

# Single-element Patch Antenna with Pattern Control

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# Acknowledgement

## Ohio University Internal Research and Development



# Outline

- **Introduction**
- **Scope**
- **Design Configuration**
- **Pattern Control Results & Discussion**
  - **Baseline Results**
  - **Pattern Control Results**
    - **Azimuth Pattern Control**
      - **Quadrant-by-Quadrant**
    - **Elevation Pattern Control**
  - **Gain & Efficiency Considerations**
- **Conclusions**



# Introduction

- **Microstrip patch antennas have numerous GNSS applications:**
  - » **Small size, low profile, easily fabricated, low cost**
  - » **Ground plane structures can affect patch antenna performance (e.g., choke rings, size/shape, composition, components, etc.)**
  - » **limited interference suppression**
- **Phased arrays, i.e., Controlled Reception Pattern Antenna (CRPA) can control pattern**
  - » **Typically much larger than a single-element**
- **Theory of Antenna Reciprocity applies**

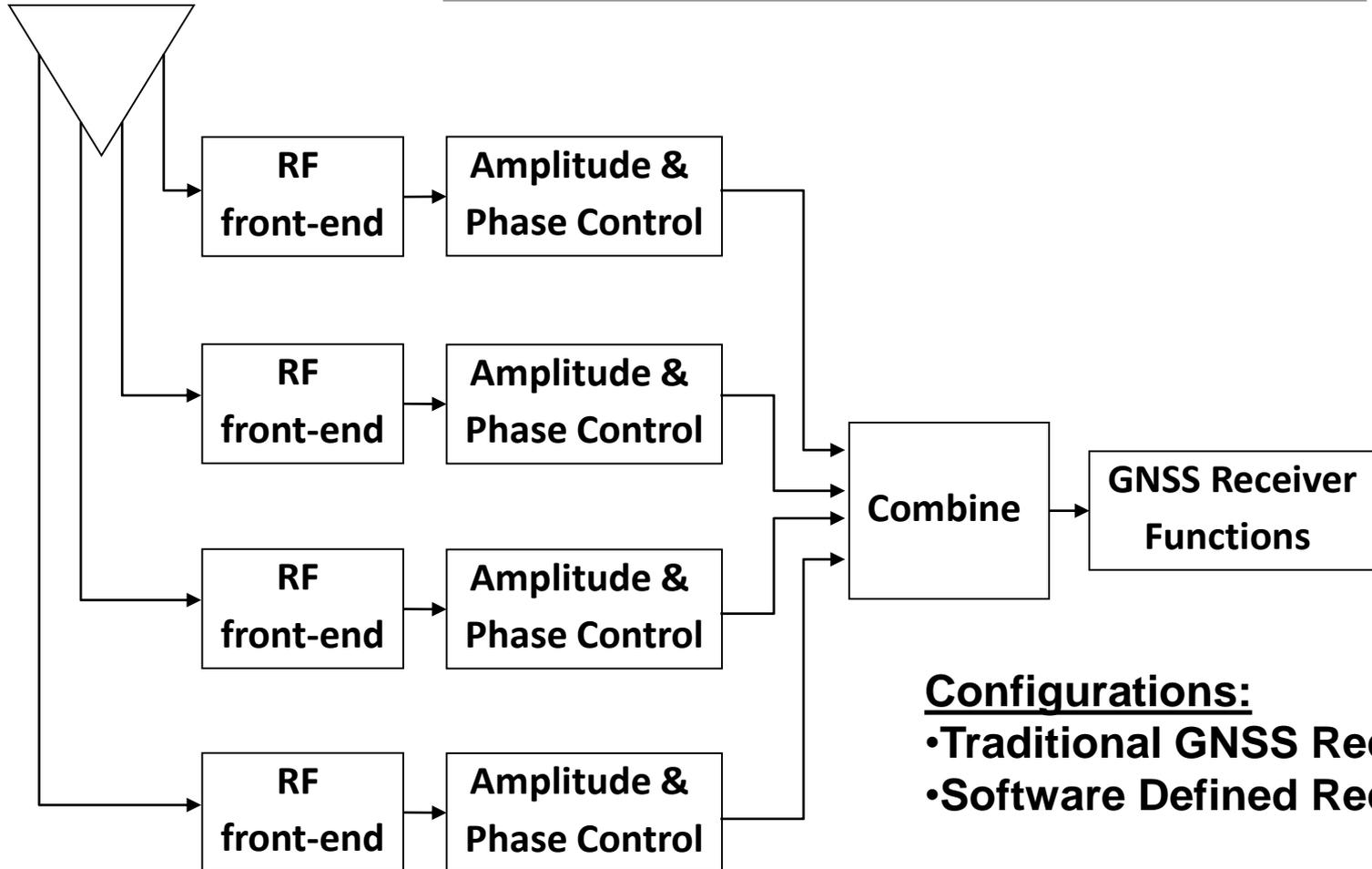


# Scope

- **Investigates and put forward a single-element GNSS patch antenna with pattern control:**
  - » **GNSS L5 frequency selected**
  - » **Circular symmetry configuration selected**
    - **Circular patch element and substrate**
    - **Circular ground plane**
  - » **Symmetric feed structure**
    - » **Four feeds, probe fed illustrated here**
  - » **Amplitude and Phase Control Subsystem**
  - » **Design implemented in a high-fidelity Computational Electromagnetic Model (CEM), Computer Simulation Technology (CST)**

Single-element  
Antenna  
(with 4 feeds)

# Design Configuration



## Configurations:

- Traditional GNSS Receiver
- Software Defined Receiver

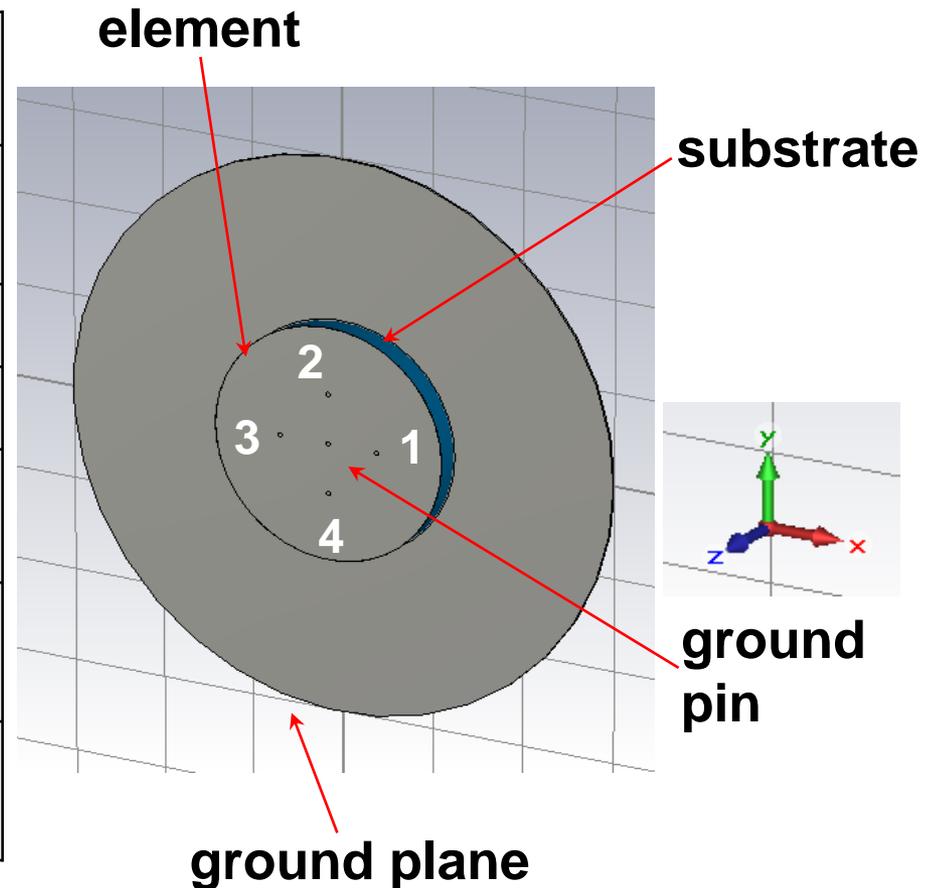
# Design Configuration

- **Analytical cavity model design used, then design refined with CEM CST**
  - » Time & frequency domain solvers with waveport
- **Substrate selection:**
  - » Higher relative permittivity to allow the antenna to fit within ARINC 743A footprint
  - » Thicker substrate to support GNSS L5 bandwidth (also consideration to ARINC 743A height profile)
- **Circular ground plane size of 120mm selected; compromise between:**
  - » ARINC 743A footprint and large curved structure
  - » RTCA/EU MOPS Specifications, i.e., 4 foot/1200mm



# GNSS L5 Single-element Antenna

Substrate Material:	Rogers TMM 10i
Substrate relative permittivity [unitless]	9.8
Substrate height, [mm]	5.08
Substrate diameter, [mm]	50.25
Feed position from center, [mm]	10.75
Diameter of circular patch element, [mm]	50.25
Diameter of circular ground plane, [mm]	120



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    - **Elevation Pattern Control**
  - **Gain & Efficiency Considerations**
- Conclusions

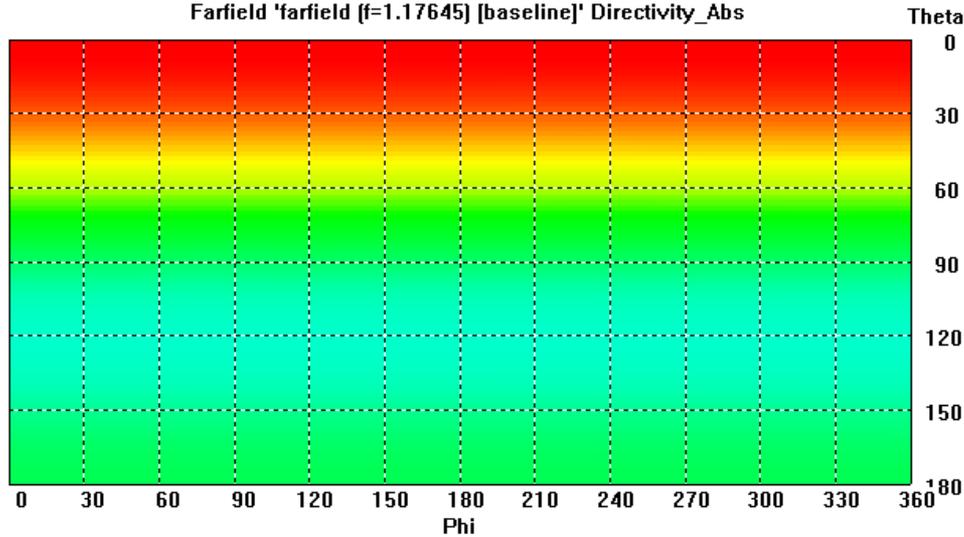


# Baseline Results

- **Good input impedance:  $Z_{in}=50+j14 \Omega$**
- **Return loss  $< 14$  dB**
- **Bandwidth  $> 45$  MHz**
- **Phase at each sequential port:**
  - » [0, 90, 180, 270] deg
- **Axial Ratio: 0 dB at boresight, RHCP**
- **Radiation efficiency  $< -0.6$  dB**
- **Excellent pattern symmetry**
- **Baseline performance used to compare pattern control performance.**

# Four-feed Circular Patch Phase Manipulation – Baseline Results

Farfield 'farfield (f=1.17645) [baseline]' Directivity\_Abs

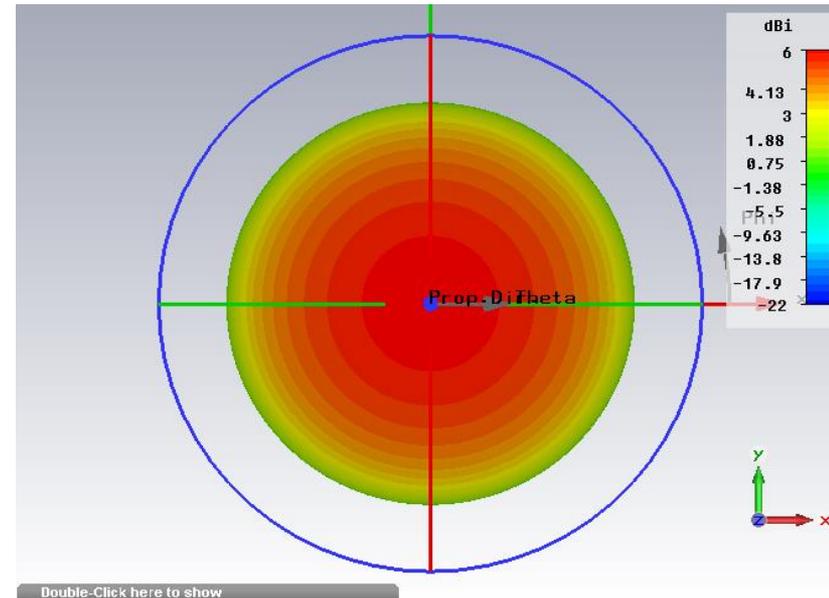


Frequency = 1.17645

Rad. effic. = -0.590903 dB

Tot. effic. = -5.03124 dB

Dir. = 6.08329 dBi



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
0	0	90	180	270

# Pattern Control Results

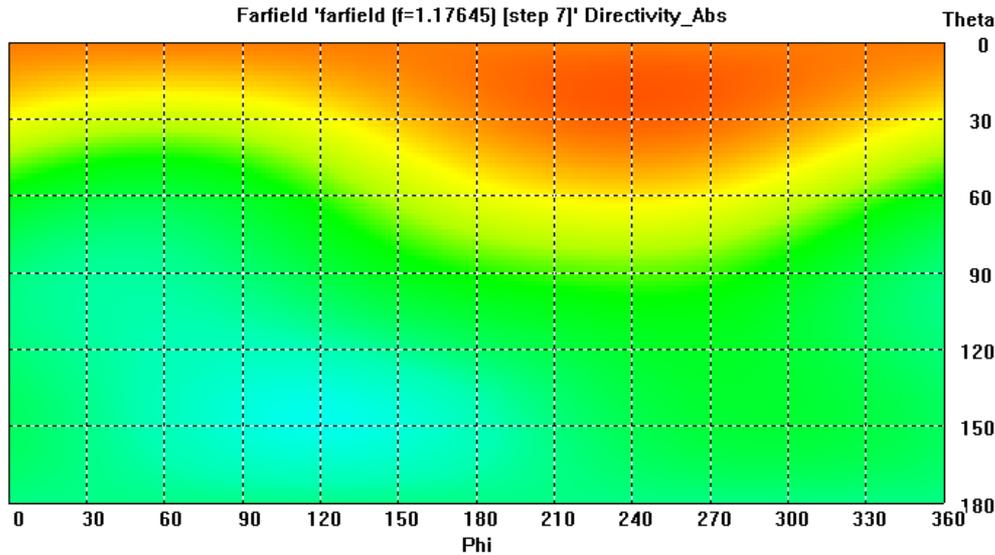
- Here, a four port configuration was used to illustrate the pattern control
- Amplitude on each port fixed at: 1
- Phase on each sequential port represented as:  $[\gamma_1, \gamma_2, \gamma_3, \gamma_4]$  deg, respectively.
- Then, signals combined
- Azimuth Pattern Control illustrated over 360 deg
  - » quadrant-by-quadrant basis
- Elevation pattern control illustrated for one elevation cut.

# Pattern Control Results- Azimuth

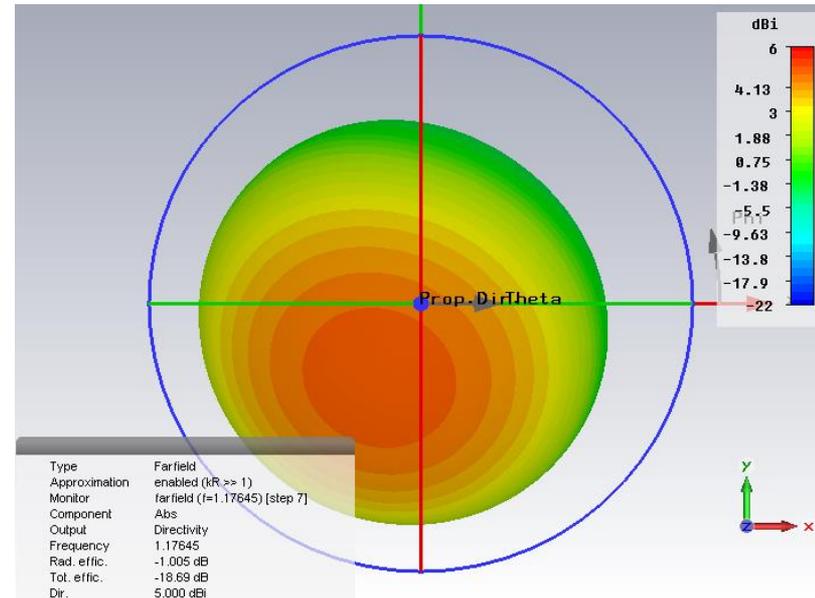
## “First Quadrant” Azimuth Pattern Control

1. Select a reference port and phase:
  - Here, Port 1, phase: 0 deg, i.e.,  $\gamma_1=0$  deg
2. Identify “opposite” port and select a phase difference to the reference port:
  - Here, Port 3, phase difference=20 deg, so  $\gamma_3=\Delta\gamma_{OPP}=20$  deg.
3. Identify “next” port to the reference port and let the phase be set considering desired polarization:
  - Here, Port 2, phase of 90 deg, so  $\gamma_2=\Delta\gamma_{POL}=90$  deg.
4. Identify “adjacent” port to the reference port, and allow phase to be controlled about its opposite port:
  - Here, Port 4, where:  $\gamma_2-\Delta\gamma_{OPP} < \Delta\gamma_{ADJ} < \gamma_2+\Delta\gamma_{OPP}$
  - Thus, port phases:  $[0, \gamma_2=90, \gamma_3=20, \Delta\gamma_{ADJ}]$  deg

# Pattern Control-AZ-First Quadrant

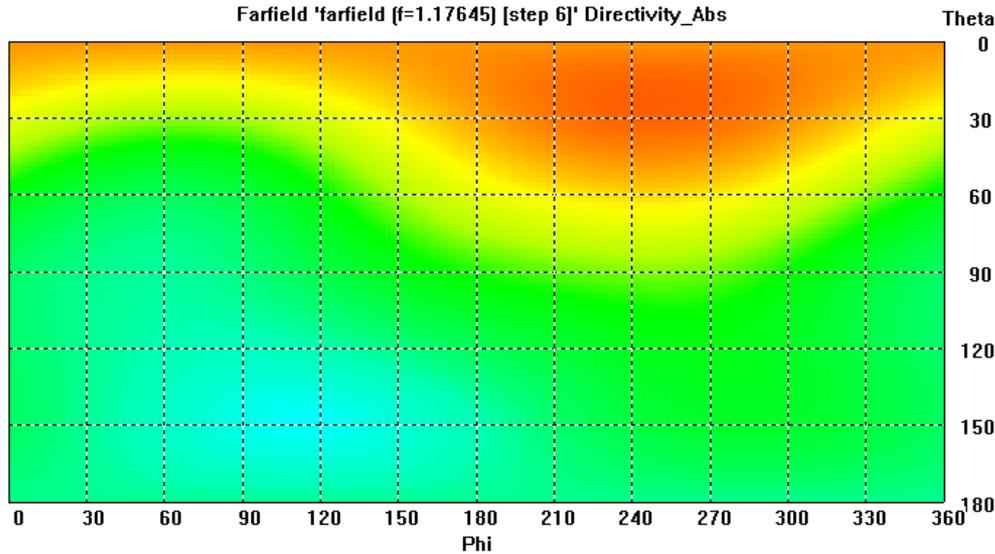


Frequency = 1.17645  
 Rad. effic. = -1.00546 dB  
 Tot. effic. = -18.6914 dB  
 Dir. = 5.00026 dBi

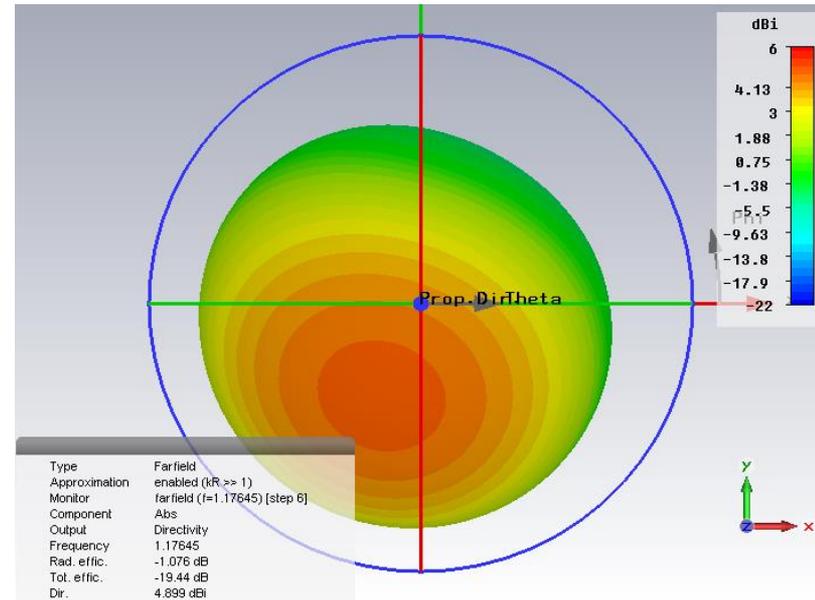


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
1	0	90	20	70

# Pattern Control-AZ-First Quadrant

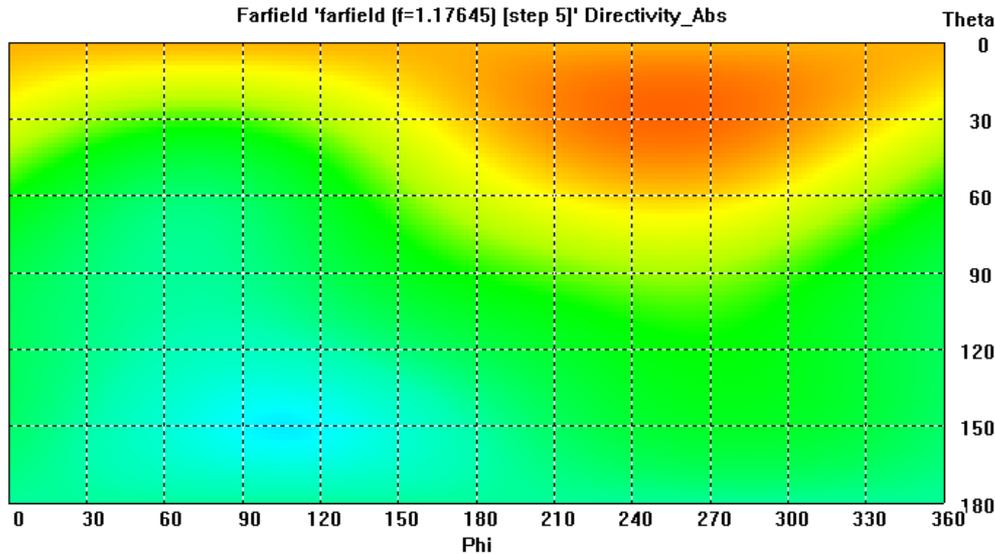


Frequency = 1.17645  
 Rad. effic. = -1.07570 dB  
 Tot. effic. = -19.4436 dB  
 Dir. = 4.89853 dBi

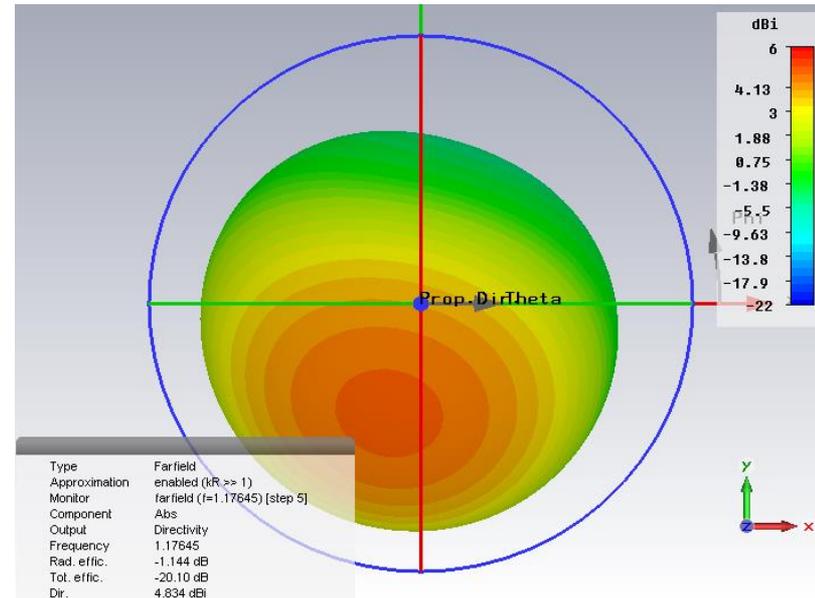


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
2	0	90	20	75

# Pattern Control-AZ-First Quadrant

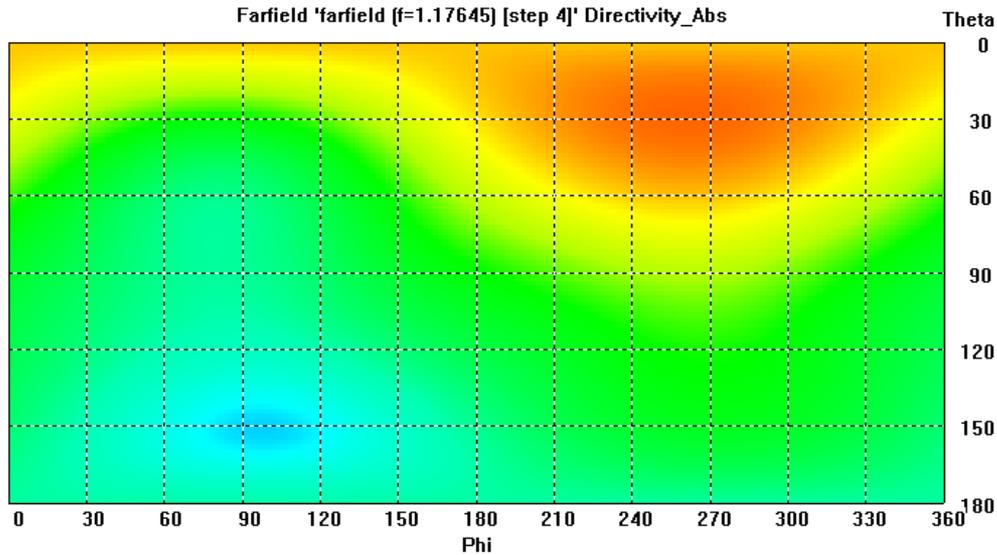


Frequency = 1.17645  
 Rad. effic. = -1.14444 dB  
 Tot. effic. = -20.0958 dB  
 Dir. = 4.83383 dBi

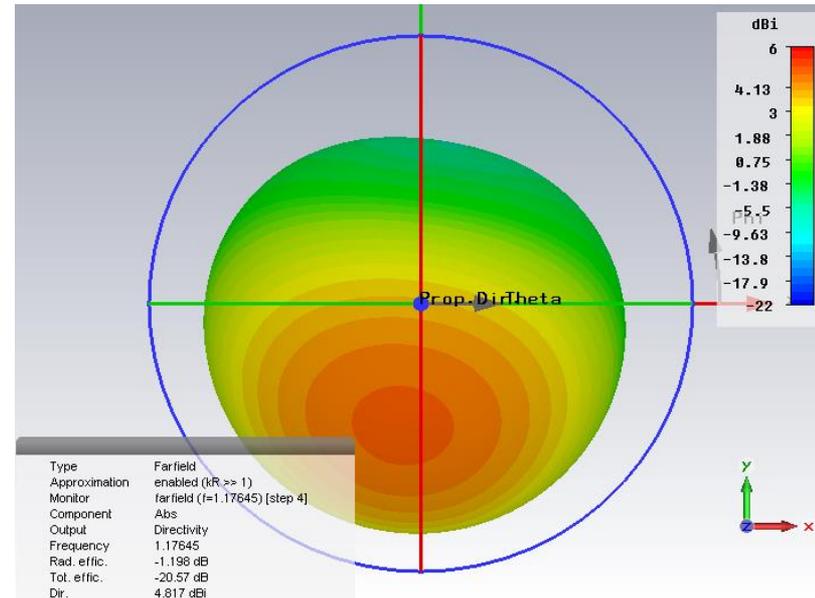


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
3	0	90	20	80

# Pattern Control-AZ-First Quadrant

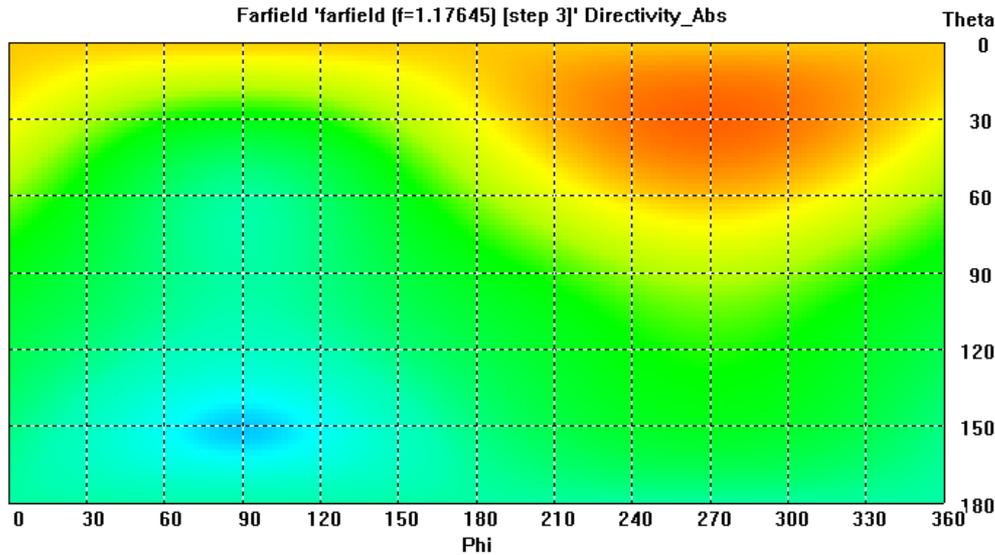


Frequency = 1.17645  
 Rad. effic. = -1.19779 dB  
 Tot. effic. = -20.5681 dB  
 Dir. = 4.81749 dBi

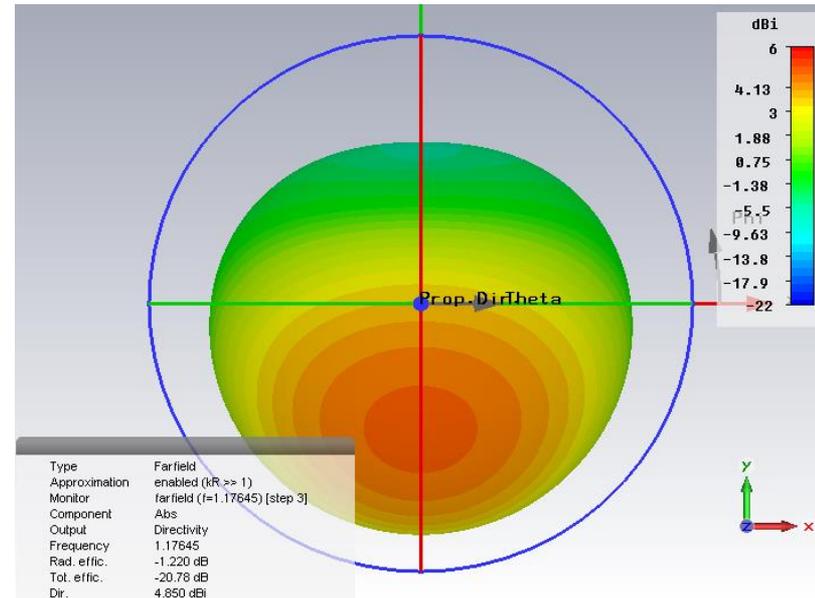


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
4	0	90	20	85

# Pattern Control-AZ-First Quadrant

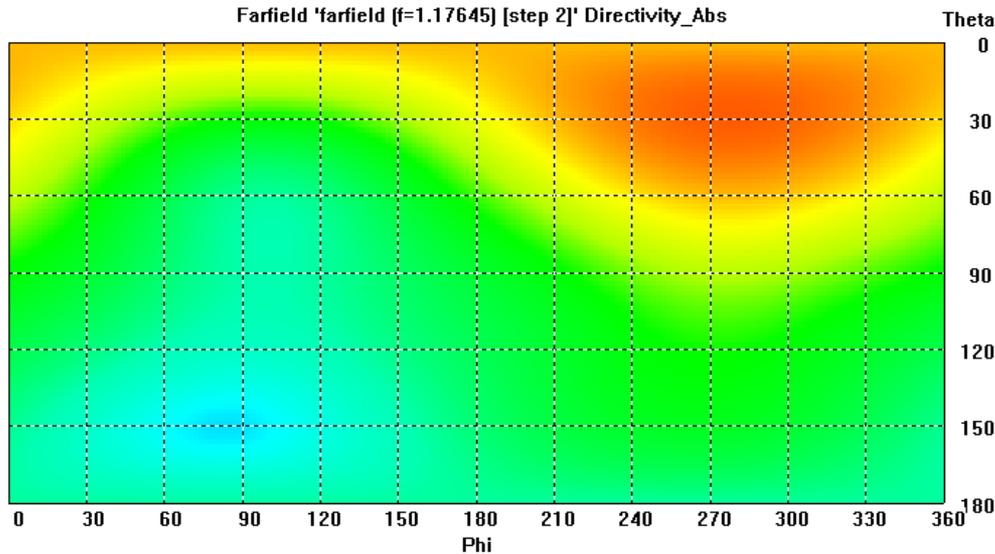


Frequency = 1.17645  
 Rad. effic. = -1.21972 dB  
 Tot. effic. = -20.7830 dB  
 Dir. = 4.84986 dBi

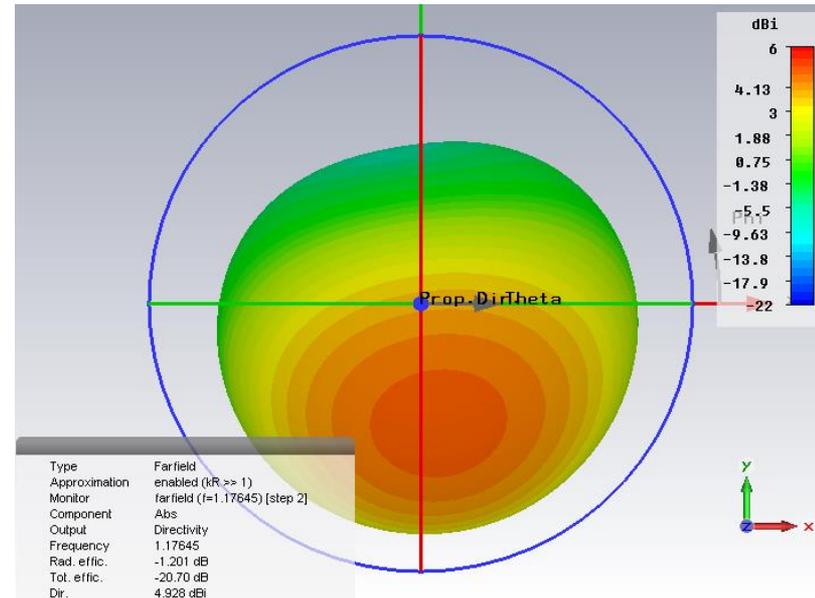


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
5	0	90	20	90

# Pattern Control-AZ-First Quadrant

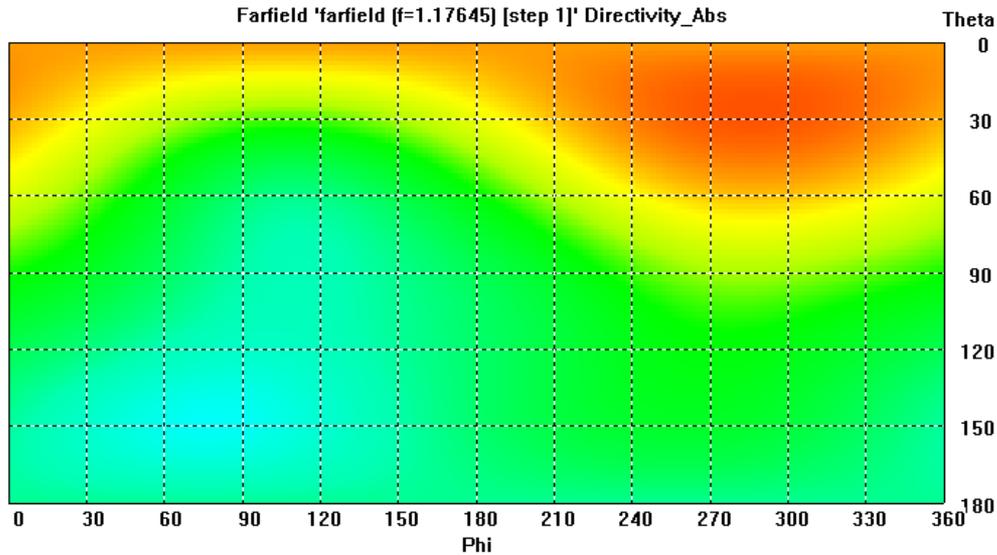


Frequency = 1.17645  
 Rad. effic. = -1.20140 dB  
 Tot. effic. = -20.6984 dB  
 Dir. = 4.92840 dBi

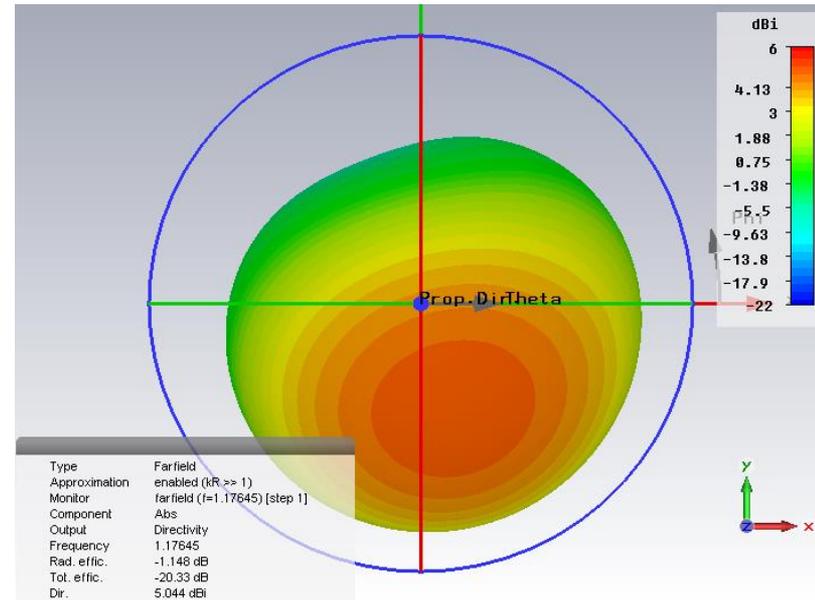


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
6	0	90	20	95

# Pattern Control-AZ-First Quadrant

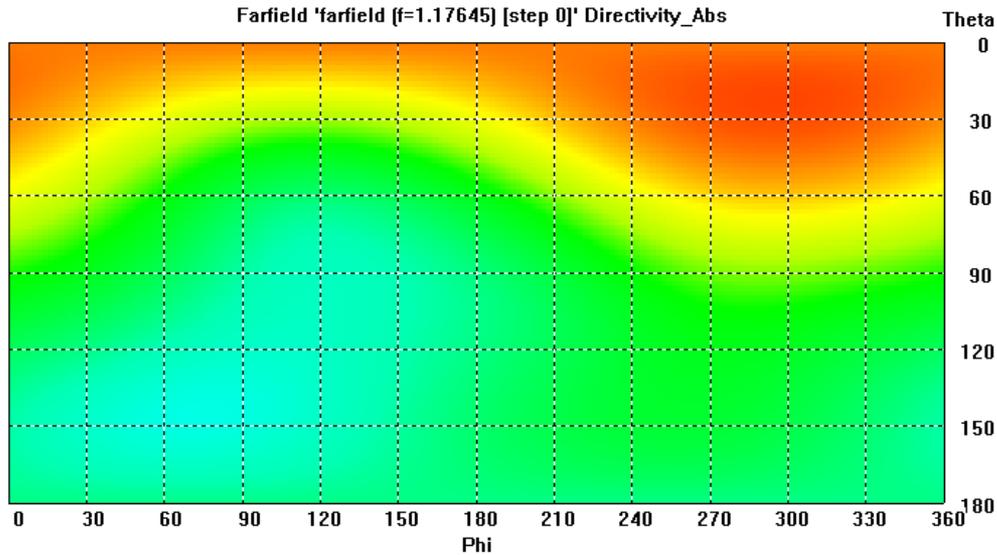


Frequency = 1.17645  
 Rad. effic. = -1.14815 dB  
 Tot. effic. = -20.3315 dB  
 Dir. = 5.04419 dBi

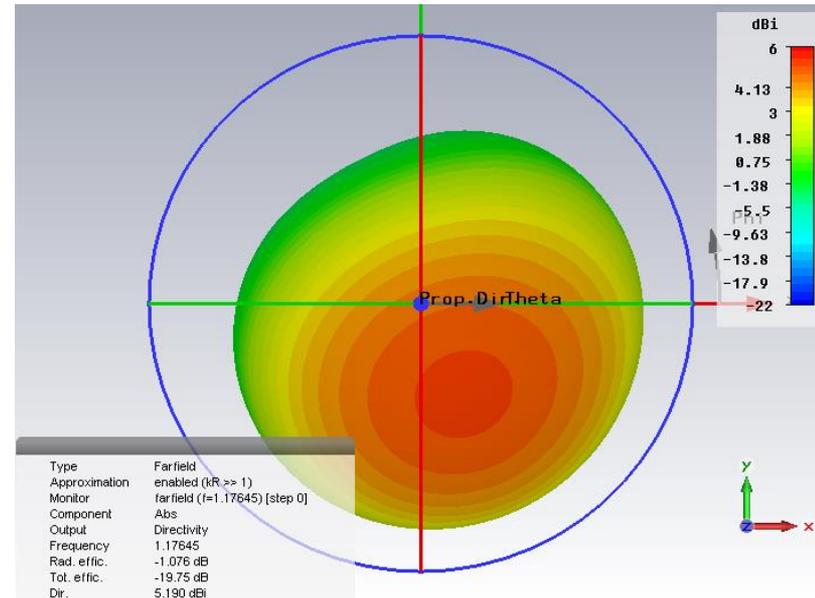


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
7	0	90	20	100

# Pattern Control-AZ-First Quadrant

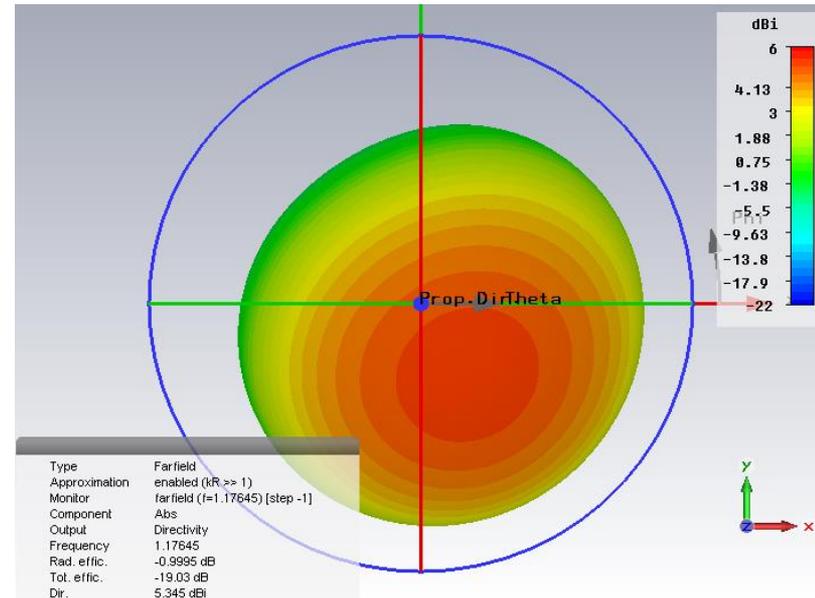
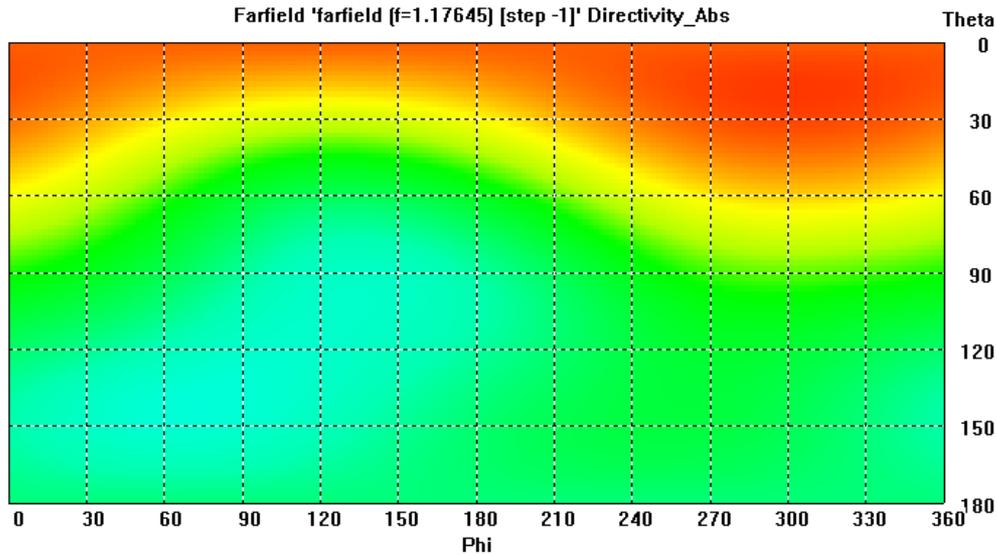


Frequency = 1.17645  
 Rad. effic. = -1.07557 dB  
 Tot. effic. = -19.7484 dB  
 Dir. = 5.19004 dBi



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
8	0	90	20	105

# Pattern Control-AZ-First Quadrant



Frequency = 1.17645  
 Rad. effic. = -0.999549 dB  
 Tot. effic. = -19.0314 dB  
 Dir. = 5.34492 dBi



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
9	0	90	20	110



# Pattern Control Results- Azimuth

## Second Quadrant Azimuth Pattern Control

- Similar procedure as proceeding quadrant (i.e., first quadrant)
- Phase at each port is respectively “progressed/regressed” to the next/previous port.
- The progression/regression will rotate the pattern in the clockwise/counterclockwise azimuth direction.

## Third & Four Quadrant Azimuth Pattern Control

- Similar procedure as above for proceeding quadrant control.

# Phase Control Summary

- Four-feed Illustration (for 360 deg rotation):

Quadrant	Port Number			
	1	2	3	4
1	0	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$
2	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	0
3	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	0	$\Delta\gamma_{POL}$
4	$\Delta\gamma_{ADJ}$	0	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$

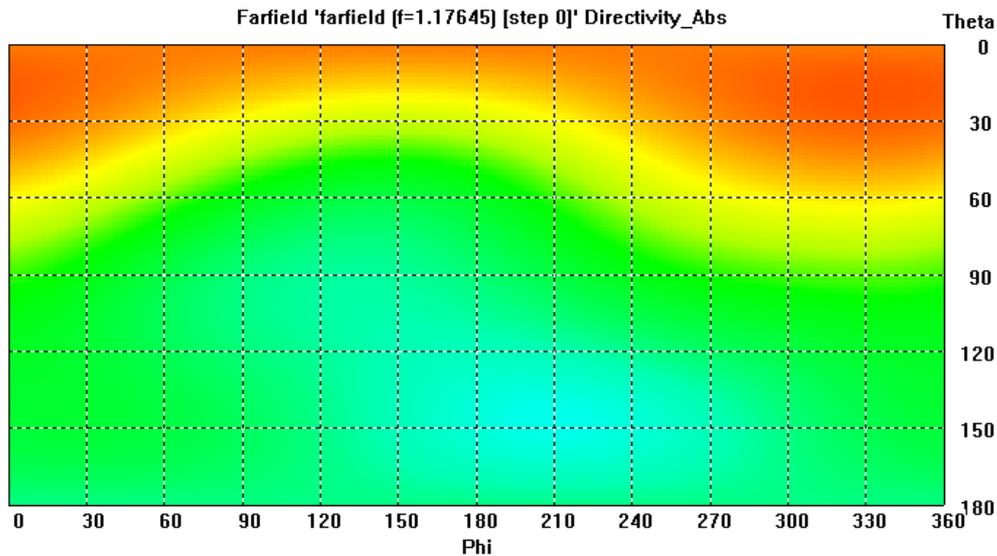
where (for azimuth pattern control):

$$\Delta\gamma_{POL} = 90 \text{ deg}$$

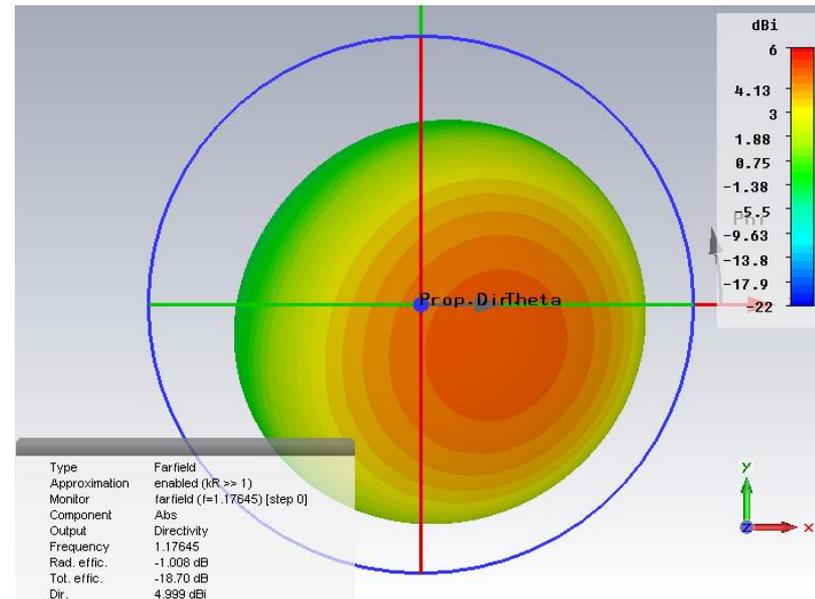
$$\Delta\gamma_{OPP} = 20 \text{ deg}$$

$$\gamma_2 - \Delta\gamma_{OPP} < \Delta\gamma_{ADJ} < \gamma_2 + \Delta\gamma_{OPP}$$

# Pattern Control-AZ-Second Quadrant

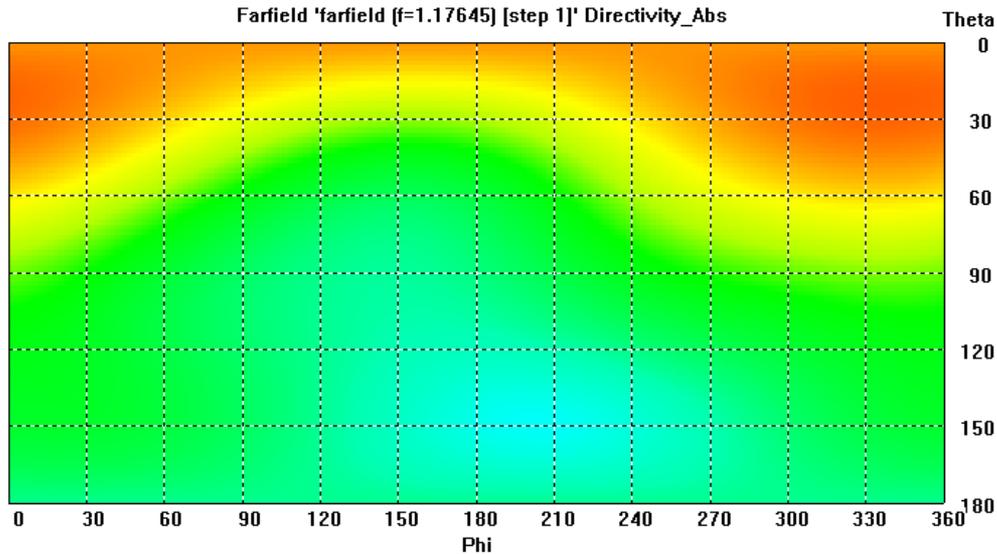


Frequency = 1.17645  
 Rad. effic. = -1.00819 dB  
 Tot. effic. = -18.6952 dB  
 Dir. = 4.99876 dBi

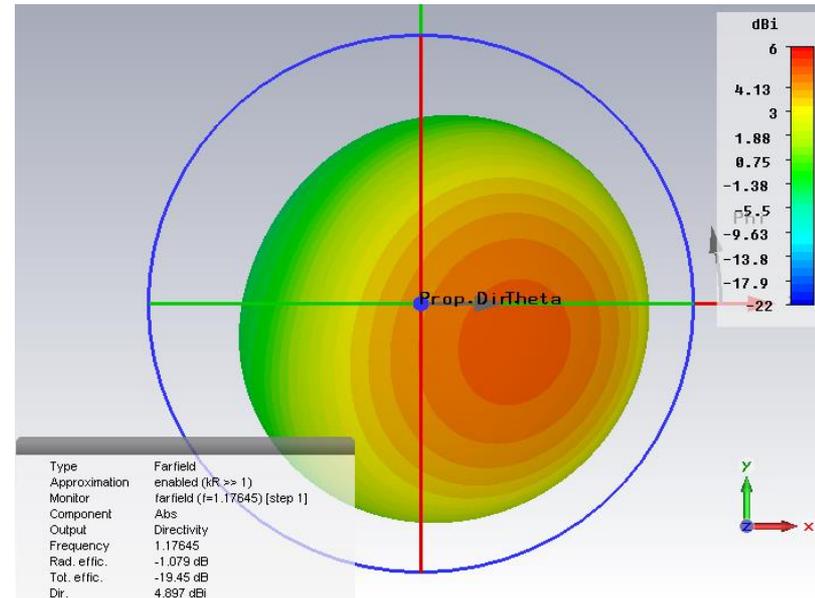


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
10	90	20	70	0

# Pattern Control-AZ-Second Quadrant



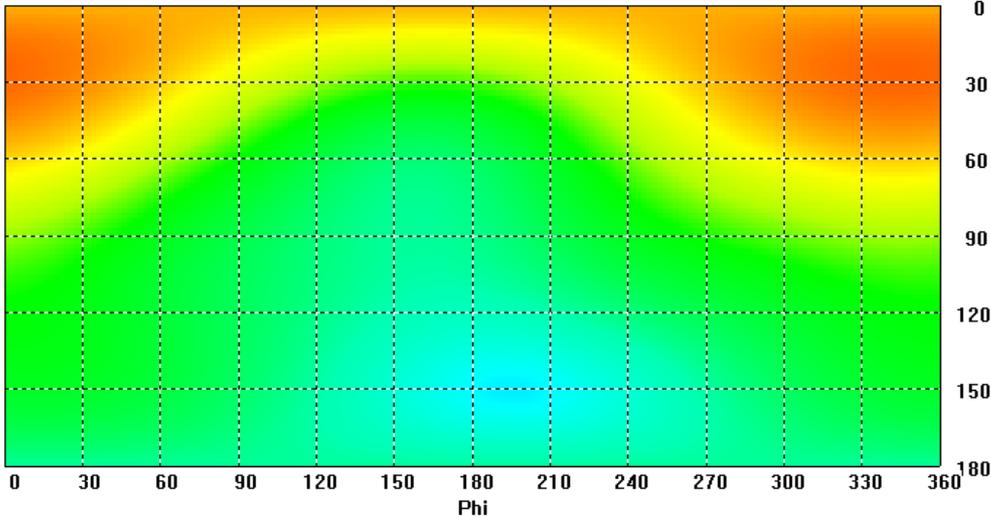
Frequency = 1.17645  
 Rad. effic. = -1.07861 dB  
 Tot. effic. = -19.4477 dB  
 Dir. = 4.89650 dBi



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
11	90	20	75	0

# Pattern Control-AZ-Second Quadrant

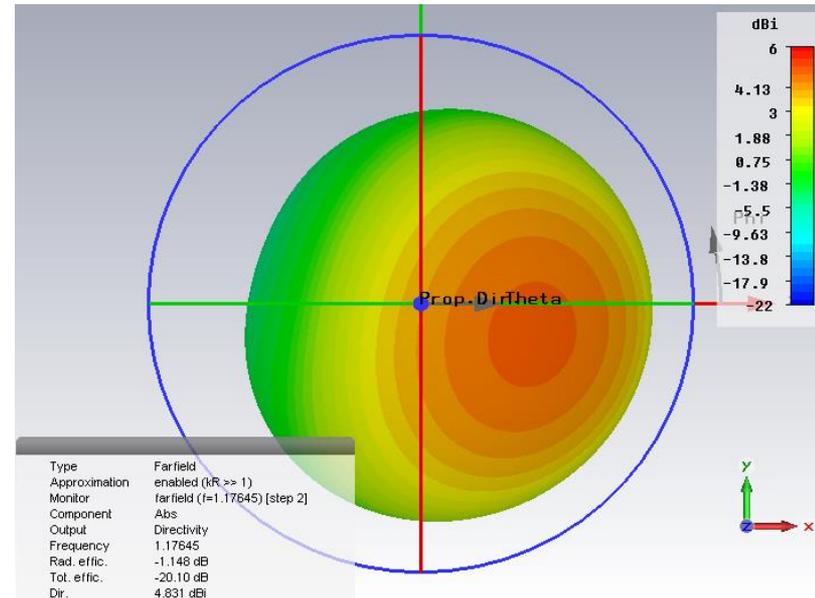
Farfield 'farfield (f=1.17645) [step 2]' Directivity\_Abs



Frequency = 1.17645  
 Rad. effic. = -1.14760 dB  
 Tot. effic. = -20.1002 dB  
 Dir. = 4.83119 dBi



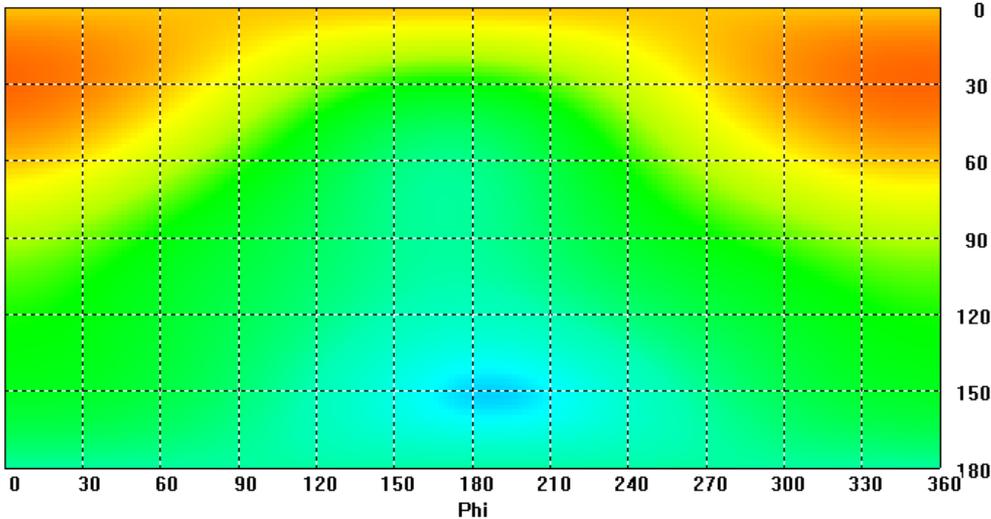
Theta



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
12	90	20	80	0

# Pattern Control-AZ-Second Quadrant

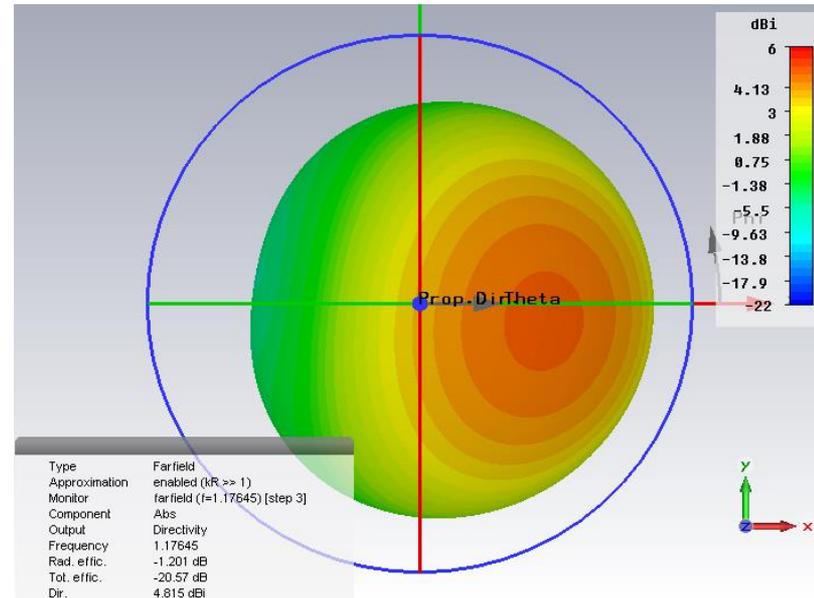
Farfield 'farfield (f=1.17645) [step 3]' Directivity\_Abs



Frequency = 1.17645  
 Rad. eff. = -1.20124 dB  
 Tot. eff. = -20.5728 dB  
 Dir. = 4.81510 dBi



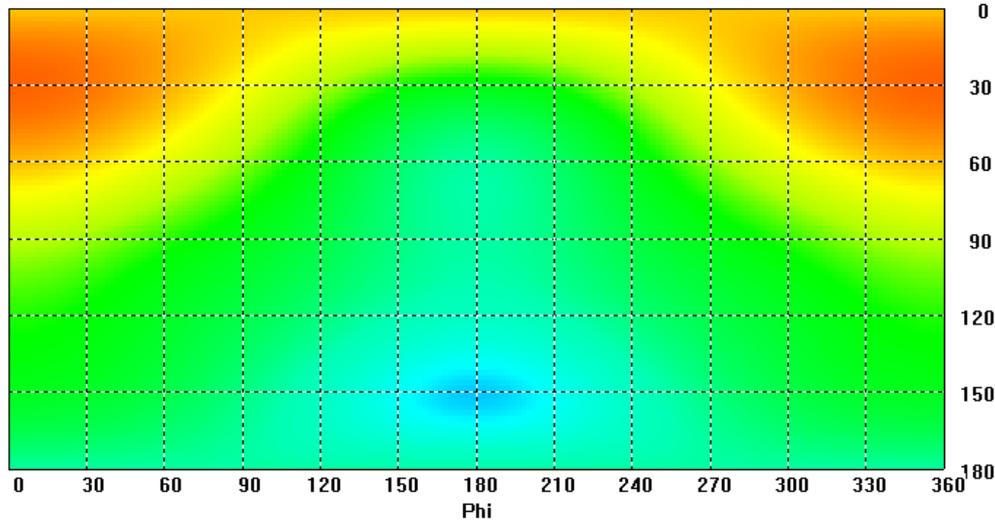
Theta



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
13	90	20	85	0

# Pattern Control-AZ-Second Quadrant

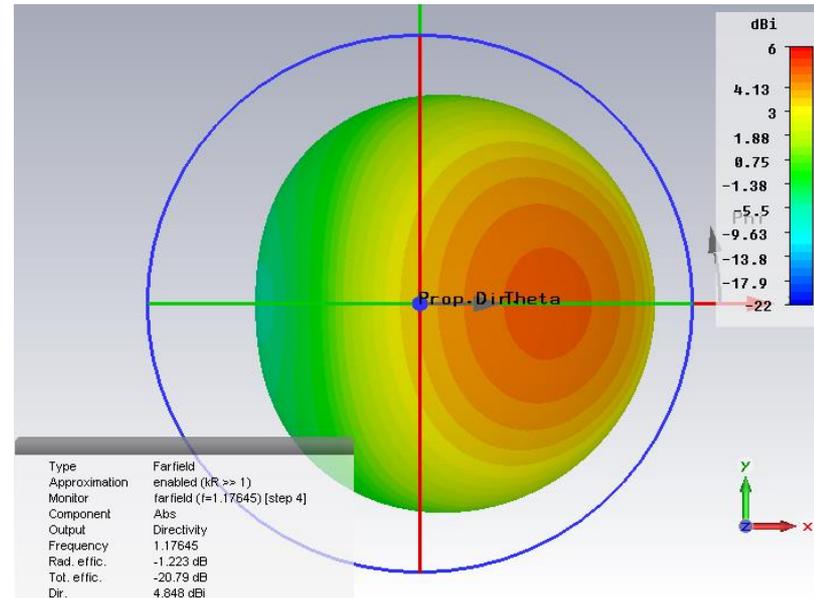
Farfield 'farfield (f=1.17645) [step 4]' Directivity\_Abs



Frequency = 1.17645  
 Rad. eff. = -1.22345 dB  
 Tot. eff. = -20.7879 dB  
 Dir. = 4.84818 dBi



Theta

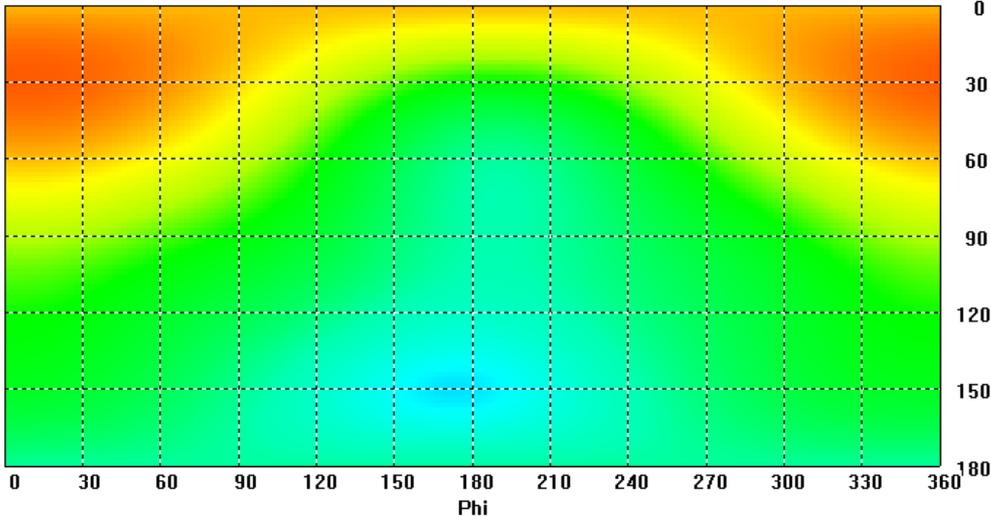


Type: Farfield  
 Approximation: enabled (kR >> 1)  
 Monitor: farfield (f=1.17645) [step 4]  
 Component: Abs  
 Output: Directivity  
 Frequency: 1.17645  
 Rad. eff.: -1.223 dB  
 Tot. eff.: -20.79 dB  
 Dir.: 4.848 dBi

Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
14	90	20	90	0

# Pattern Control-AZ-Second Quadrant

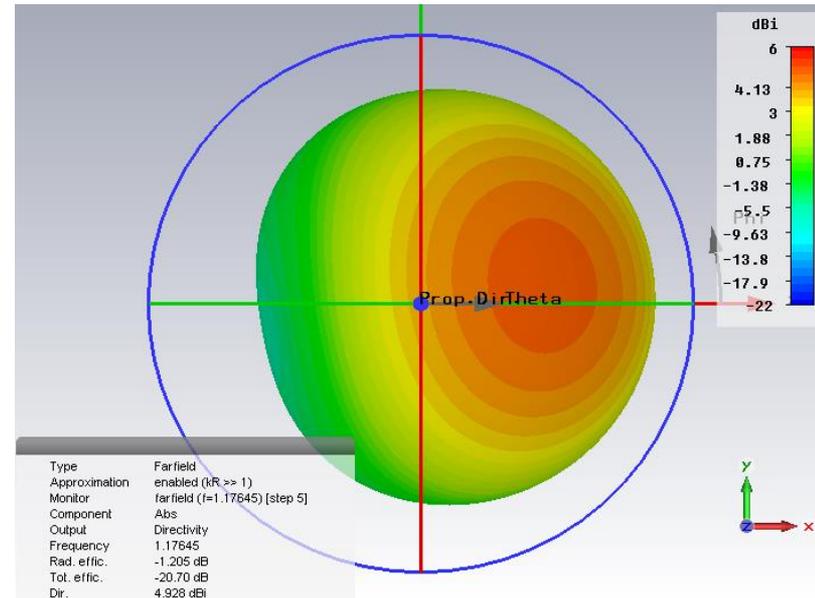
Farfield 'farfield (f=1.17645) [step 5]' Directivity\_Abs



Frequency = 1.17645  
 Rad. effic. = -1.20533 dB  
 Tot. effic. = -20.7034 dB  
 Dir. = 4.92762 dBi



Theta  
 0  
 30  
 60  
 90  
 120  
 150  
 180

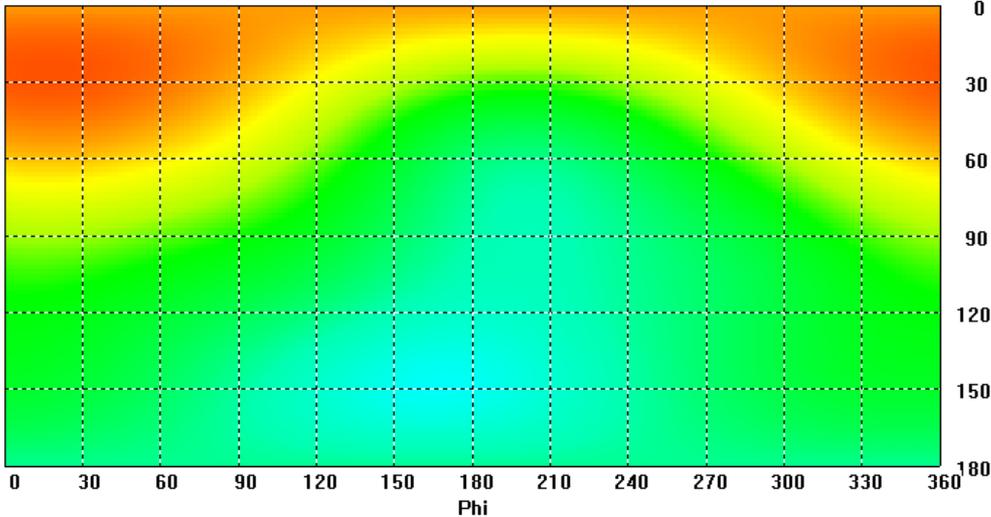


Type: Farfield  
 Approximation: enabled (kR >> 1)  
 Monitor: farfield (f=1.17645) [step 5]  
 Component: Abs  
 Output: Directivity  
 Frequency: 1.17645  
 Rad. effic.: -1.205 dB  
 Tot. effic.: -20.70 dB  
 Dir.: 4.928 dBi

Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
15	90	20	95	0

# Pattern Control-AZ-Second Quadrant

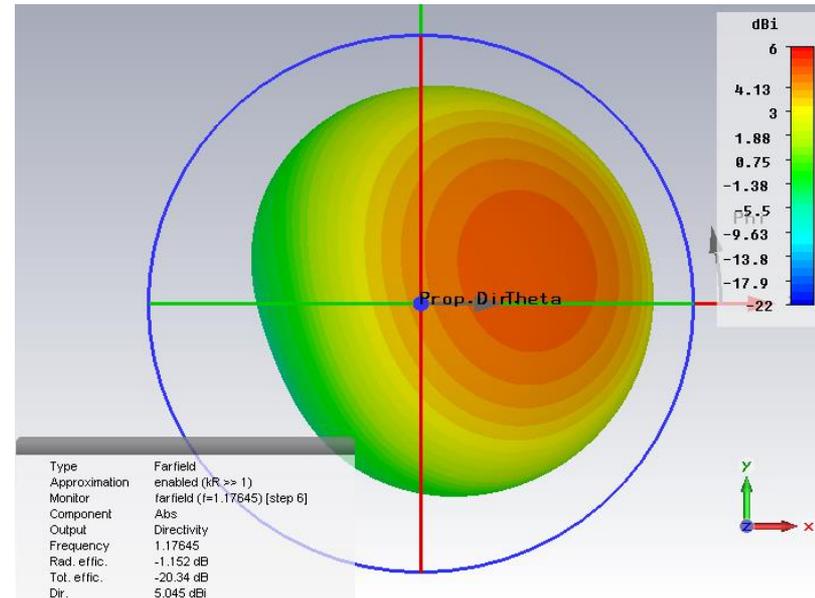
Farfield 'farfield (f=1.17645) [step 6]' Directivity\_Abs



Frequency = 1.17645  
 Rad. effic. = -1.15218 dB  
 Tot. effic. = -20.3363 dB  
 Dir. = 5.04494 dBi



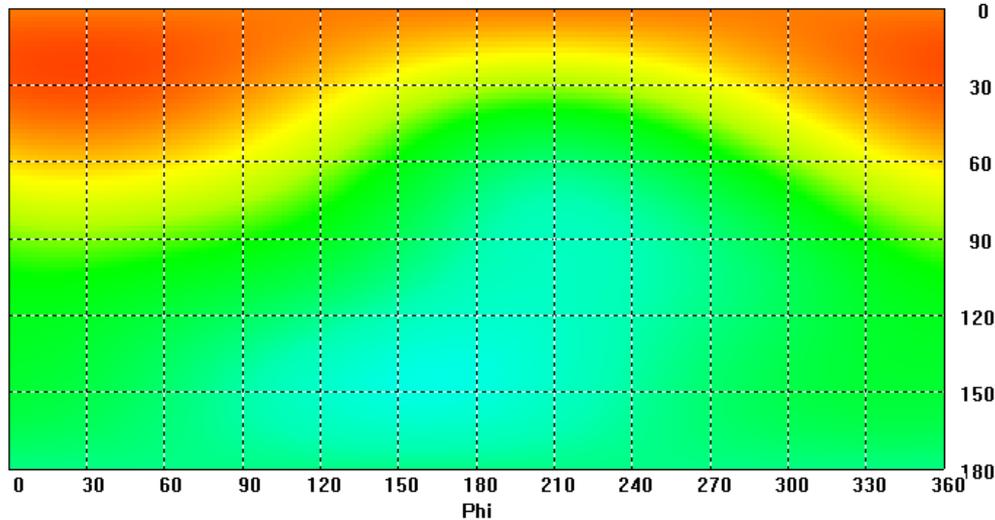
Theta  
 0  
 30  
 60  
 90  
 120  
 150  
 180



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
16	90	20	100	0

# Pattern Control-AZ-Second Quadrant

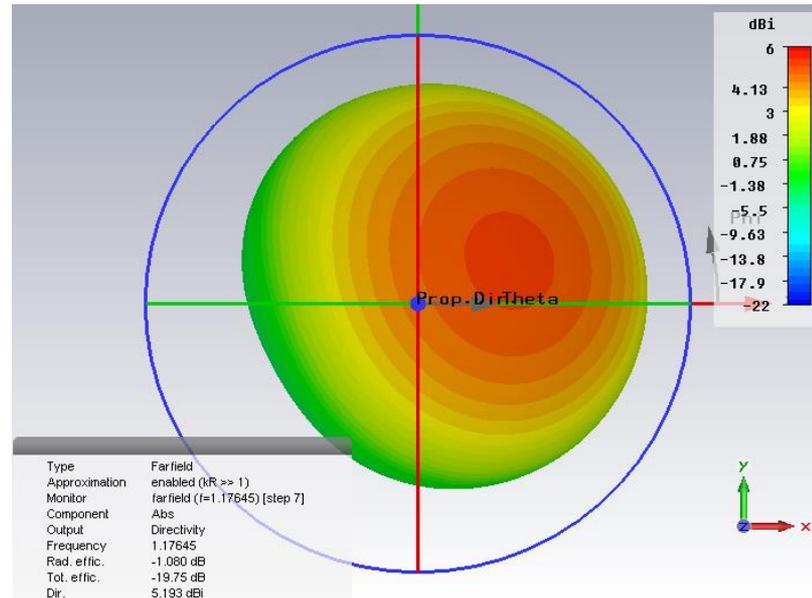
Farfield 'farfield (f=1.17645) [step 7]' Directivity\_Abs



Frequency = 1.17645  
 Rad. effic. = -1.07961 dB  
 Tot. effic. = -19.7530 dB  
 Dir. = 5.19287 dBi

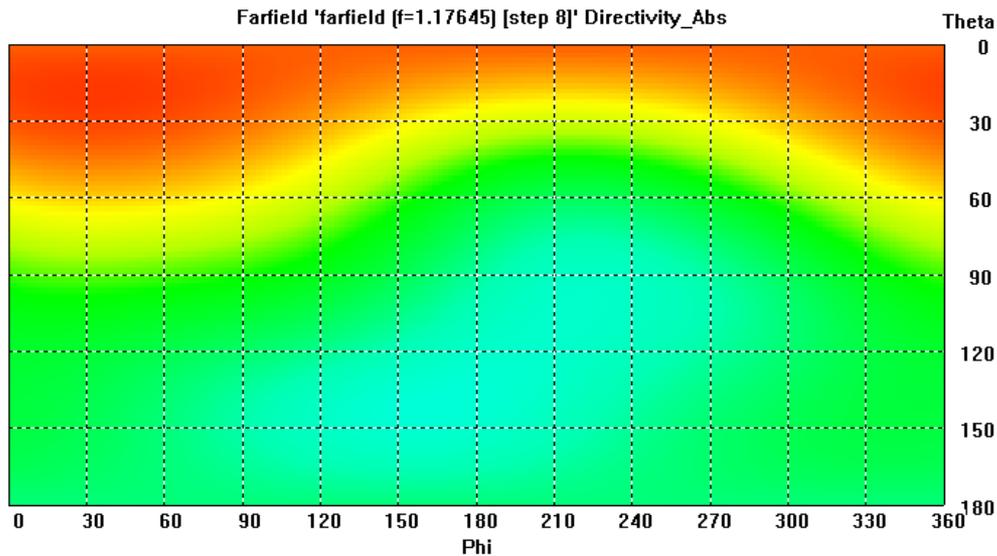


Theta

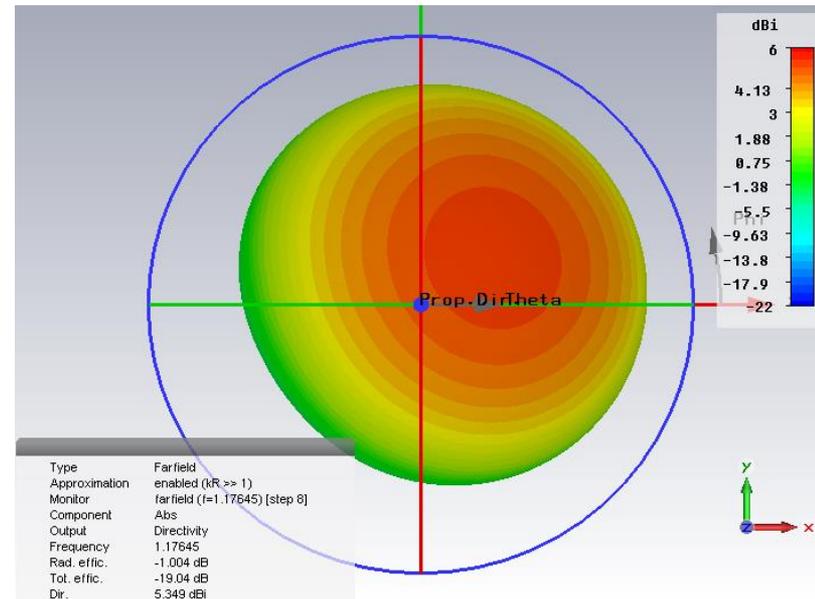


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
17	90	20	105	0

# Pattern Control-AZ-Second Quadrant

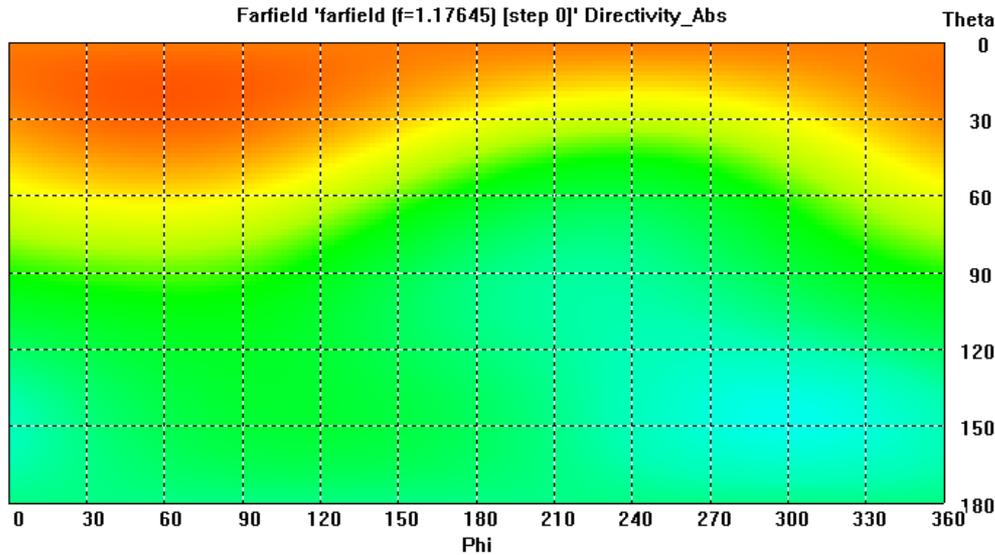


Frequency = 1.17645  
 Rad. eff. = -1.00353 dB  
 Tot. eff. = -19.0359 dB  
 Dir. = 5.34929 dBi

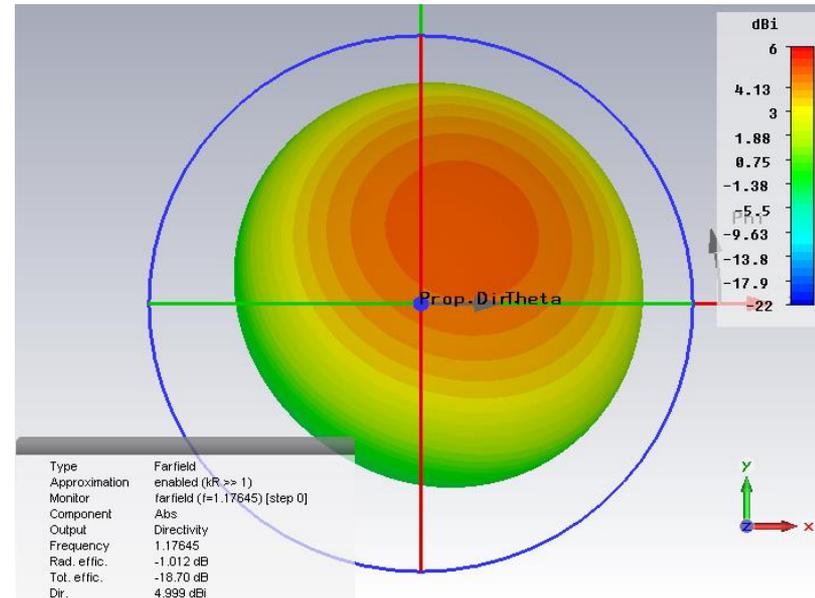


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
18	90	20	110	0

# Pattern Control-AZ-Third Quadrant

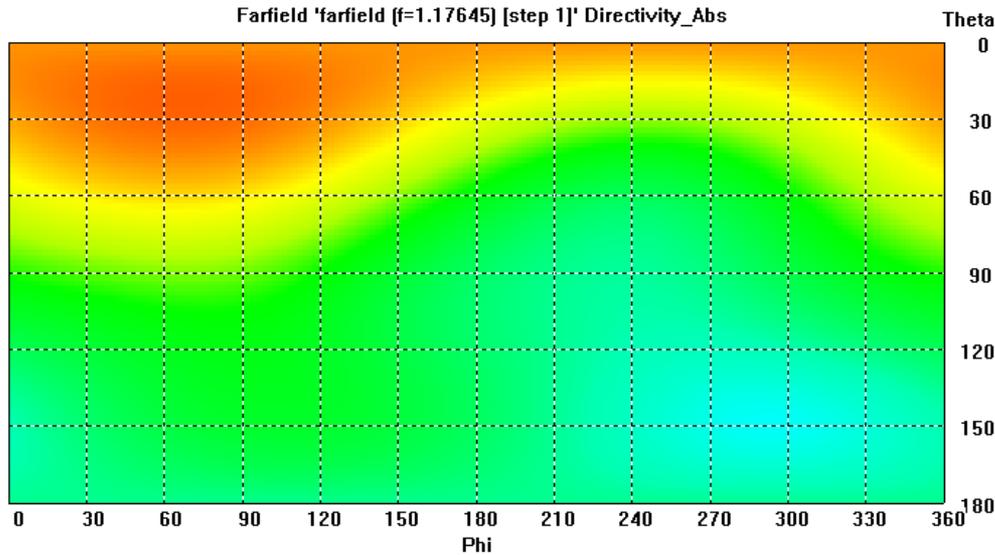


Frequency = 1.17645  
 Rad. effic. = -1.01179 dB  
 Tot. effic. = -18.6996 dB  
 Dir. = 4.99889 dBi

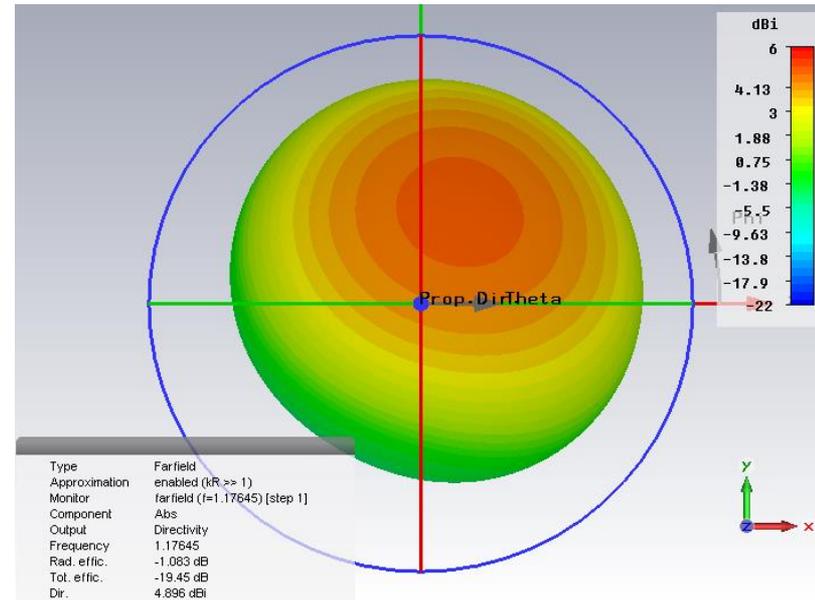


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
19	20	70	0	90

# Pattern Control-AZ-Third Quadrant



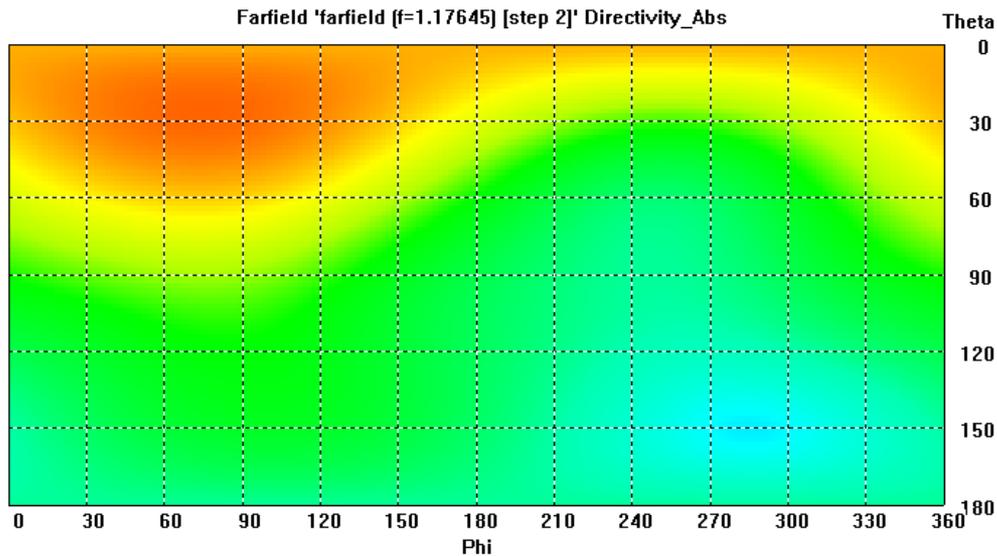
Frequency = 1.17645  
 Rad. eff. = -1.08254 dB  
 Tot. eff. = -19.4524 dB  
 Dir. = 4.89576 dBi



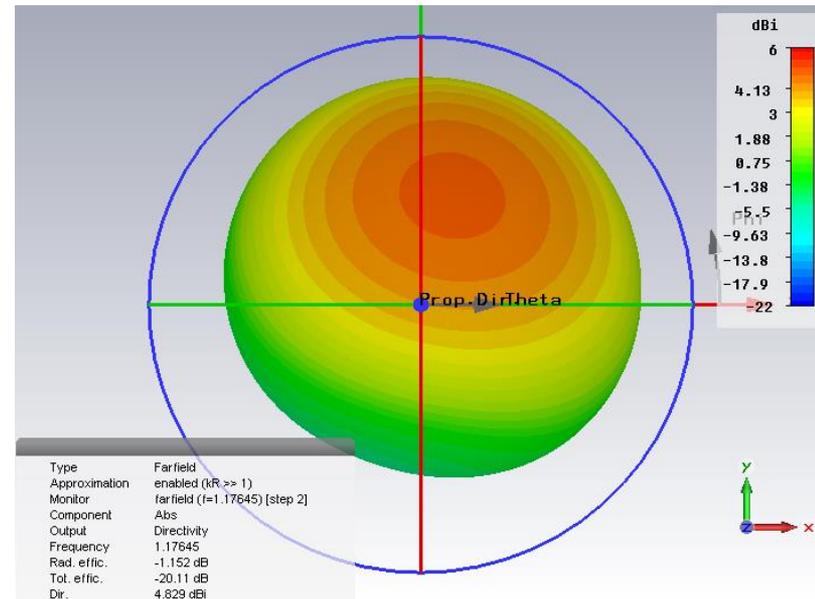
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
20	20	75	0	90



# Pattern Control-AZ-Third Quadrant

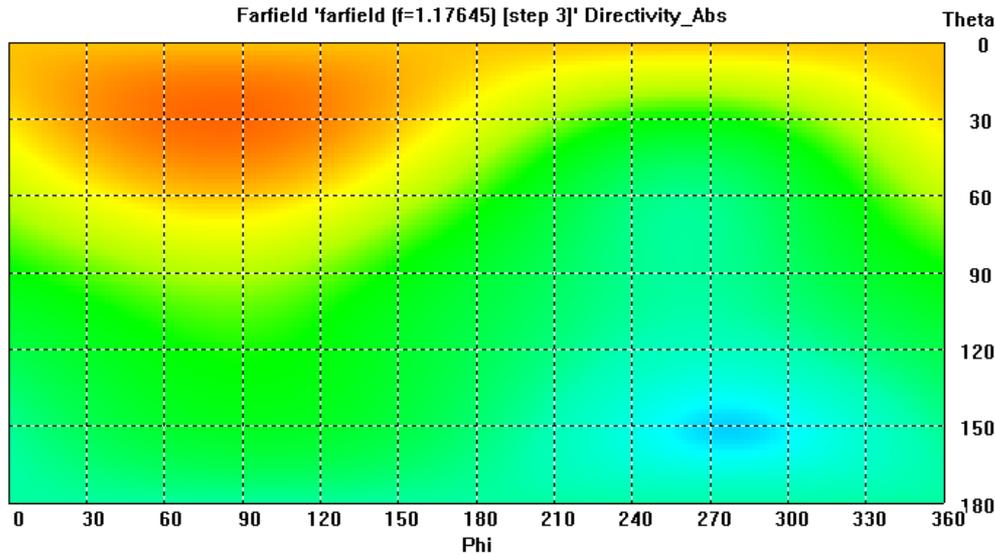


Frequency = 1.17645  
 Rad. effic. = -1.15188 dB  
 Tot. effic. = -20.1051 dB  
 Dir. = 4.82889 dBi

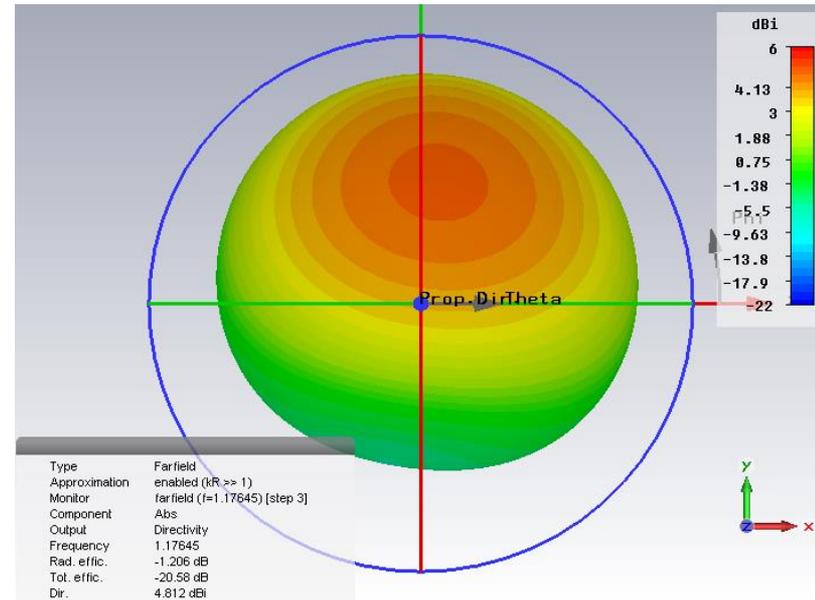


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
21	20	80	0	90

# Pattern Control-AZ-Third Quadrant

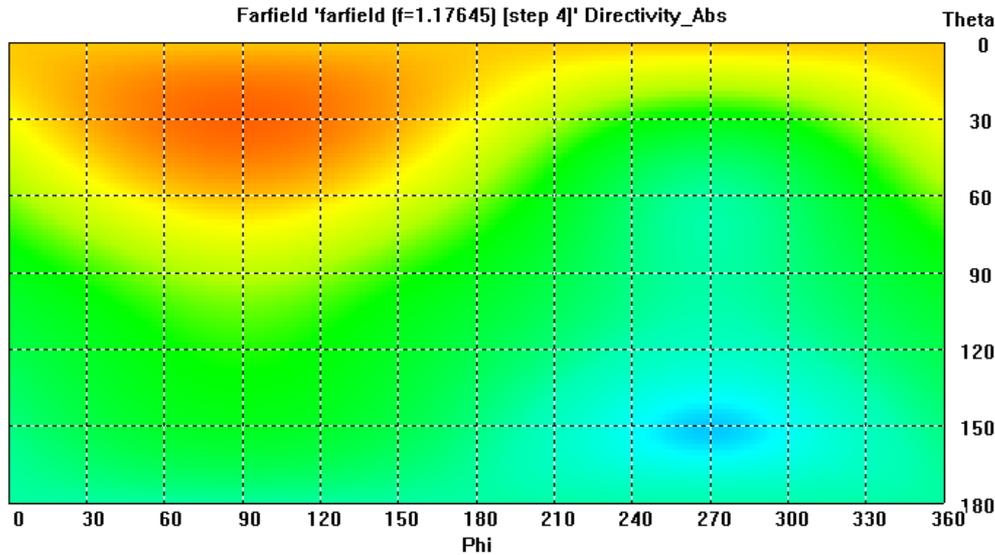


Frequency = 1.17645  
 Rad. eff. = -1.20582 dB  
 Tot. eff. = -20.5780 dB  
 Dir. = 4.81173 dBi

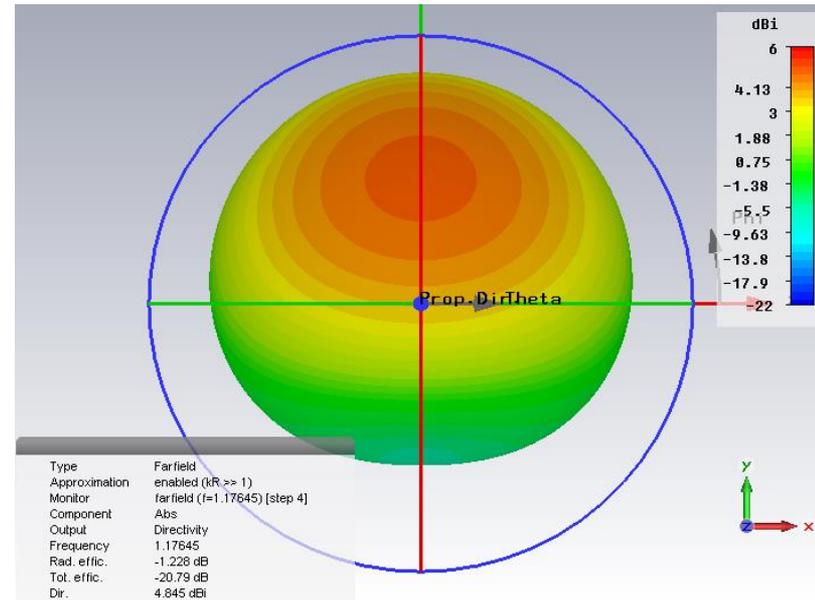


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
22	20	85	0	90

# Pattern Control-AZ-Third Quadrant

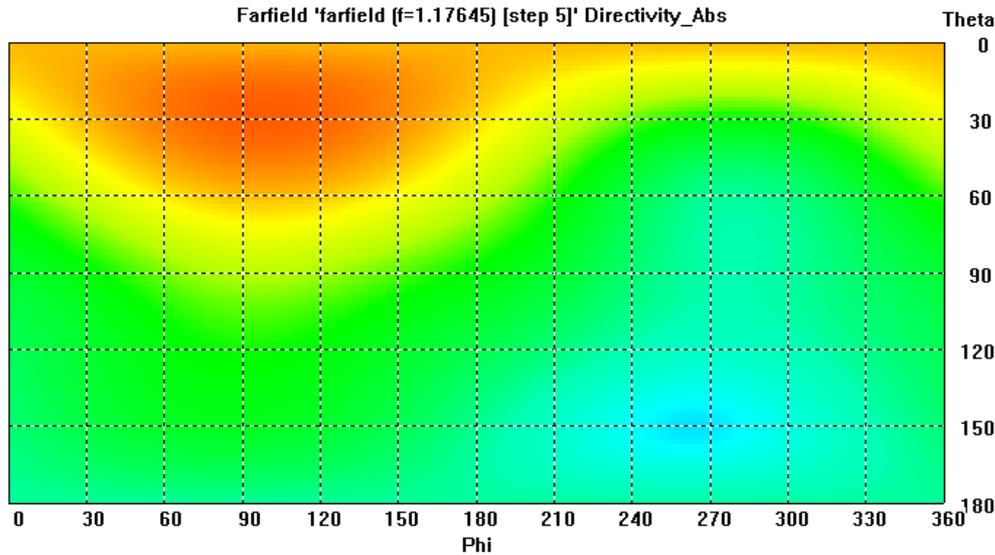


Frequency = 1.17645  
 Rad. eff. = -1.22823 dB  
 Tot. eff. = -20.7933 dB  
 Dir. = 4.84486 dBi

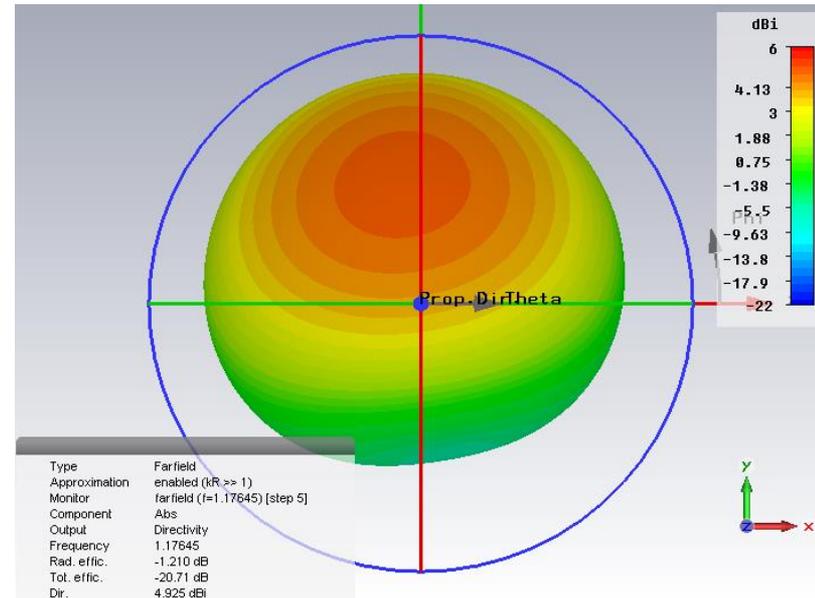


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
23	20	90	0	90

# Pattern Control-AZ-Third Quadrant

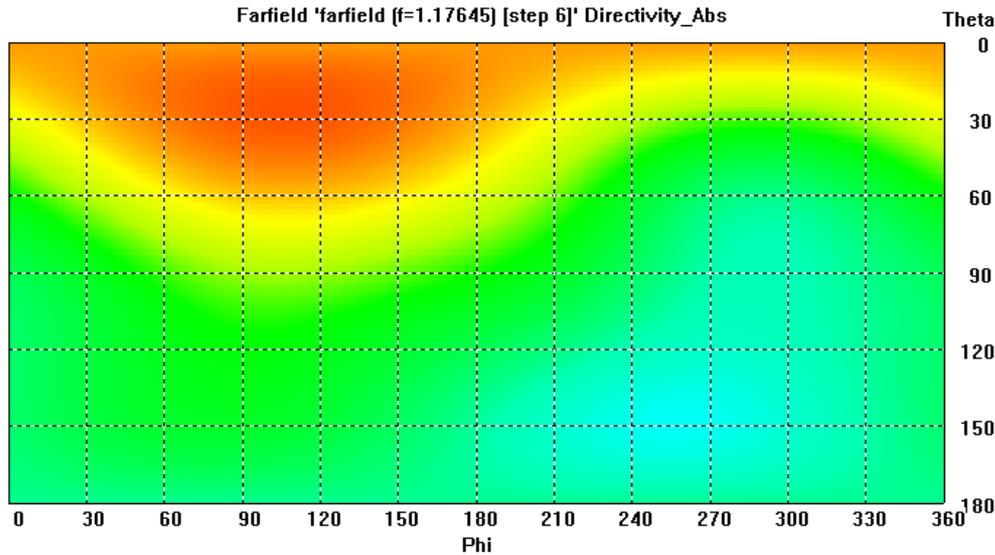


Frequency = 1.17645  
 Rad. effic. = -1.21013 dB  
 Tot. effic. = -20.7090 dB  
 Dir. = 4.92504 dBi

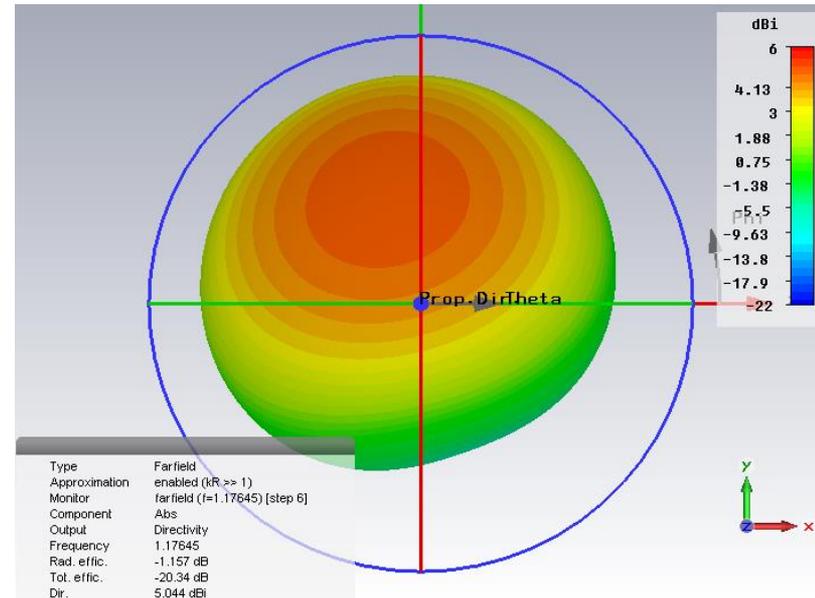


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
24	20	95	0	90

# Pattern Control-AZ-Third Quadrant

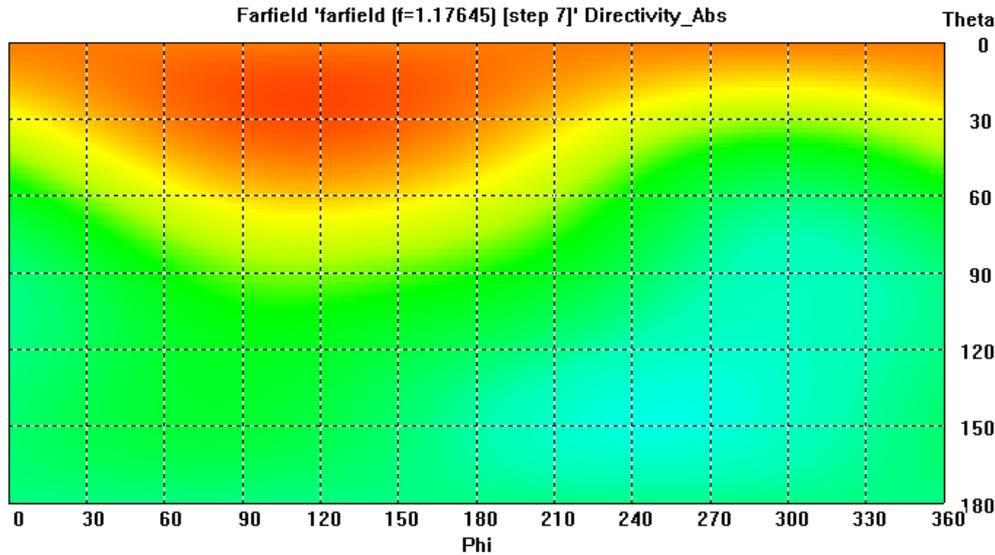


Frequency = 1.17645  
 Rad. effic. = -1.15683 dB  
 Tot. effic. = -20.3420 dB  
 Dir. = 5.04359 dBi

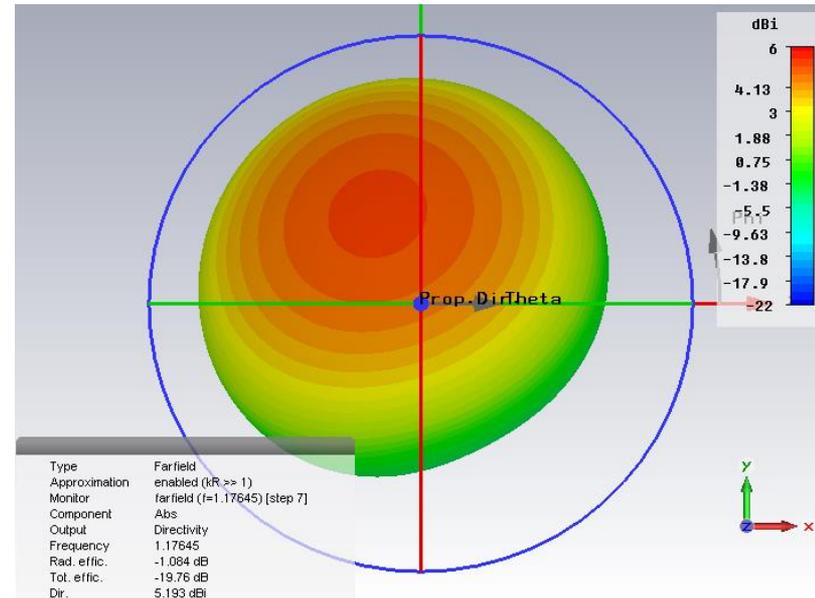


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
25	20	100	0	90

# Pattern Control-AZ-Third Quadrant

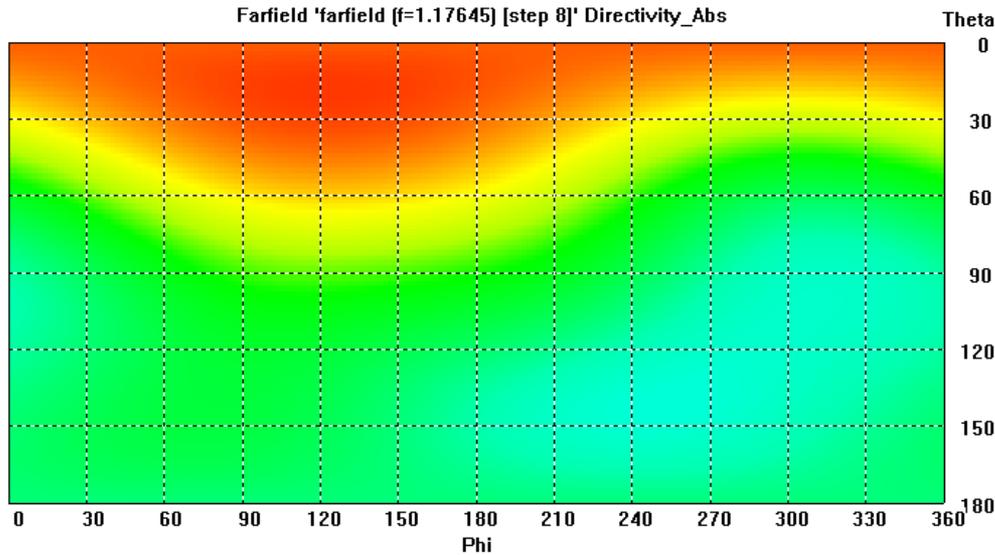


Frequency = 1.17645  
 Rad. effic. = -1.08400 dB  
 Tot. effic. = -19.7586 dB  
 Dir. = 5.19250 dBi

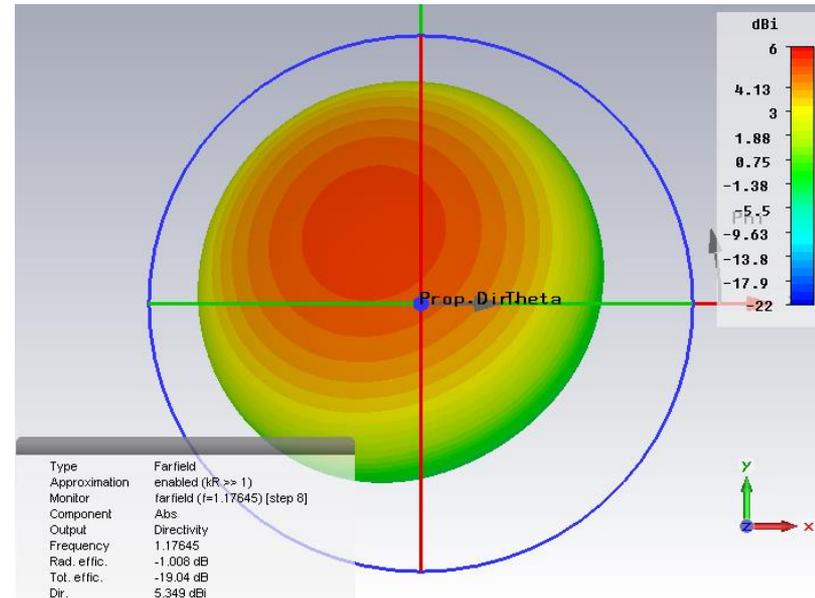


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
26	20	105	0	90

# Pattern Control-AZ-Third Quadrant

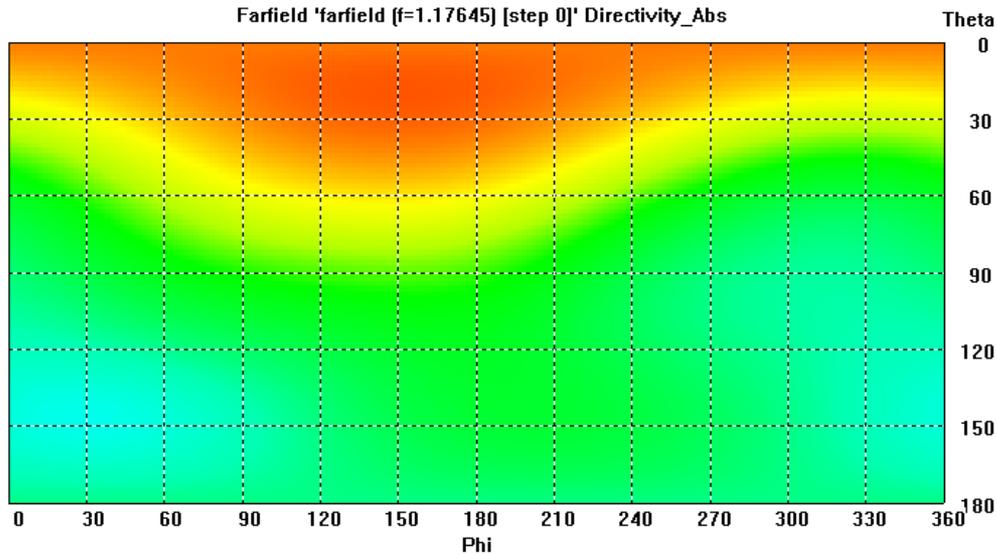


Frequency = 1.17645  
 Rad. effic. = -1.00761 dB  
 Tot. effic. = -19.0413 dB  
 Dir. = 5.34941 dBi

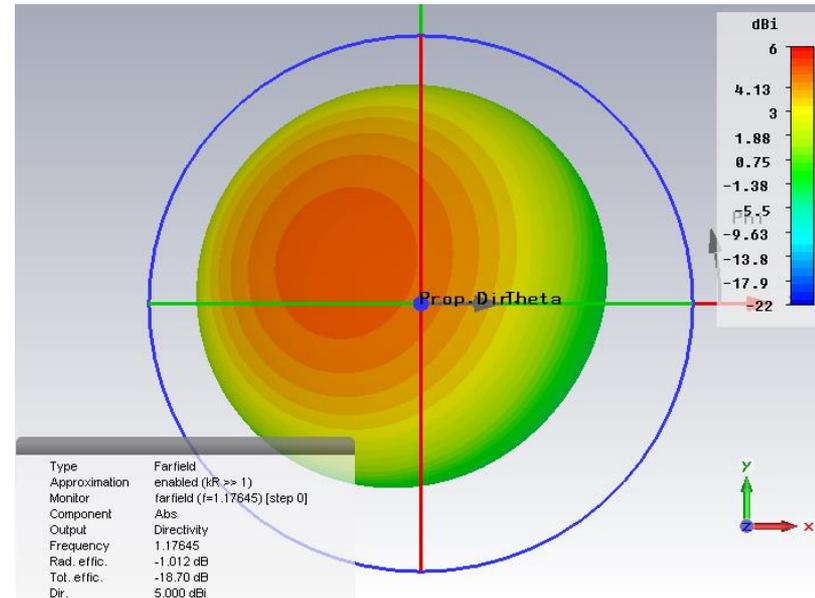


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
27	20	110	0	90

# Pattern Control-AZ-Fourth Quadrant

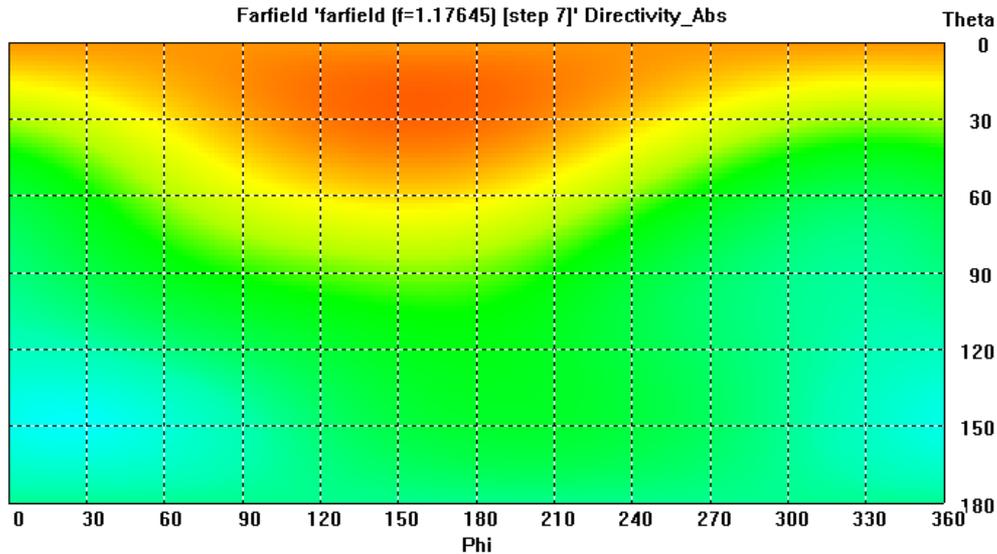


Frequency = 1.17645  
 Rad. effic. = -1.01201 dB  
 Tot. effic. = -18.6996 dB  
 Dir. = 5.00038 dBi

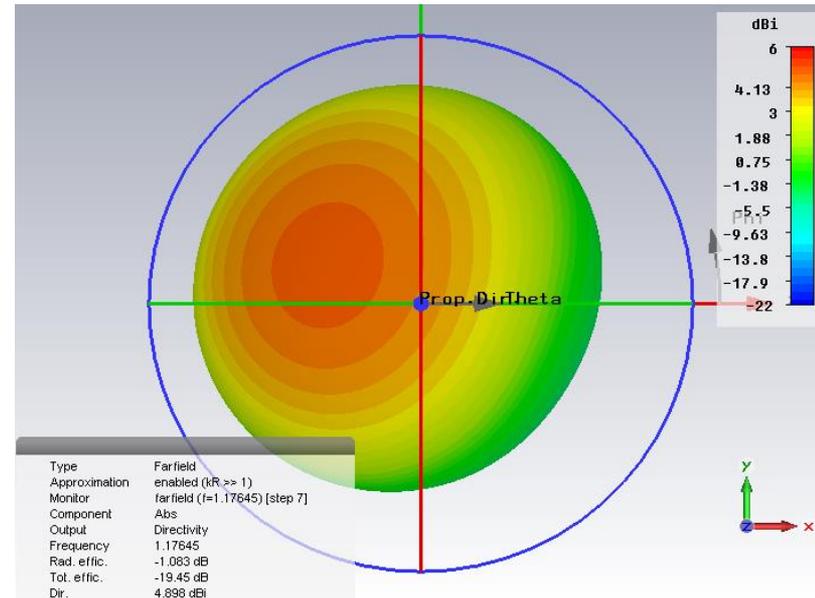


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
28	70	0	90	20

# Pattern Control-AZ-Fourth Quadrant

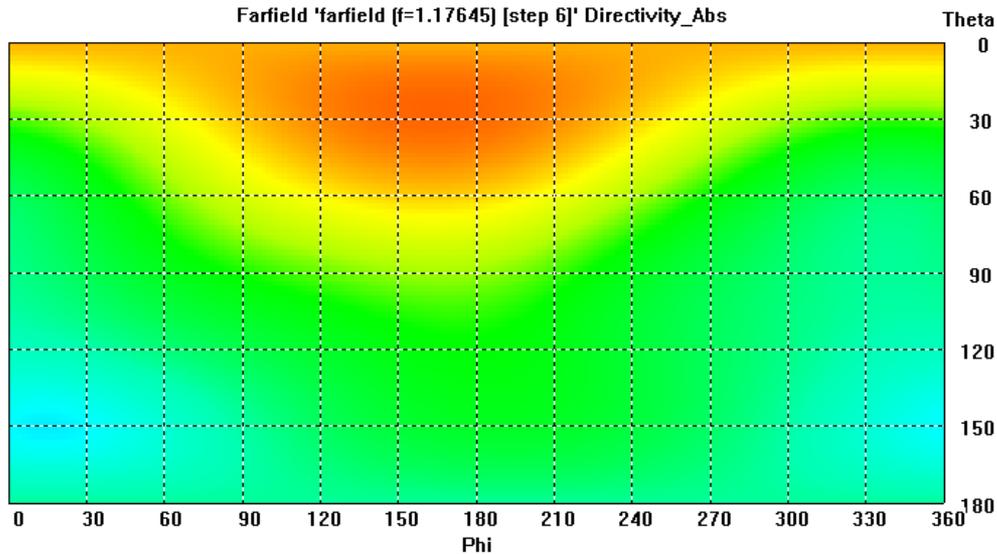


Frequency = 1.17645  
 Rad. effic. = -1.08252 dB  
 Tot. effic. = -19.4522 dB  
 Dir. = 4.89777 dBi

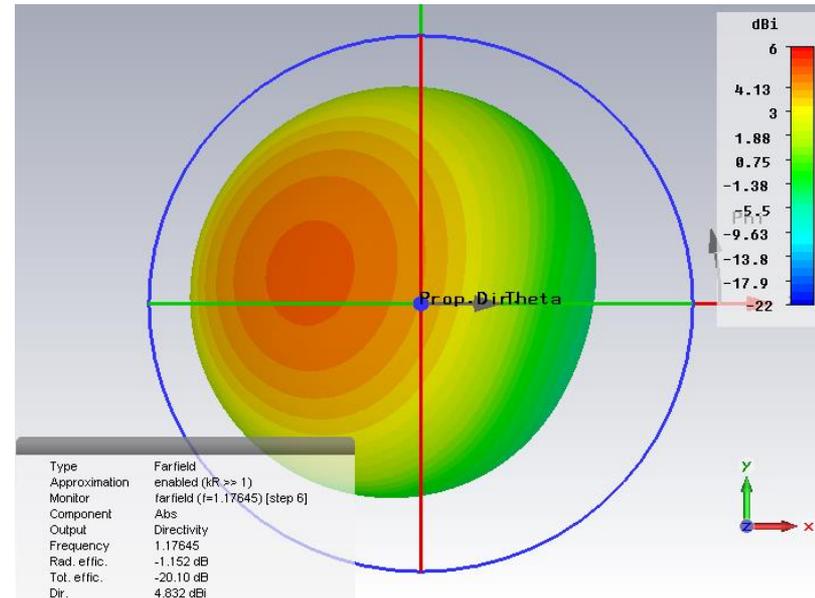


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
29	75	0	90	20

# Pattern Control-AZ-Fourth Quadrant

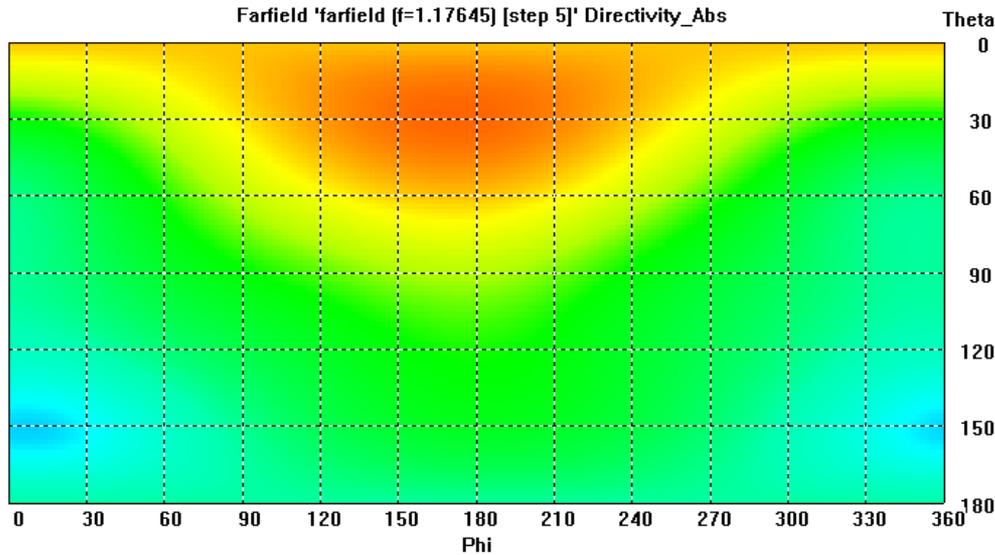


Frequency = 1.17645  
 Rad. effic. = -1.15159 dB  
 Tot. effic. = -20.1047 dB  
 Dir. = 4.83161 dBi

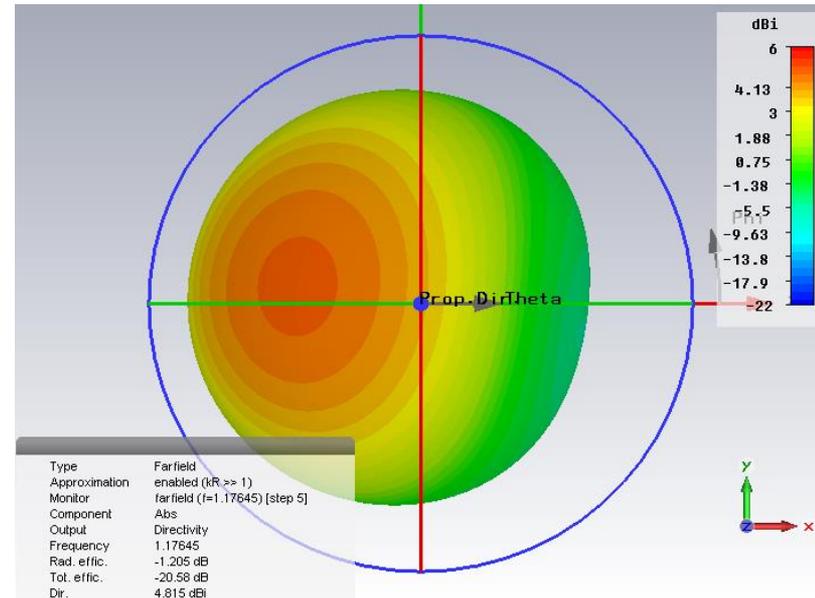


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
30	80	0	90	20

# Pattern Control-AZ-Fourth Quadrant

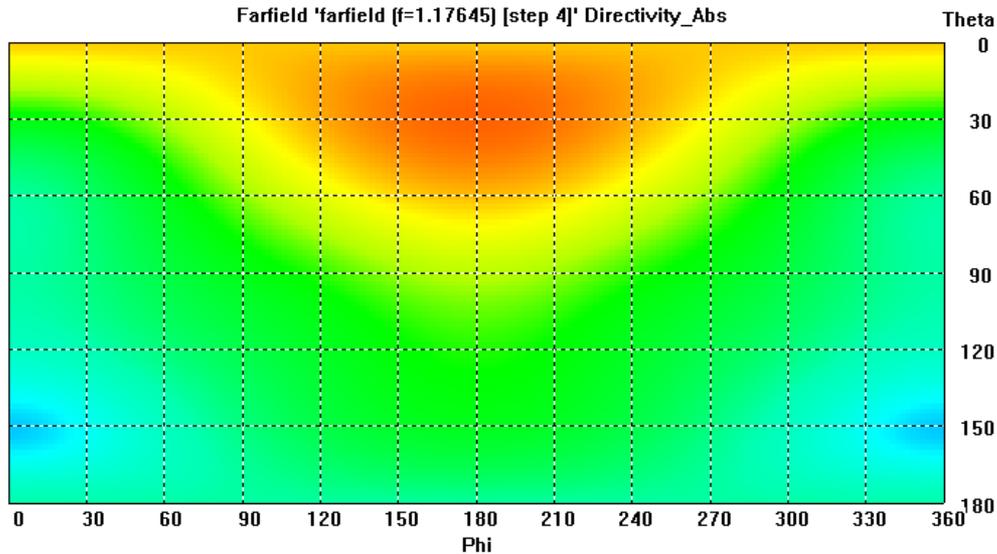


Frequency = 1.17645  
 Rad. effic. = -1.20529 dB  
 Tot. effic. = -20.5774 dB  
 Dir. = 4.81506 dBi

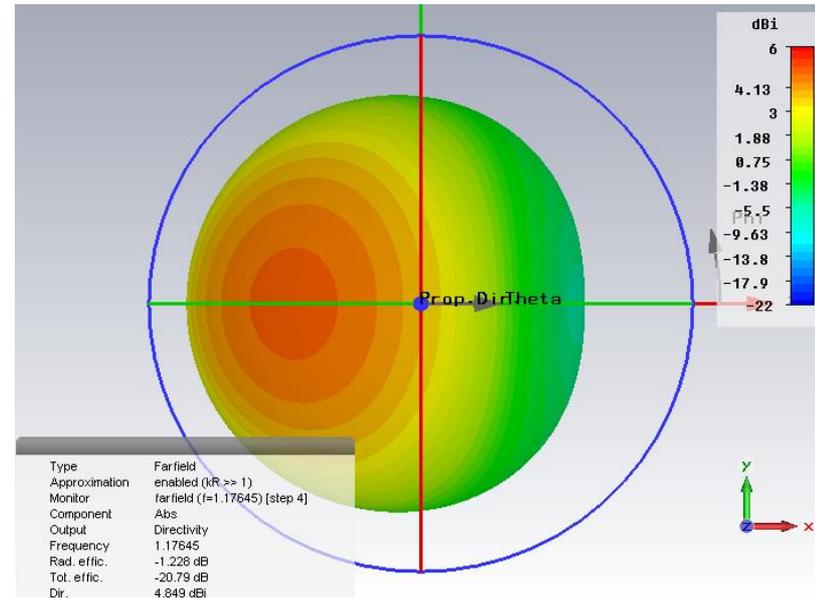


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
31	85	0	90	20

# Pattern Control-AZ-Fourth Quadrant

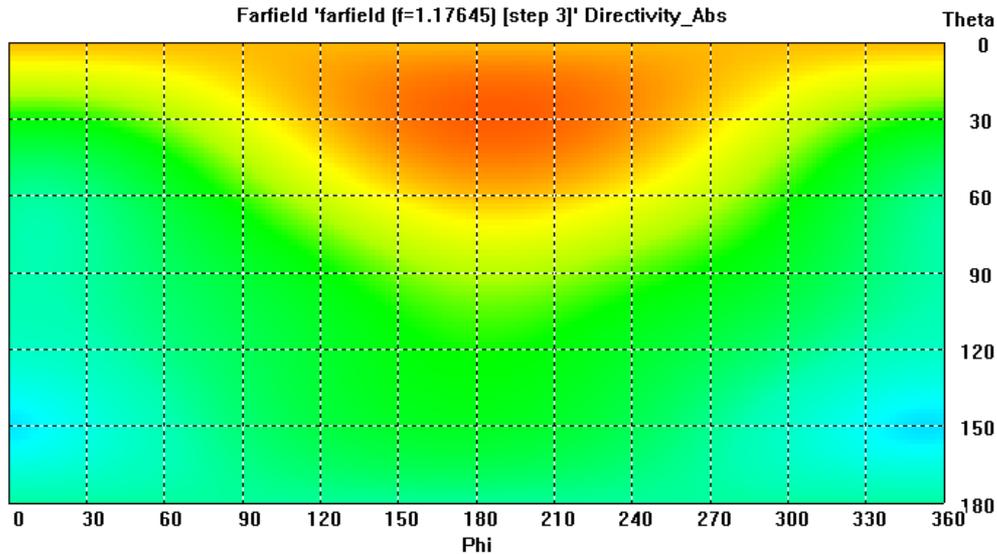


Frequency = 1.17645  
 Rad. eff. = -1.22752 dB  
 Tot. eff. = -20.7927 dB  
 Dir. = 4.84856 dBi

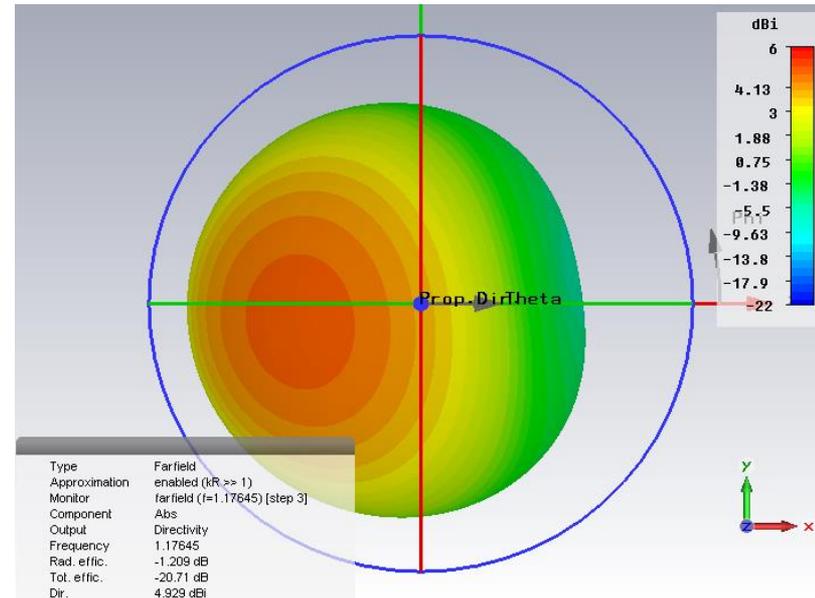


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
32	90	0	90	20

# Pattern Control-AZ-Fourth Quadrant

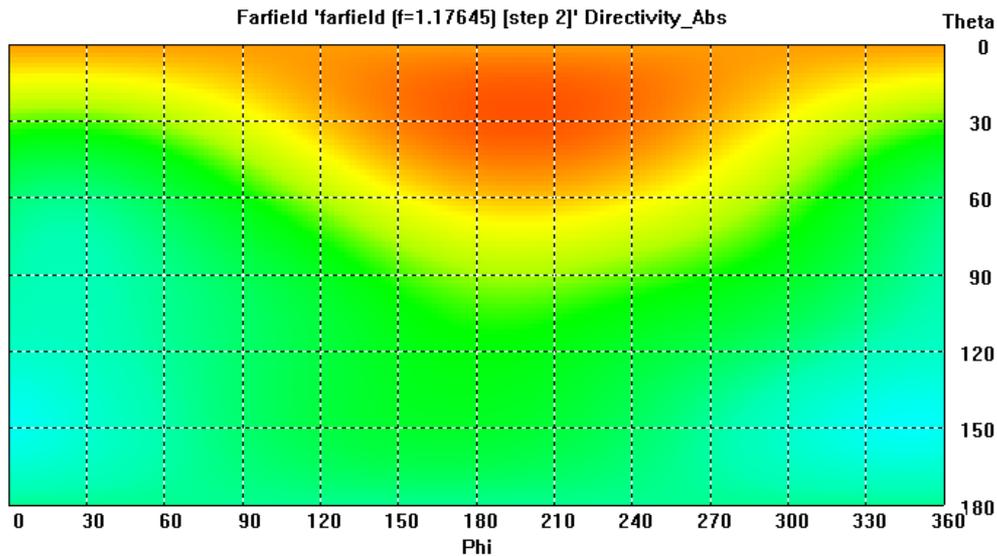


Frequency = 1.17645  
 Rad. eff. = -1.20938 dB  
 Tot. eff. = -20.7084 dB  
 Dir. = 4.92875 dBi

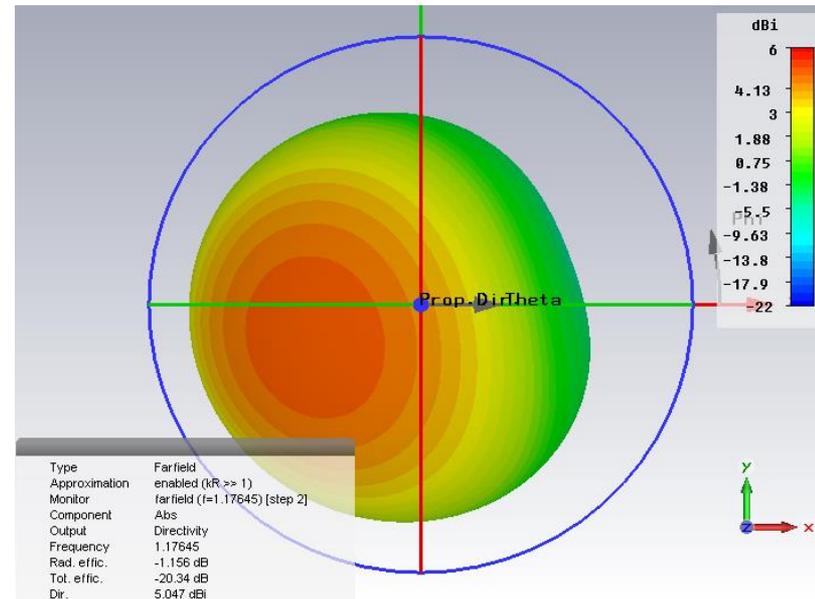


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
33	95	0	90	20

# Pattern Control-AZ-Fourth Quadrant



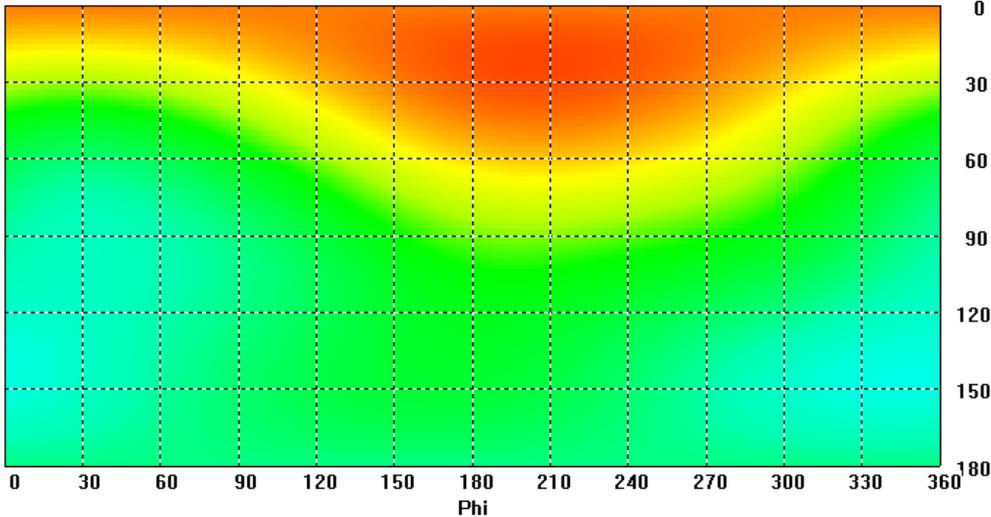
Frequency = 1.17645  
 Rad. effic. = -1.15614 dB  
 Tot. effic. = -20.3415 dB  
 Dir. = 5.04691 dBi



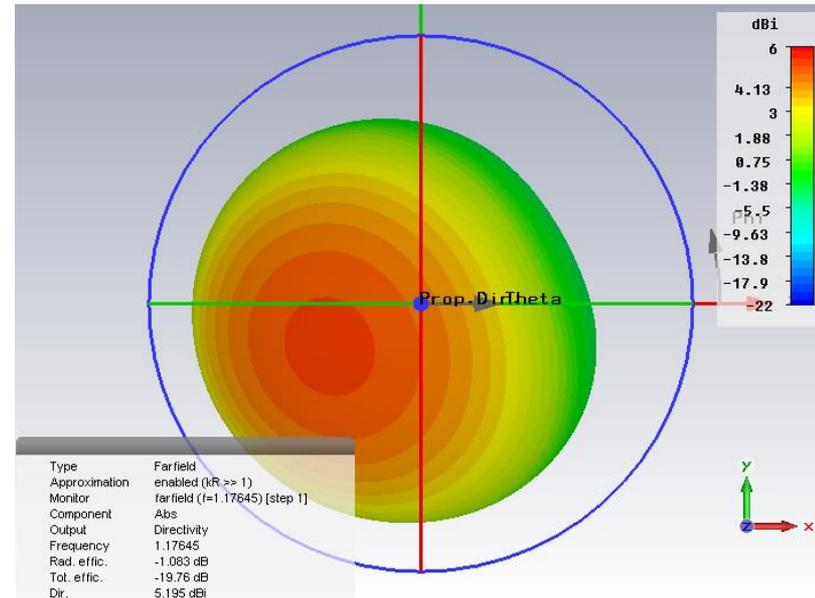
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
34	100	0	90	20

# Pattern Control-AZ-Fourth Quadrant

Farfield 'farfield (f=1.17645) [step 1]' Directivity\_Abs

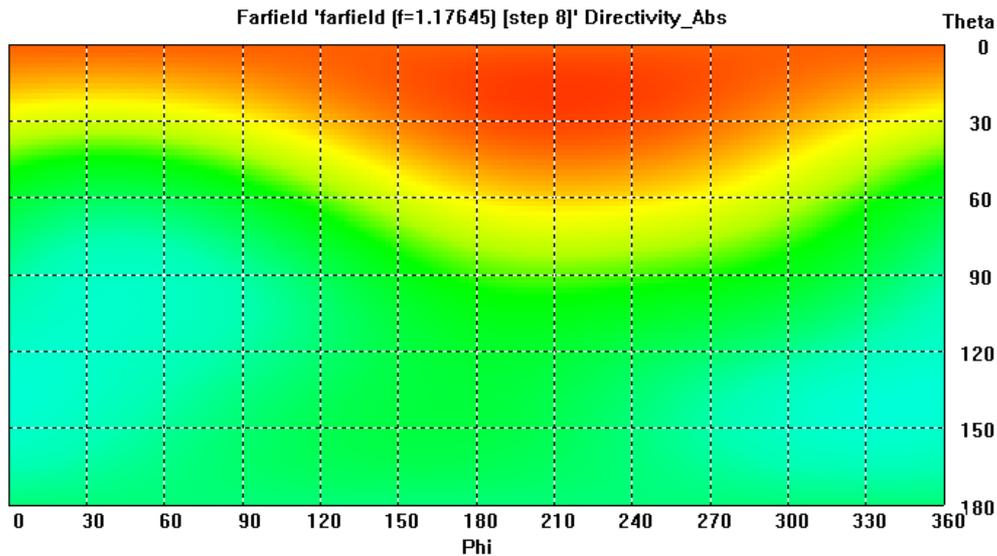


Frequency = 1.17645  
 Rad. effic. = -1.08347 dB  
 Tot. effic. = -19.7583 dB  
 Dir. = 5.19520 dBi

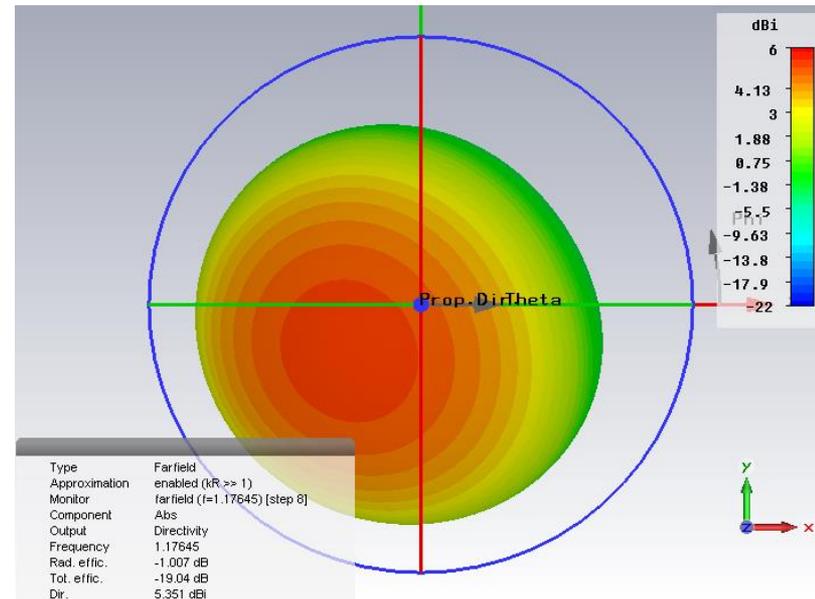


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
35	105	0	90	20

# Pattern Control-AZ-Fourth Quadrant



Frequency = 1.17645  
 Rad. effic. = -1.00727 dB  
 Tot. effic. = -19.0412 dB  
 Dir. = 5.35150 dBi



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
36	110	0	90	20

# Elevation Pattern Control

- **Illustrate here at one azimuth angle:**
  - » One of “first quadrant” cuts corresponding to area of high directivity at a given azimuth.
  - » Port phases:  $[0, \gamma_2=90, \Delta\gamma_{OPP}, \Delta\gamma_{ADJ}=90]$  deg
    - Puts area of high directivity at  $\phi=270$  deg
    - Now, vary  $\Delta\gamma_{OPP}$  to illustrate elevation pattern control
- **Elevation pattern control at other azimuth angles (not shown here)**
  - » Control phases for desired azimuth angles (previously shown), then vary  $\Delta\gamma_{OPP}$  for elevation pattern control

# Phase Control Summary

- Four-feed Illustration (for one elevation cut):

Quadrant	Port Number			
	1	2	3	4
1	0	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$
2	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	0
3	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	0	$\Delta\gamma_{POL}$
4	$\Delta\gamma_{ADJ}$	0	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$

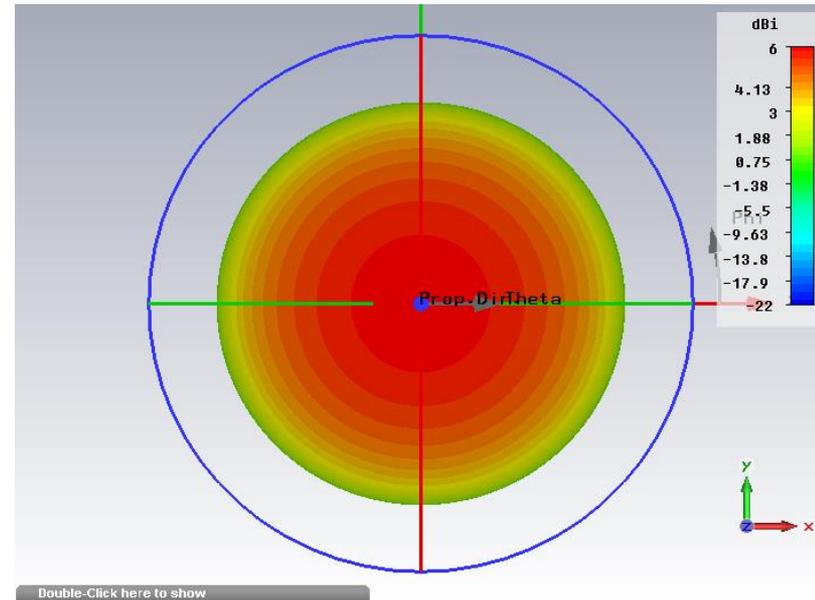
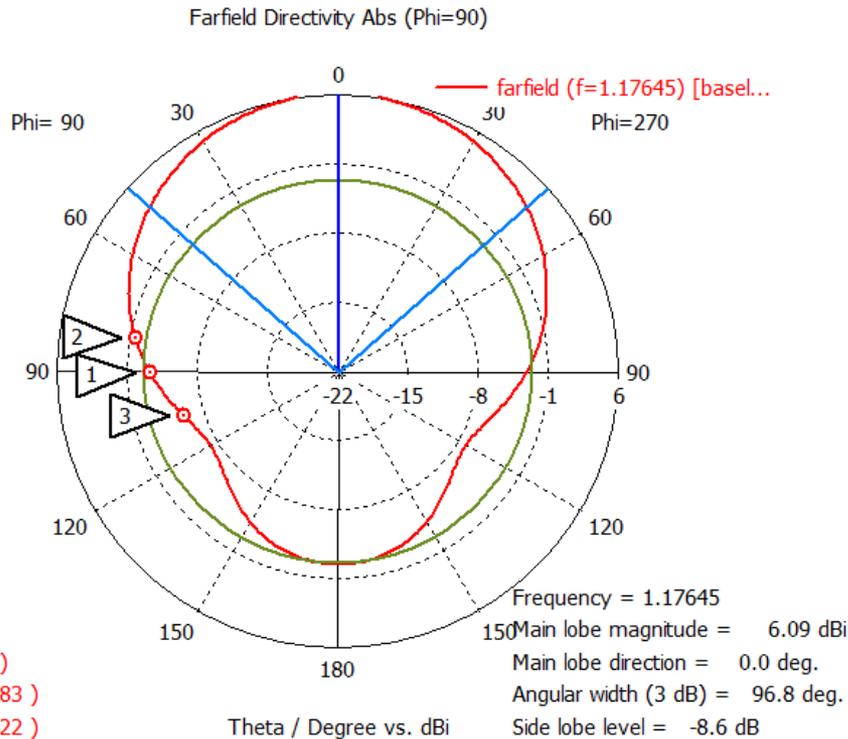
where (for elevation pattern control):

$$\Delta\gamma_{POL} = 90 \text{ deg}$$

$$10 < \Delta\gamma_{OPP} < 90, [\text{deg}]$$

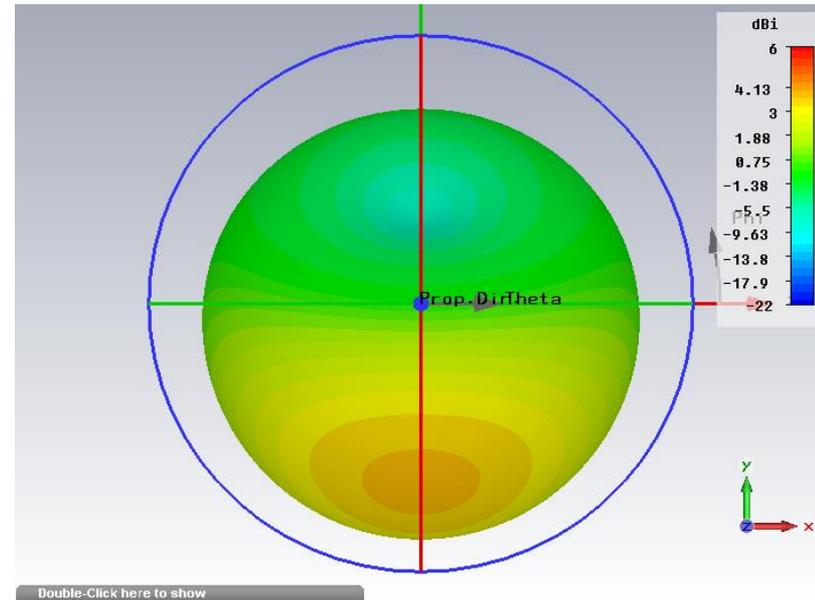
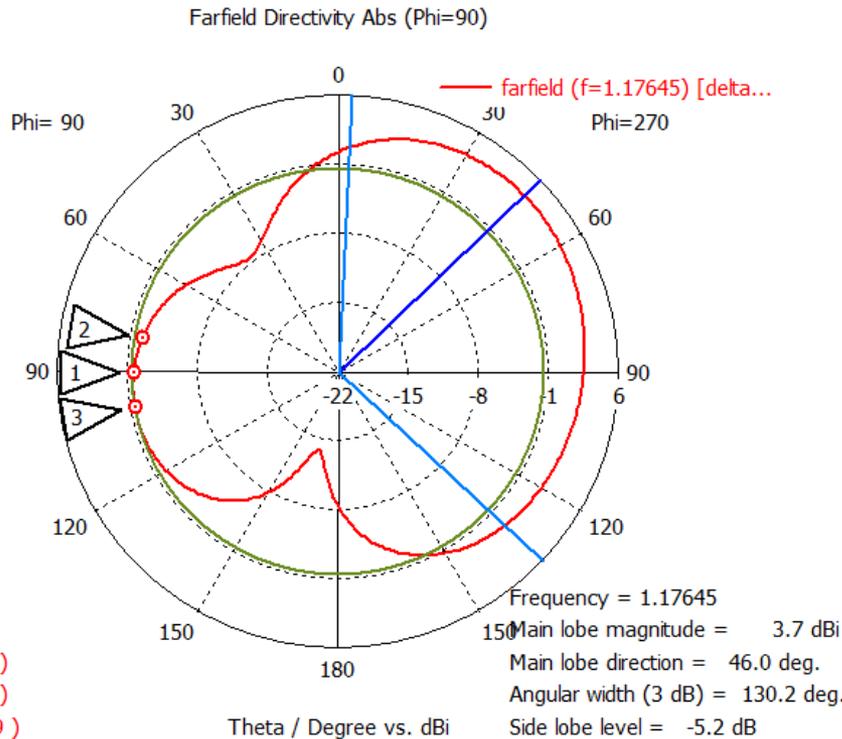
$$\Delta\gamma_{ADJ} = 90 \text{ deg (here, high directivity at } \phi=270 \text{ deg)}$$

# Pattern Control-Elevation-Baseline



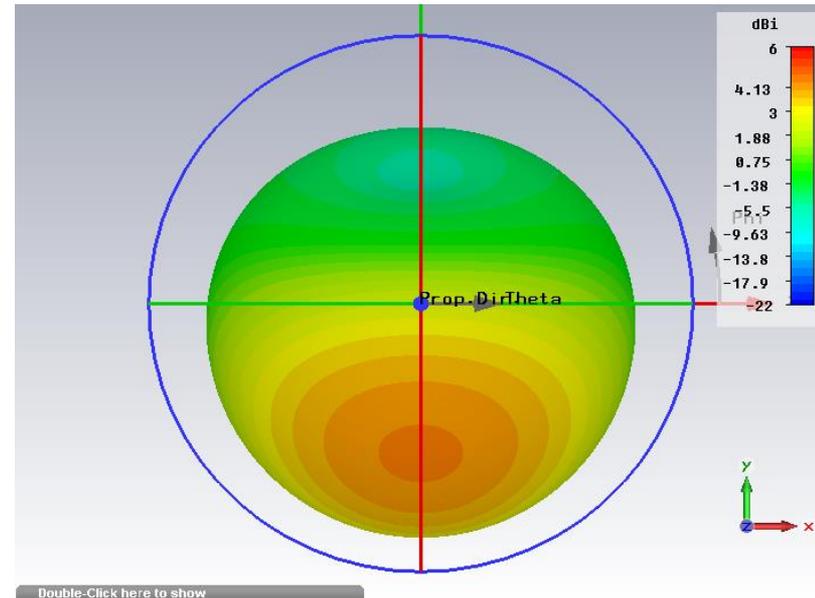
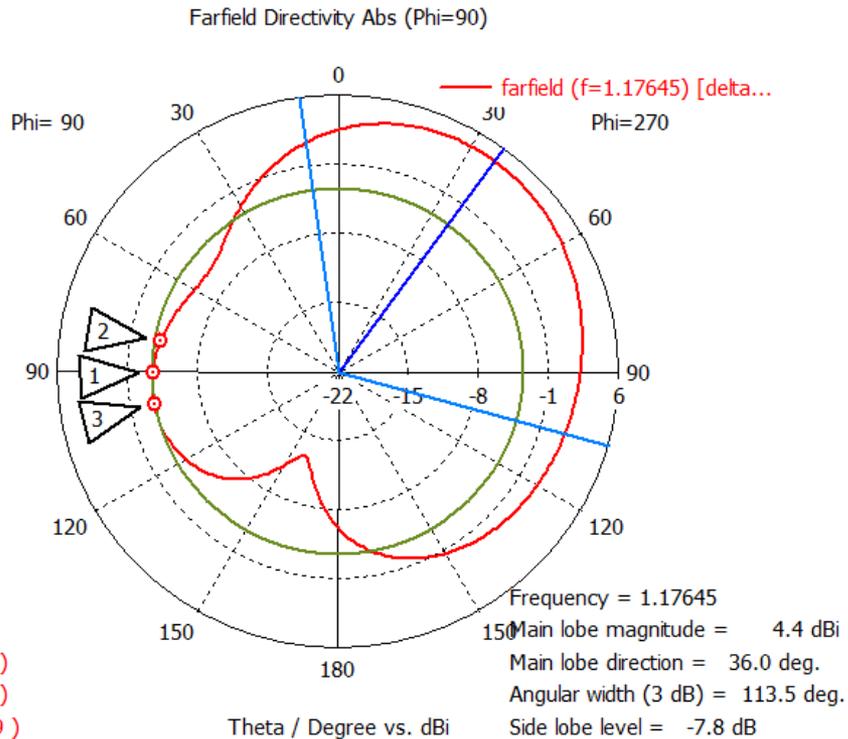
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
1	0	90	180	270

# Pattern Control-Elevation



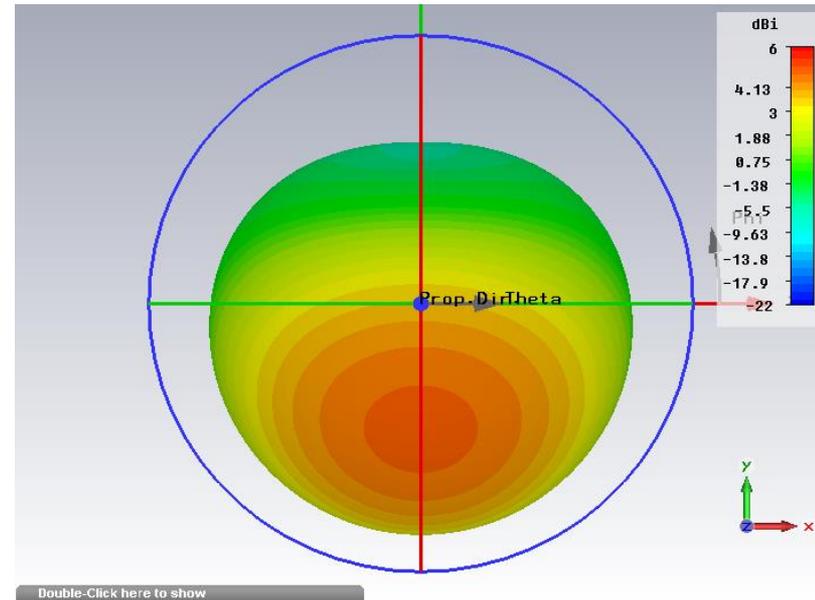
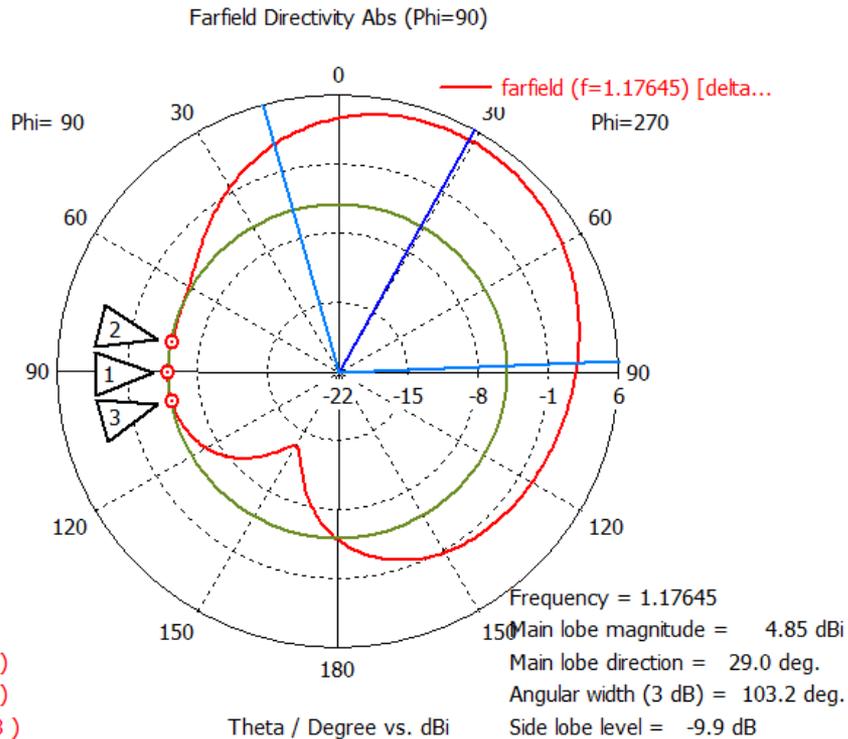
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
<b>2</b>	<b>0</b>	<b>90</b>	<b>10</b>	<b>90</b>

# Pattern Control-Elevation



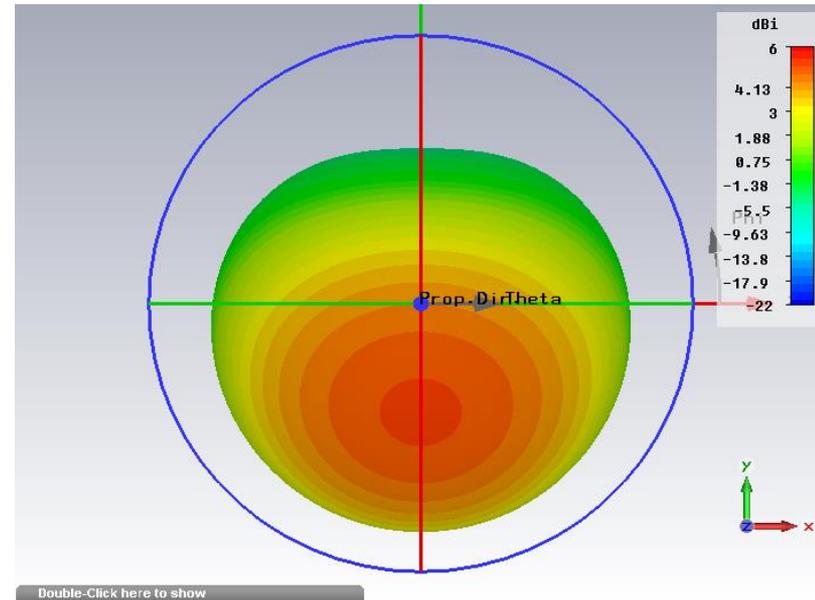
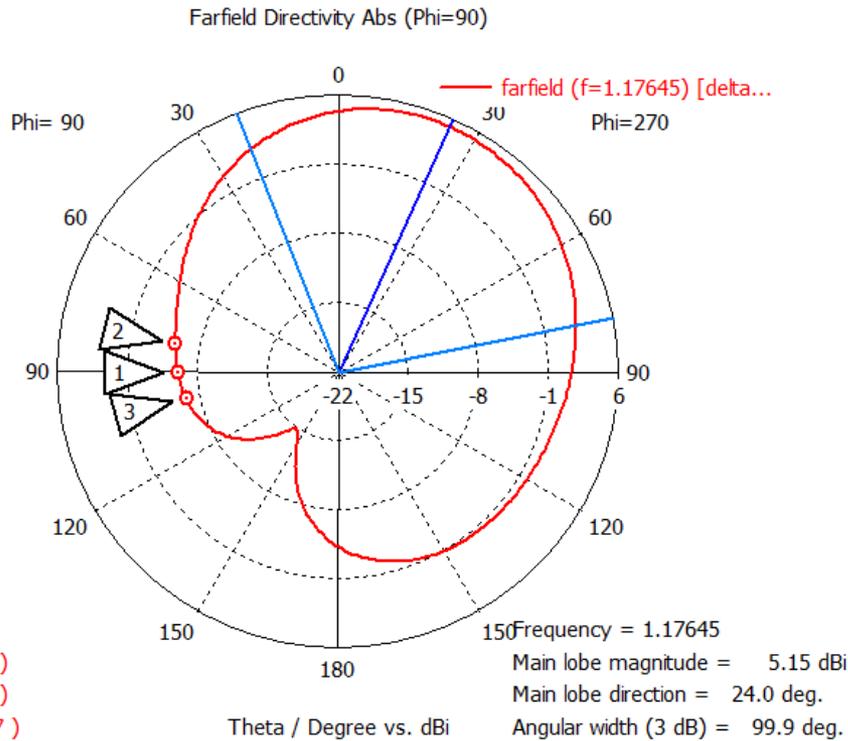
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
<b>3</b>	<b>0</b>	<b>90</b>	<b>15</b>	<b>90</b>

# Pattern Control-Elevation



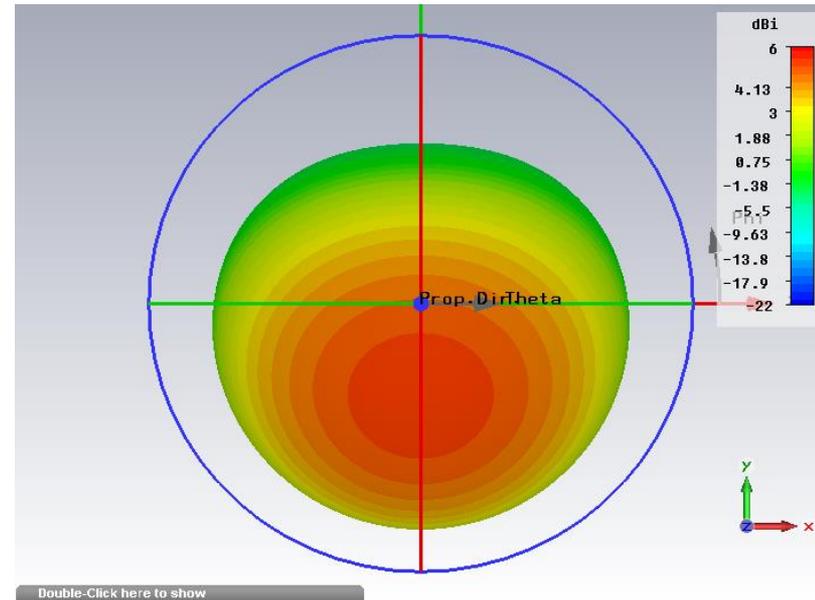
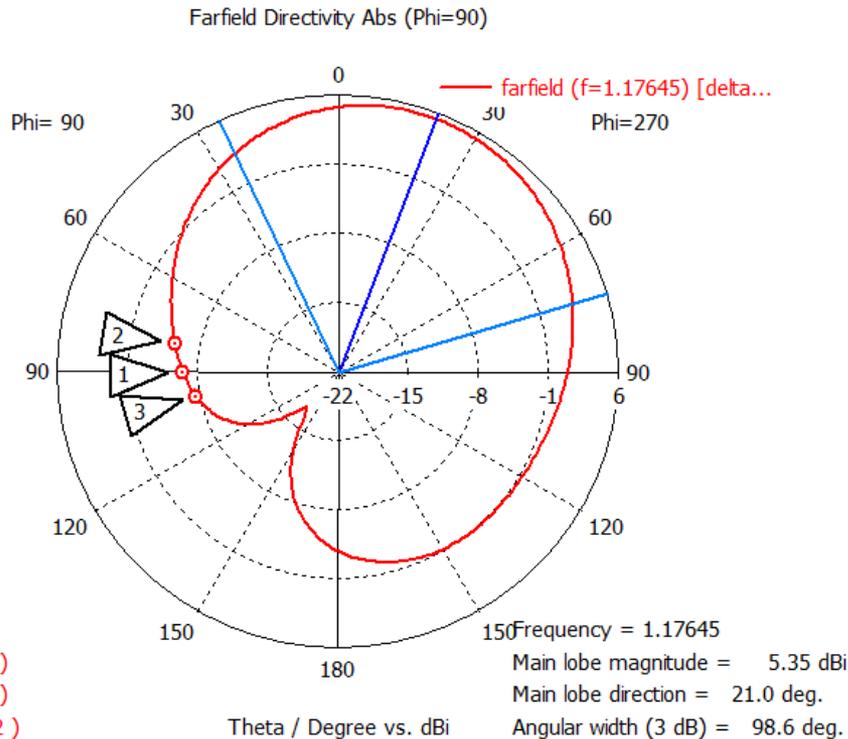
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
4	0	90	20	90

# Pattern Control-Elevation



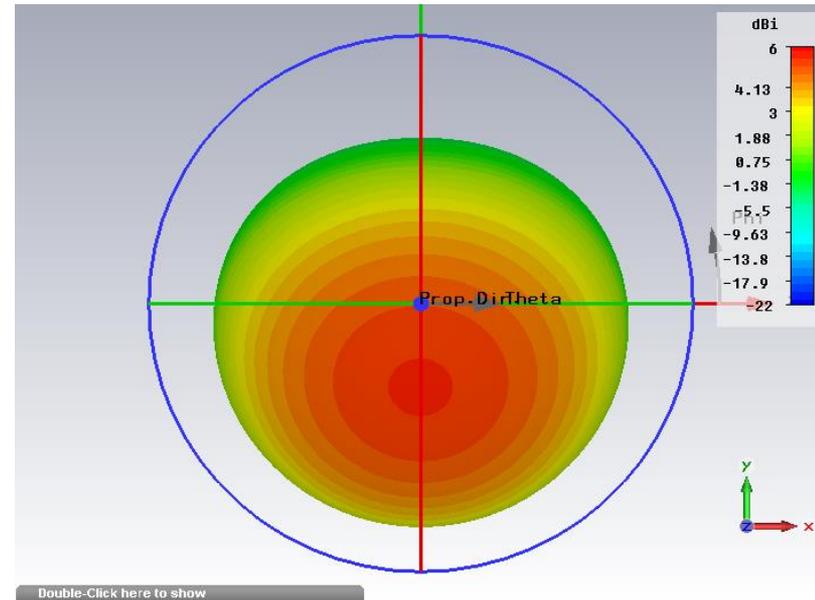
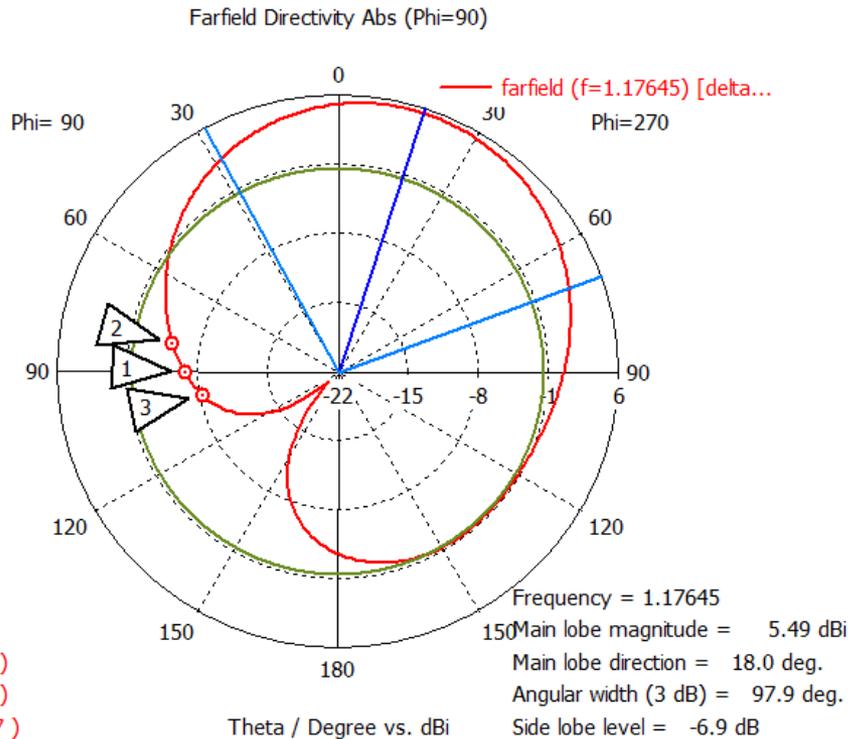
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
5	0	90	25	90

# Pattern Control-Elevation



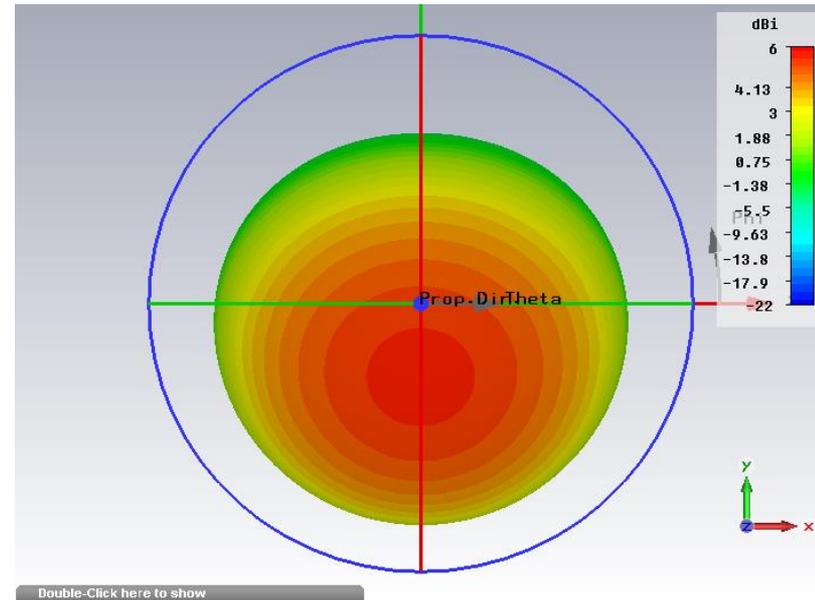
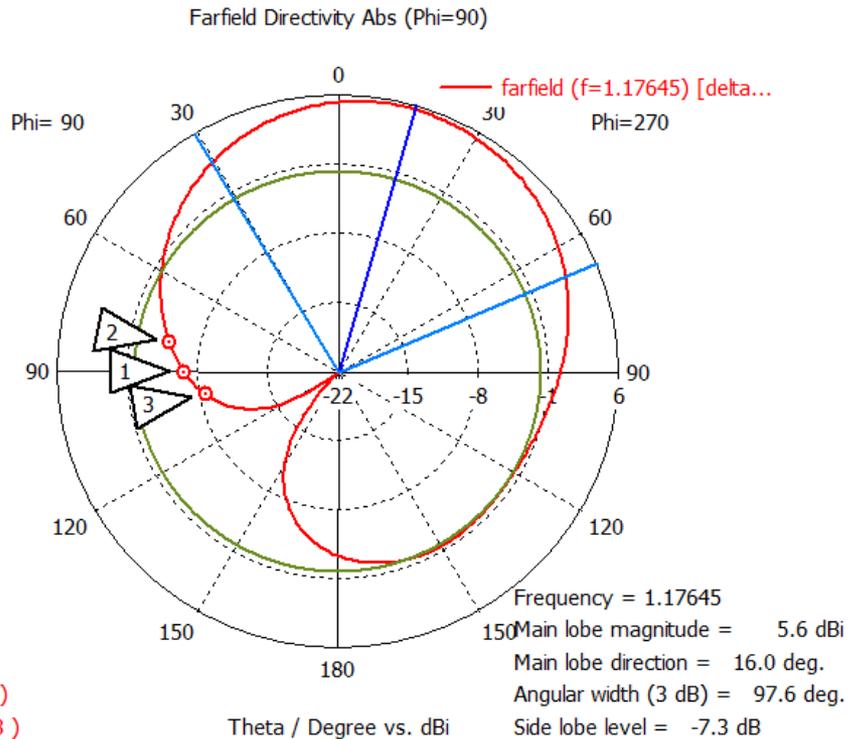
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
6	0	90	30	90

# Pattern Control-Elevation



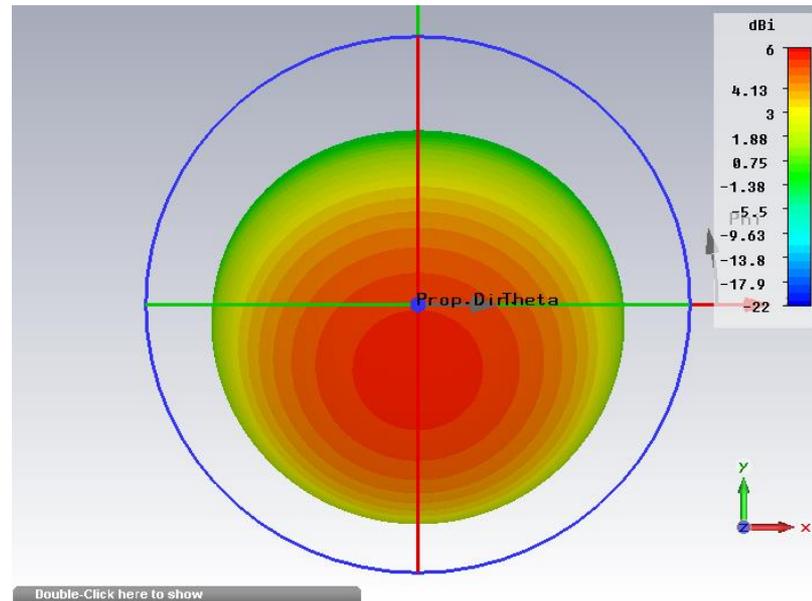
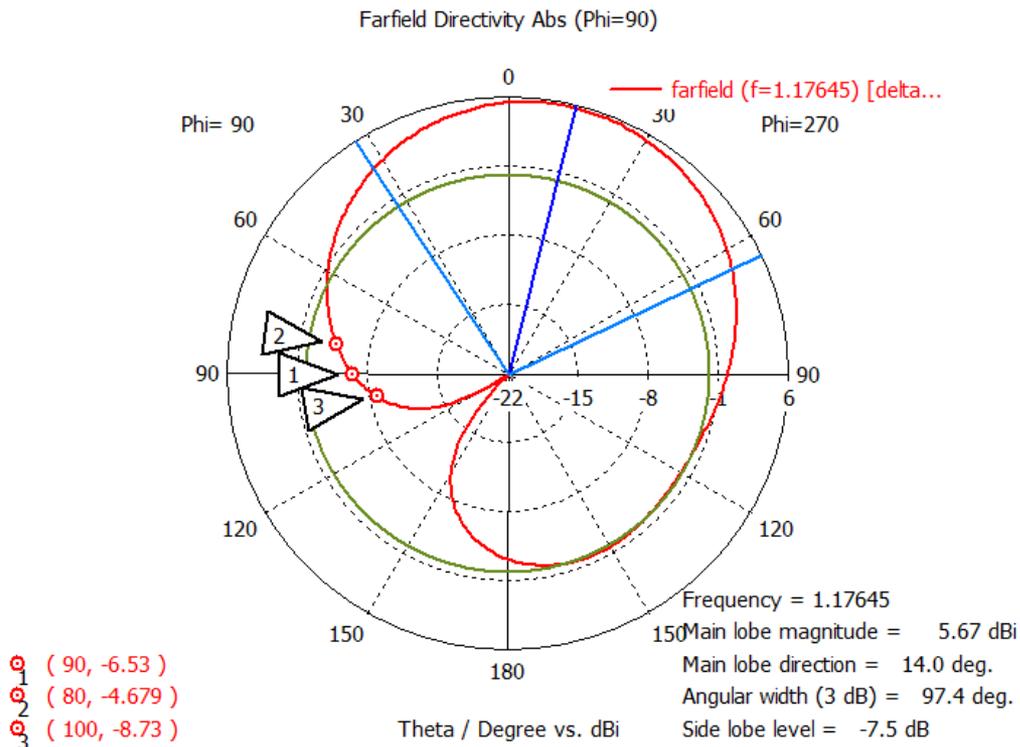
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
7	0	90	35	90

# Pattern Control-Elevation



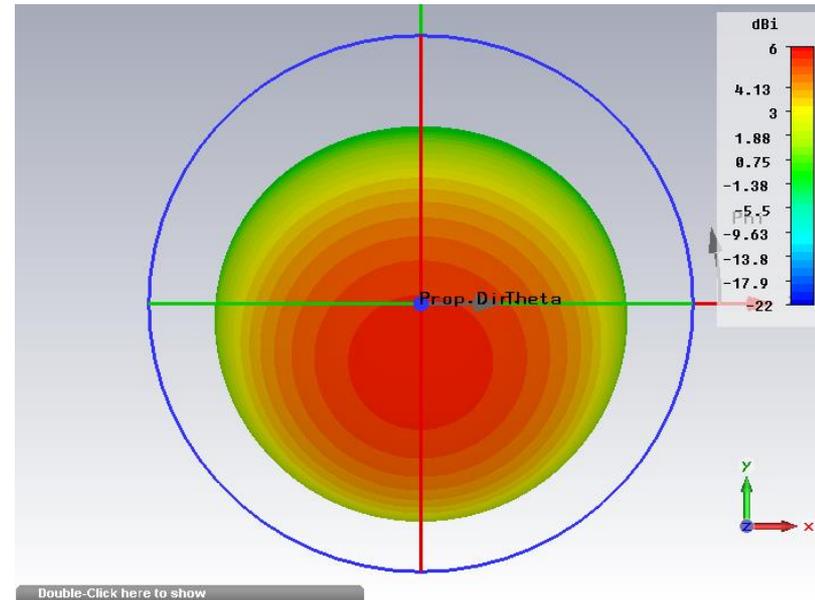
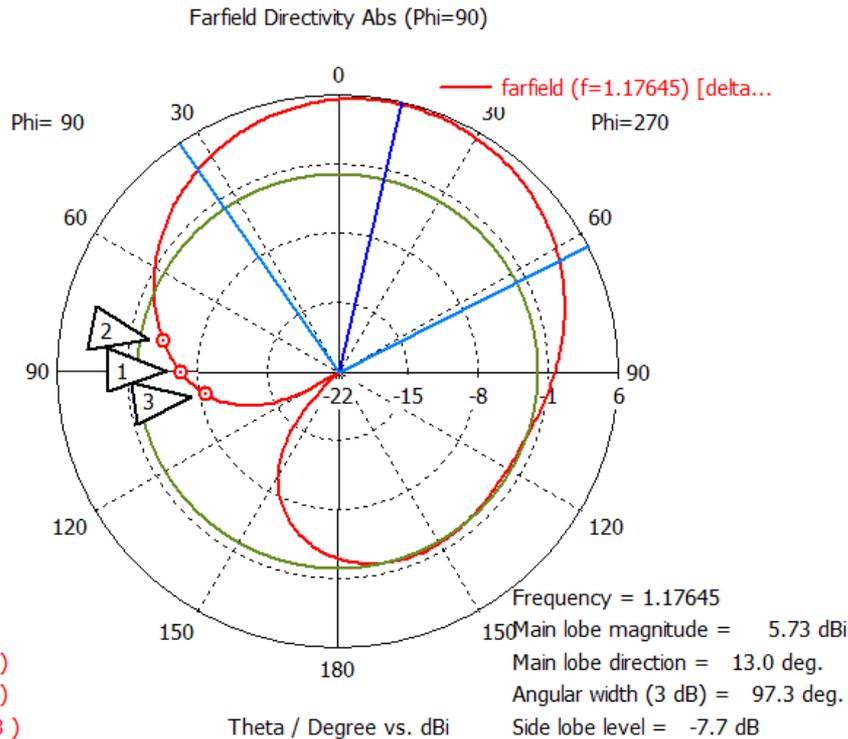
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
8	0	90	40	90

# Pattern Control-Elevation



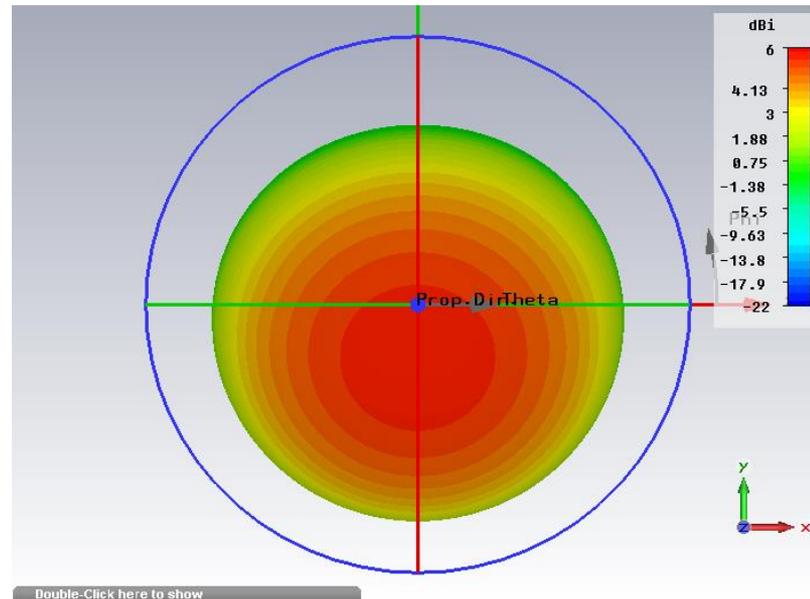
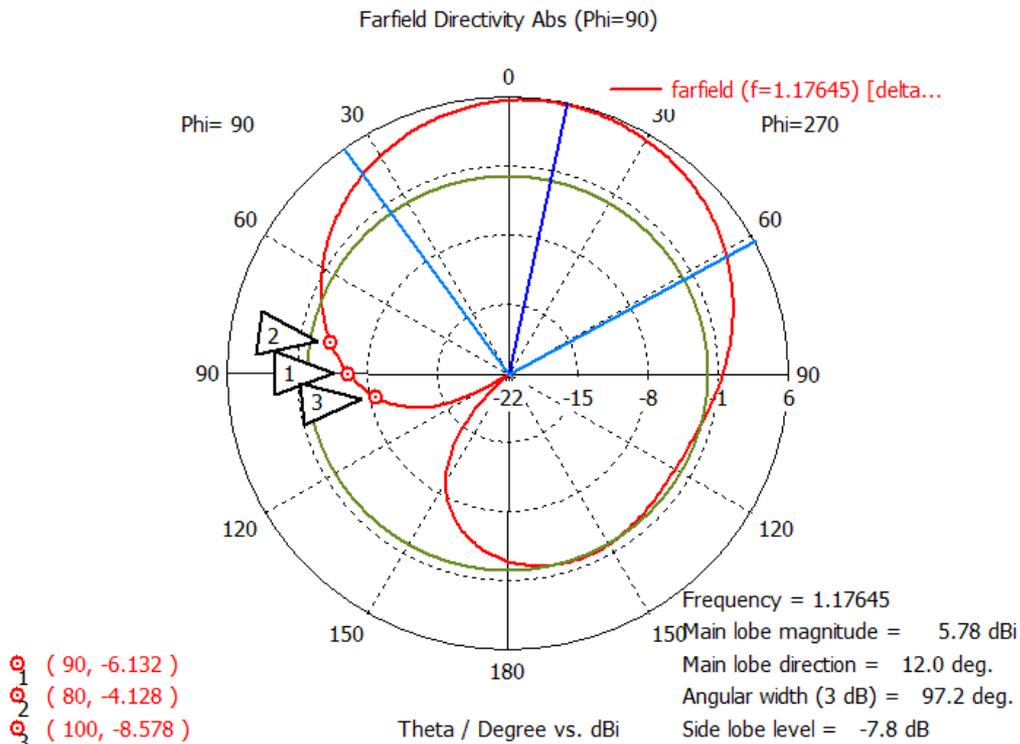
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
9	0	90	45	90

# Pattern Control-Elevation



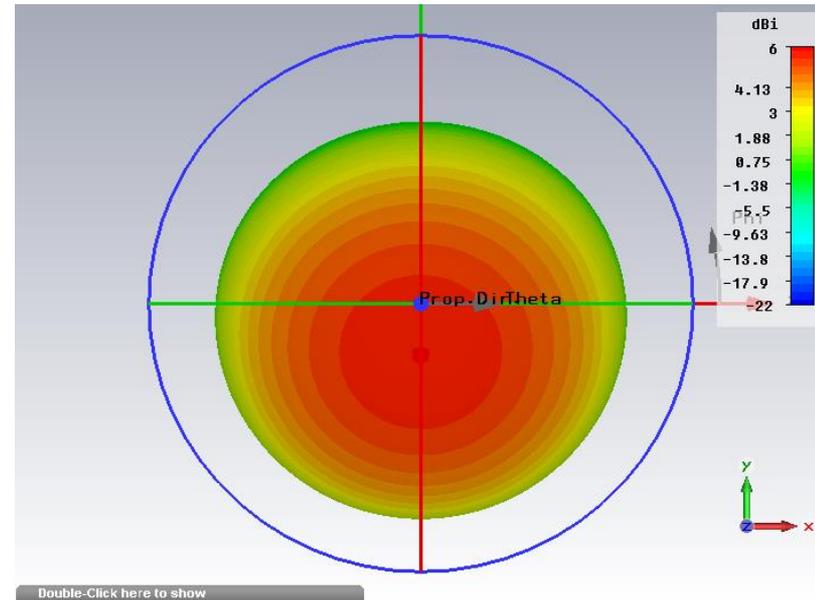
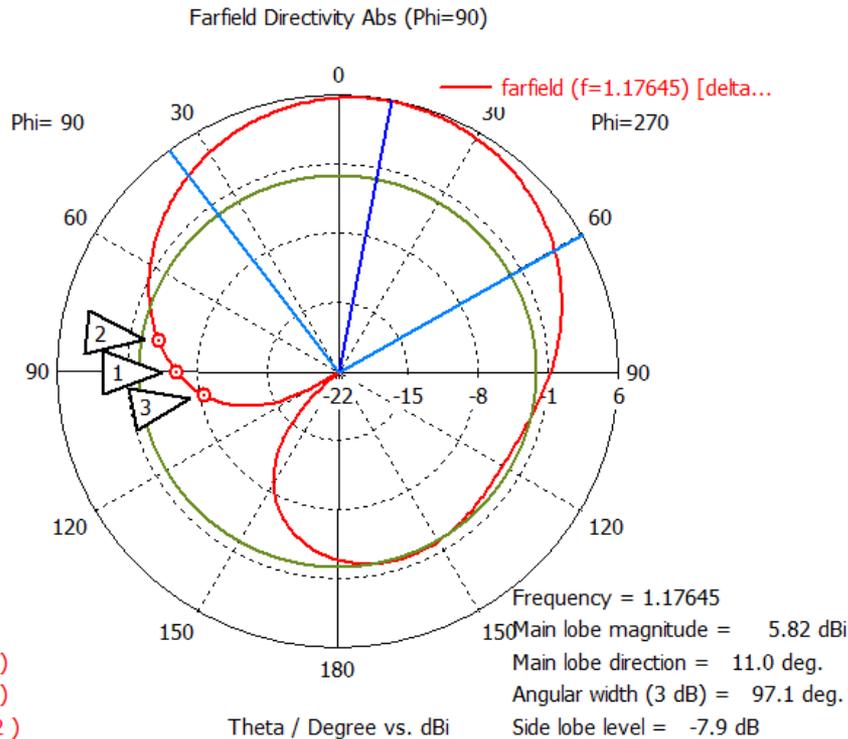
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
10	0	90	50	90

# Pattern Control-Elevation



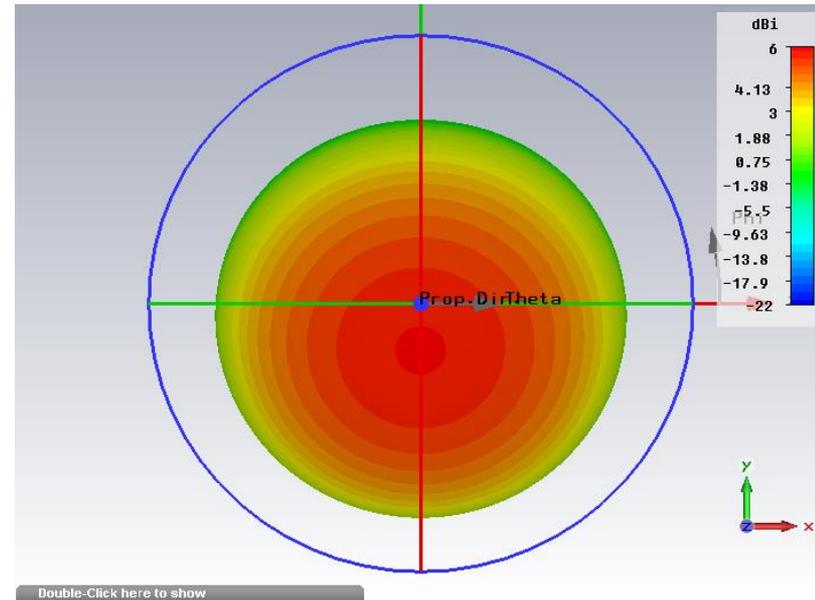
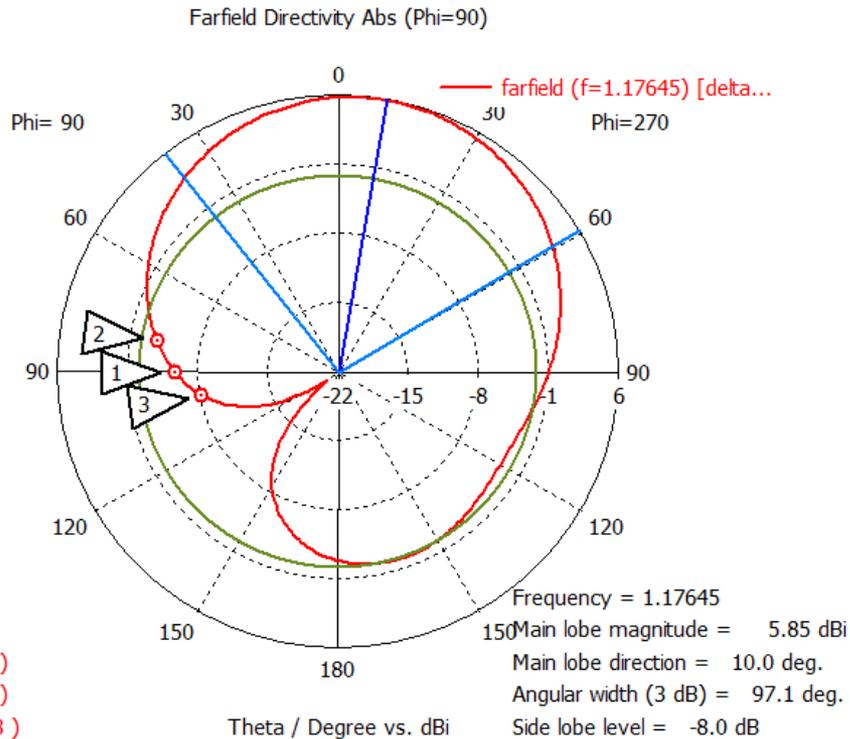
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
11	0	90	55	90

# Pattern Control-Elevation



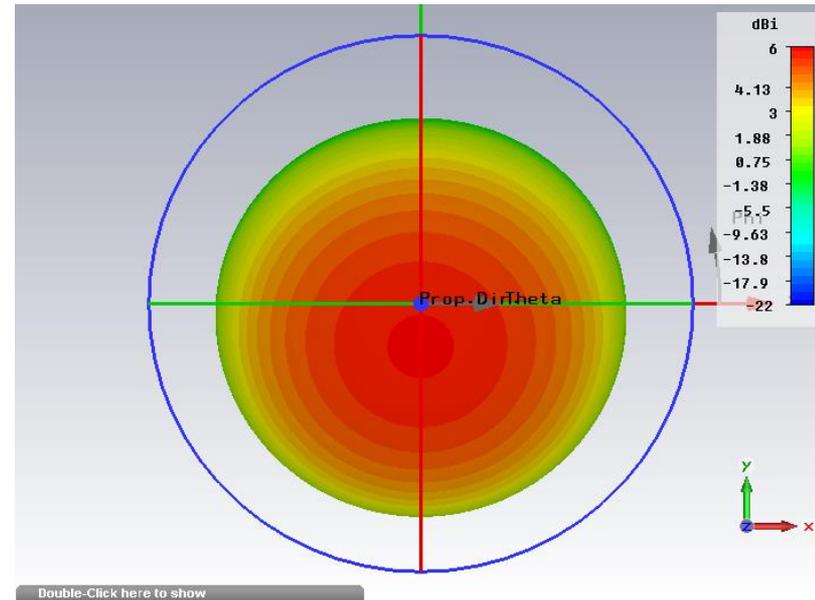
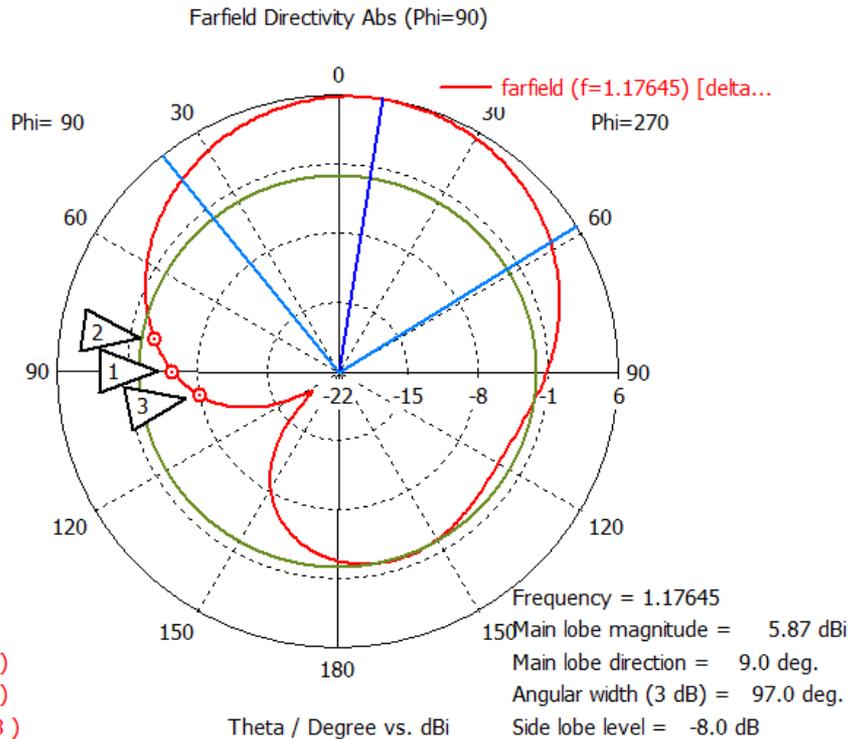
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
12	0	90	60	90

# Pattern Control-Elevation



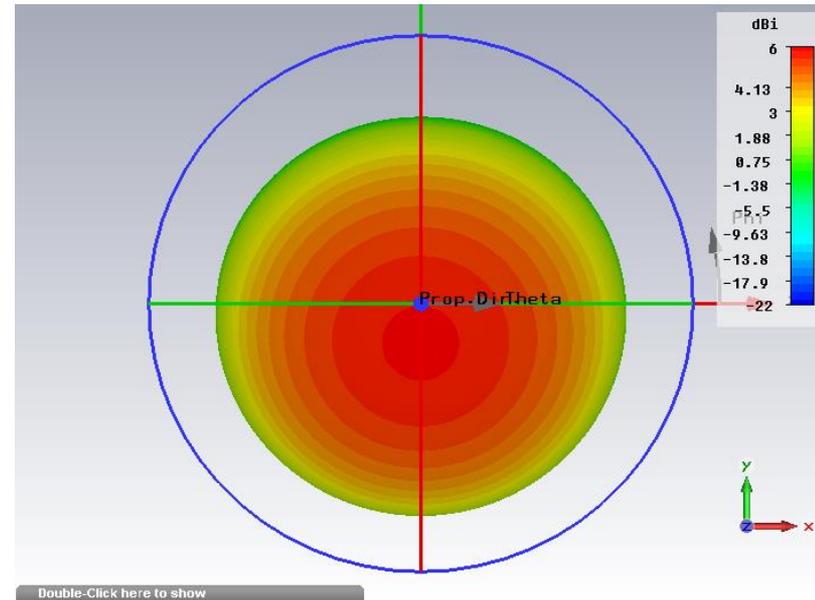
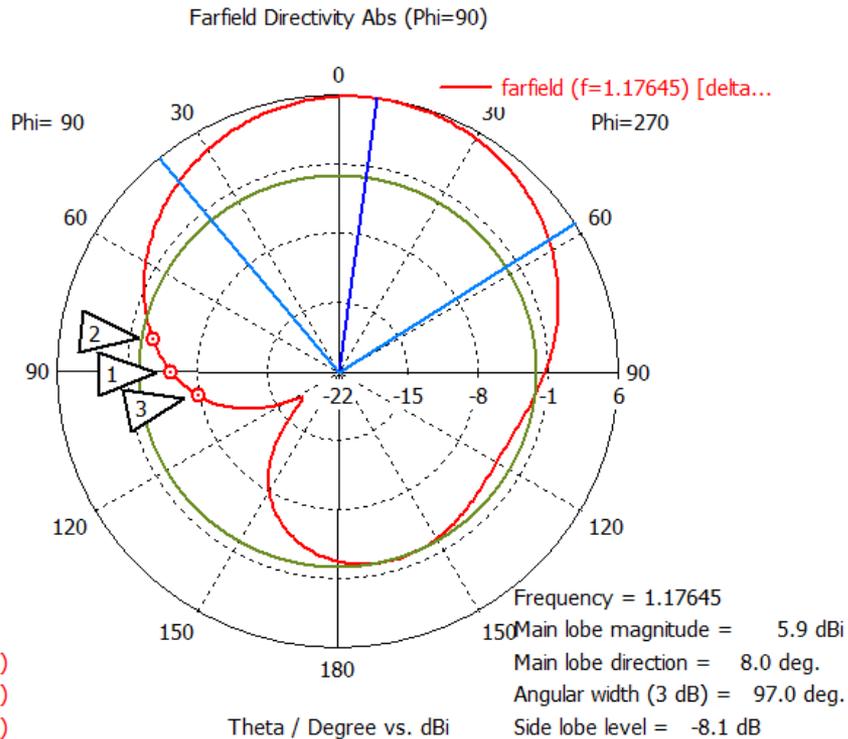
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
13	0	90	65	90

# Pattern Control-Elevation



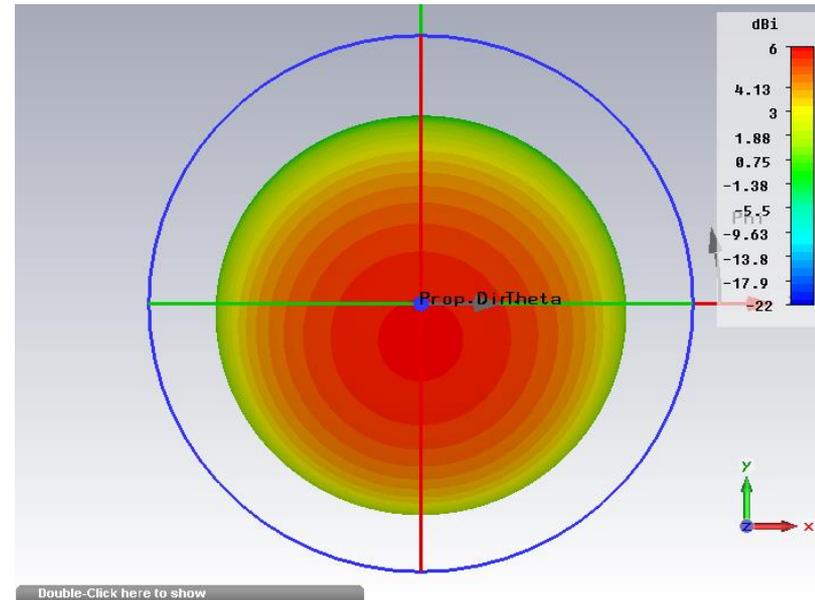
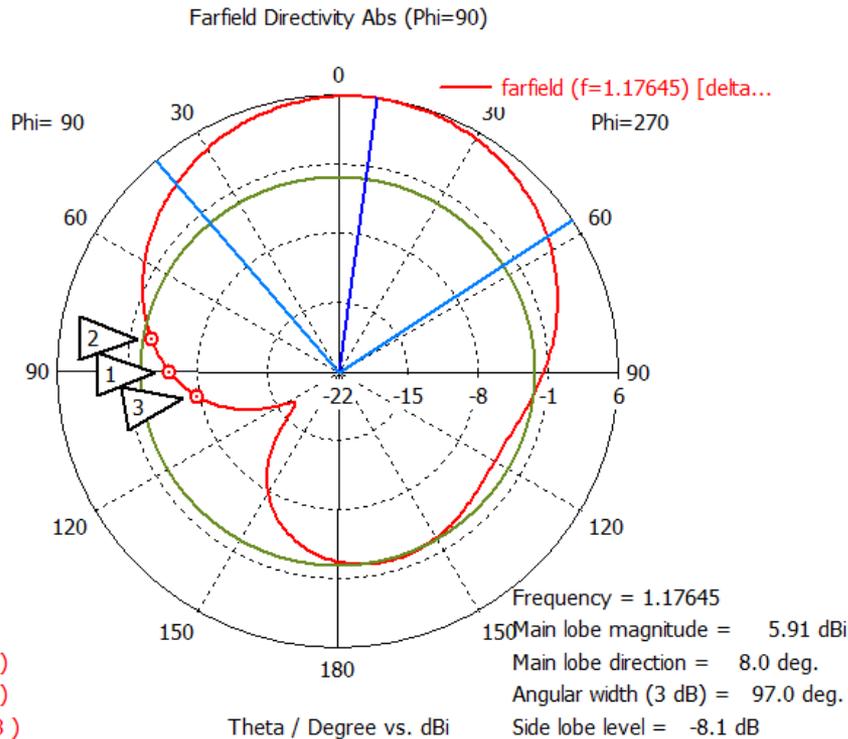
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
14	0	90	70	90

# Pattern Control-Elevation



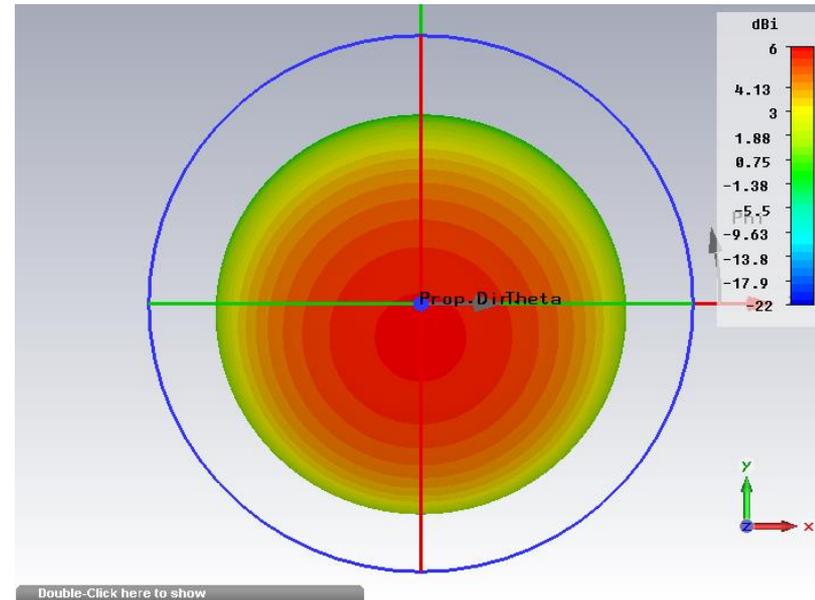
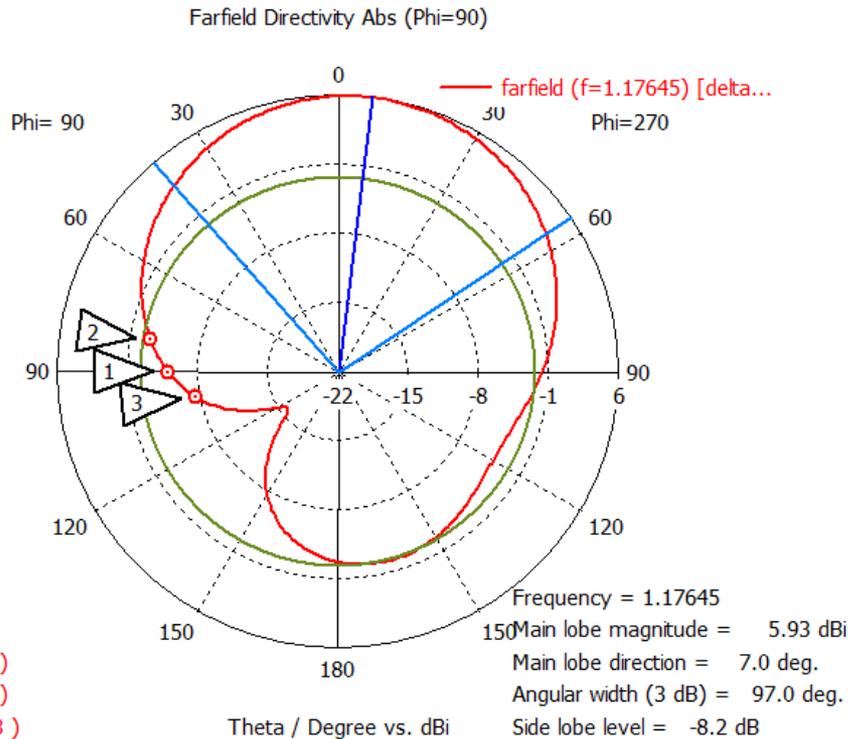
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
15	0	90	75	90

# Pattern Control-Elevation



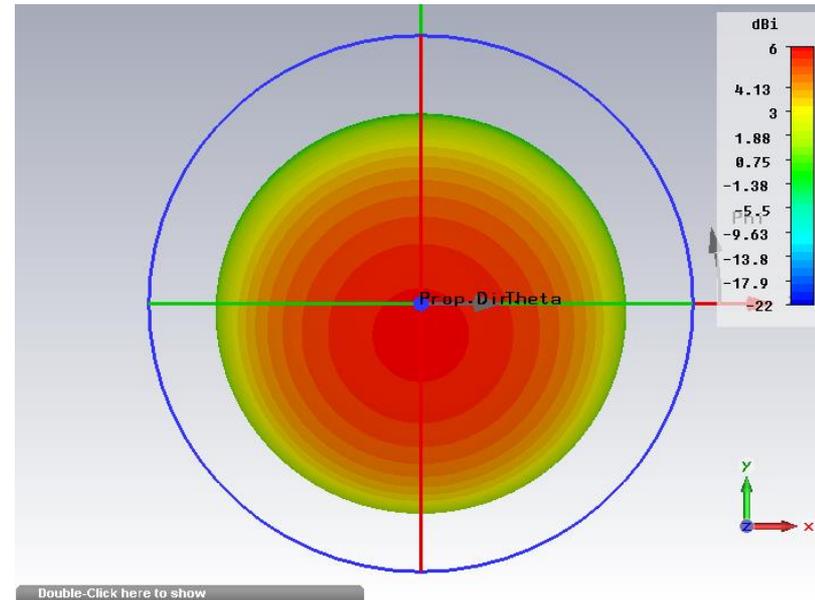
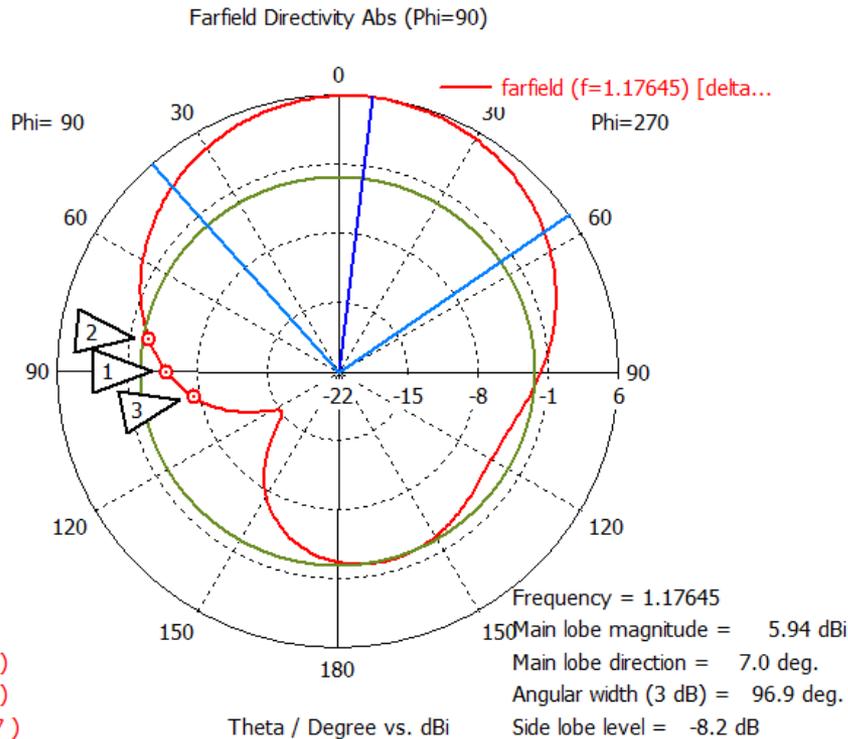
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
16	0	90	80	90

# Pattern Control-Elevation



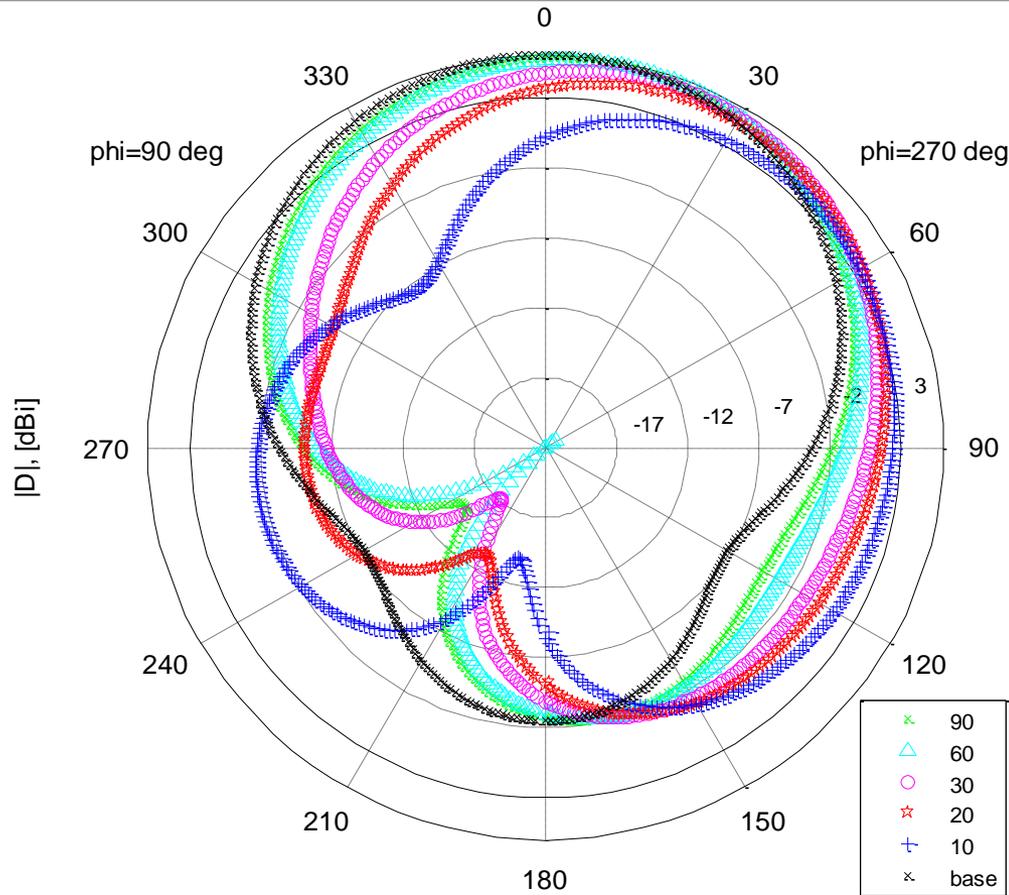
Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
17	0	90	85	90

# Pattern Control-Elevation



Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
18	0	90	90	90

# Pattern Control-Elevation with phases: $[0, 90, \Delta\gamma_{OPP}, 90]$



Theta (0-180deg (phi=270deg) & 180-360 (phi=290), [deg])

# Gain and Efficiency Considerations

- **Under benign conditions, nominal RHCP performance is obtained with phases: [0, 90, 180, 270] deg**
- **Under beam control conditions, obtain:**
  - » **Good directivity,**
  - » **Efficiency, polarization, and gain performance decreases substantially**
  - » **Additional gain may be added in RF front-end (e.g., LNA), prior to phase control, to make up these losses.**

# Conclusions

- **Single-element GNSS L5 patch antenna design, with dynamic pattern control was illustrated.**
- **Circular geometry selected: element, ground plane, feed structure.**
- **Configuration illustrated with four-feed, RF front-end, amplitude & phase control, and combine.**
- **Control area of high directivity and commensurate area of low directivity in:**
  - » **Azimuth** (full 360 deg), varying the  $\Delta\gamma_{ADJ}$  parameter
  - » **Elevation**, varying the  $\Delta\gamma_{OPP}$  parameter
- **Dynamic pattern control advantageous for:**
  - » **Baseline/Benign operations**
  - » **Interference operations, where interference sources are above, at, or below the local horizon.**

# Single-element Patch Antenna with Pattern Control

**Thank You !!!**

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