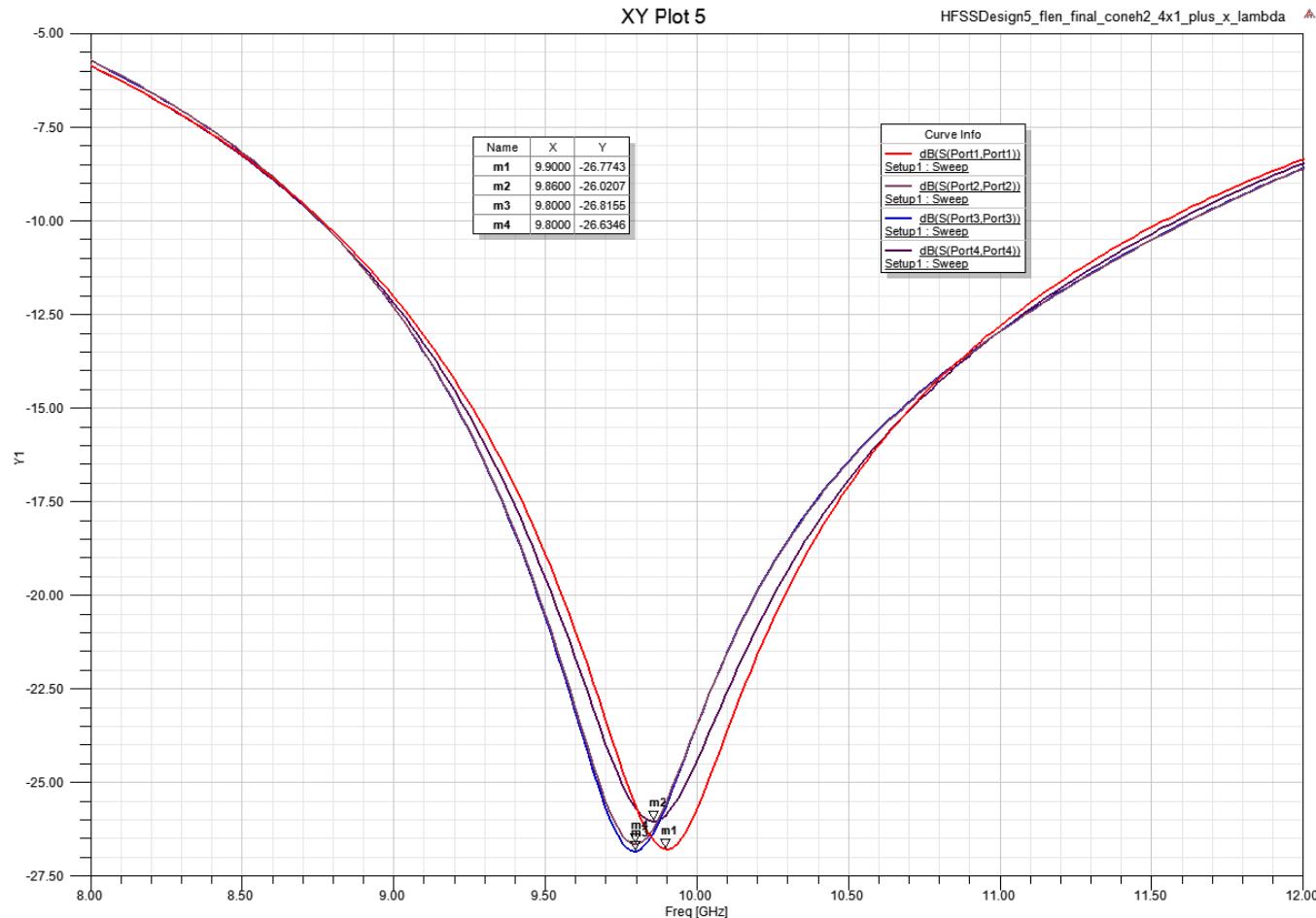
HPBW = 12.2446° (smaller), SLL = -0.3891 dB, BWEN = 27° (Not symmetrical)
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1D beam, Uniform Beam Scanning, $d = \lambda$ spacing, 3D Polar Plot

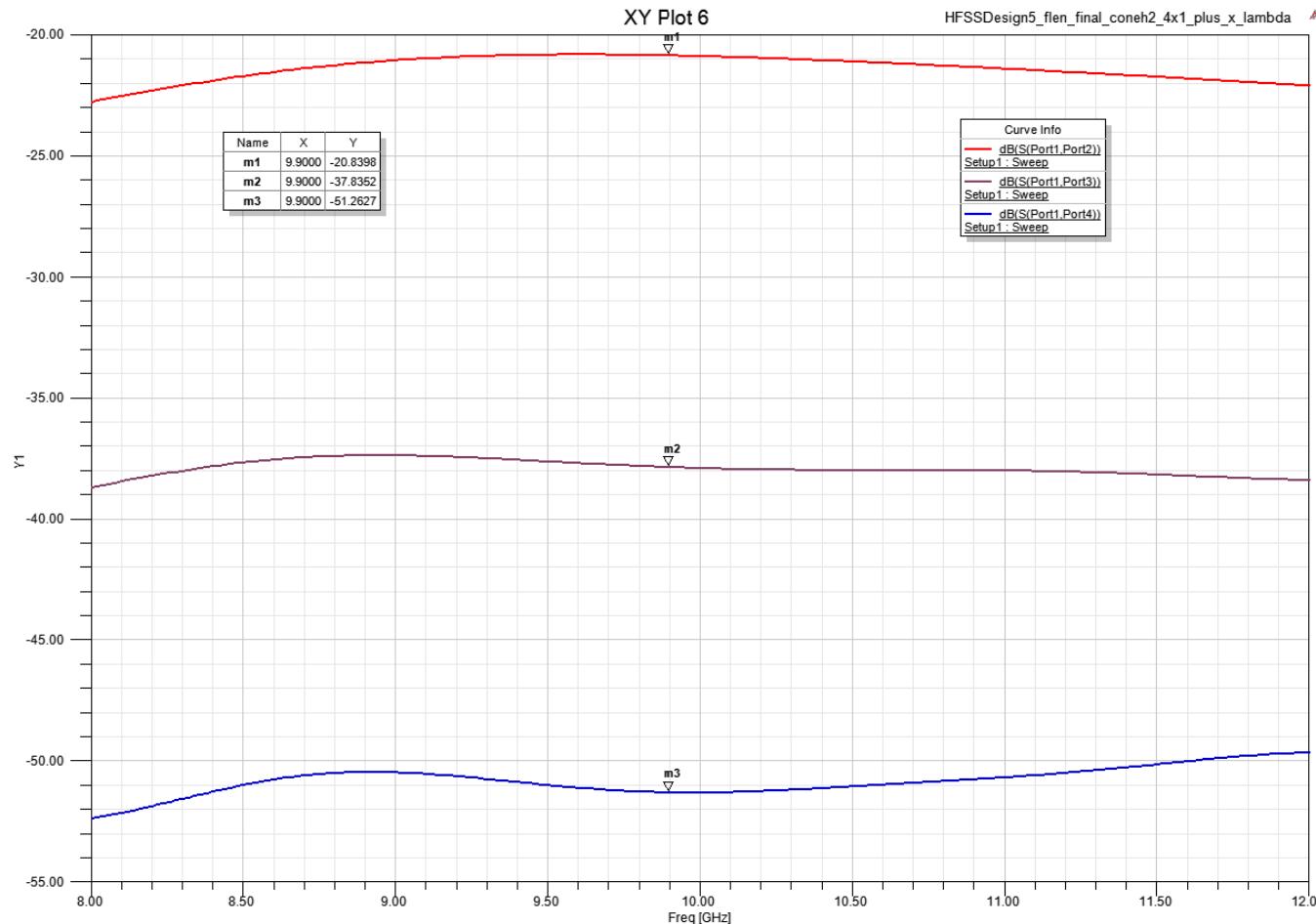


Gain at 9.7889 dB (original) compared to 9.8215 dB (not much change, pattern does)

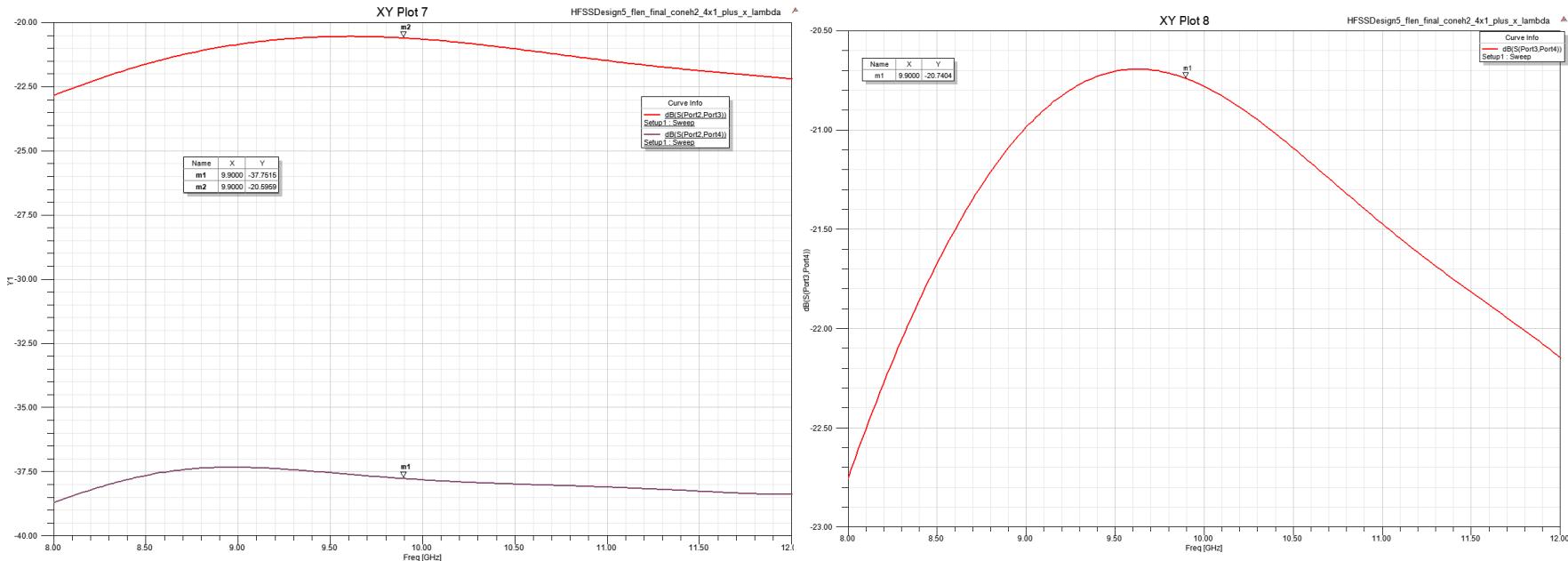
1D beam, Uniform Beam Scanning, $d = \lambda$ spacing: S11, S22, S33, S44 parameters



1D beam, Uniform Beam Scanning, $d = \lambda$ spacing: S12, S13, S14, parameters



1D beam, Uniform Beam Scanning, $d = \lambda$ spacing: S23, S24, S34 parameters



1D beam, Uniform Beam Scanning, S-parameter and coupling

	Original	Uniform 1D beam scanning
S11	-26.8199 dB	-26.7743 dB
S22	-26.6285 dB	-26.6285 dB
S33	-26.8786 dB	-26.8155 dB
S44	-25.9436 dB	-26.0207 dB
S12	-20.8366 dB	-20.8398 dB
S13	-37.8183 dB	-37.8352 dB
S14	-51.2493 dB	-51.26227 dB
S23	-37.7456 dB	-20.5959 dB
S24	-37.7456 dB	-37.7516 dB
S34	-13.4844 dB	-20.7404 dB

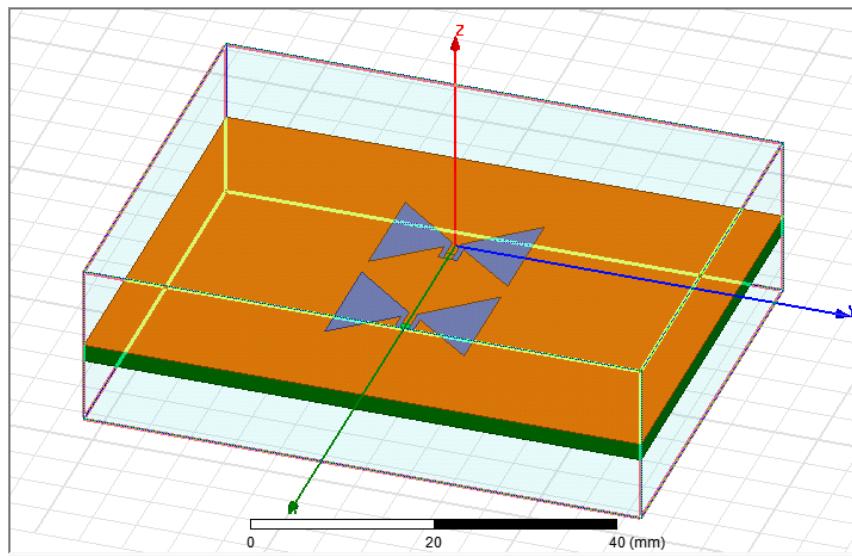
Not much of change to the S-parameters except for S23 and S34 (perhaps

Appendix: Phase I Comparison (Optional, if not enough time)

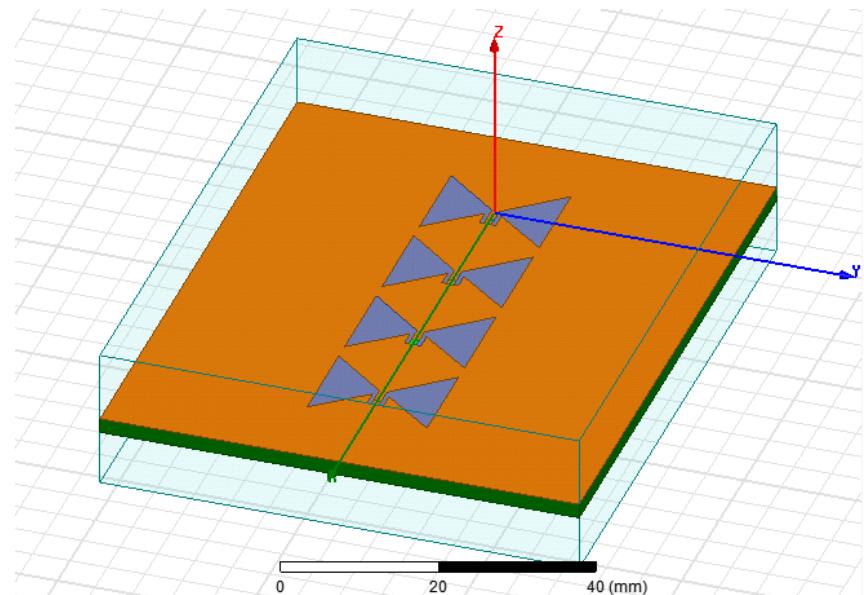
- Semi-Replacement for Phase I slides.
 - What to expect:
 - Higher Gain for 4x1 Array antenna
 - More/Multiple complex side-lobes for λ spacing
 - S-parameters are similar (not reciprocal).
 - Effect of Grating lobes for lambda spacing becomes more probable.
 - Plots are redone to make up for the spiky ones from Phase I.
 - Main/Side Lobes merged with other lobes for higher element array. (not as distinct)

Layout: 2×1 Array, 4×1 Array $d = \lambda/2$,

2x1 Array

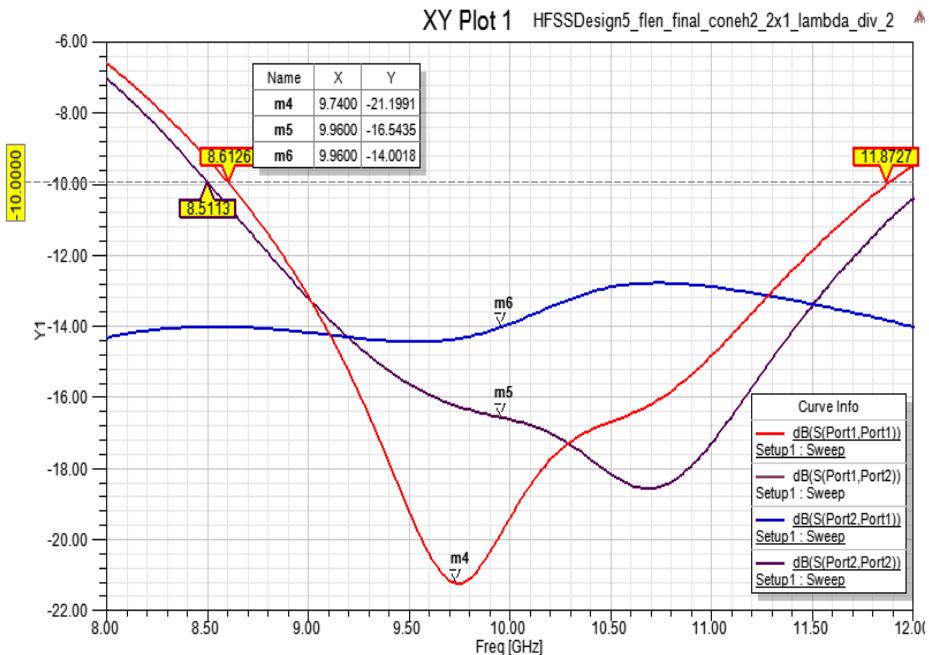


4x1 Array

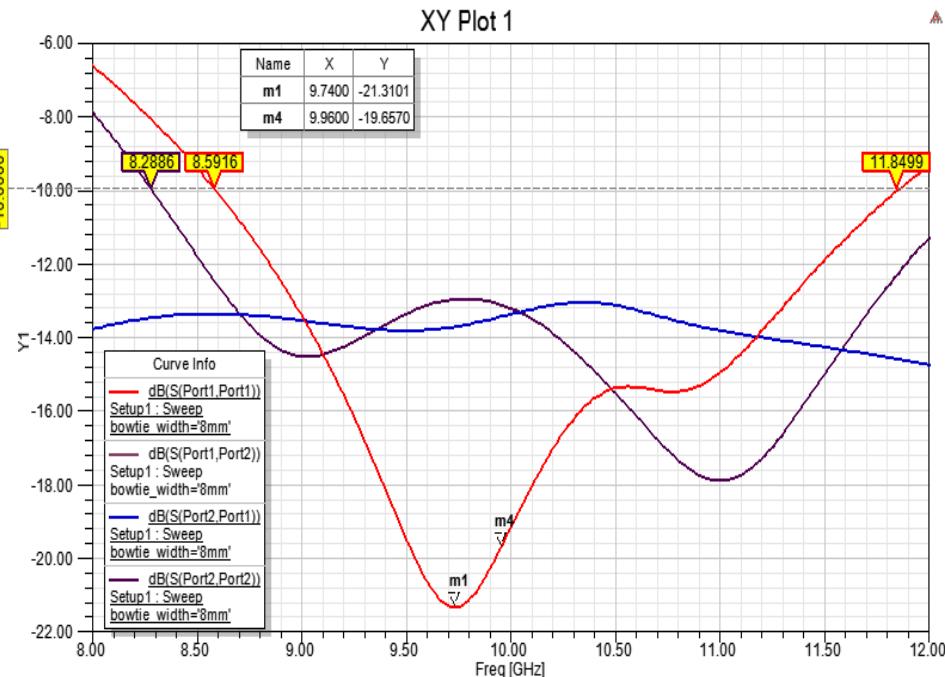


S parameters, $d = \lambda/2$

2 x 1 Array



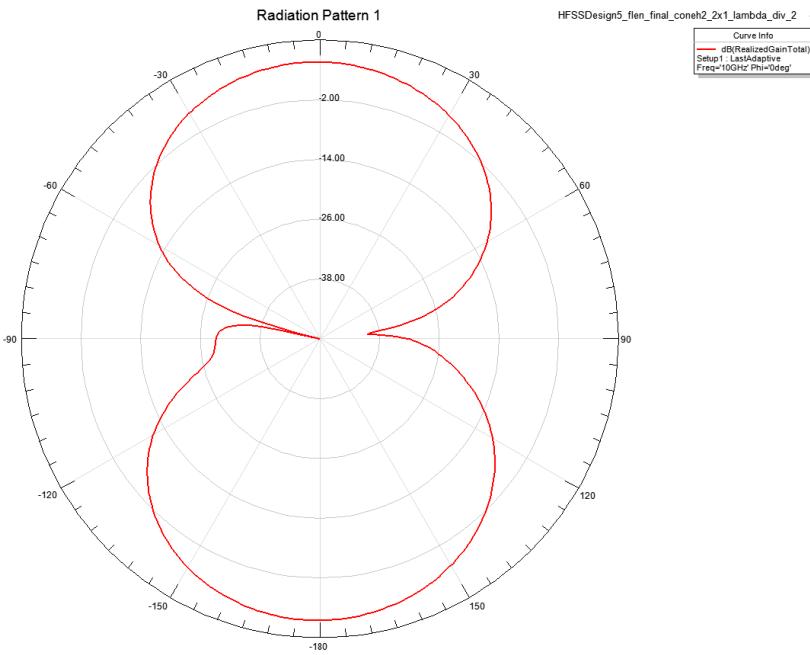
4x1 Array



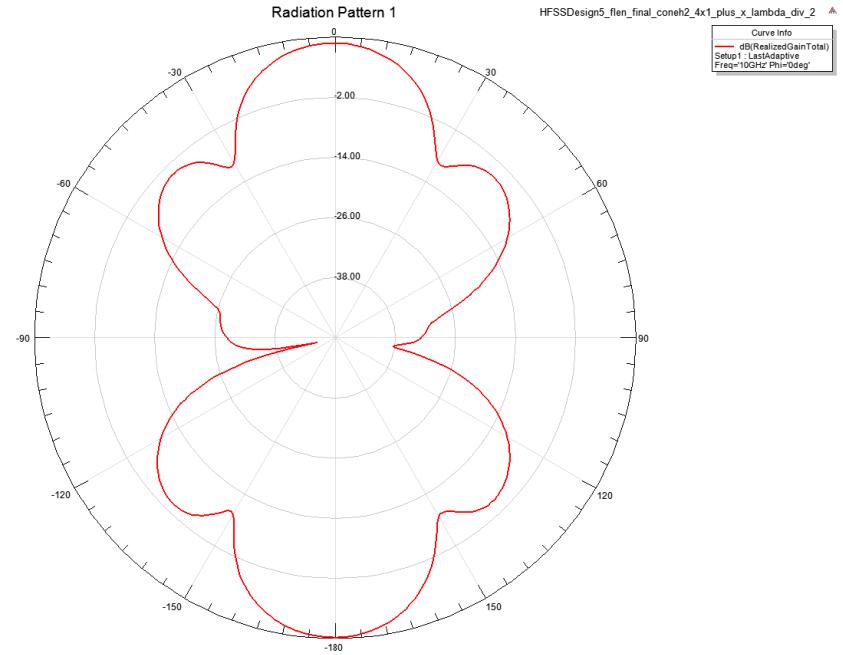
$S_{12} = S_{21}$ same, S_{11} not equal to S_{22}

E-plane ($d = \lambda/2$)

2x1 Array

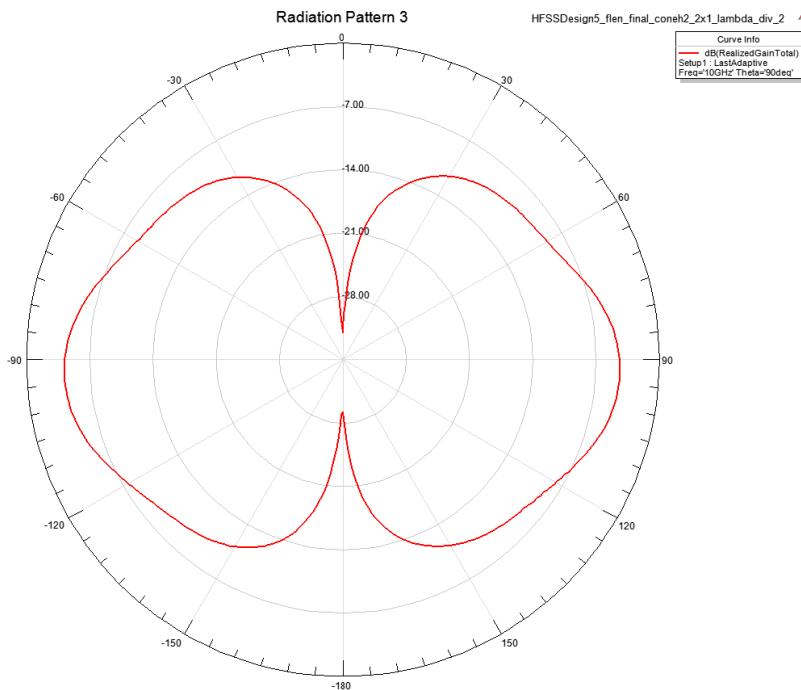


4x1 Array

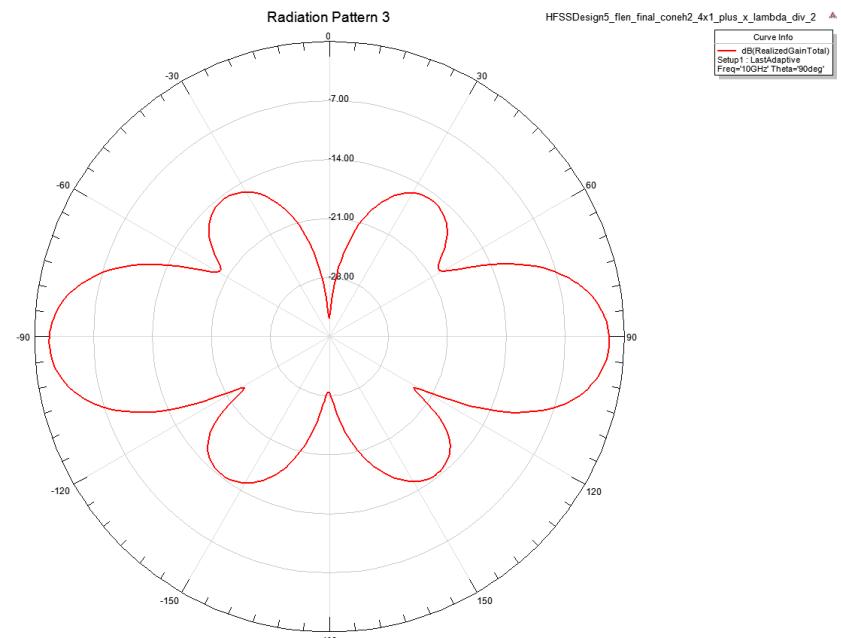


H-plane ($d = \lambda/2$)

2x1 Array

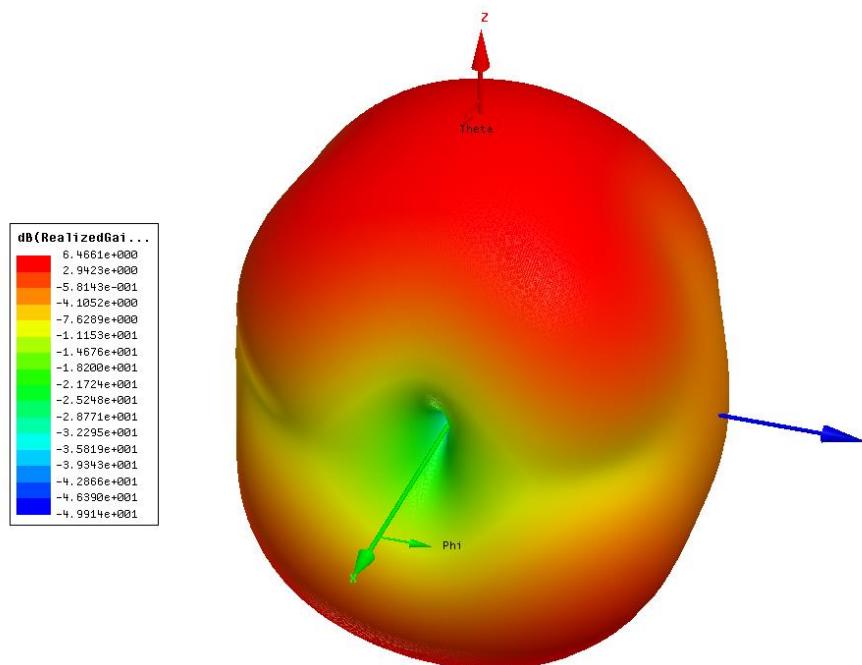


4x1 Array

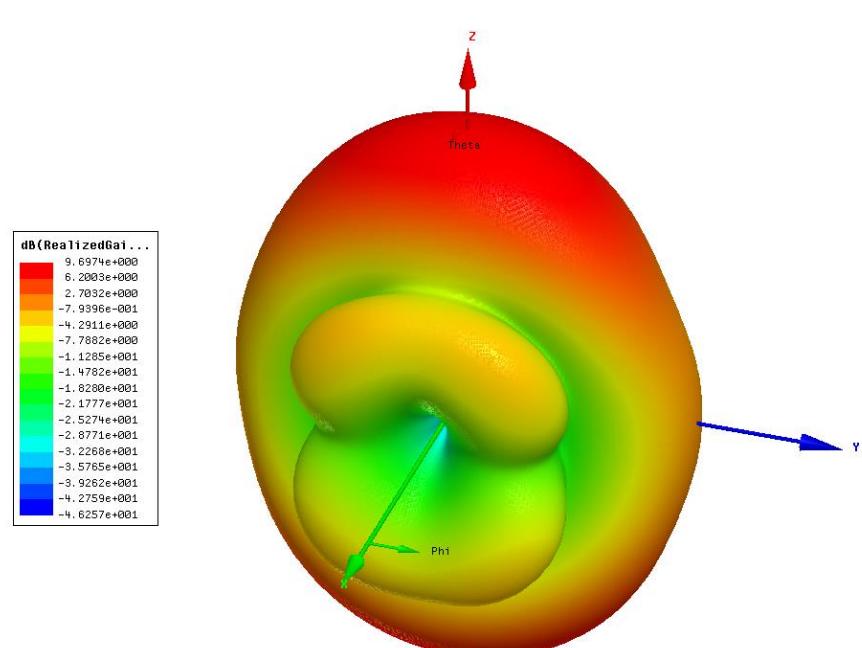


3D Polar Plot: $d = \lambda/2$

2x1 Array

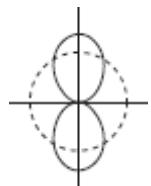
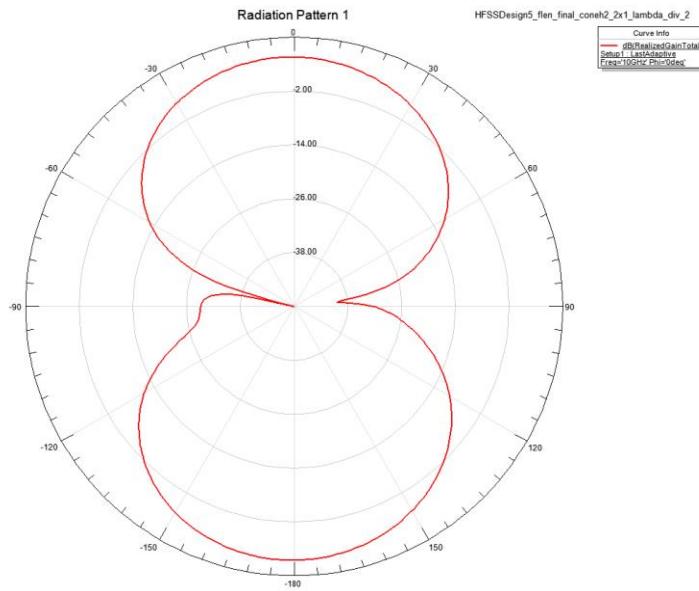


4x1 Array



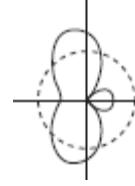
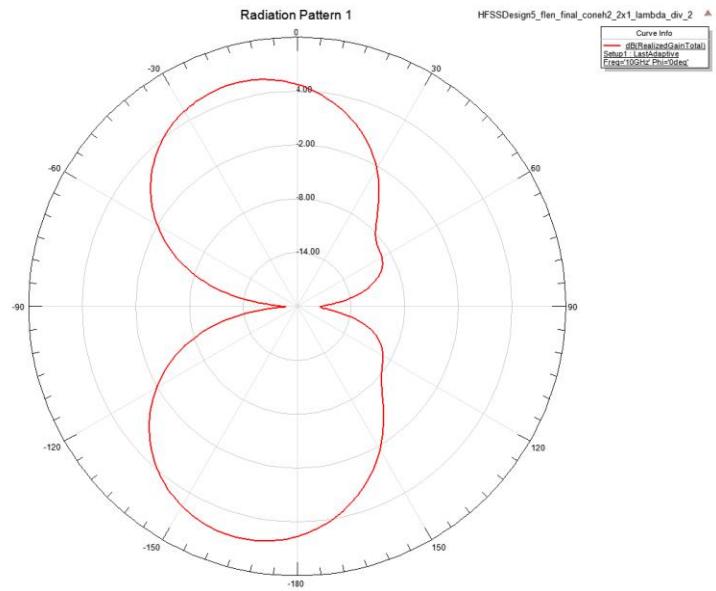
Excitation Phase, $d = \lambda/2$, 2x1 Array

Phase = 0 degrees



[2]

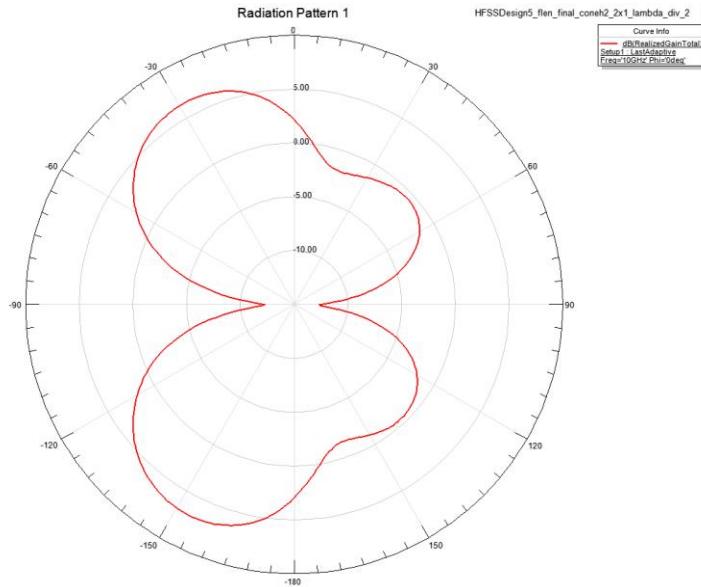
Phase = 45 degrees



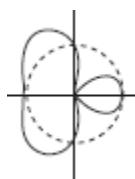
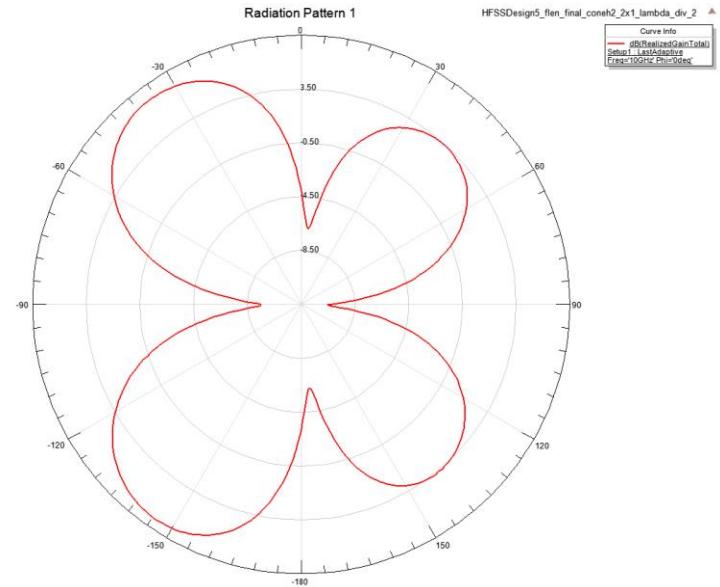
[2]

Excitation Phase, $d = \lambda/2$, 2x1 Array

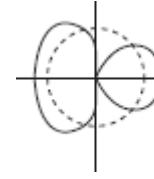
Phase = 90 degrees



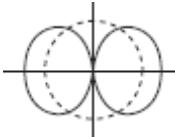
Phase = 135 degrees



[2]

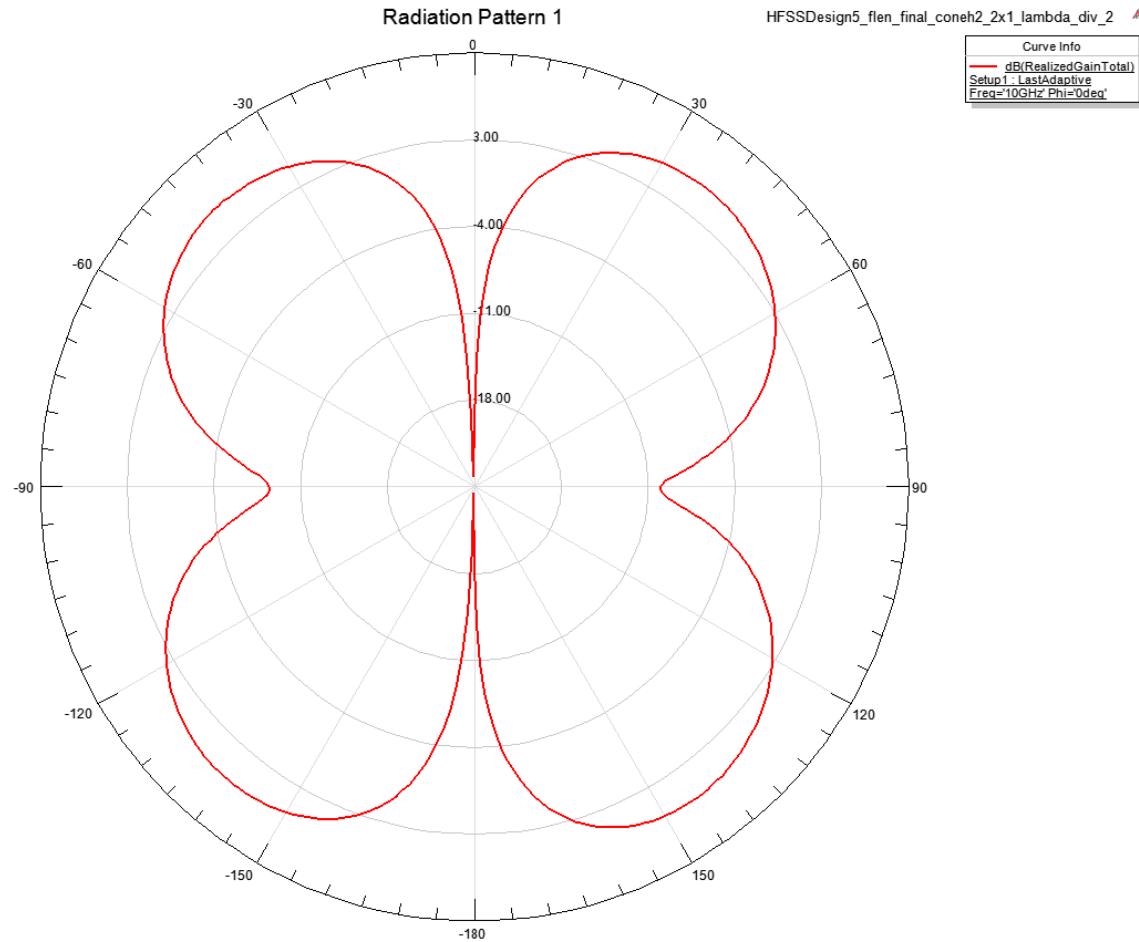


[2]



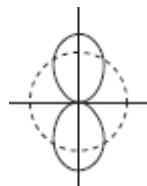
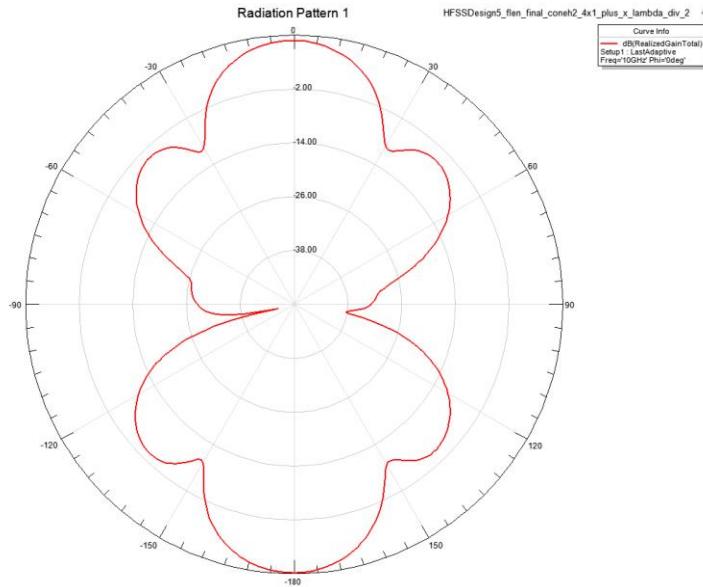
[2]

Excitation Phase, $d = \lambda$ Phase = 180 degrees, 2x1 Array



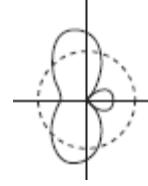
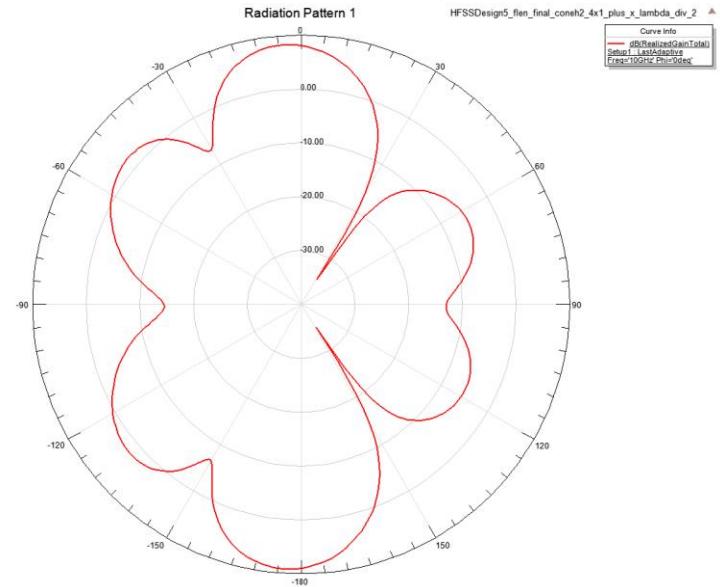
Excitation Phase, $d = \lambda/2$, 4x1 Array

Phase = 0 degrees



[2]

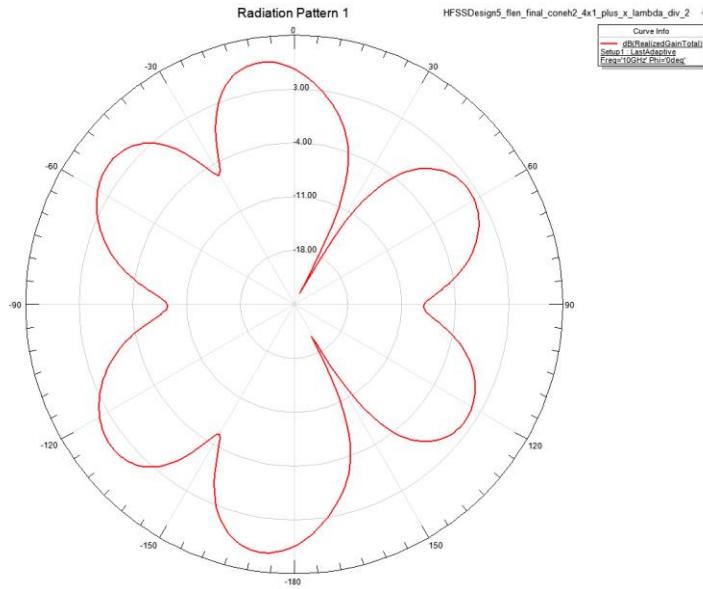
Phase = 45 degrees



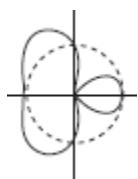
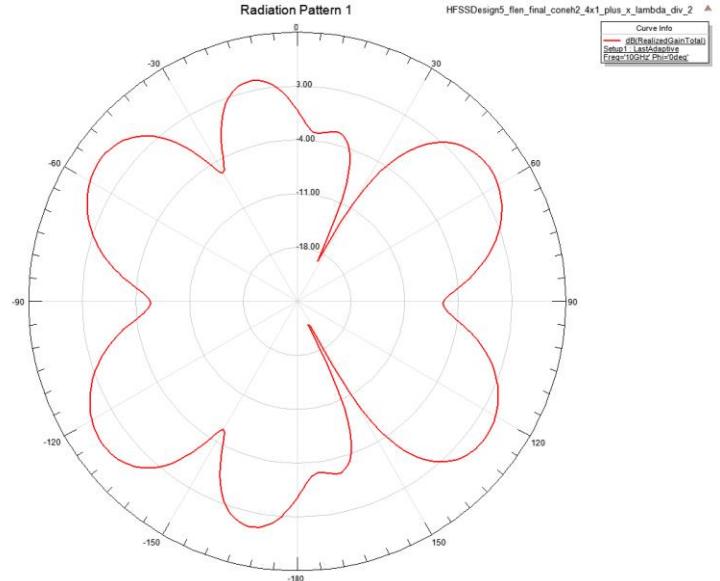
[2]

Excitation Phase, $d = \lambda/2$, 4x1 Array

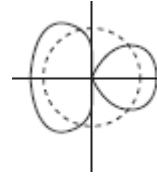
Phase = 90 degrees



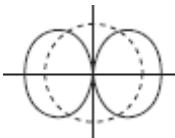
Phase = 135 degrees



[2]

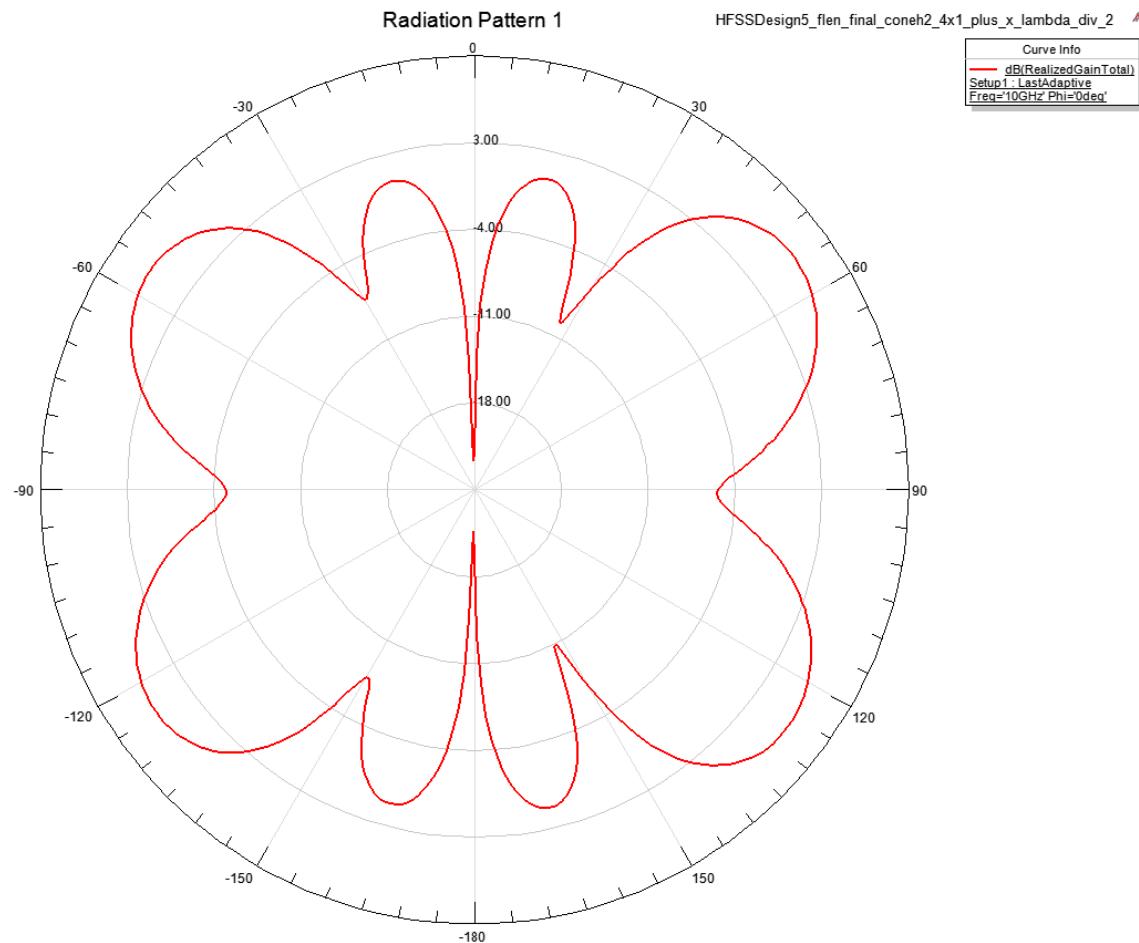


[2]



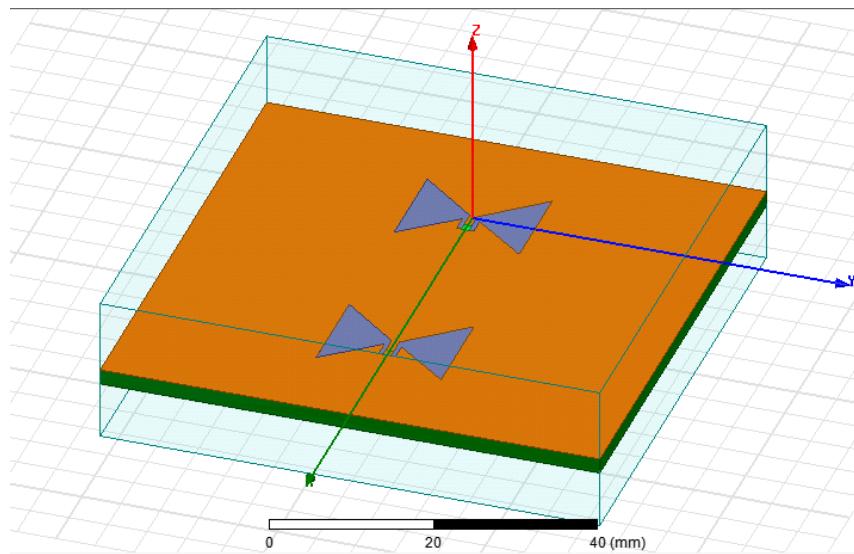
[2]

Excitation Phase, $d = \lambda$ Phase = 180 degrees, 4x1 Array

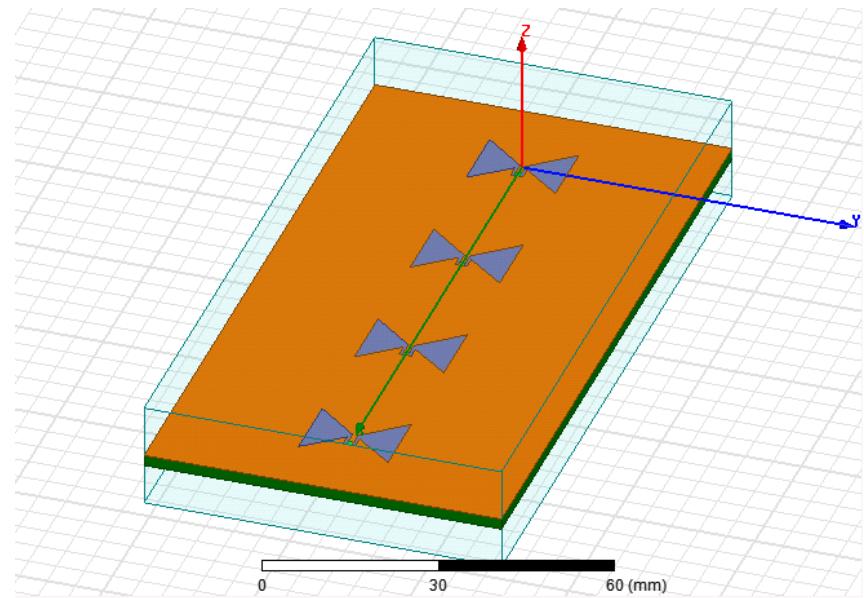


Layout: 2x1 Array, 4x1 Array, $d = \lambda$

2x1 Array

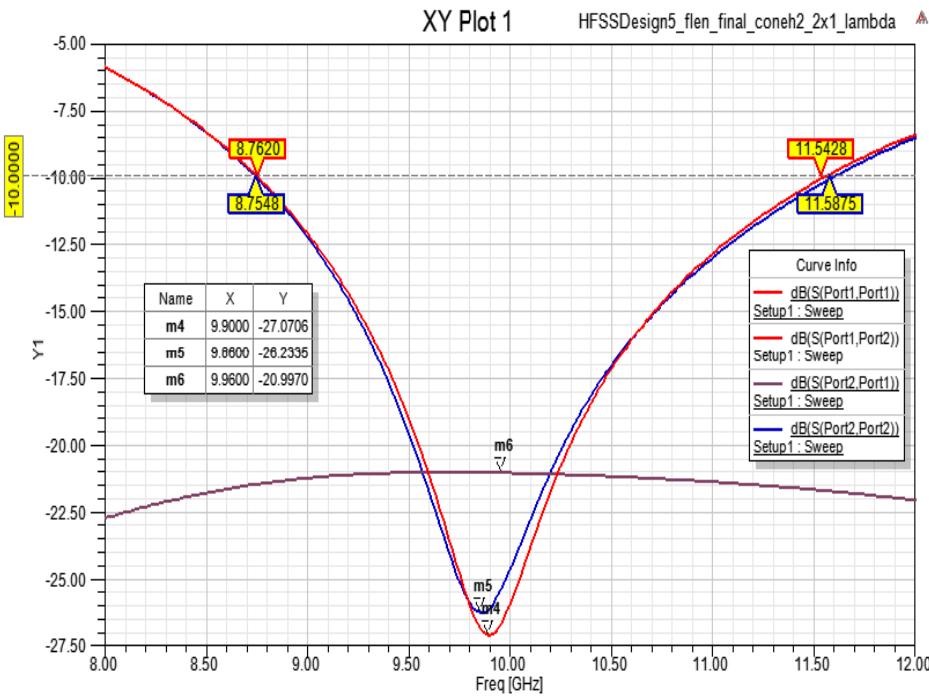


4x1 Array

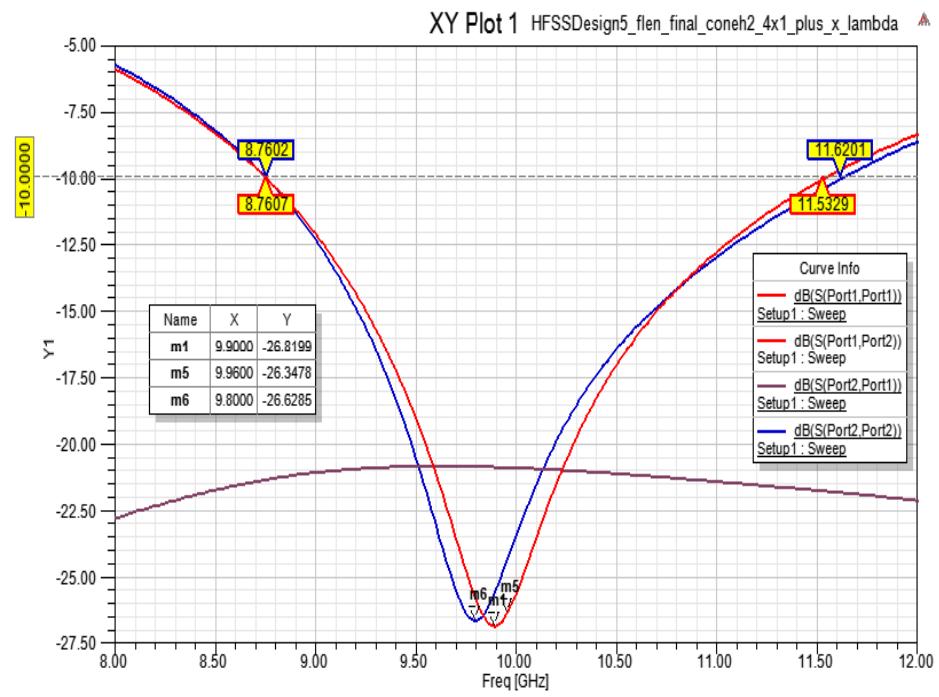


S parameters, $d = \lambda$

2x1 Array

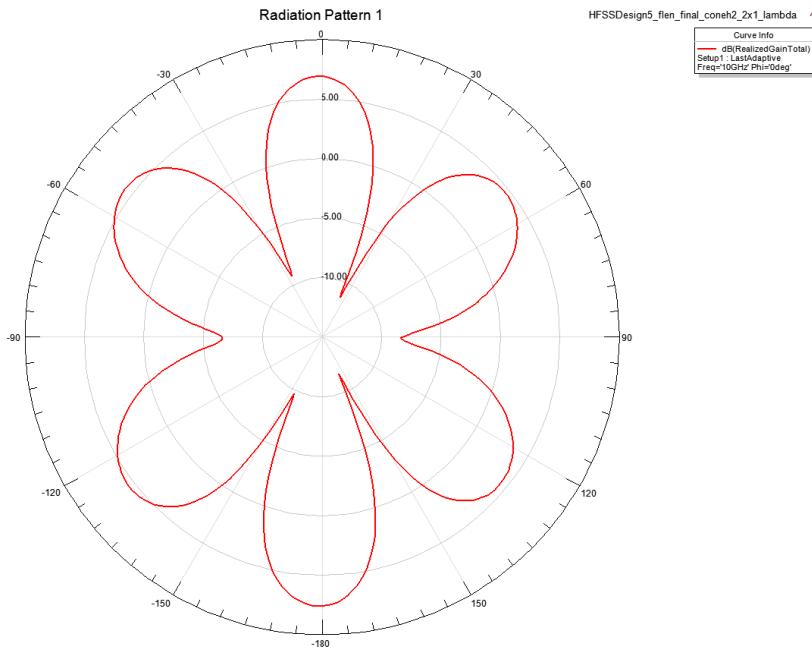


4x1 Array

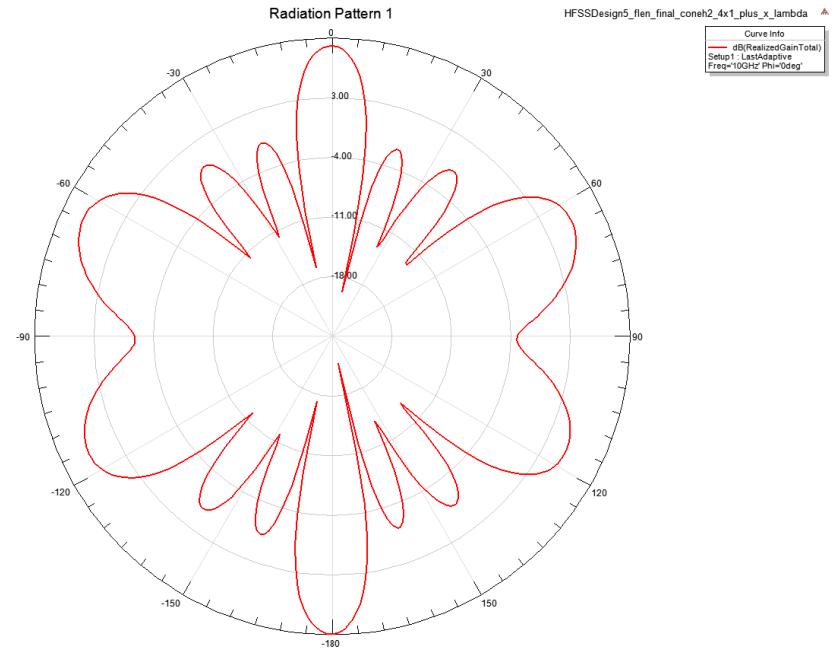


E-plane ($d = \lambda$)

2x1 Array

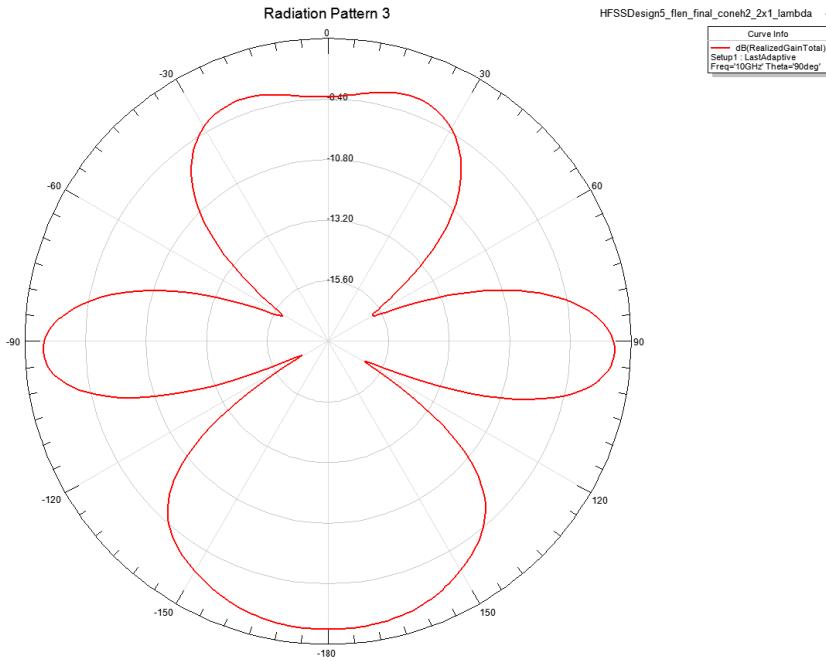


4x1 Array

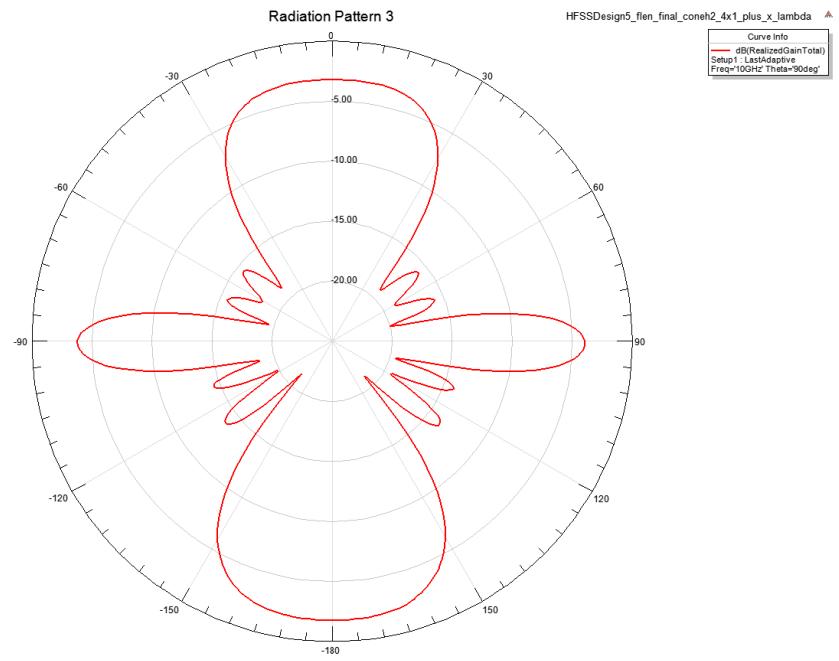


H-plane ($d = \lambda$)

2x1 Array

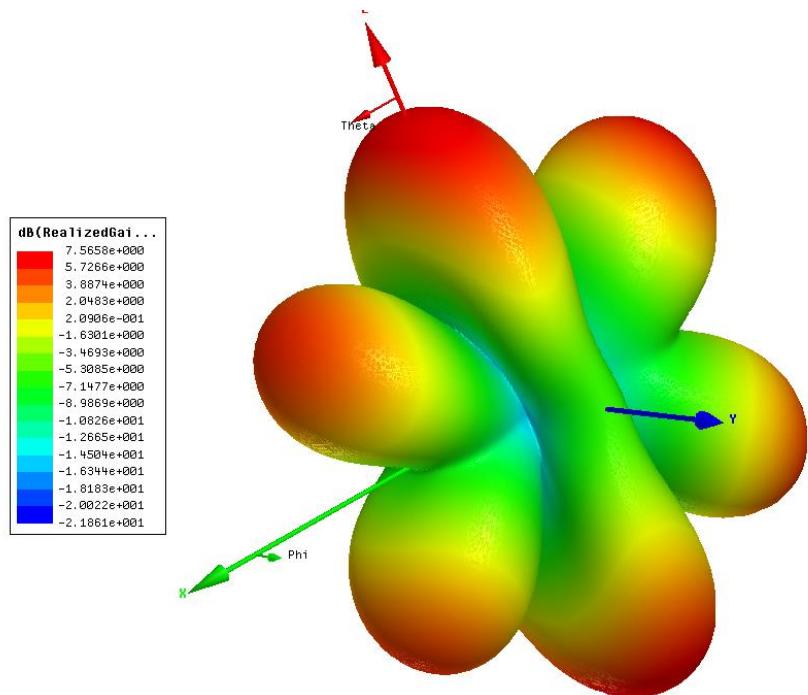


4x1 Array

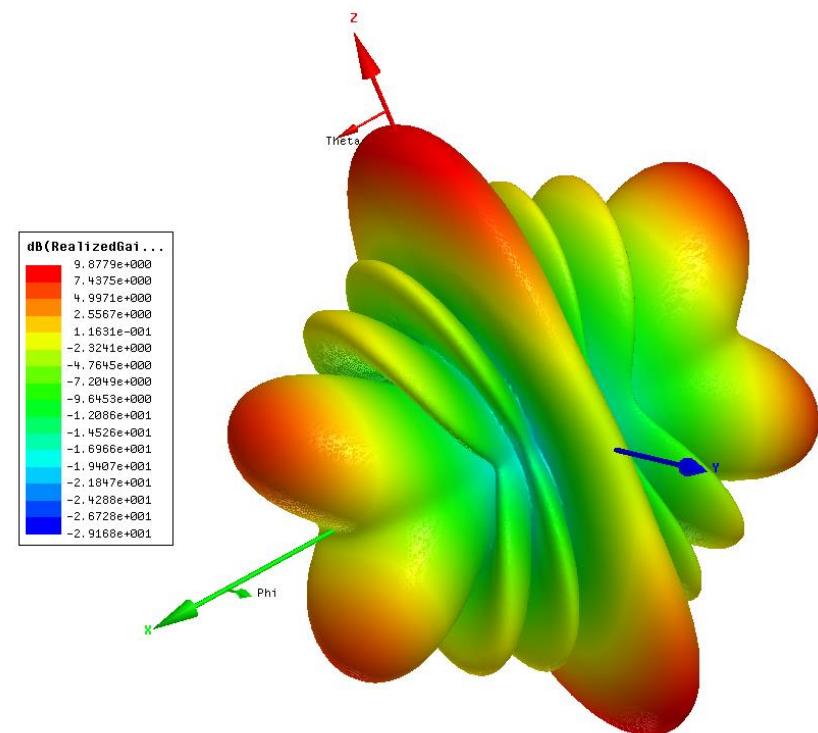


3D Polar Plot: $d = \lambda$

2x1 Array



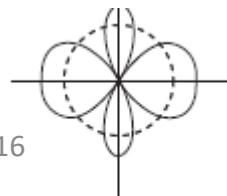
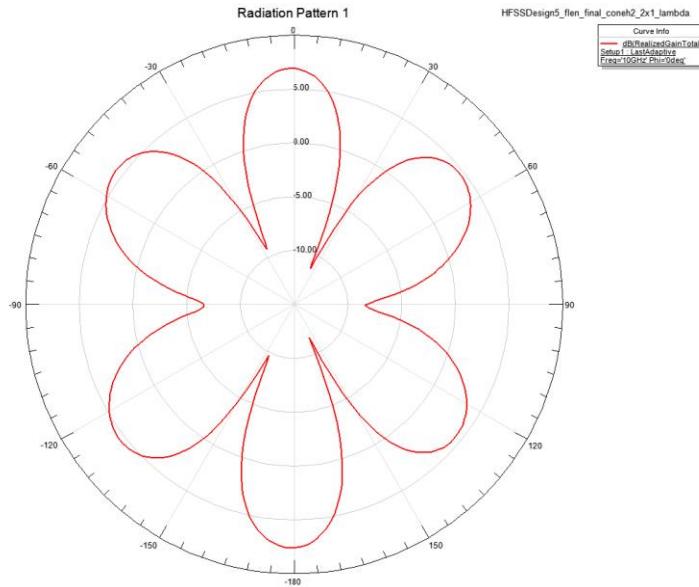
4x1 Array



Larger Gain for 4x1 array, growth of multiple sidelobes for λ .

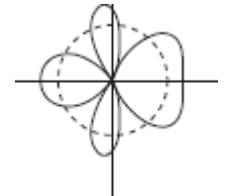
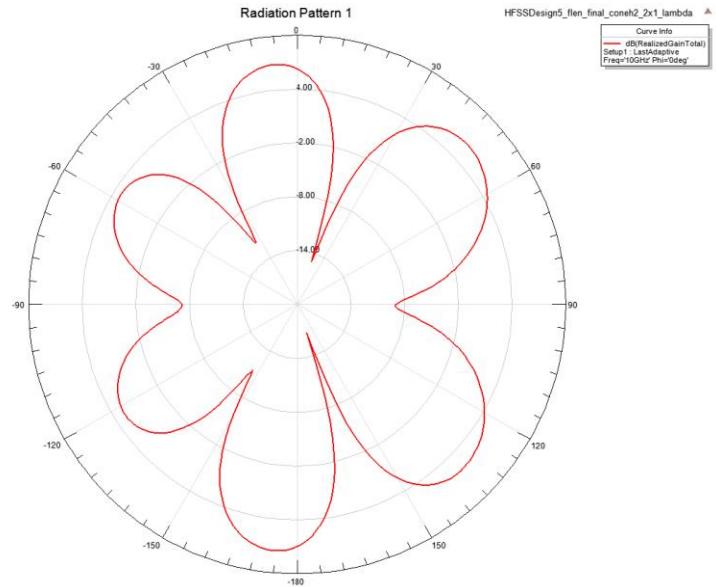
Excitation Phase, $d = \lambda$, 2x1 Array

Phase = 0 degrees



[2]

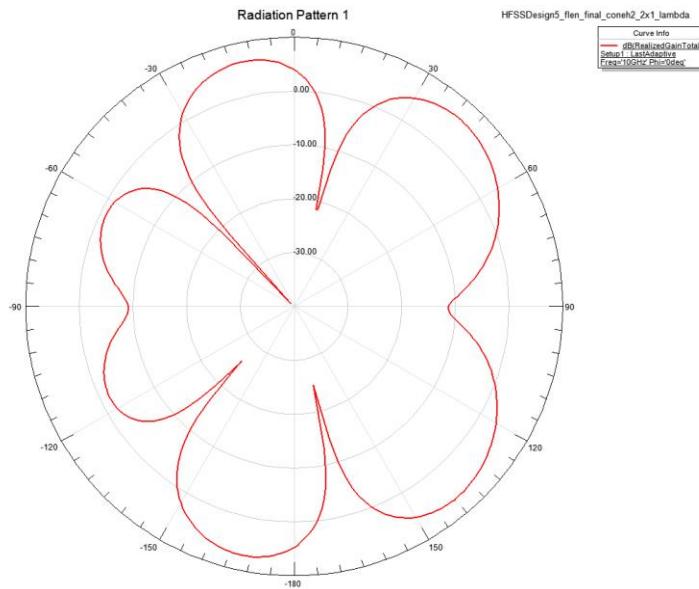
Phase = 45 degrees



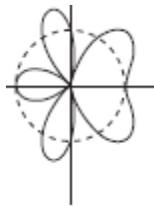
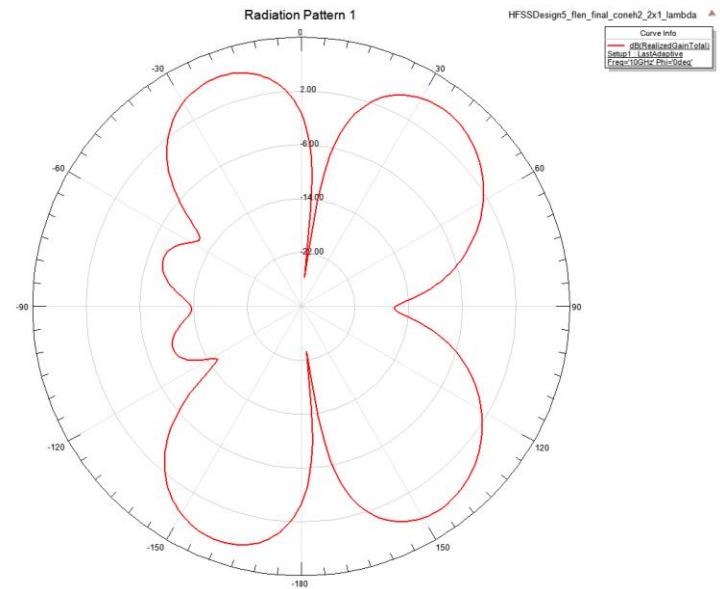
[2]

Excitation Phase, $d = \lambda$, 2x1 Array

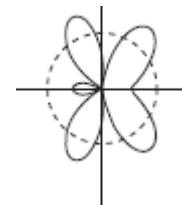
Phase = 90 degrees



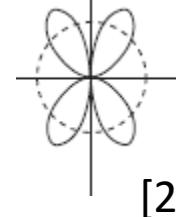
Phase = 135 degrees



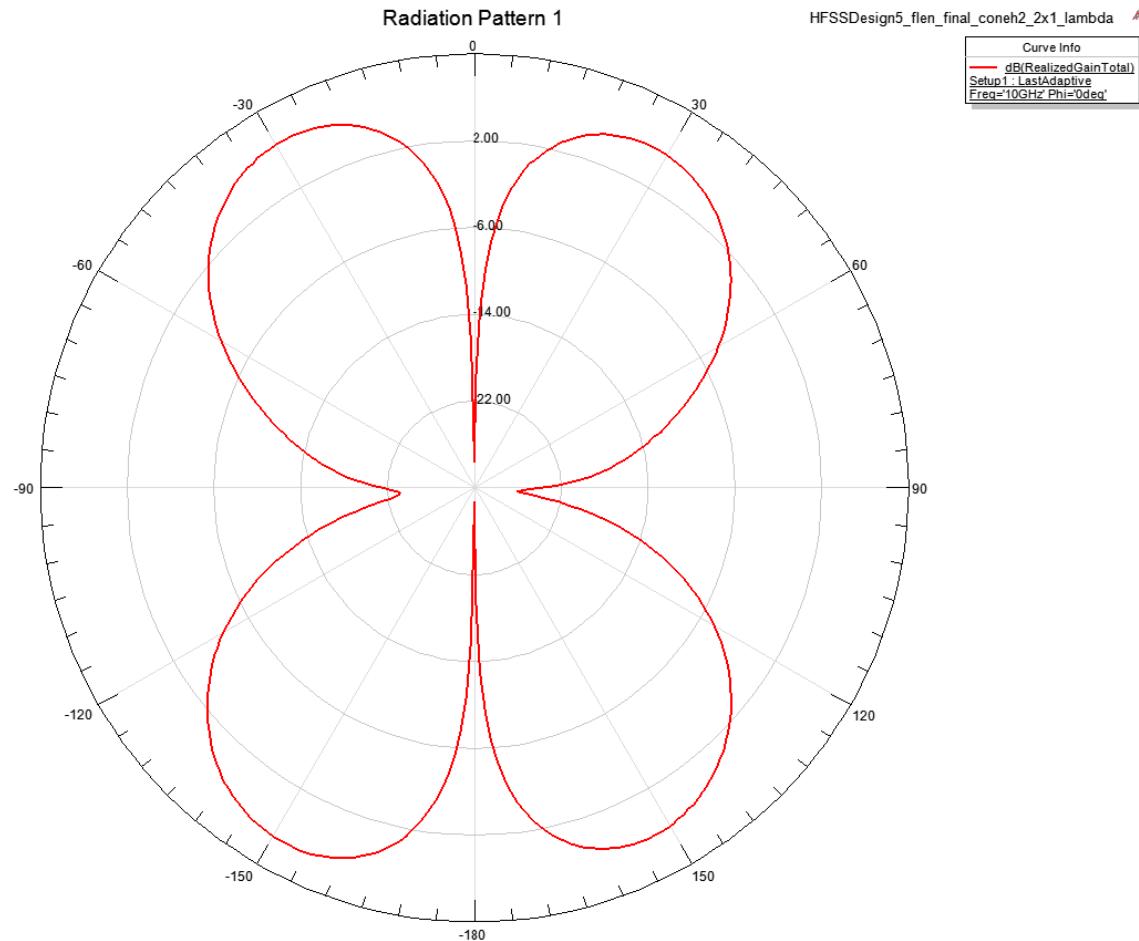
[2]



[2]

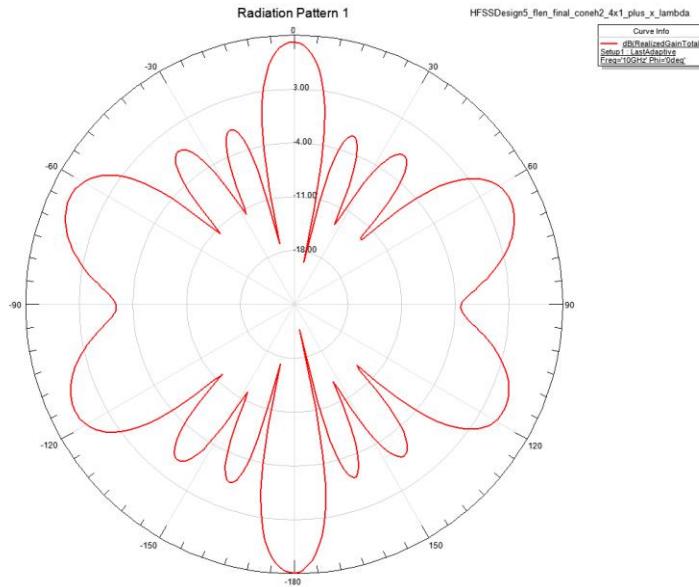


Excitation Phase, $d = \lambda$ Phase = 180 degrees, 2x1 Array

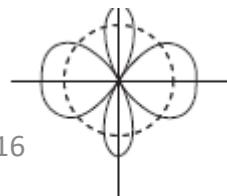
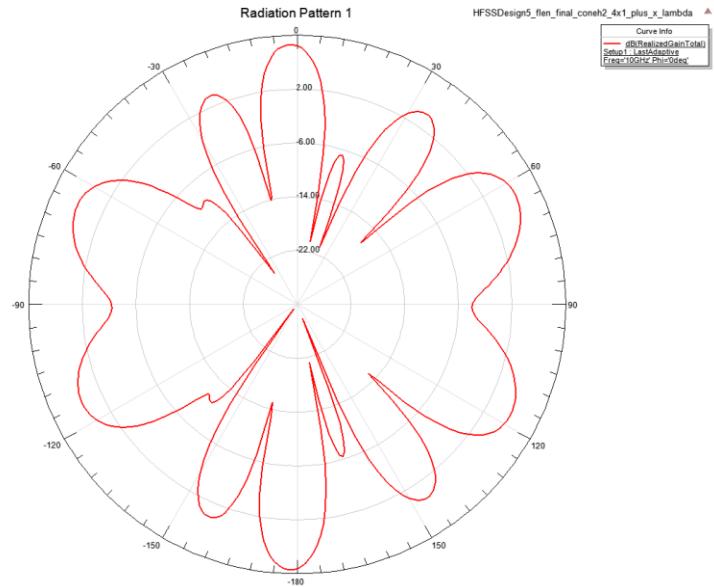


Excitation Phase, $d = \lambda$, 4x1 Array

Phase = 0 degrees

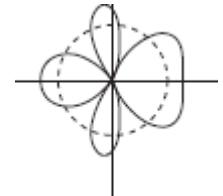


Phase = 45 degrees



[2]

10/30/2016



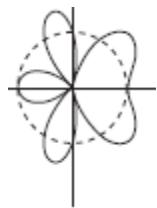
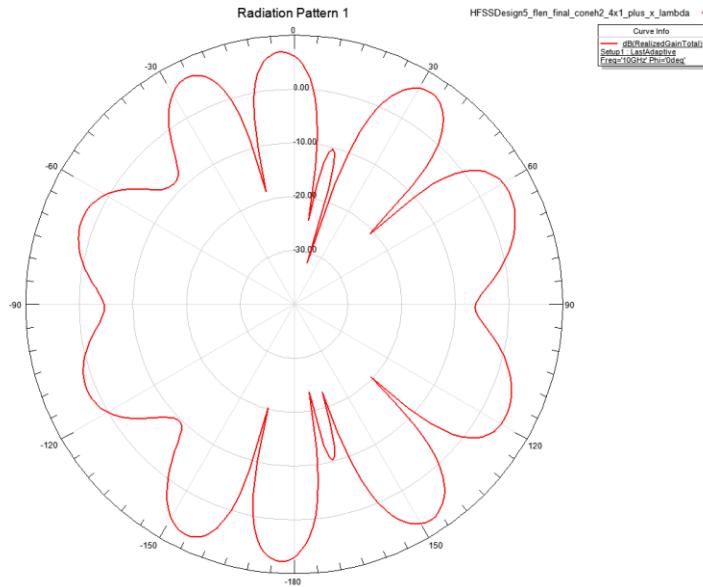
[2]

Troy Pandhumsoporn

60

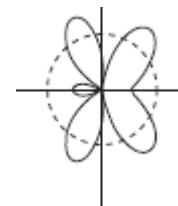
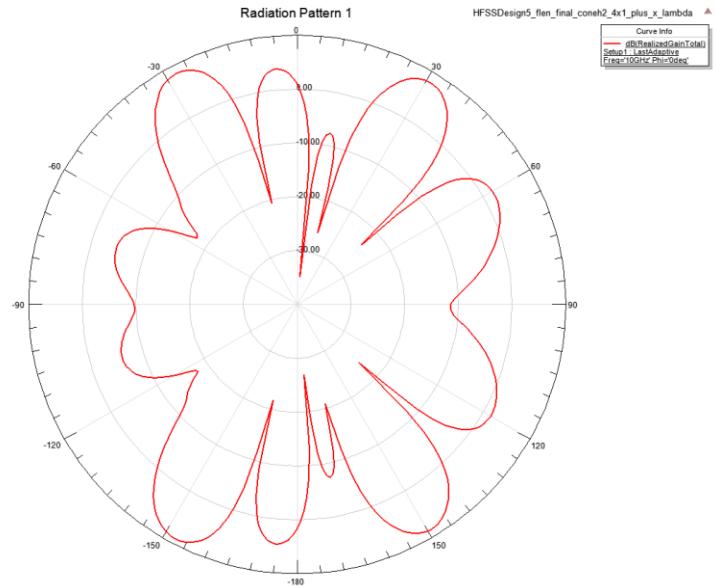
Excitation Phase, $d = \lambda$, 4x1 Array

Phase = 90 degrees

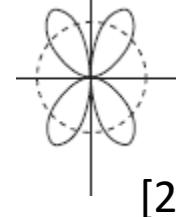


[2]

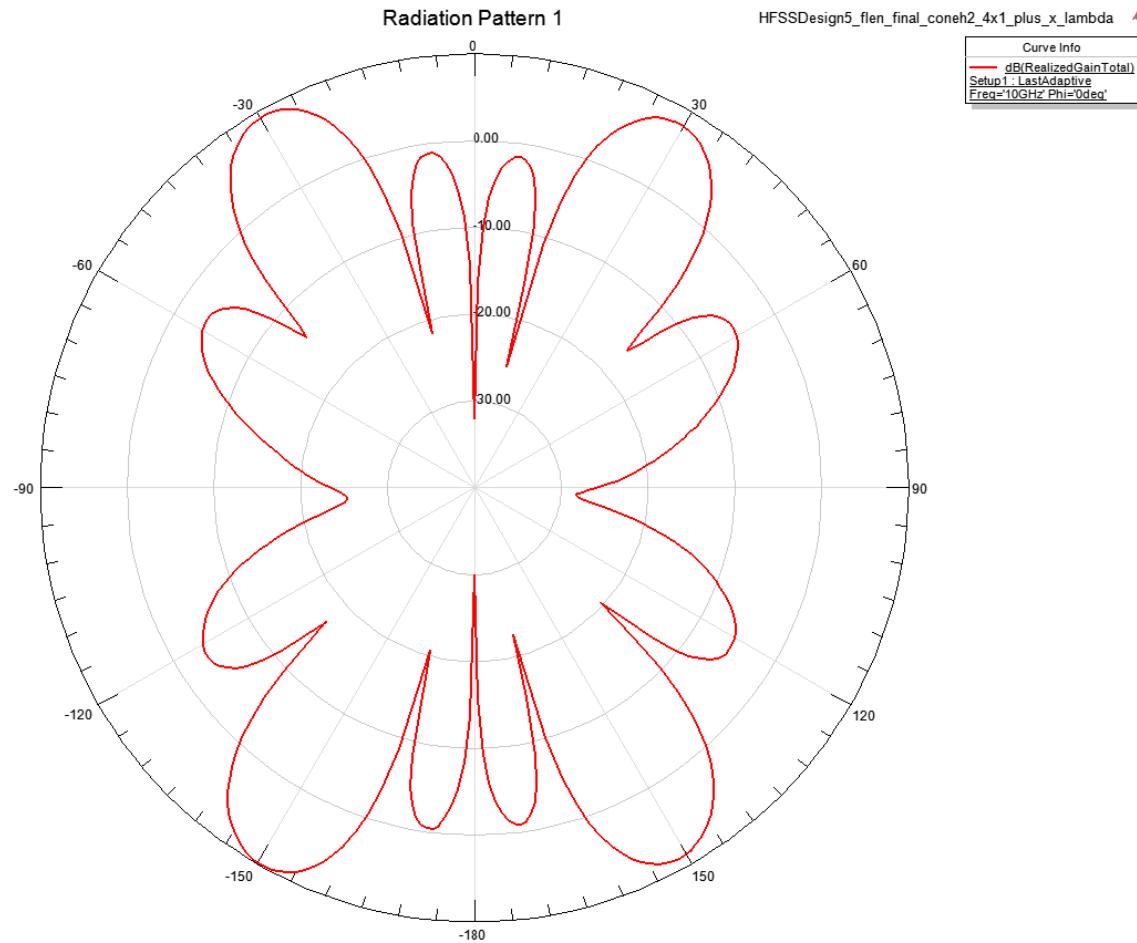
Phase = 135 degrees



[2]



Excitation Phase, $d = \lambda$ Phase = 180 degrees, 4x1 Array



Conclusions

- Gain increases with added N elements in array.
- Coupling increases when element spacing is closer.
- Shorting ports 2 and 3, or shorting two ports that contribute to higher coupling can reduce the overall mutual coupling of the array. Have to play around with the different combinations.
- 1D uniform beam scanning does not impact the S-parameters that much, only the radiation pattern characteristics (it is asymmetrical)

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References (Continued)

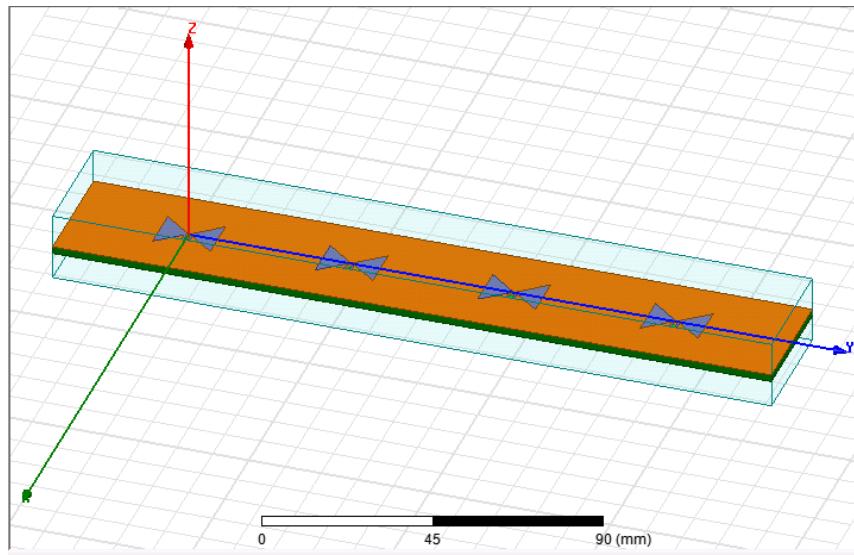
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[<http://anlage.umd.edu/HFSSv10UserGuide.pdf>](http://anlage.umd.edu/HFSSv10UserGuide.pdf)
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References (Continued)

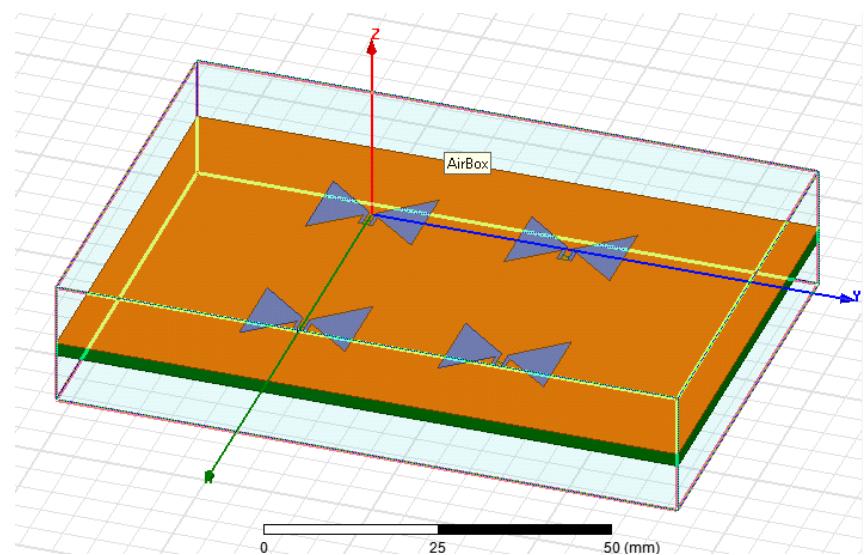
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4x1 array (+y direction, 2x2) layout

λ spacing, +y direction array



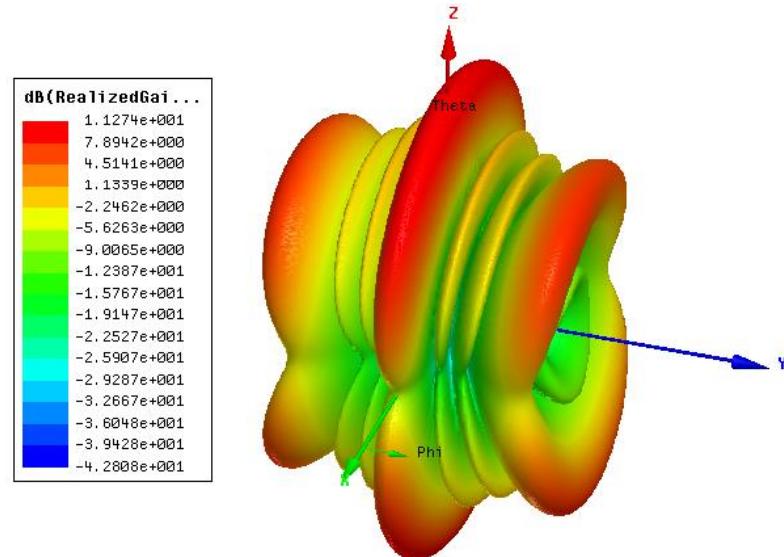
λ spacing, 2x2 array



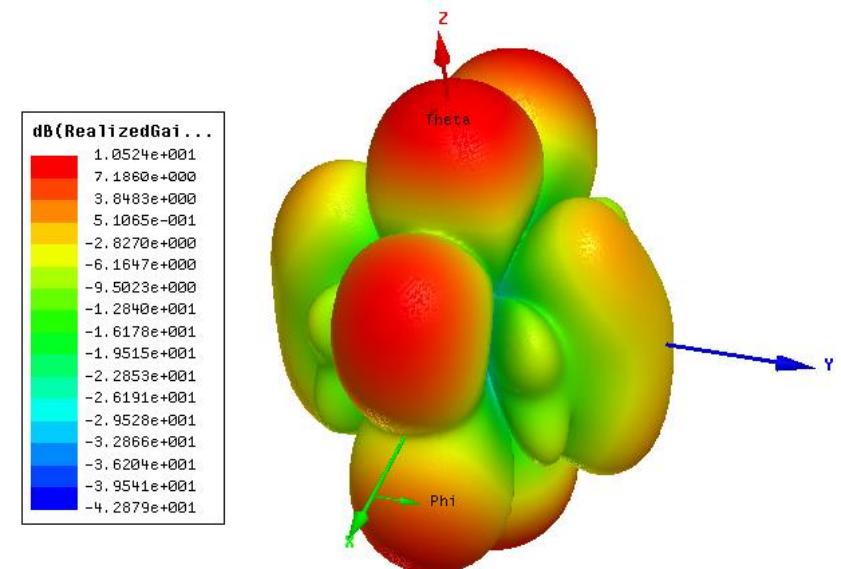
When coupling is concerned, we can assume it's much worse for the 2x2 element array since the elements are much closer together, and for the y-axis, the radiation pattern may influence the other neighboring element (ears)

3D Polar Plot

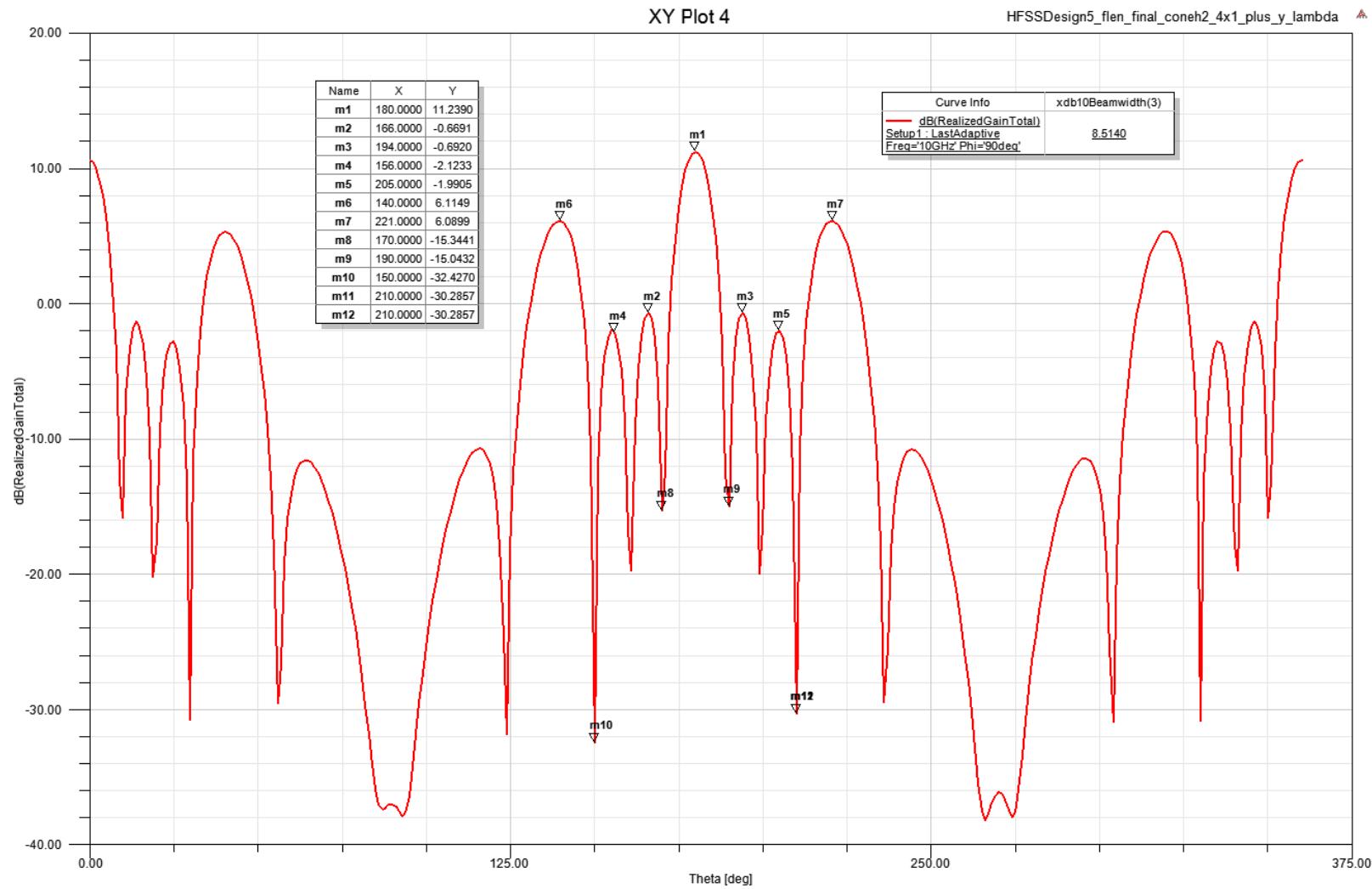
λ spacing, +y direction array



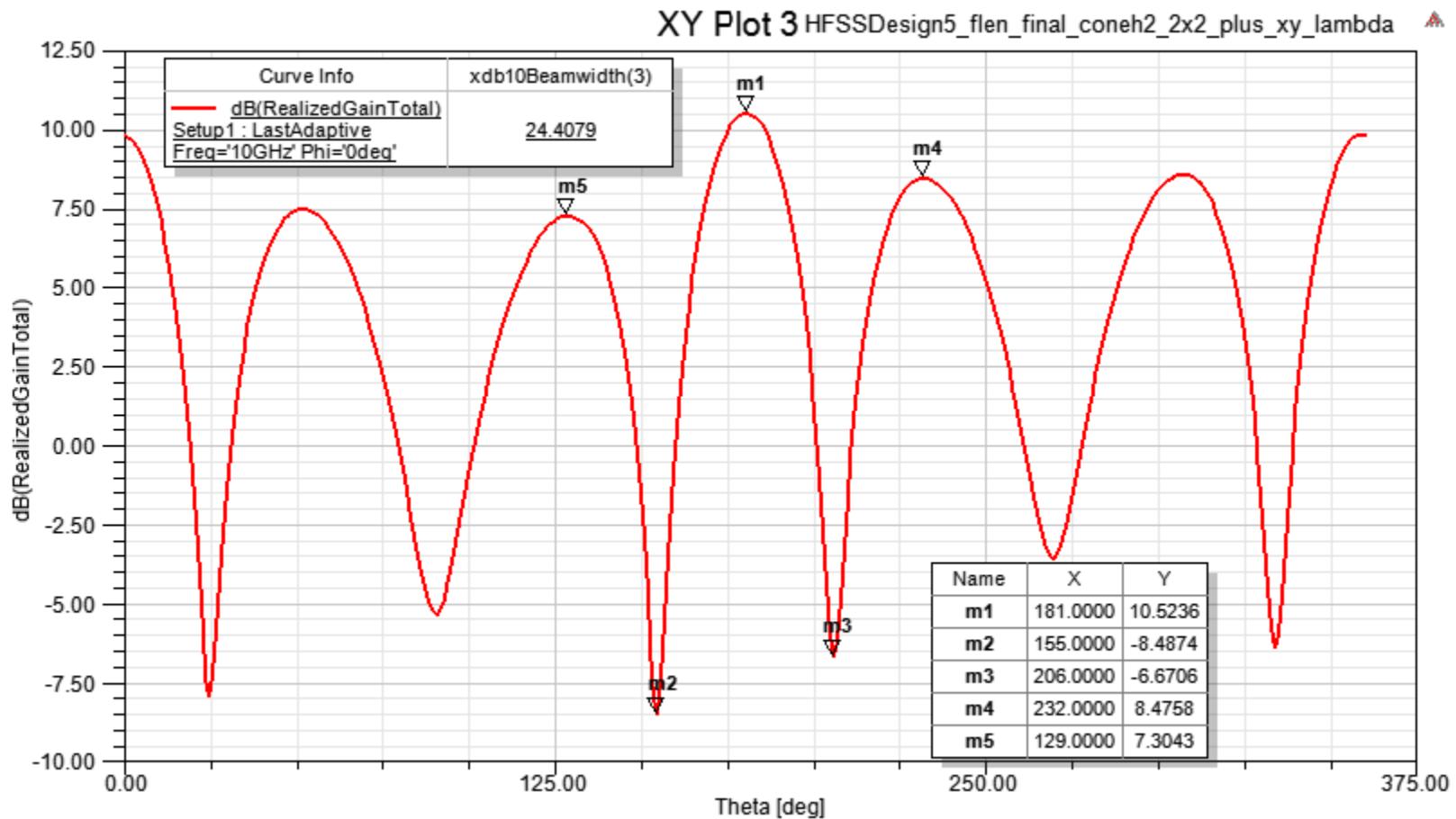
λ spacing, 2x2 array



4x1 array (+y direction), λ spacing



2x2 array, λ spacing



$$\text{HPBW} = 24.4079^\circ, \text{SLL} = -2.0656 \text{ dB}, \text{BWFN} = 51^\circ$$