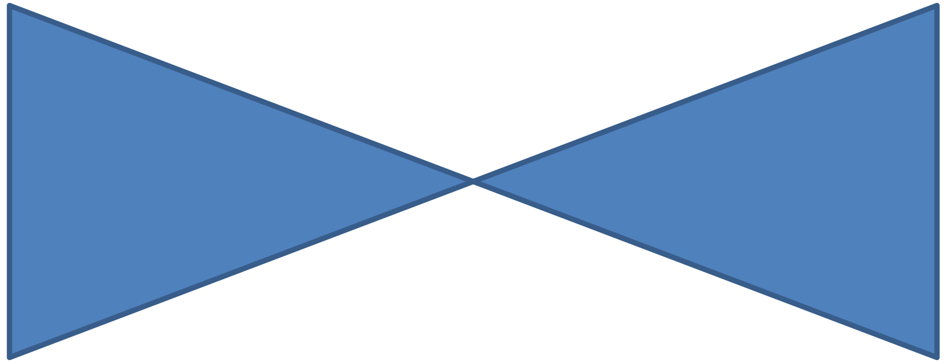


ELEN716 Phase II: Coplanar Waveguide Bowtie Antenna

By Troy Pandhumsoporn

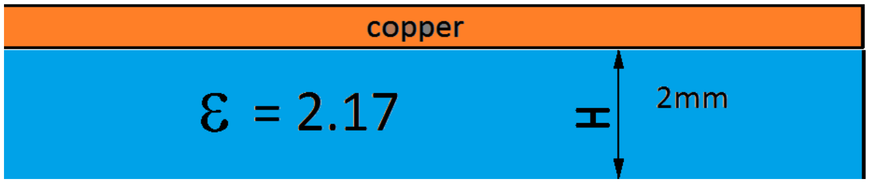
Introduction

[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)

Table 8-2 Elements for Array Antennas

Element	Examples	Advantages; Disadvantages
Dipole-based elements, backed by a ground plane		
Dipole	Fig. 3-20 Fig. 8-35*a*	Wide beam, simple structure; narrow band
Bow-tie	Fig. 7-32	Wide beam, simple structure, broadband
Microstrip elements	Sec. 11.2	Wide beam, low-profile; narrow band in basic form
Slot elements	Fig. 8-35*b* Fig. 8-34*b*	High-power applications; many are narrow band
Aperture elements		
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
Tapered slot antennas	Fig. 8-35*c* and *d*	Wide beam, broadband; not low-profile
Low-profile, broadband elements	Fig. 8-38 Sec. 8-11	Broadband, low-profile

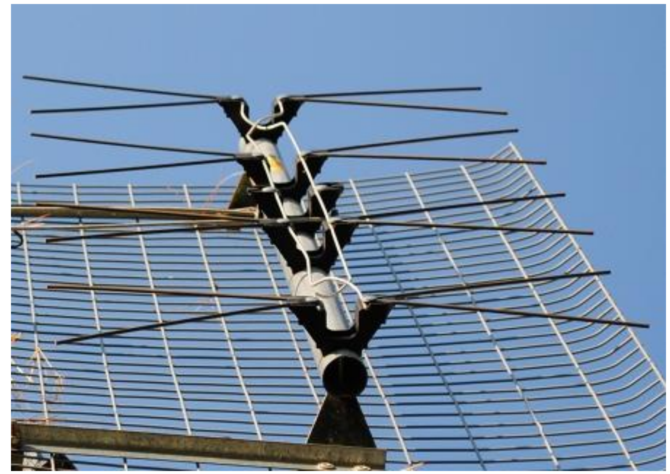


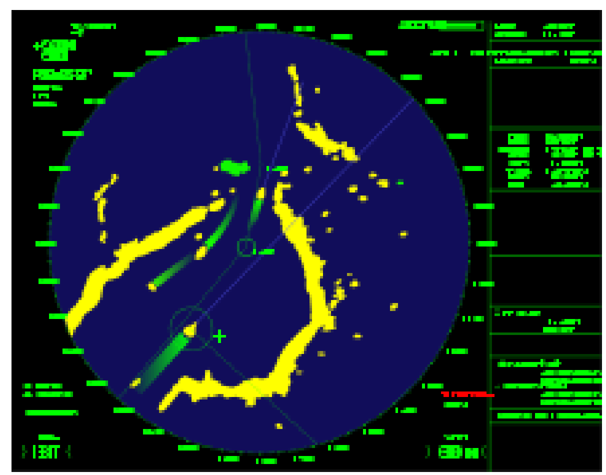
Main Objective: Investigate 4-element array radiation characteristics, Phase I comparison

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





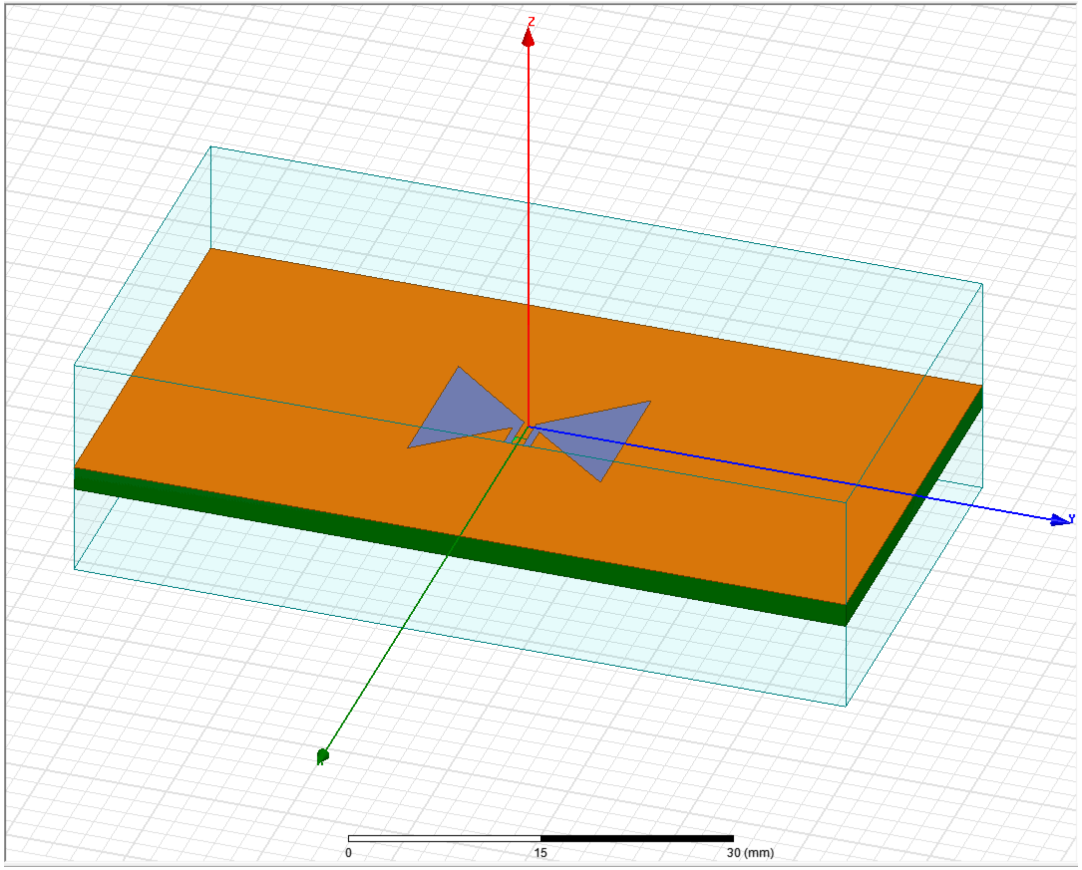
[5]

Main Outline

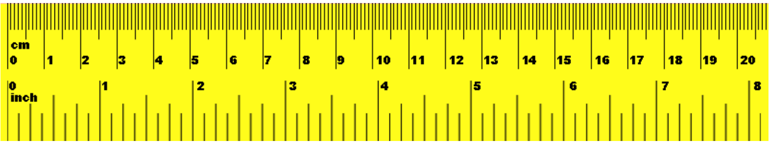
- 4-Element Array (Radiation Characteristics: HPBW, SLL, S-parameters, coupling)
  - Array Arrangement/Spacing ($\lambda/2$, λ in +x direction)
  - Changing port excitations (4x1 in +x direction)
    - Shorting a port, monitoring impact
    - 2D or 1D beam scanning with excitation scheme (uniform/non-uniform)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

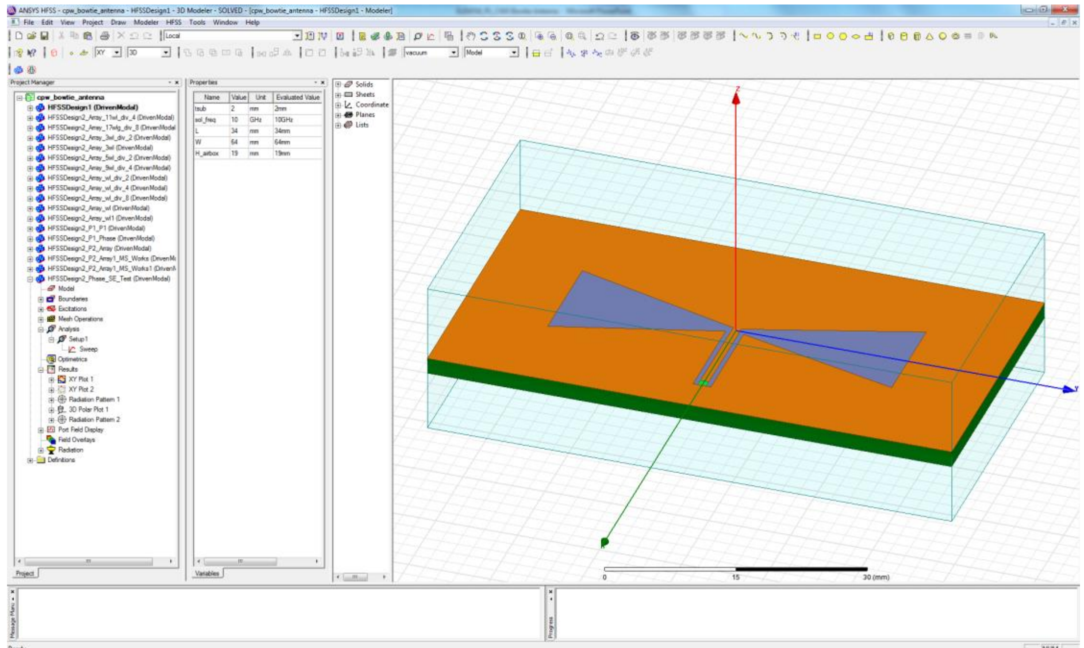
•Copper Cladding with Cutout (serves as ground and antenna shape etched)

•Simulated in 8 – 12 GHz range as used in the paper.

•Polyline Draw Tool and Arlon Cu Clad 217(tm) chosen (εr = 2.17)

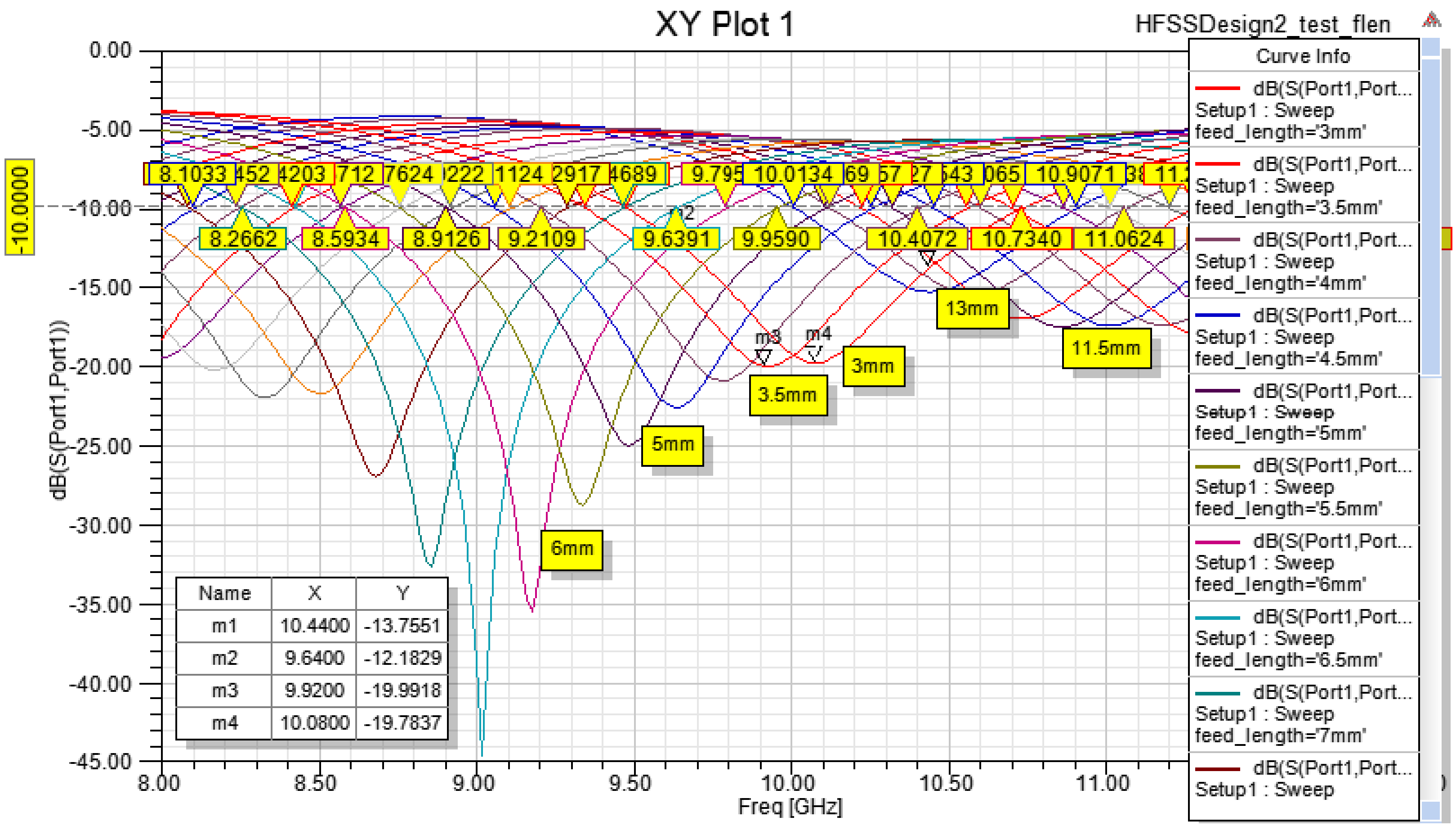
•Height = 21 mm, Base = 12.7 mm (triangle dimensions)

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



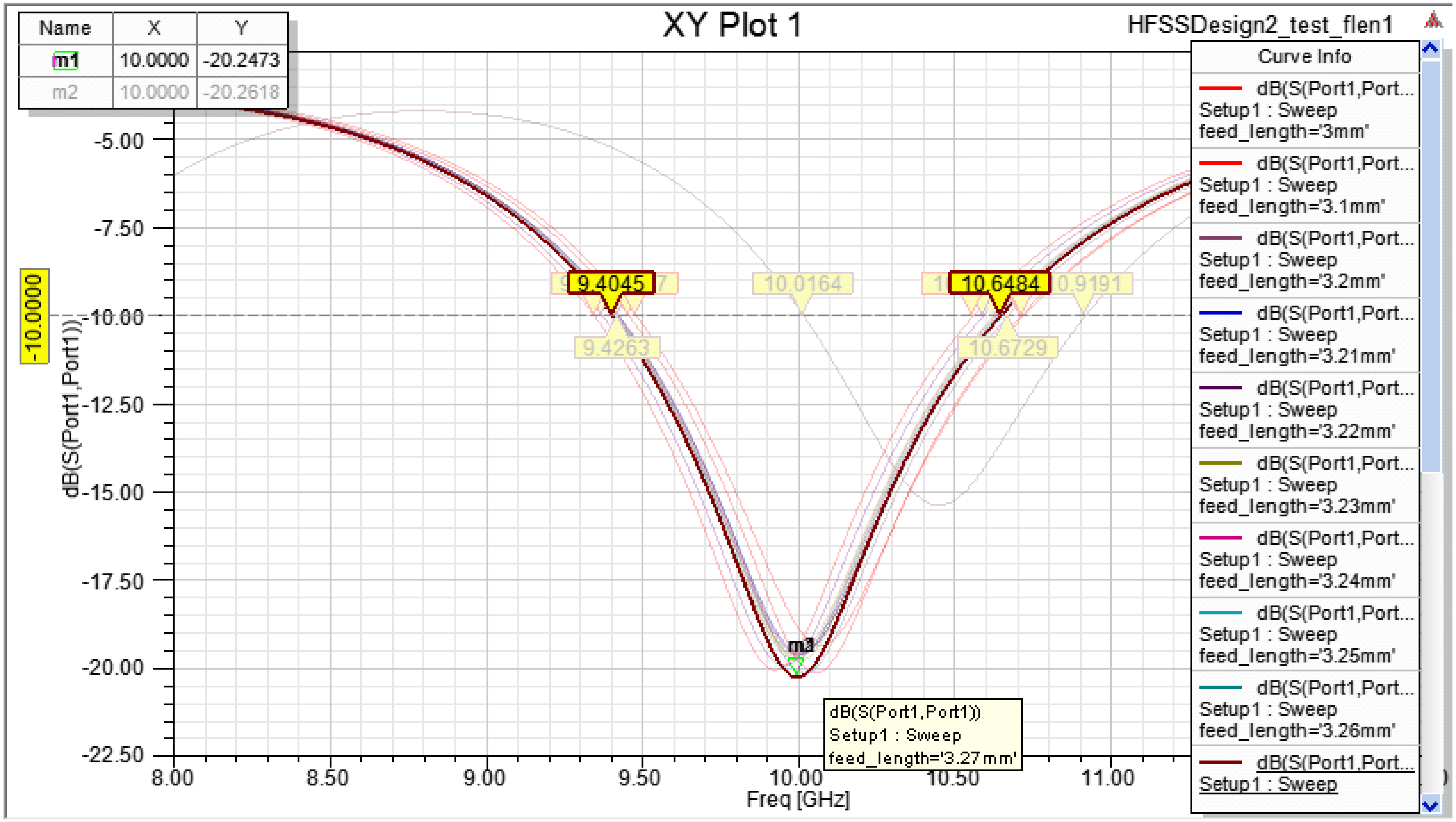
Name	Value	Unit	Evaluated Value
tsub	2	mm	2mm
sol_freq	10	GHz	10GHz
L	34	mm	34mm
W	64	mm	64mm
H_airbox	19	mm	19mm

Parametric Analysis (optimal feed length)



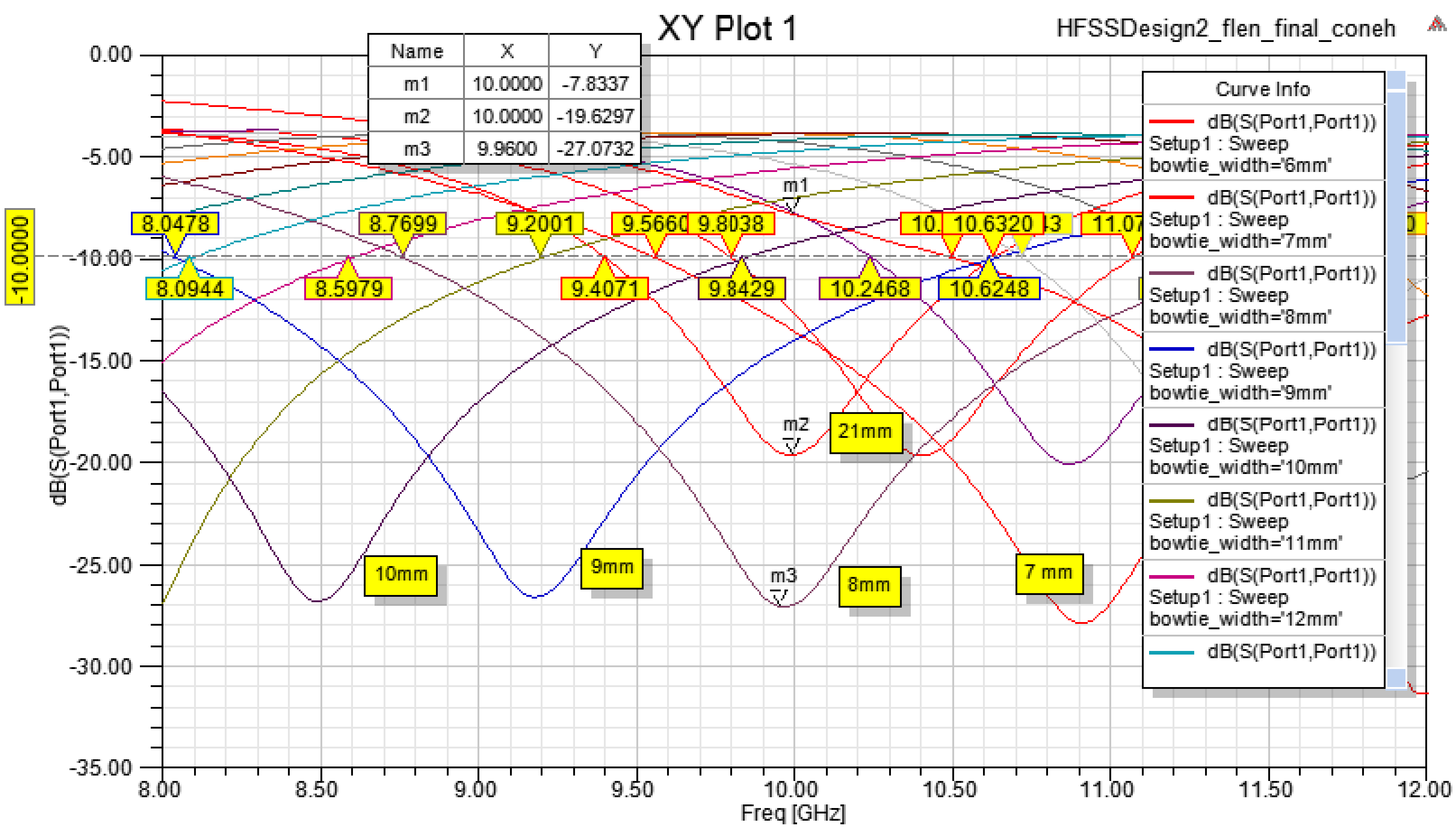
From 3mm to 13 mm, 1mm step increments. Somewhere between 3-3.5 mm.

Parametric Analysis (optimal feed length) (continued)



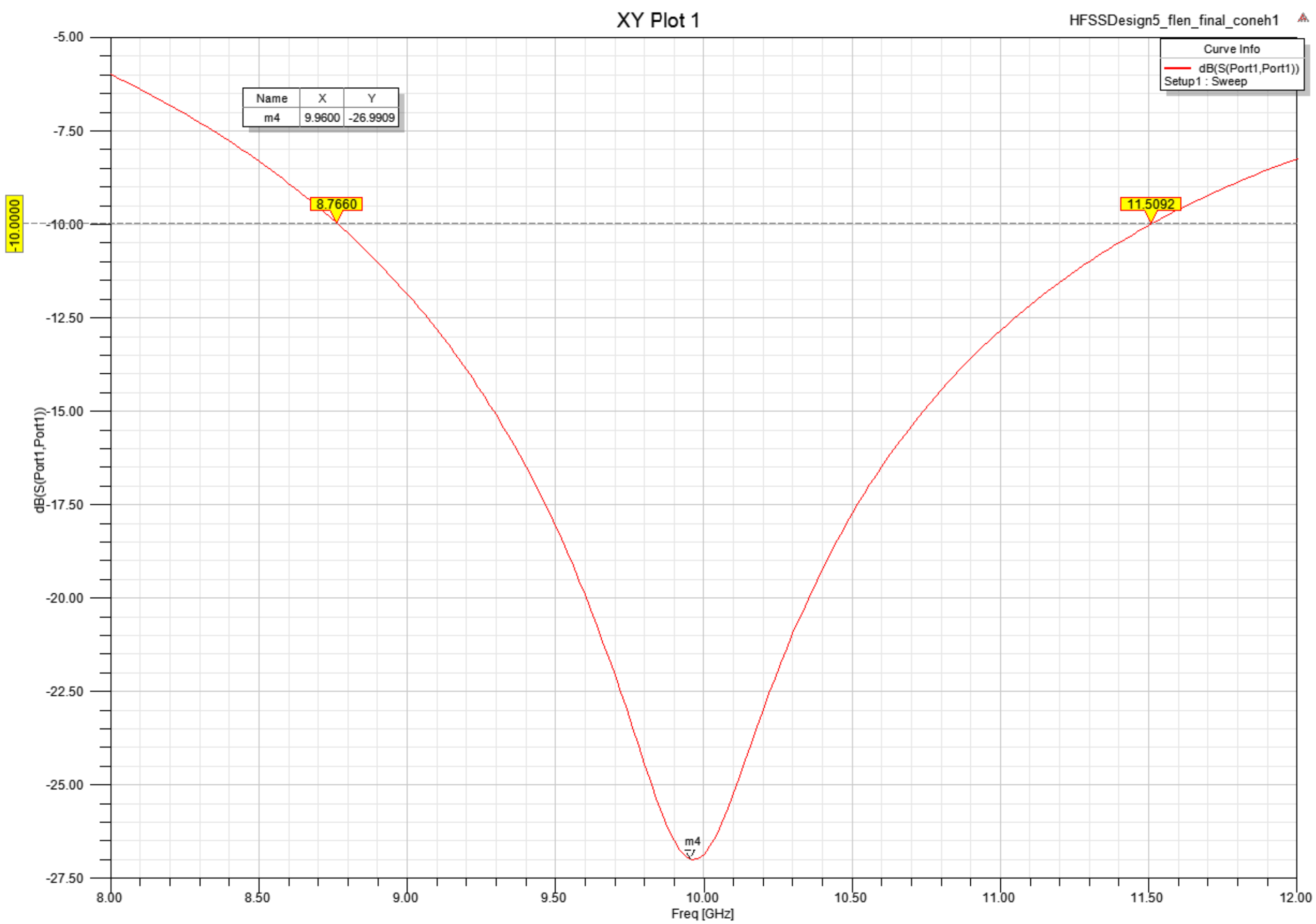
From 3.2 mm to 3.3 mm, 0.01 mm increments

Aperture Base (with optimized feed length)



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

Final Antenna Element S11 plot



S11 = -26.9909 dB, ~2.75 GHz BW (trade-off for array characteristics 2x2, y- direction)

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 = λ	**30 mm**	**No**

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

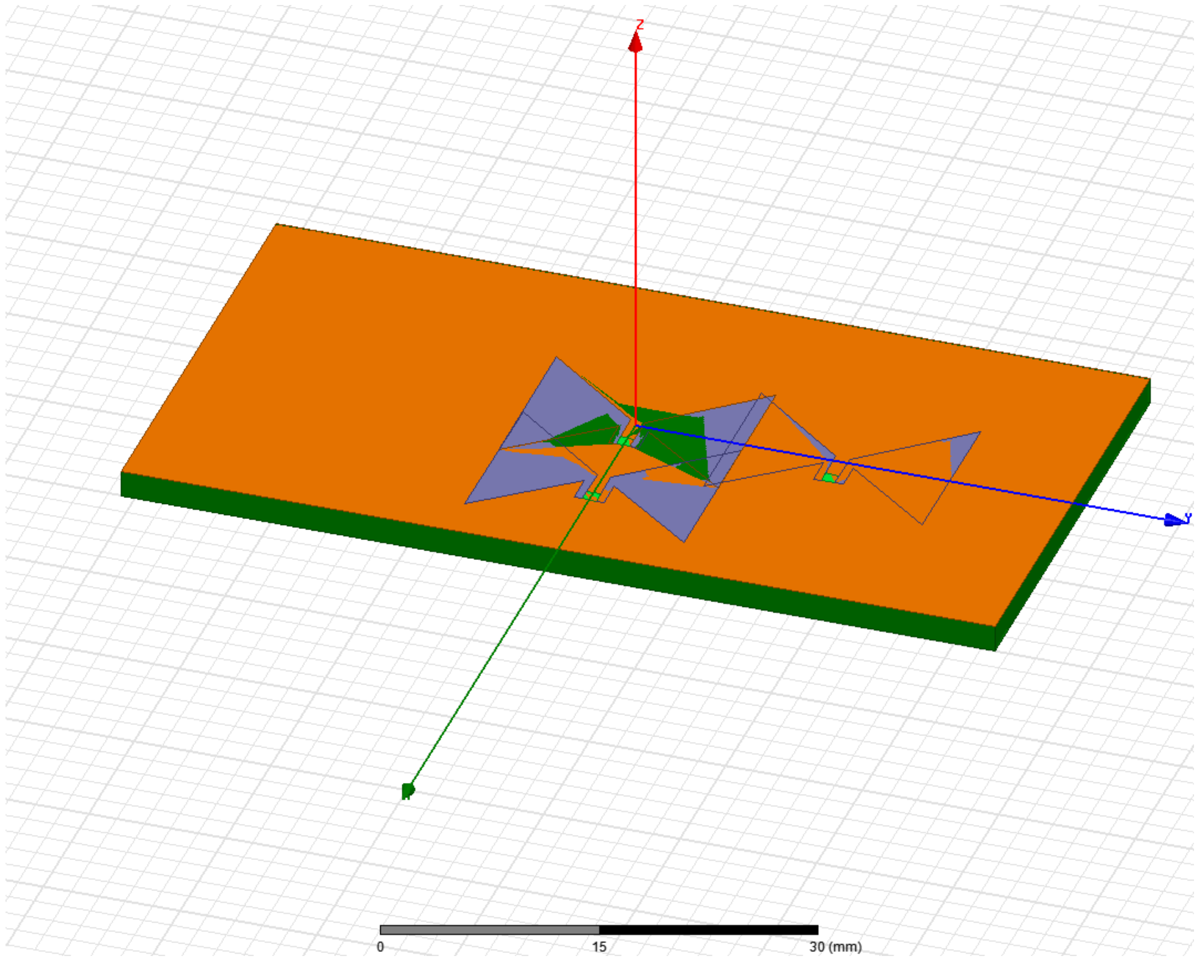
$\alpha-\beta d < \psi$ (visible region) $< \alpha+\beta d$

The pattern should repeat every λ spacing (array factor is 2π periodic)
Phase + $2\pi N$ = Equivalent Phase

The dimensions of antenna are W x L = 64 mm x **34 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, $d = \lambda/2$.

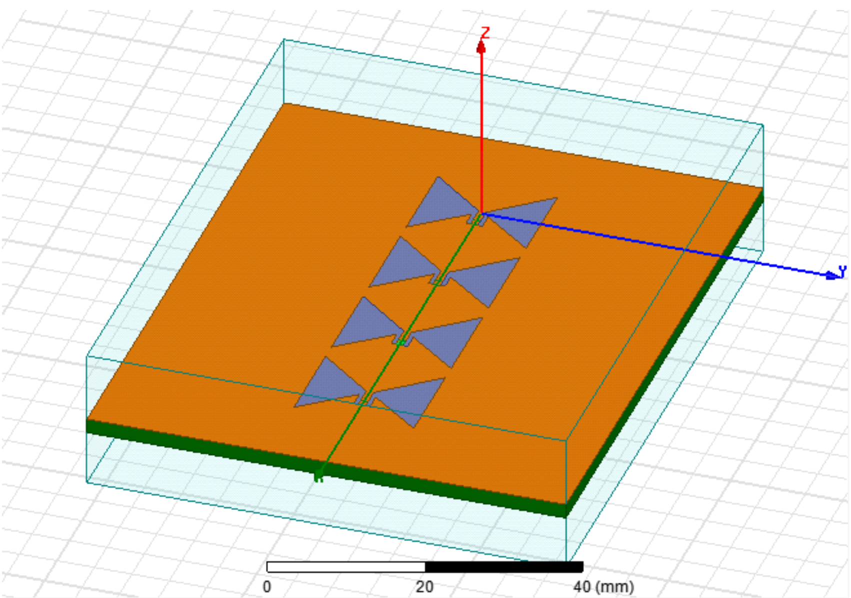
Bottlenecked Center-to Center Spacing



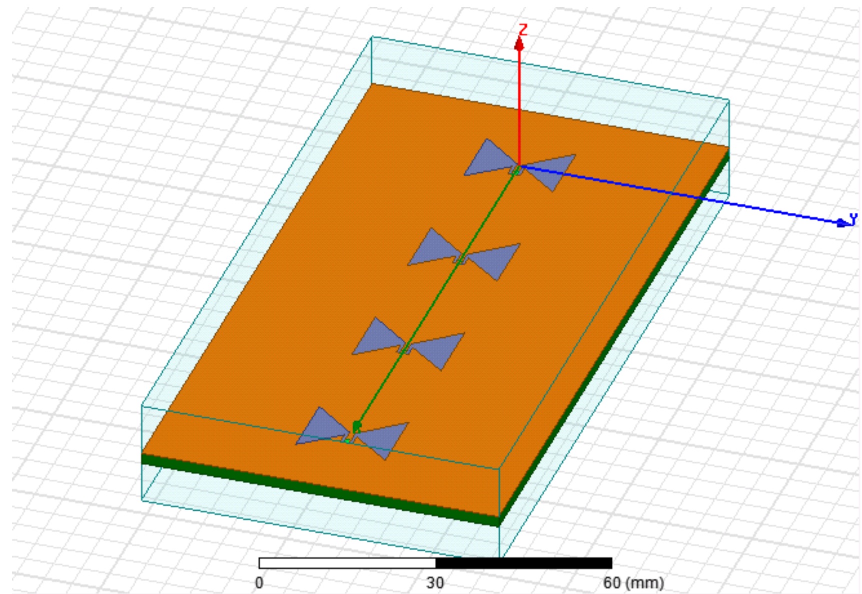
Therefore, Min Spacing +X-axis is $d > \lambda/4$, Min-spacing +Y-axis for $d > \lambda/2$

4x1 array (+x direction) layout [best way]

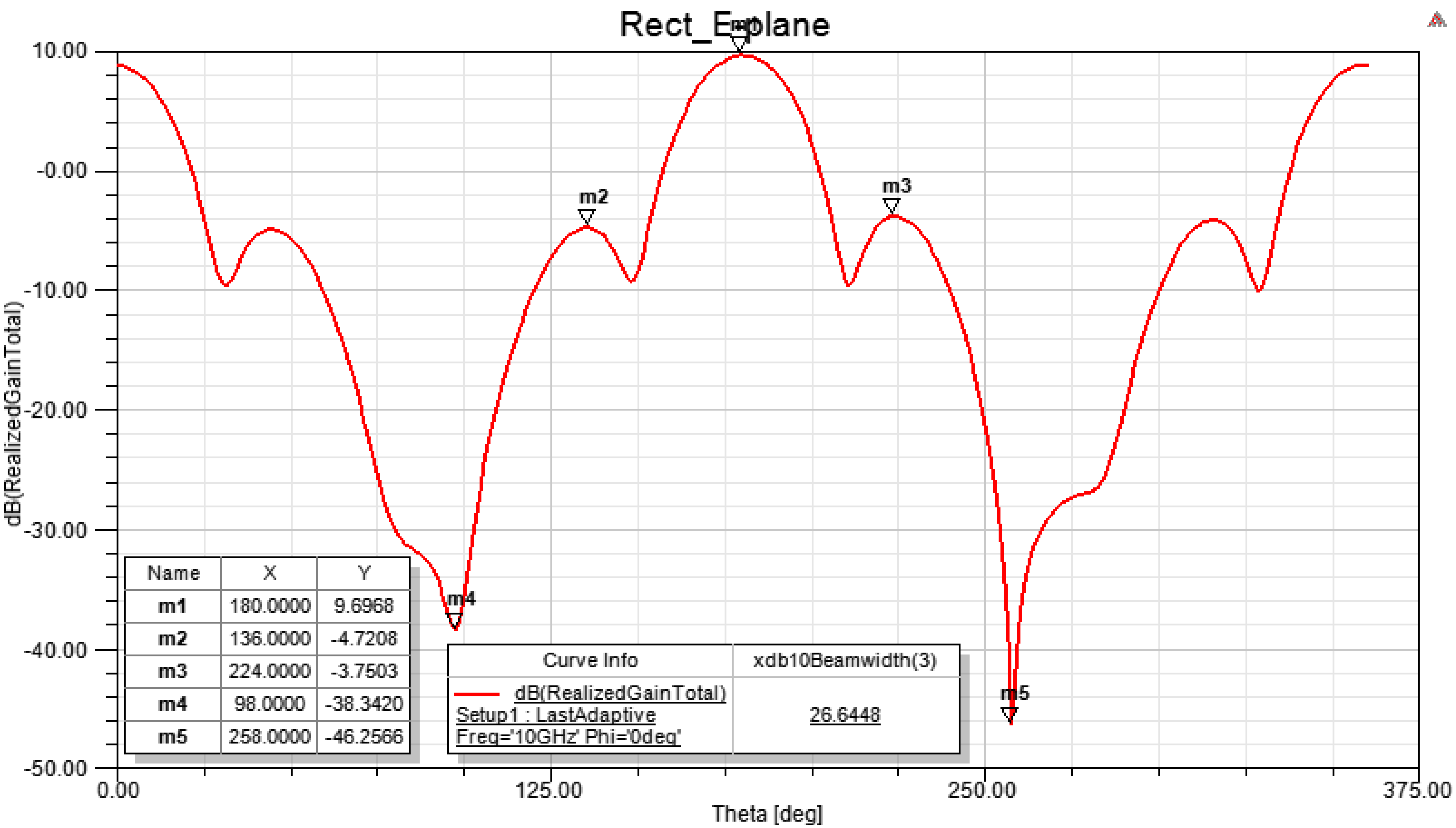
$\frac{\lambda}{2}$ ***spacing***



λ ***spacing***

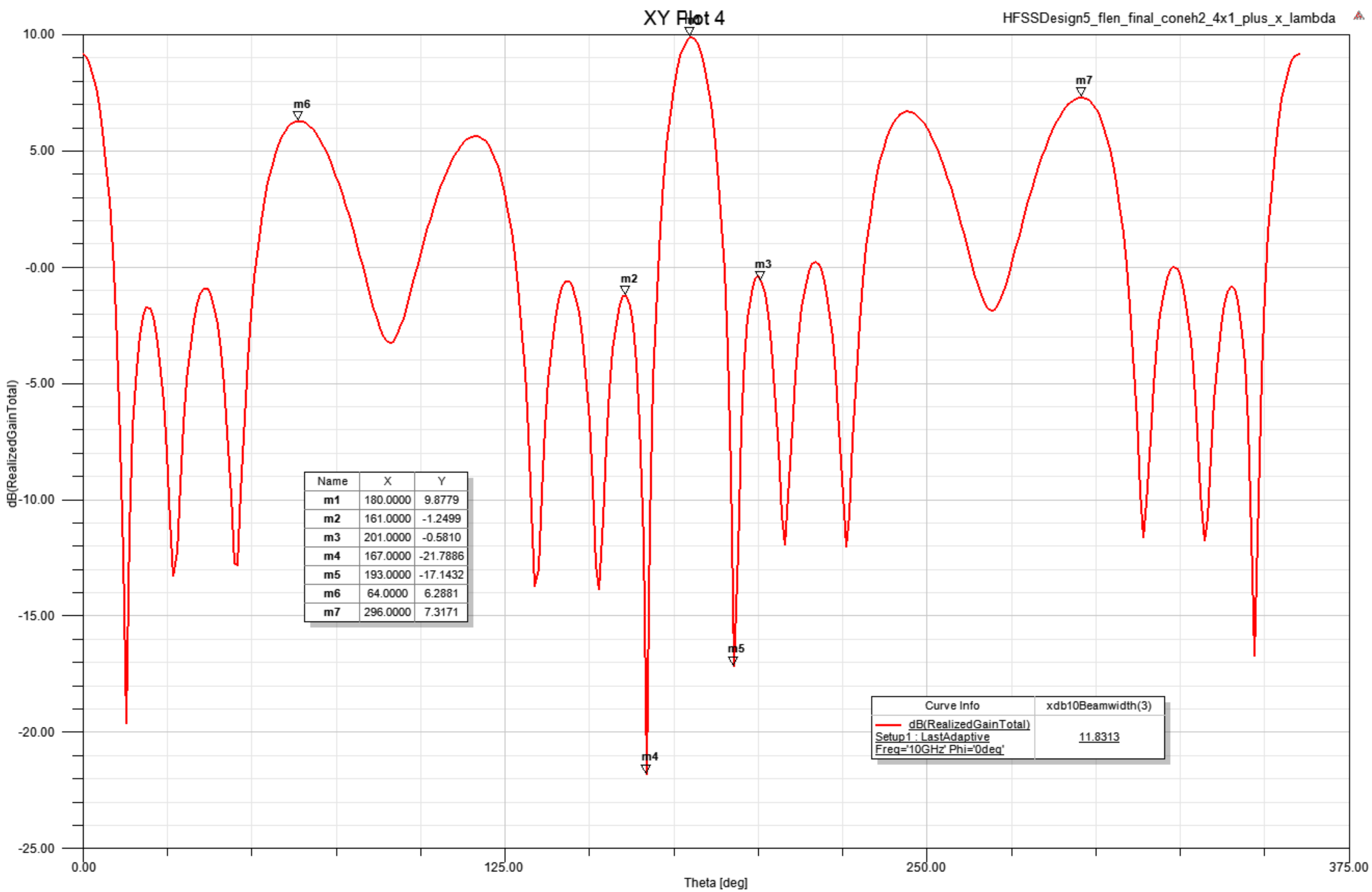


4x1 array (+x direction), λ/2 spacing



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

4x1 array (+x direction), λ spacing

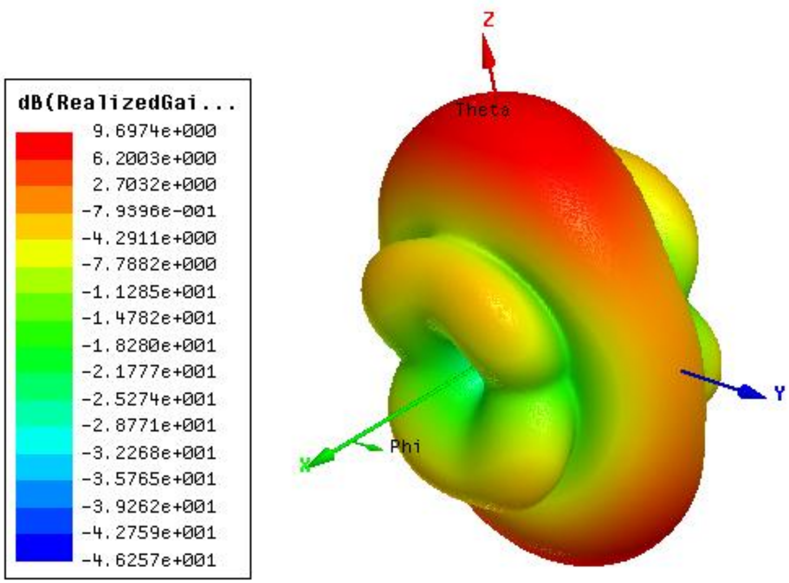


Name	X	Y
m1	180.0000	9.8779
m2	161.0000	-1.2499
m3	201.0000	-0.5810
m4	167.0000	-21.7886
m5	193.0000	-17.1432
m6	64.0000	6.2881
m7	296.0000	7.3171

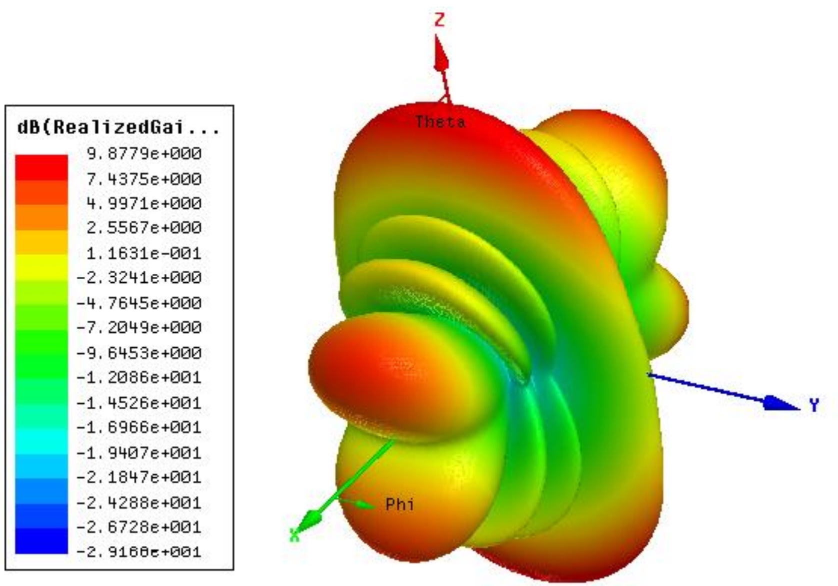
HPBW = 11.8313˚(more than halved), SLL = -2.5608 dB, BWFN = 26˚

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

λ/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 a elements with a broad beam.

c. Elements with polarizations (i.e., electric field orientations) that are parallel couple more than when collinear.

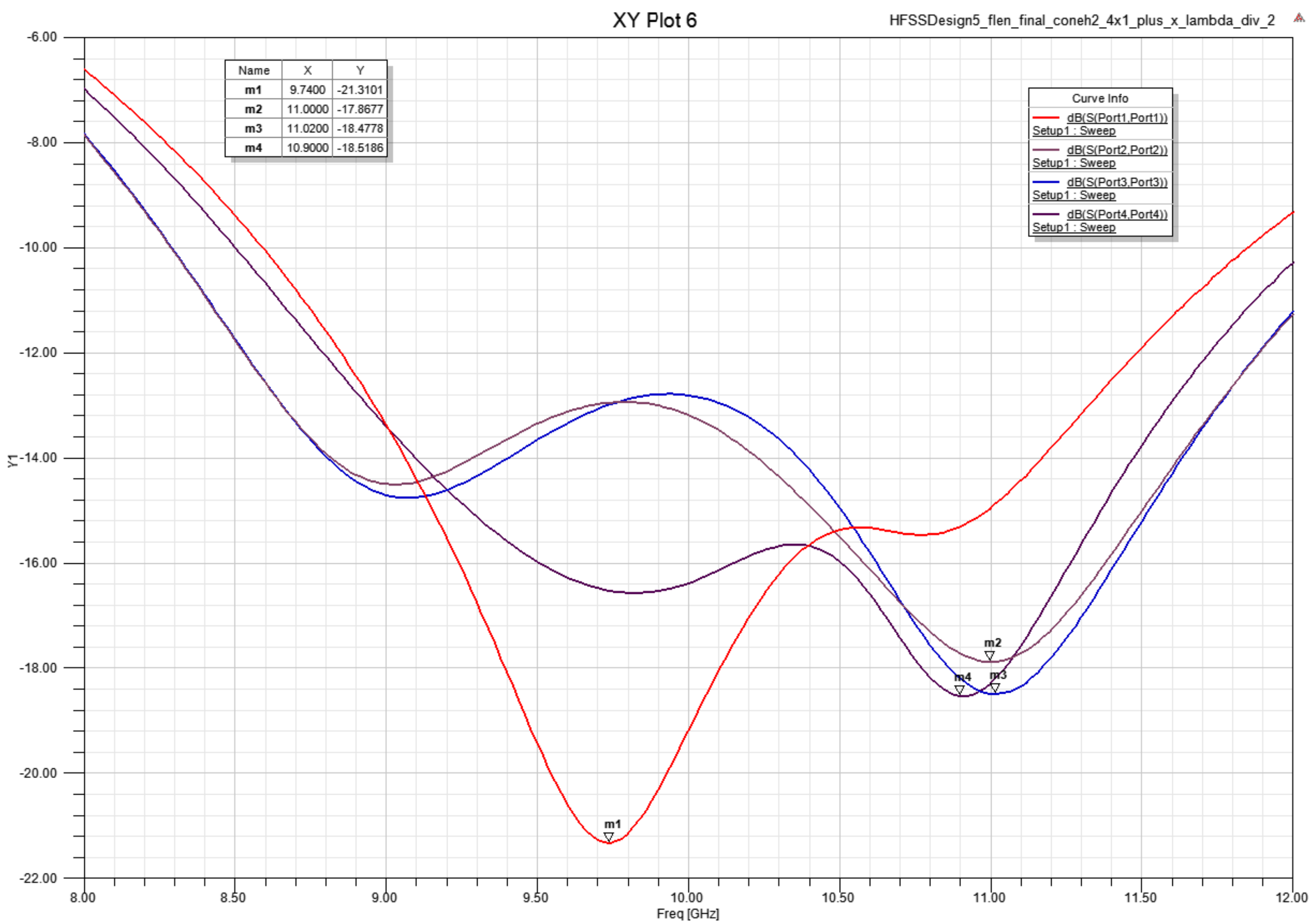
d. Larger elements have smaller coupling.

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

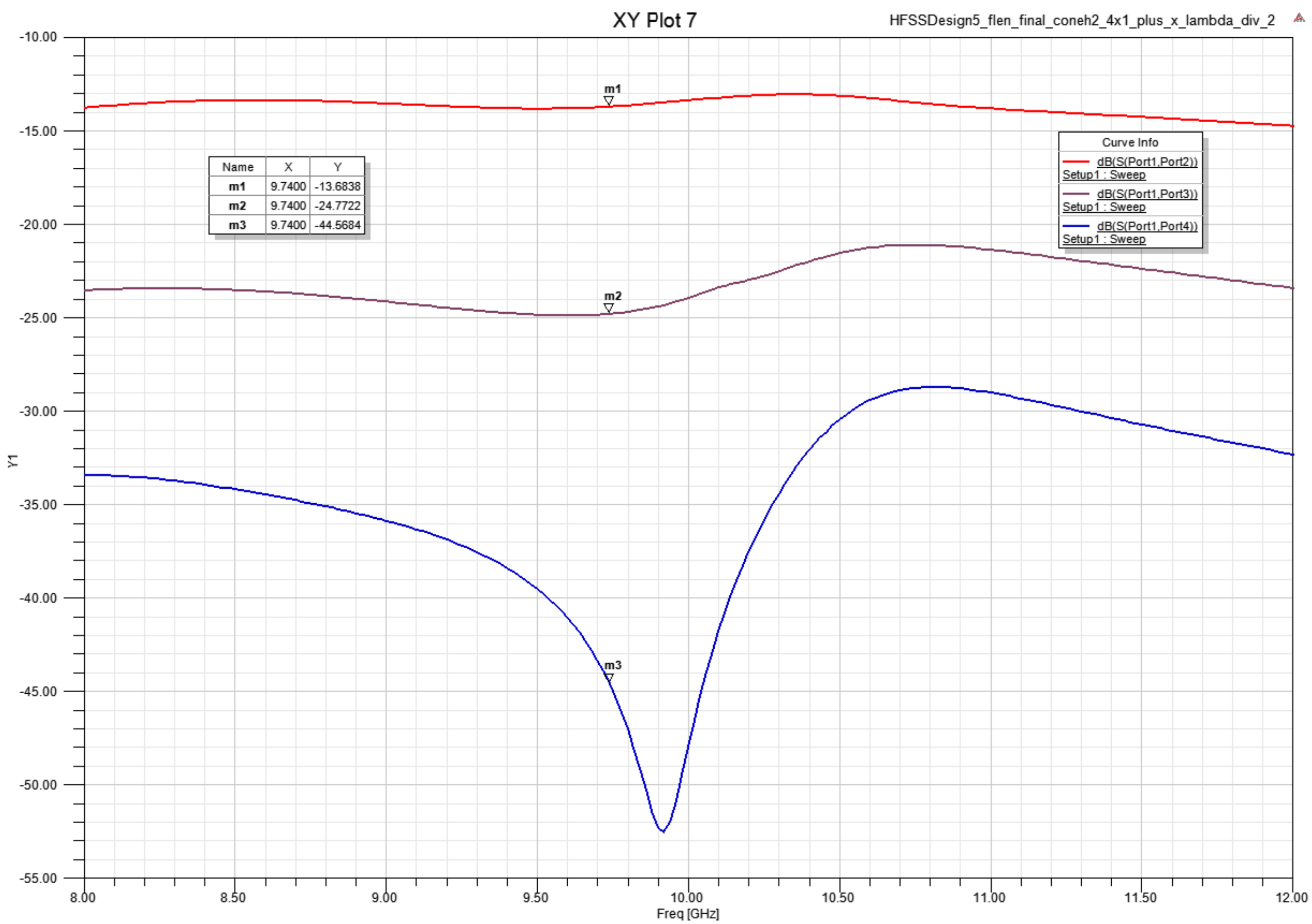
$$C_{\mathrm{mn}} = 20 \log |S_{\mathrm{mn}}| \qquad [\mathrm{dB}] \tag{8-96}$$

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

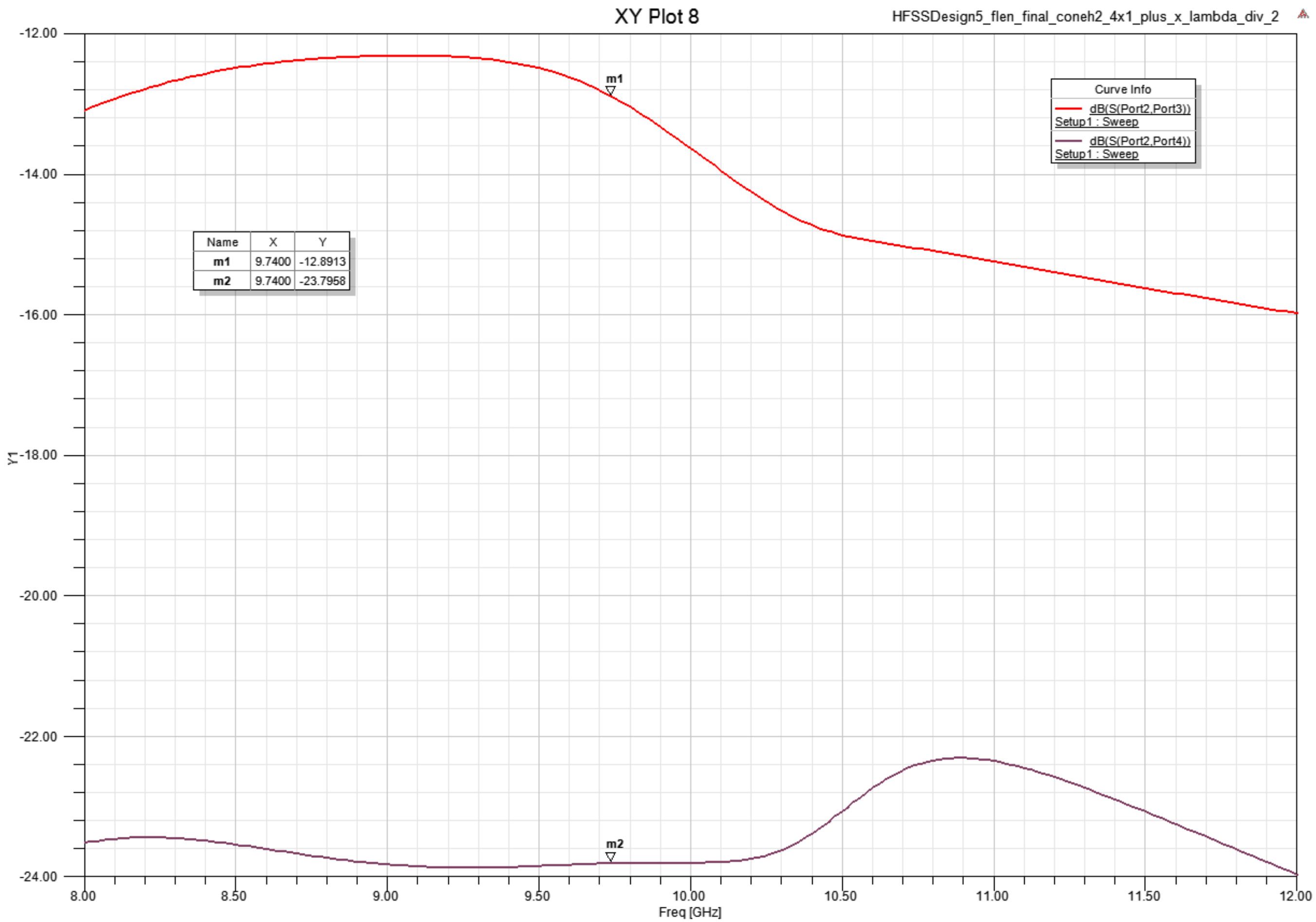
4x1 array (+x direction): S11, S22, S33, S44 parameters, λ/2 spacing



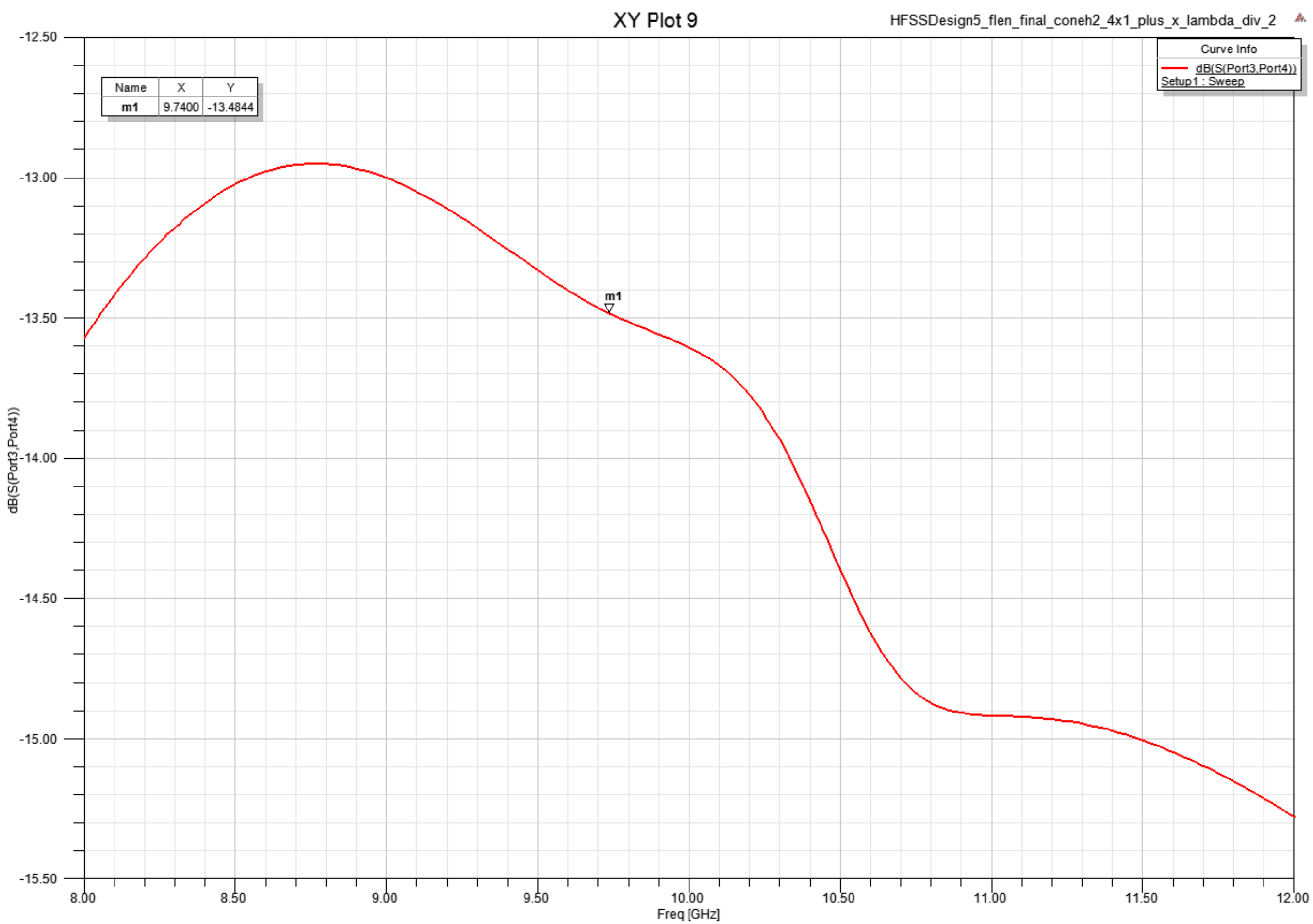
4x1 array (+x direction): S12, S13, S14, parameters, λ/2 spacing



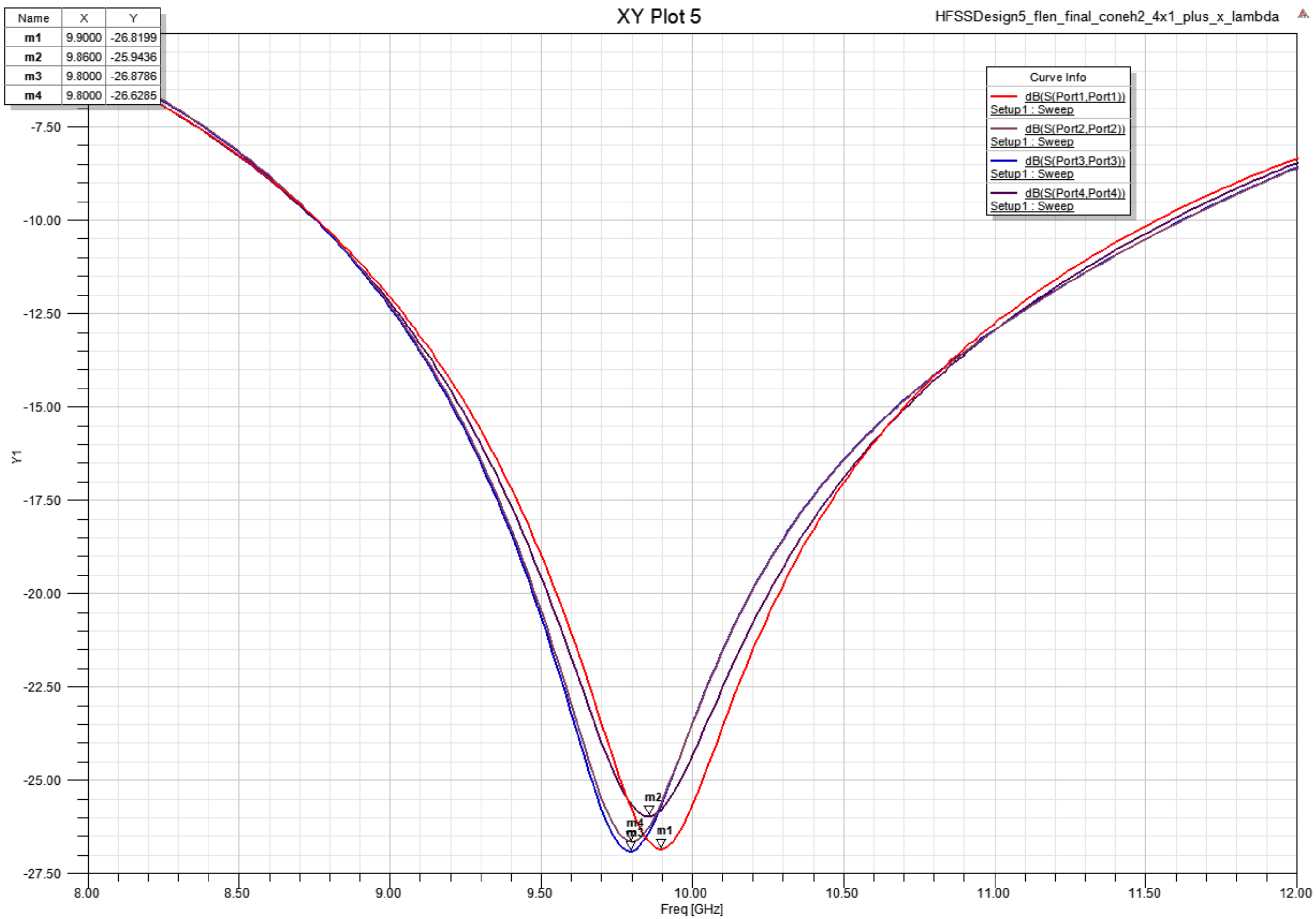
4x1 array (+x direction): S23, S24, parameters, λ/2 spacing



4x1 array (+x direction): S34, parameters, λ/2 spacing

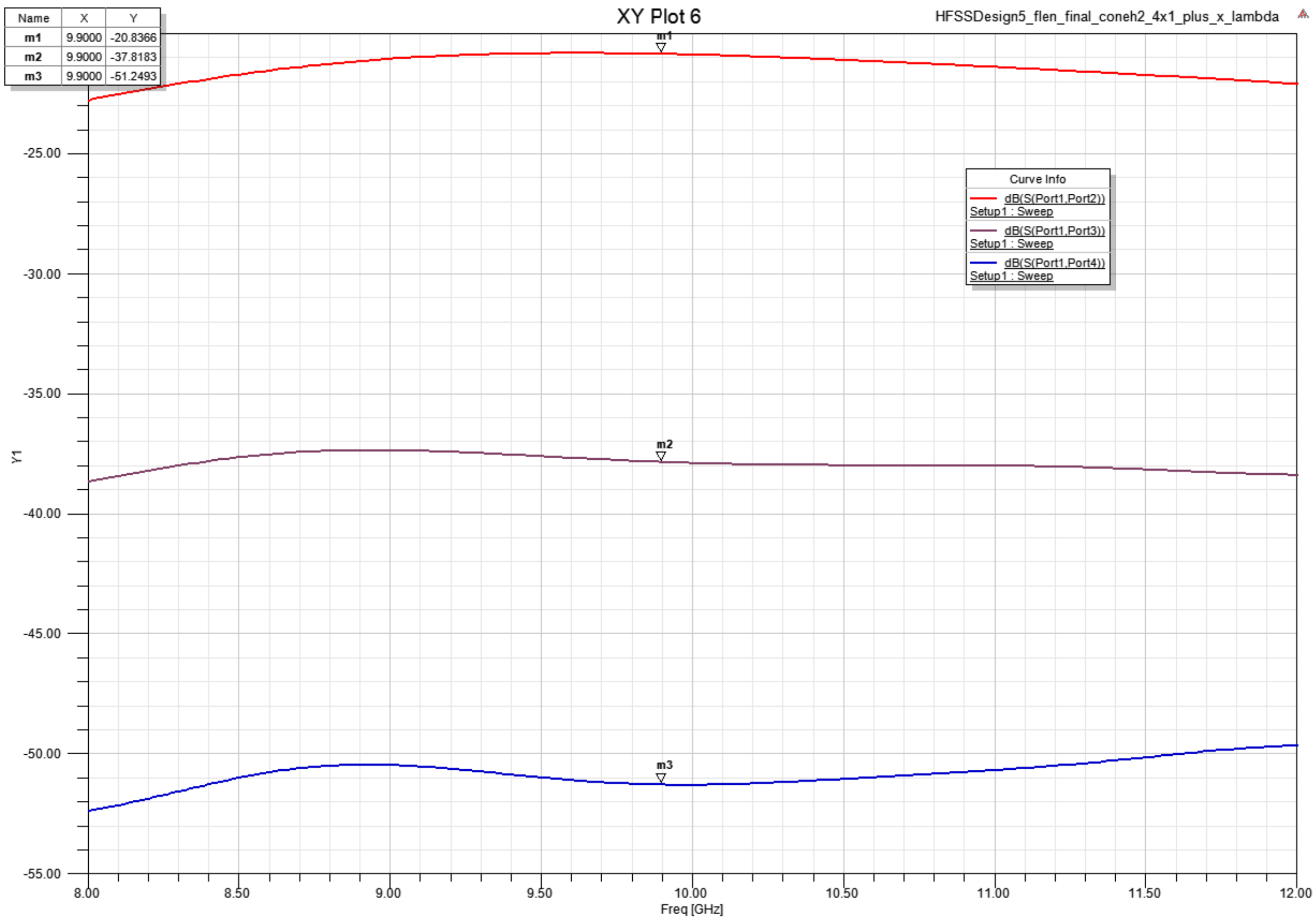


4x1 array (+x direction): S11, S22, S33, S44 parameters, λ spacing



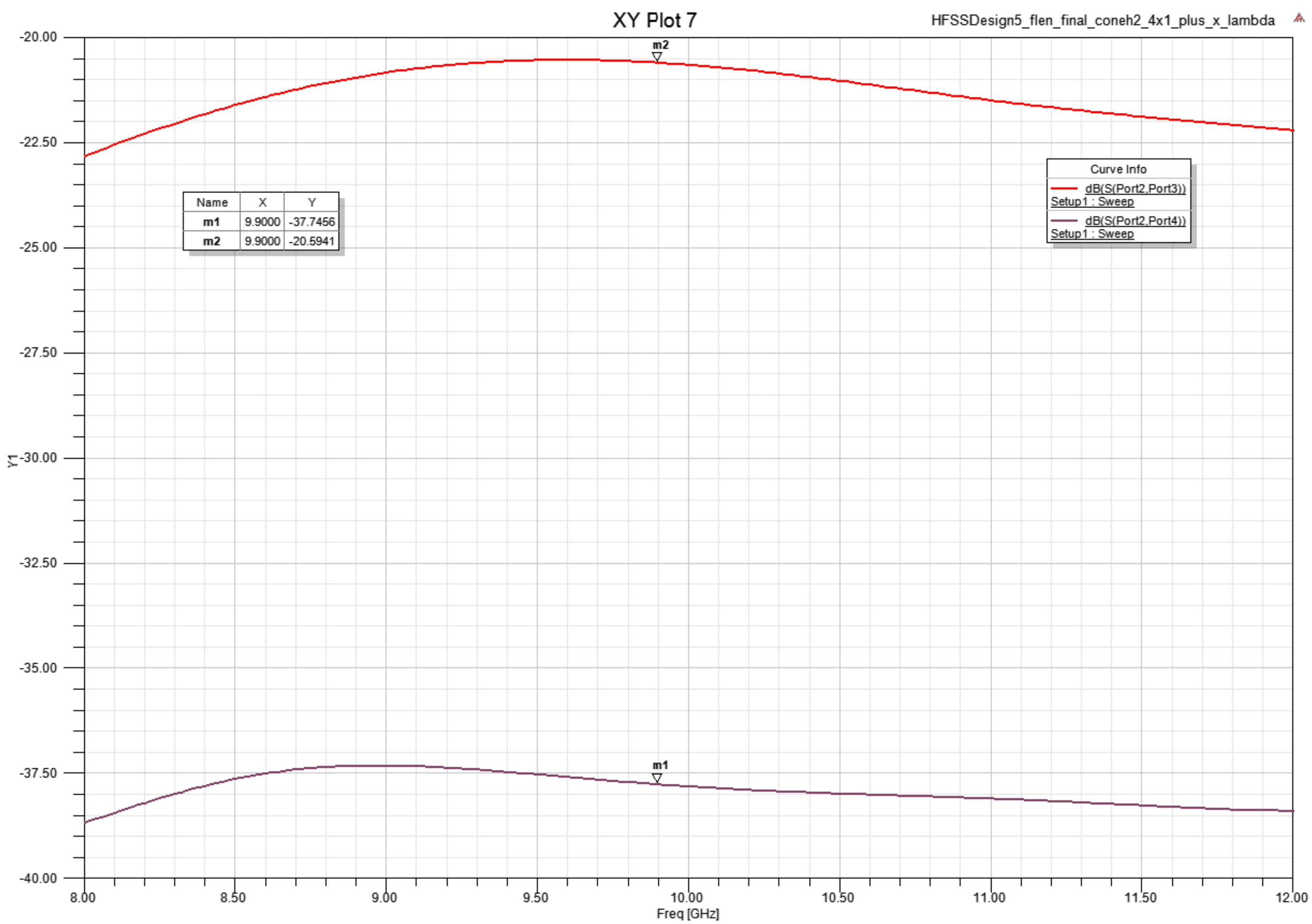
Coupling moves the return loss a little, not much change.

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



Expected coupling by arrangement by distance between each element

4x1 array (+x direction): S23, S24, parameters, λ spacing



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

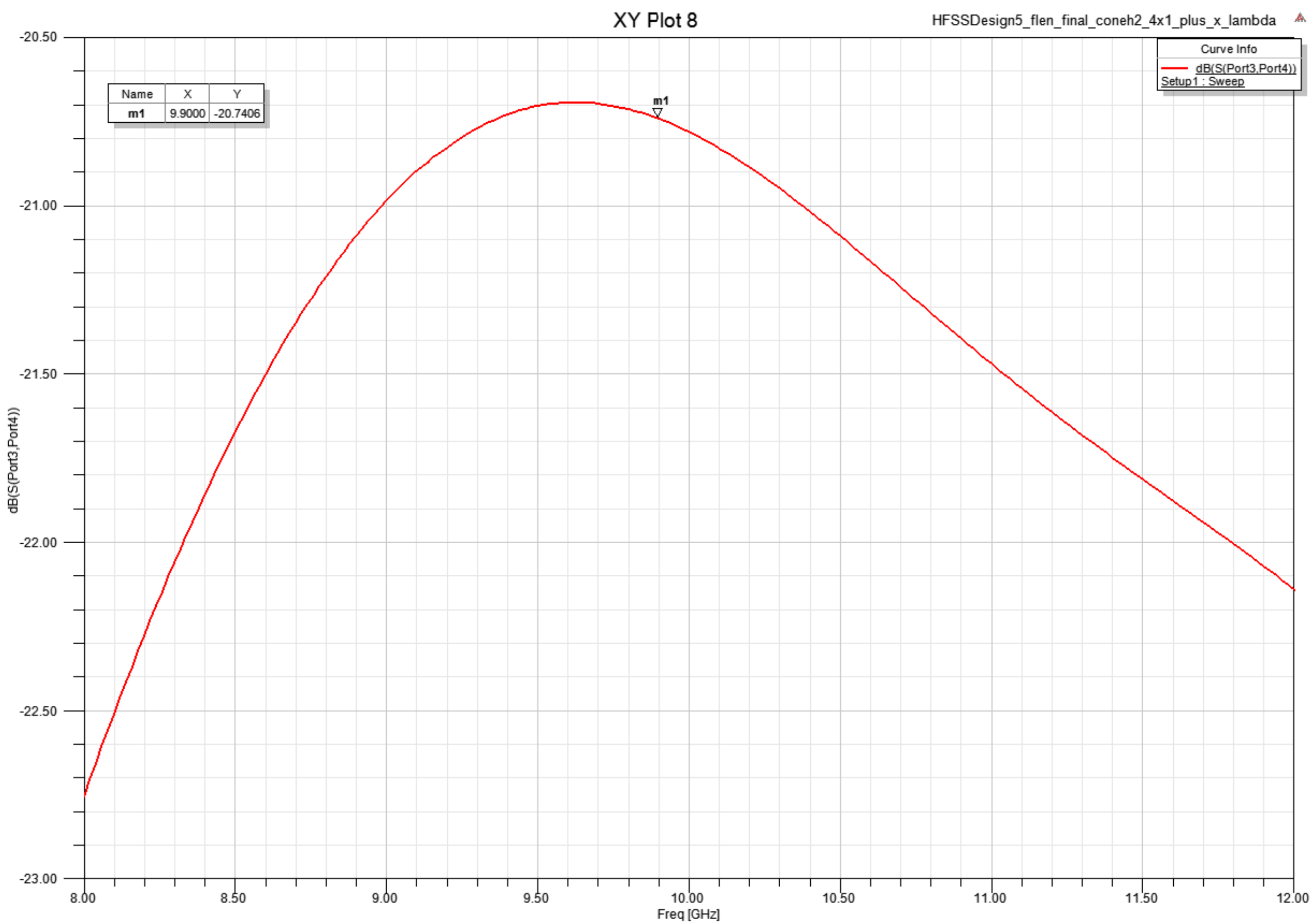


Table Summary

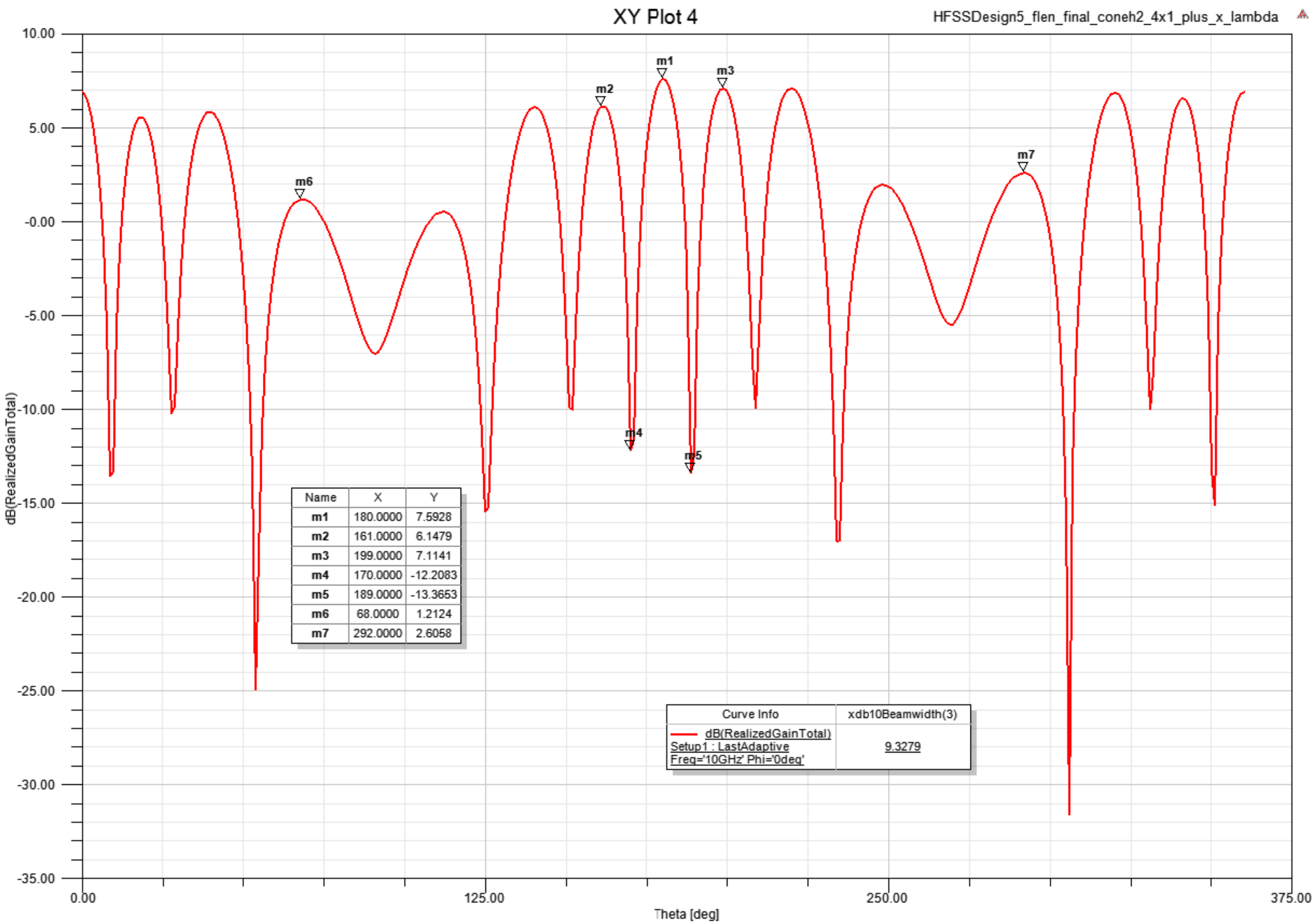
	Original λ spacing	Original λ/2 spacing
S11	-26.8199 dB	-21.3101 dB
S22	-26.6285 dB	-17.8677 dB
S33	-26.8786 dB	-18.4778 dB
S44	-25.9436 dB	-18.5186 dB
S12	-20.8366 dB	-13.6838 dB
S13	-37.8183 dB	-24.7722 dB
S14	-51.2493 dB	-44.5684 dB
S23	-37.7456 dB	-12.8913 dB
S24	-37.7456 dB	-23.7958 dB
S34	-13.4844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

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

Changing Port Excitation, λ spacing

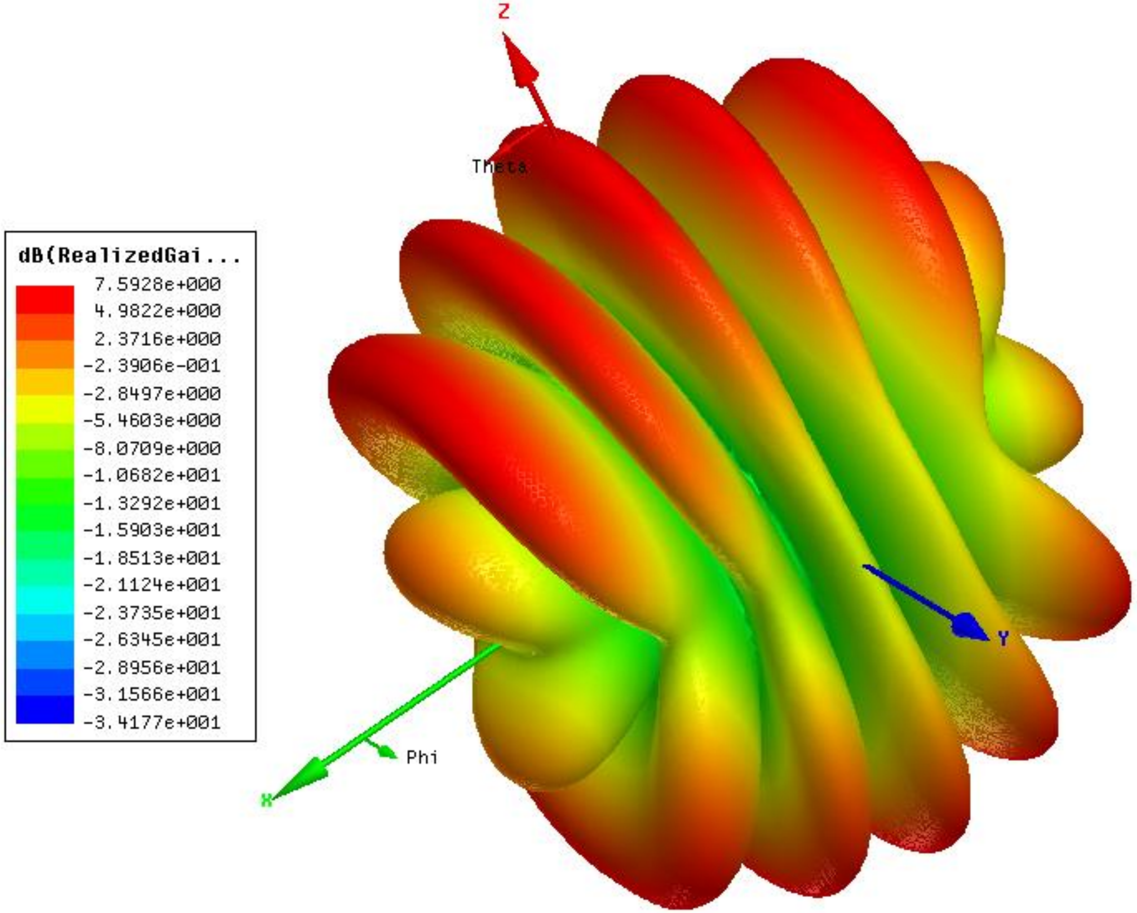
- From the difference between λ/2 and λ spacing, we can see from the S-parameter plots, the smaller spacing increases the coupling between elements.
- Lower variations of return loss plots for λ spacing .
- Respective (similar) reflection/transmission coefficients are better for λ (little deviation of 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



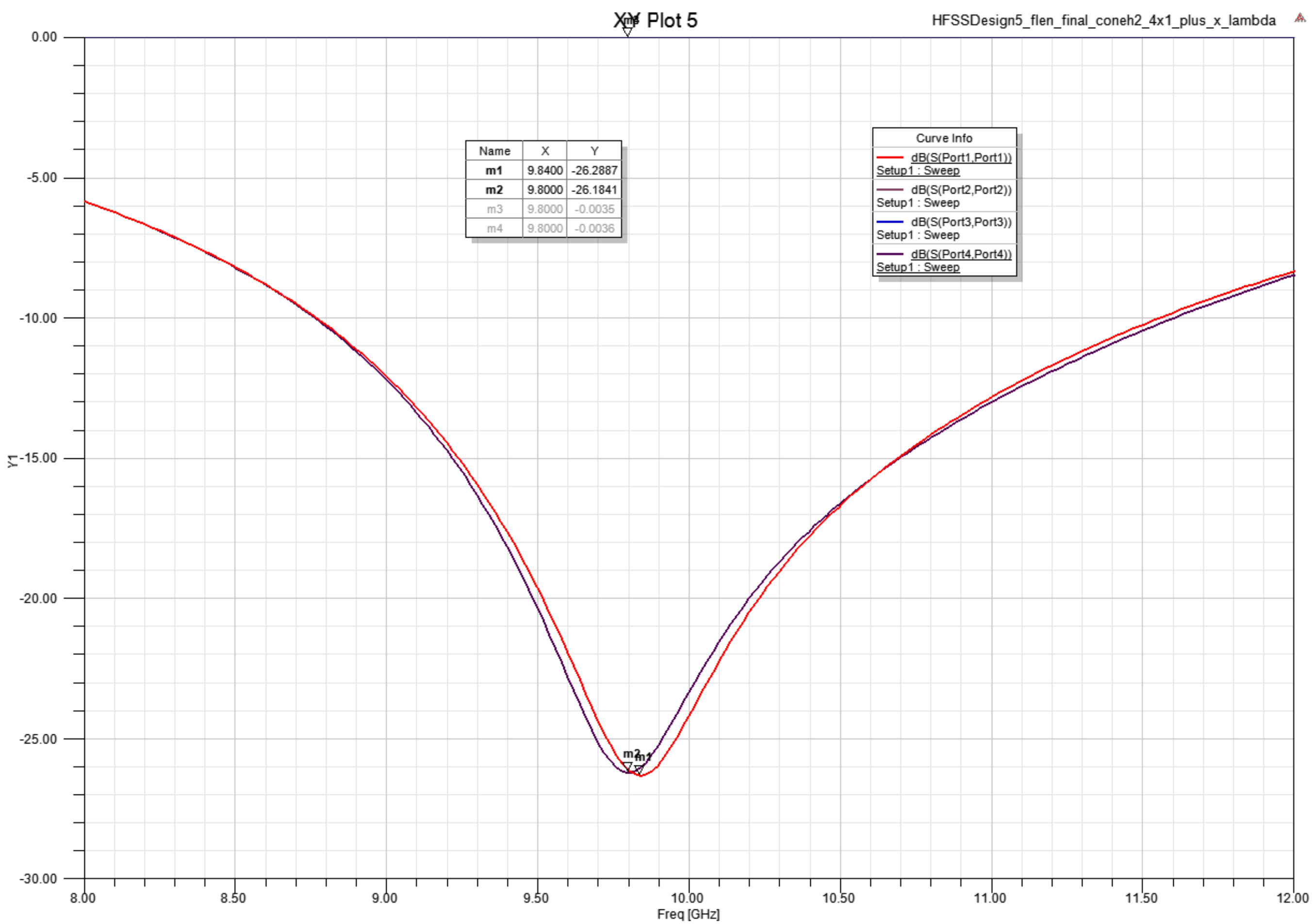
HPBW = 9.3279˚ (smaller), SLL = -0.4787 dB , BWFN = 29˚

Port 2 and 3 Shorted: 3D Polar Plot



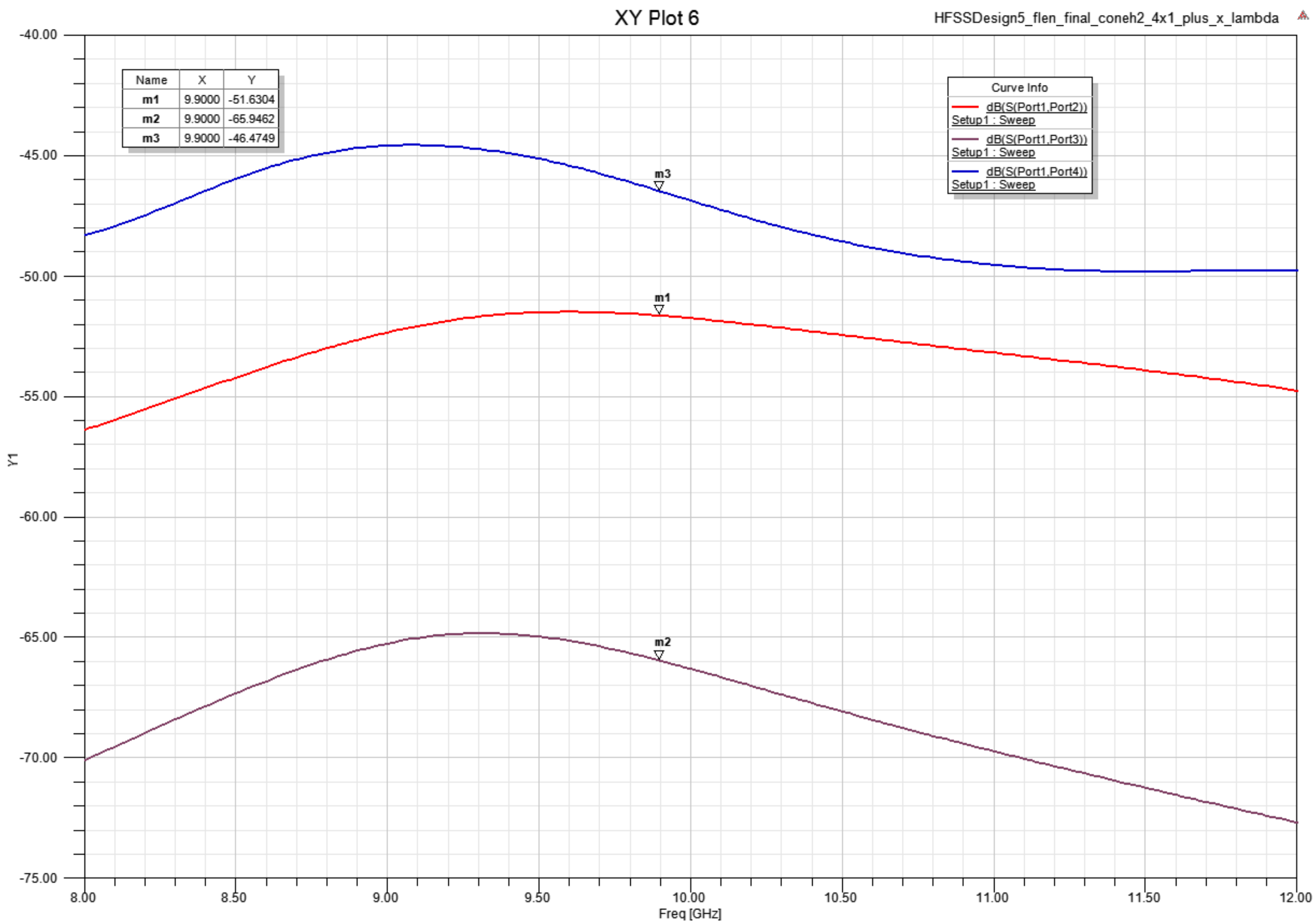
Gain at 7.5928 dB vs. Gain at 9.7889 dB (original)

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

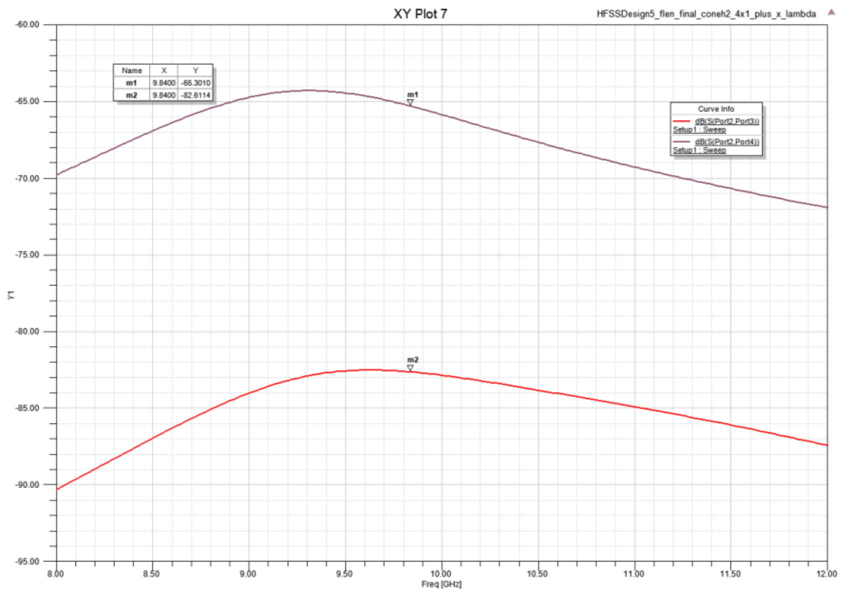


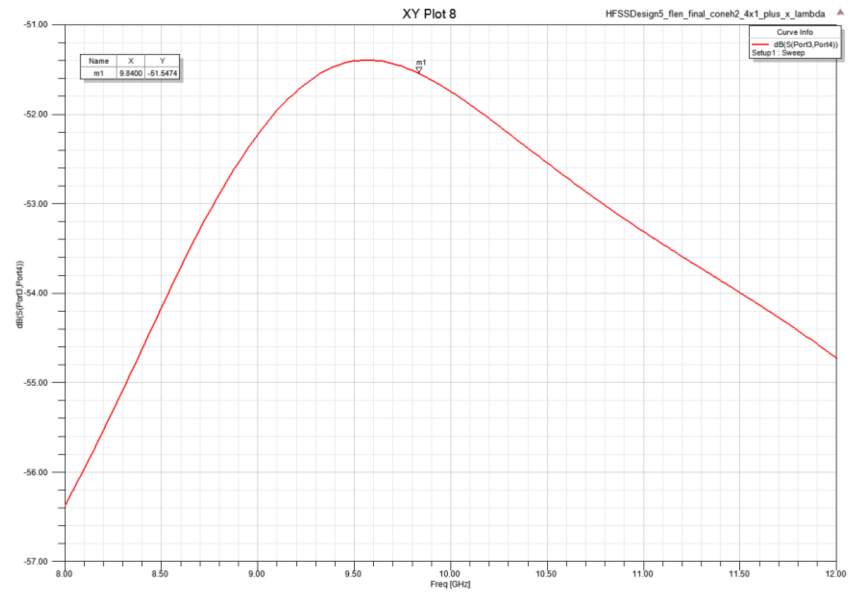
S11 and S44 remain unchanged, S22 and S33 are voided

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



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



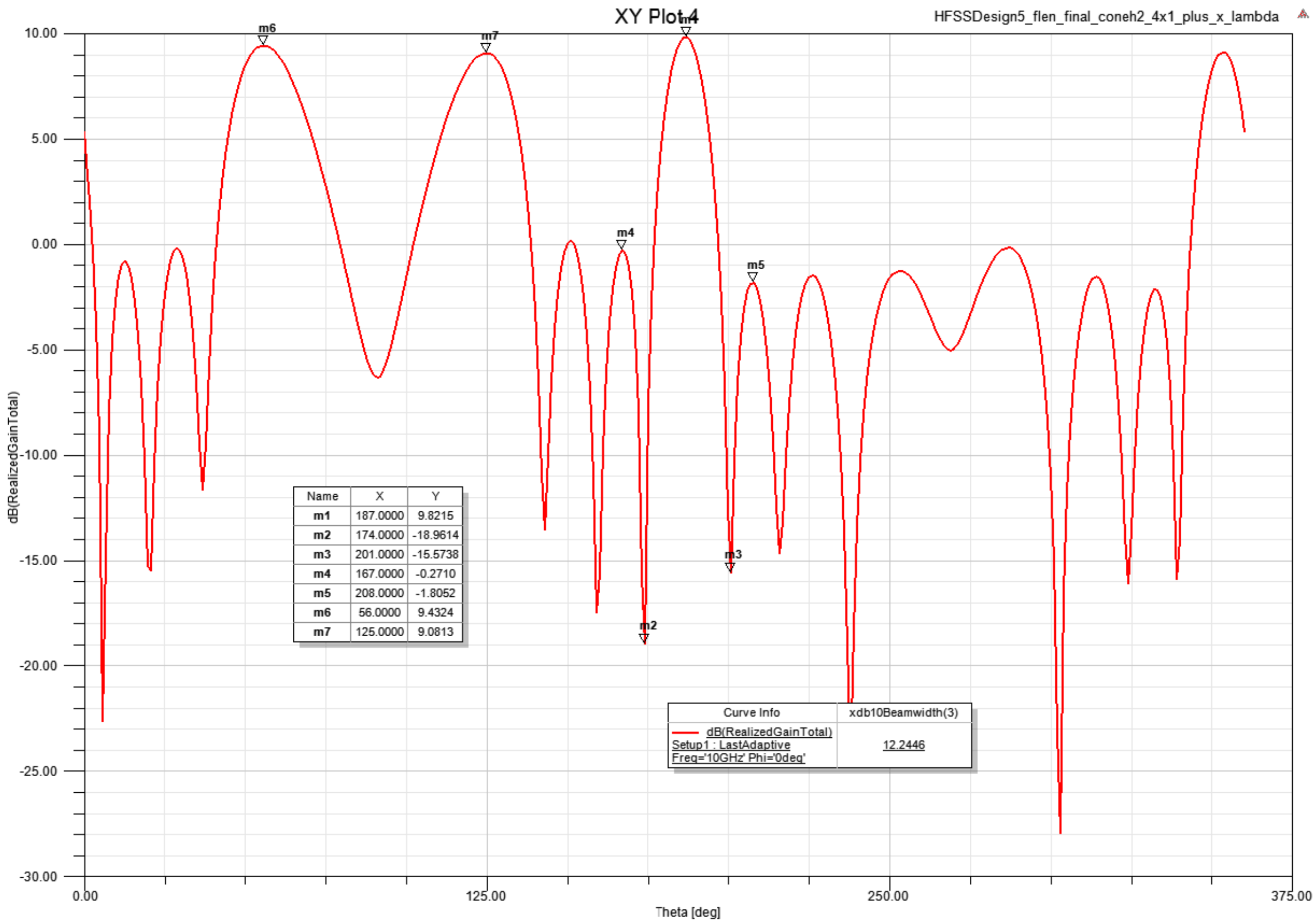


Shorted Port Changes

	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)

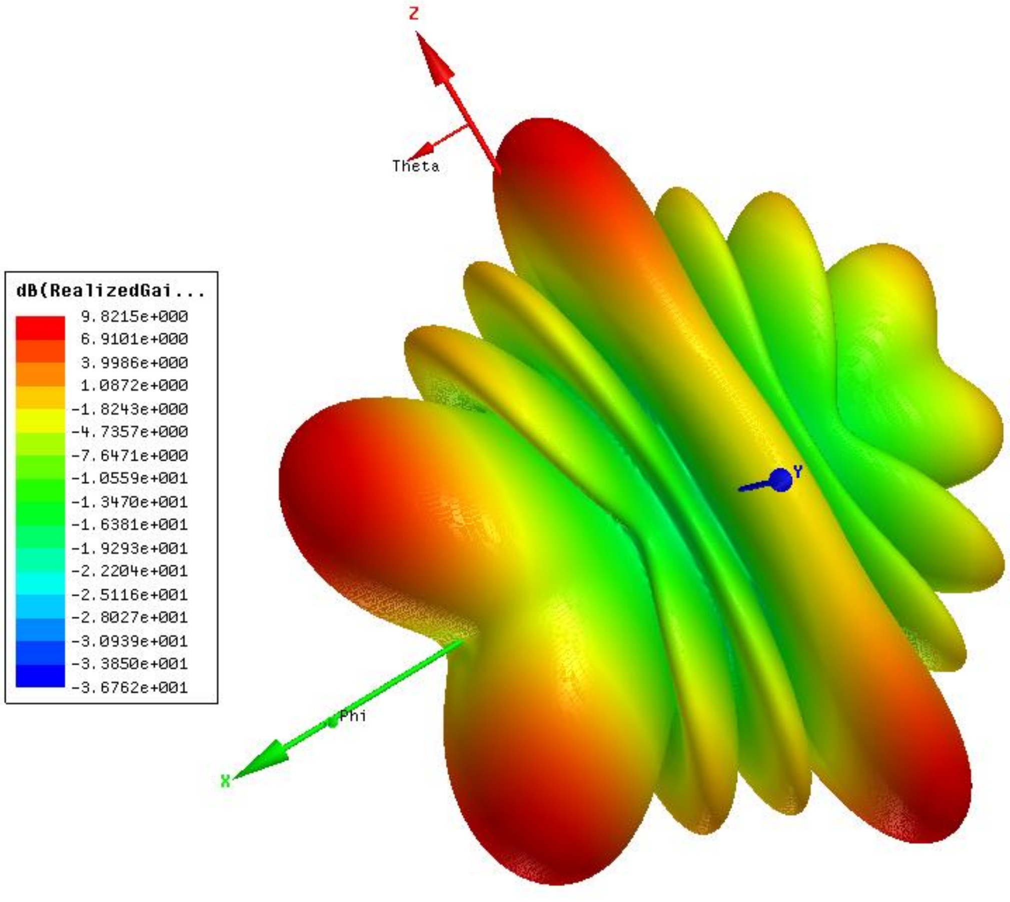
1D beam, Uniform Beam Scanning, d = λ spacing.



Name	X	Y
m1	187.0000	9.8215
m2	174.0000	-18.9614
m3	201.0000	-15.5738
m4	167.0000	-0.2710
m5	208.0000	-1.8052
m6	56.0000	9.4324
m7	125.0000	9.0813

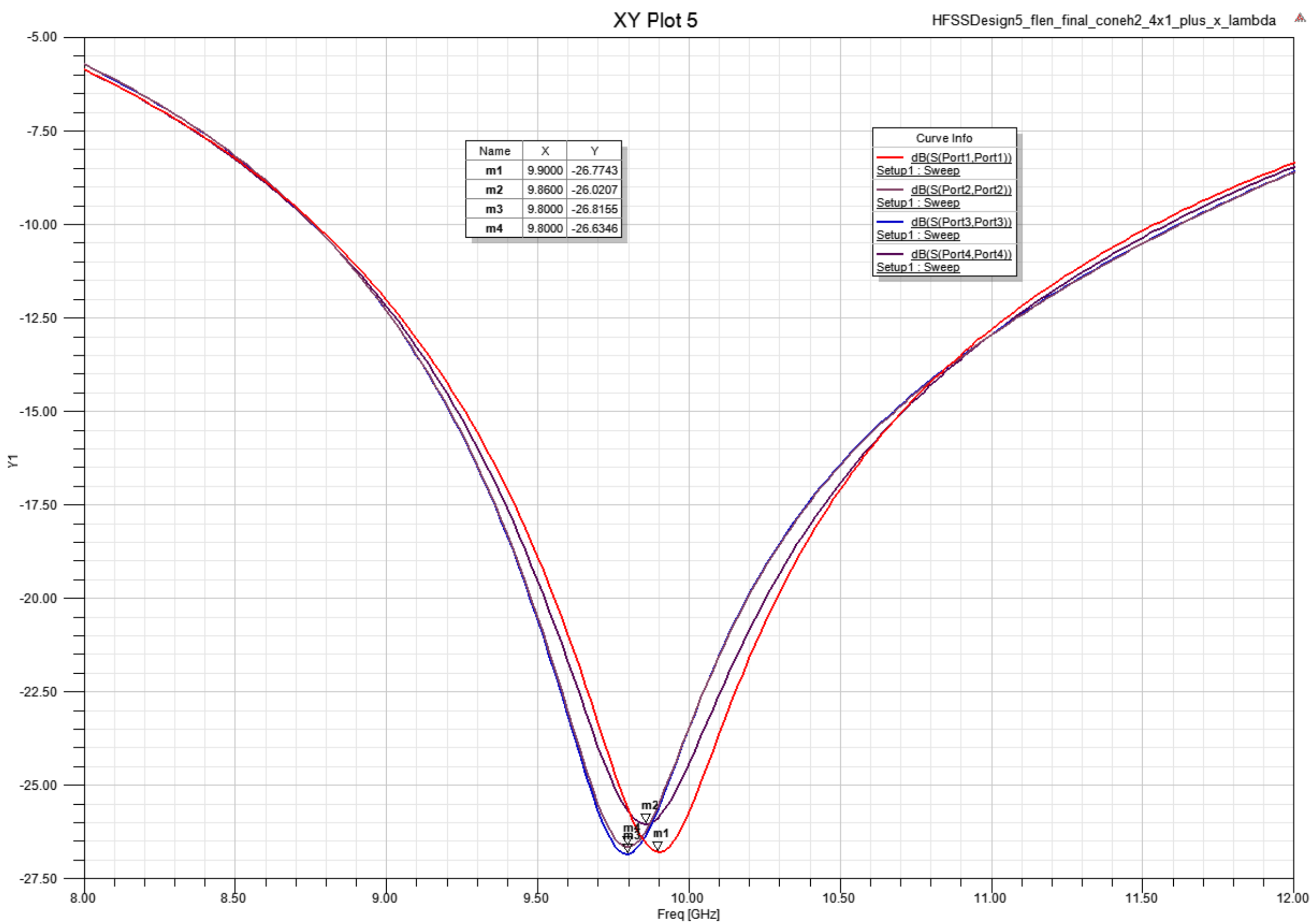
HPBW = 12.2446˚ (smaller), SLL = -0.3891 dB , BWFN = 27˚ (Not symmetrical)

1D beam, Uniform Beam Scanning, d = λ spacing, 3D Polar Plot

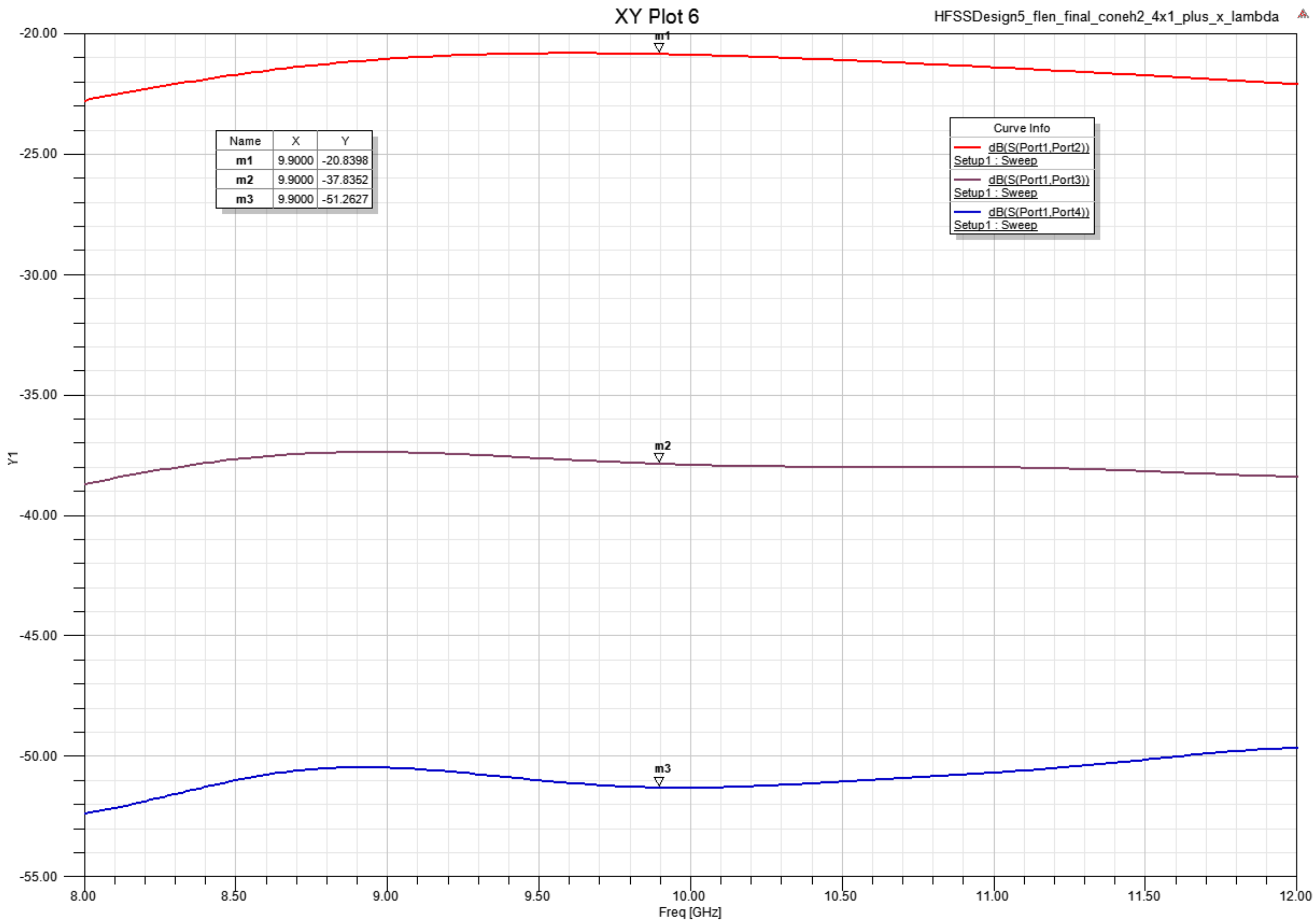


Gain at 9.7889 dB (original) compared to 9.8215 dB (not much change, pattern does)

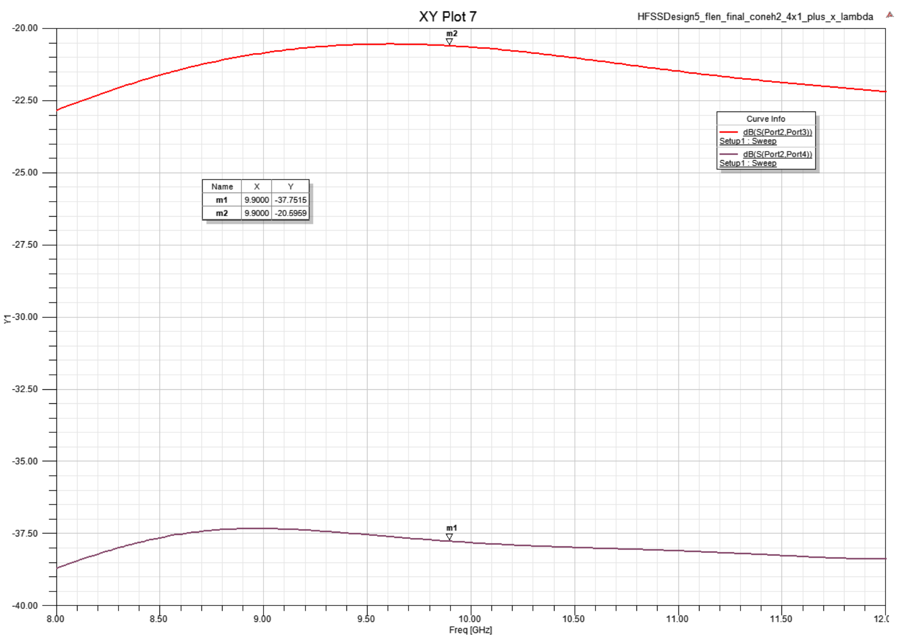
1D beam, Uniform Beam Scanning, d = λ spacing: S11, S22, S33, S44 parameters

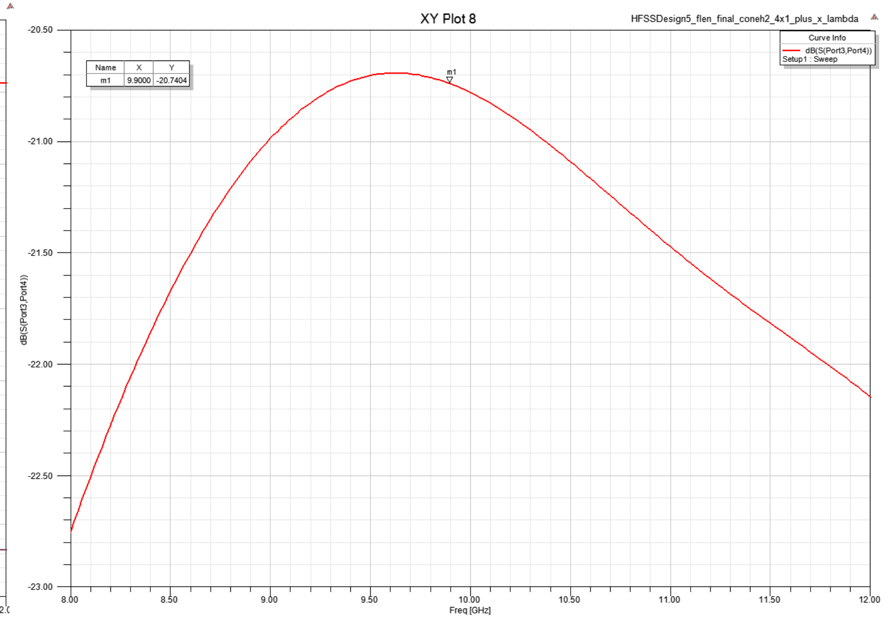


1D beam, Uniform Beam Scanning, d = λ spacing: S12, S13, S14, parameters



1D beam, Uniform Beam Scanning, d = λ 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

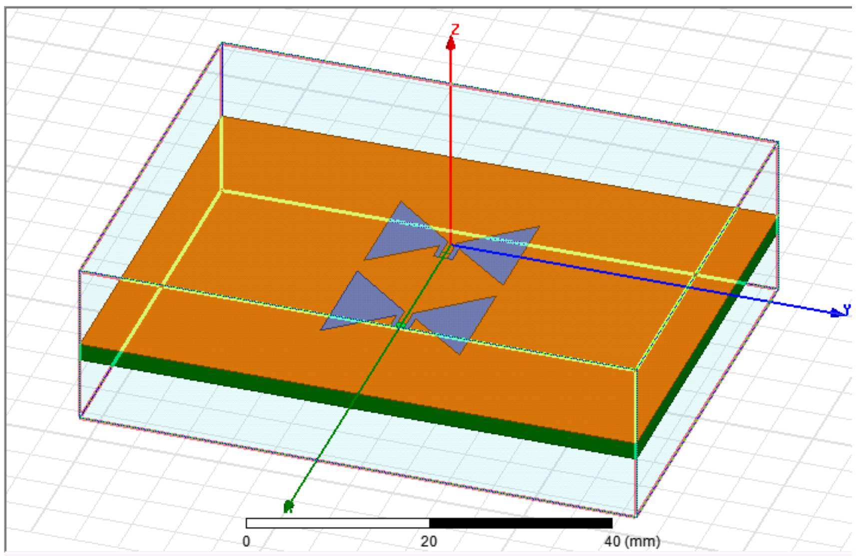
Not much of change to the S-parameters except for S23 and S34 (perhaps to the higher phase excitation.

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

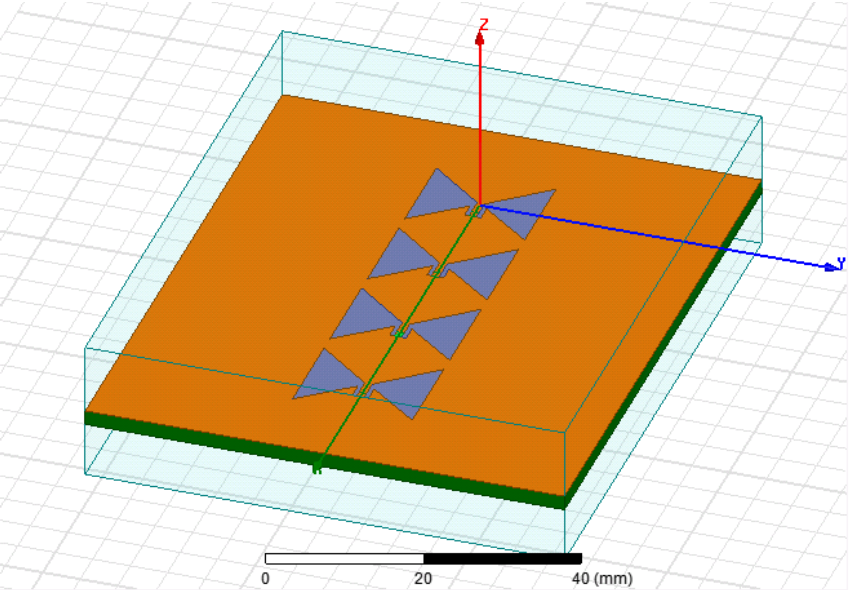
- Semi-Replacement for Phase I slides.
  - What to expect:
    - Higher Gain for 4x1 Array antenna
    - More/Multiple complex side-lobes for λ spacing
    - S-parameters are similar (not reciprocal).
    - Effect of Grating lobes for lambda spacing becomes more probable.
    - Plots are redone to make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

Layout: 2 x 1 Array, 4x1 Array d = λ/2,

2x1 Array

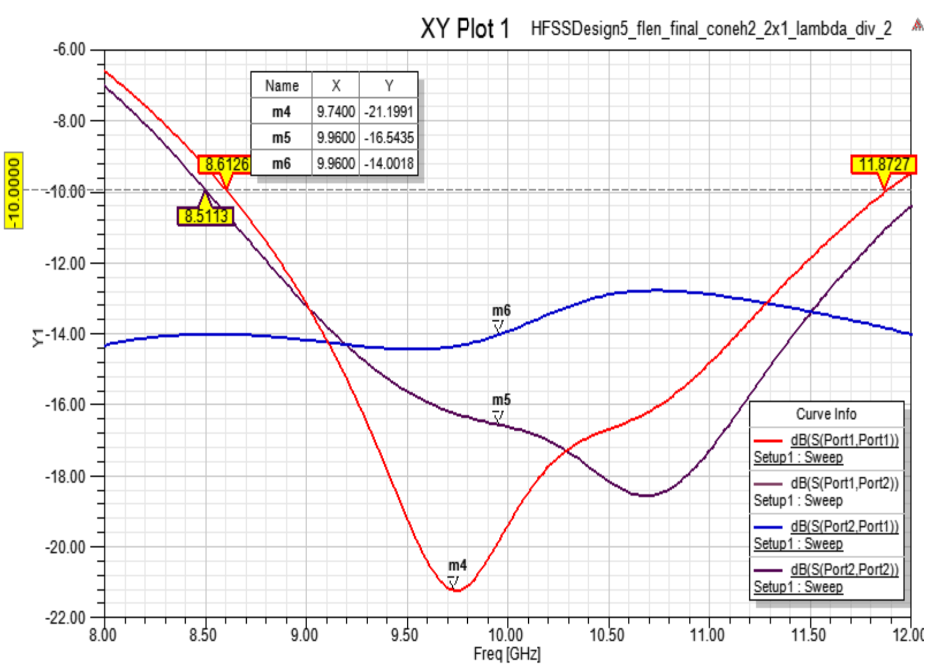


4x1 Array

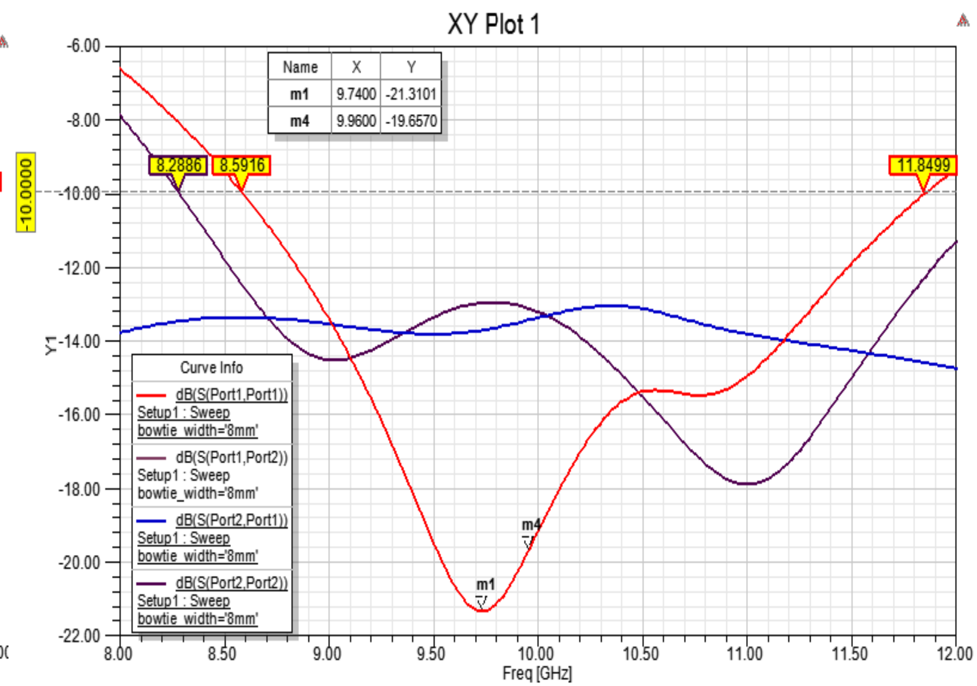


S parameters, d = λ/2

2 x 1 Array



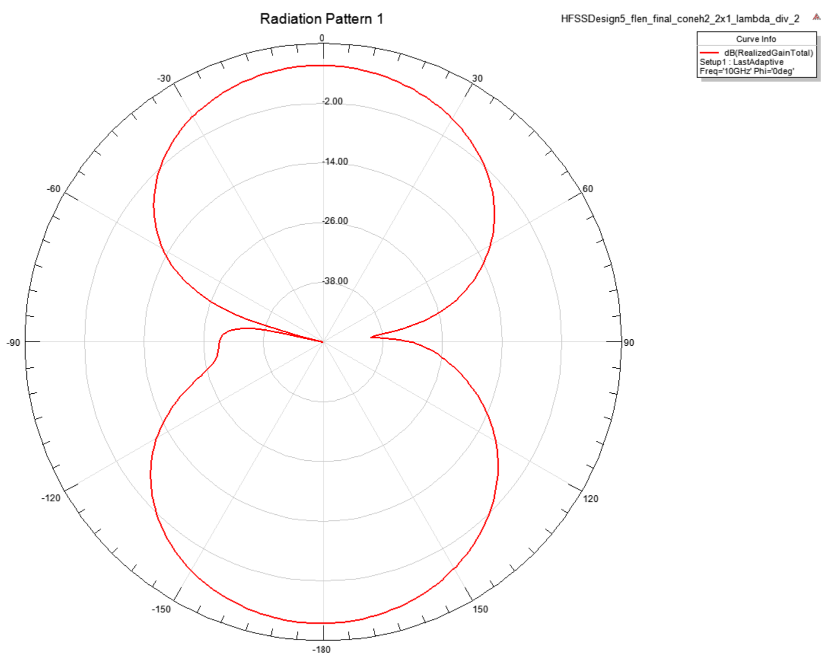
4x1 Array



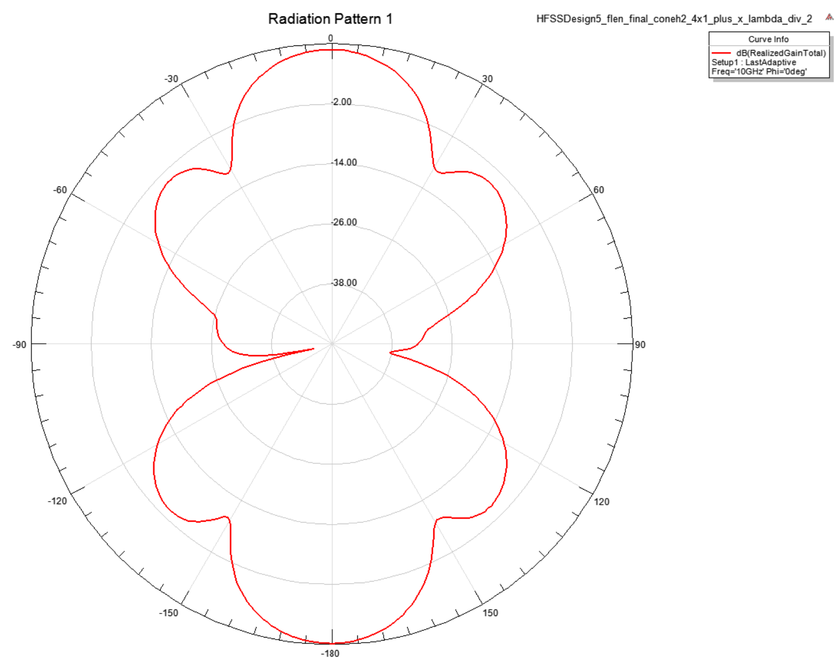
S12 = S21 same, S11 not equal to S22

E-plane (d = λ/2)

2x1 Array

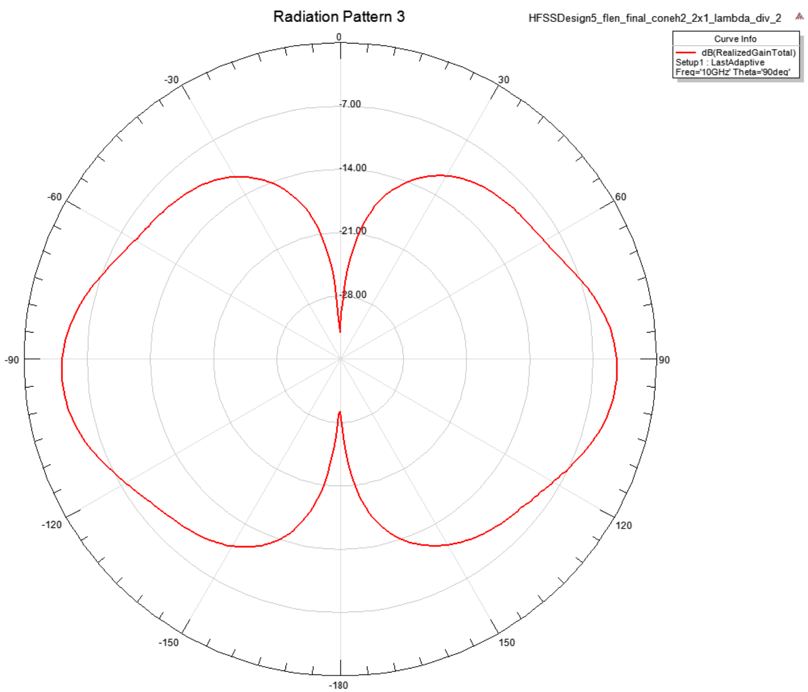


4x1 Array

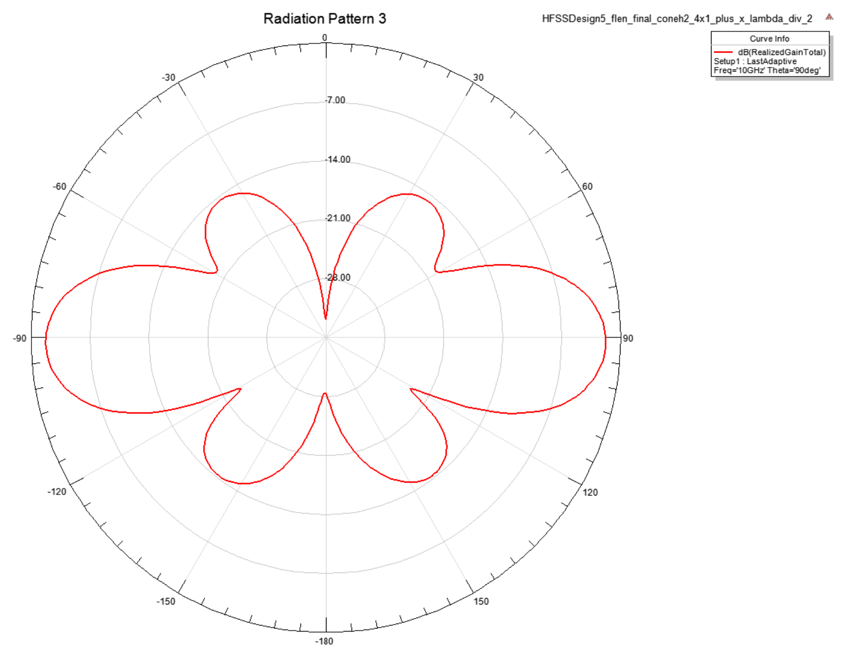


H-plane (d = λ/2)

2x1 Array

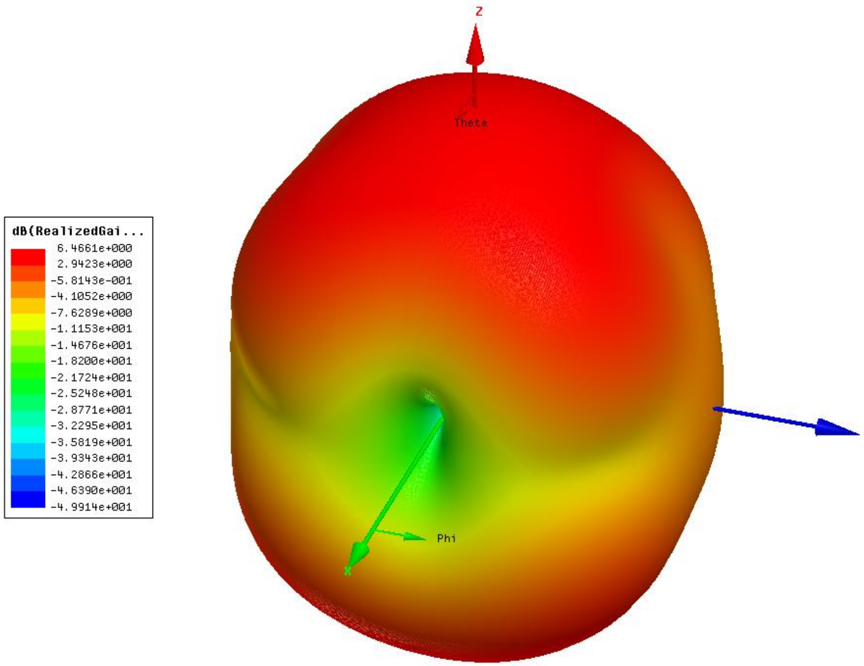


4x1 Array

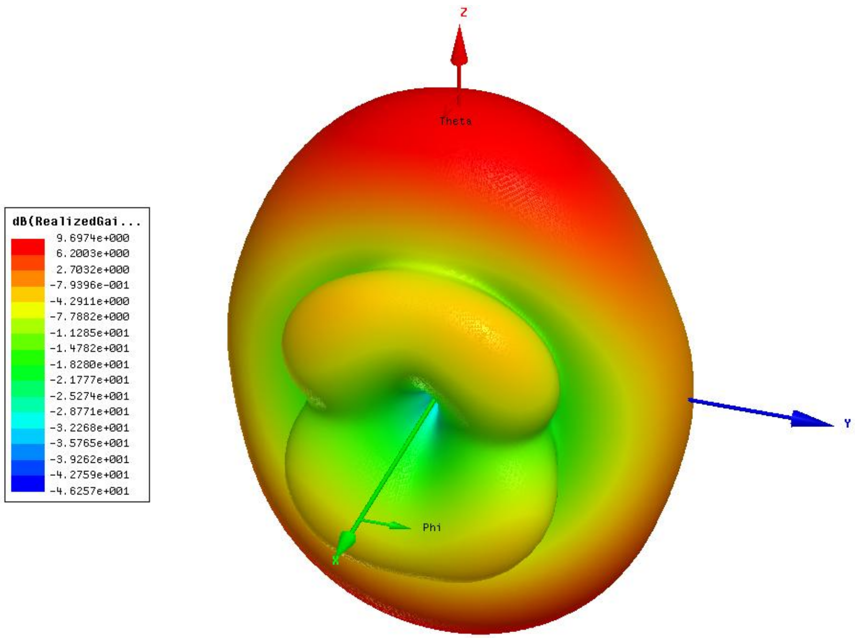


3D Polar Plot: d = λ/2

2x1 Array

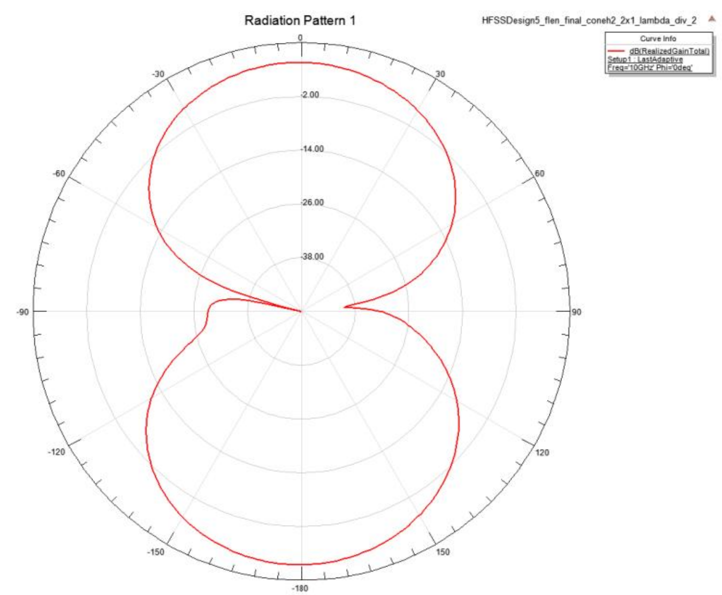


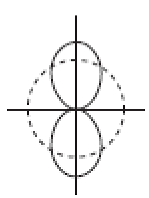
4x1 Array



Excitation Phase, d = λ/2, 2x1 Array

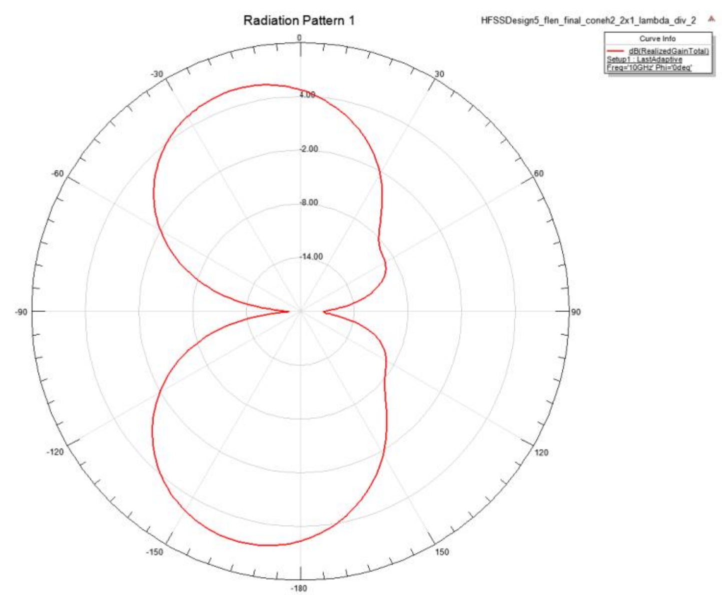
Phase = 0 degrees

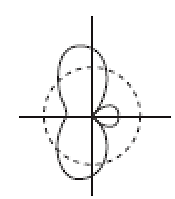




[2]

Phase = 45 degrees

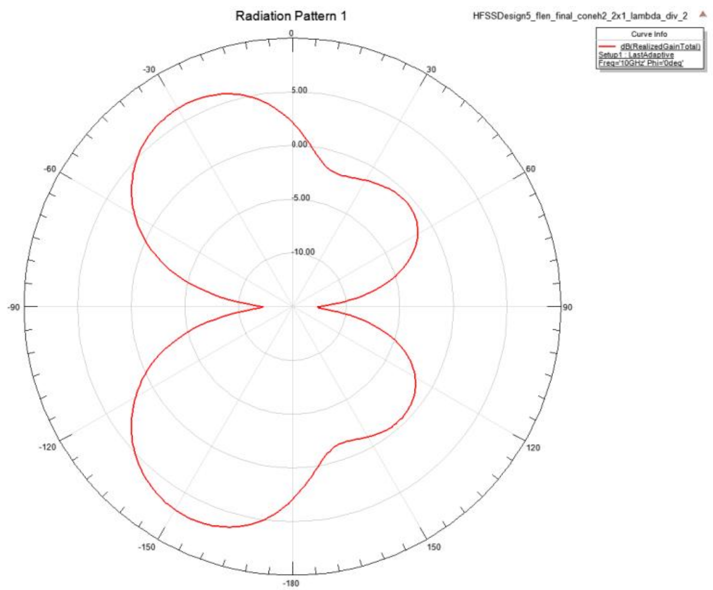


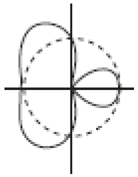


[2]

Excitation Phase, d = λ/2, 2x1 Array

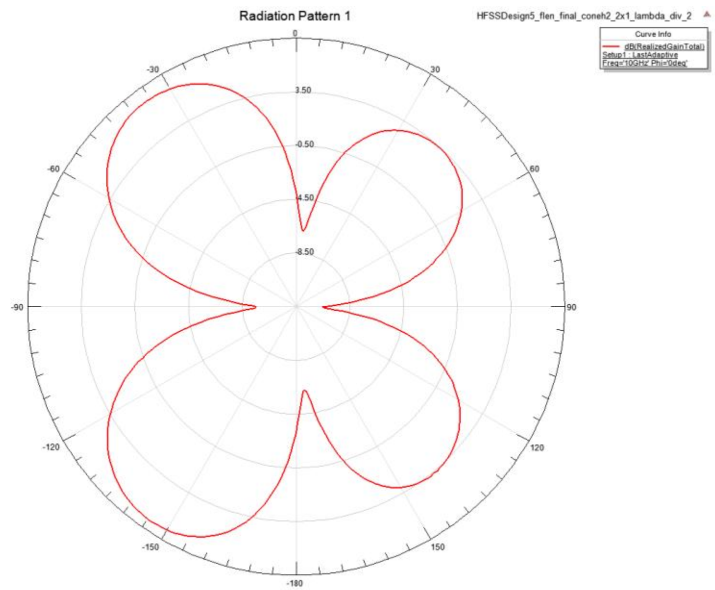
Phase = 90 degrees

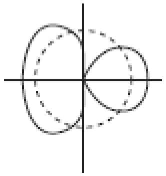




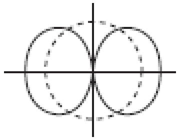
[2]

Phase = 135 degrees



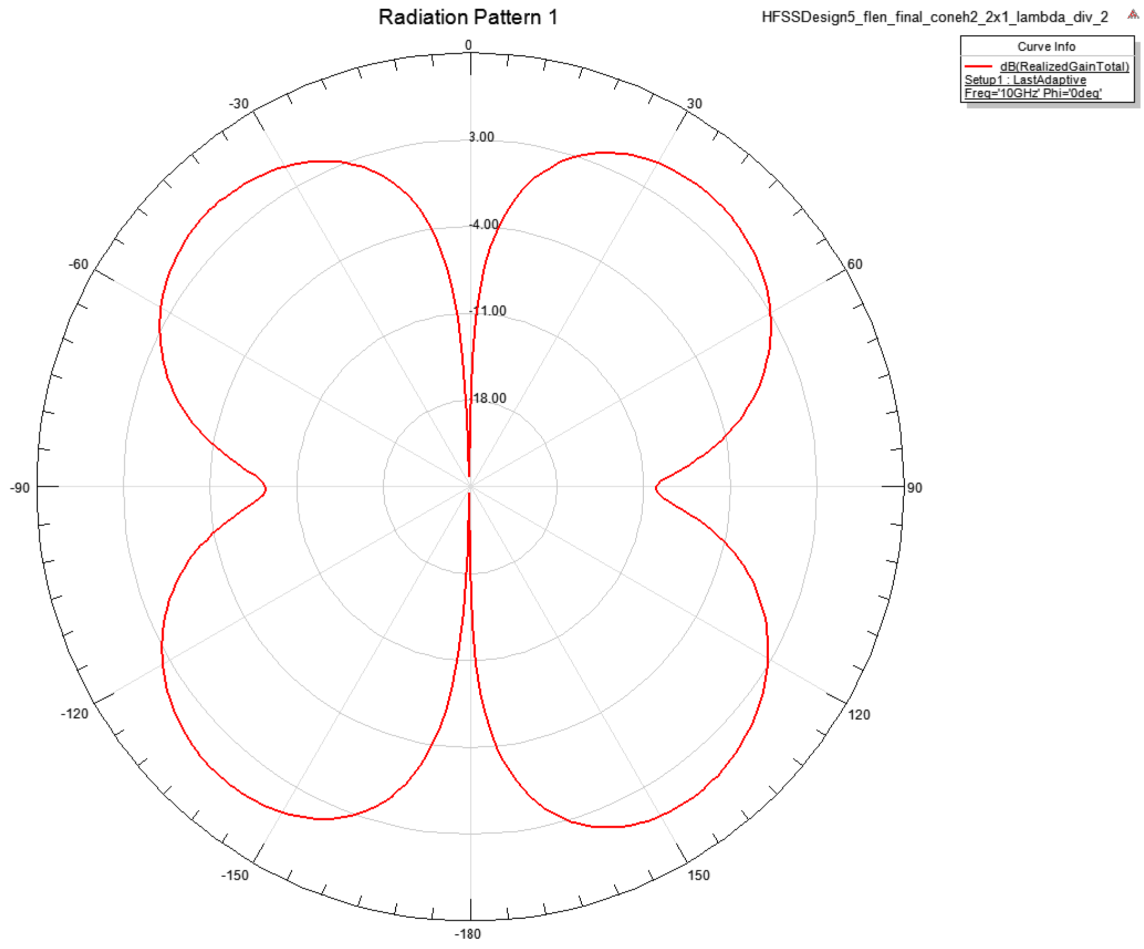


[2]



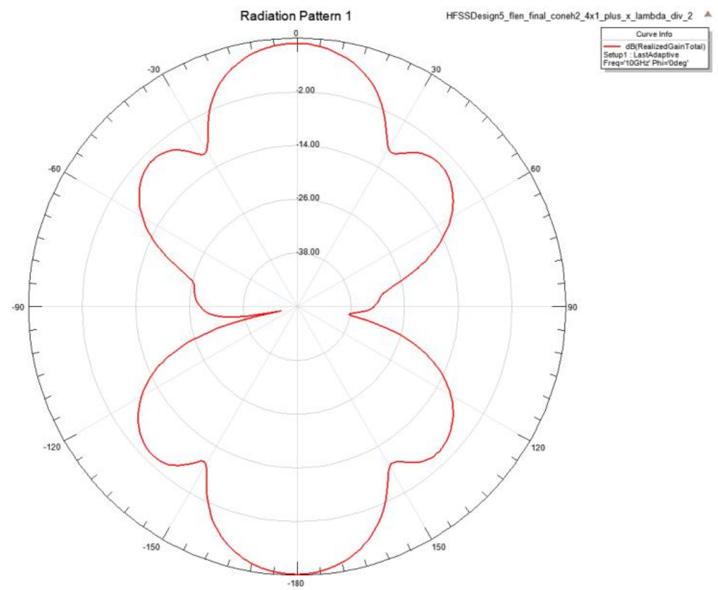
[2]

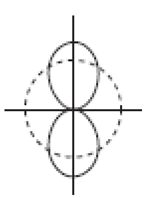
Excitation Phase, d = λ Phase = 180 degrees, 2x1 Array



Excitation Phase, d = λ/2, 4x1 Array

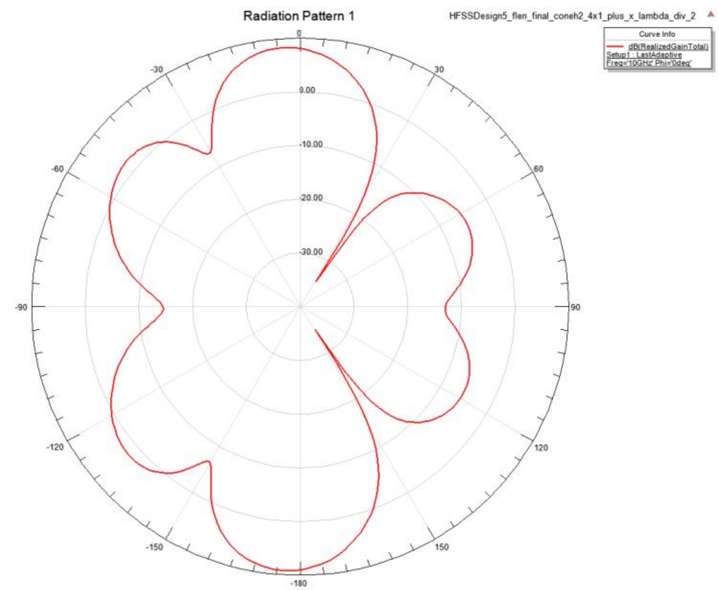
Phase = 0 degrees

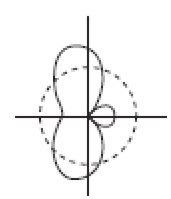




[2]

Phase = 45 degrees

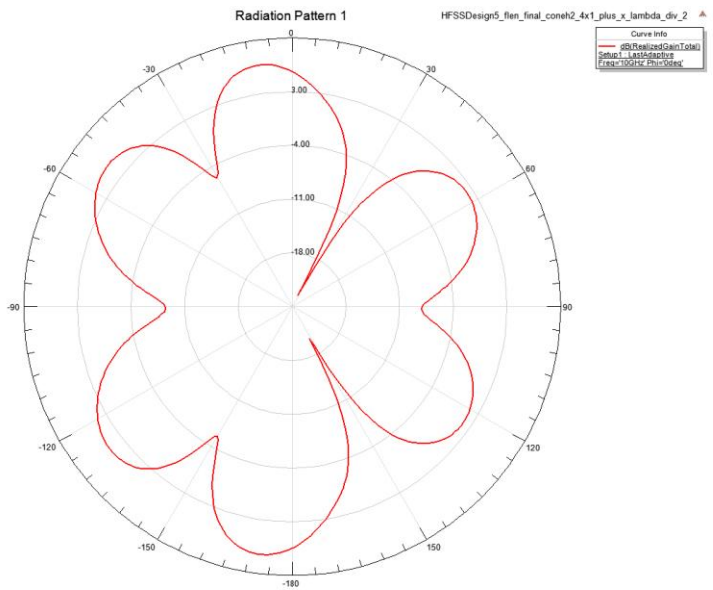


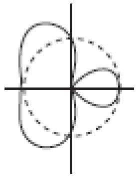


[2]

Excitation Phase, d = λ/2, 4x1 Array

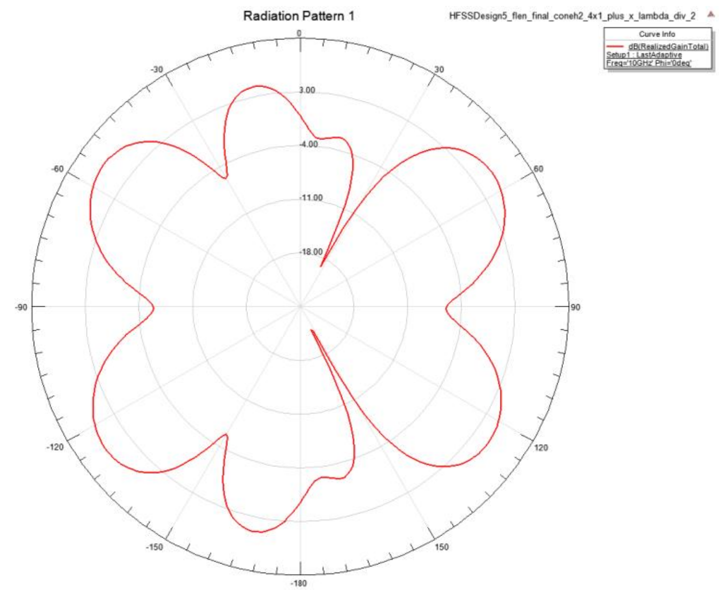
Phase = 90 degrees

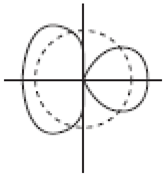




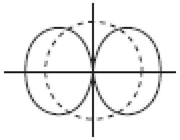
[2]

Phase = 135 degrees



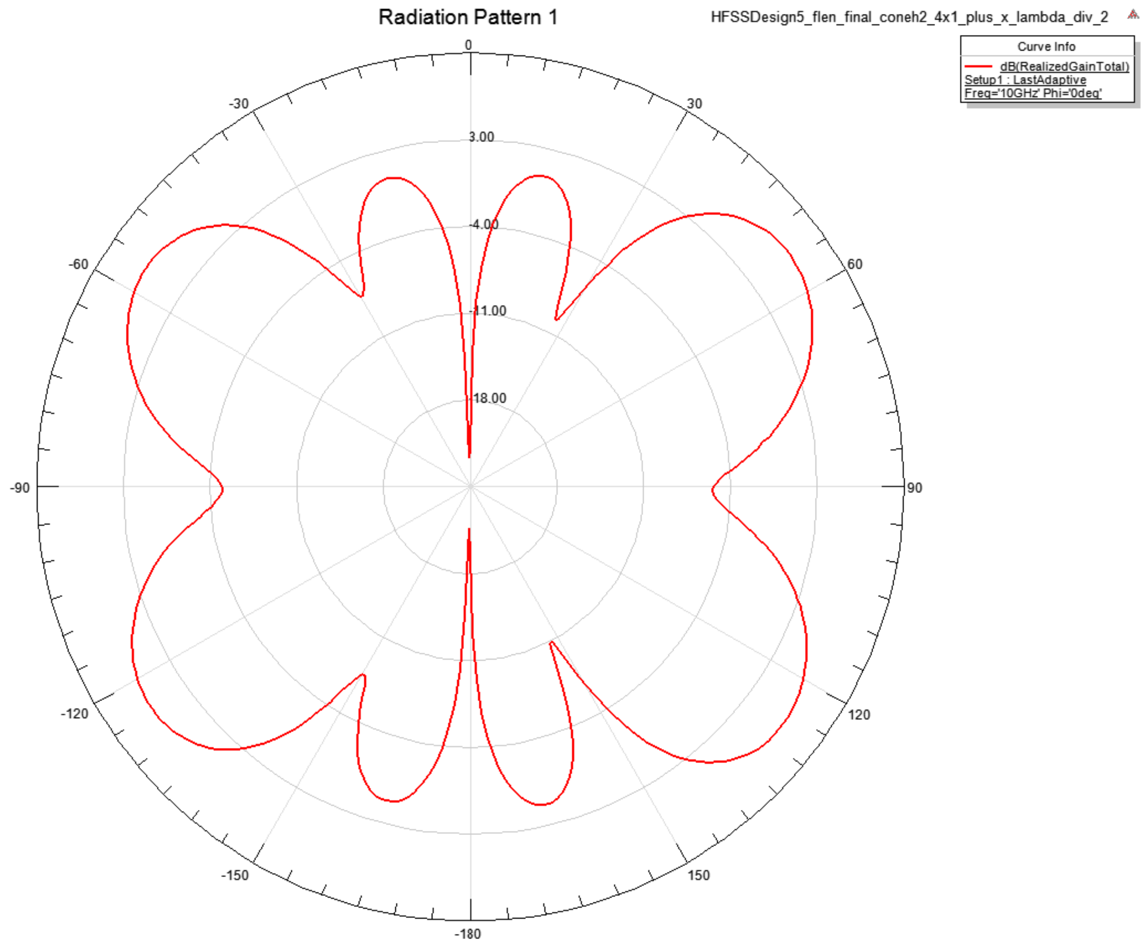


[2]



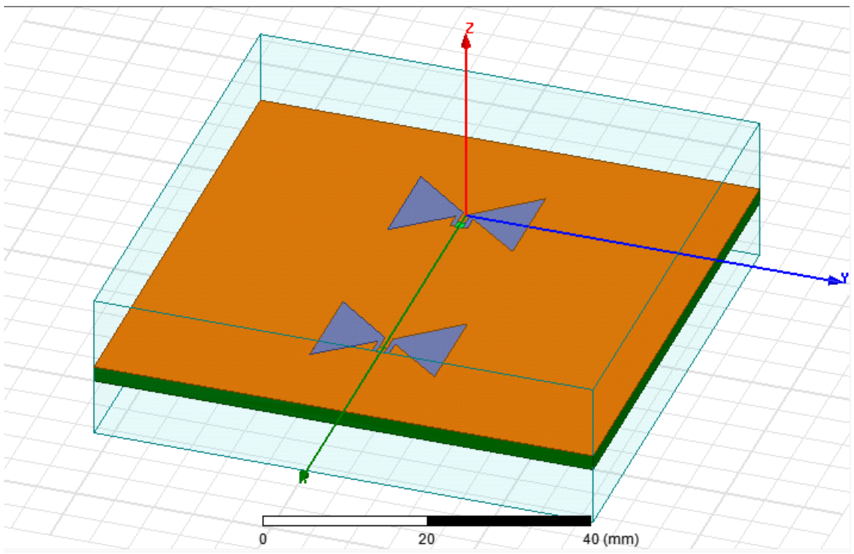
[2]

Excitation Phase, d = λ Phase = 180 degrees, 4x1 Array

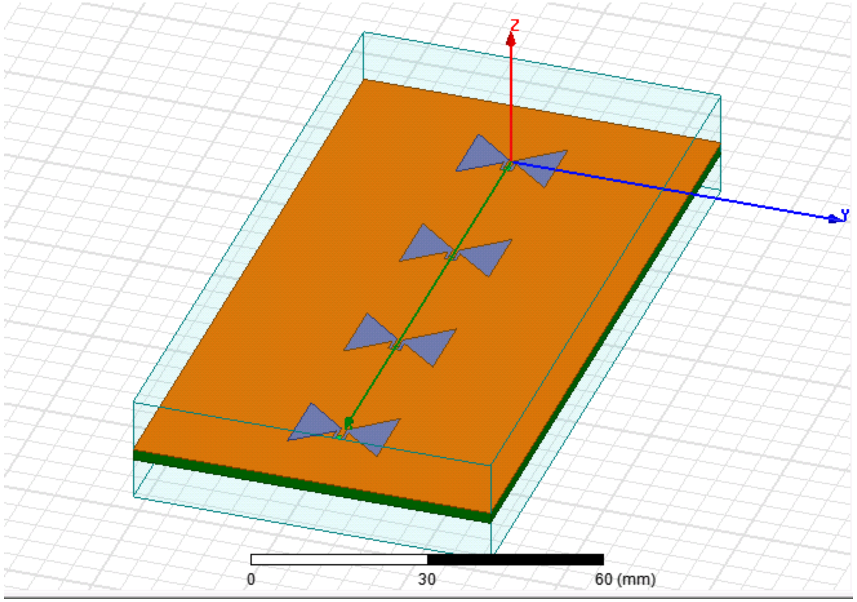


Layout: 2x1 Array, 4x1 Array, d = λ

2x1 Array

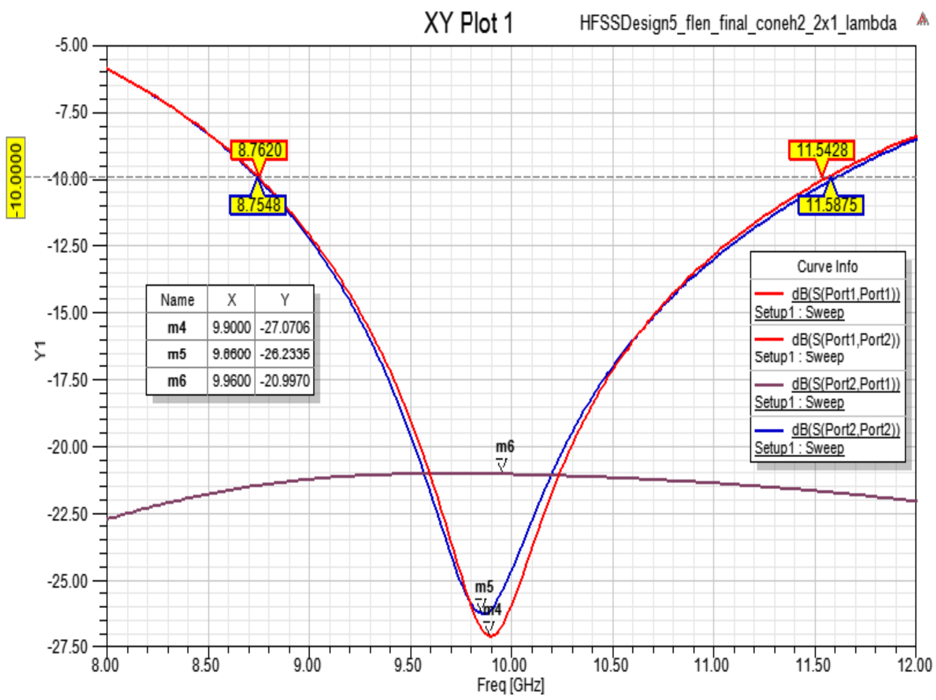


4x1 Array

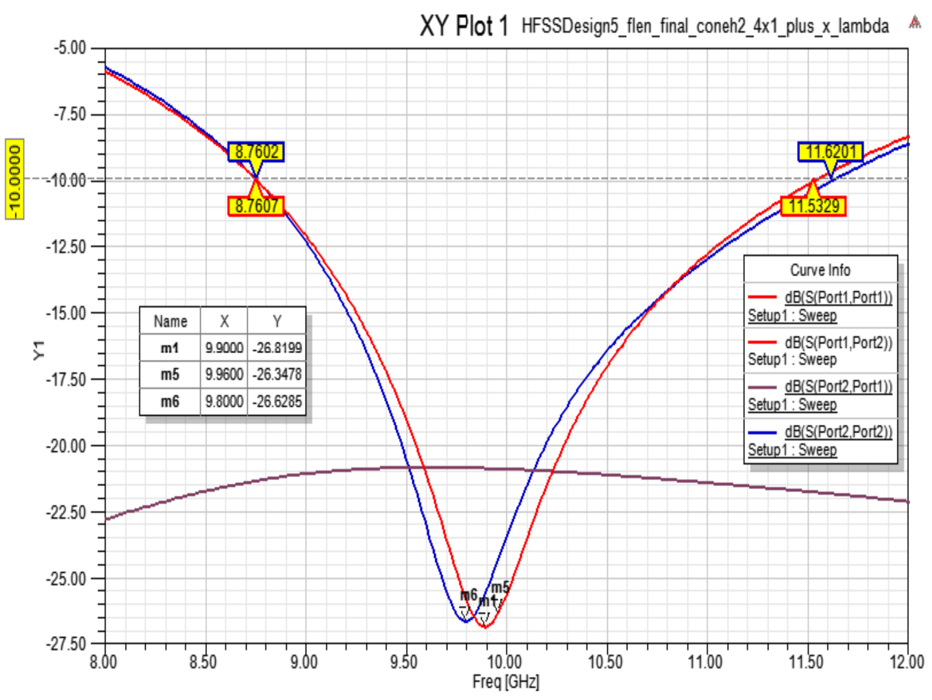


S parameters, d = λ

2x1 Array

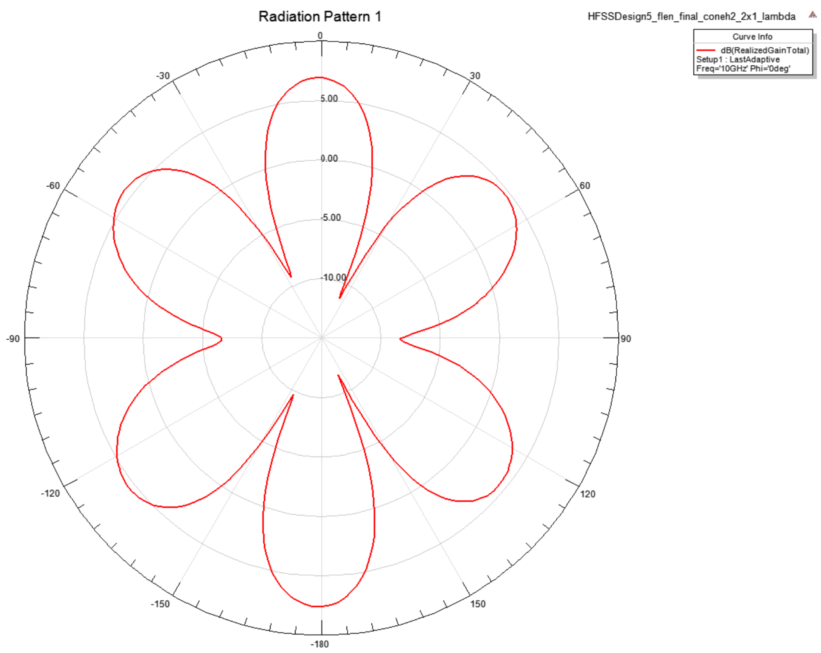


4x1 Array

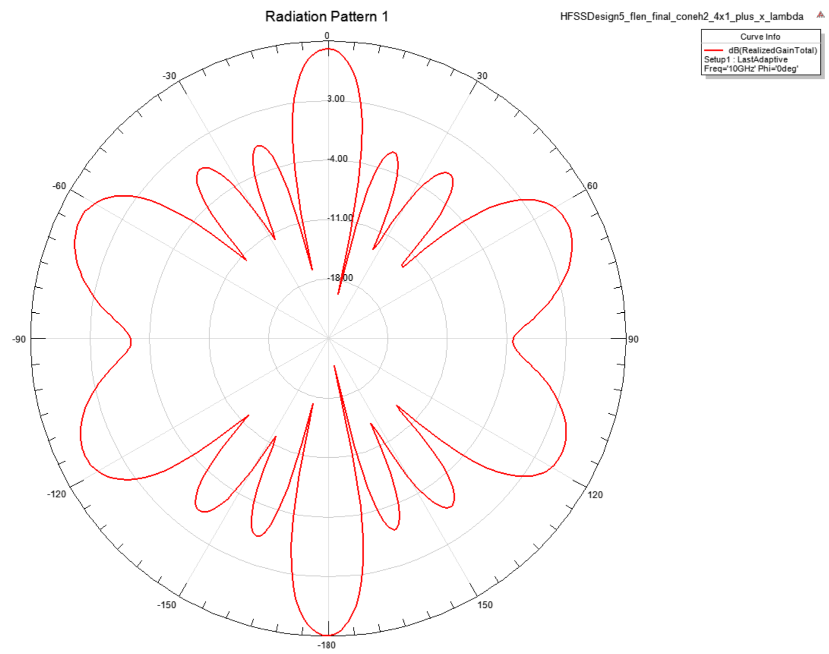


E-plane (d = λ)

2x1 Array

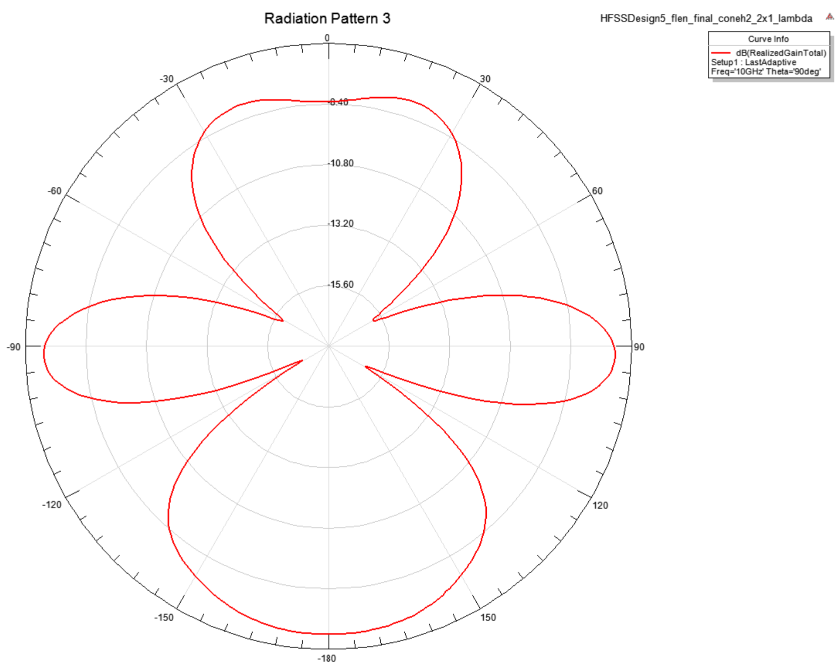


4x1 Array

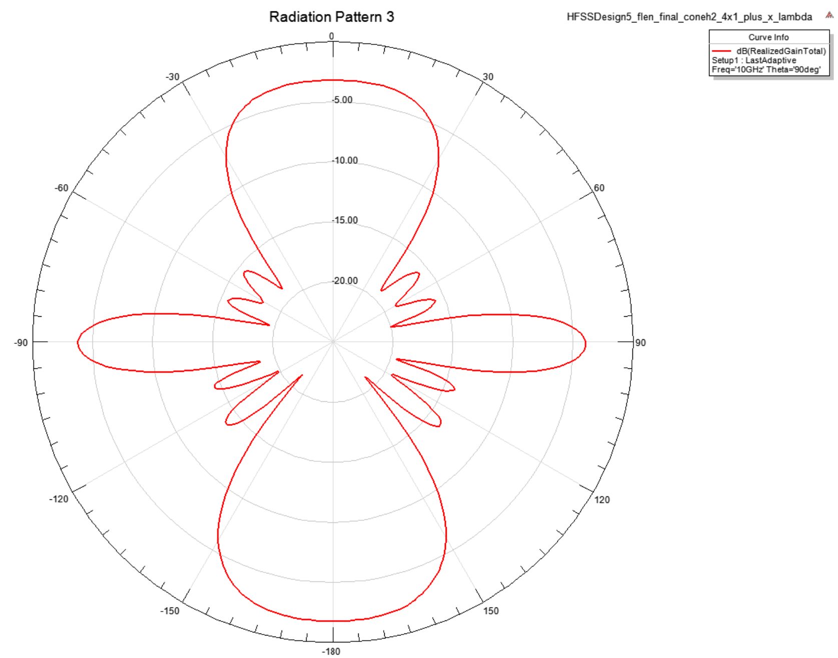


H-plane (d = λ)

2x1 Array

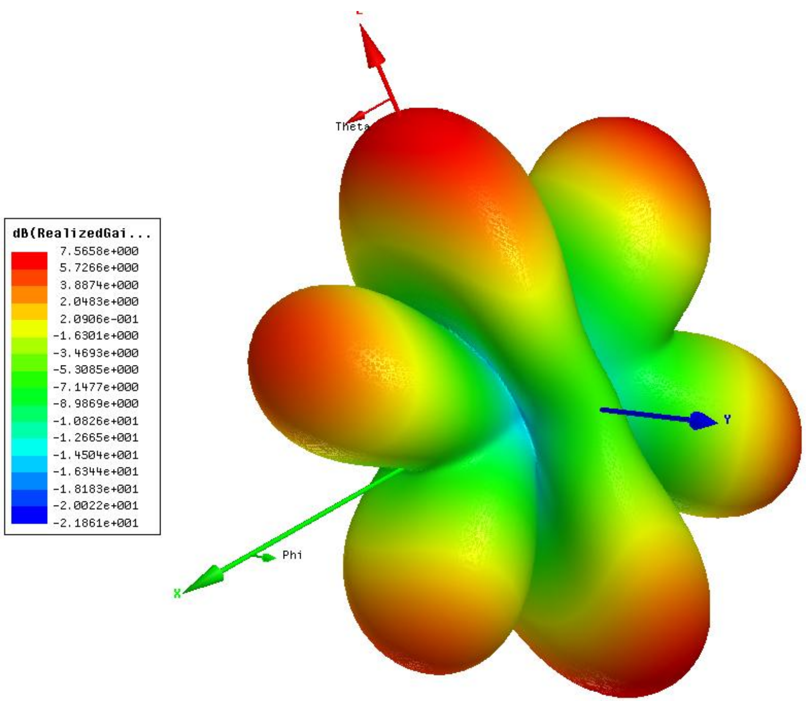


4x1 Array

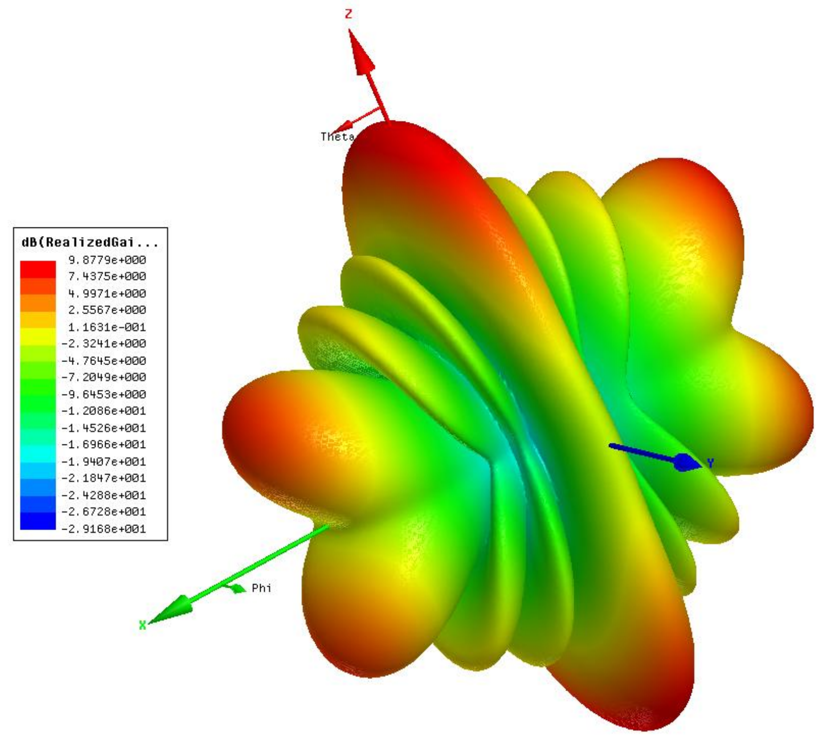


3D Polar Plot: d = λ

2x1 Array



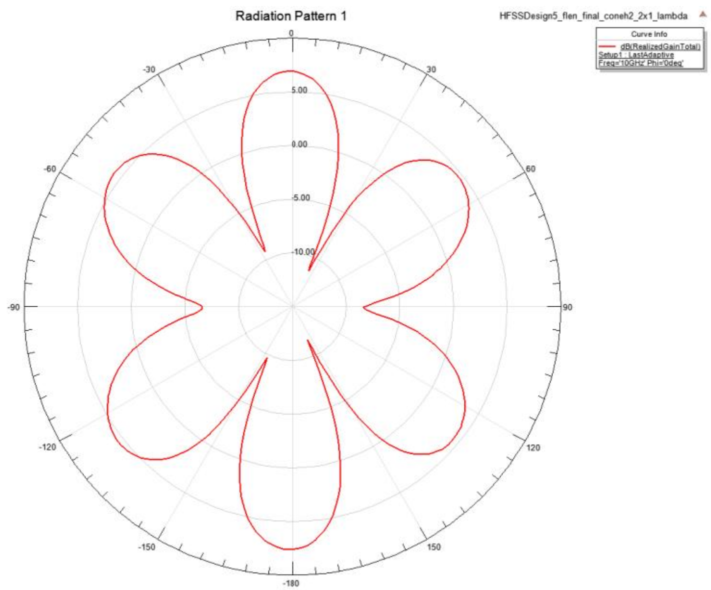
4x1 Array

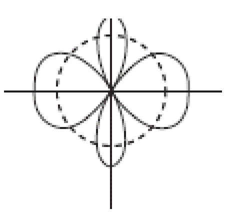


Larger Gain for 4x1 array, growth of multiple sidelobes for λ.

Excitation Phase, d = λ, 2x1 Array

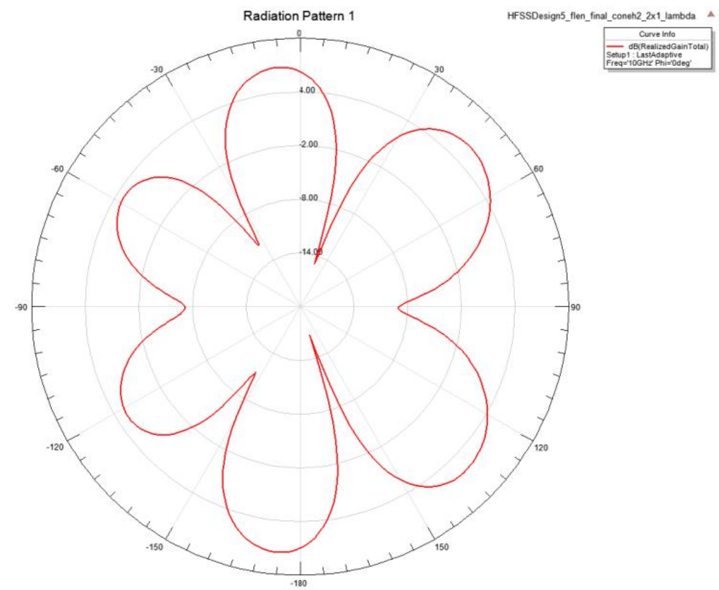
Phase = 0 degrees

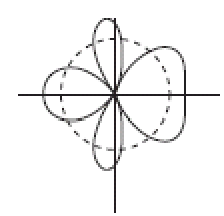




[2]

Phase = 45 degrees

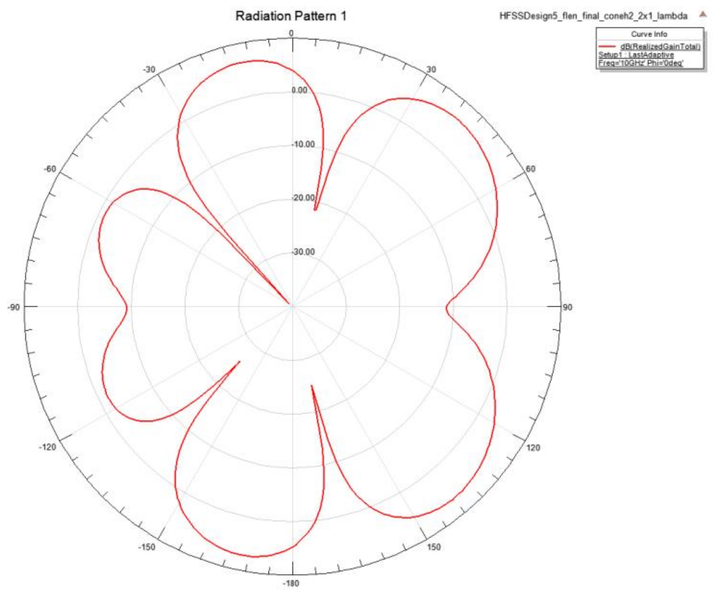


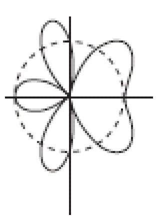


[2]

Excitation Phase, d = λ, 2x1 Array

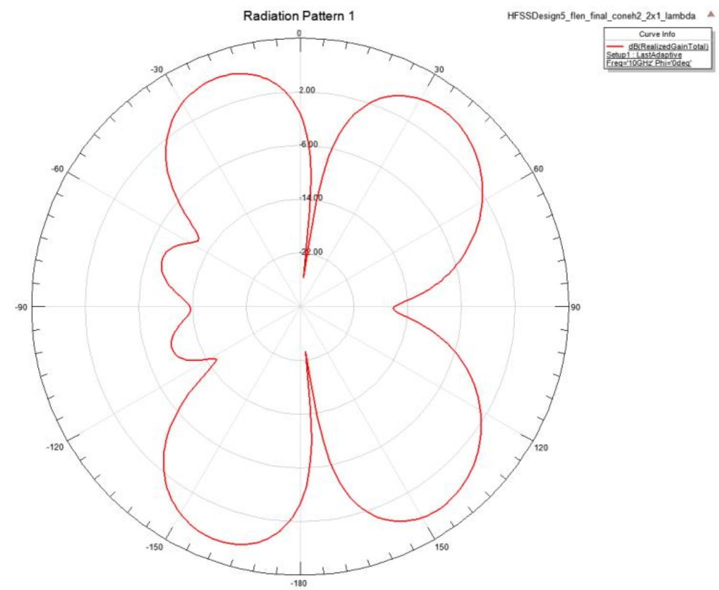
Phase = 90 degrees

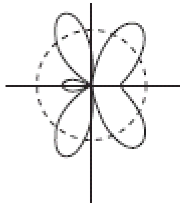




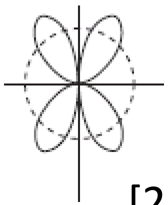
[2]

Phase = 135 degrees

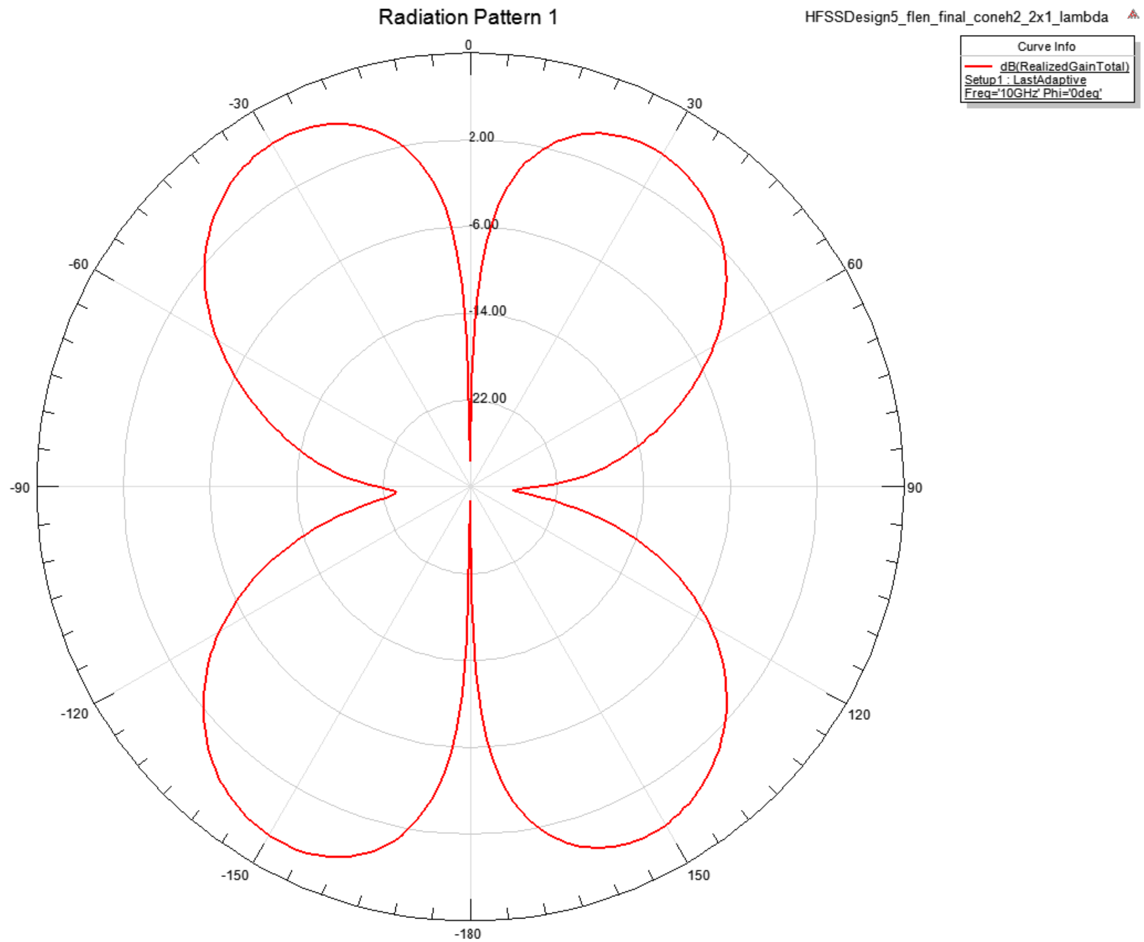




[2]

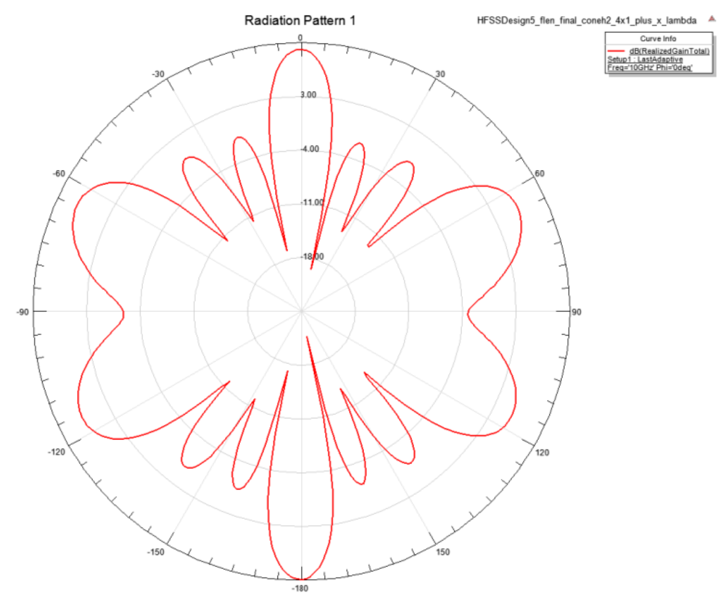

[2]

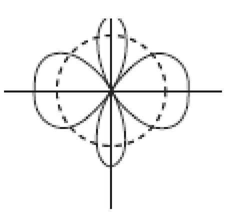
Excitation Phase, d = λ Phase = 180 degrees, 2x1 Array



Excitation Phase, d = λ, 4x1 Array

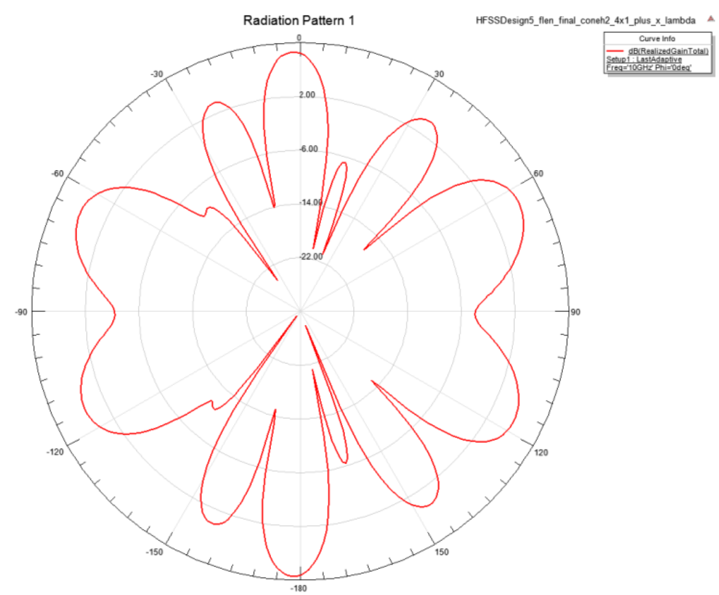
Phase = 0 degrees

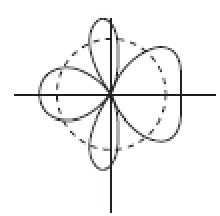




[2]

Phase = 45 degrees

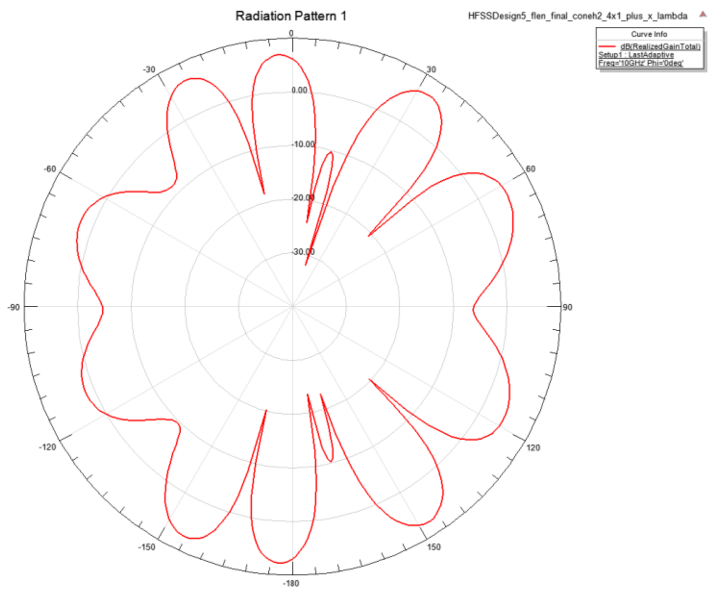


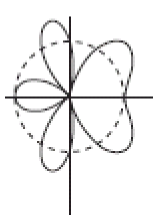


[2]

Excitation Phase, d = λ, 4x1 Array

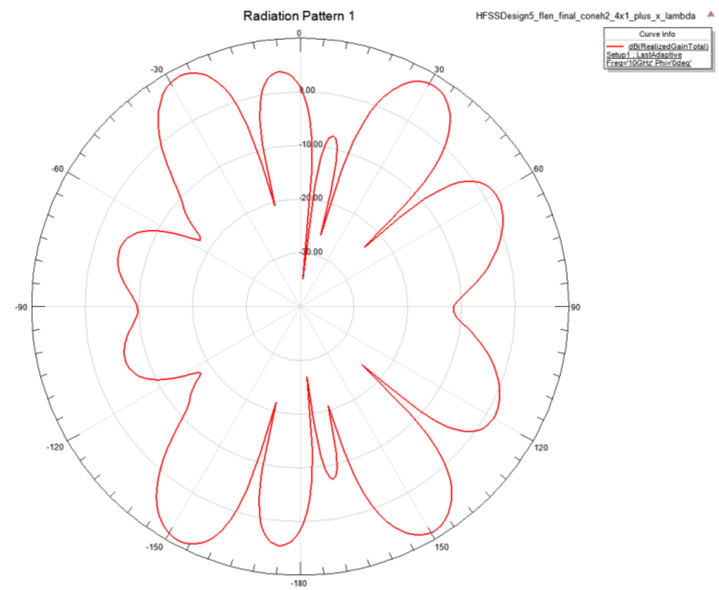
Phase = 90 degrees

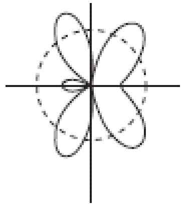




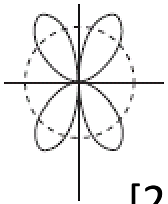
[2]

Phase = 135 degrees



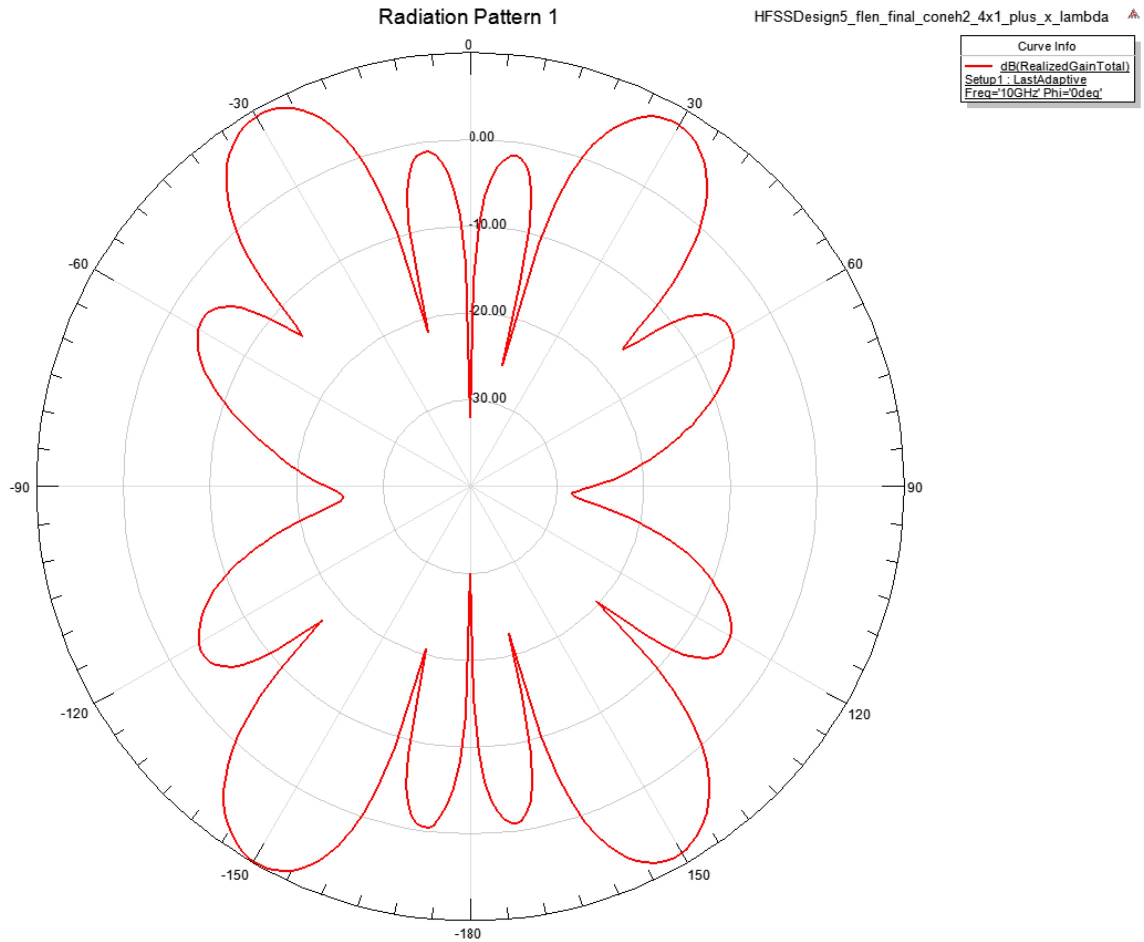


[2]



[2]

Excitation Phase, d = λ 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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- [2] Thiele, Gary A. "3.5 Two-Element Arrays.“, “Chapter 7, 8”, *Antenna Theory and Design*. By Warren L. Stutzman. 3rd ed. Hoboken: John Wiley & Sons, 2013. 94-95. 306-308 Print.

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- [5] Oza, Nick. "The Various Types of Active Remote Sensing." *Bright Hub*. BRIGHTHUB.COM, 26 May 2011. Web. 14 May 2015.

- [6] Ken Vo and Nivedita Parthasarathy

- [7] "HFSS V10 User Guide." (2005): 260-80. *Anlage Research Group*. Ansoft Corporation, 21 June 2005. Web. 9 May 2015. <http://anlage.umd.edu/HFSSv10UserGuide.pdf>.

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- [9] Durgun, A.C.; Reese, M.S.; Balanis, C.A.; Birtcher, C.R.; Allee, D.R.; Venugopal, S., "Flexible bow-tie antennas," *Antennas and Propagation Society International Symposium (APSURSI), 2010 IEEE* , vol., no., pp.1,4, 11-17 July 2010

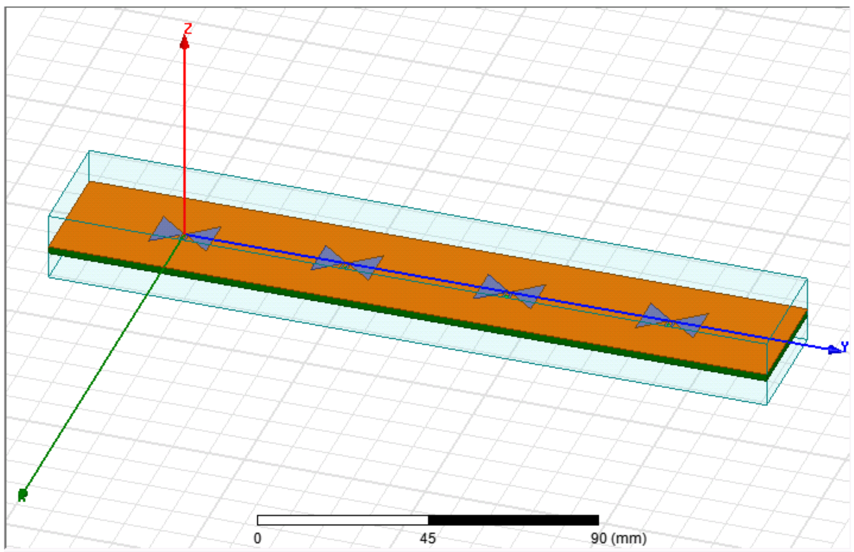
- [10] Wusheng Ji; Ge Liu; Dongsheng Yang; Hong Guo, "Analysis and Study of CPW-Fed Bow-Tie-Slot-Coupled Antenna," *Computational and Information Sciences (ICCIS), 2013 Fifth International Conference on* , vol., no., pp.1111,1113, 21-23 June 2013

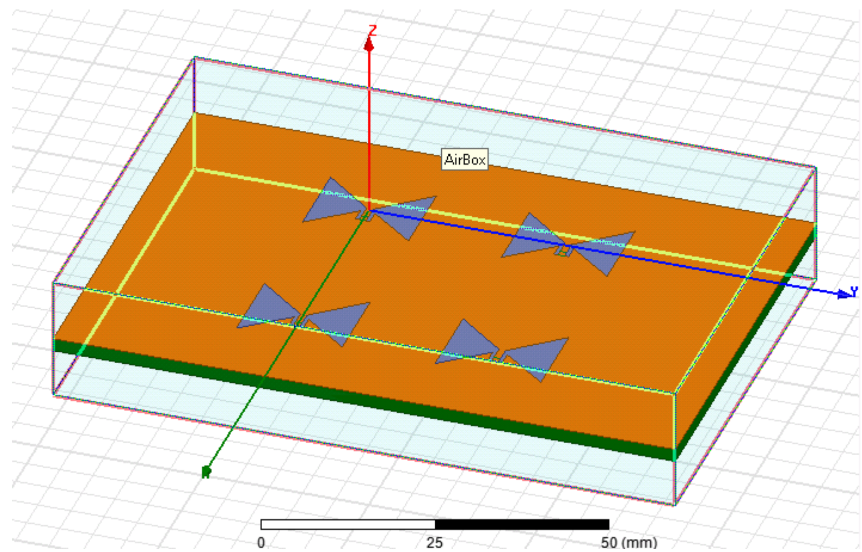
- [11] Pierce, R.G.; Blanchard, A.J.; Henderson, R.M., "Broadband Planar Modified Aperture Bowtie Antenna," *Antennas and Wireless Propagation Letters, IEEE* , vol.12, no., pp.1432,1435, 2013

- [12] "Online Ruler." *In Actual Size*. Online Ruler, n.d. Web. 05 June 2015.

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

λ spacing, +y direction array **λ spacing, 2x2 array**

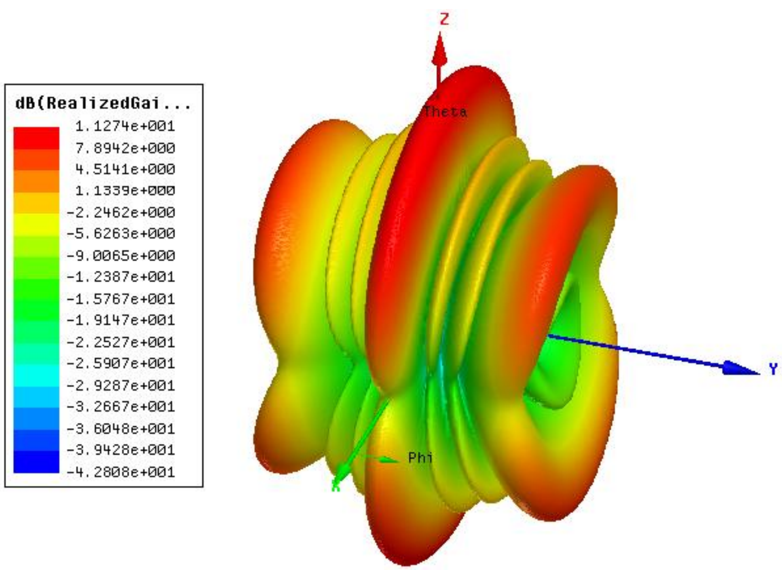


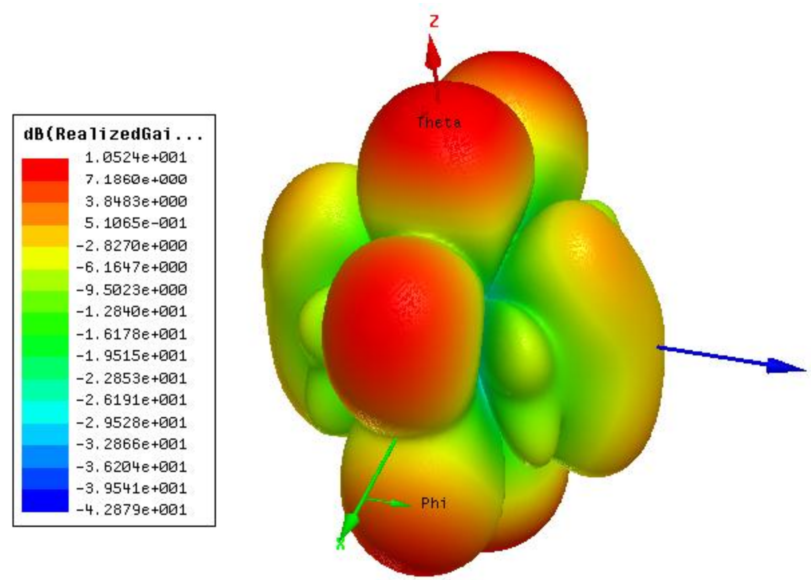


When coupling is concerned, we can assume it's much worse for the 2x2 element array since the elements are much closer together, and for the y-axis, the radiation pattern may influence the other neighboring element (ears)

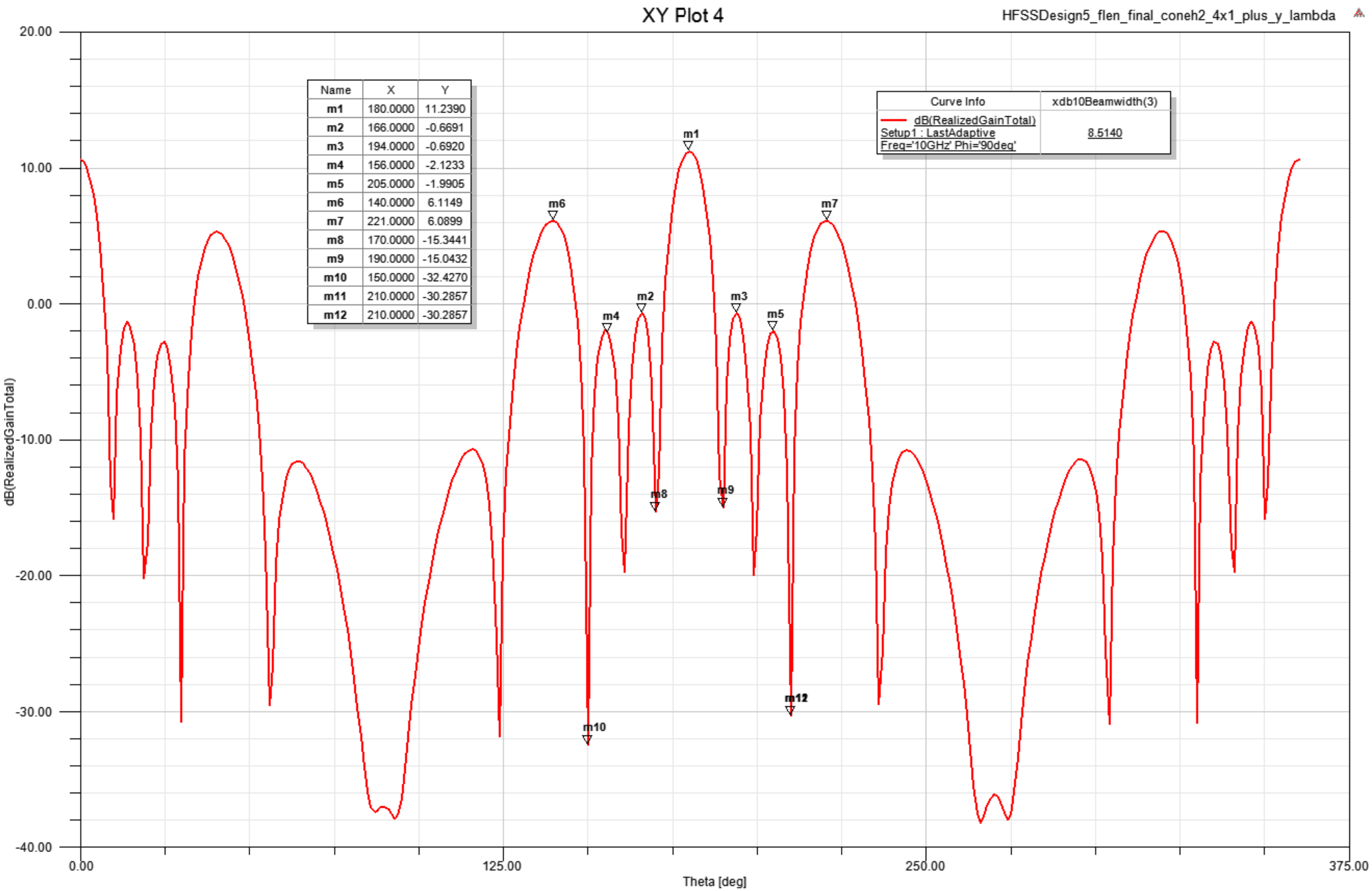
3D Polar Plot

λ spacing, +y direction array **λ spacing, 2x2 array**



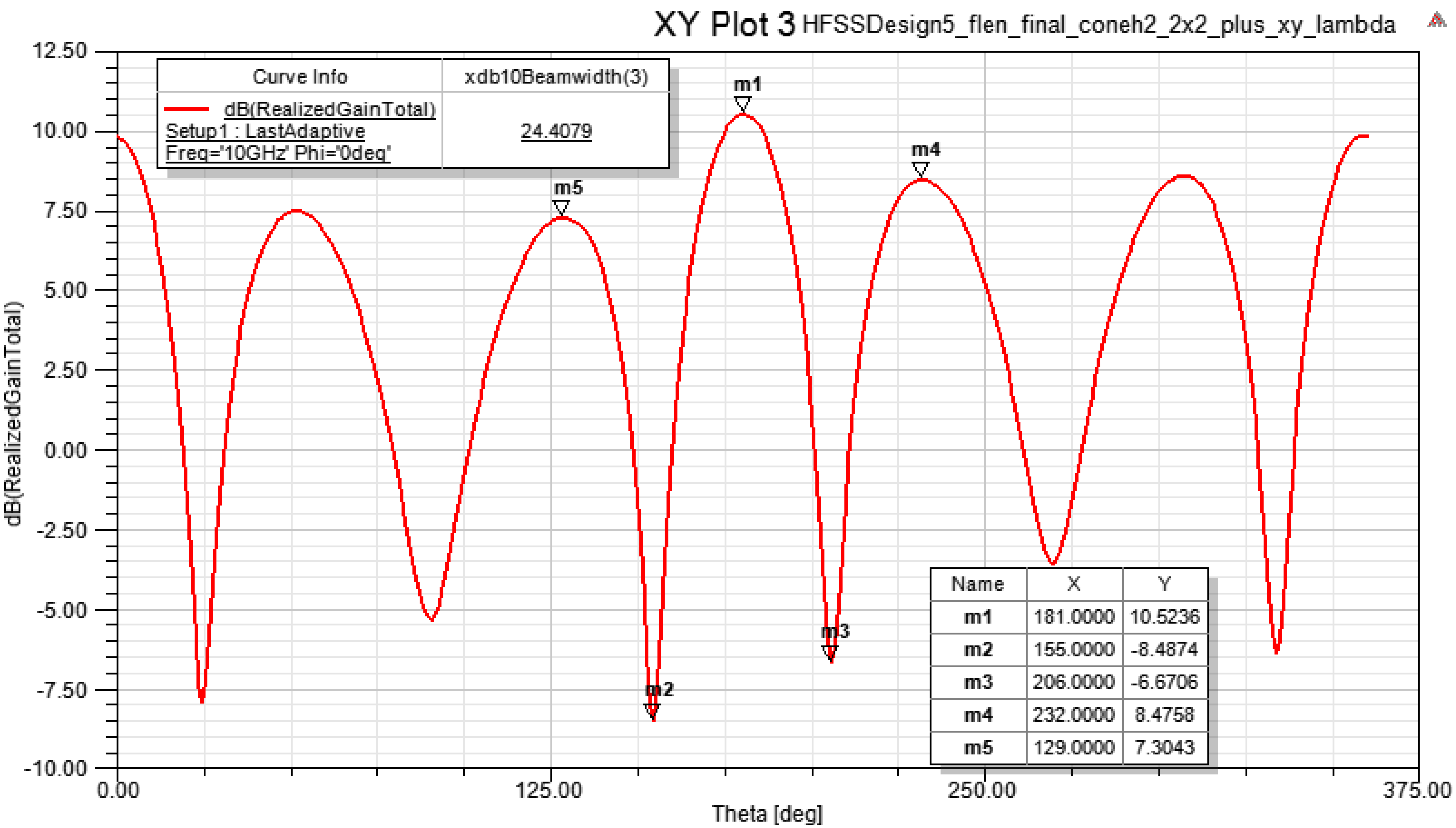


4x1 array (+y direction), λ spacing



HPBW = 8.5140˚, SLL = -5.1241 dB, BWFN = 20˚

2x2 array, λ spacing



HPBW = 24.4079˚, SLL = -2.0656 dB, BWFN = 51˚