GNSS Patch Antenna with Pattern Control for Aviation

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FAA JUP Spring 2016
January 21-22, 2016
William J. Hughes Technical Center
Atlantic City, NJ, USA

Acknowledgement

Ohio University
Internal Research and Development

Outline

- Purpose
- Background - Previous Works on GNSS Patch Antennas
  - » 1. Pattern Control
  - » 2. Asymmetric Ground Plane Performance
- Going Forward - Pattern Control with an Asymmetric Ground Plane
  - » Pattern Control with Square Patch Antenna
  - » Broadband-frequency Pattern Control
  - » Ground Plane Effects (size, shape, curvature)
- Summary

Purpose

- **Demonstrate a rectangular GNSS patch antenna with pattern control over a curved asymmetric ground plane, suitable for aviation applications.**

- **Utilize a high-fidelity Computational Electromagnetic Model (CEM), Computer Simulation Technology (CST), Microwave Studio**

- **Multiple GNSS patch antenna designs:**
  - » **Circular, Square, and Rectangular patch antennas**
  - » **Four-feeds with center ground pin**
  - » **Various ground plane shapes and sizes**

Previous Works on GNSS Patch Antennas

Concentrated in two major areas:

1. Beam Control with a single-element patch antenna

- » Circular patch antenna element
- » Circular Ground Plane (GP) - (120mm diameter)

2. Asymmetric performance of a single-element patch antenna

- » Baseline 1; square antenna & square GP
- » Baseline 2; square antenna & rectangular GP
- » Asymmetric performance mitigation techniques

Ref: Bartone, Schopis. Single-element Patch Antenna with Pattern Control. August 14, 2015
Bartone, Schopis. Patch Antenna Asymmetry Performance Considerations and Mitigation. September 20, 2015

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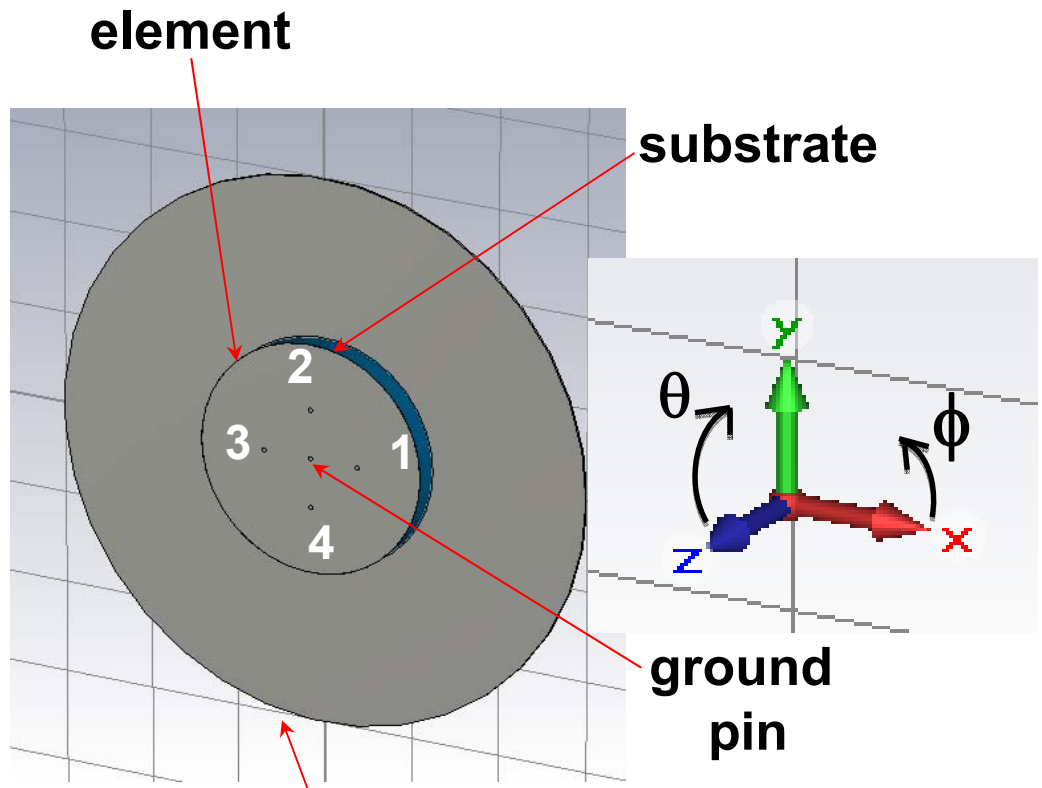
1. Pattern Control with a GNSS L5 Single-element Antenna

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



Phase Control Summary

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

	Port Number			
Quadrant	**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):

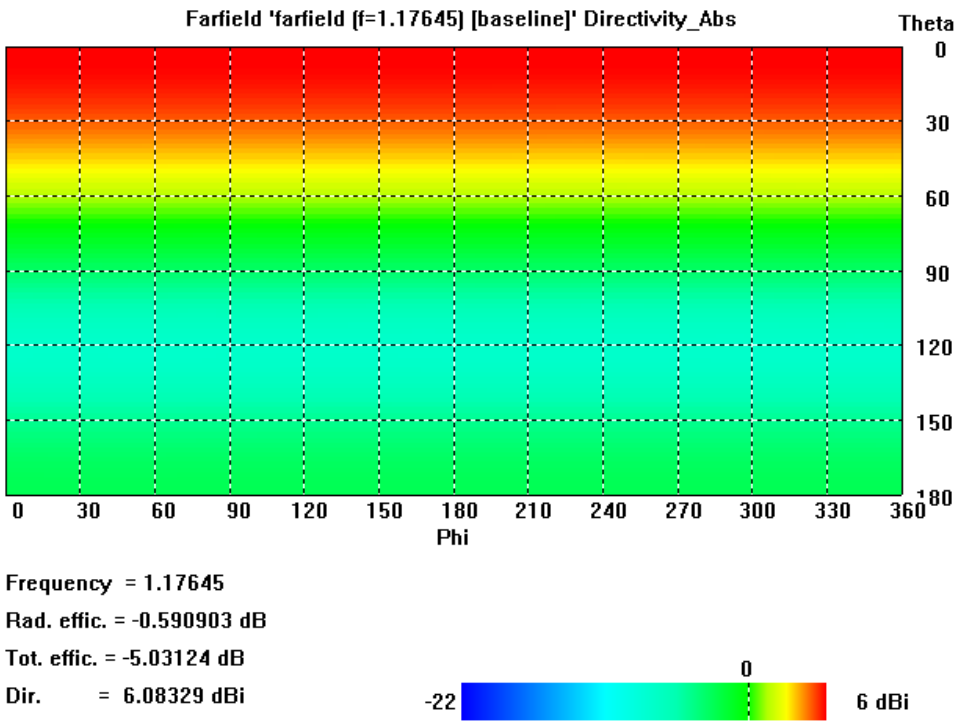
0 phase for reference

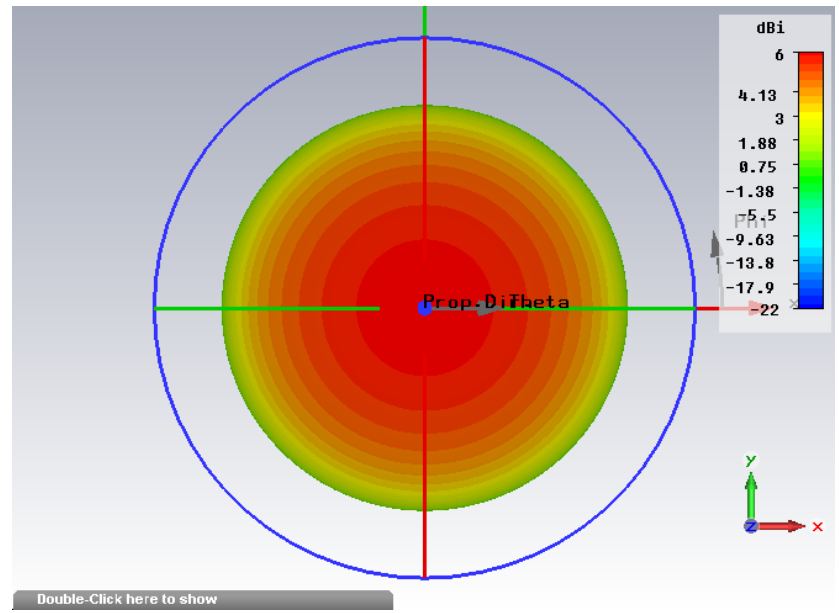
$\Delta\gamma_{POL}$ ***= 90 deg (fixed here per RHCP signal)***

$\Delta\gamma_{OPP}$ ***= 20 deg (can be used for elevation control; fixed here)***

$\gamma_2 - \Delta\gamma_{OPP} < \Delta\gamma_{ADJ} < \gamma_2 + \Delta\gamma_{OPP}$ ***(for azimuth control)***

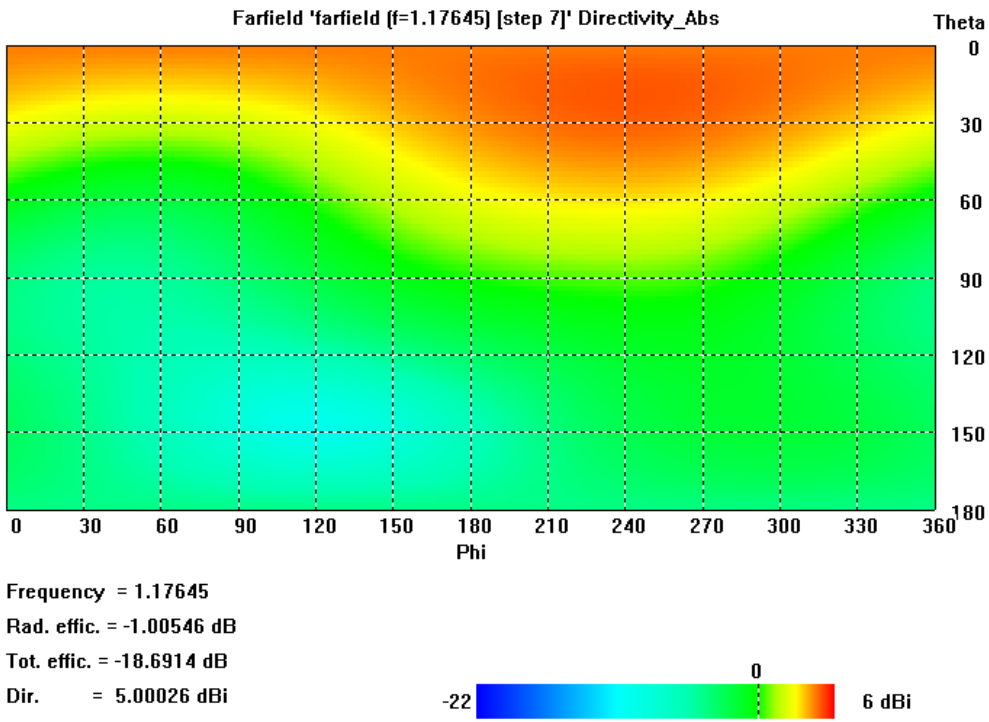
Four-feed Circular Patch Phase Manipulation – Baseline Results

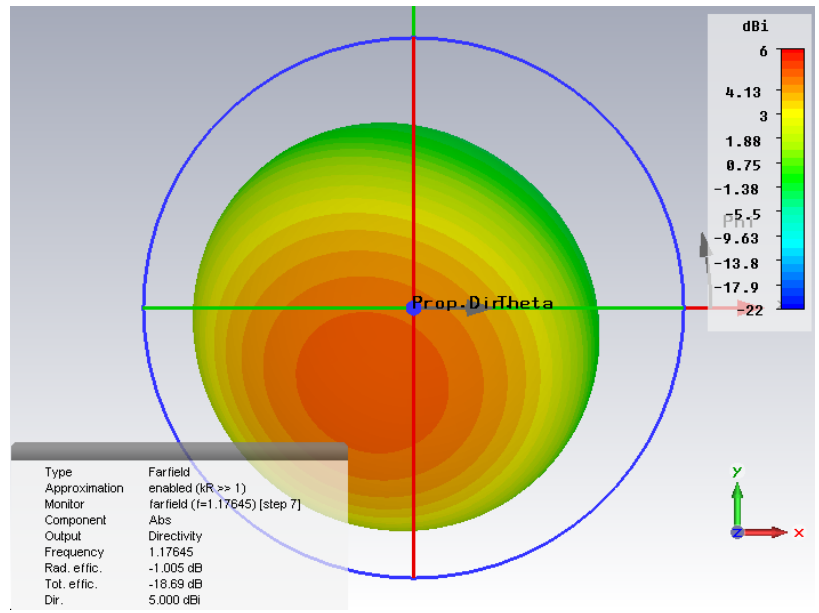




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
1	0	90	180	270

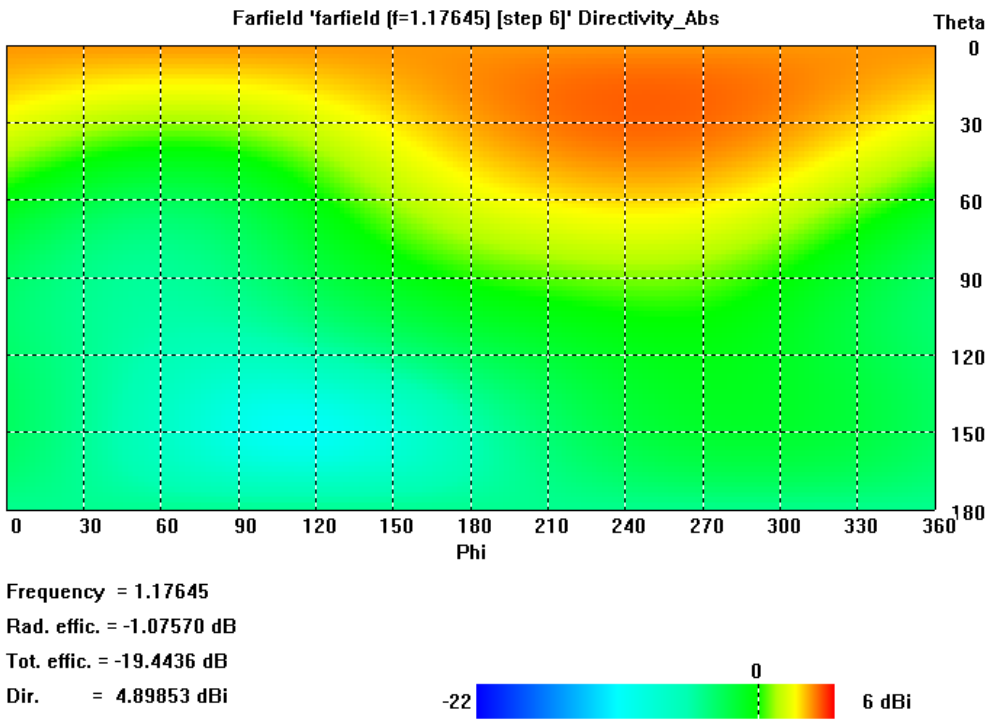
Pattern Control-AZ-First Quadrant

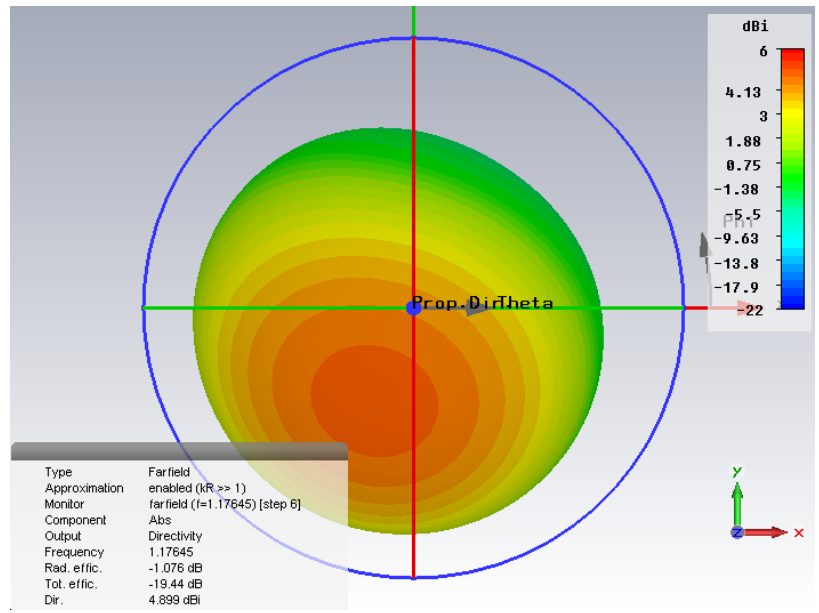




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
1	0	90	20	70

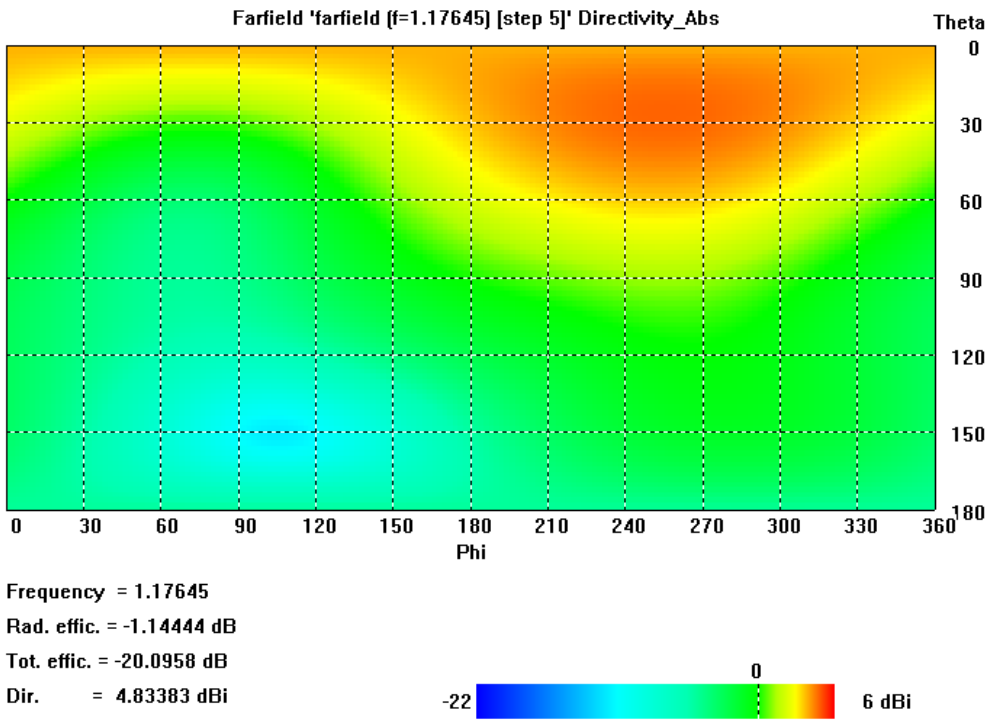
Pattern Control-AZ-First Quadrant

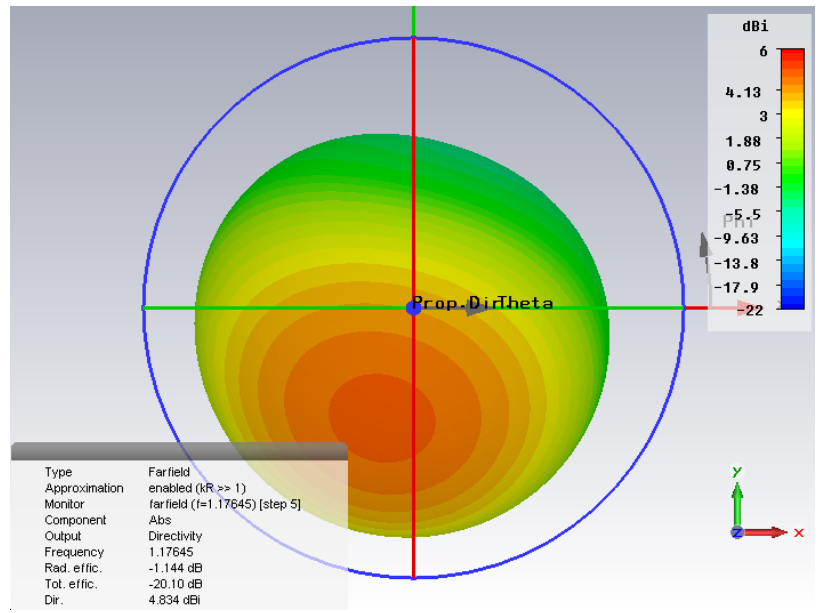




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
2	0	90	20	75

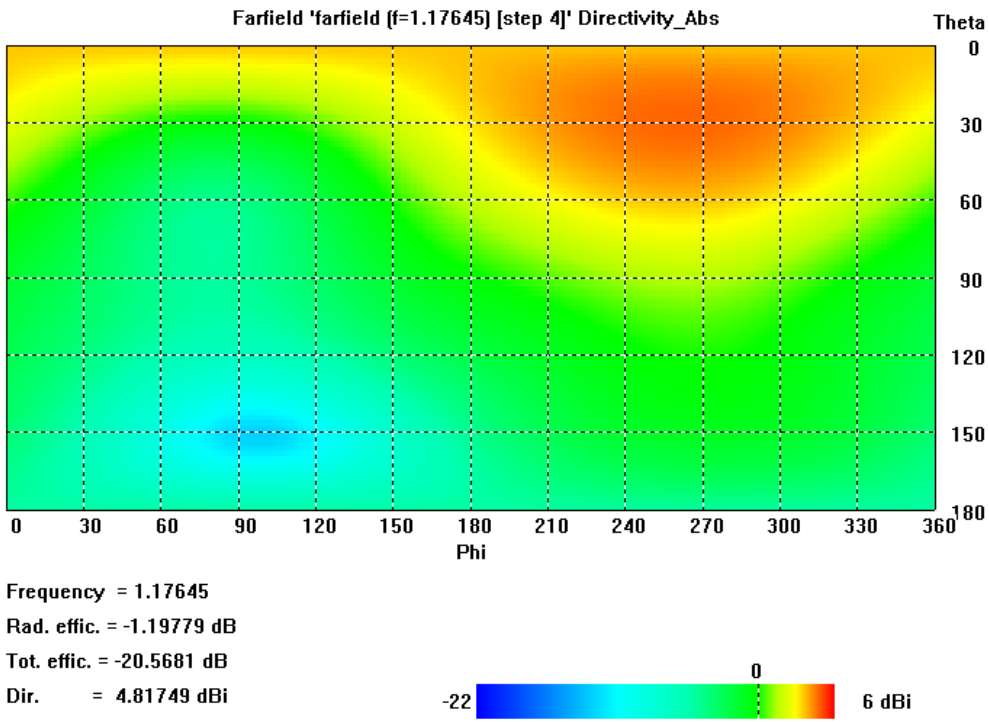
Pattern Control-AZ-First Quadrant

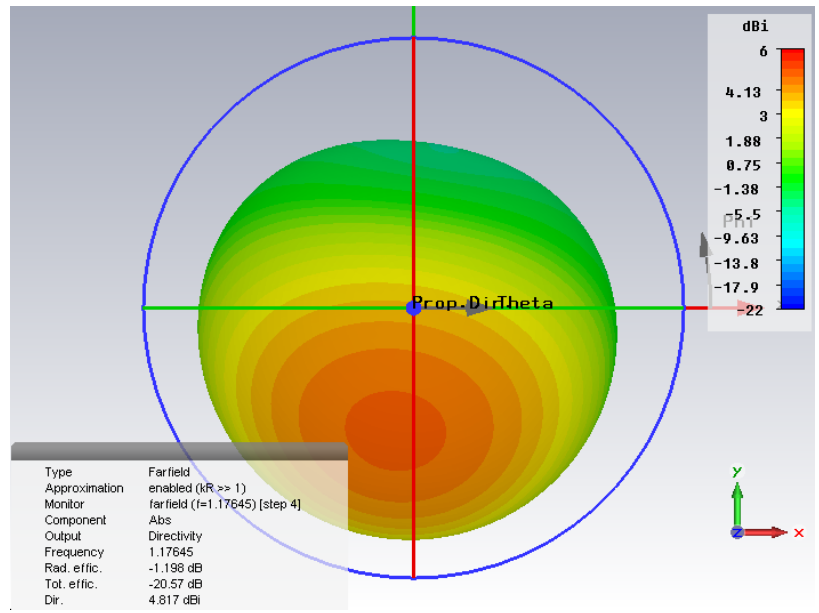




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
3	0	90	20	80

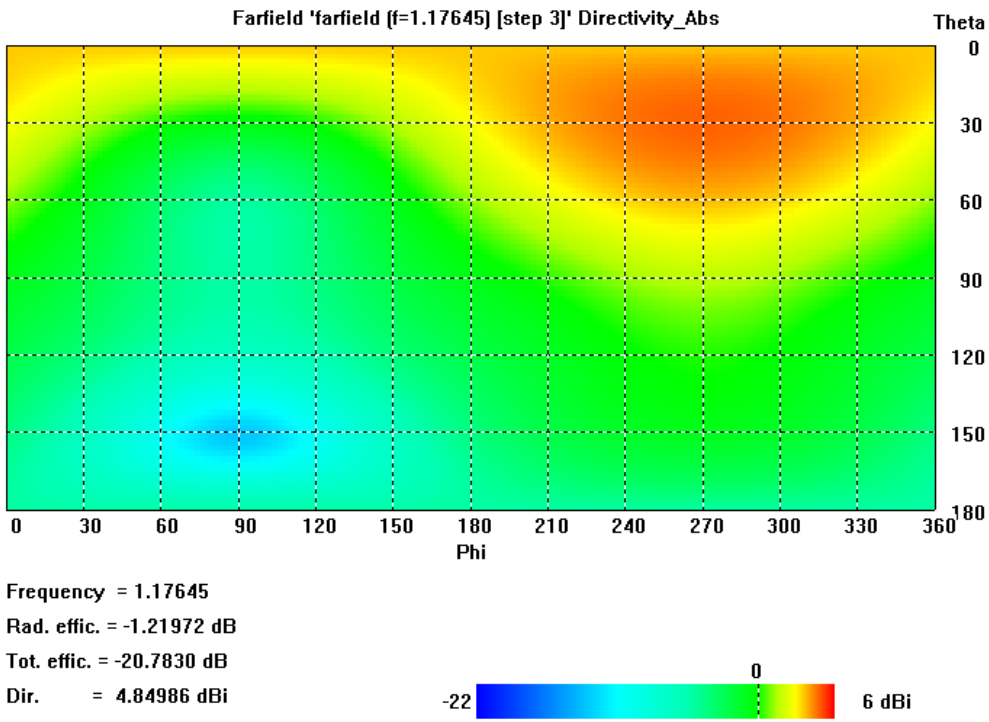
Pattern Control-AZ-First Quadrant

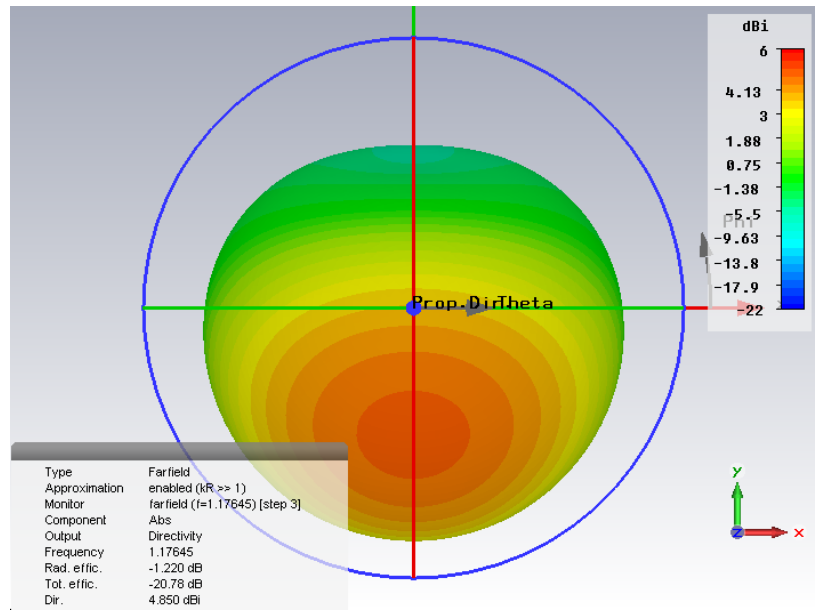




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
4	0	90	20	85

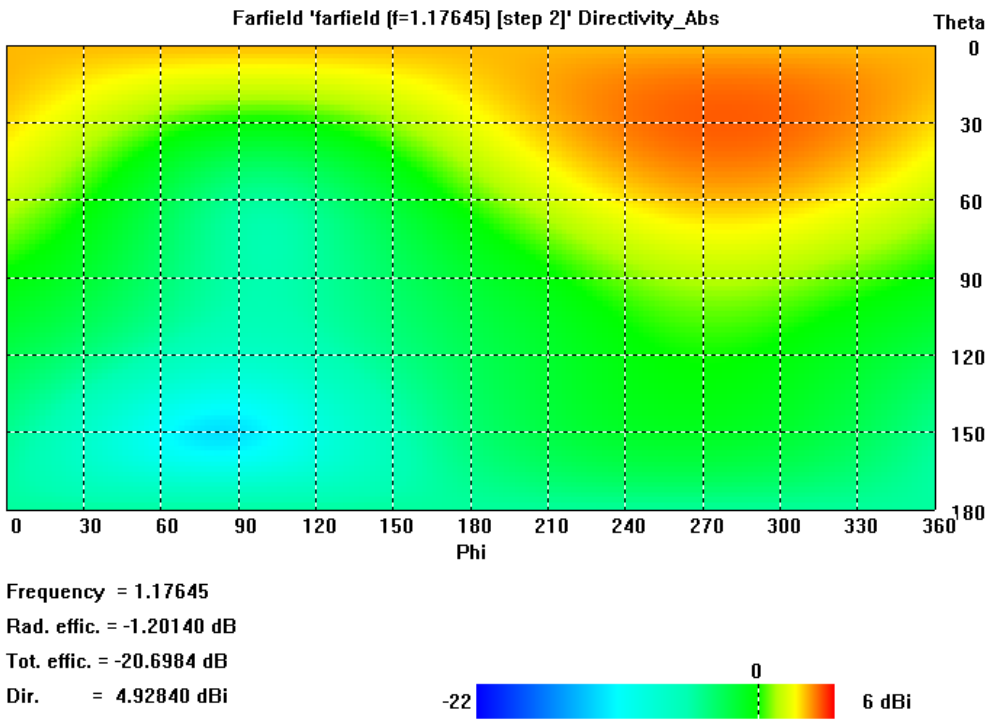
Pattern Control-AZ-First Quadrant

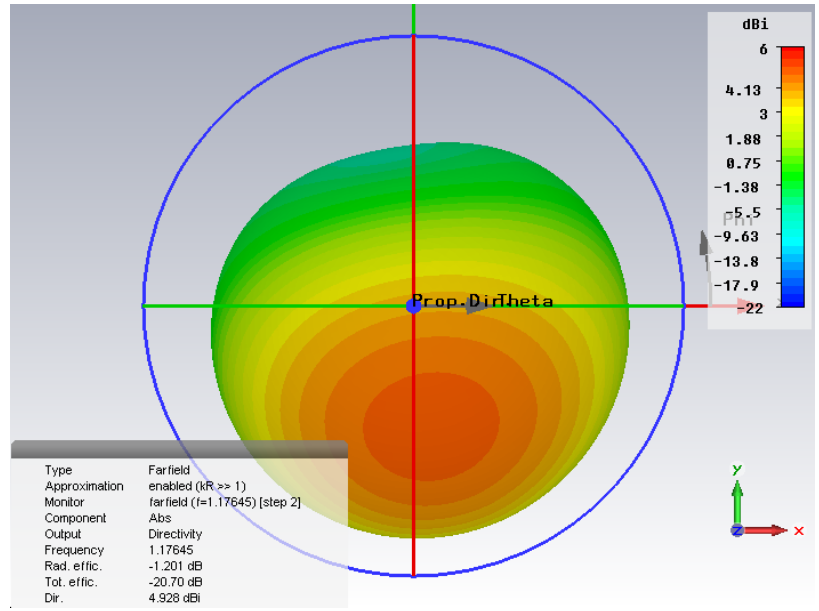




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
5	0	90	20	90

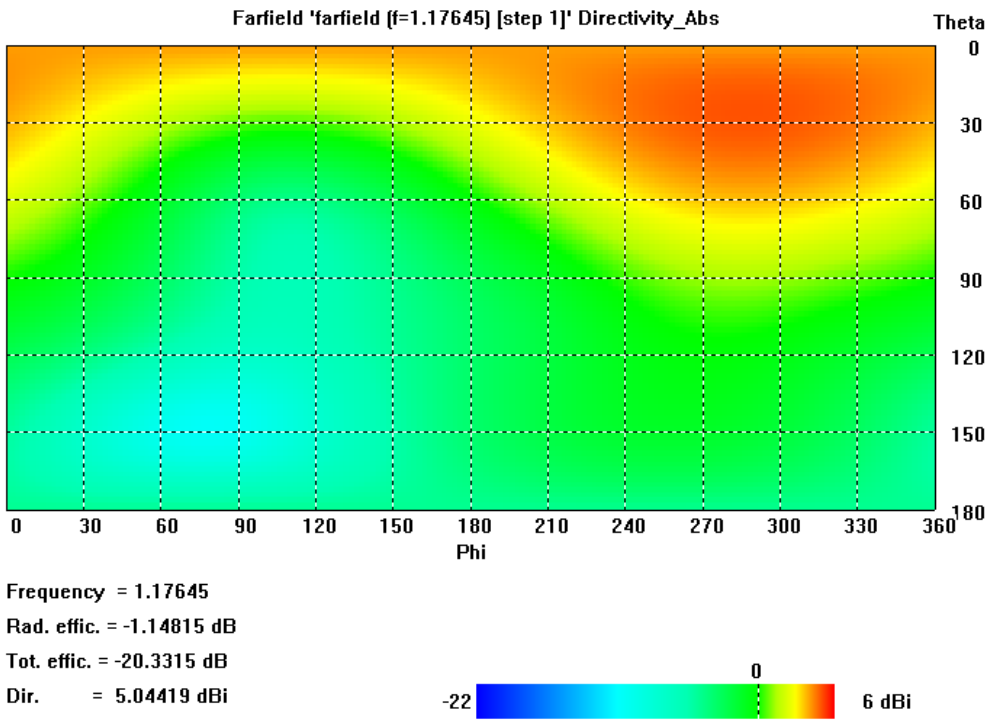
Pattern Control-AZ-First Quadrant

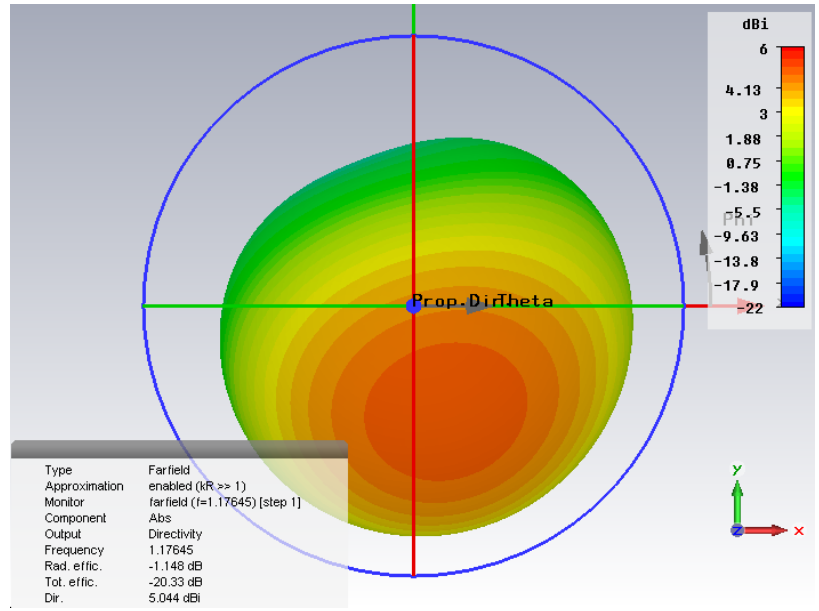




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
6	0	90	20	95

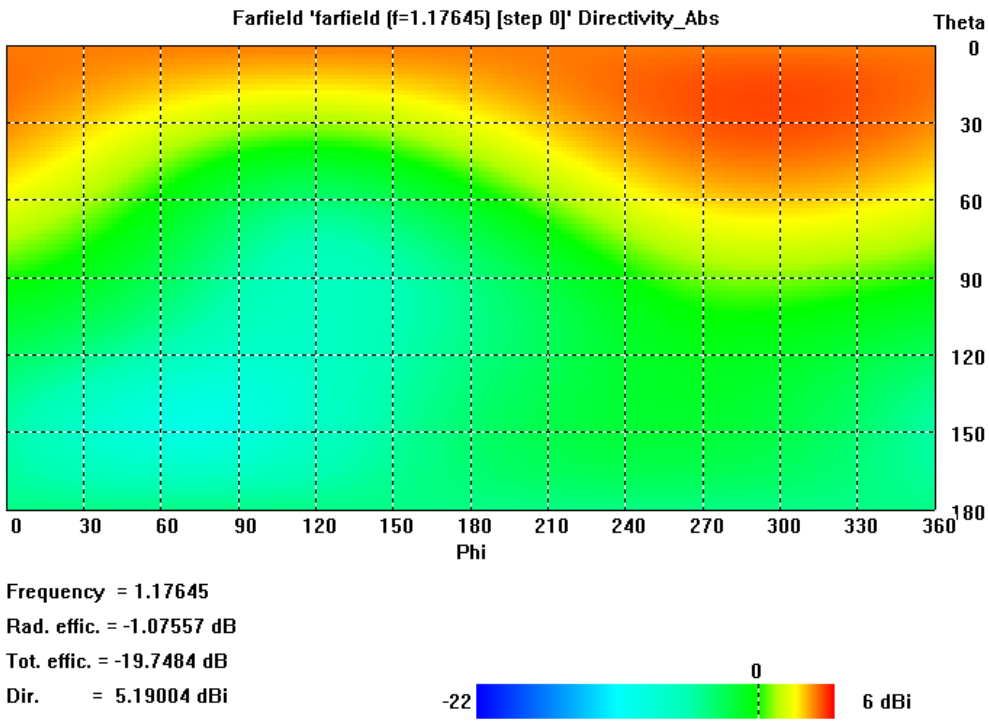
Pattern Control-AZ-First Quadrant

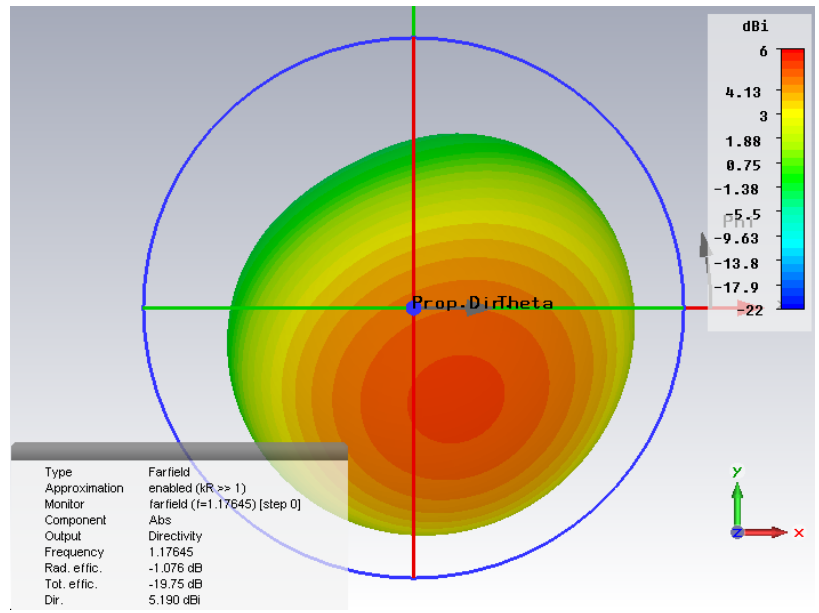




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
7	0	90	20	100

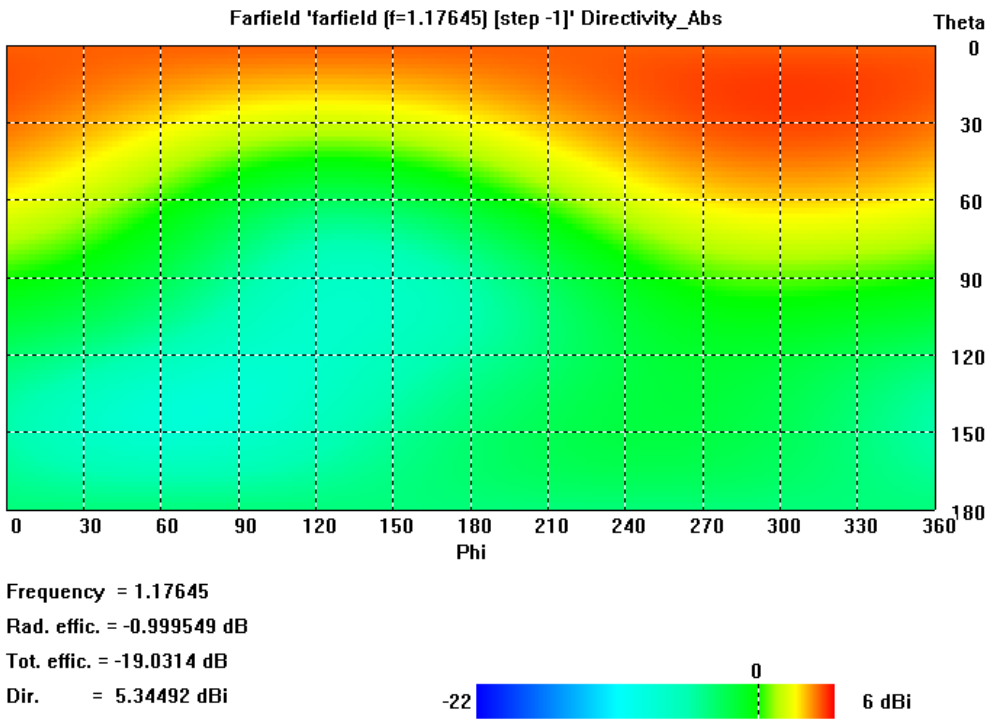
Pattern Control-AZ-First Quadrant

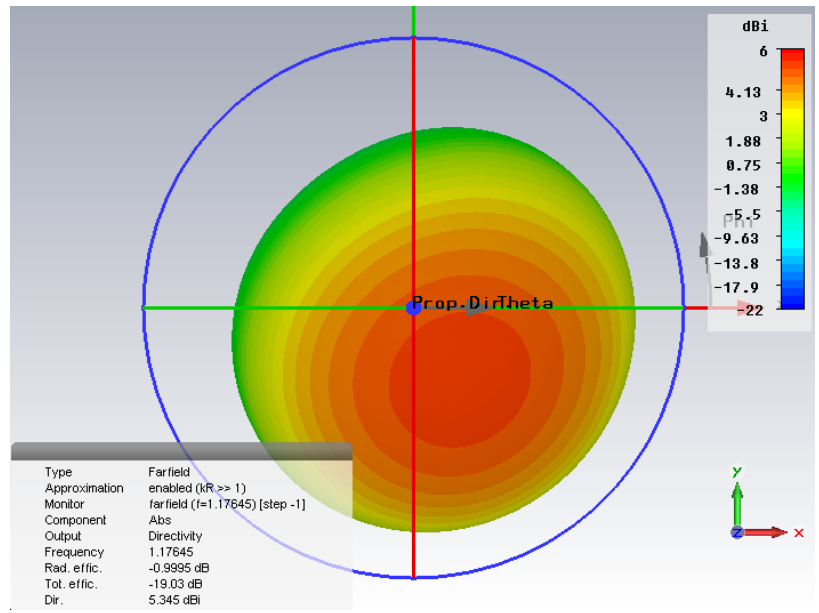




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
8	0	90	20	105

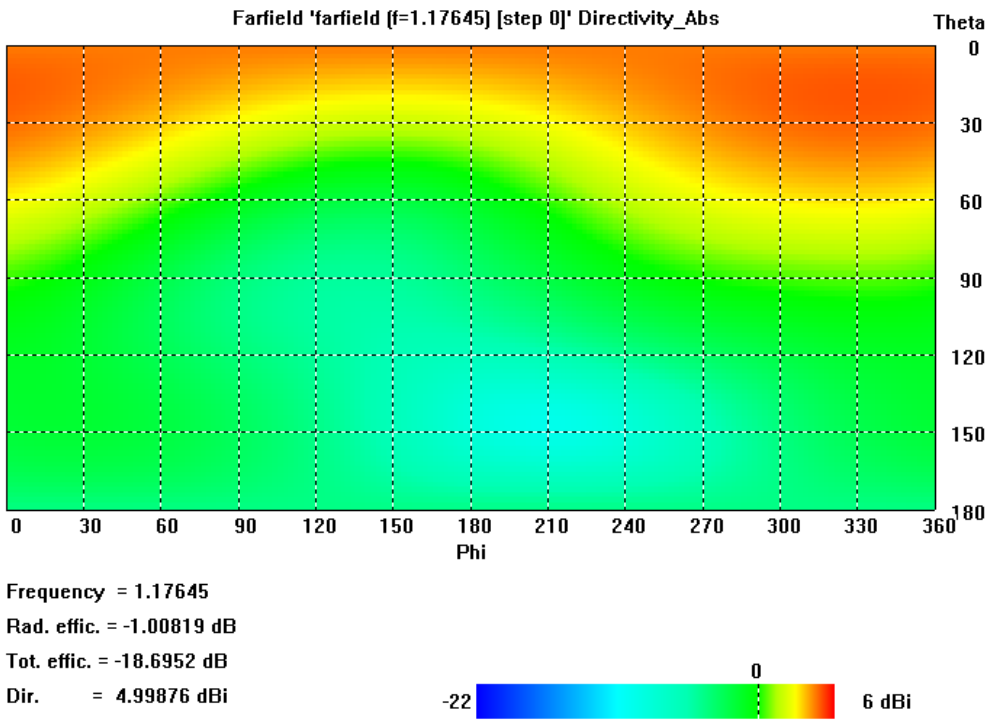
Pattern Control-AZ-First Quadrant

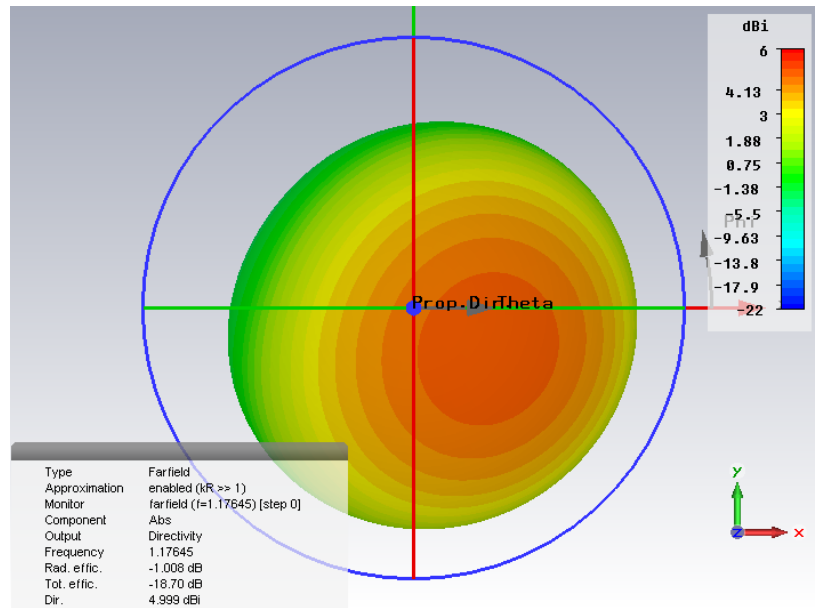




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
9	0	90	20	110

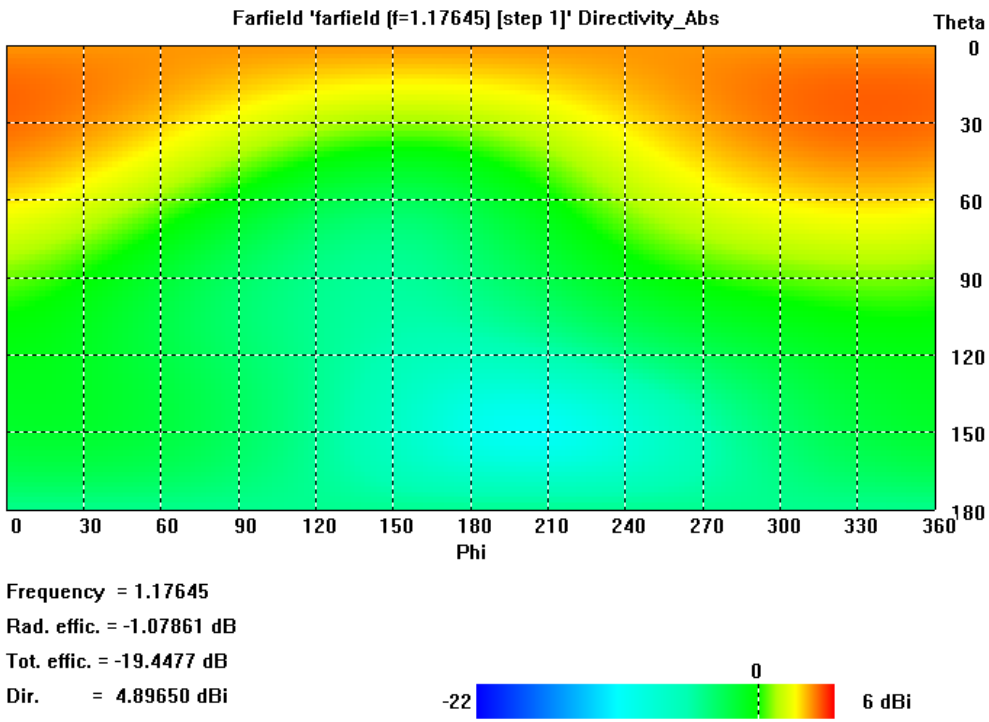
Pattern Control-AZ-Second Quadrant

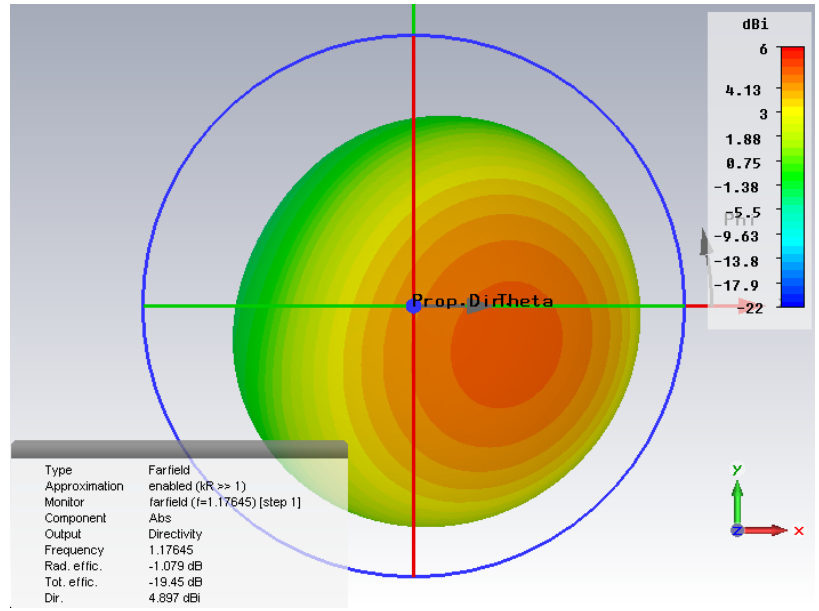




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
10	90	20	70	0

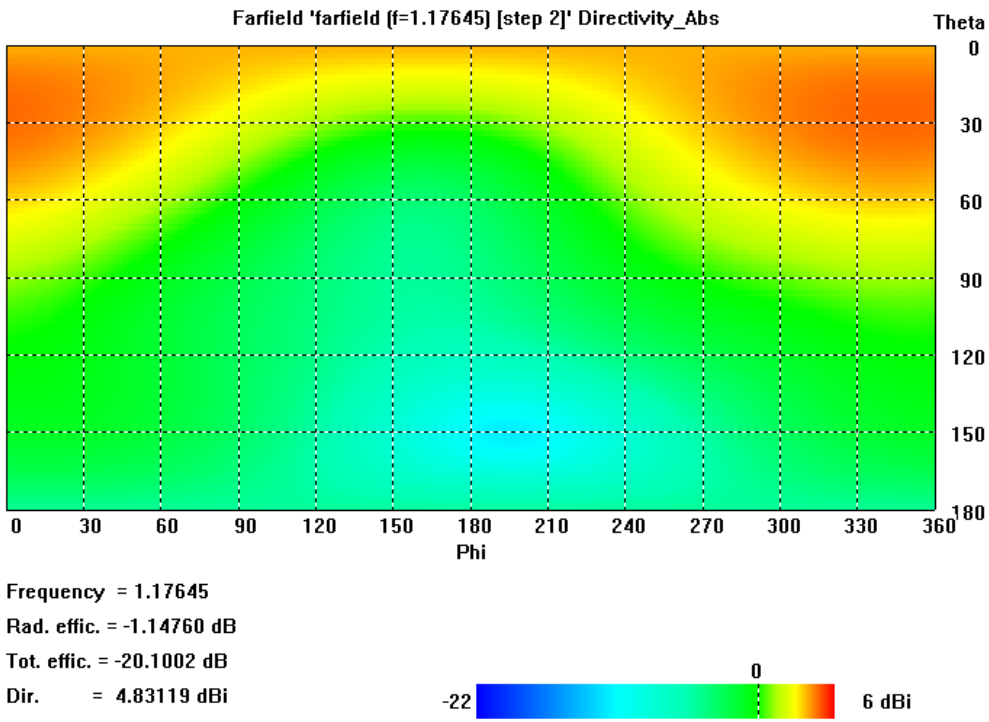
Pattern Control-AZ-Second Quadrant

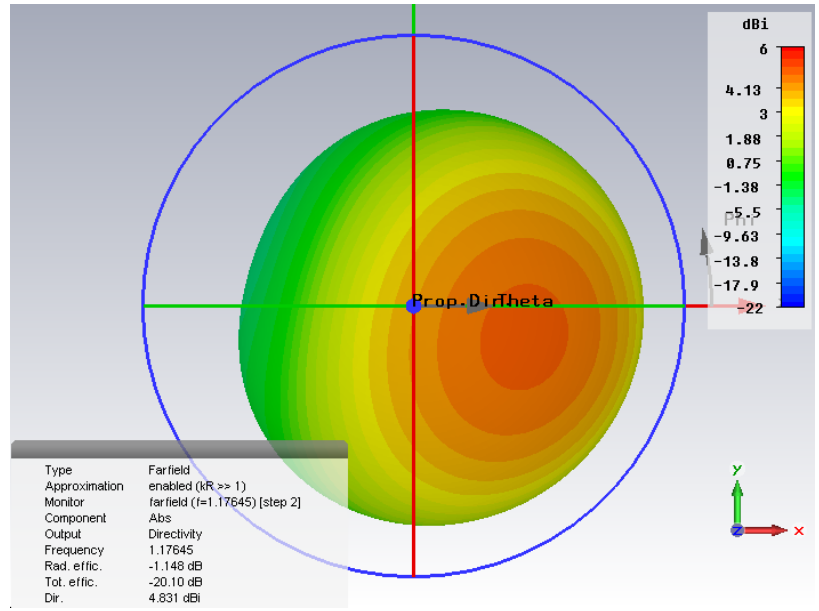




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
11	90	20	75	0

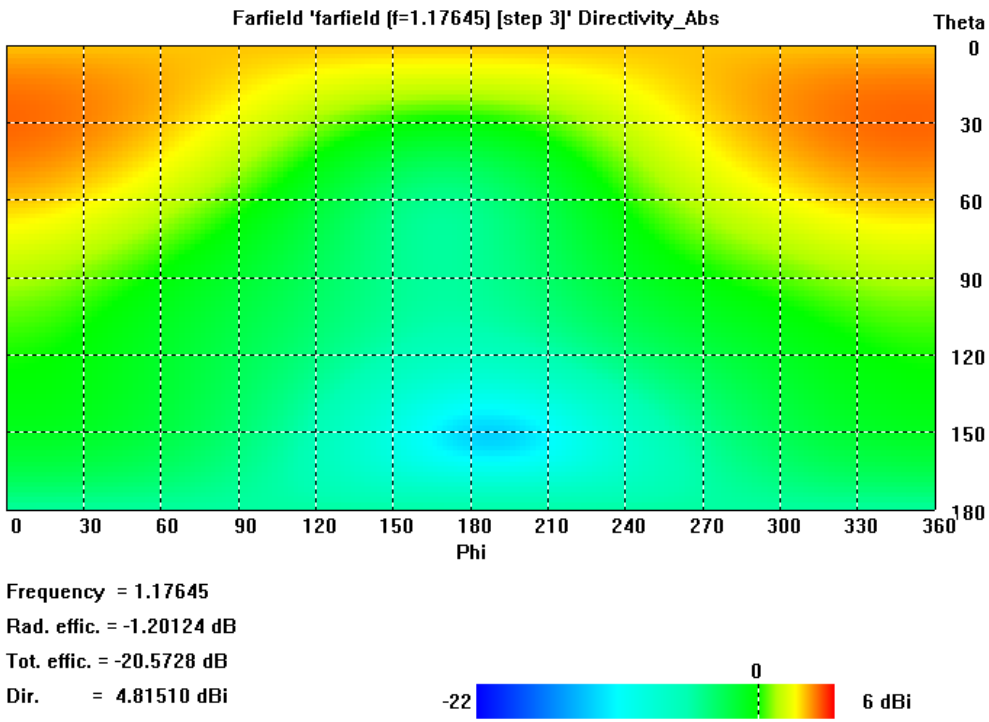
Pattern Control-AZ-Second Quadrant

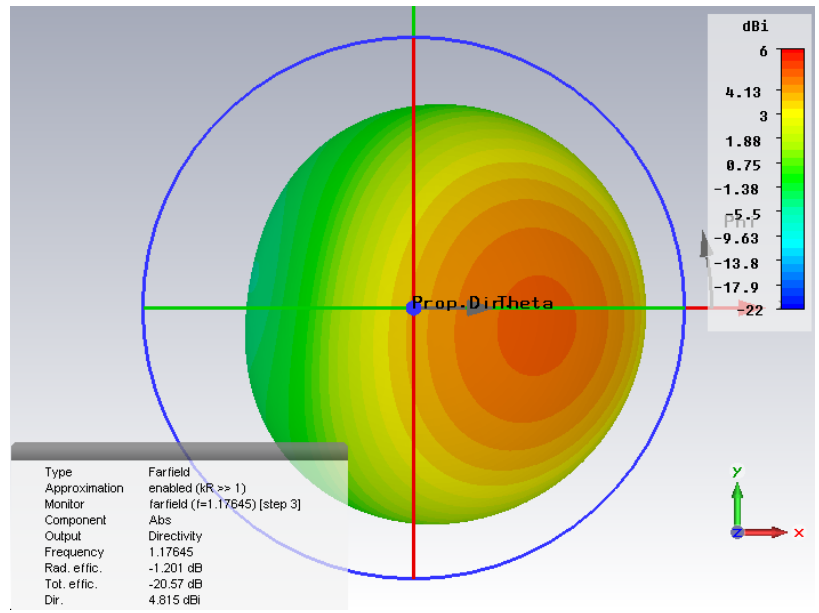




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
12	90	20	80	0

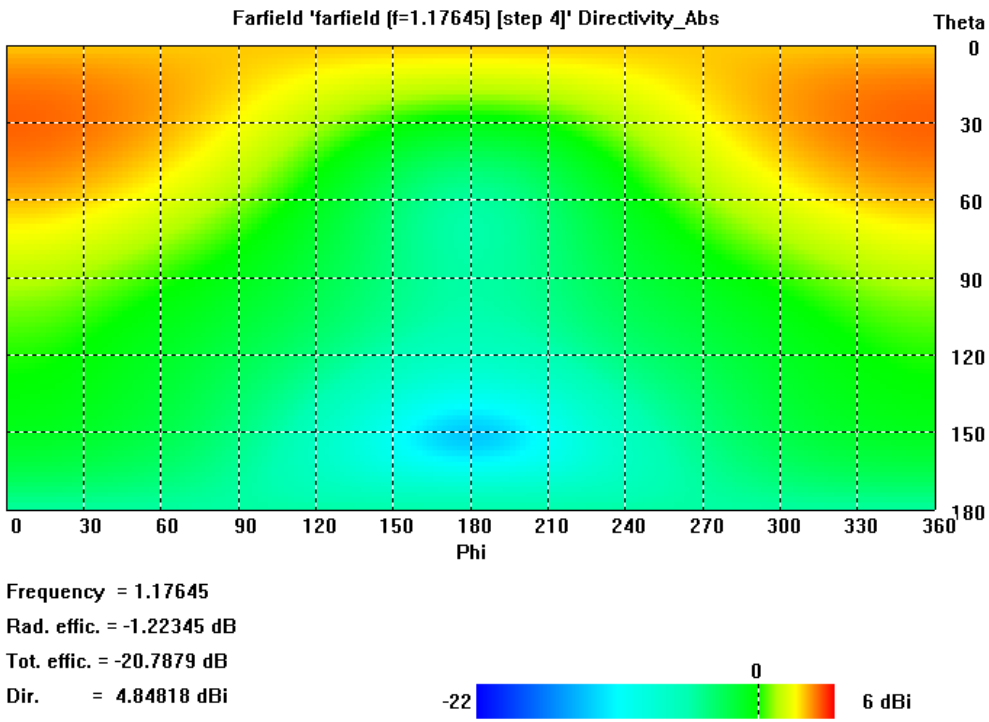
Pattern Control-AZ-Second Quadrant

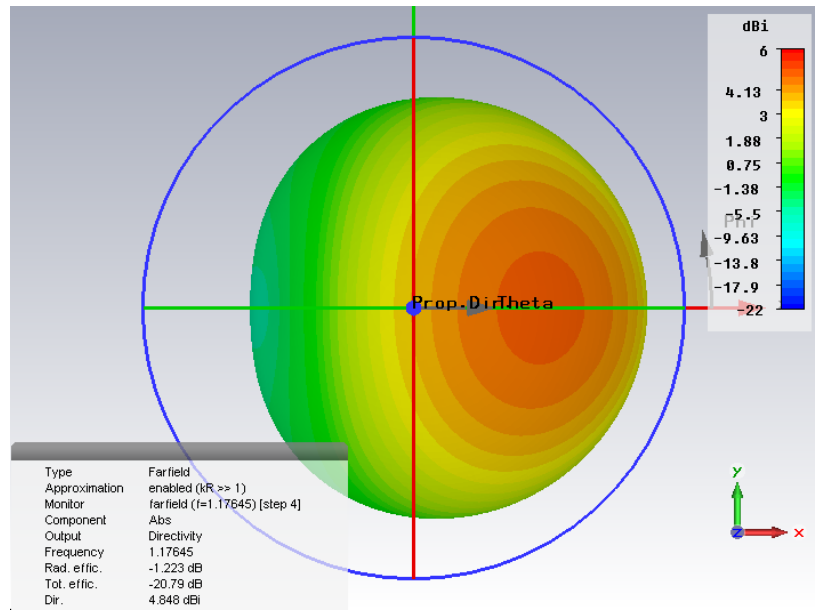




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
13	90	20	85	0

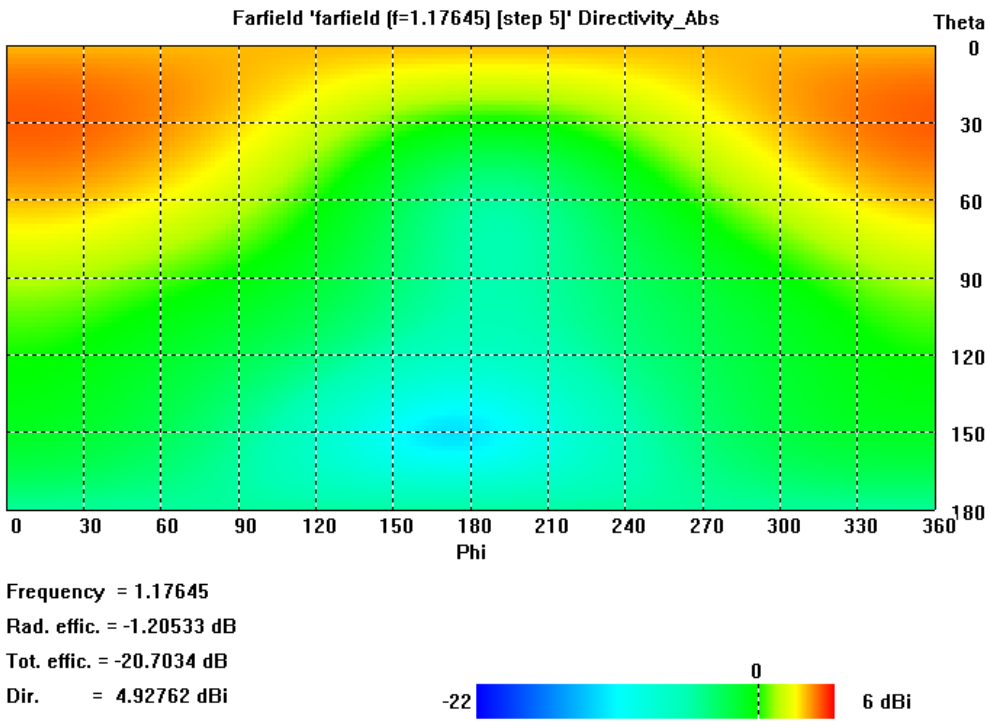
Pattern Control-AZ-Second Quadrant

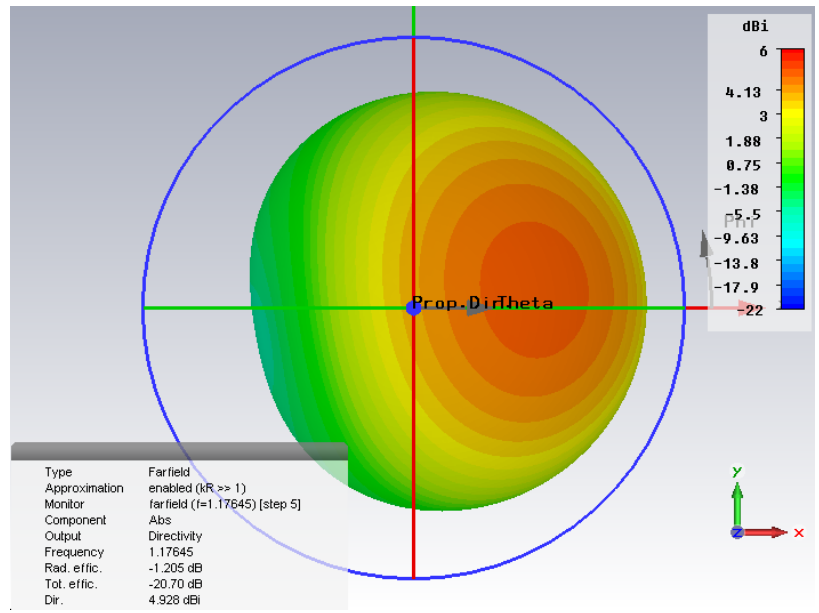




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
14	90	20	90	0

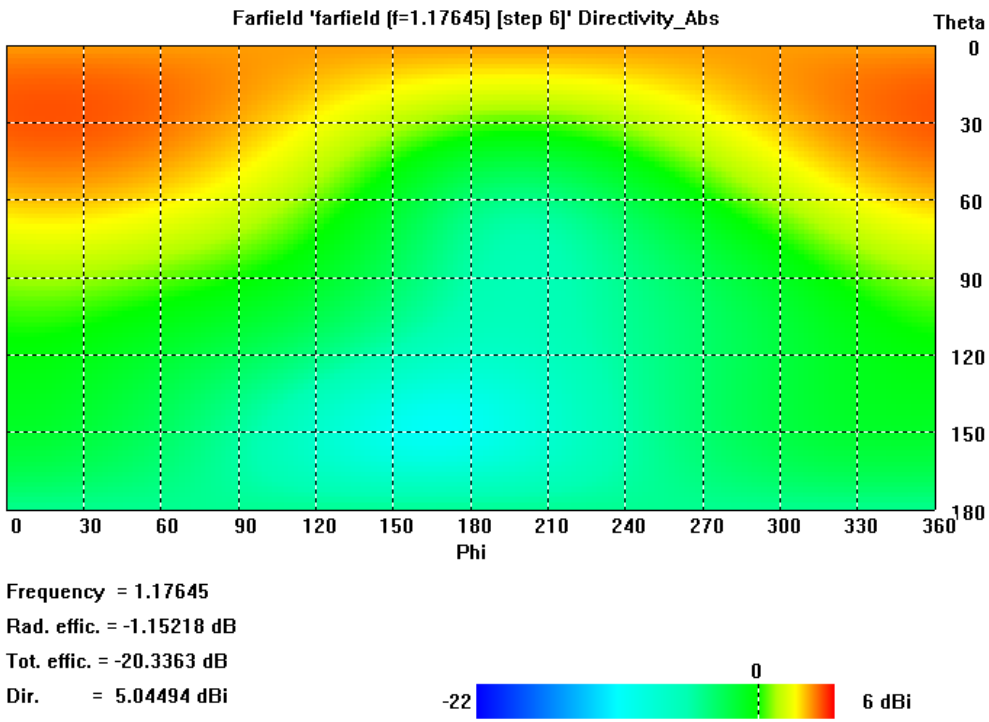
Pattern Control-AZ-Second Quadrant

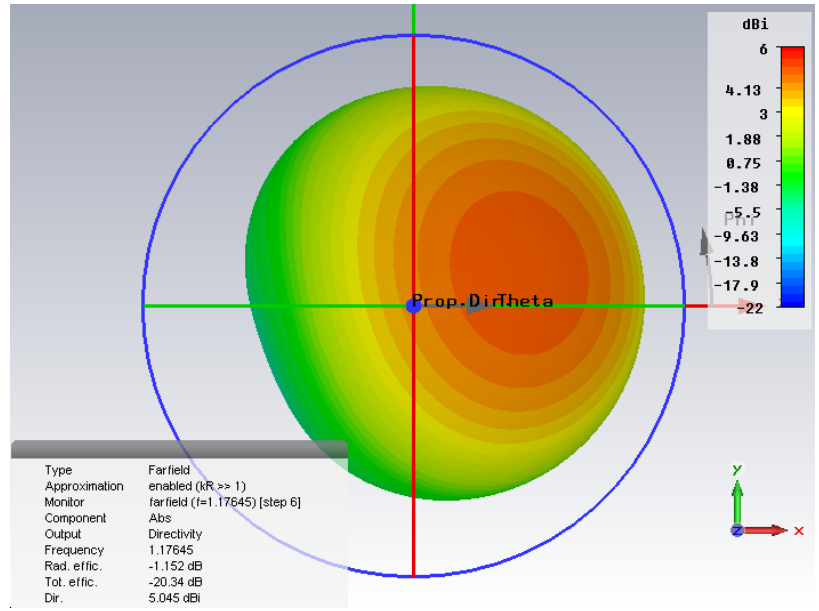




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
15	90	20	95	0

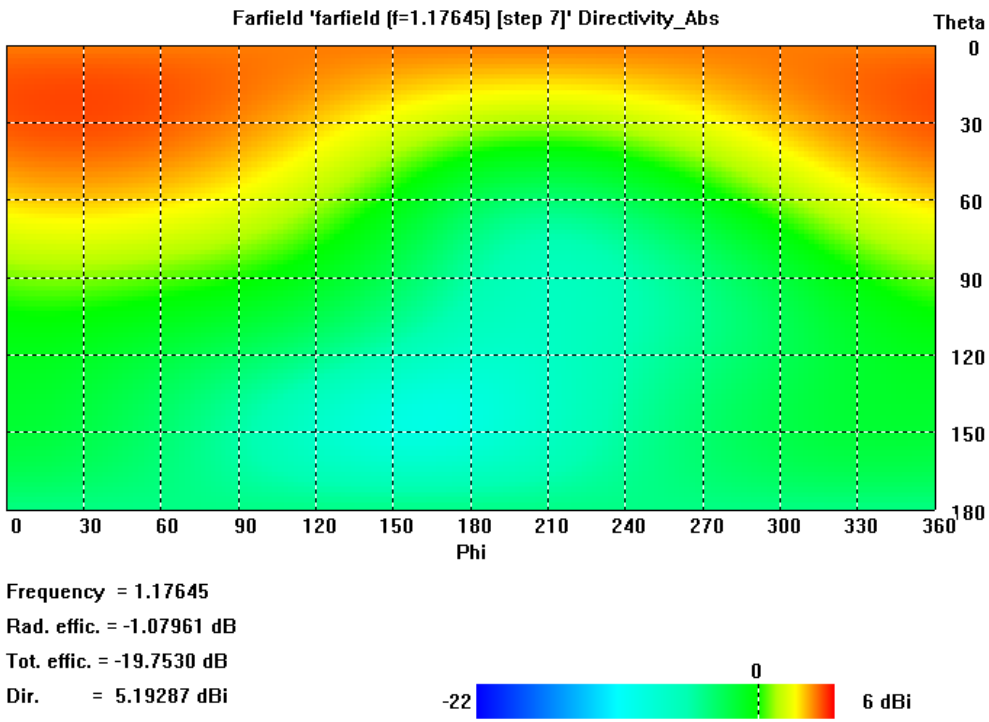
Pattern Control-AZ-Second Quadrant

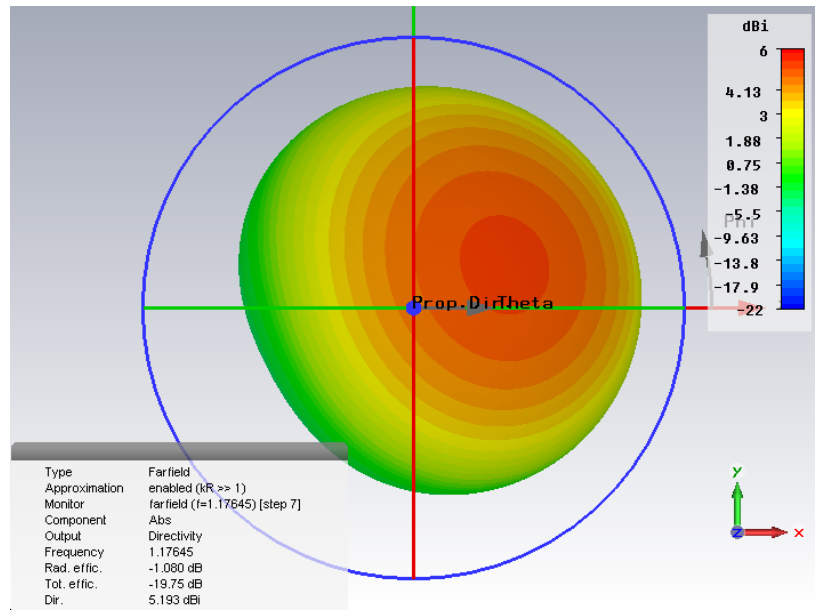




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
16	90	20	100	0

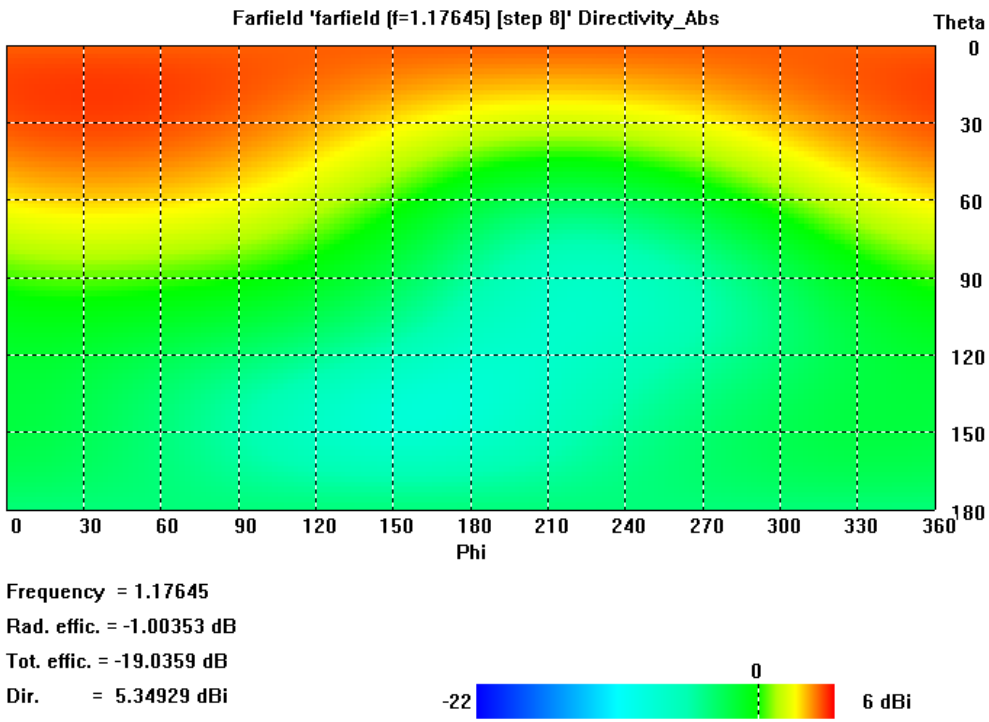
Pattern Control-AZ-Second Quadrant

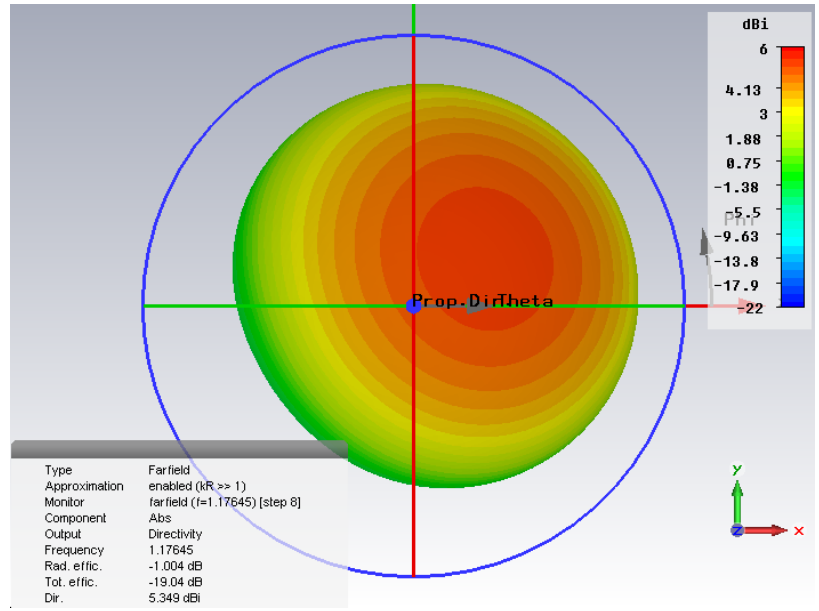




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
17	90	20	105	0

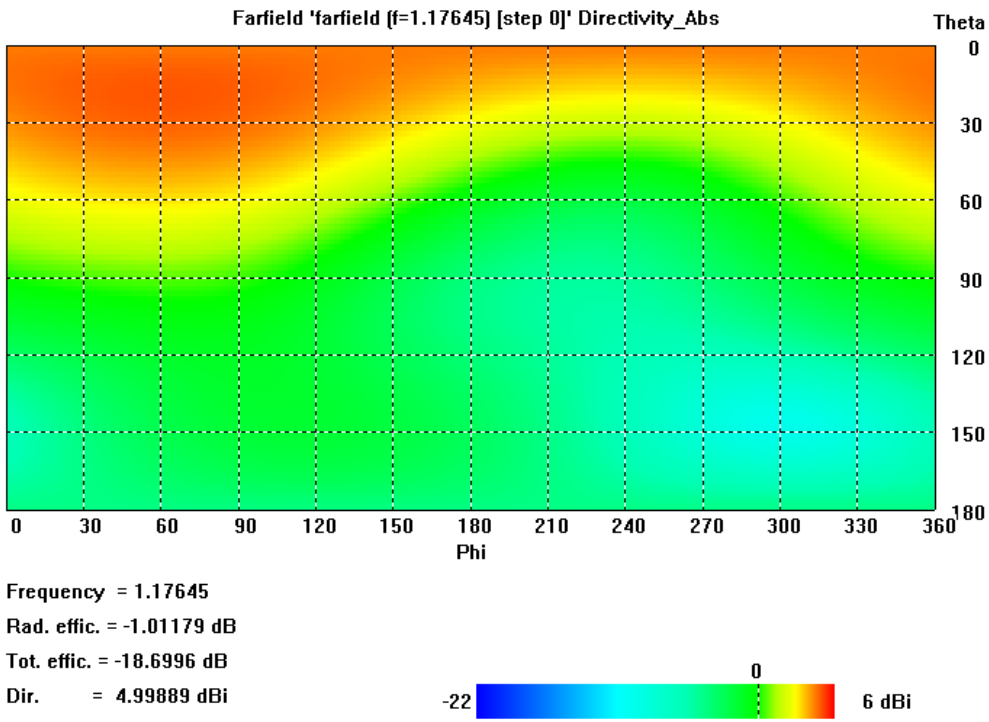
Pattern Control-AZ-Second Quadrant

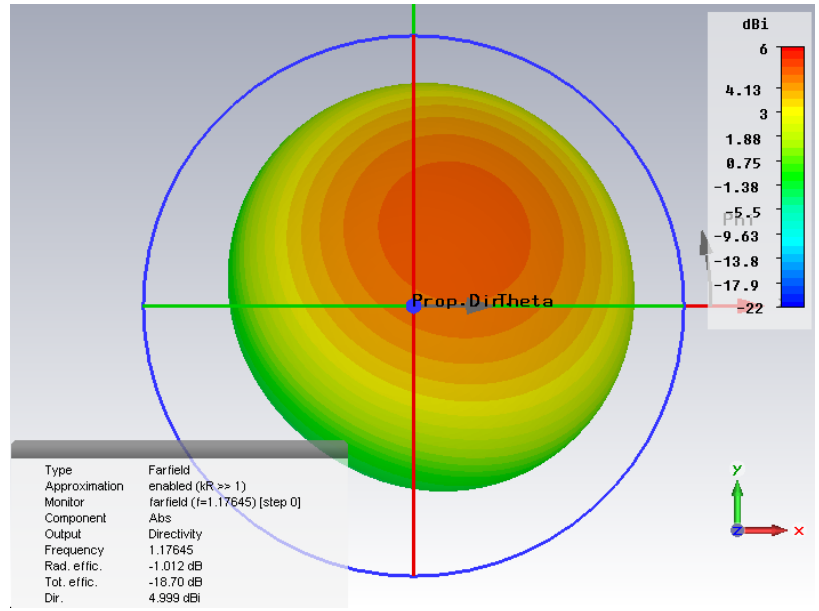




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
18	90	20	110	0

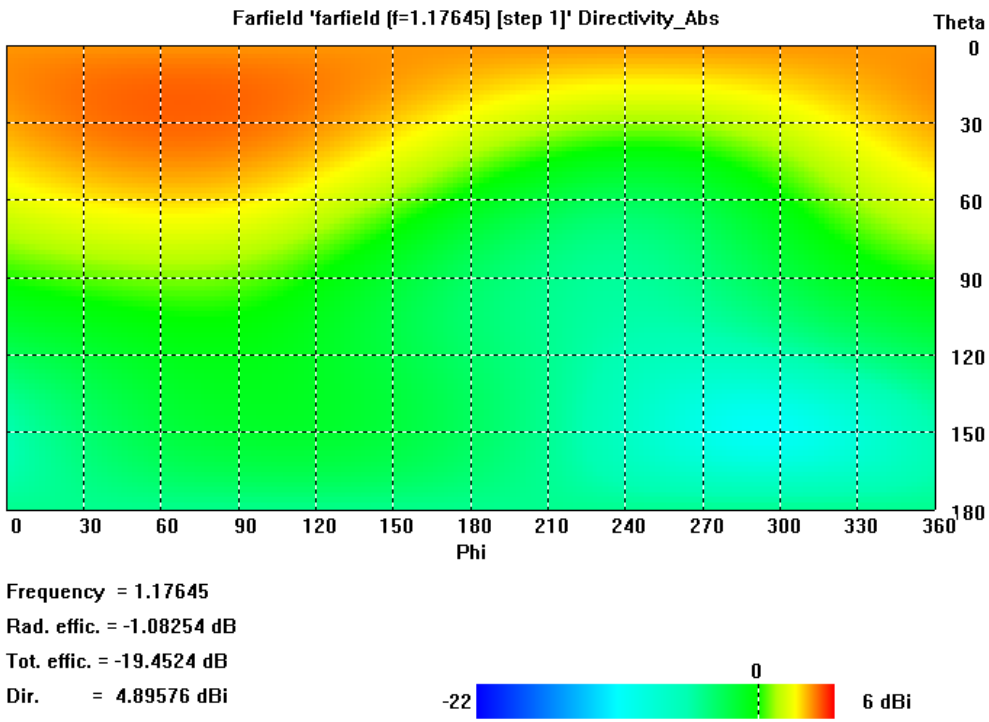
Pattern Control-AZ-Third Quadrant

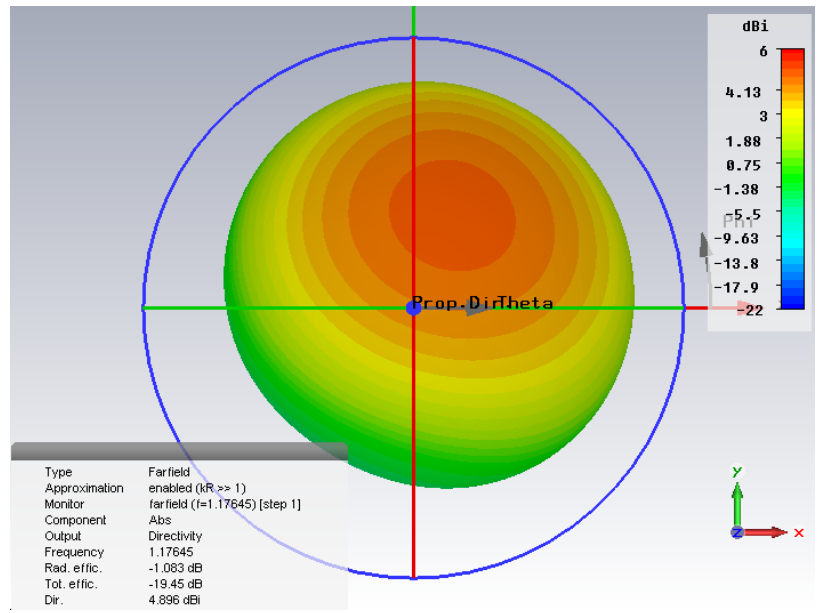




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
19	20	70	0	90

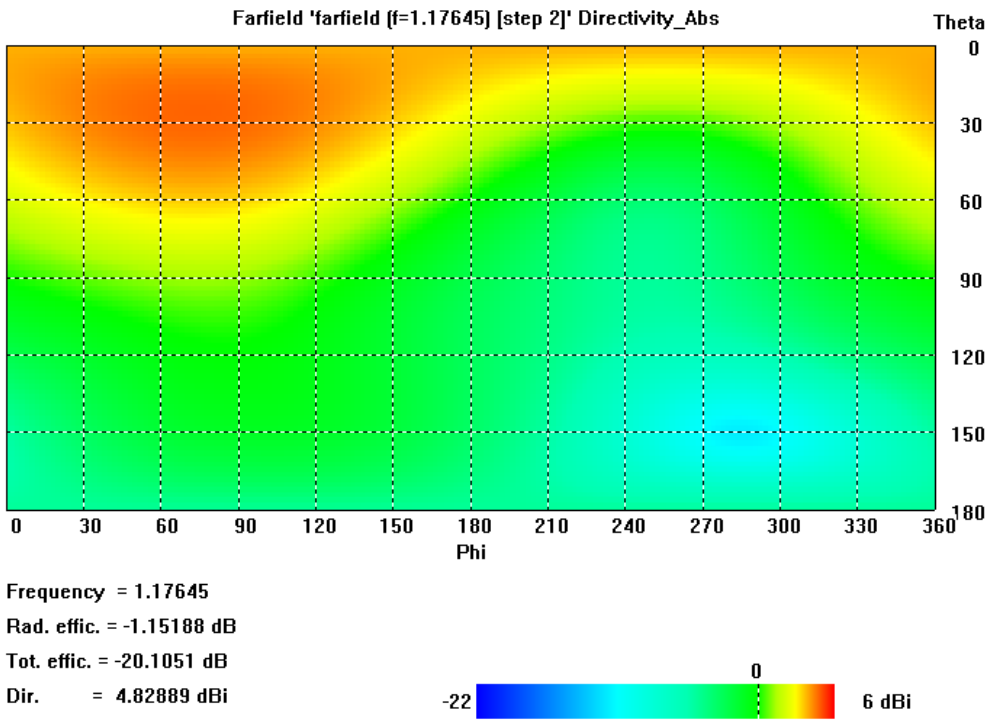
Pattern Control-AZ-Third Quadrant

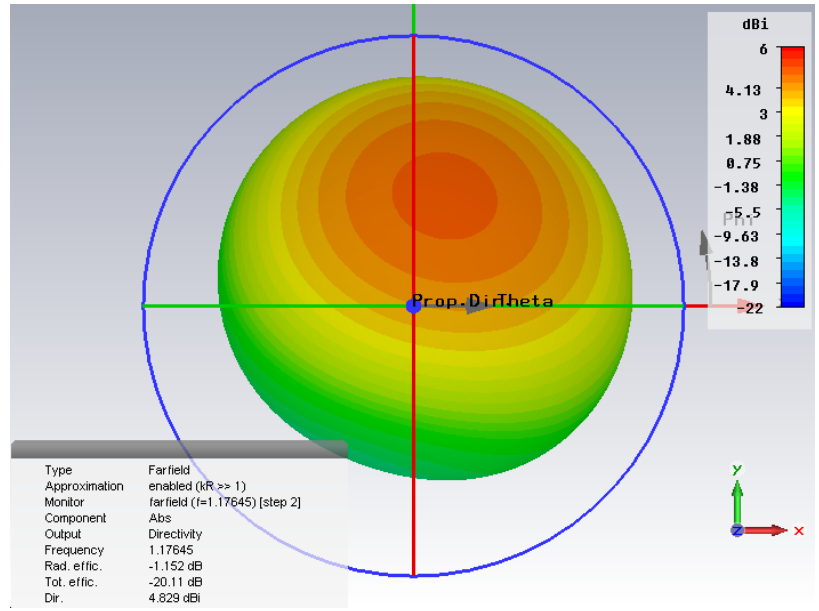




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
20	20	75	0	90

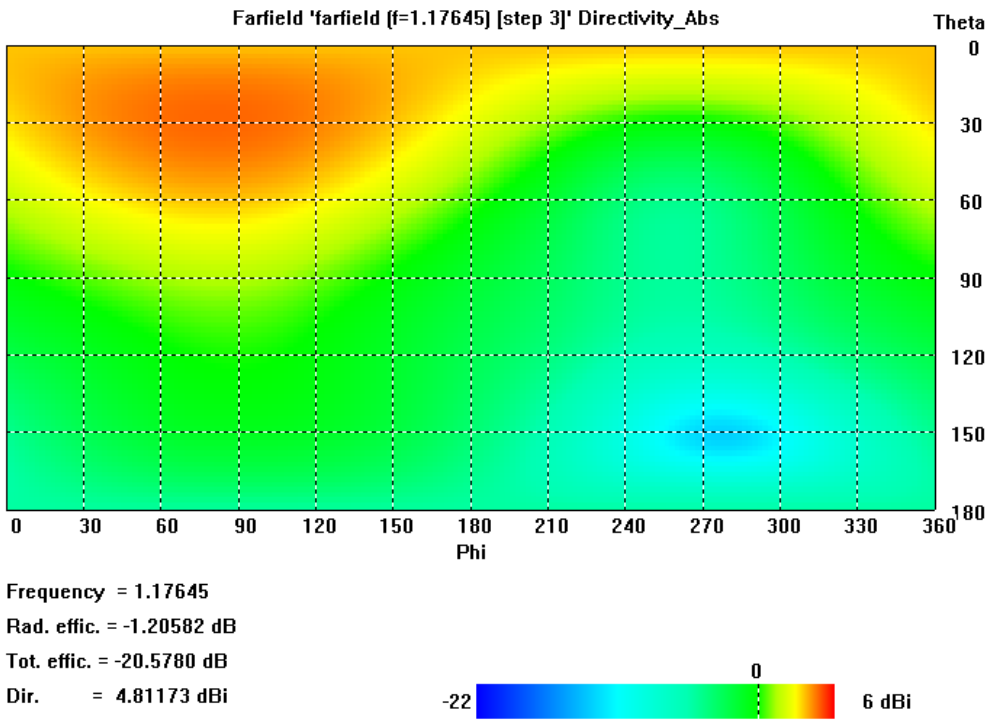
Pattern Control-AZ-Third Quadrant

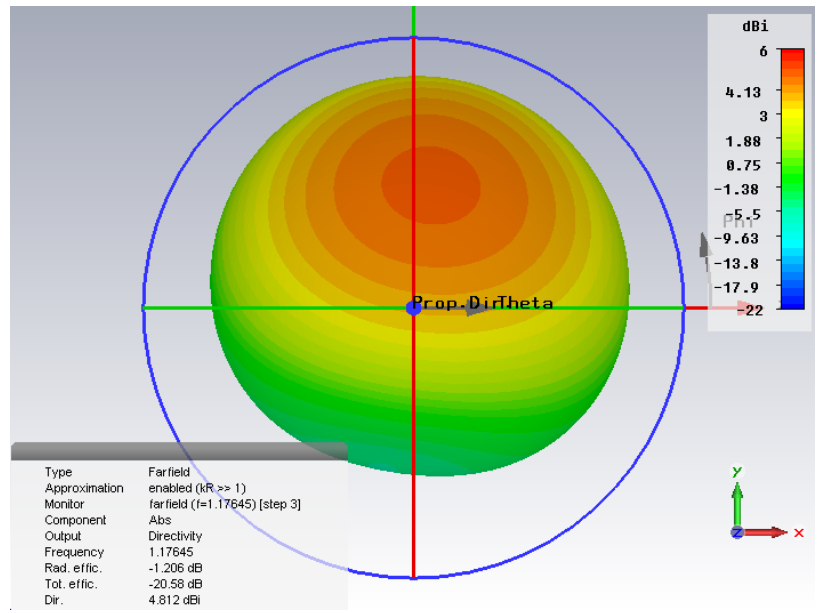




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
21	20	80	0	90

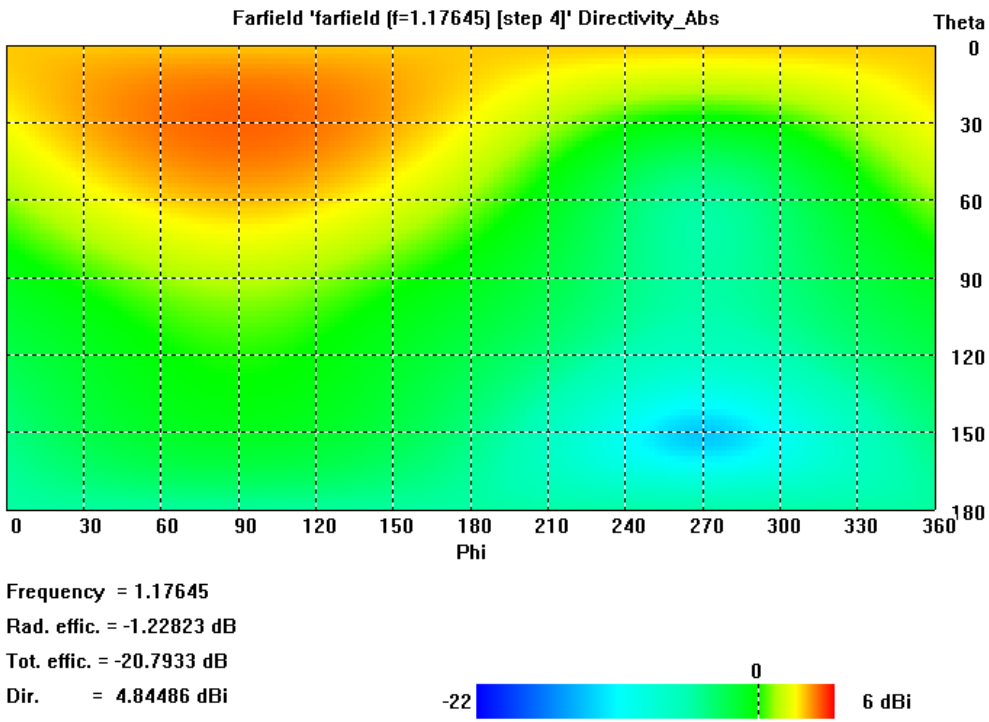
Pattern Control-AZ-Third Quadrant

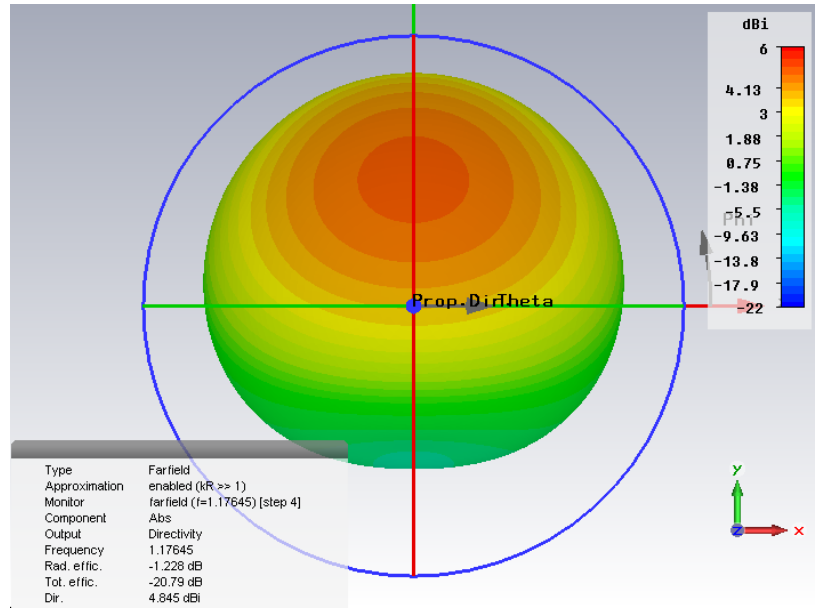




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
22	20	85	0	90

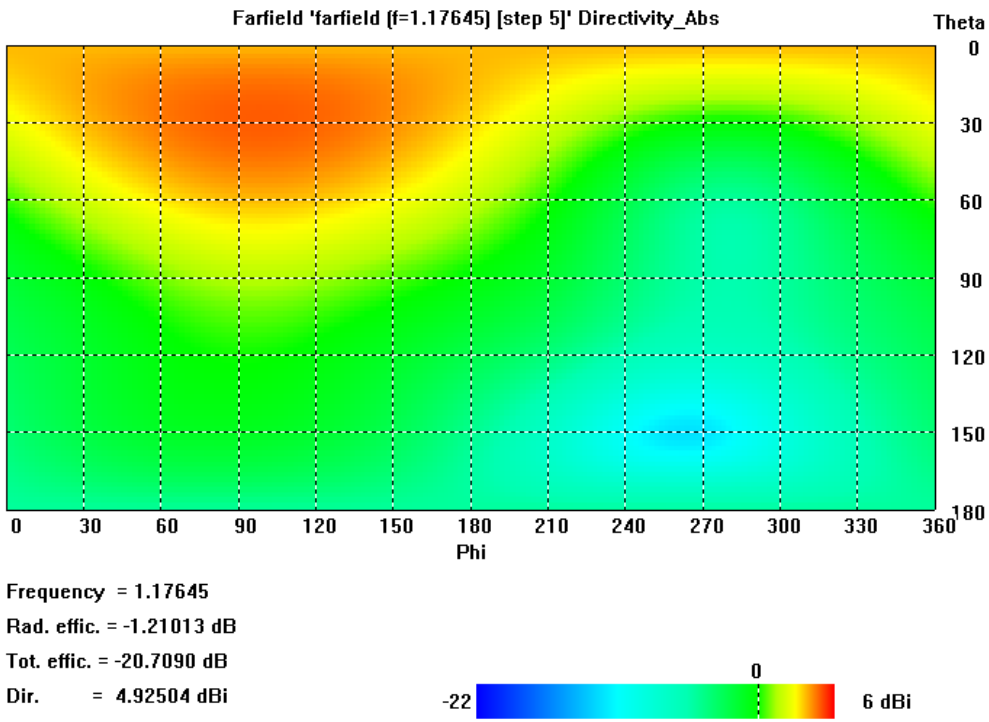
Pattern Control-AZ-Third Quadrant

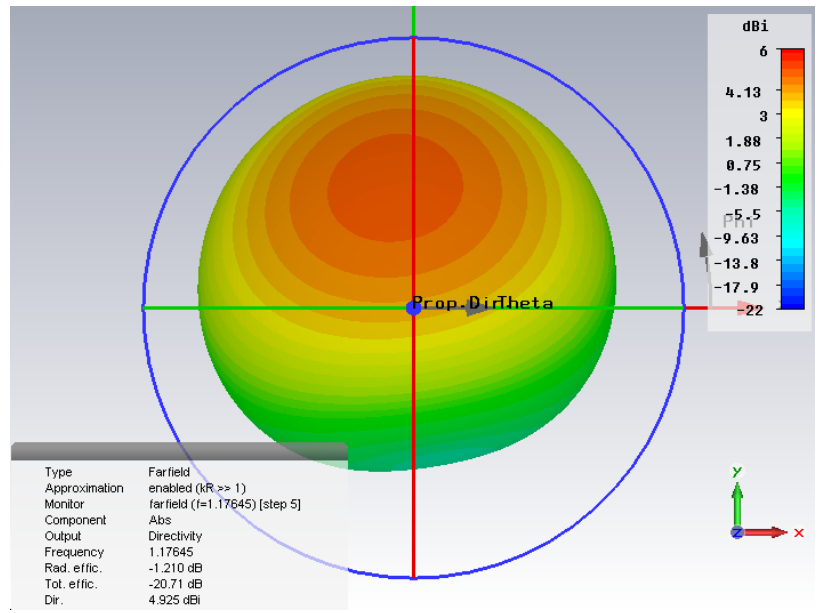




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
23	20	90	0	90

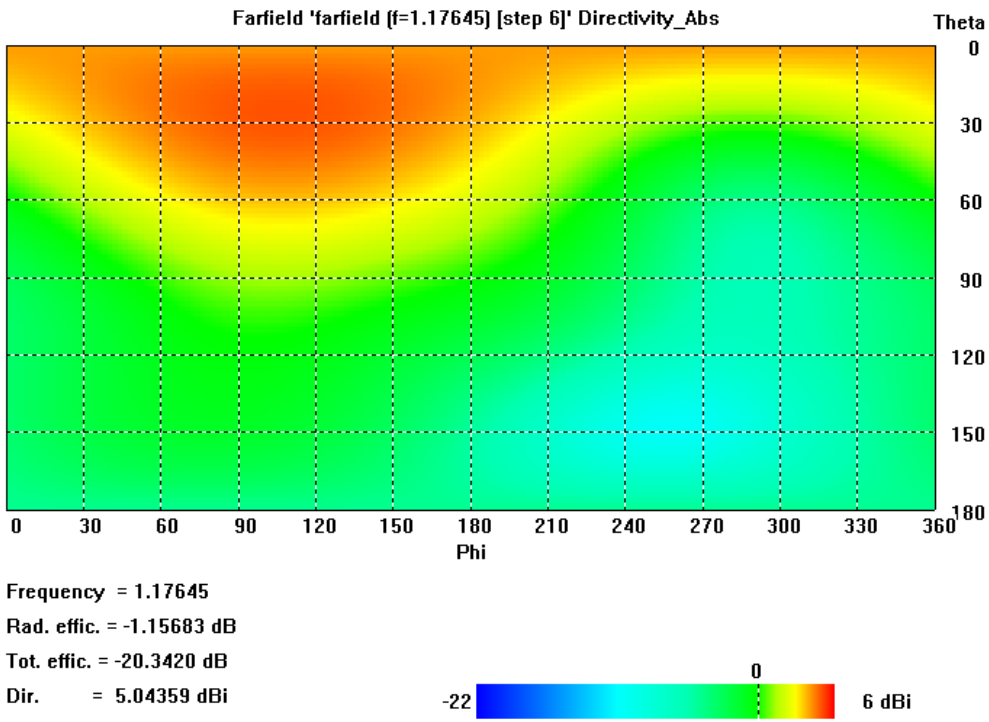
Pattern Control-AZ-Third Quadrant

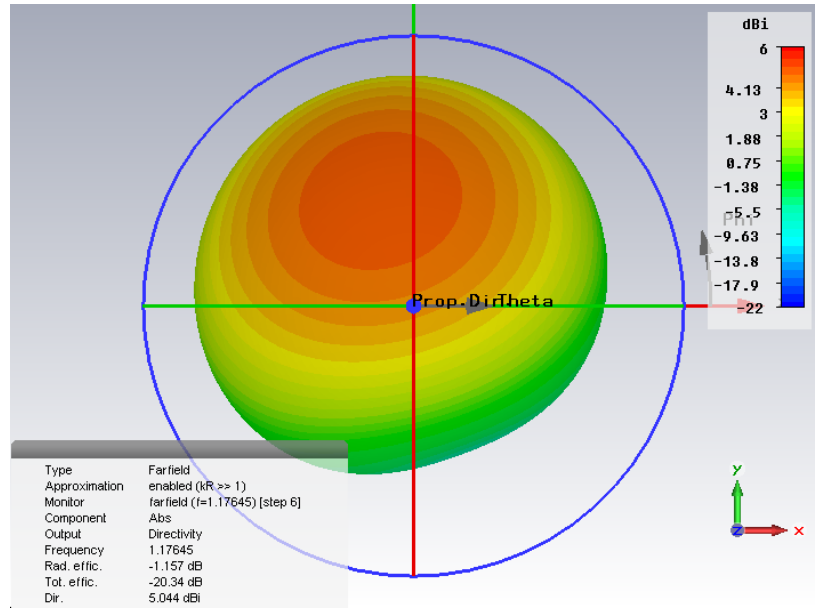




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
24	20	95	0	90

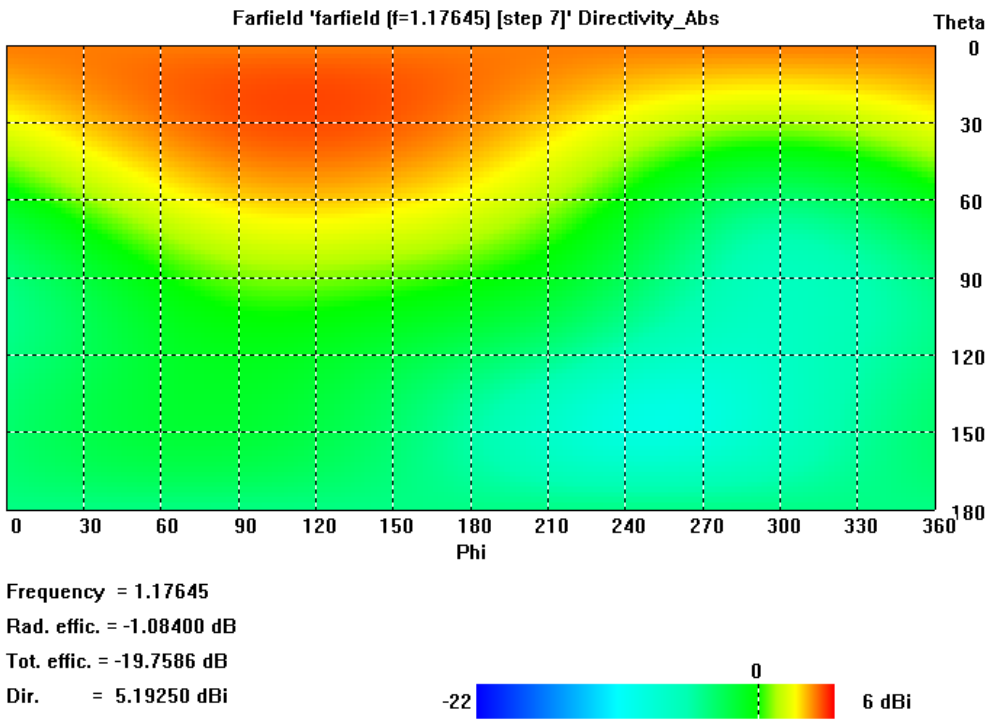
Pattern Control-AZ-Third Quadrant

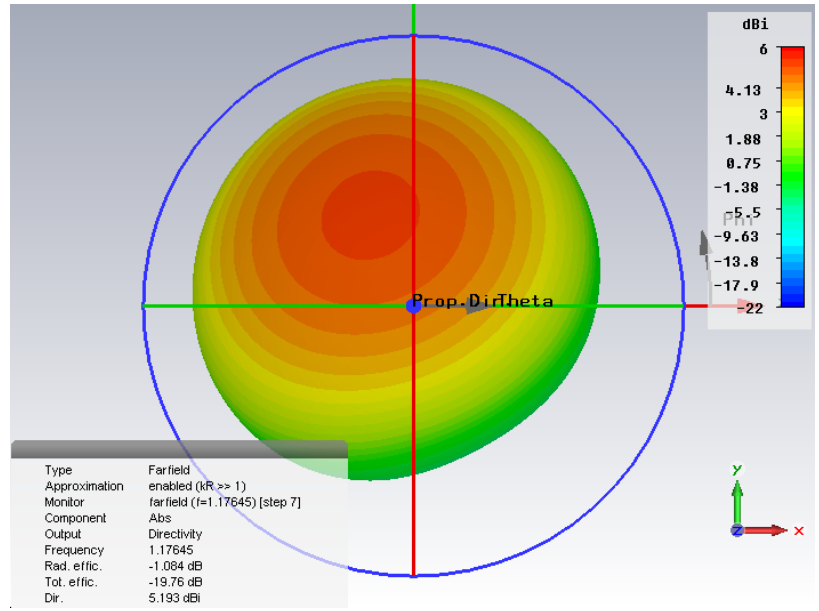




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
25	20	100	0	90

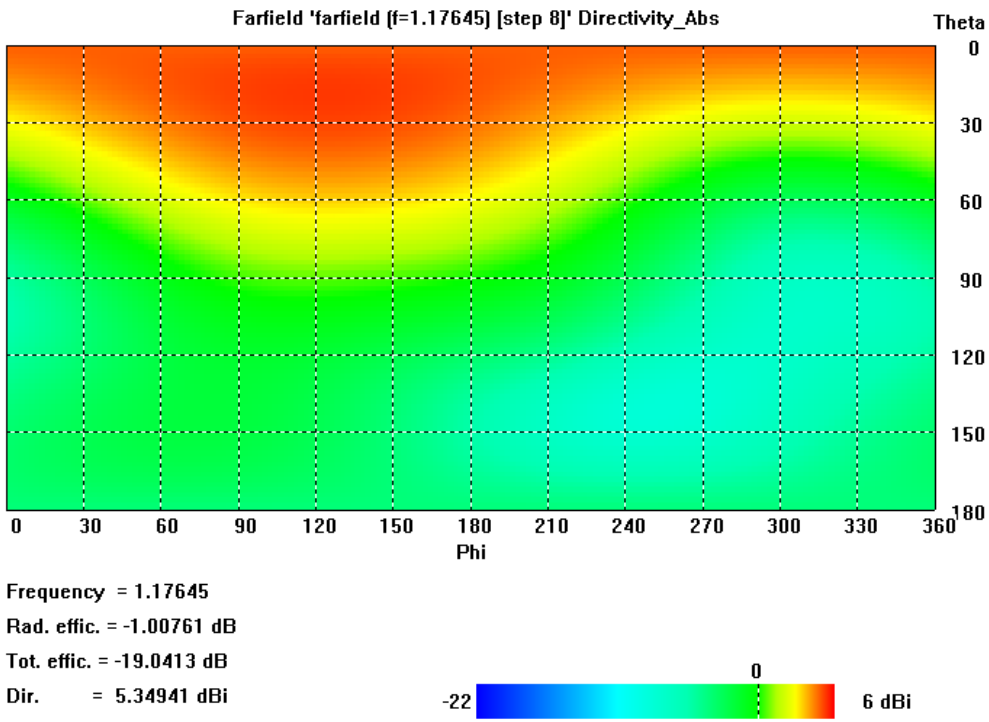
Pattern Control-AZ-Third Quadrant

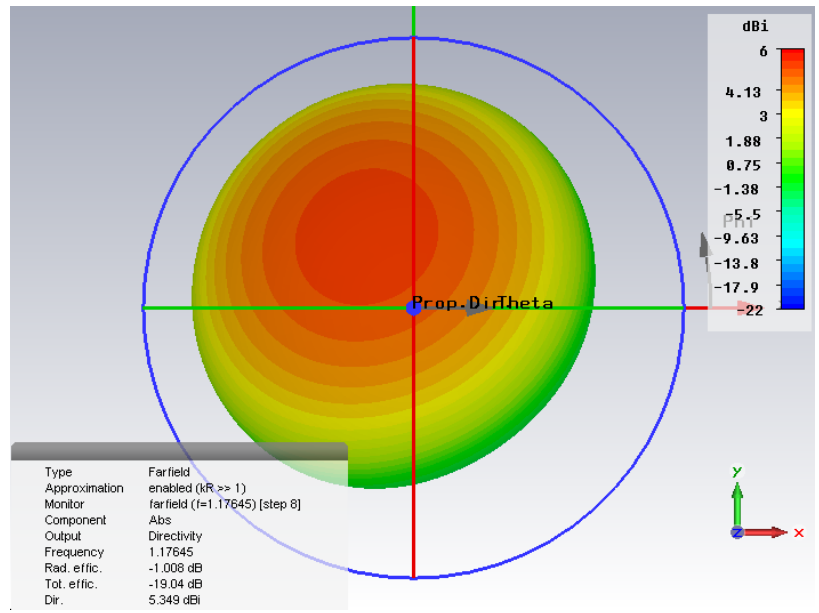




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
26	20	105	0	90

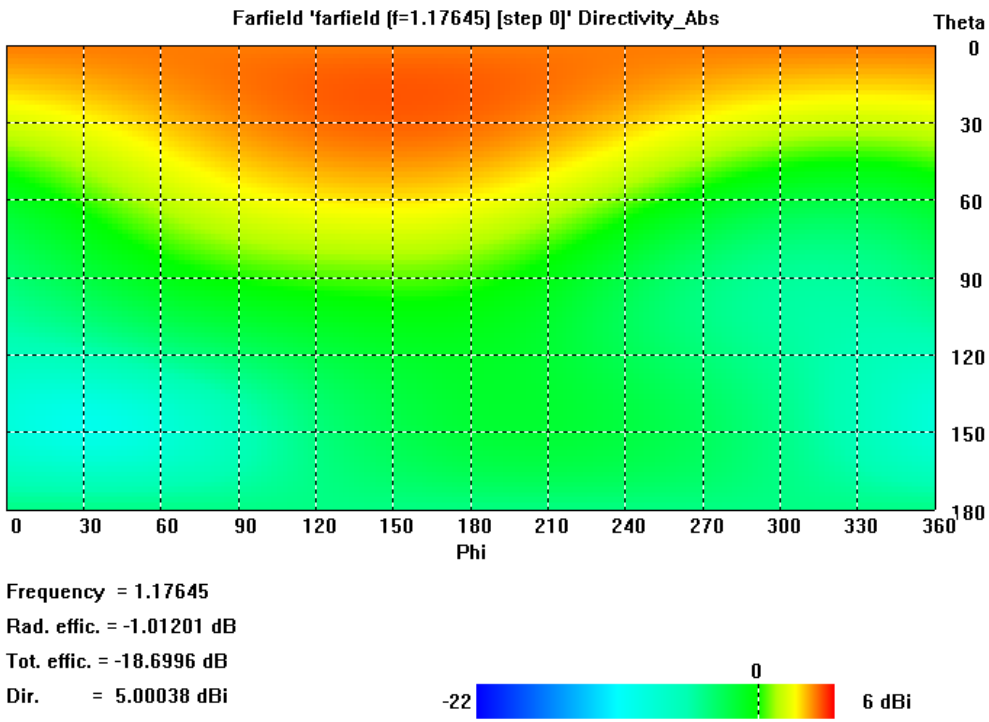
Pattern Control-AZ-Third Quadrant

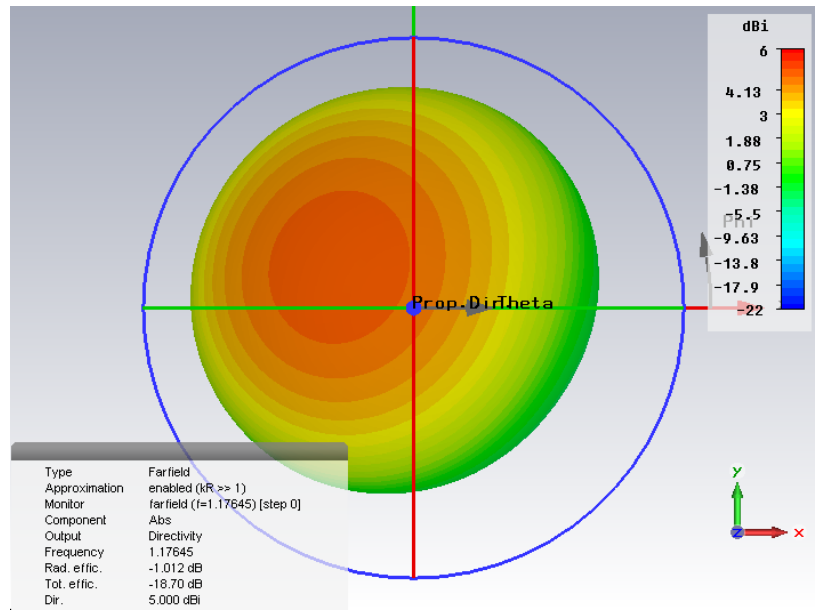




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
27	20	110	0	90

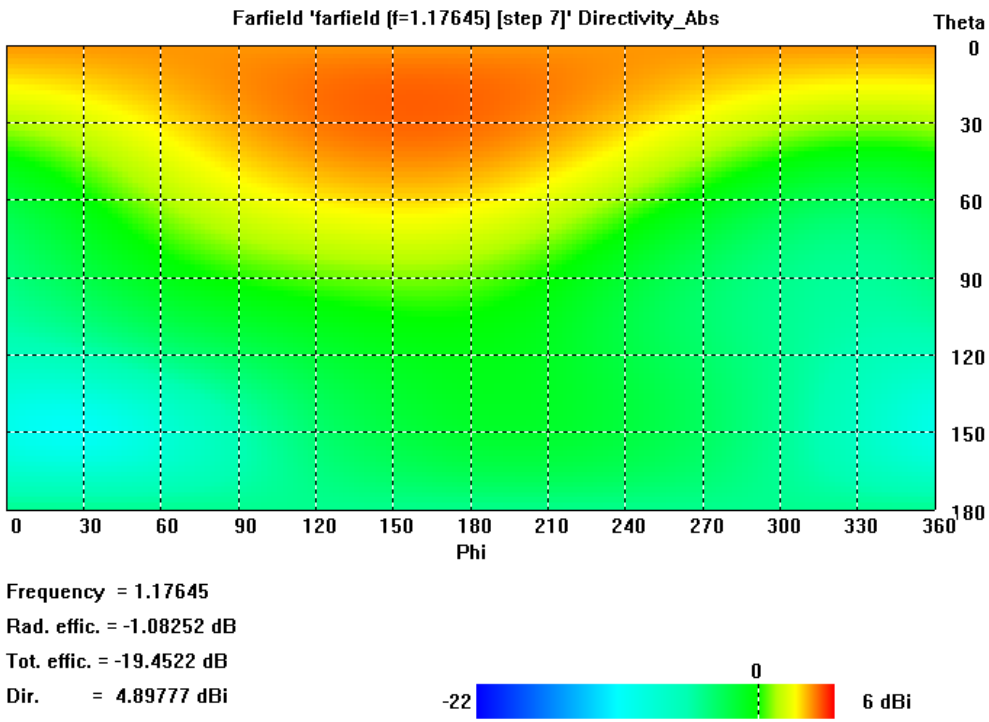
Pattern Control-AZ-Fourth Quadrant

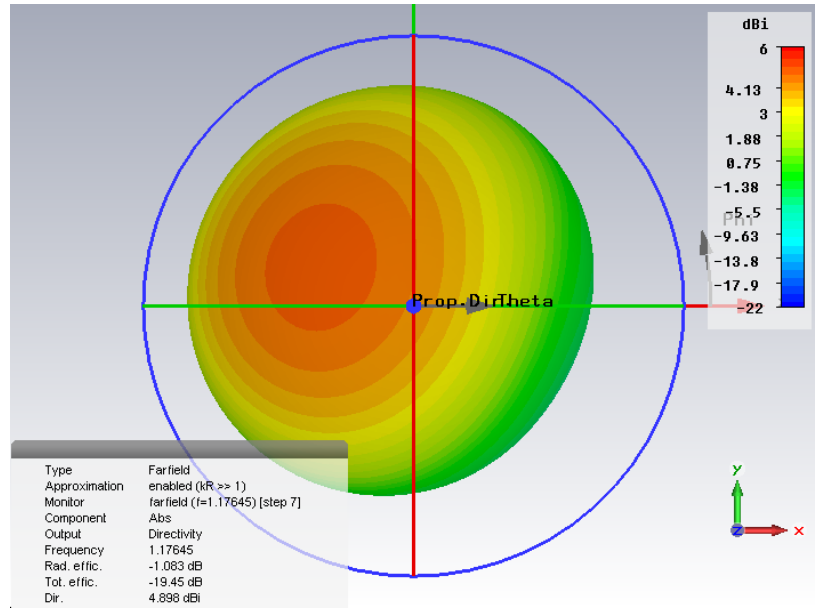




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
28	70	0	90	20

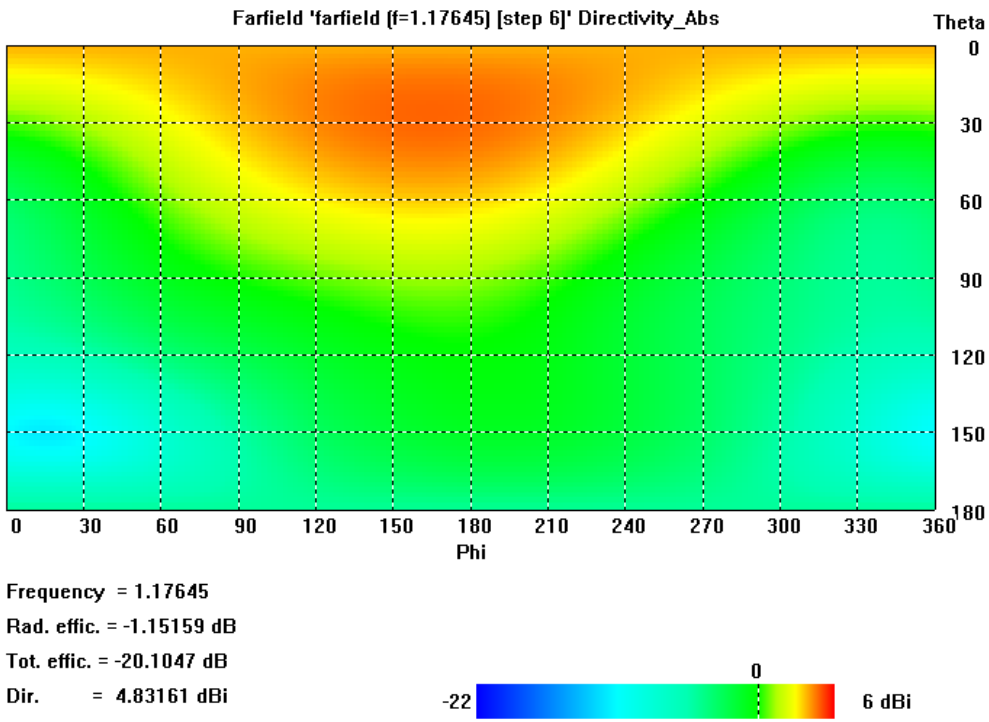
Pattern Control-AZ-Fourth Quadrant

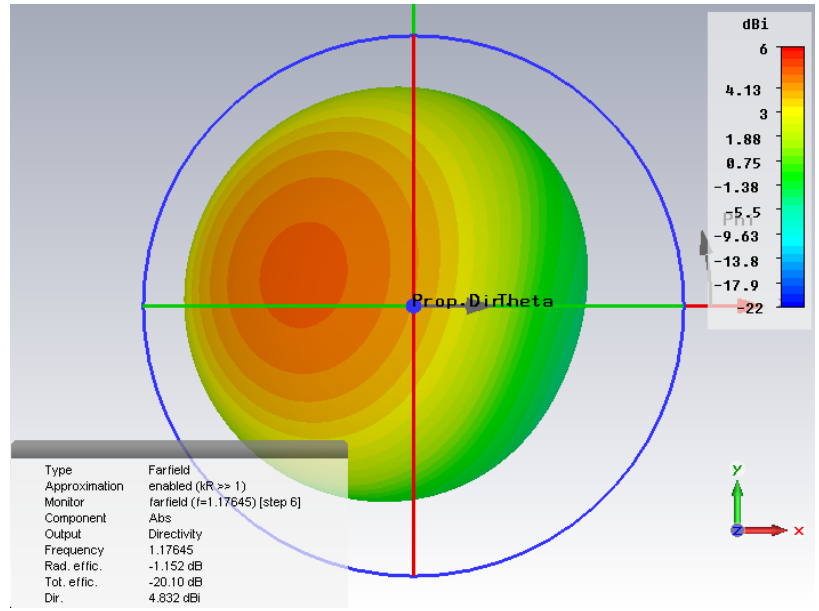




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
29	75	0	90	20

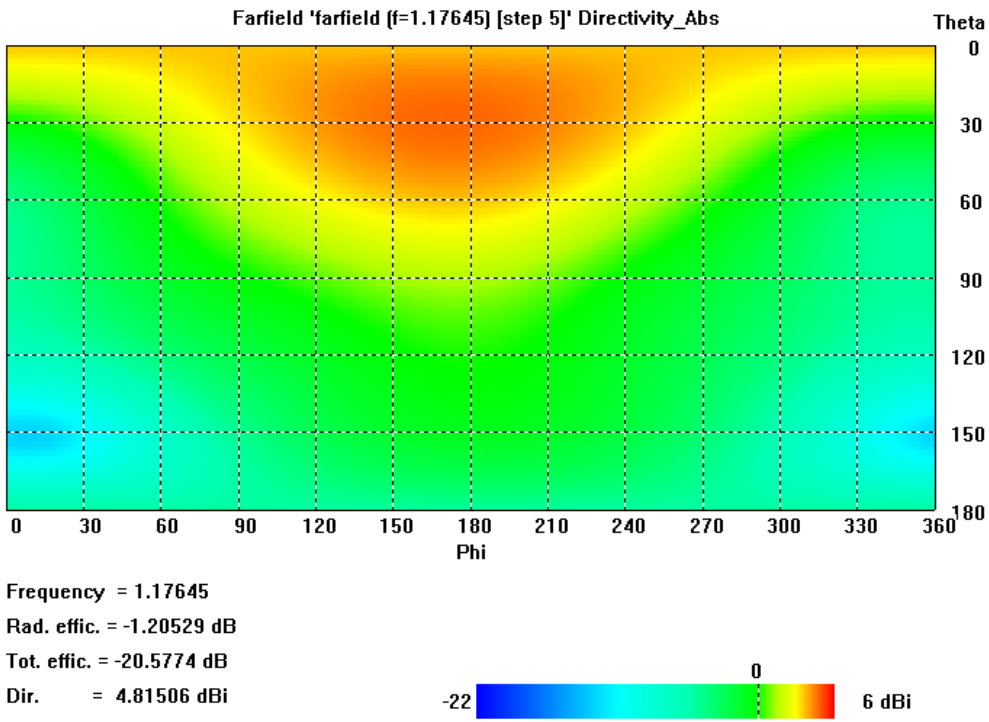
Pattern Control-AZ-Fourth Quadrant

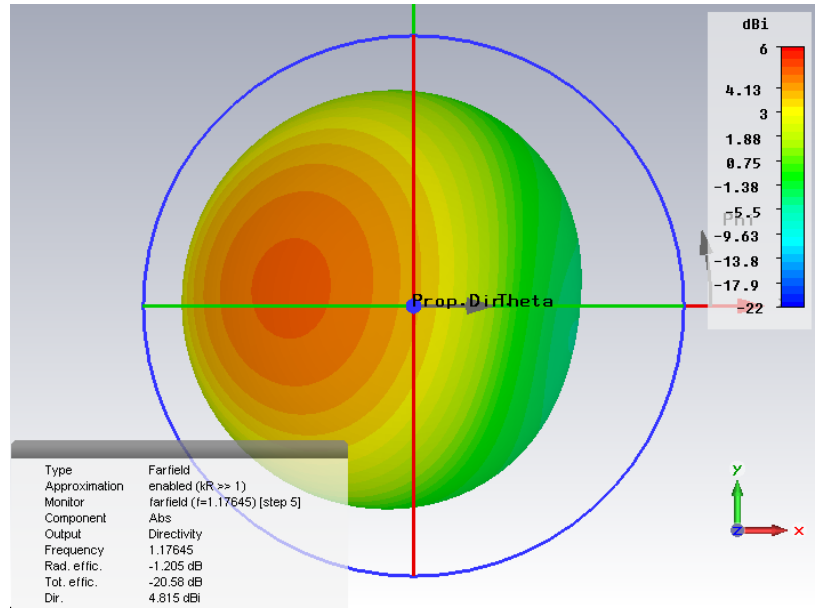




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
30	80	0	90	20

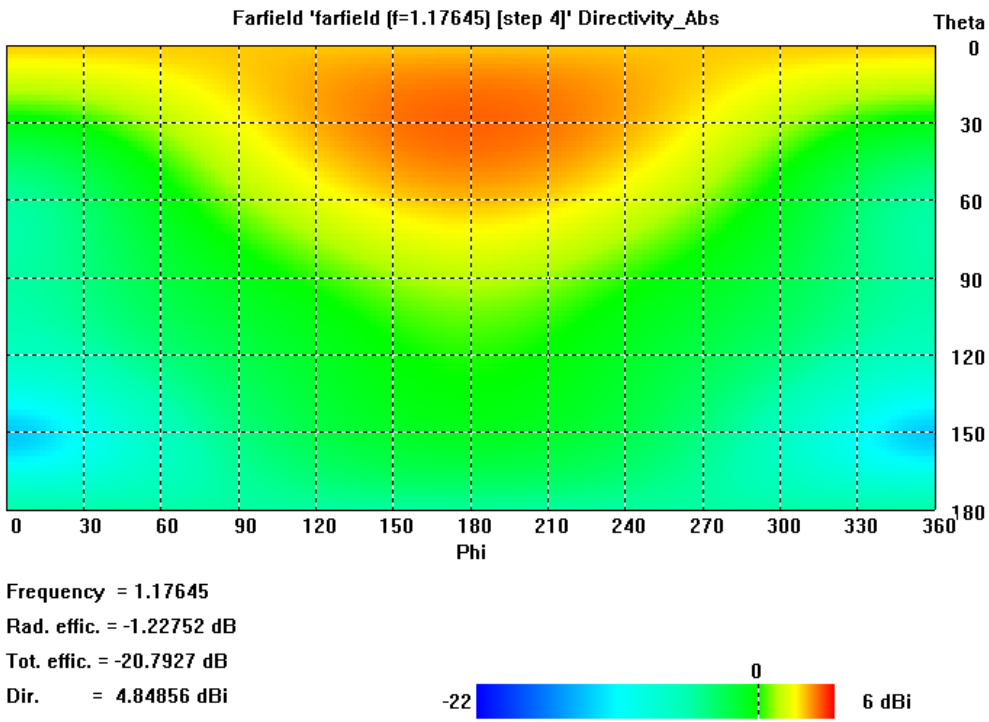
Pattern Control-AZ-Fourth Quadrant

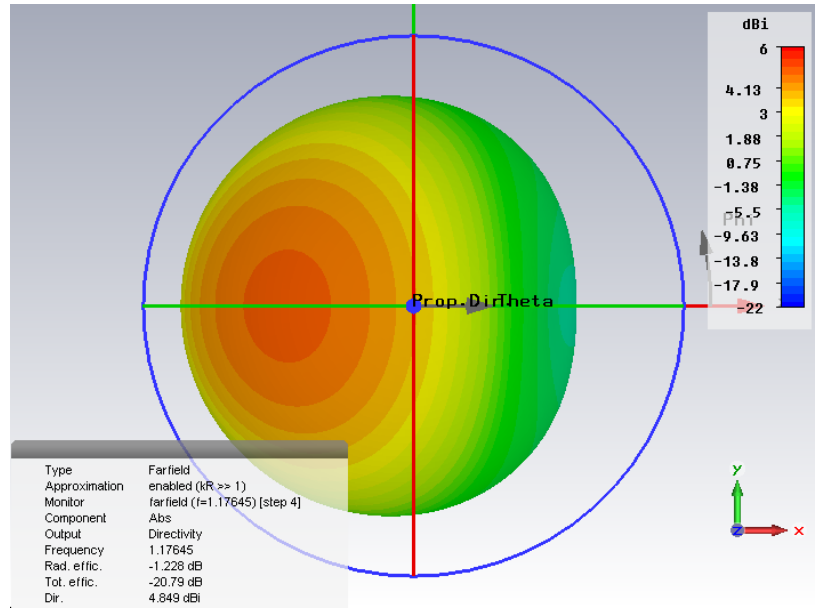




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
31	85	0	90	20

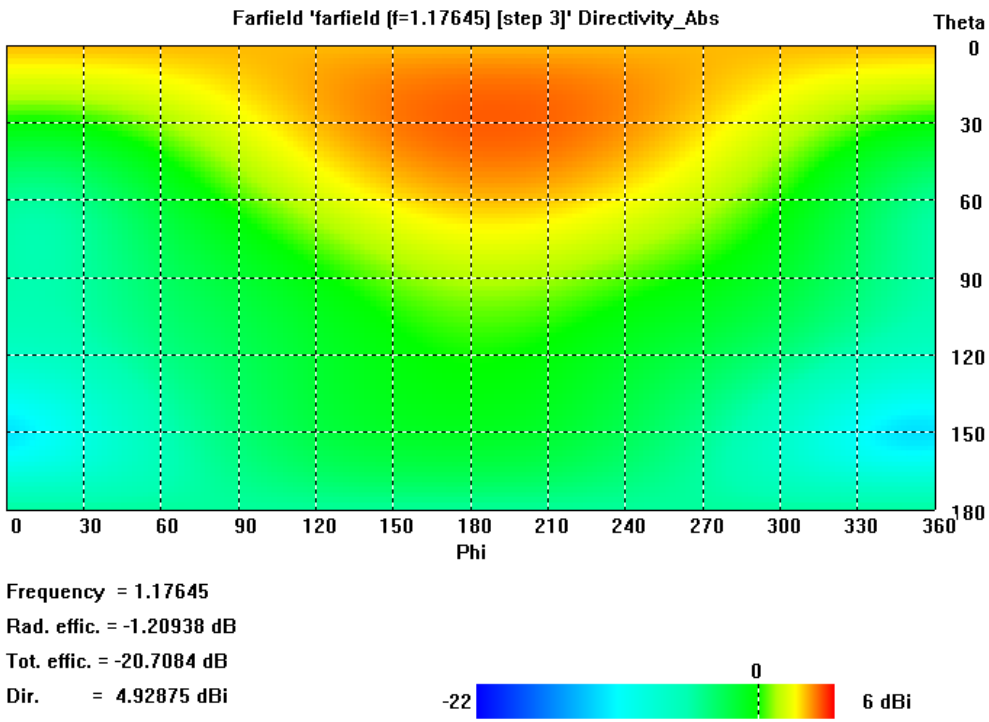
Pattern Control-AZ-Fourth Quadrant

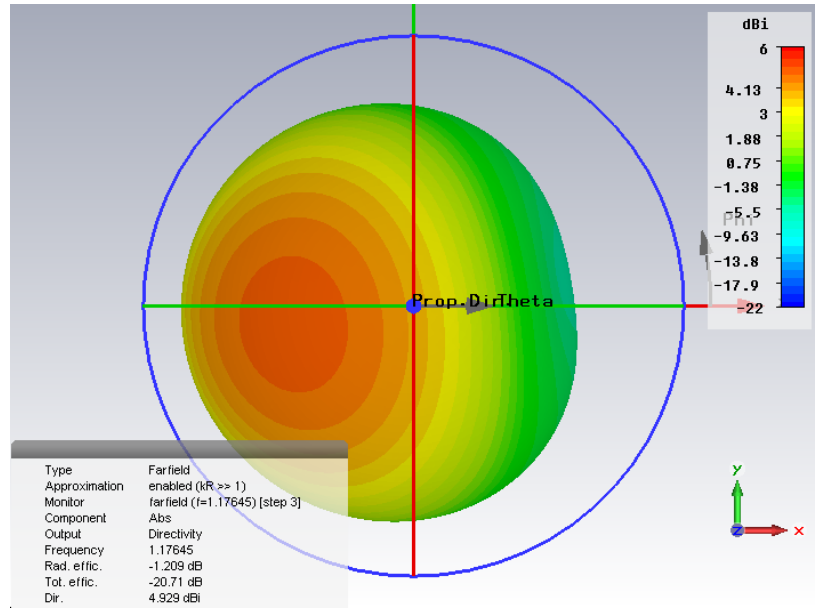




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
32	90	0	90	20

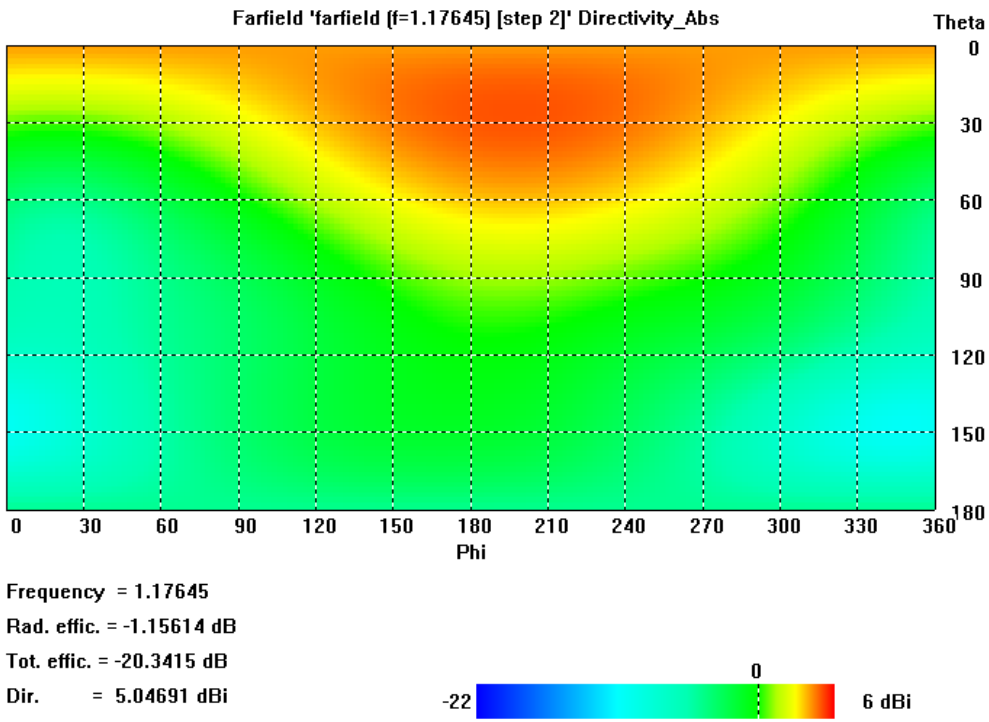
Pattern Control-AZ-Fourth Quadrant

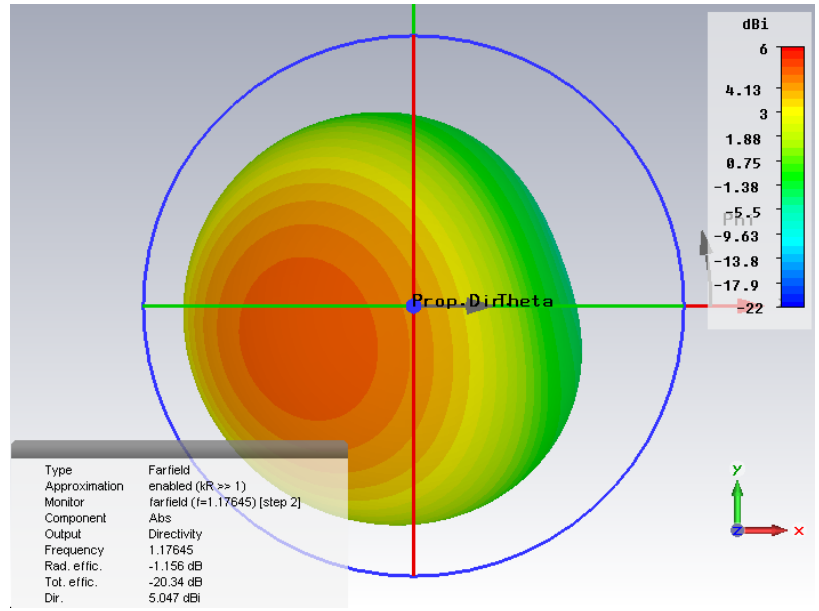




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
33	95	0	90	20

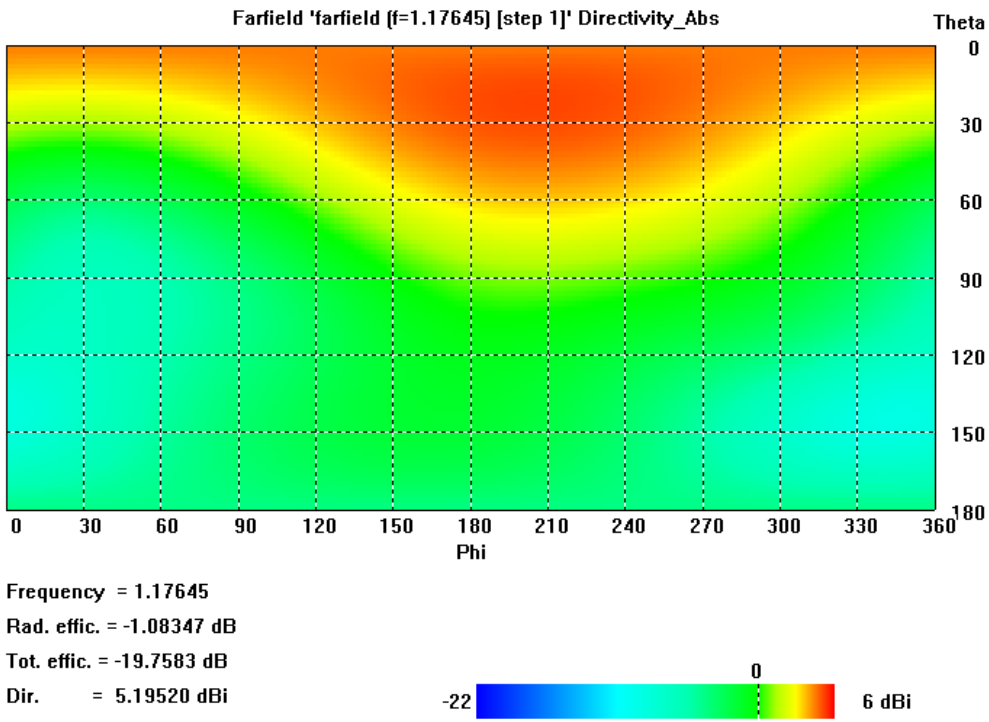
Pattern Control-AZ-Fourth Quadrant

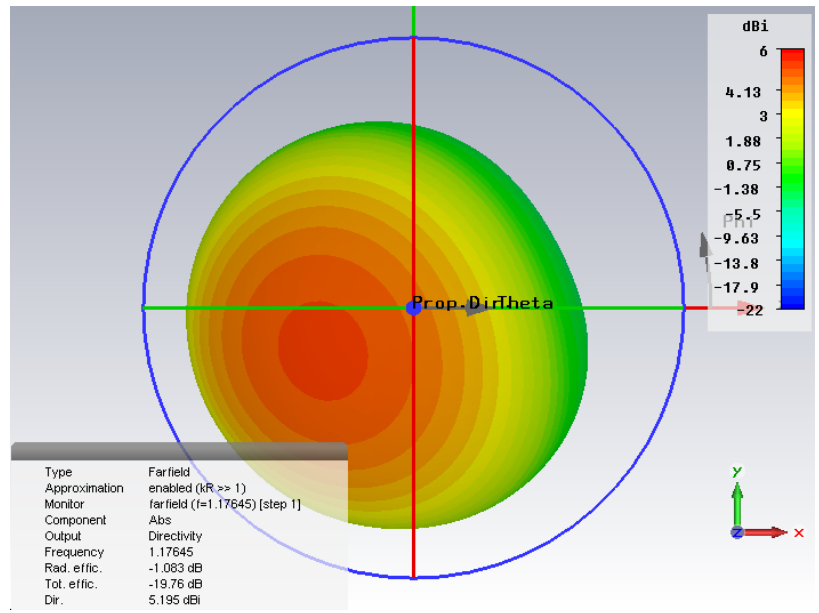




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
34	100	0	90	20

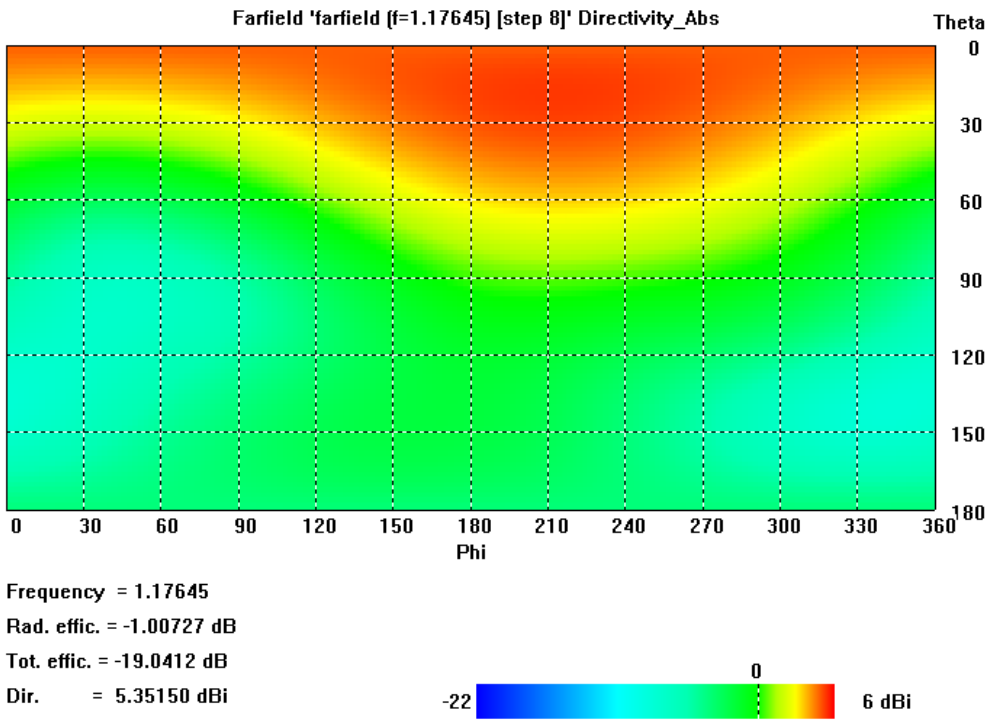
Pattern Control-AZ-Fourth Quadrant

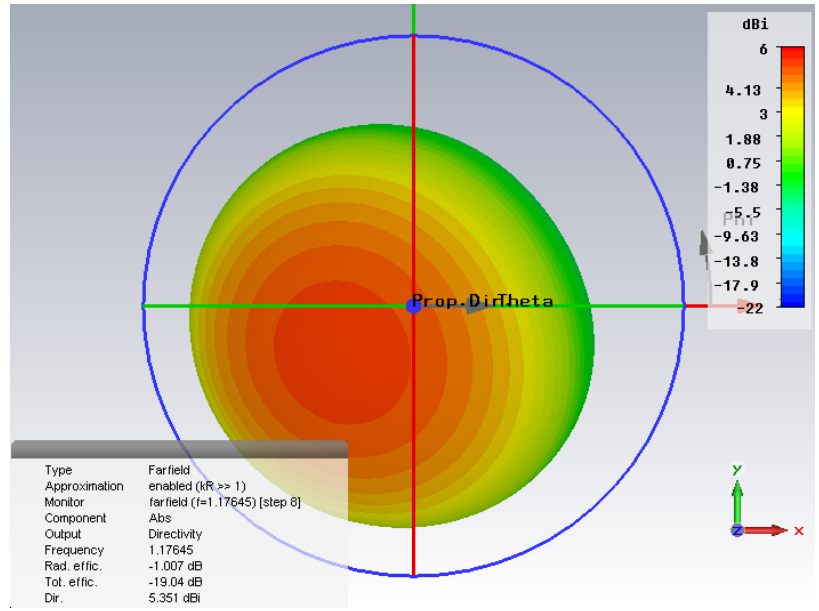




Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
35	105	0	90	20

Pattern Control-AZ-Fourth Quadrant





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

Single-element Patch Antenna with Pattern Control - Summary

- Control area of high directivity and corresponding area of low directivity in the azimuth (full 360 deg) and elevation planes by controlling the phases of the RF feeds.
- Dynamic pattern control advantageous for:
  - » Baseline/Benign operations
  - » Interference operations, where interference sources are above, at, or below the local horizon.
- Enables a certain level of pattern control in the size of a single-element patch antenna.

Outline

- Purpose
- Background - Previous Works on GNSS Patch Antennas
  - » 1. Pattern Control
  - » 2. Asymmetric Ground Plane Performance
- Going Forward - Pattern Control with an Asymmetric Ground Plane
  - » Pattern Control with Square Patch Antenna
  - » Broadband-frequency Pattern Control
  - » Ground Plane Effects (size, shape, curvature)
- Summary

2. Asymmetric Ground Plane Performance

- When a patch antenna is mounted on an asymmetric ground plane, an asymmetric performance is obtained.
- The asymmetric performance of a GNSS L5 patch antenna was investigated, considering the draft RTCA and ARINC specifications using a high fidelity model in CST.
- Baseline performances were obtained in two cases:
  - » Baseline 1: Square Patch over Square Ground Plane
  - » Baseline 2: Square Patch over Asymmetric Ground Plane
- Two mitigation techniques investigated to correct polarization losses from the baseline performances.

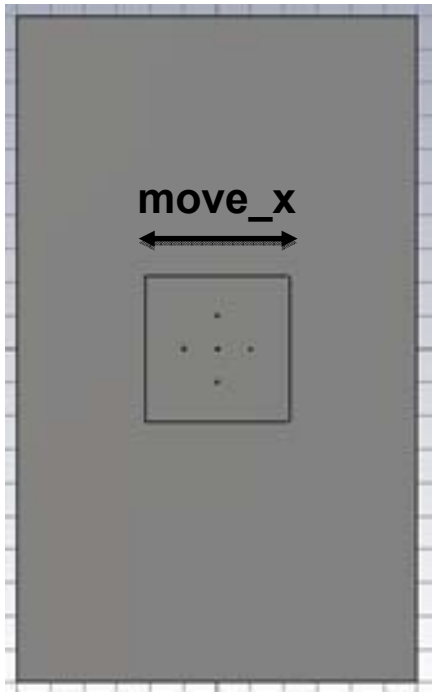
Wave Polarization Terms

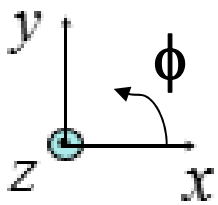
- **Polarization of GNSS signals are RHCP (Right Hand Circular Polarization)**
  - » **Polarization: Direction E-field points as wave travels away from the source.**

- **Axial Ratio (AR): The ratio of the two orthogonal E-field components:**
  - » **AR = 1 (i.e., 0 dB) is ideal**
  - » **AR > 3 dB is poor.**
  - » **AR Beamwidth (Metric to assess AR < 3 dB in the spatial domain)**
    - **Big AR beamwidth is good**

2. Asymmetric Ground Plane Performance

- **Mitigation Technique 1:**
  Patch <u>element</u> manipulation.
- **Mitigation Technique 2:**
  Patch <u>substrate</u> manipulation.
- **Manipulation in both x and y directions were investigated.**
- **Performance increase occurs when X dimensions was increased (minimal performance increase when Y dimension was increased)**
- **"move_x" variable used in manipulate X dimension.**





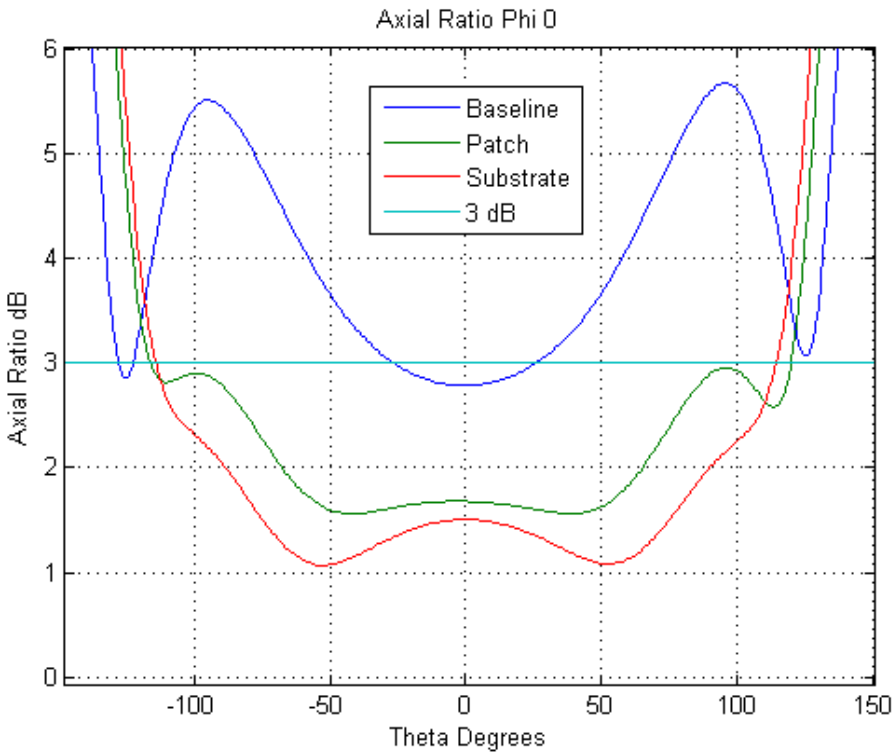
Asymmetric Performance Summary

- **Baseline 2 performed worse than Baseline 1 due to asymmetry.**

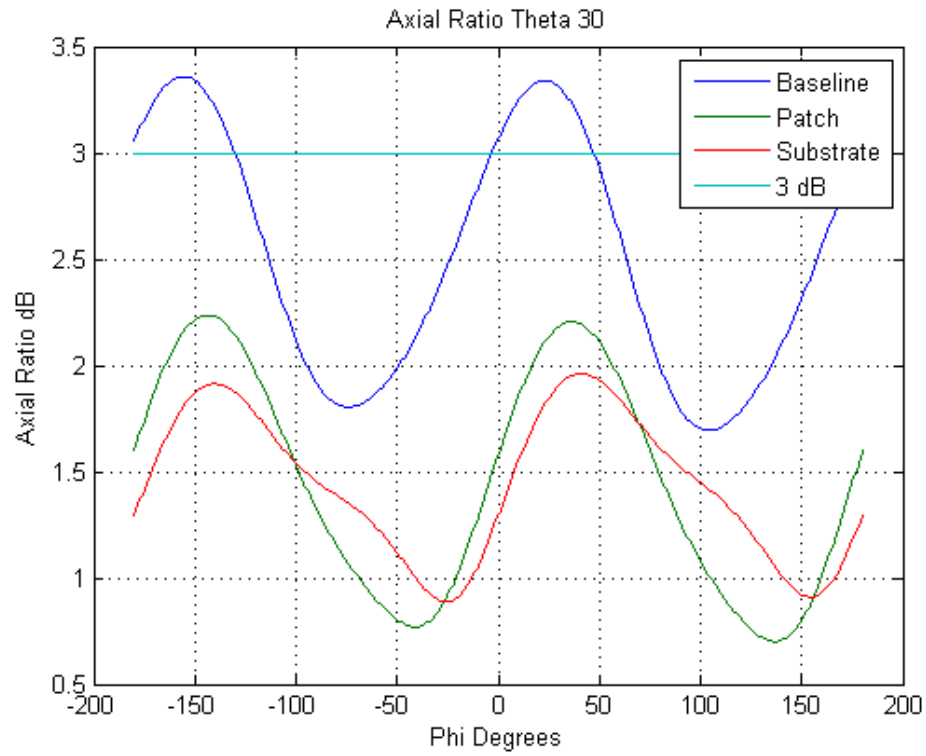
- **Asymmetric Performance Mitigation Techniques Investigated**
  - » **Patch <u>element</u> manipulation**
    - **Improved AR performance; best when move_x=1.25 mm.**
  - » **Patch <u>substrate</u> manipulation**
    - **Improved AR performance; best when move_x=3.0 mm.**
  - » **BOTH patch <u>element</u> and patch <u>substrate</u> manipulation techniques improved the overall axial ratio performance; substrate manipulation a little bit better.**

Asymmetric Performance Mitigation with Rectangular GP-Manipulation Techniques Compared

Elevation cut (ϕ=0deg)



Azimuth cut (θ=30deg)



- **Both patch element and substrate manipulation techniques improve the AR performance vs. the Baseline 2 configuration.**

Outline

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  - » Broadband-frequency Pattern Control
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- Summary

Going Forward

- Investigate rectangular GNSS patch antennas with pattern control over curved asymmetric ground plane, suitable for aviation applications.
- Target design within ARINC 743A footprint.
- Model in CST Microwave Studio.
- Target simulations on new dedicated CEM machine.

Going Forward (cont.)

- **Refine GNSS patch antenna designs:**
  - » **Concentrate on Square/Rectangular antenna designs using previous Square/Rectangular and Circular patch element designs**
  - » **Four-feeds with center ground pin**
  - » **Broadband-frequency Pattern Control**
    - **Consider multi-frequency performance L1/L5: 1575.42 & 1176.45 MHz**
    - **Other GNSS bands (e.g., GLONASS, Galileo)**

Going Forward (cont.)

- **Study Ground Plane Effects:**
  - » **Size: pervious work used a relatively small Ground Plane (e.g., 120mmx200mm); plan to expand**
    - **4 ft. diameter flat ground plane with rolled edge**
  - » **Shape, i.e., Curvature:**
    - **Implement ARINC 743A relatively large curved ground plane**
    - **Aircraft Body: TBD.**

Summary

- **Background - Previous Works on GNSS Patch Antennas**
  - » **1. Pattern Control**
  - » **2. Asymmetric Ground Plane Performance**
- **Going Forward - Pattern Control with an Asymmetric Ground Plane**
  - » **Pattern Control with Square Patch Antenna**
  - » **Broadband-frequency Pattern Control**
  - » **Ground Plane Effects (size, shape, curvature)**

GNSS Patch Antenna with Pattern Control for Aviation

Thank You !!!

Levi Moore
Ohio University

For additional information:
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Professor, School of EECS
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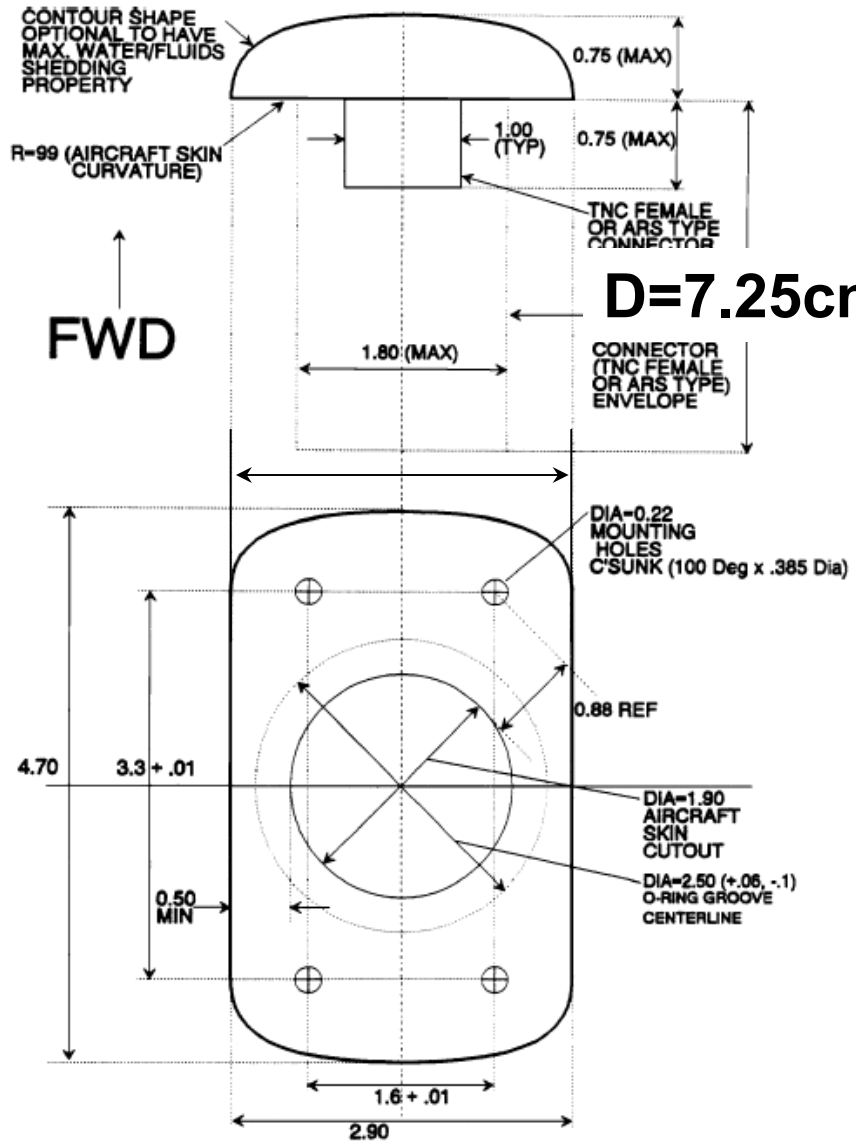
740-591-1660 (m)
bartone@ohio.edu

Additional Information

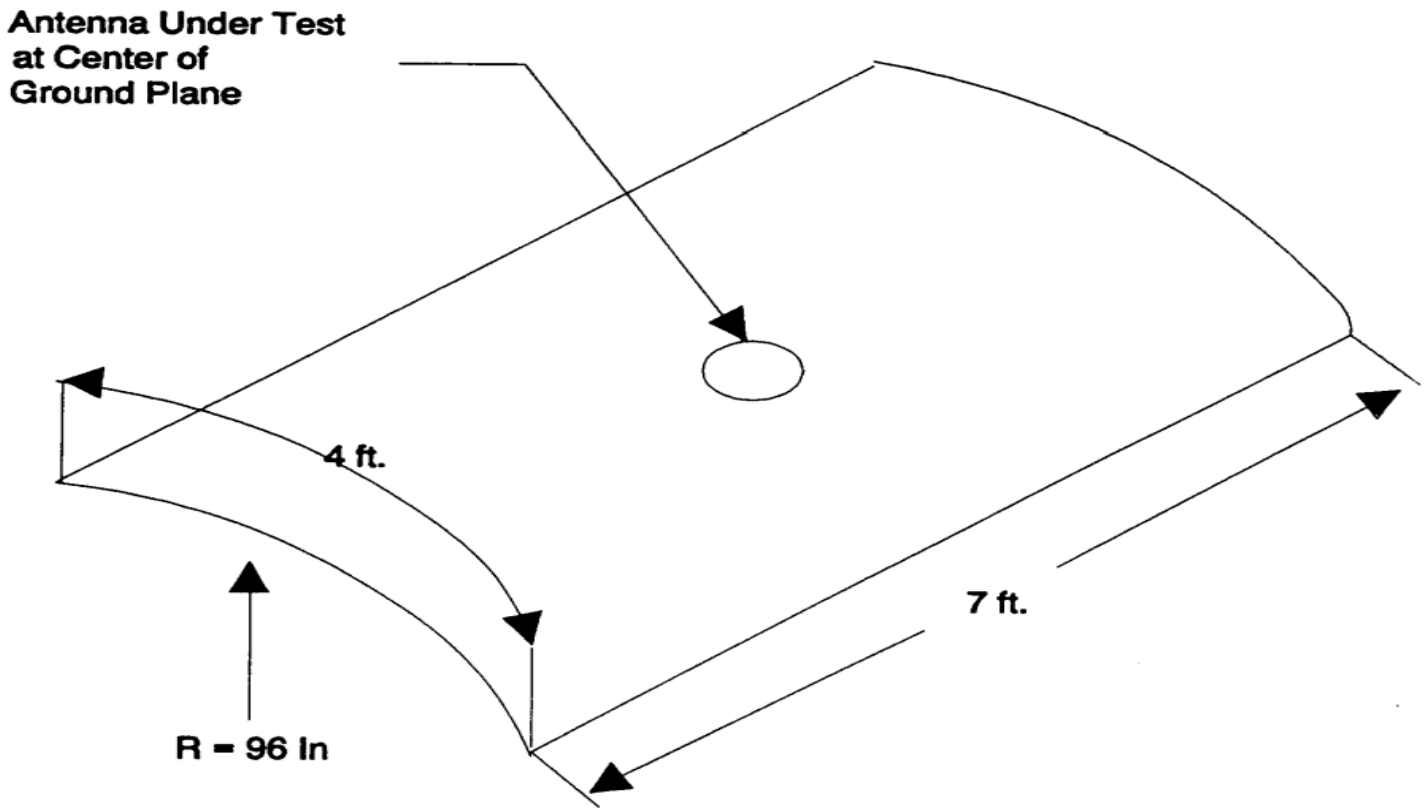
ARINC Civil GNSS Antenna for Aviation



D=7.25cm=2.95”

Ref: ARINC, GNSS SENSOR ARINC CHARACTERISTIC 743A-4, PUBLISHED: December 27, 2001

ARINC 743A Large Curved Ground Plane Specification



Ref: ARINC, GNSS SENSOR ARINC CHARACTERISTIC 743A-4, PUBLISHED: December 27, 2001