Single-aperture Patch Antenna with Pattern Control

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Acknowledgement

Ohio University
Internal Research and Development

Outline

- Introduction
- Design configuration
- Computational Electromagnetic Model (CEM) simulations
  - Baseline results
  - Pattern control results (Azimuth Pattern Control)
- Fabrication and Test Results
  - Component level results
  - Anechoic chamber results
- Conclusions

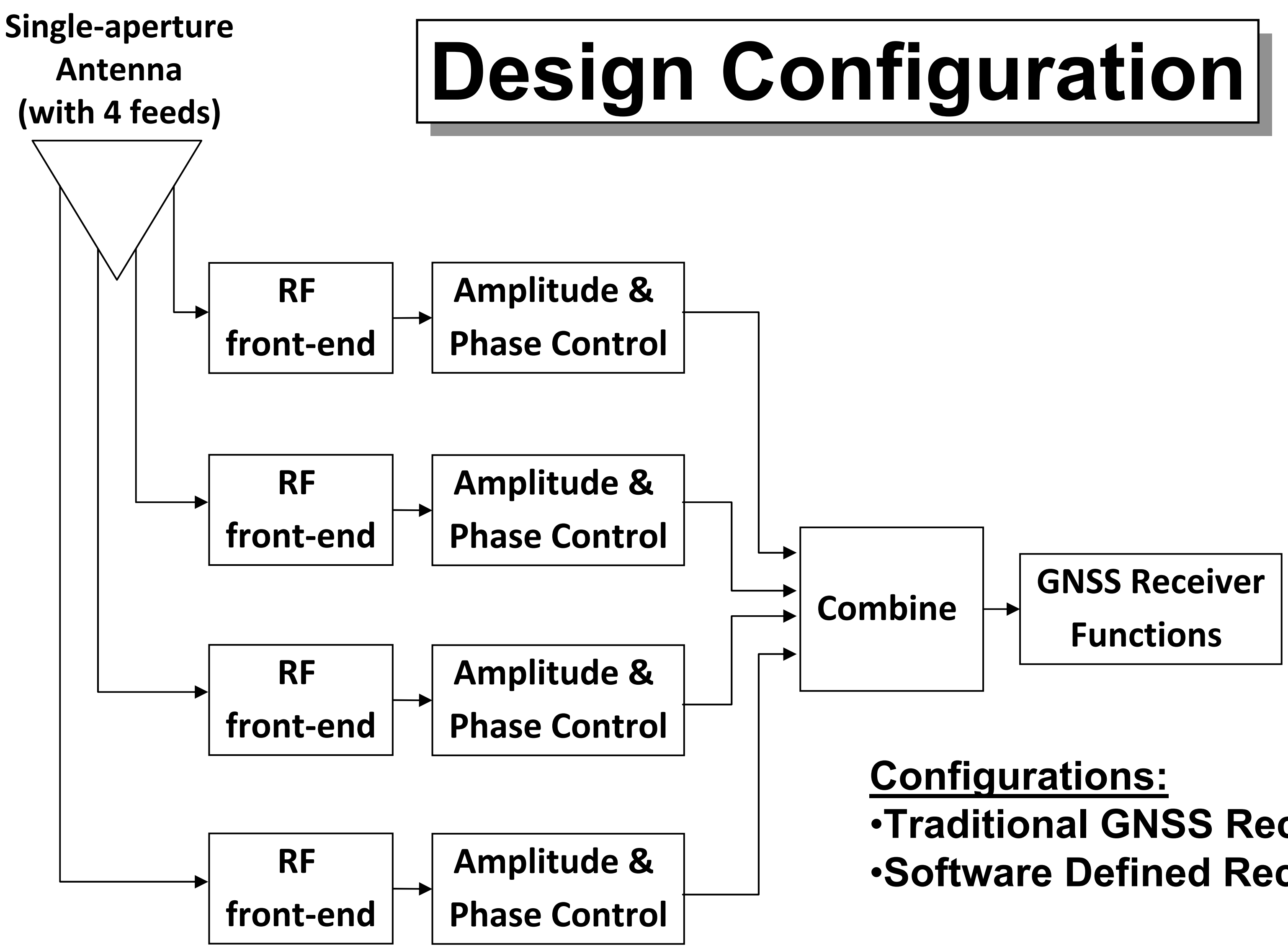
Introduction

- **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**

Design Configuration

- **A single-aperture (i.e., single-element) GNSS patch antenna with pattern control:**
  - » **GNSS L5 frequency selected**
  - » **Circular symmetry configuration selected:**
    - **Circular patch element, substrate, ground plane (120mm & 2 ft), and 4-feed probe structure illustrated here**
  - » **Amplitude and Phase Control Subsystem**
- **Analytical cavity model design used, then refined with CEM CST**
  - » **Time & <u>frequency domain</u> solvers with waveport**
- **Substrate selection: Higher relative permittivity; to support wide bandwidth signal and ARINC 743A mounting requirements.**

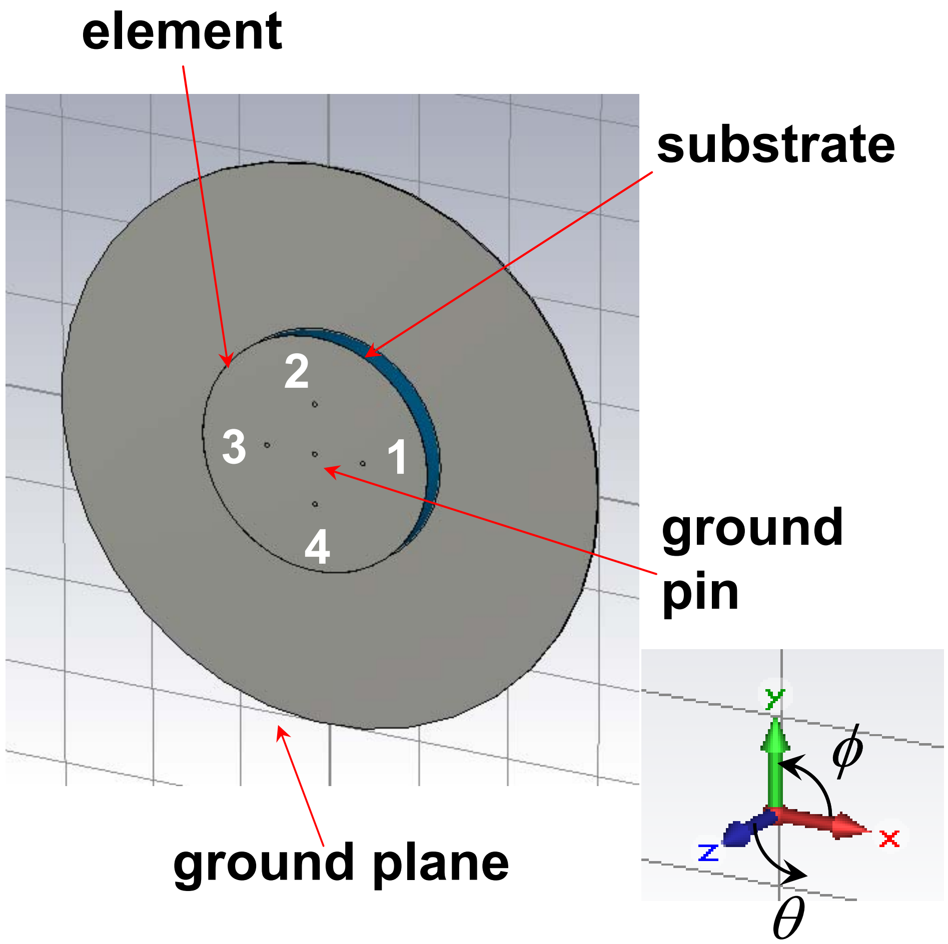
Design Configuration



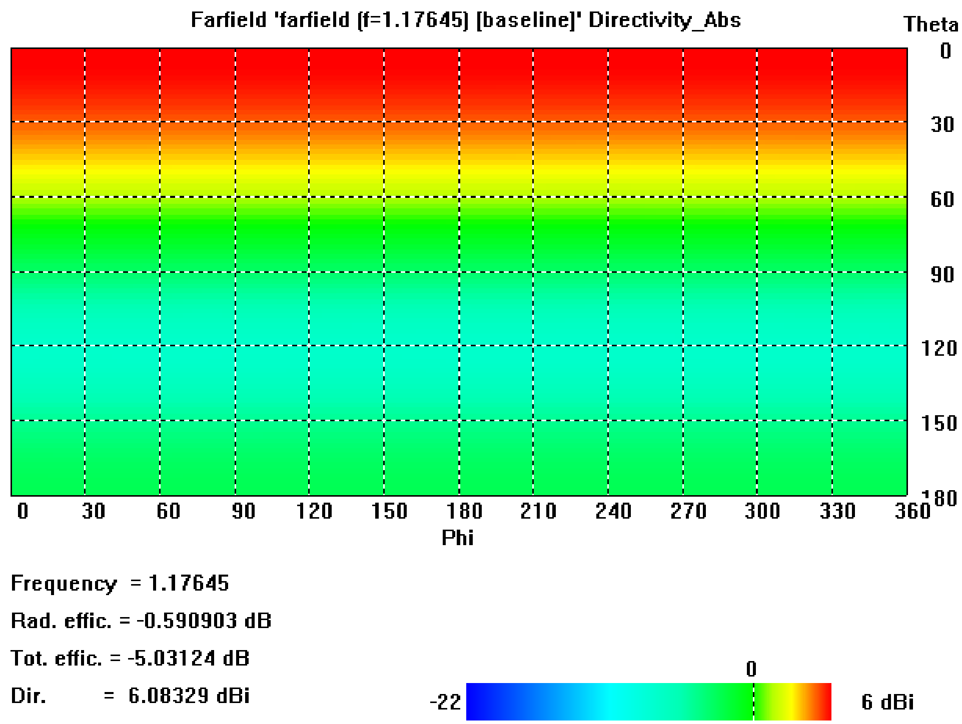
Configurations:
- Traditional GNSS Receiver
- Software Defined Receiver

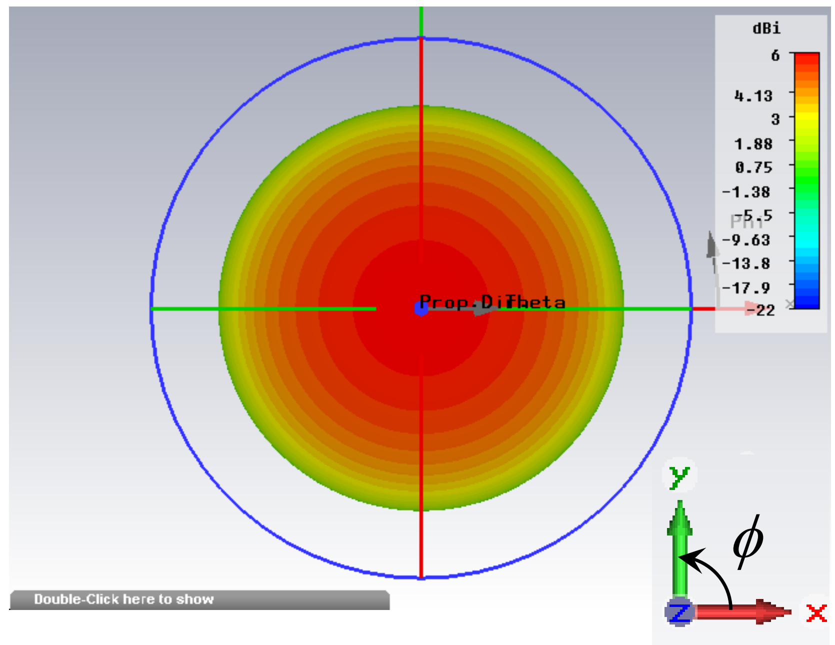
GNSS L5 Single-aperture Patch Antenna

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



Four-feed Circular Patch Phase [0 90 180 270] – Baseline Results





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

Phase Control Summary for Pattern Control

- **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):

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

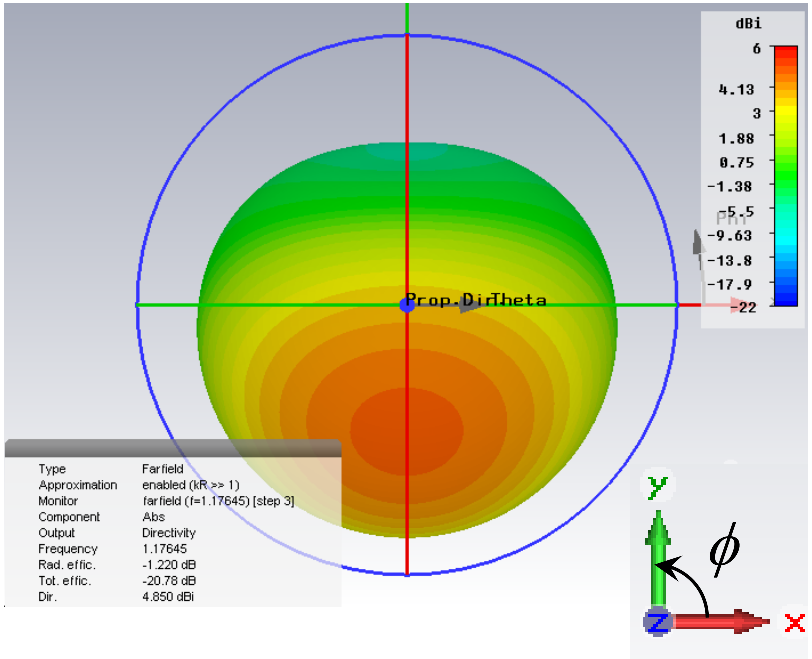
$\Delta\gamma_{OPP}$ = ***20 deg in CEM simulations, 80 deg in chamber***

$\gamma_2 - \Delta\gamma_{OPP} < \Delta\gamma_{ADJ} < \gamma_2 + \Delta\gamma_{OPP}$, **to scan pattern in azimuth.**

- **Steps 0 (baseline), and 5, 14, 23, 32 illustrated here.**

Pattern Control: [0 90 20 90]-<u>First</u> Quadrant

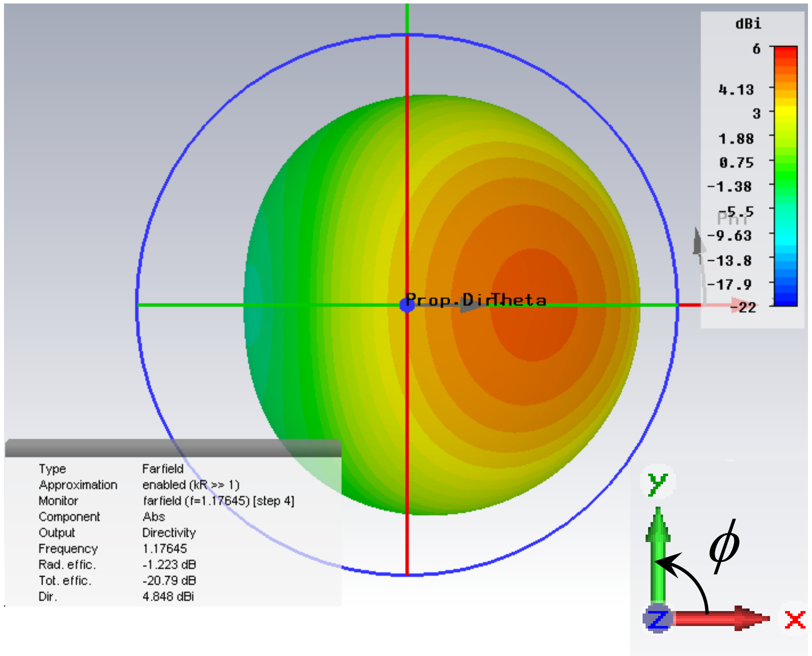
	Port Number			
Quadrant	1	2	3	4
1	0	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$
2	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	0
3	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	0	$\Delta\gamma_{POL}$
4	$\Delta\gamma_{ADJ}$	0	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$



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

Pattern Control: [90 20 90 0]-<u>Second</u> Quadrant

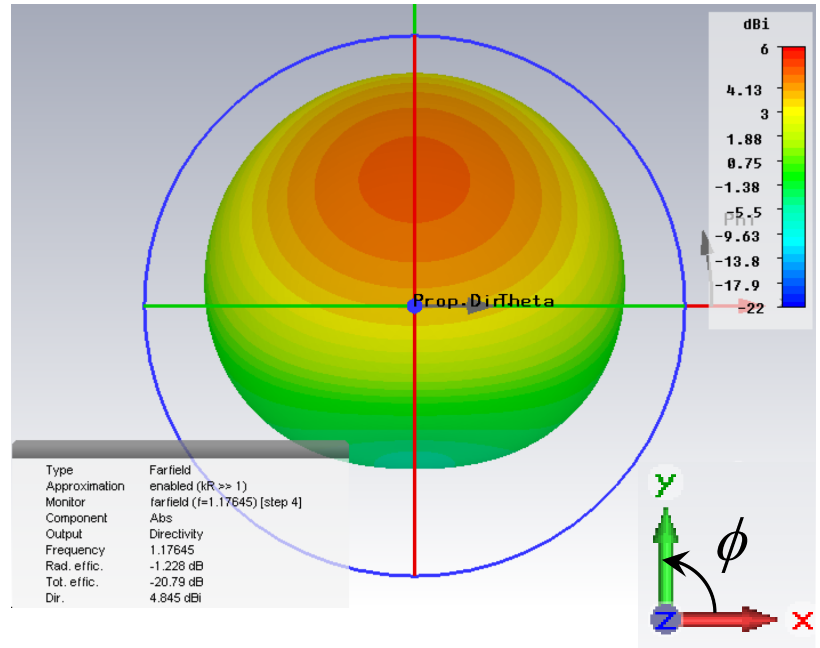
	Port Number			
Quadrant	**1**	**2**	**3**	**4**
1	**0**	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$
2	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	**0**
3	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	**0**	$\Delta\gamma_{POL}$
4	$\Delta\gamma_{ADJ}$	**0**	$\Delta\gamma_{POL}$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



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

Pattern Control: [20 90 0 90]-<u>Third</u> Quadrant

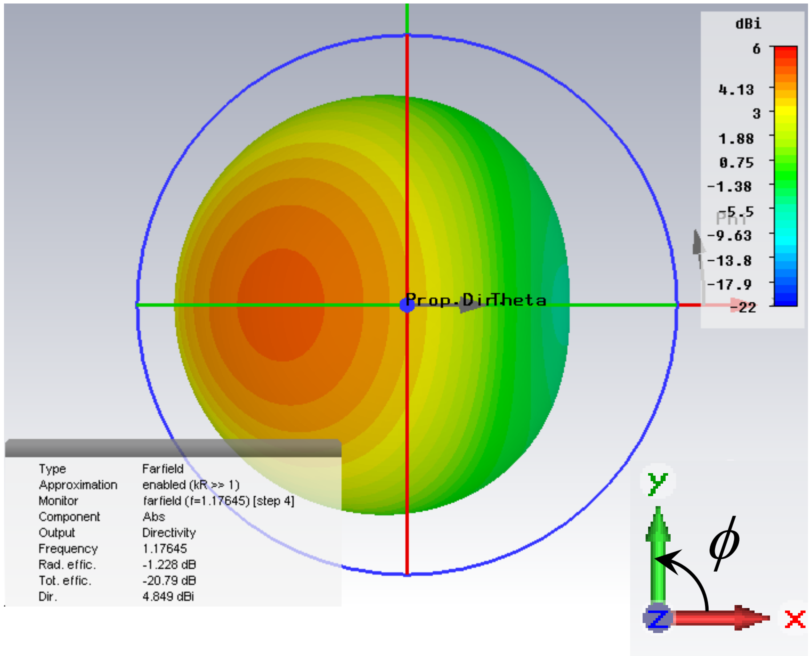
	Port Number			
Quadrant	**1**	**2**	**3**	**4**
1	**0**	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$
2	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	**0**
3	$\Delta\gamma_{OPP}$	$\Delta\gamma_{ADJ}$	**0**	$\Delta\gamma_{POL}$
4	$\Delta\gamma_{ADJ}$	**0**	$\Delta\gamma_{POL}$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



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

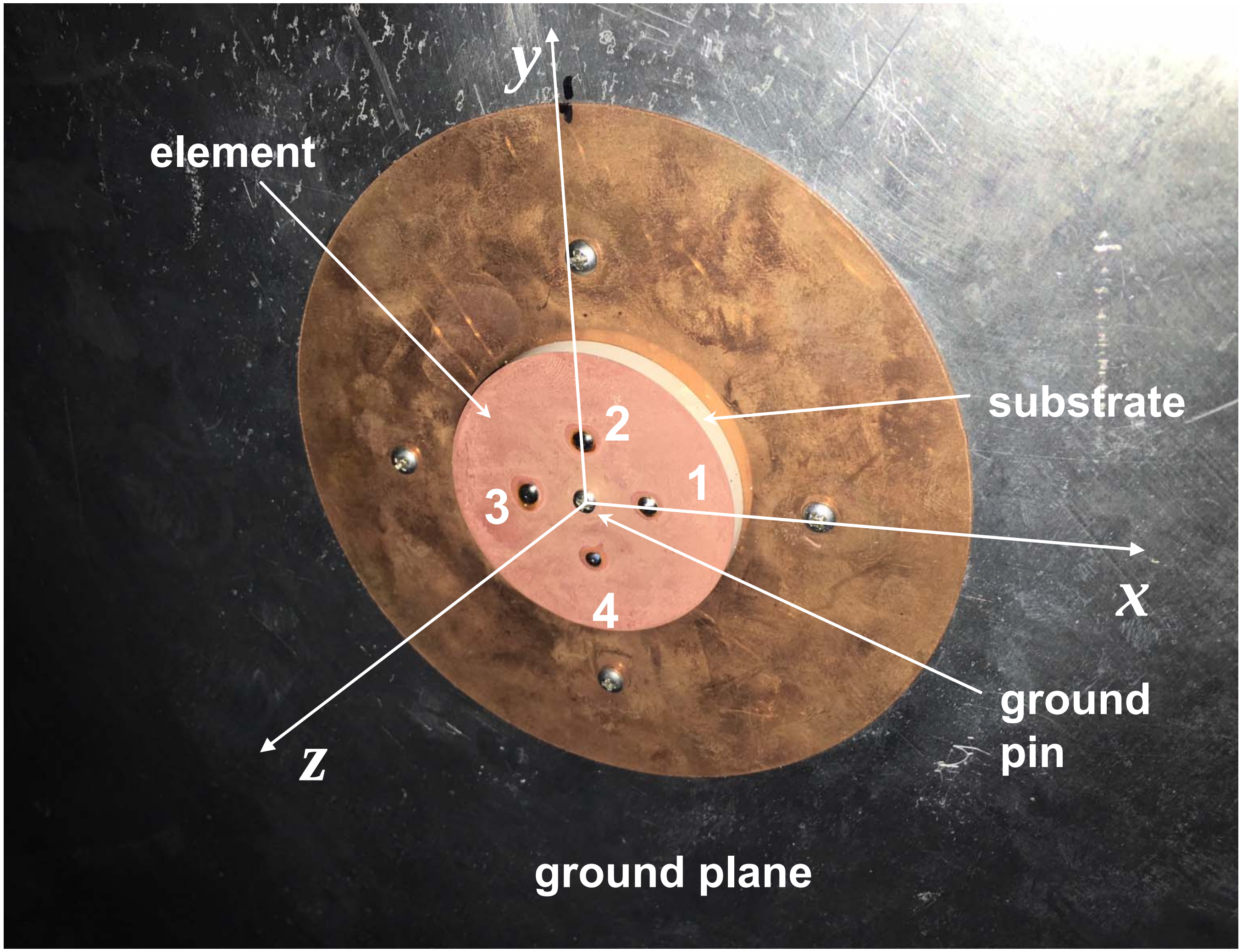
Pattern Control: [90 0 90 20]-Fourth Quadrant

	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	$\Delta\gamma_{POL}$	$\Delta\gamma_{OPP}$

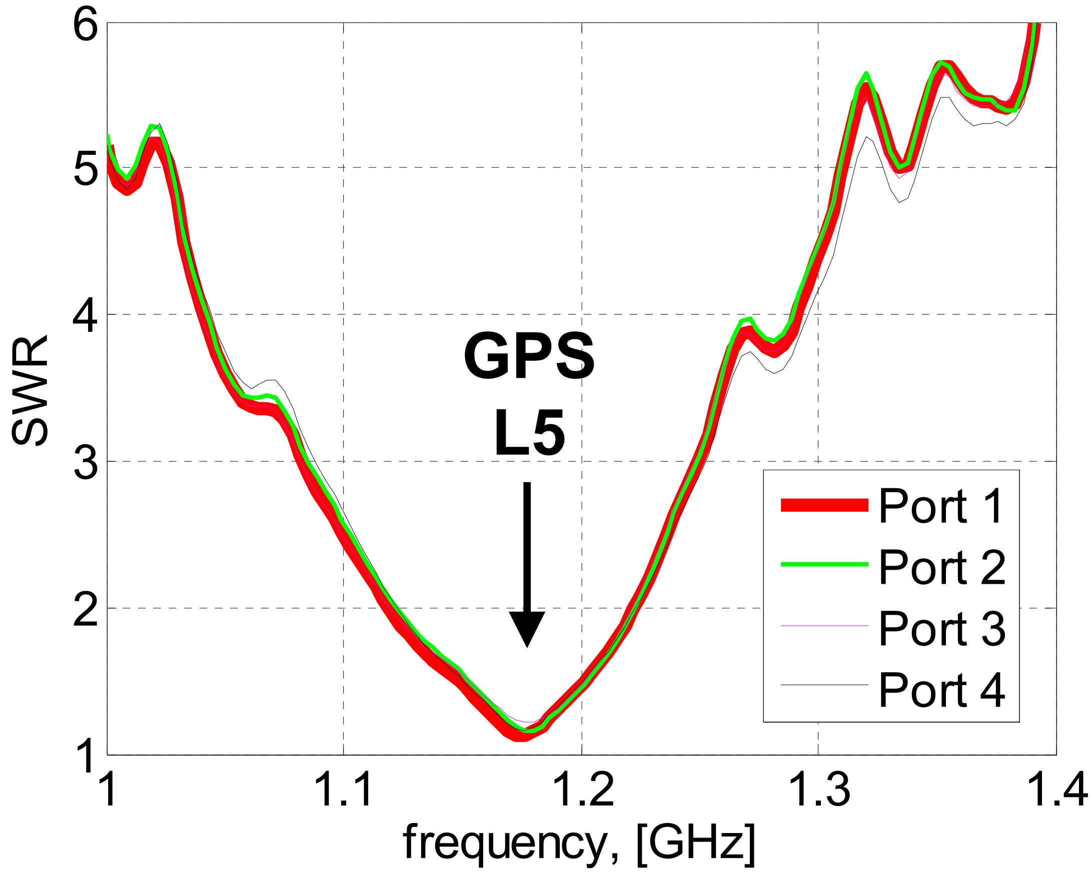


Step	Feed 1 phase (deg)	Feed 2 phase (deg)	Feed 3 phase (deg)	Feed 4 phase (deg)
32	90	0	90	20

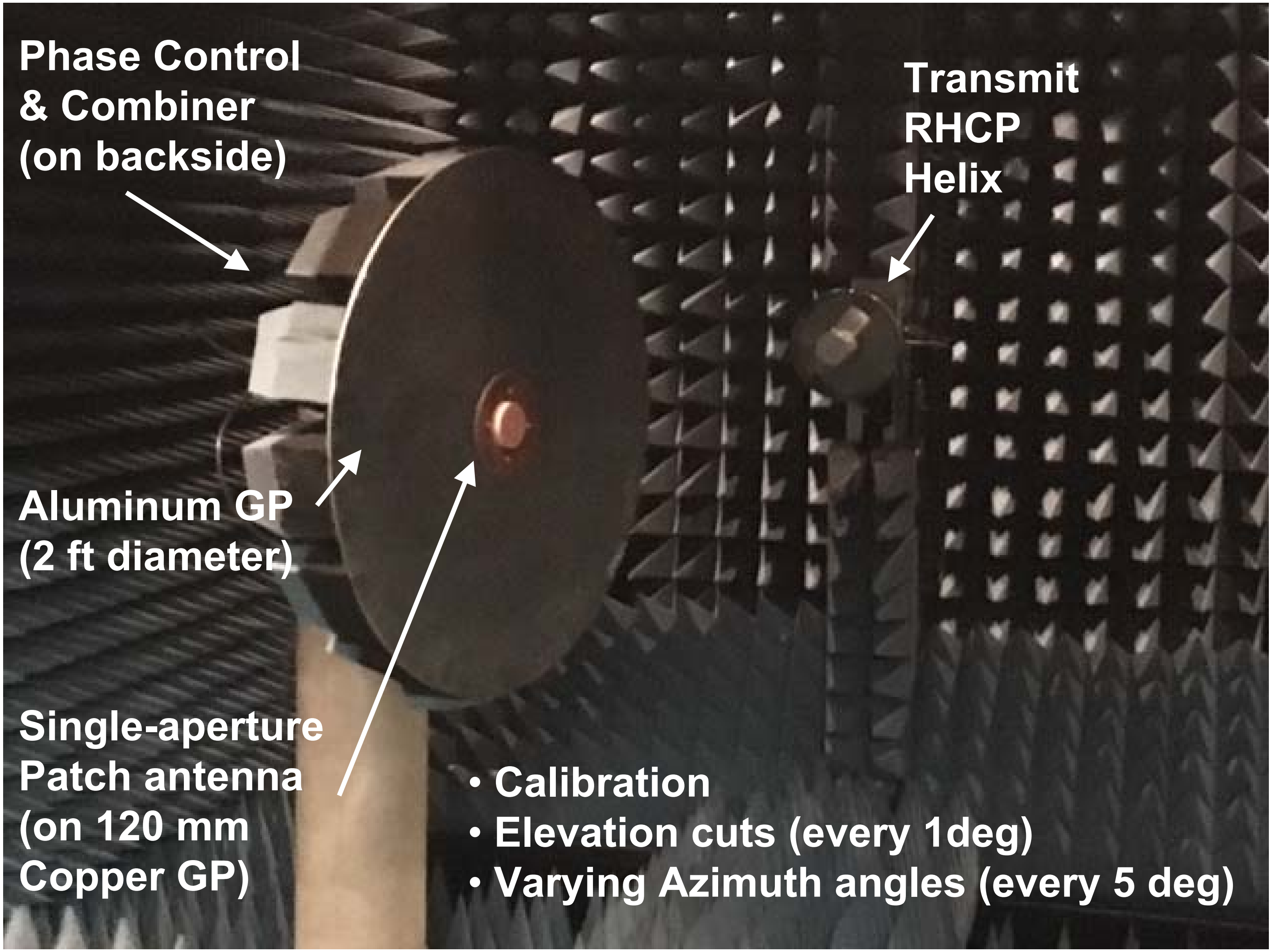
Fabricated GNSS L5 Circular Patch, 4 probe feeds



Fabricated GNSS L5 Circular Patch, 4 probe feeds



- **Excellent match on each port**
- **Excellent agreement between ports**
- **Bandwidth of each port:**
  - **~ 100MHz (2:1 SWR metric)**

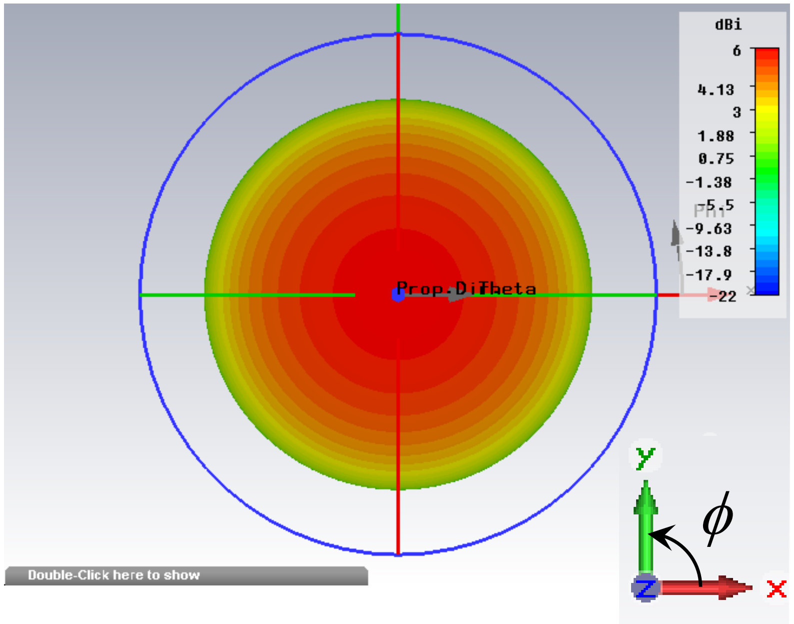

Phase Control
& Combiner
(on backside)
Transmit
RHCP
Helix
Aluminum GP
(2 ft diameter)
Single-aperture
Patch antenna
(on 120 mm
Copper GP)
• Calibration
• Elevation cuts (every 1deg)
• Varying Azimuth angles (every 5 deg)

Calibration Considerations

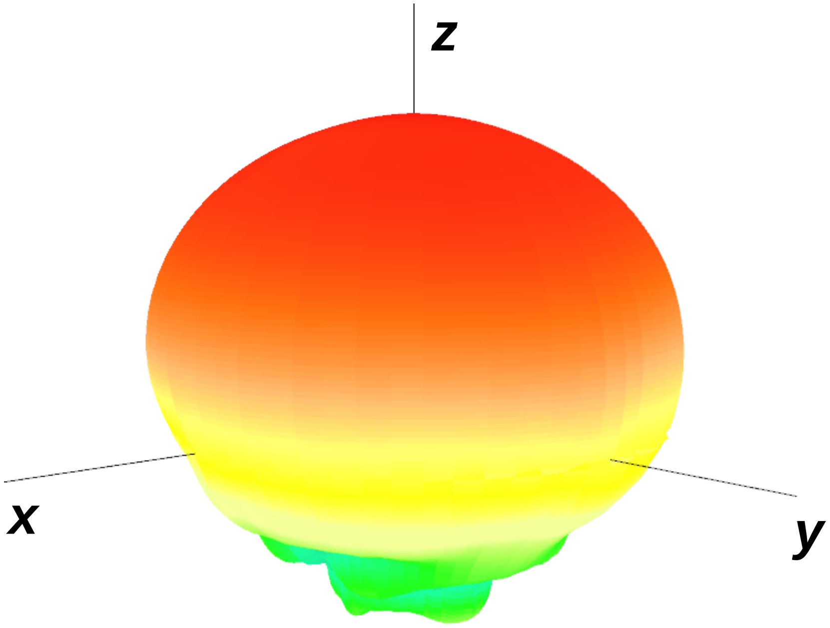
- **Phase shifter bench checked directly to VNA.**
- **L-band RHCP Helix transmission antenna used**
  - » **AUT rotated to 4 port positions (with phase shifter bypassed)**
    - **Phase measurement not exactly 90 deg apart at each port location; as much as 13 deg off.**
- **Port path calibration (with phase shifter in place) at boresight**
  - » **Measured phase at each port, in 10deg steps**
  - » **Developed phase calibration table, at boresight, and used for final commanded phase settings.**

Step 0: Baseline with phases [0 90 180 270]

CEM CST Simulation Results



Anechoic Chamber Measured Results

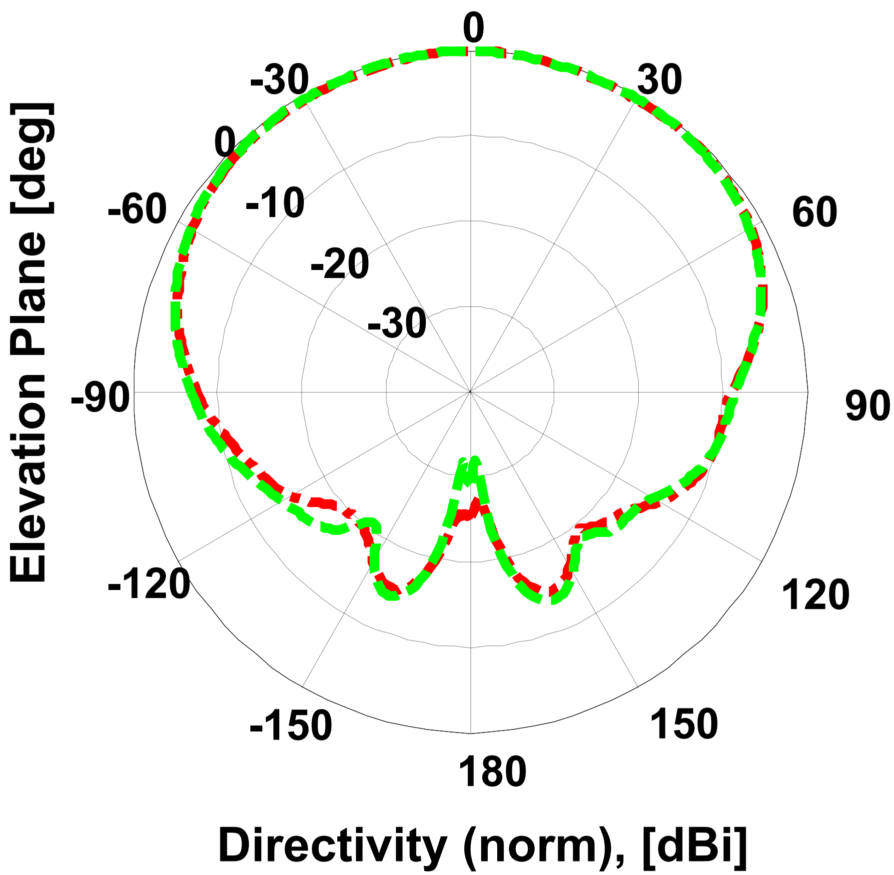


- **Measured results consistent with CEM results**

Ref: Step 0: se[0_90_180_270]{311_26_109_213}ff36apr5_16.DF1, Apr 5, 2016, 12:24pm

Step 0: Baseline with phases [0 90 180 270]

Baseline Phase Control: [0 90 180 270]



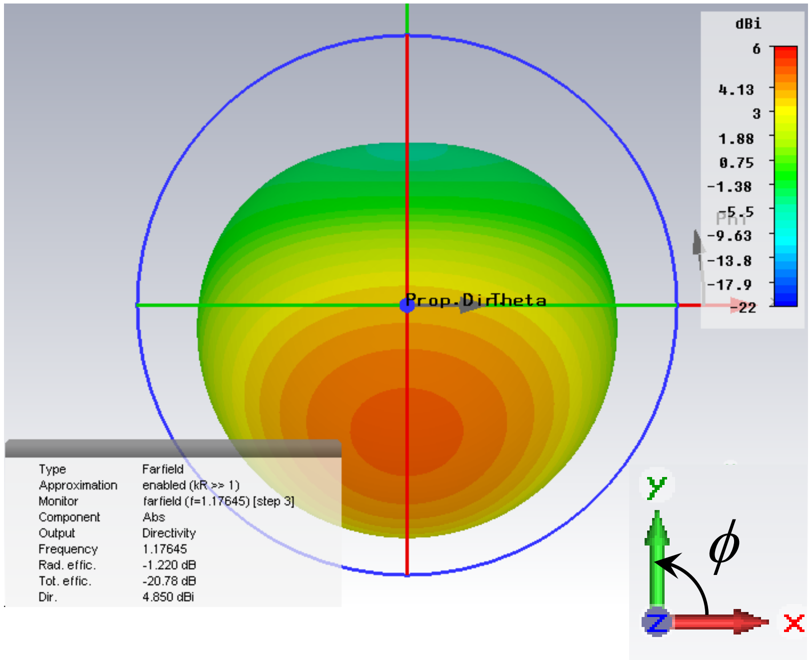
P1 & P3 plane, LS: ϕ = 0 deg, RS: ϕ =180deg
P2 & P4 plane, LS: ϕ =90deg, RS: ϕ =270deg

Filled later for comparison to Baseline on Left

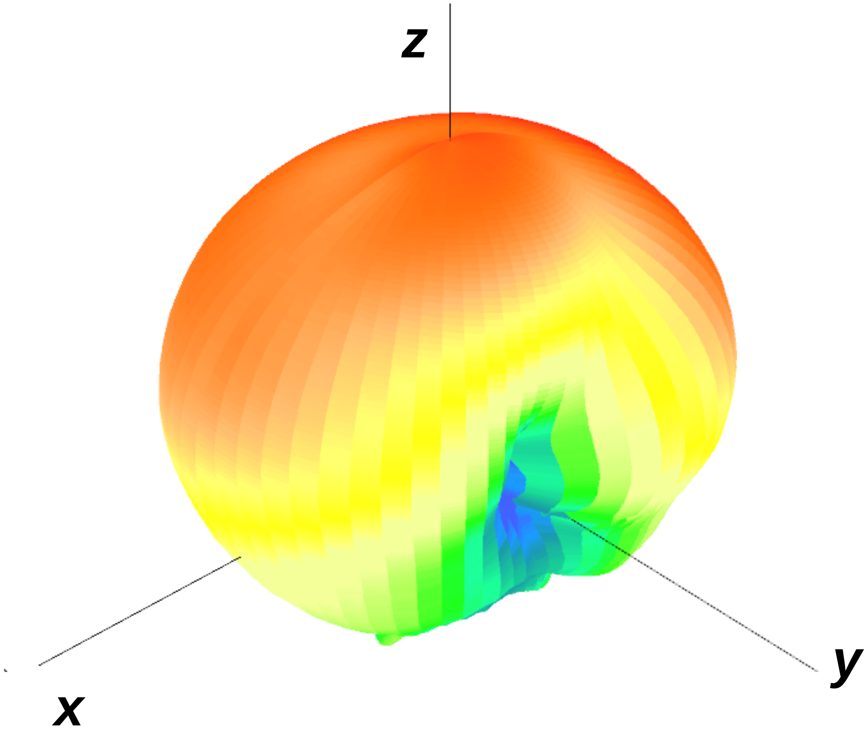
Ref: Step 0: se[0_90_180_270]{311_26_109_213}apr5_16.DF1, Apr 5, 2016, 12:24pm

Pattern Control: [0 90 80 90]-First Quadrant

CEM CST Simulation Results

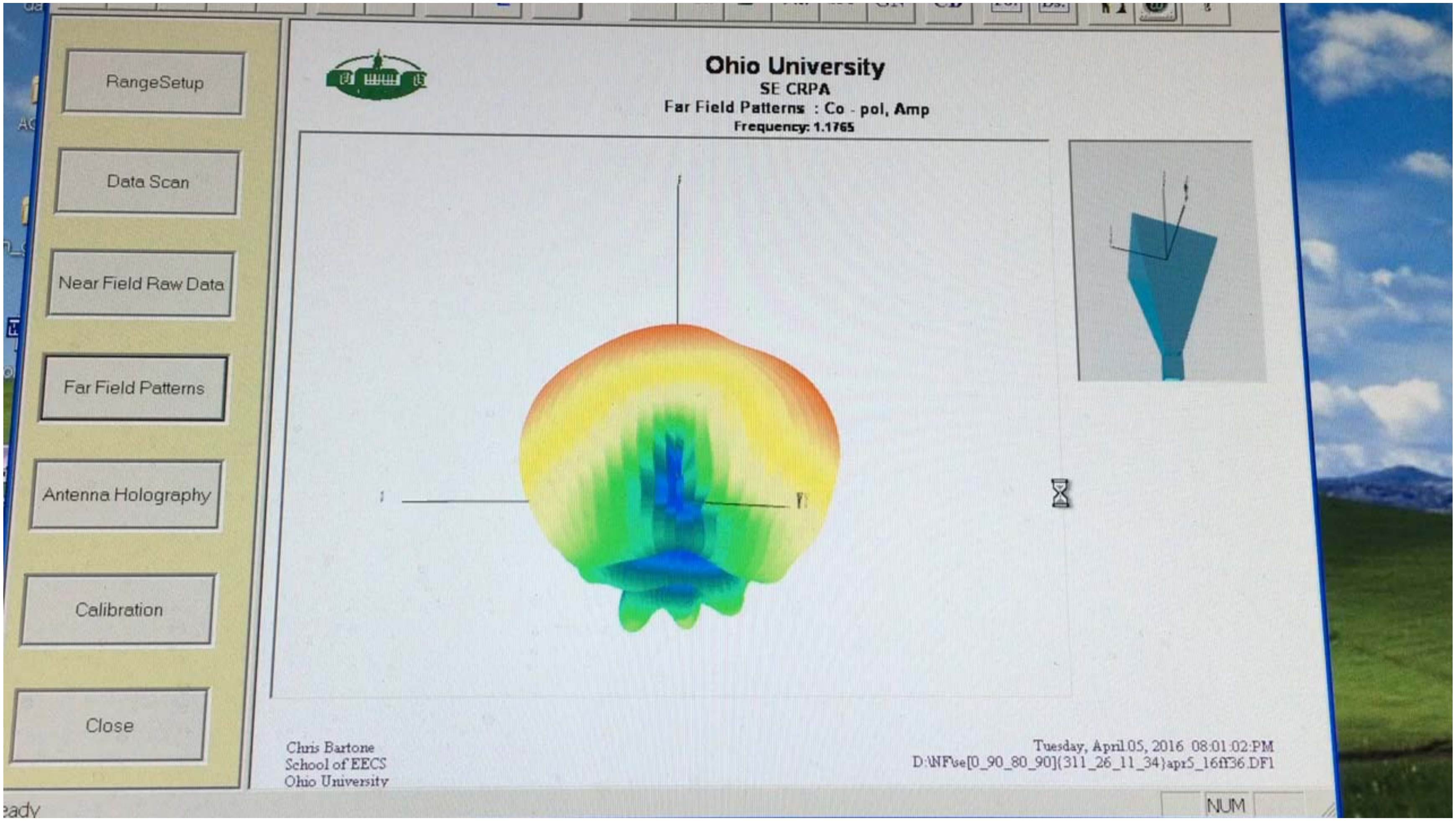


Anechoic Chamber Measured Results



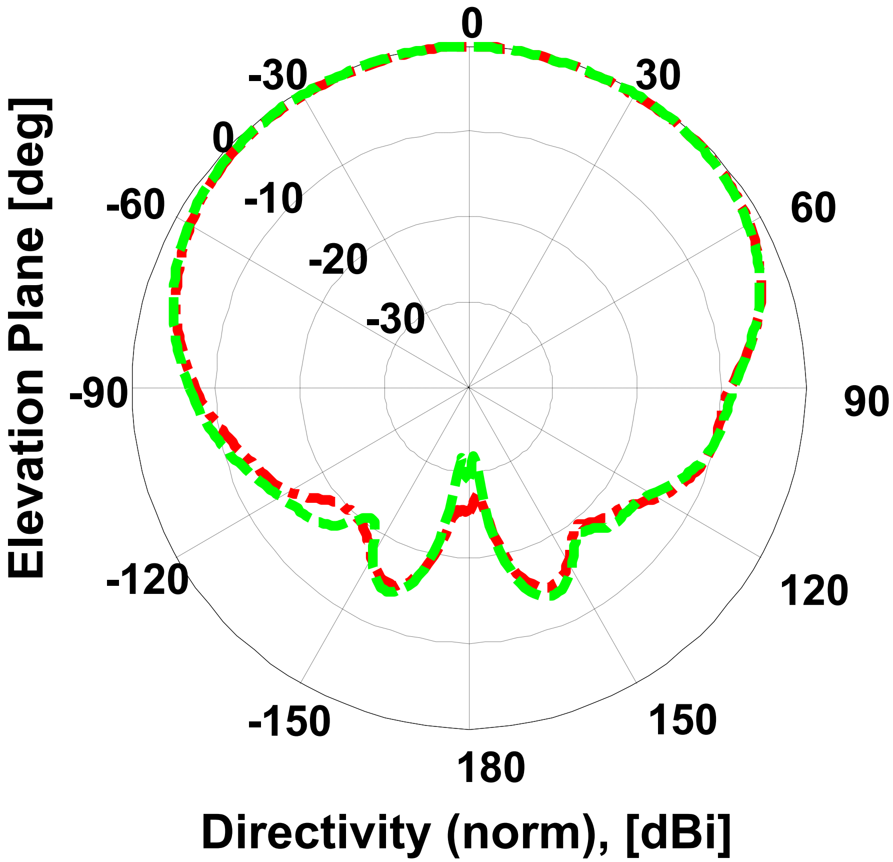
- "High" directivity toward phi=270deg
- "Low" directivity towards phi=90deg
- Measured results consistent with CEM results

Pattern Control: [0 90 80 90]-First Quadrant

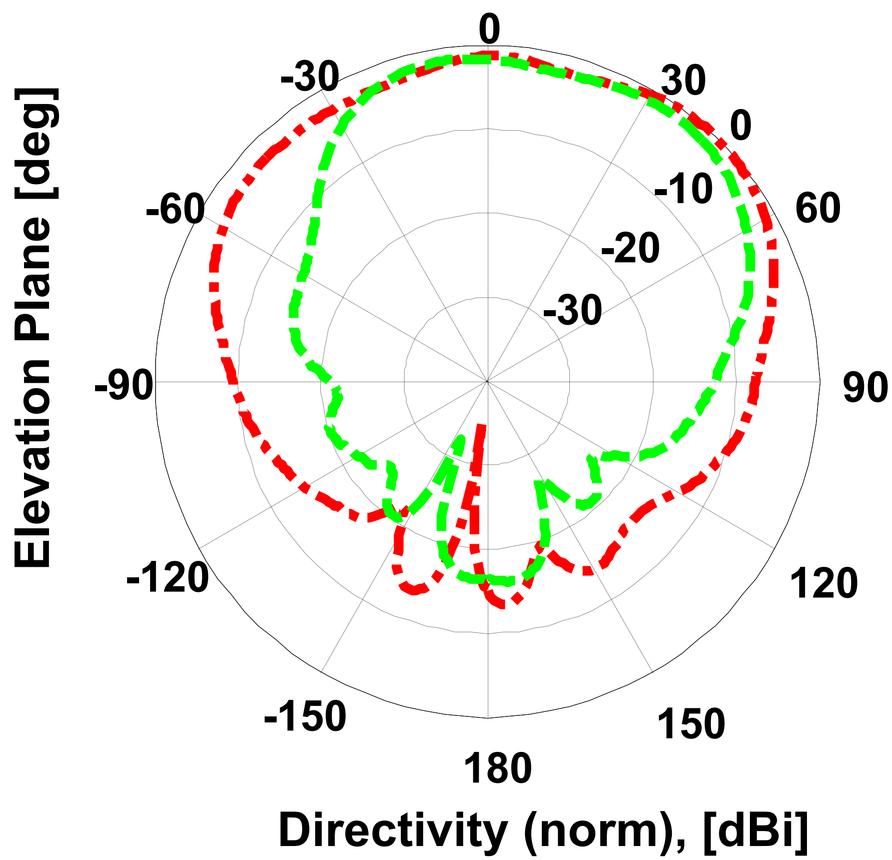


Pattern Control-AZ-First Quadrant

Baseline Phase Control: [0 90 180 270]

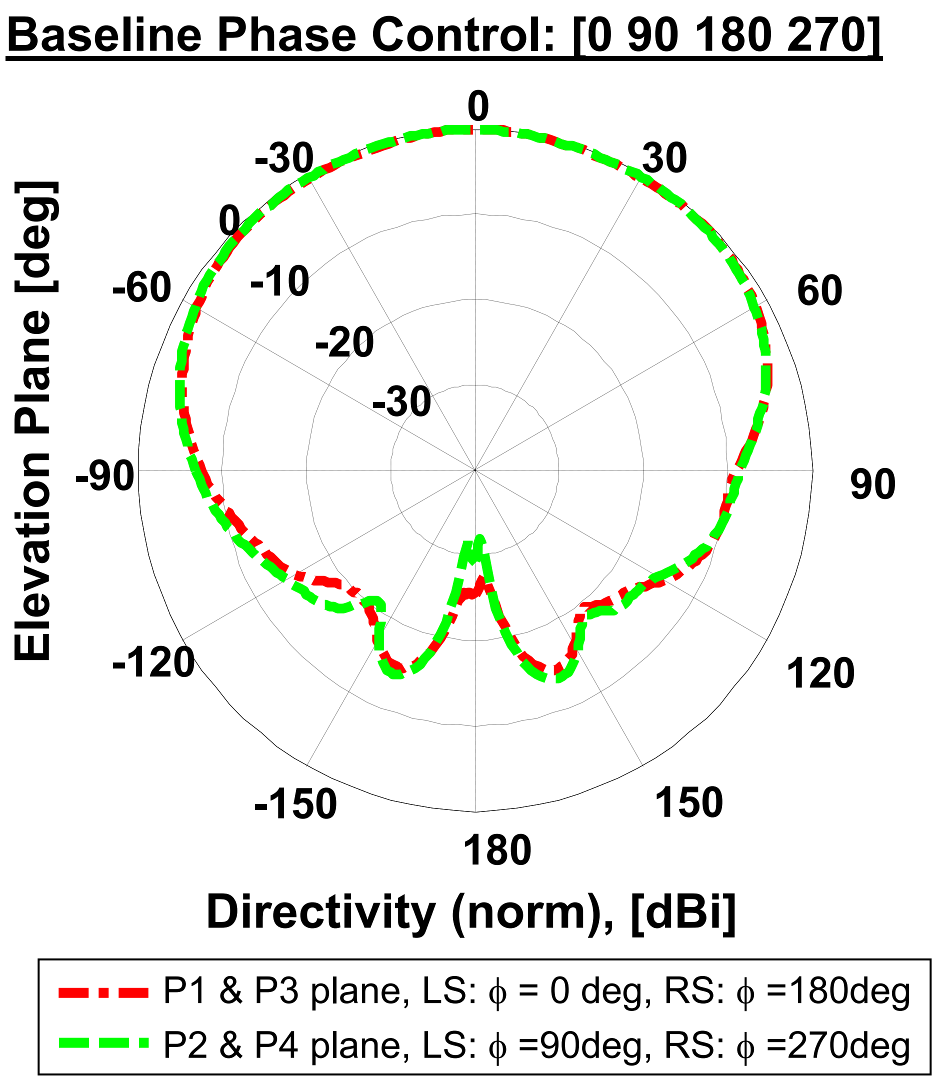


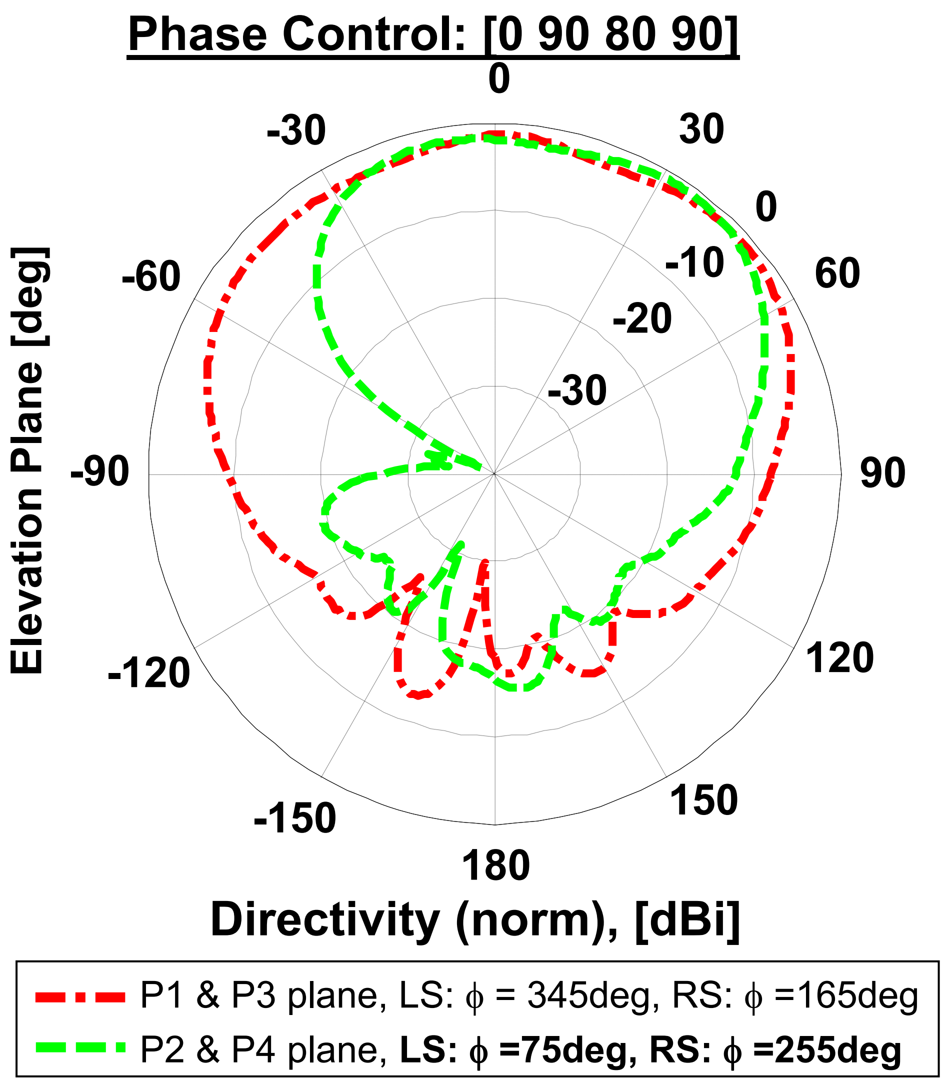
Phase Control: [0 90 80 90]



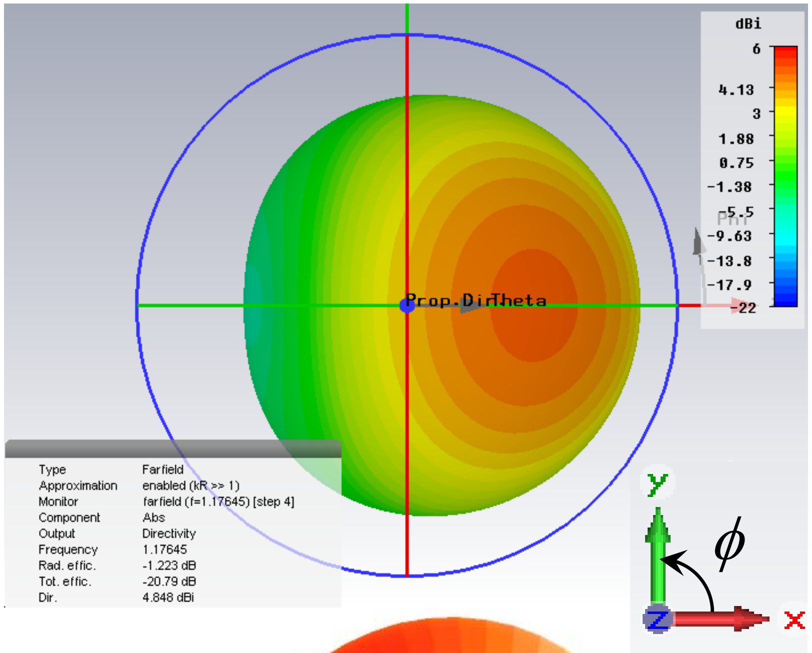
P1 & P3 plane, LS: ϕ = 0 deg, RS: ϕ =180deg
P2 & P4 plane, LS: ϕ =90deg, RS: ϕ =270deg

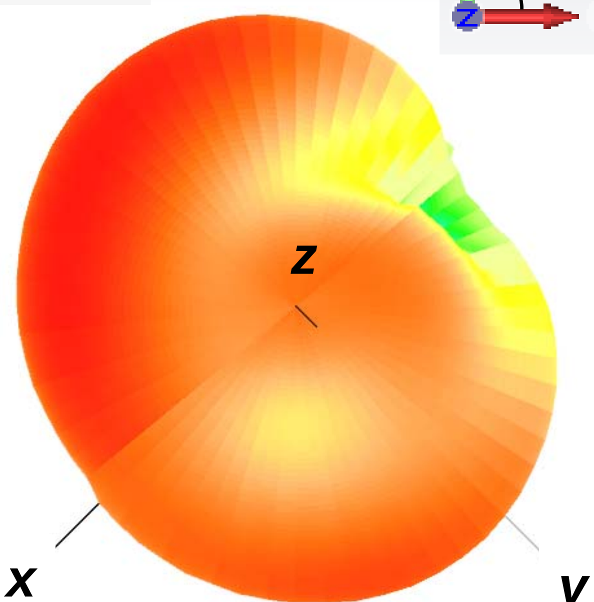
Pattern Control-AZ-First Quadrant

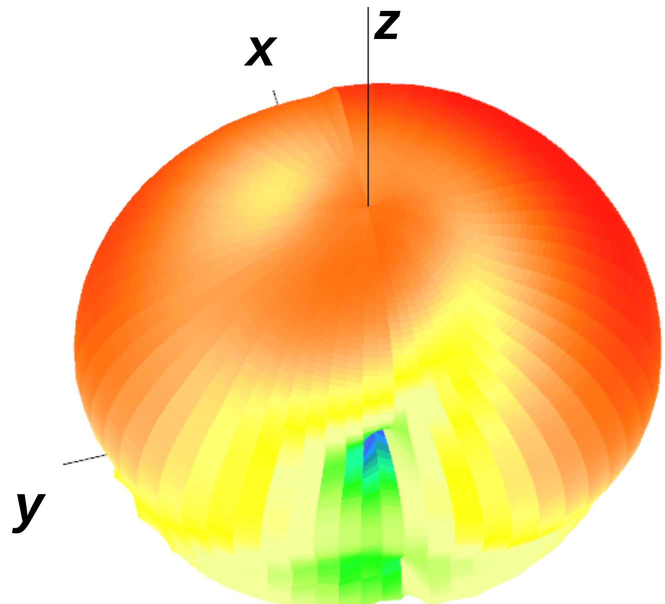




Pattern Control-AZ-Second Quadrant



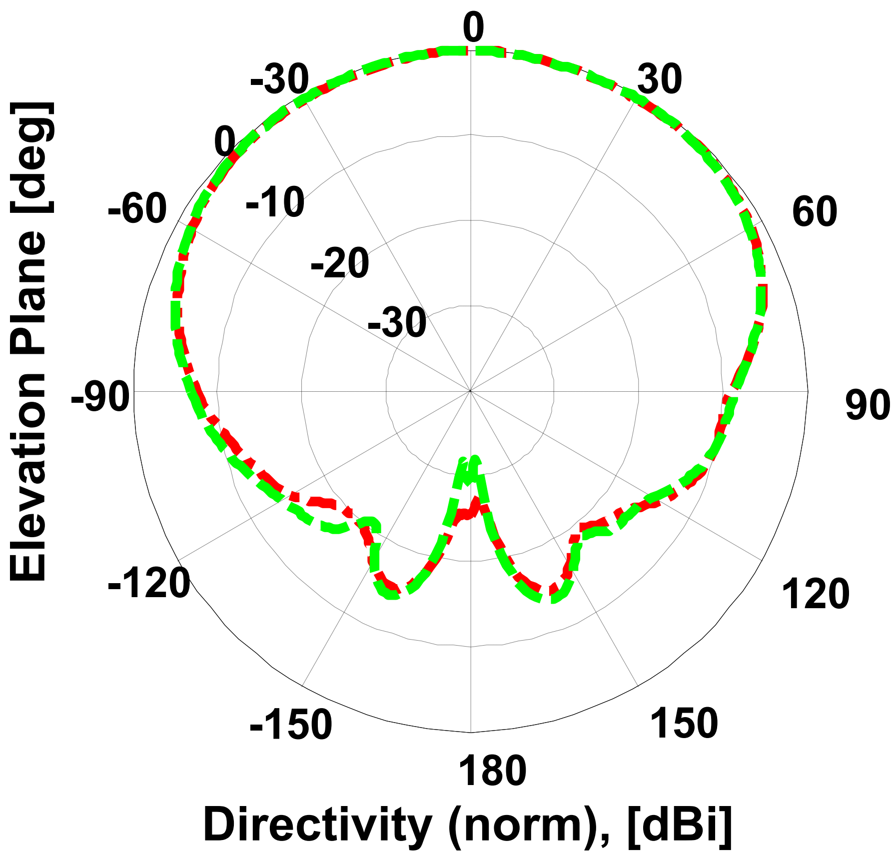




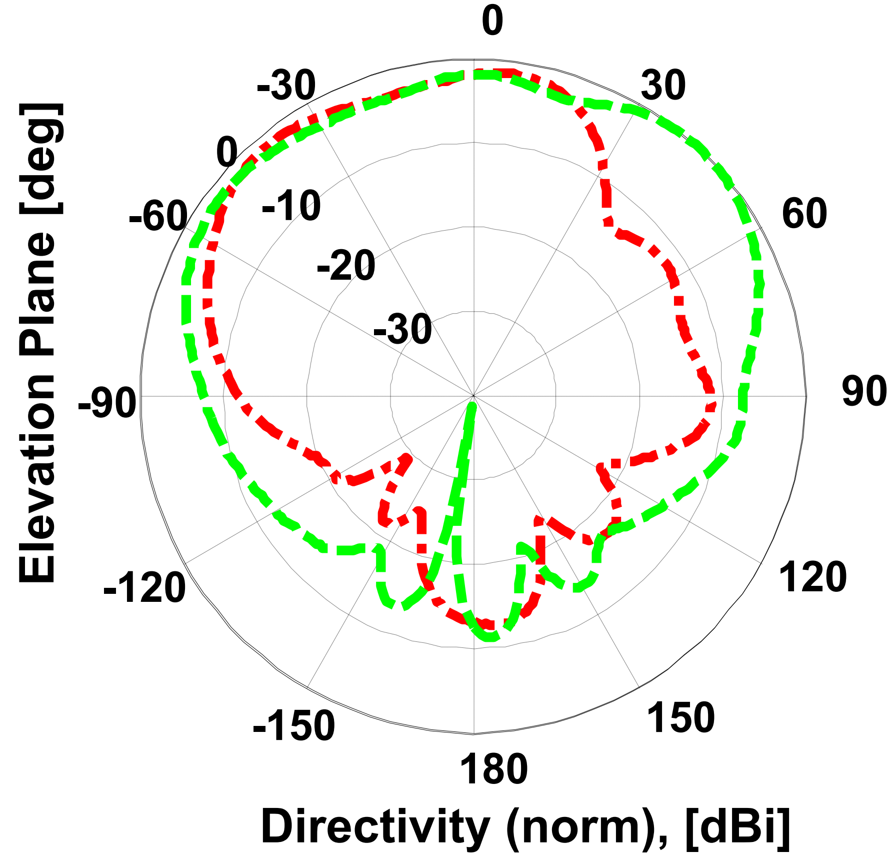
- "High" directivity toward phi=0deg
- "Low" directivity towards phi=180deg
- Measured results consistent with CEM results

Pattern Control-AZ-Second Quadrant

Baseline Phase Control: [0 90 180 270]



Phase Control: [90 80 90 0]

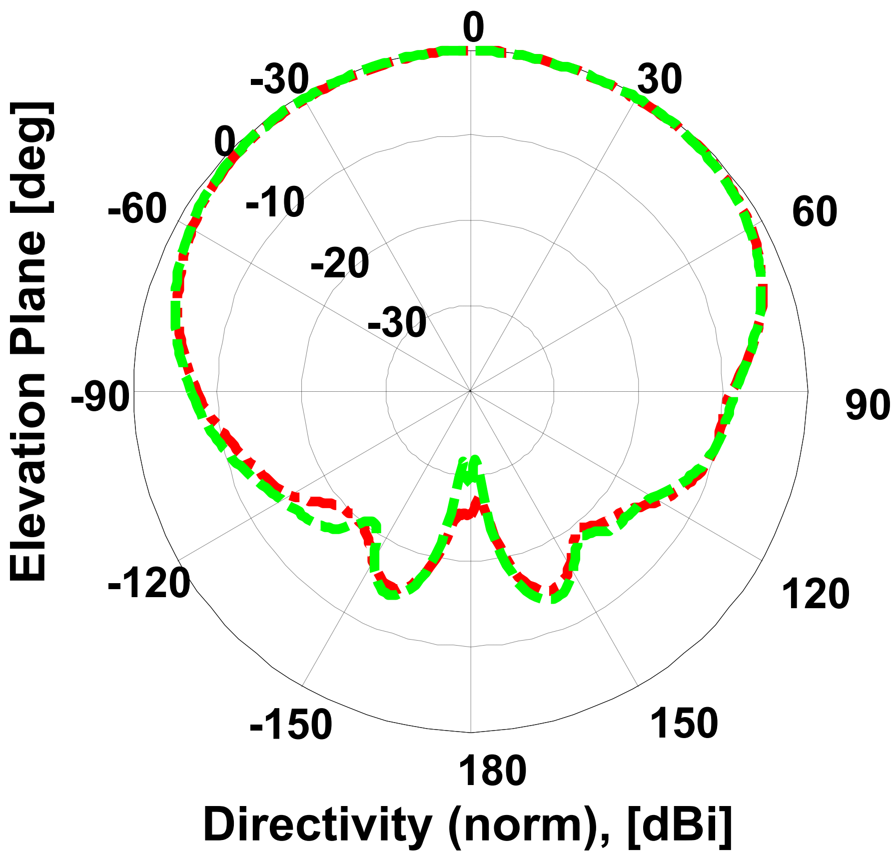


P1 & P3 plane, LS: ϕ = 0 deg, RS: ϕ =180deg

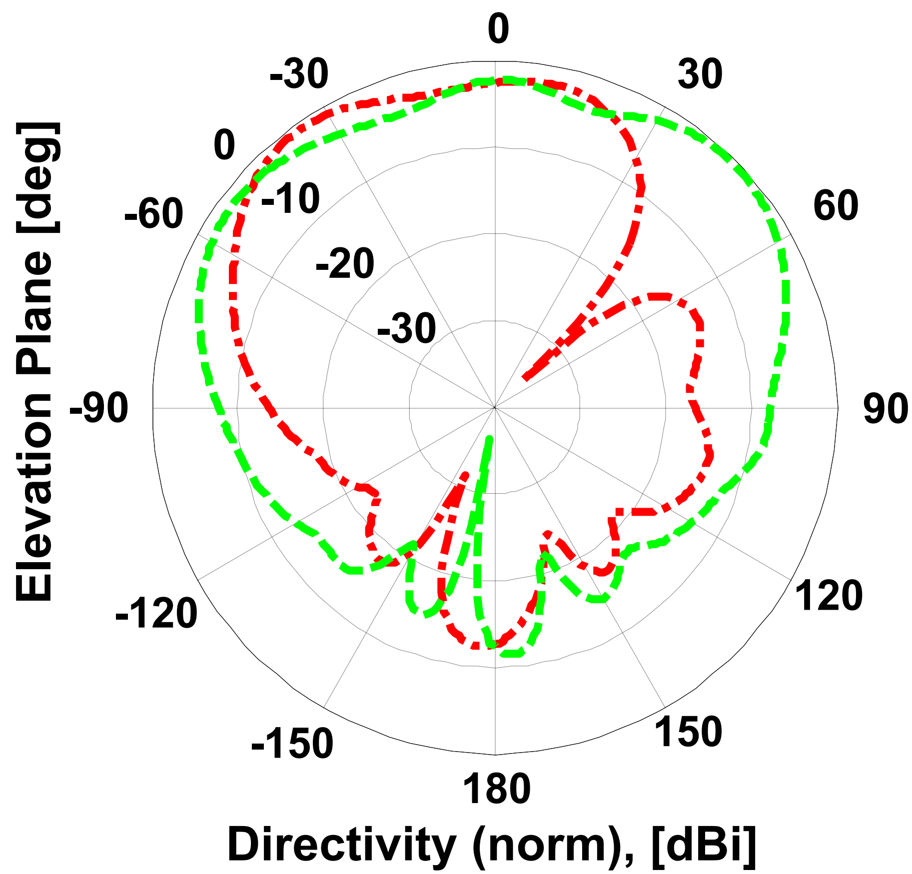
P2 & P4 plane, LS: ϕ =90deg, RS: ϕ =270deg

Pattern Control-AZ-Second Quadrant

Baseline Phase Control: [0 90 180 270]



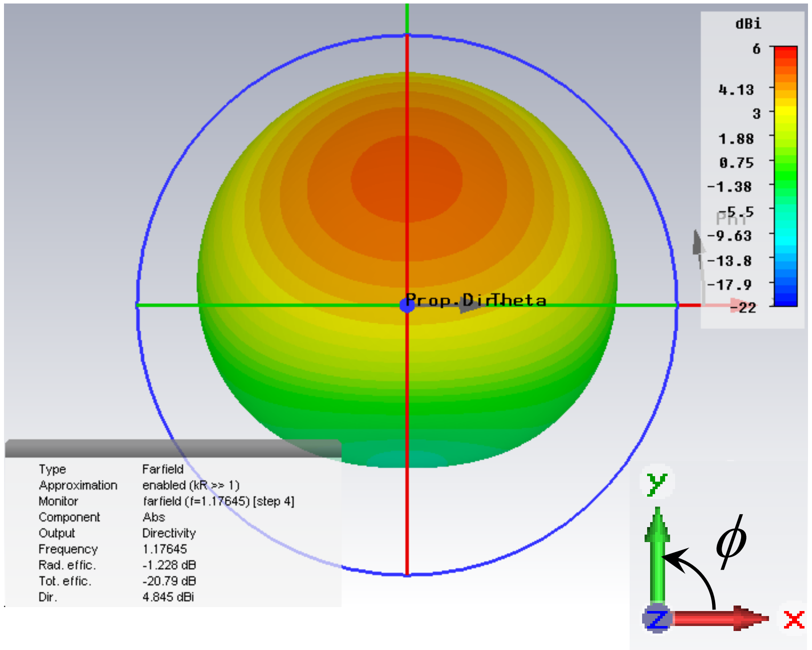
Phase Control: [90 80 90 0]

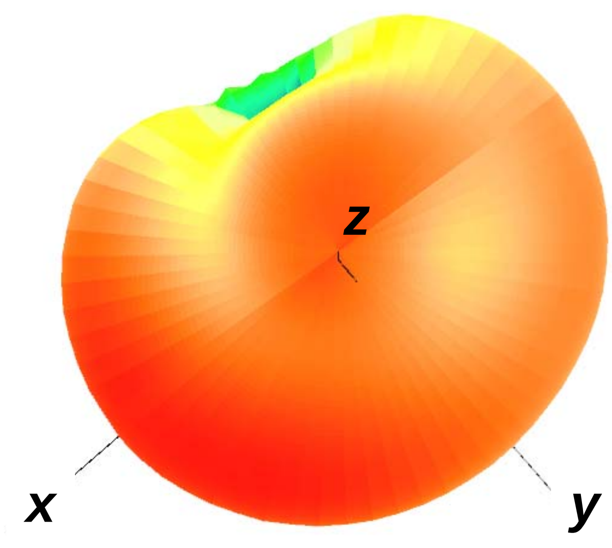


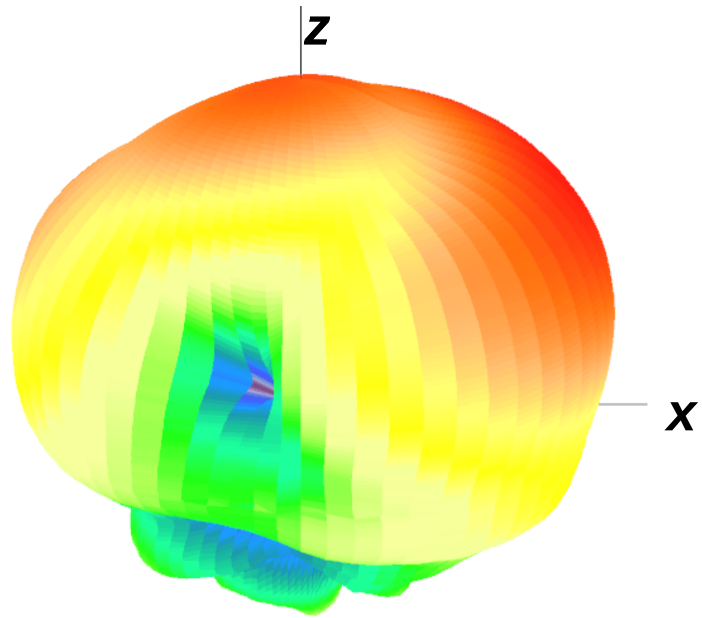
P1 & P3 plane, **LS: ϕ = 350 deg, RS: ϕ =170deg**
P2 & P4 plane, LS: ϕ =80deg, RS: ϕ =260deg

Ref: Step 14: se[90_80_90_0]{45_16_19_302}ff36apr5_16.DF1, Apr 7, 2016, 2:47pm

Pattern Control-
AZ-Third Quadrant



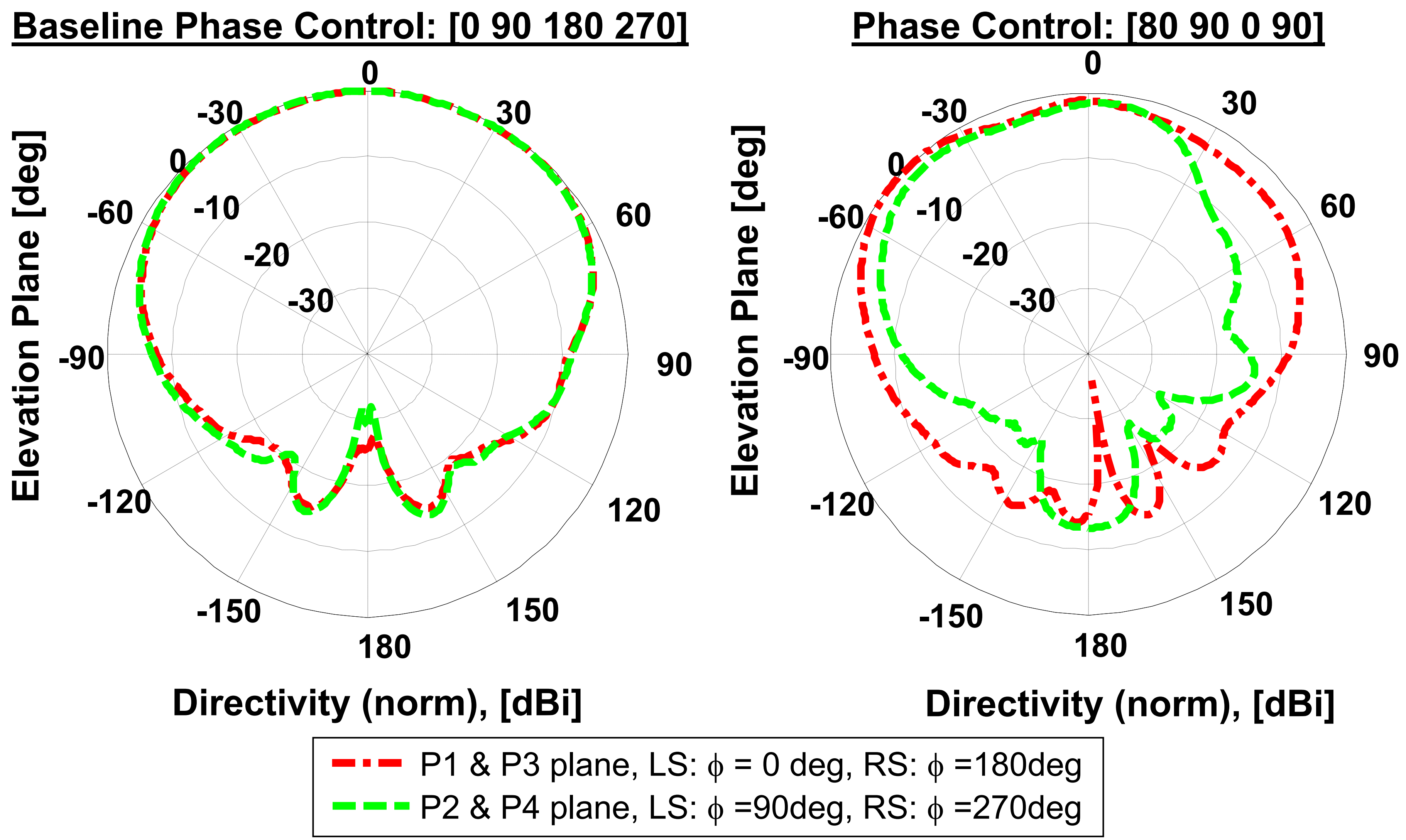




y: straight in from origin

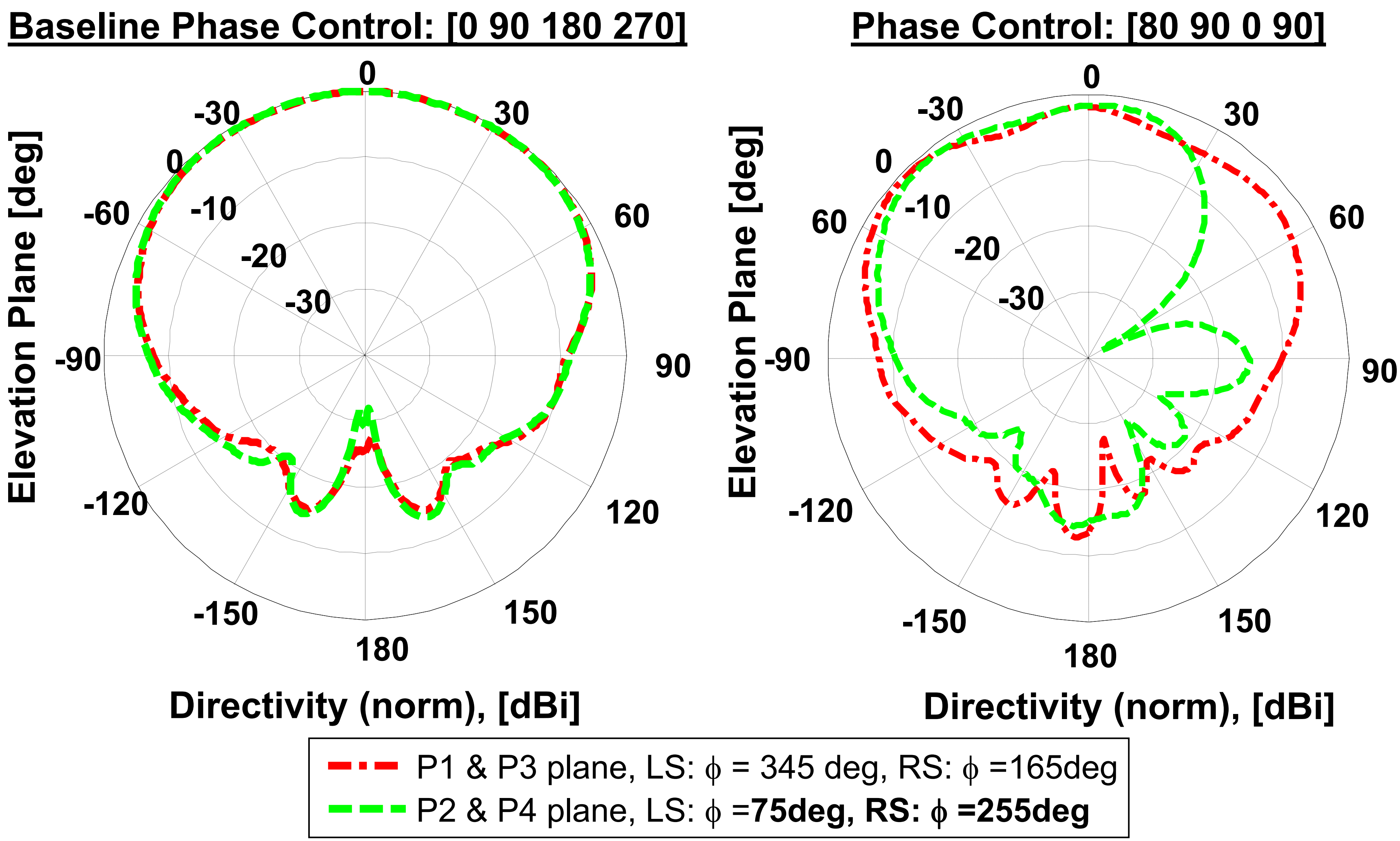
- **"High" directivity toward phi=90deg**
- **"Low" directivity towards phi=270deg**
- **Measured results consistent with CEM results**

Pattern Control-AZ-Third Quadrant



Ref: Step 23: se[80_90_0_90]{35_126_290_34}apr5_16.DF1, Apr 5, 2016, 1:24pm

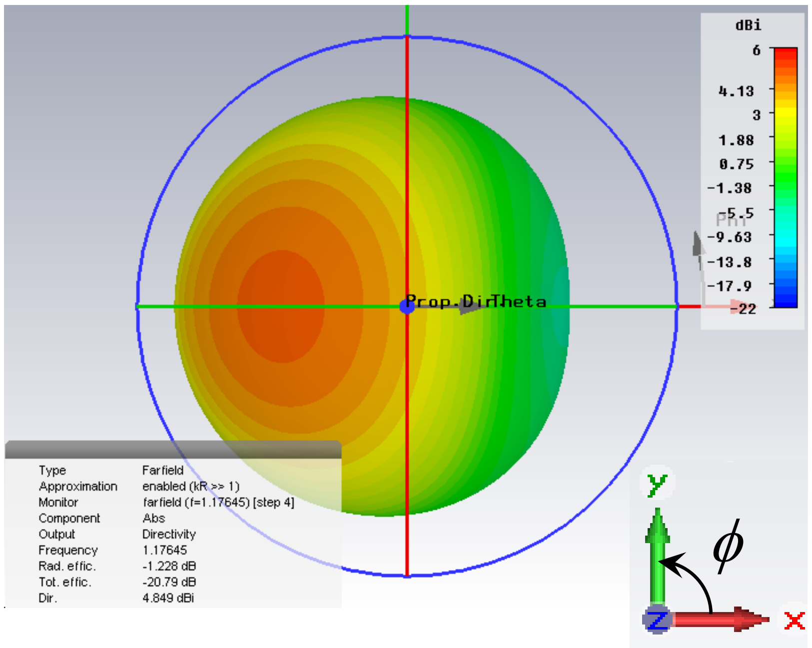
Pattern Control-AZ-Third Quadrant



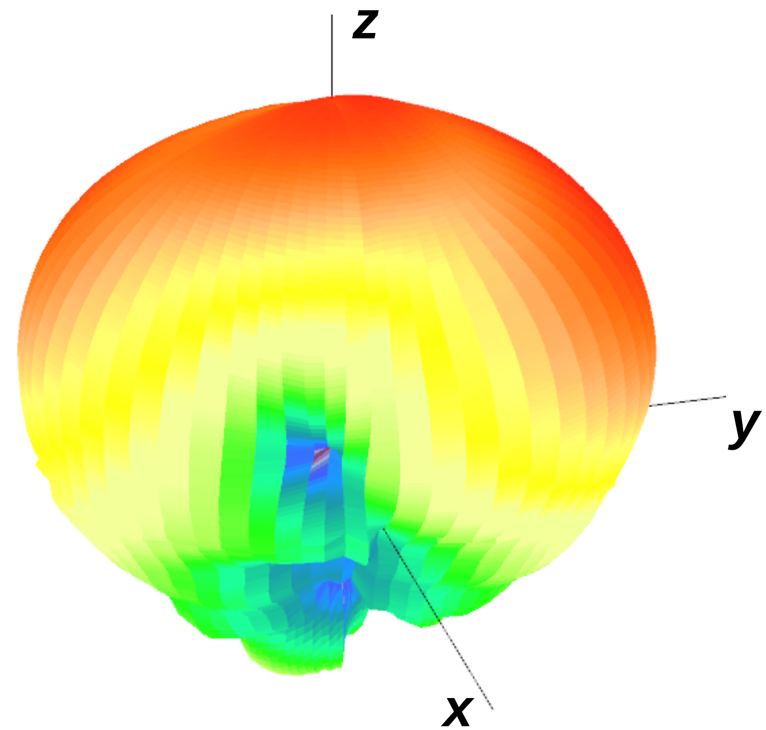
Ref: Step 23: se[80_90_0_90]{35_126_290_34}apr5_16.DF1, Apr 5, 2016, 1:24pm

Pattern Control-AZ-Fourth Quadrant

CEM CST Simulation Results



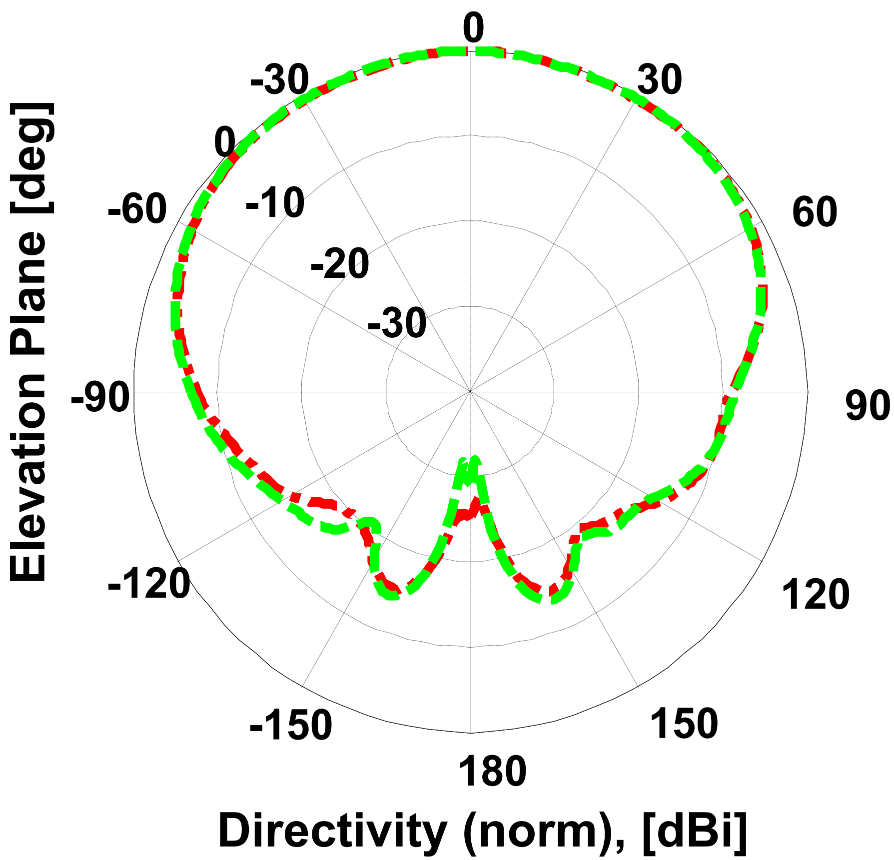
Anechoic Chamber Measured Results



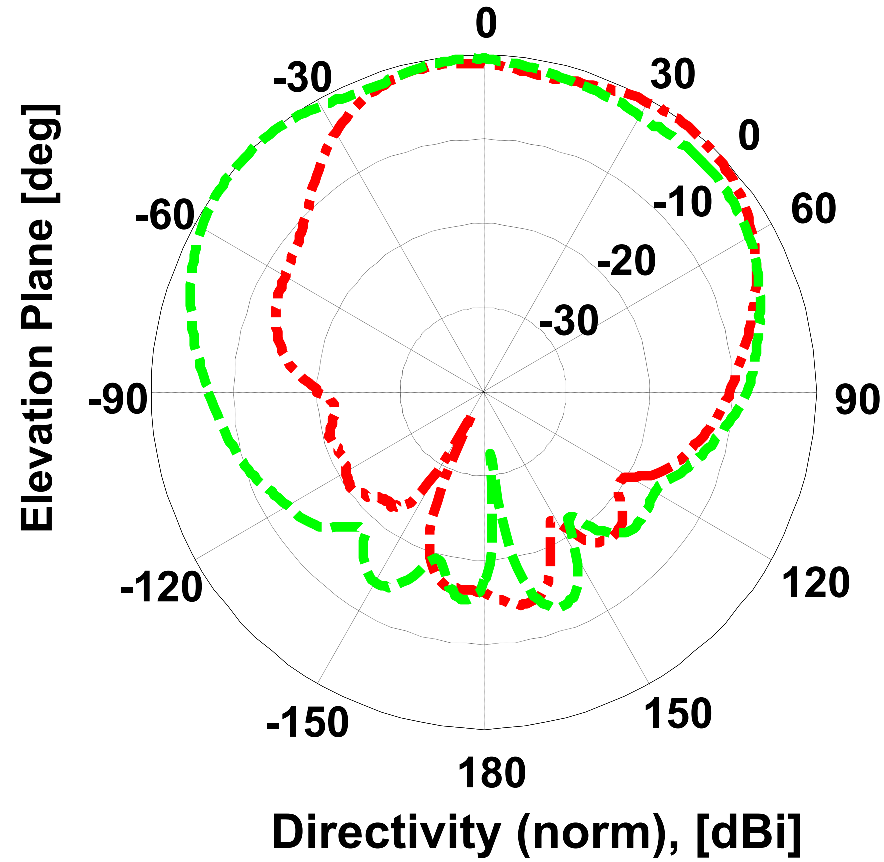
- **"High" directivity toward phi=180deg**
- **"Low" directivity towards phi=0deg**
- **Measured results consistent with CEM results**

Pattern Control-AZ-Fourth Quadrant

Baseline Phase Control: [0 90 180 270]



Phase Control: [90 0 90 80]



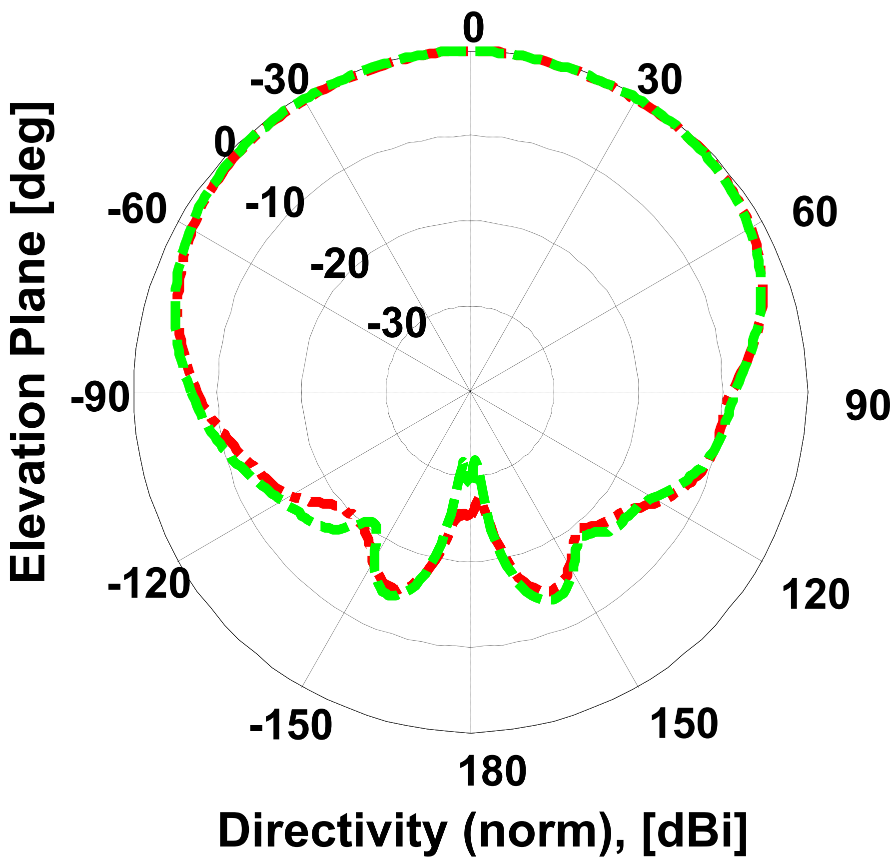
P1 & P3 plane, LS: ϕ = 0 deg, RS: ϕ =180deg

P2 & P4 plane, LS: ϕ =90deg, RS: ϕ =270deg

Ref: Step 32: se[90_0_90_80]{45_295_19_24}apr5_16.DF1, Apr 5, 2016, 1:40pm

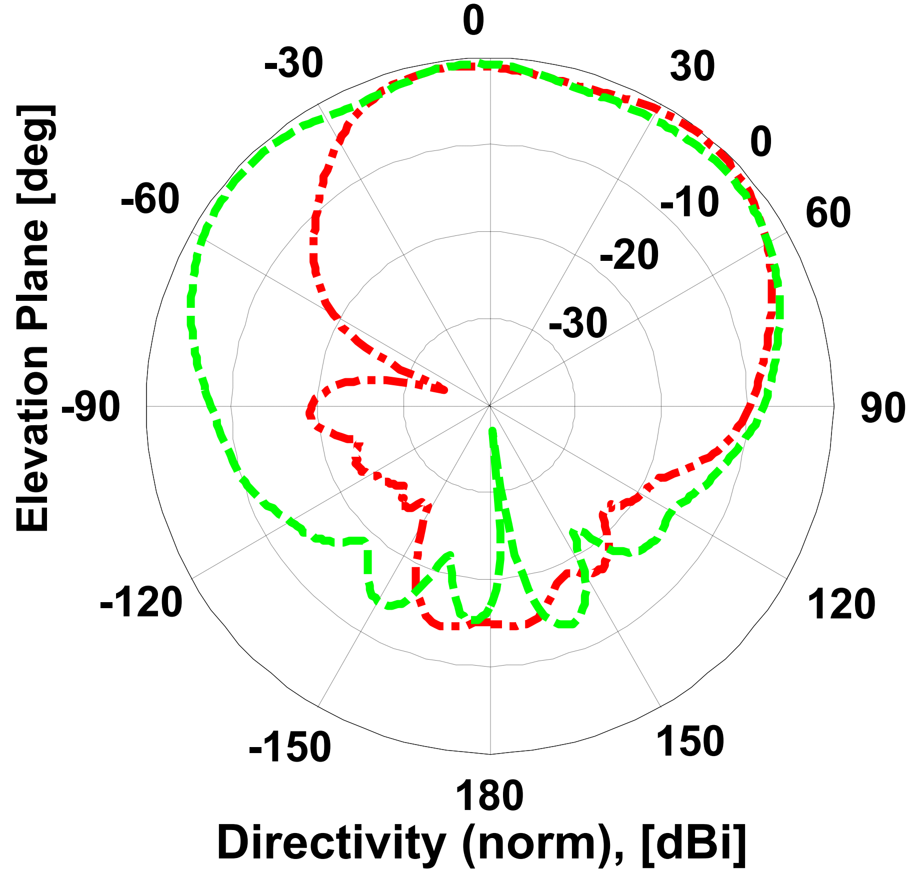
Pattern Control-AZ-Fourth Quadrant

Baseline Phase Control: [0 90 180 270]



P1 & P3 plane, LS: ϕ = 0 deg, RS: ϕ =180deg
P2 & P4 plane, LS: ϕ =90deg, RS: ϕ =270deg

Phase Control: [90 0 90 80]



P1 & P3 plane, LS: ϕ = 345deg, RS: ϕ =165deg
P2 & P4 plane, **LS: ϕ =75deg, RS: ϕ =255deg**

Ref: Step 32: se[90_0_90_80]{45_295_19_24}apr5_16.DF1, Apr 5, 2016, 1:40pm

Conclusions

- Single-aperture GNSS L5 patch antenna design, with dynamic pattern control was demonstrated.
- Circular geometry selected: element, substrate, ground plane, 4 port feed structure shown here.
  - » Excellent port performance in terms of SWR, repeatability, BW~100MHz
- Configuration supports a four-feed, RF front-end, amplitude & phase control (phase done here), and combine.
- Control area of "high" directivity and commensurate area of "low" directivity in:
  - » <u>Azimuth</u> (full 360 deg), varying the $\Delta\gamma_{ADJ}$ parameter, and quadrant phase approach.

Conclusions (cont.)

- **Measured results from fabricated antenna are consistent with CEM CST simulations**
- **Gain (i.e., directivity suppression) at, above, and below the horizon at commanded angles has been shown:**
  - » **Using RHCP Helix Transmission antenna, and boresight calibration:**
    - **At the horizon, varied from ~4-13 dB on principle axis direction**
    - **Null depth on the order of 20-28 dB off principle axis.**
- **Dynamic pattern control advantageous for:**
  - » **Baseline/Benign operations**
  - » **Interference operations, where interference sources are above, at, or below the local horizon.**

Single-aperture Patch Antenna with Pattern Control

Thank You !!!

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