ATTACHMENT C
Astro Digital U.S., Inc.
FCC Form 312, Exhibit 43

LANDMAPPER SATELLITE SYSTEM ANTENNA PATTERNS – PHASES 1,2 AND 3

The antenna patterns for the Landmapper Satellite System are provided in this attachment. Tables C-1 and C-2 provide a summary of the antenna patterns for the space stations and ground stations.

Table C-1: Space Station Antenna Patterns							
Phase 1 through Phase 3:	**Early 2017 and Beyond**						
Pattern No.:	*Antenna:*	*Purpose:*	*Antenna Type:*	*Frequency:*	*Peak Gain:*	*Polarization:*	
C-UHF-TX-BC-1	UHF TX	TLM	Dipole Like	400.175 MHz	2.1 dBi	Linear	Rotating
C-UHF-RX-BC-2	UHF RX	CMD	Dipole Like	402.600 MHz	2.1 dBi	Linear	Rotating
C-UHF-TX-HD-3	UHF TX	TLM	Dipole Like	400.175 MHz	2.1 dBi	Linear	Rotating
C-UHF-RX-HD-4	UHF RX	CMD	Dipole Like	402.600 MHz	2.1 dBi	Linear	Rotating
C-Ka-TX-5	Ka-band TX	H. S. Data	Lens Aided Horn	26.800 GHz	23.5 dBi	Circular	RHCP
C-L-TX-6	L-band TX	G* FWD TLM	Patch	1618 MHz	6.0 dBi	Circular	RHCP
C-S-TX-7	S-band RX	G* RTN CMD	Patch	2492 MHz	6.0 dBi	Circular	LHCP
Phase 2 and Phase 3:	**2018 and Beyond**						
C-S-RX-8	S-band RX	H.S. CMD	Patch	2025.6 MHz	6.0 dBi	Circular	RHCP
C-Ka-RX-9	Ka-band RX	H.S Data Up	Horn	29.950 GHz	15.0 dBi	Circular	LHCP

Table C-2: Ground Station Antenna Patterns										
Phase 1 through Phase 3:	**Early 2017 and Beyond**									
Pattern No.:	*Antenna:*	*Purpose:*	*Antenna Type:*	*Frequency:*	*Peak Gain:*	*Polarization:*		*Stn. Location:*	*Latitude:*	*Longitude:*
C-UHF-TX-GS-10	UHF TX	CMD	4 X-Pole Yagi System	400.175 MHz	24.0 dBi	Circular	RHCP/LHCP	Mt. View, CA	37.4094 N	122.0533 W
C-UHF-RX-GS-11	UHF RX	TLM	4 X-Pole Yagi System	402.600 MHz	23.5 dBi	Circular	RHCP/LHCP	Mt. View, CA	37.4094 N	122.0533 W
C-Ka-RX-GS-12	Ka-band RX	H.S. Data	2.8 m Parabola	26.800 GHz	55.3 dBi	Circular	RHCP/LHCP	Svalbard, No.	78.2321 N	15.4014 W
C-Ka-TX-GS-13	Ka-band TX	H.S. Control	2.8 m Parabola	29.950 GHz	56.3 dBi	Circular	LHCP/RHCP	Svalbard, No.	78.2321 N	15.4014 W
Phase 2 and Phase 3:	**2018 and Beyond**									
C-S-TX-GS-14	S-band TX	H.S. CMD	1.5 m Parabola	2025.6 MHz	27.5 dBi	Circular	RHCP/LHCP	Mt. View, CA	37.4094 N	122.0533 W

Satellite Antenna Patterns:

The spacecraft antenna patterns for the Corvus-BC and Corvus-HD satellites are the same for the S-band and L-band patch antennas and for the high gain Ka-band lens-aided horn antennas used by both satellite types. The UHF antenna patterns for both satellites are however, somewhat different due to the interaction between the satellite UHF monopole and the physical shape of each satellite. The two coordinate systems assigned to the satellites are different from one another as defined in Figures C-UHF-BC-1A and C-UHF-HD-3A.

The polarization of the UHF pattern is also linear, however, the received signal rotates in space, not just due to a rotation of the satellite itself but, due to:

a) The rotation of the linearly polarized wave in space due to Faraday rotation, which always occurs in an NGSO orbit and,

b) The motion of the satellite relative to the ground station on any pass (whether the satellite is held fixed in attitude in inertial space or is pointing toward the center of the Earth or toward a ground station located on the Earth) rotates as seen by the ground station.

For this reason, a linear polarization reference cannot be defined for the downlink or uplink UHF signal. Therefore, the technique used to receive the linear signal (or transmit a linear signal to the spacecraft) is to use a circularly polarized antenna on the Earth to receive/transmit the signal and accept at least a 3 dB loss in C/N on the far end of the link, accordingly.

The two Globalstar patch antennas (using L-band or S-band frequencies) are located on the +Z or zenith-facing surface of either the CORVUS-BC or Corvus-HD satellites. Hence the patterns are directed upward away from the Earth.

There are two S-band patch antennas oriented with their boresight directions aligned with the +Y and –Y axes. The two receive patches (using 2025.6 MHz), which are then fed in-phase create a near-omnidirectional antenna pattern. The individual patterns of these antennas are presented in this attachment.

Antenna Patterns C-UHF-TX-BC-1 and C-UHF-RX-BC-2

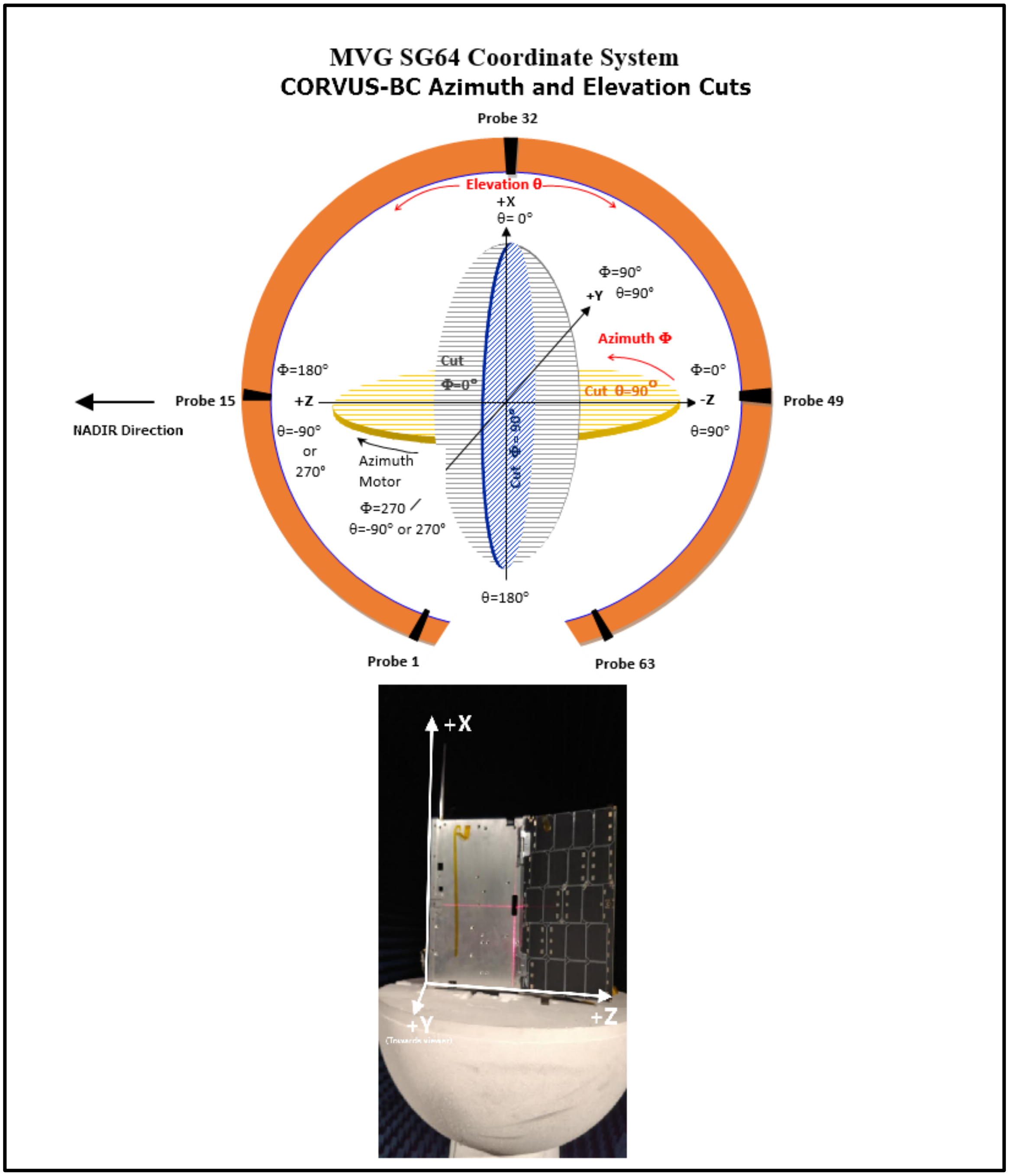
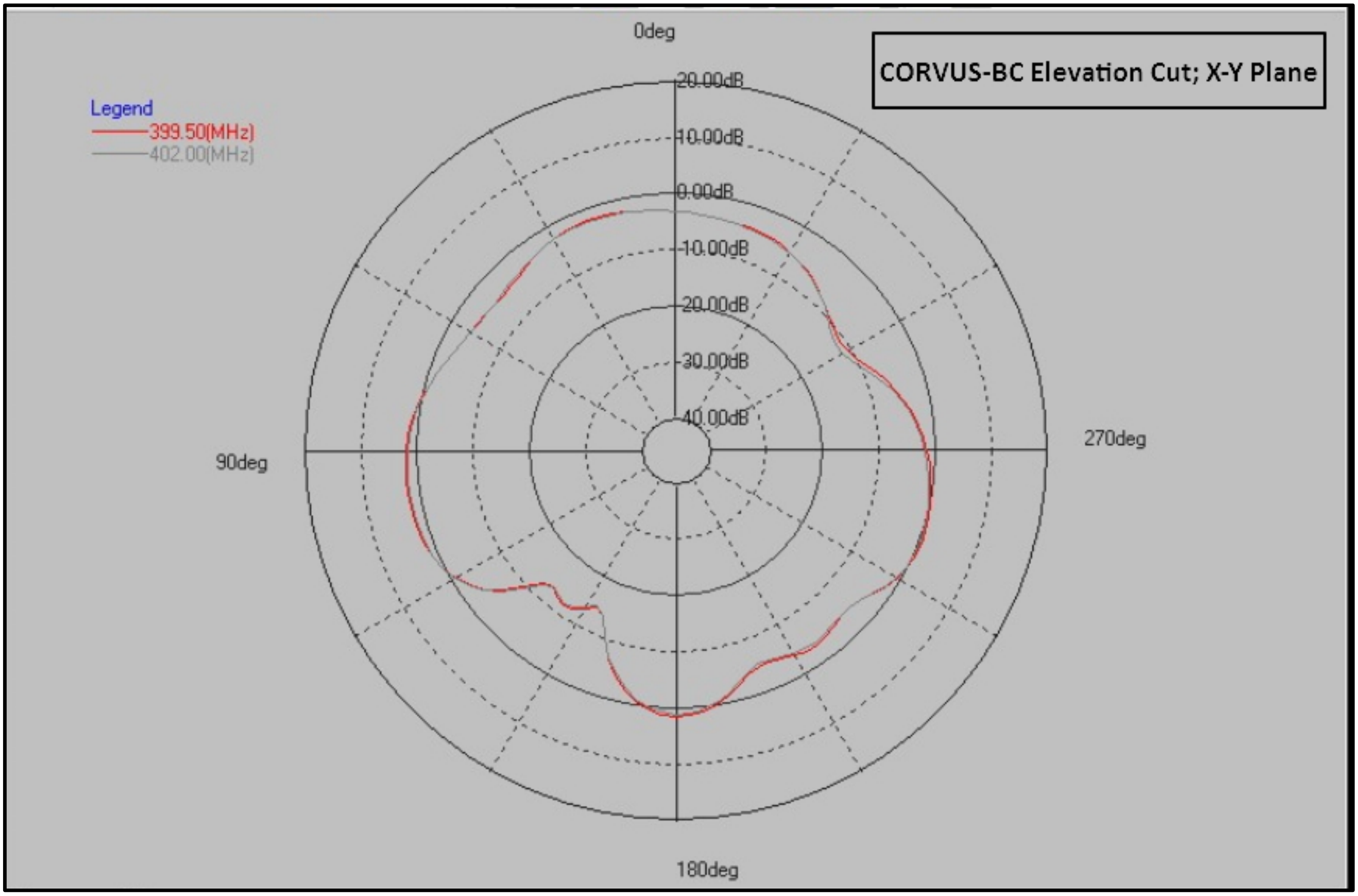
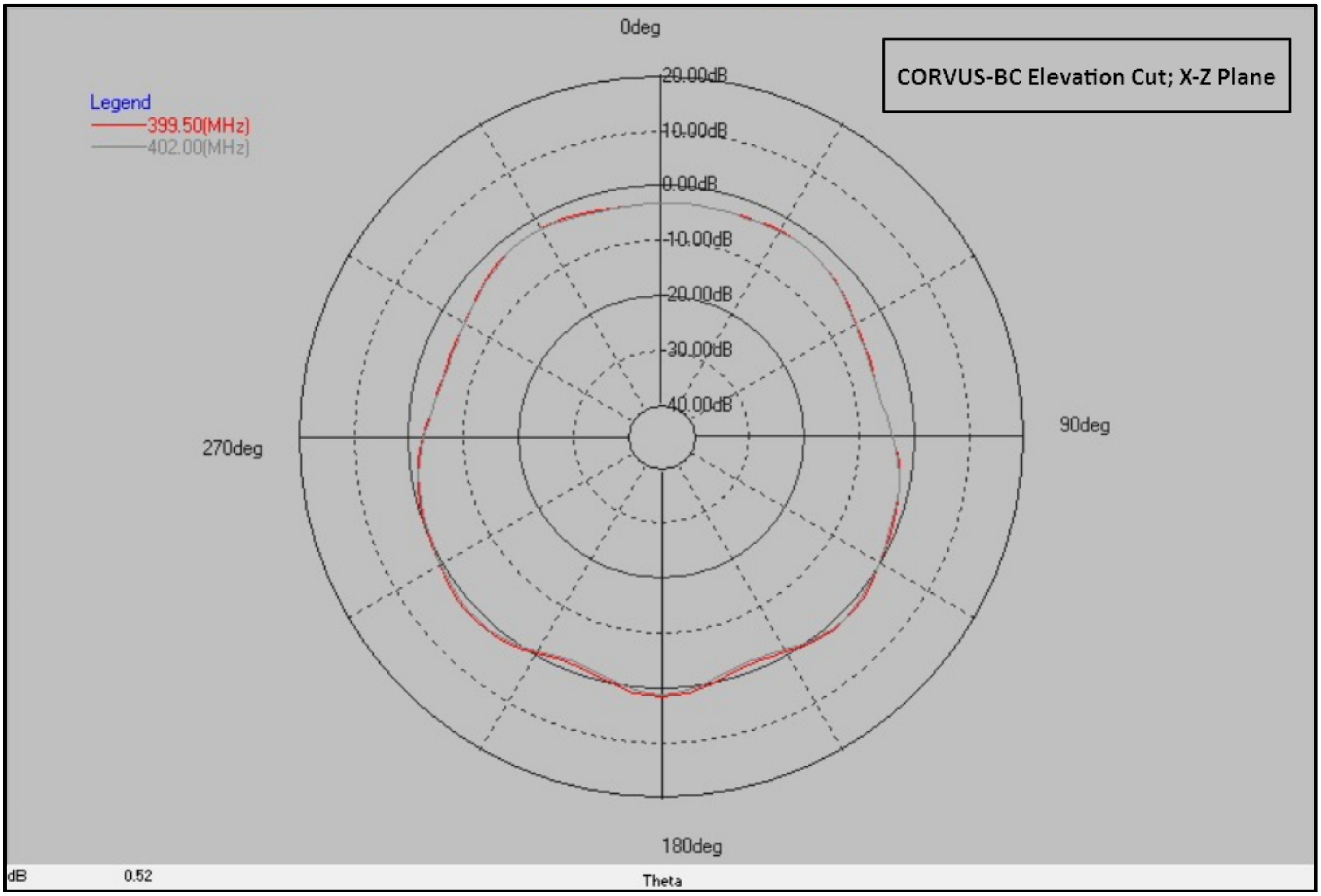


Figure C-UHF-TX-BC-1 A: Measurement Coordinate System for CORVUS-BC



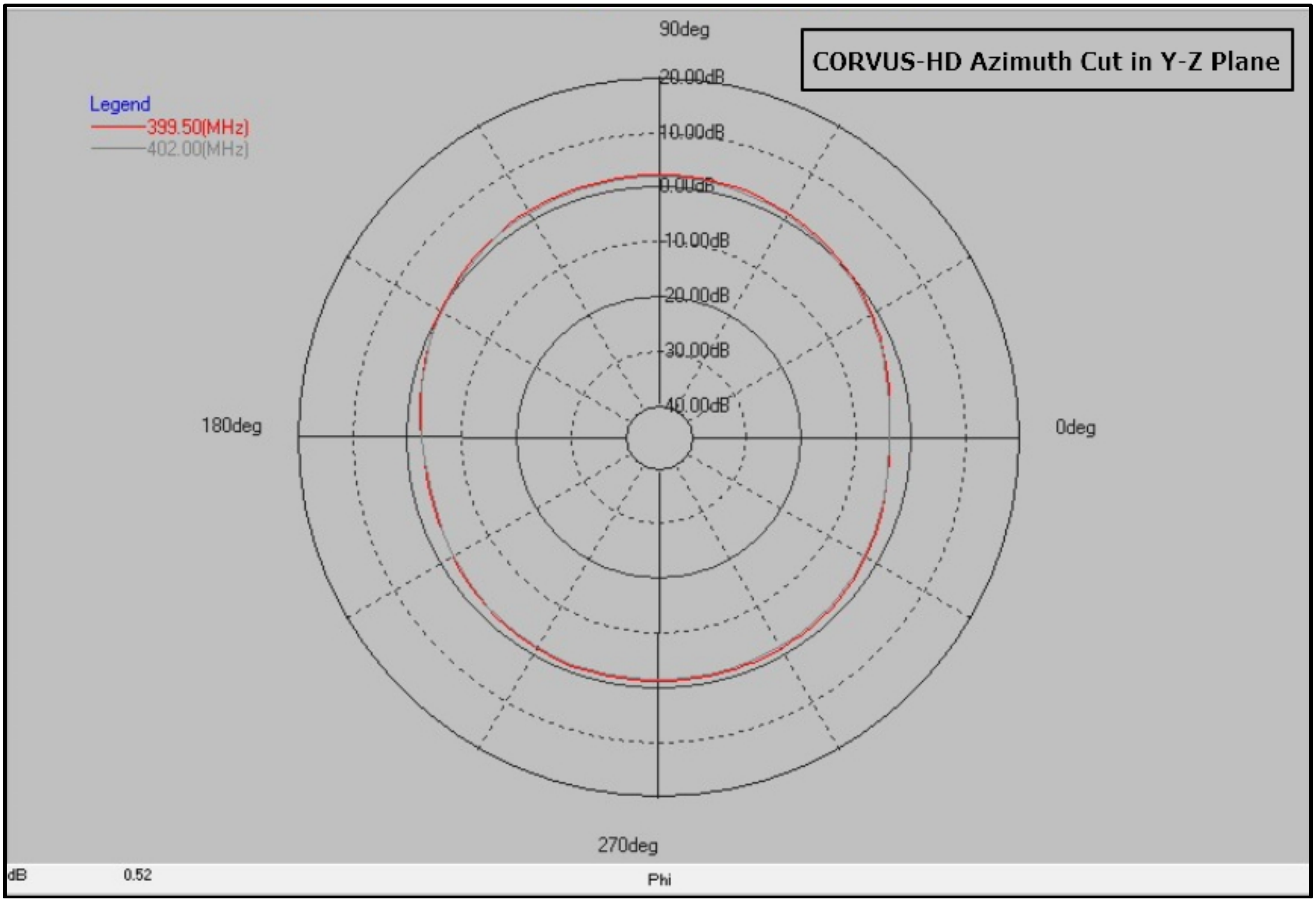
Theta (θ)

<u>Figures C-UHF-TX-BC-1B and C-UHF-RX-BC-2B</u>: CORVUS-BC Elevation Cut; X-Y Plane



Theta (θ)

Figures C-UHF-TX-BC-1C and C-UHF-RX-BC-2C: CORVUS-BC Elevation Cut; X-Z Plane



Phi (φ)

Figures C-UHF-TX-BC-1D and C-UHF-RX-BC-2D: CORVUS-BC Azimuth Cut; Y-Z Plane

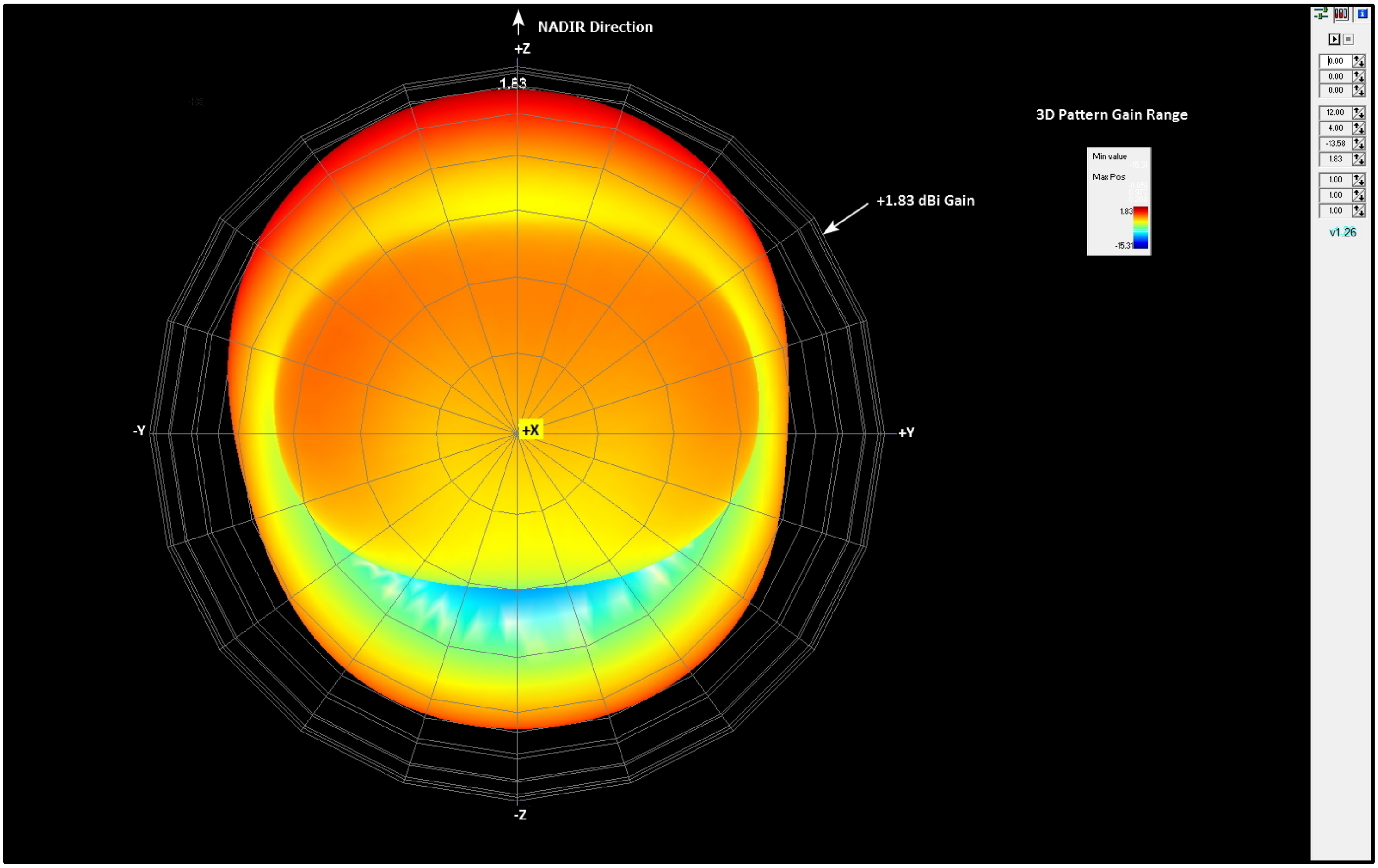


Figure C-UHF-TX-BC-1E and C-UHF-RX-BC-2E: 3D Pattern Plot; +X View

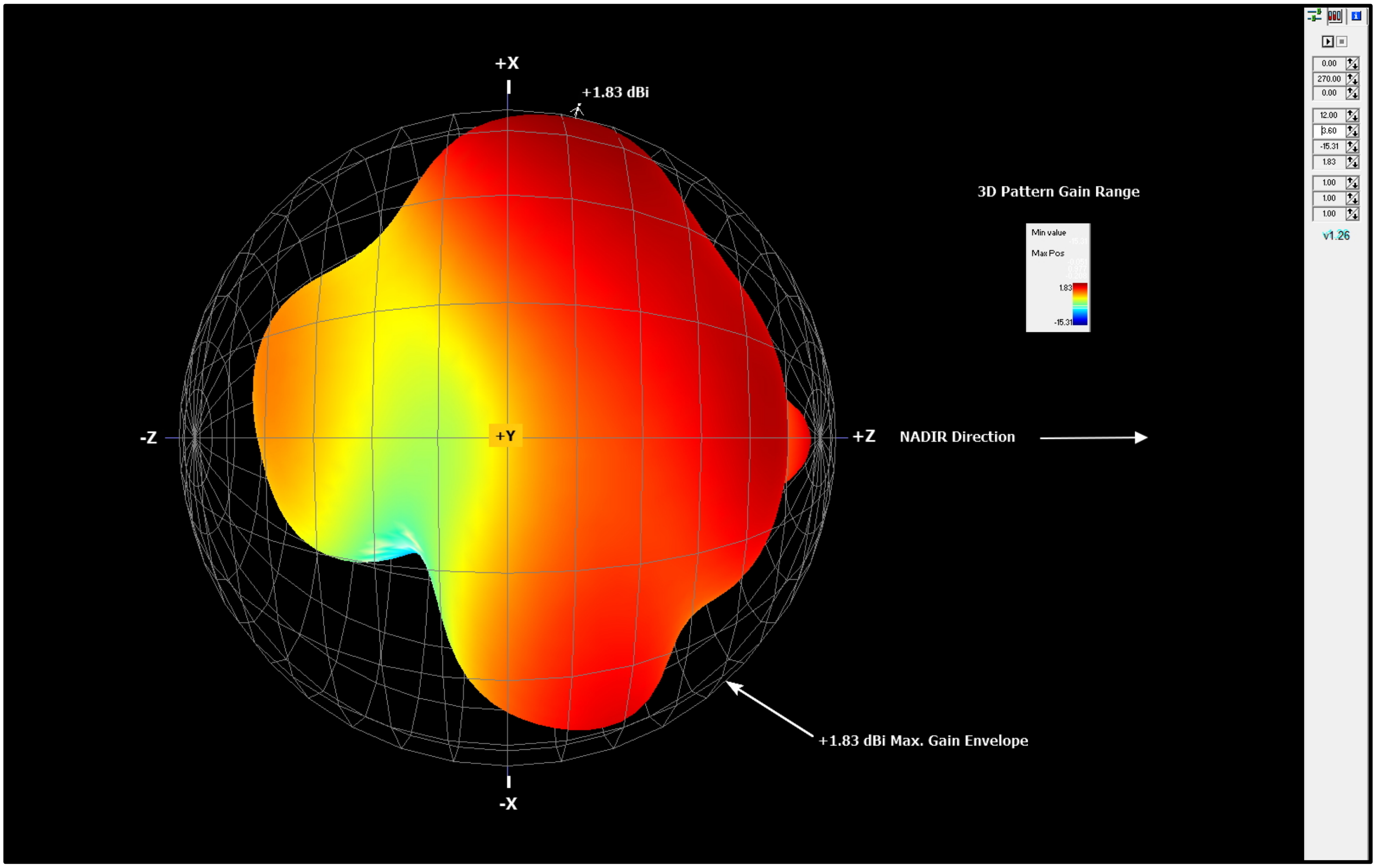


Figure C-UHF-TX-BC-1F and C-UHF-RX-BC-2F: 3D Pattern Plot; +Y View

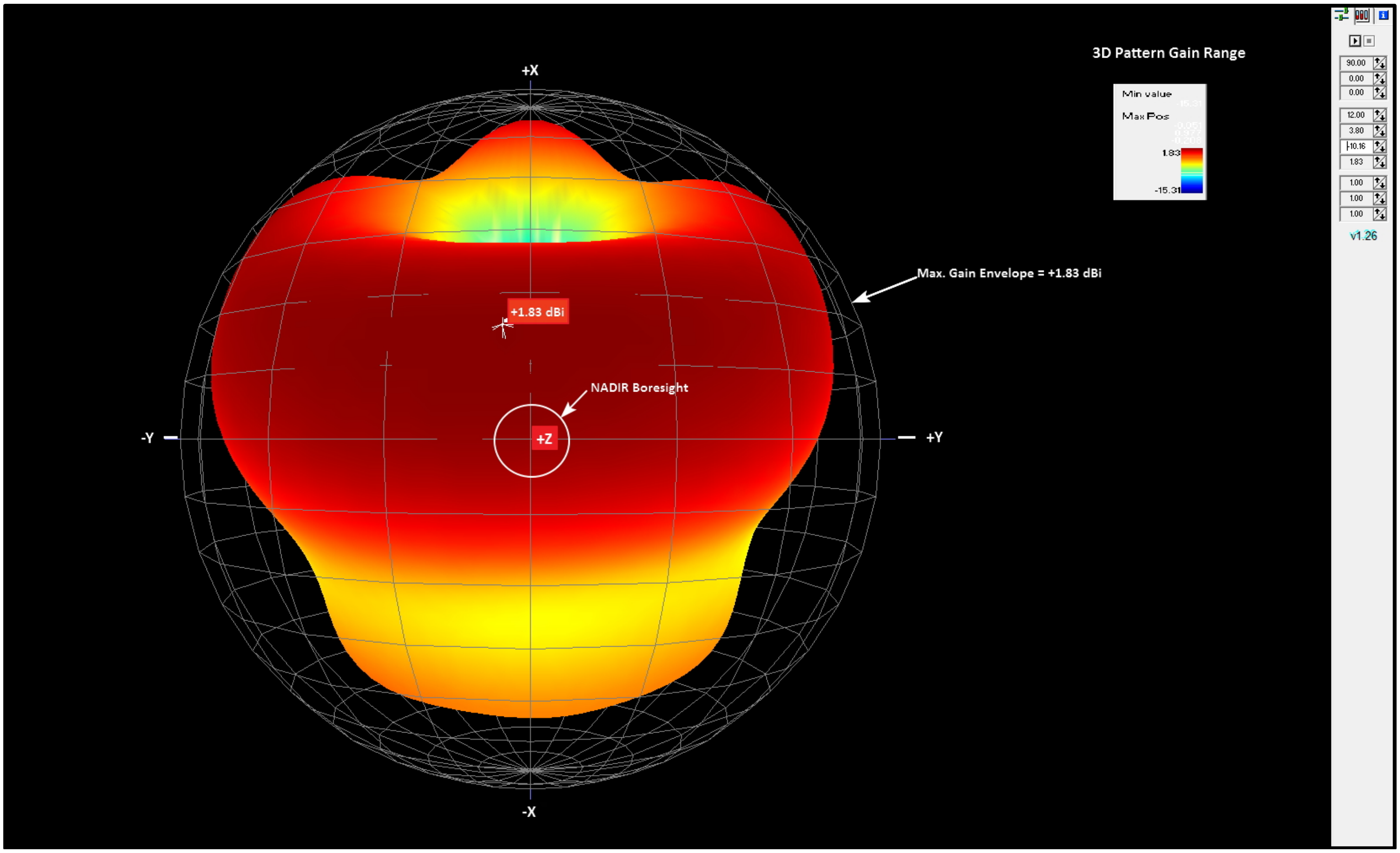


Figure C-UHF-TX-BC-1G and C-UHF-RX-BC-2G: 3D Pattern Plot; +Z View

Antenna Pattern C-UHF-TX-HD-3 and C-UHF-RX-HD-5

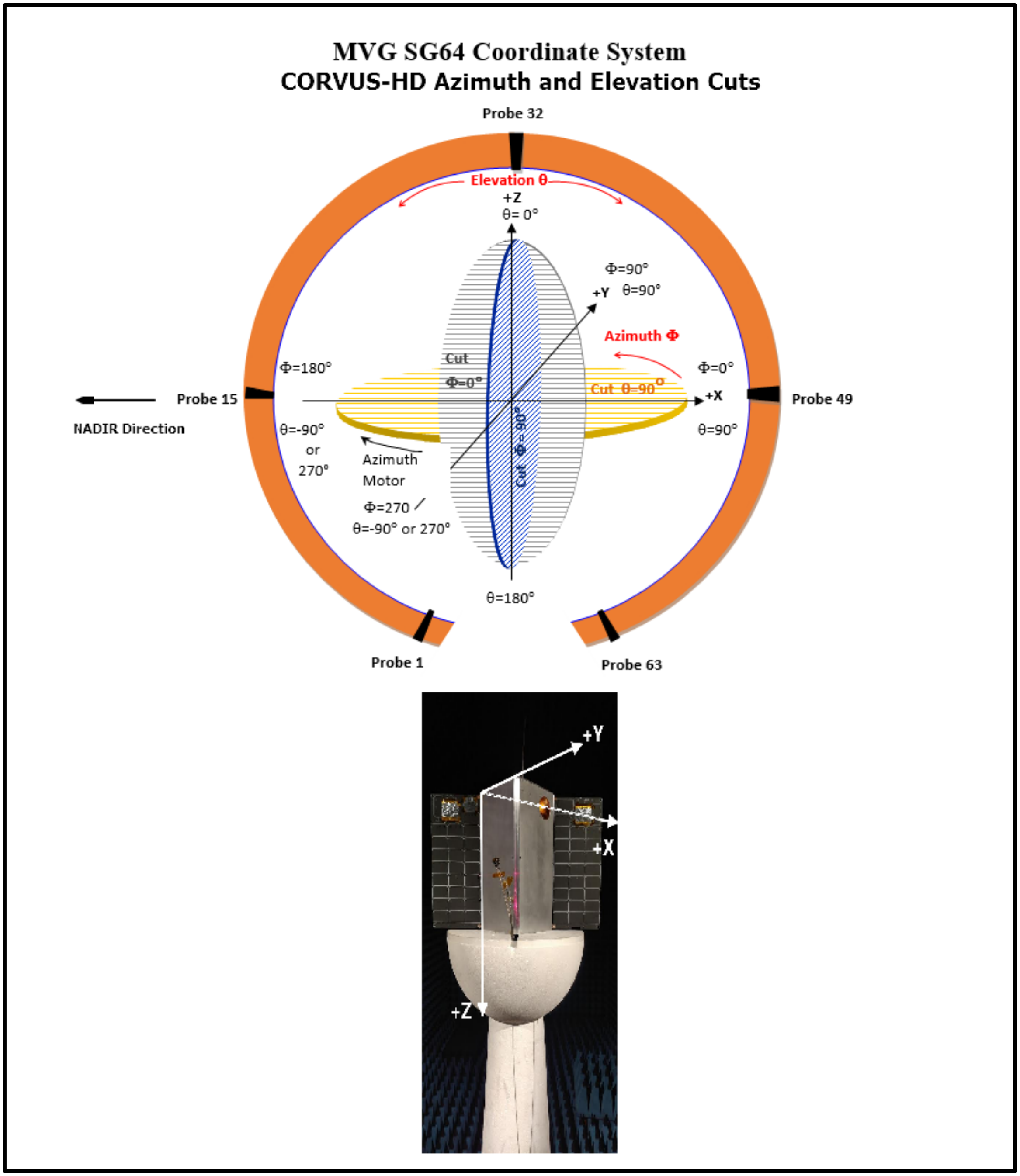
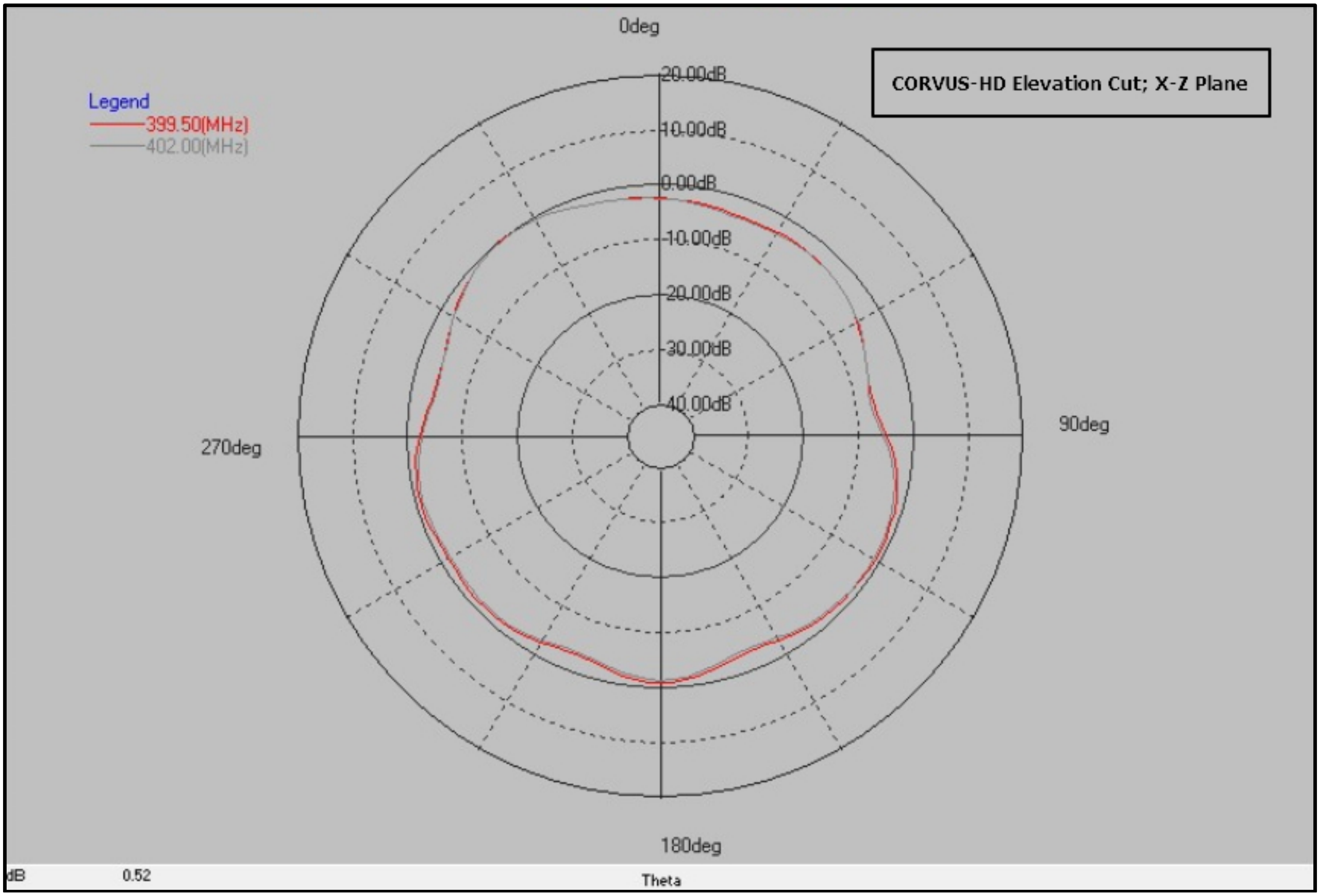
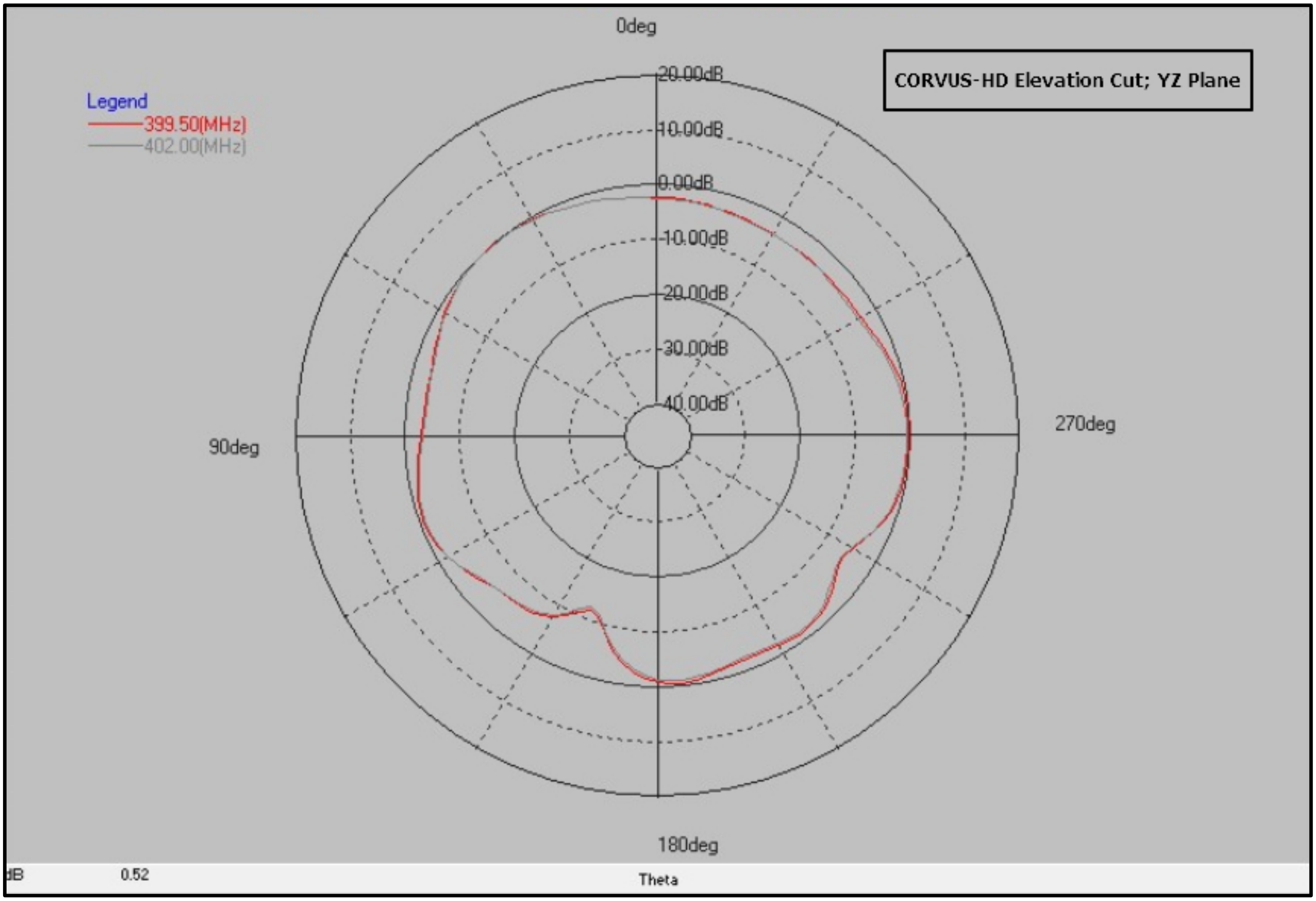


Figure C-UHF-TX-HD-3 A: Measurement Coordinate System for CORVUS-HD



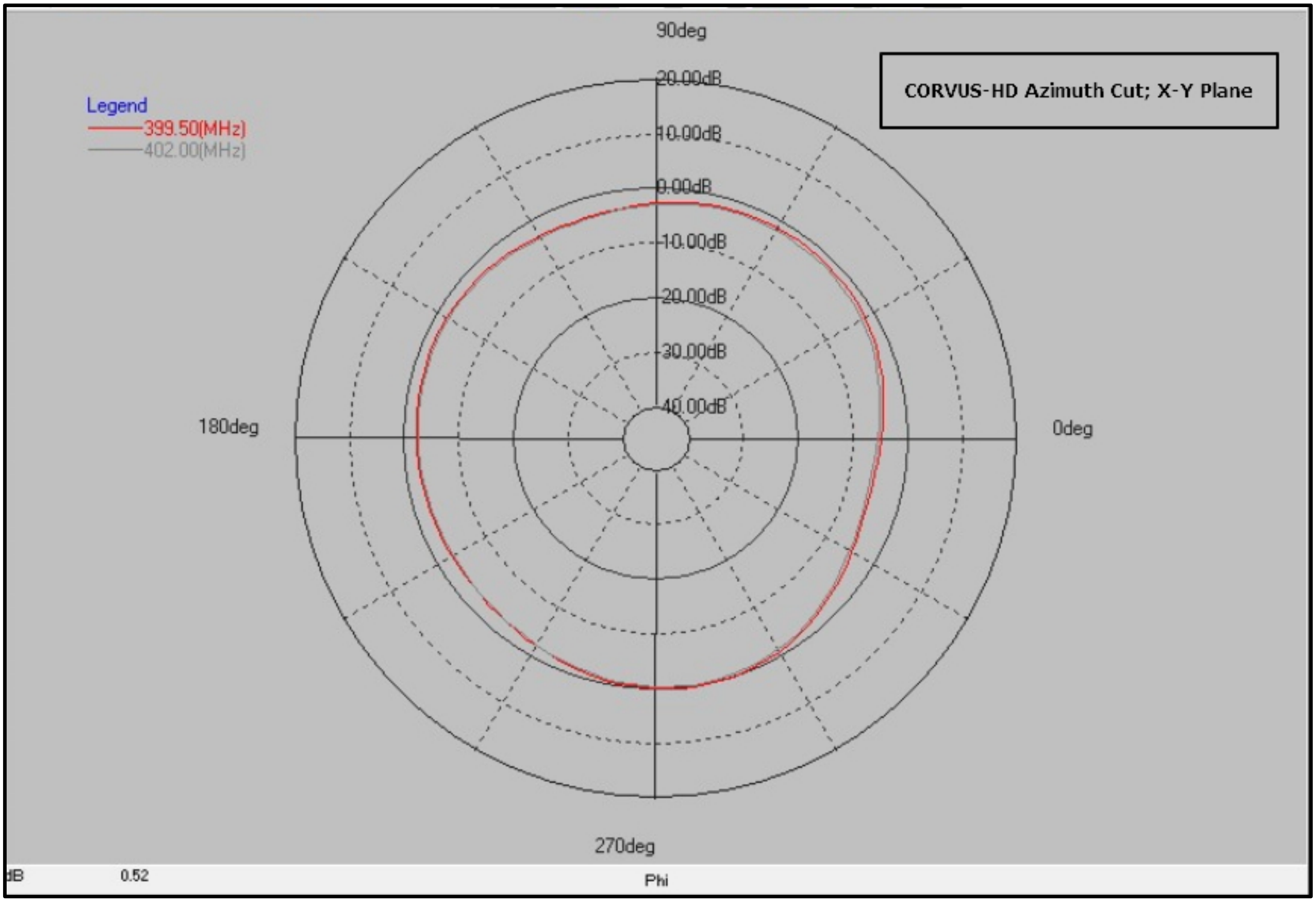
Theta (θ)

<u>Figures C-UHF-TX-HD-3B and C-UHF-RX-HD-4B</u>: CORVUS-HD Elevation Cut; X-Z Plane



Theta (θ)

<u>Figures C-UHF-TX-HD-3C and C-UHF-RX-HD-4C</u>: CORVUS-HD Elevation Cut; Y-Z Plane



Phi (φ)

<u>Figures C-UHF-TX-HD-3D and C-UHF-RX-HD-4D</u>: CORVUS-BC Azimuth Cut; X-Y Plane

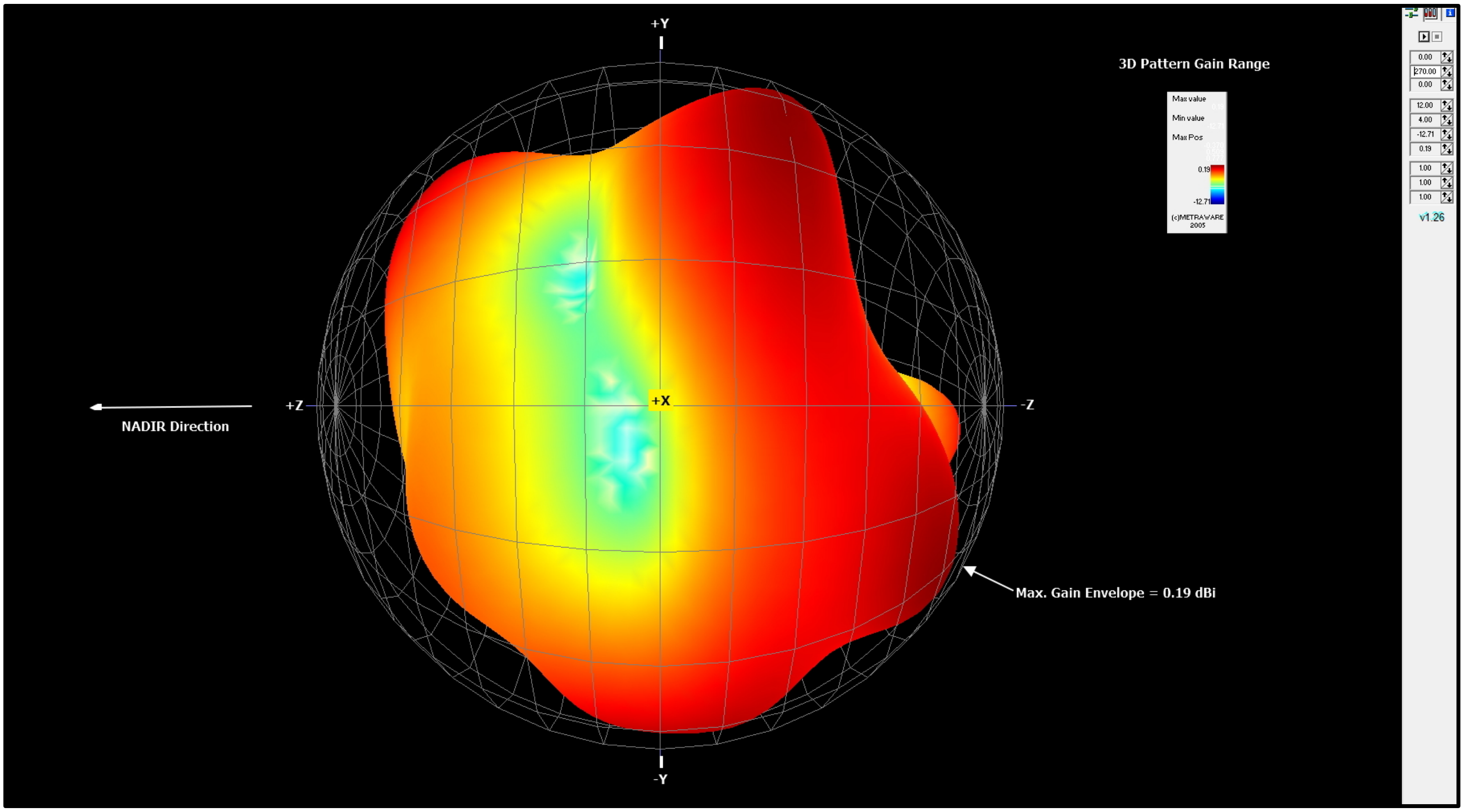


Figure C-UHF-TX-HD-3E and C-UHF-RX-HD-4E: 3D Pattern Plot; +X View

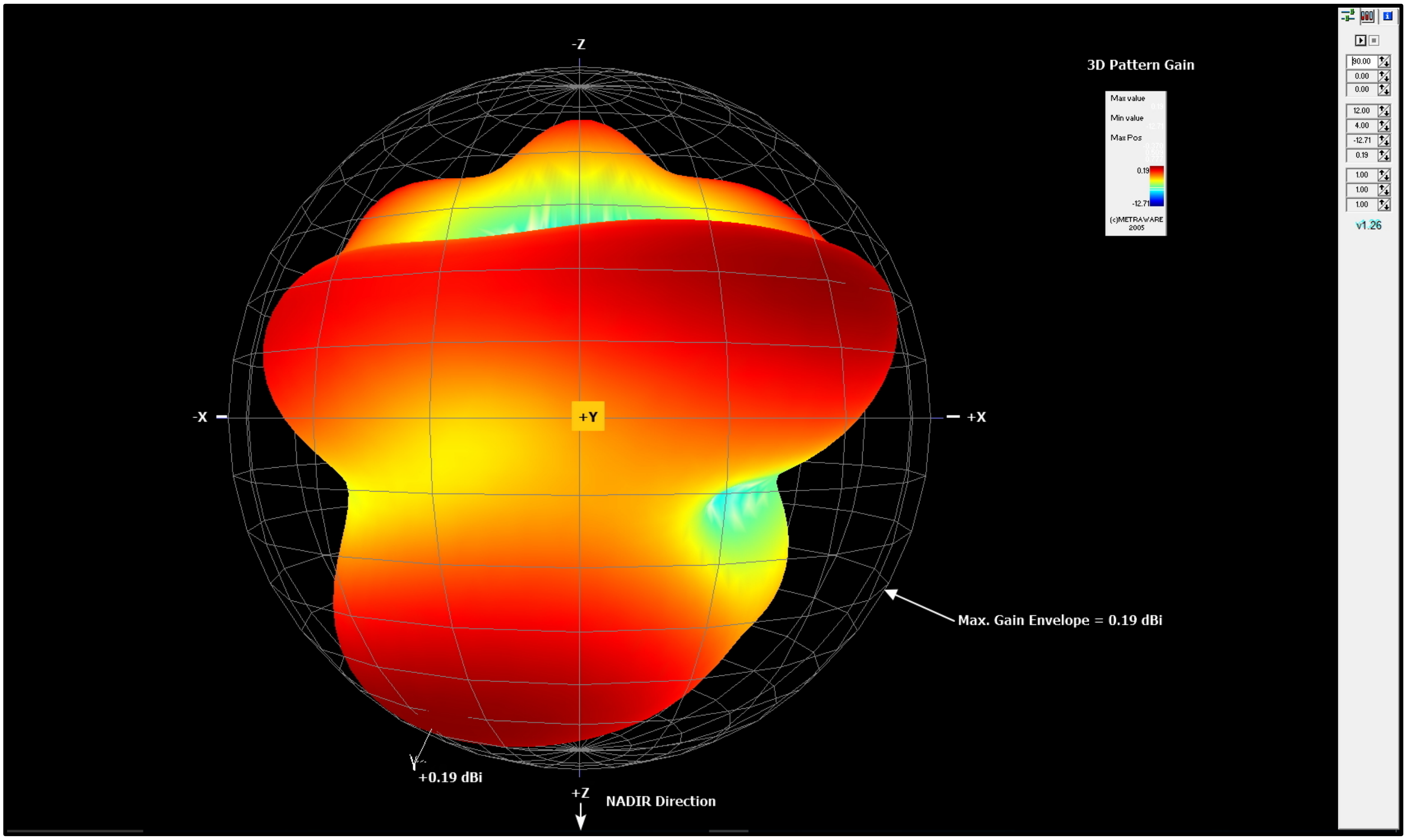


Figure C-UHF-TX-HD-3F and C-UHF-RX-HD-4F: 3D Pattern Plot; +Y View

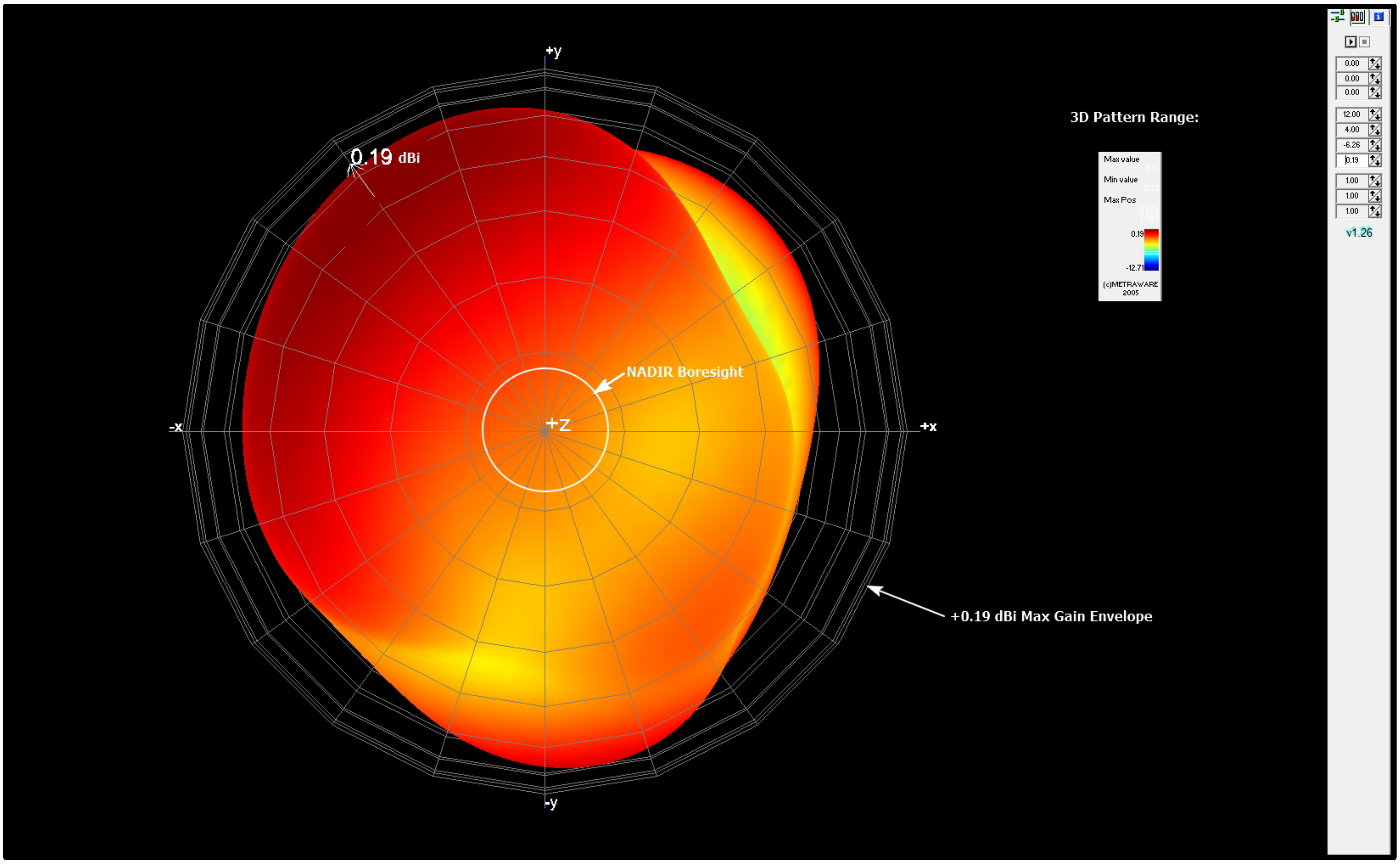
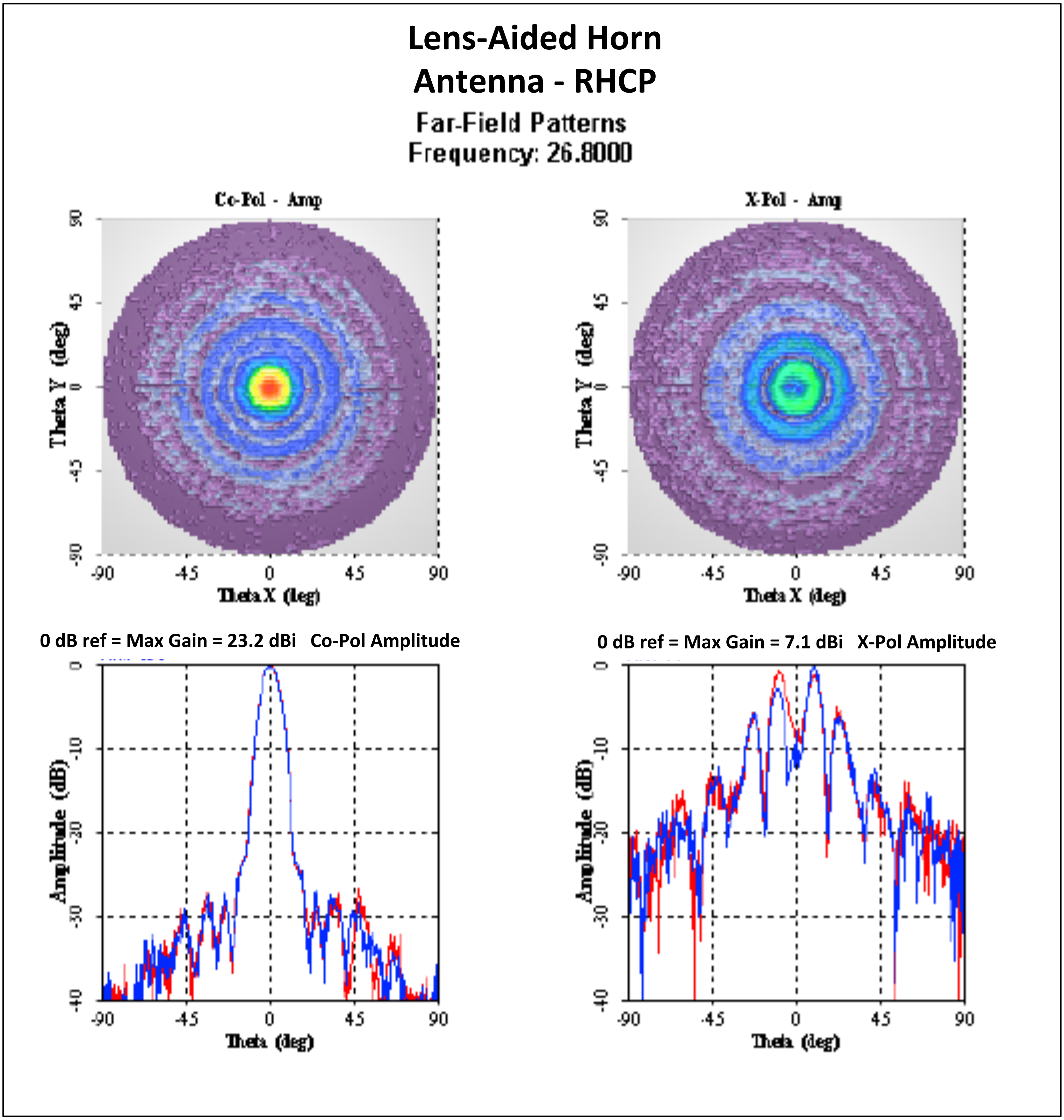
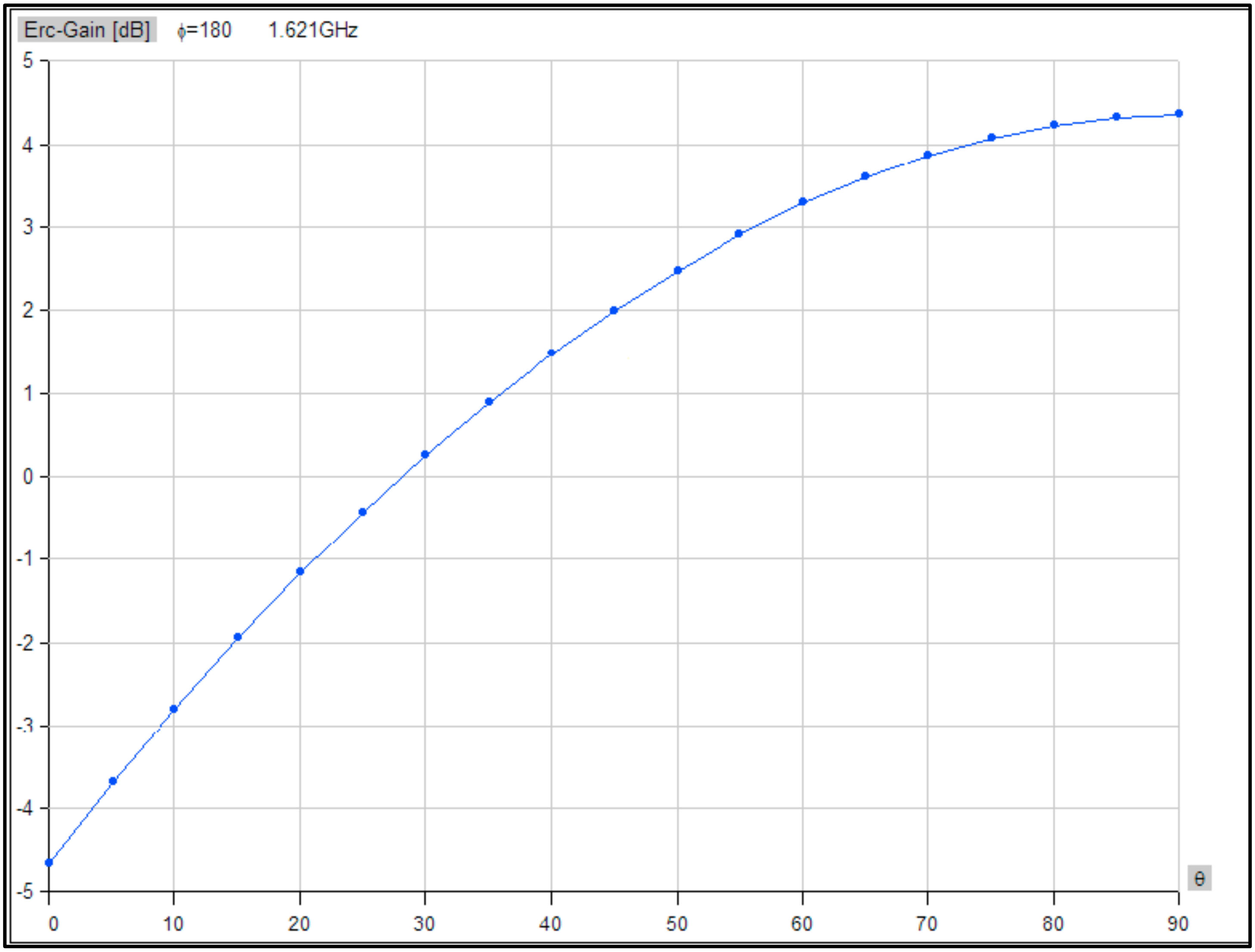


Figure C-UHF-TX-HD-3G and C-UHF-RX-HD-4G: 3D Pattern Plot; +Z View

Antenna Pattern C-Ka-TX-5

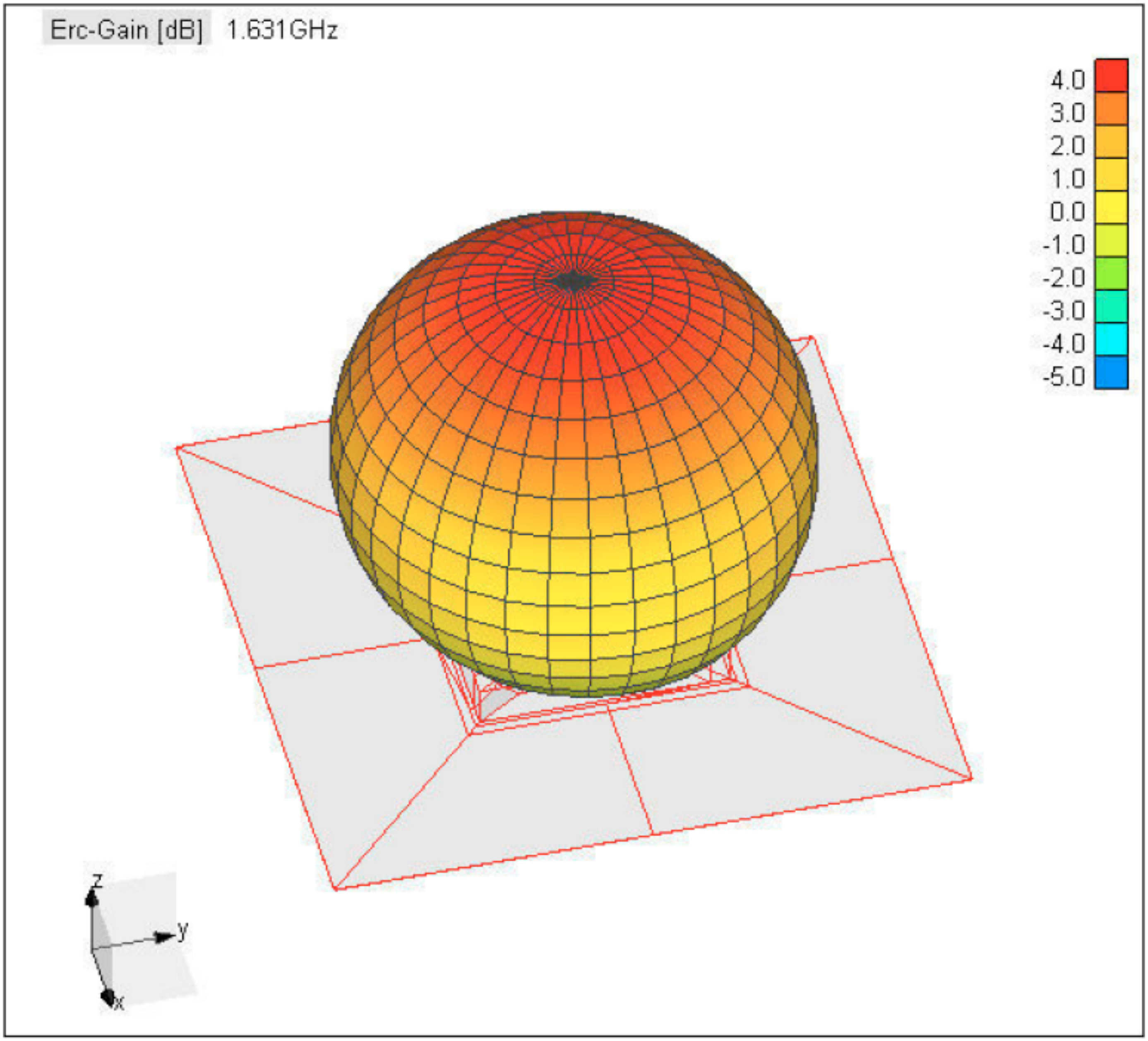


Antenna Pattern C-L-TX-6A (Globalstar Transmit Patch)

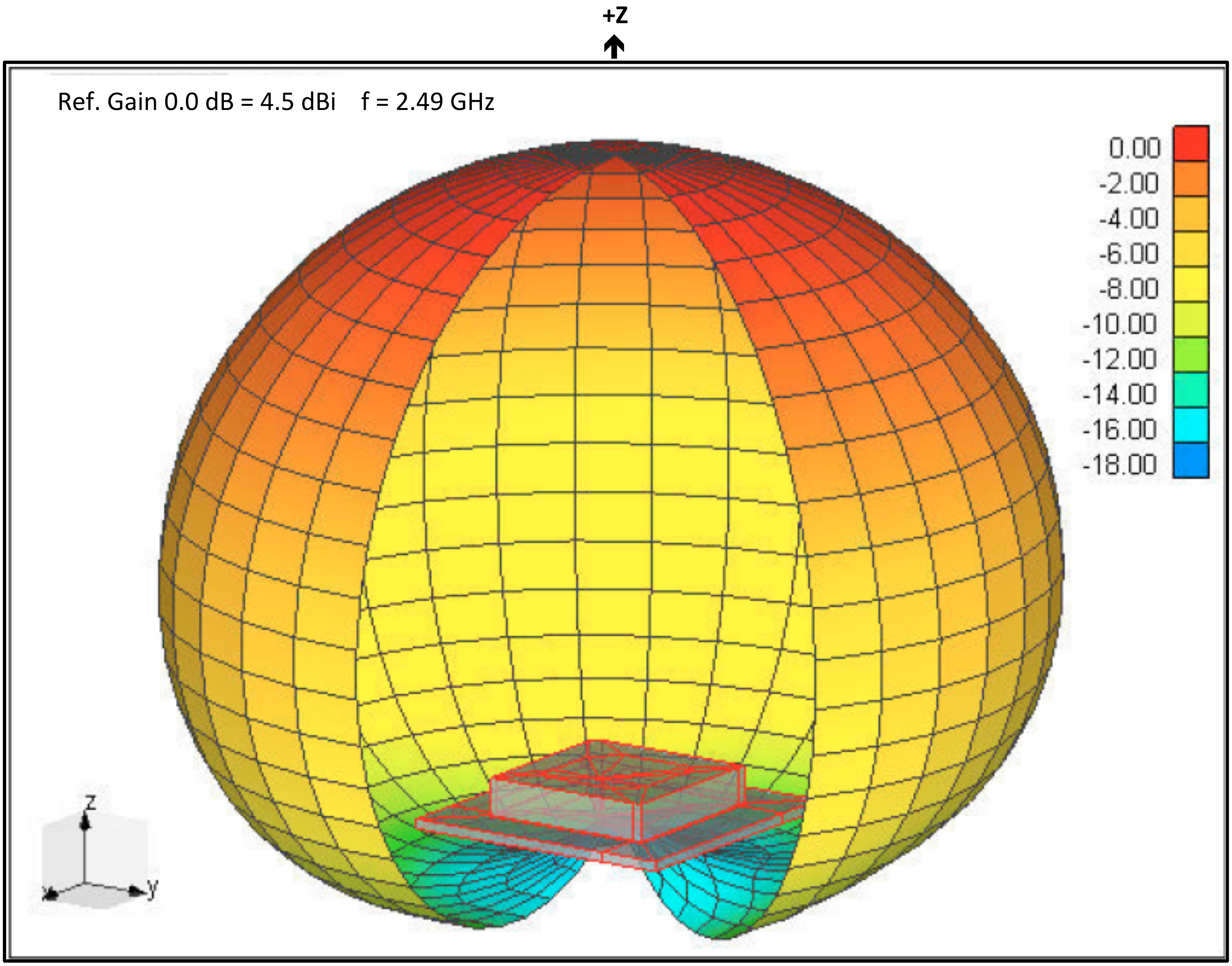


Gain vs. Elevation (θ)

Antenna Pattern C-L-TX-6B (Globalstar Transmit Patch)

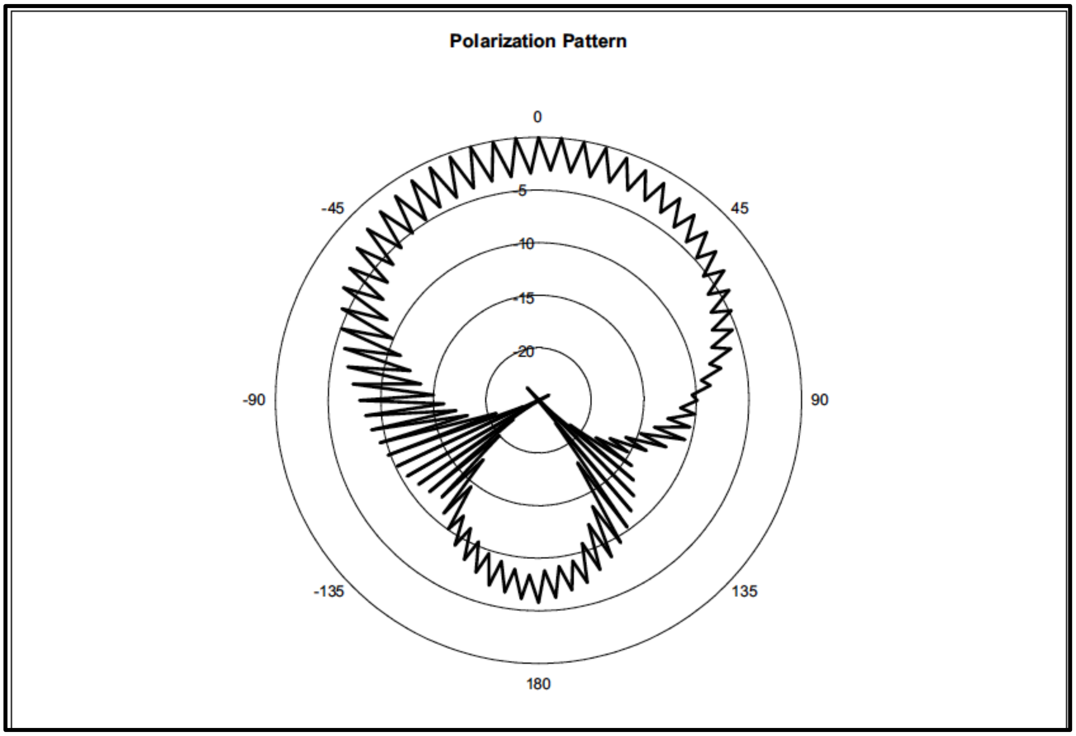


Antenna Pattern C-S-RX-7A (Globalstar Receive Patch)



Antenna Pattern C-S-RX-7B (Globalstar Receive Patch)

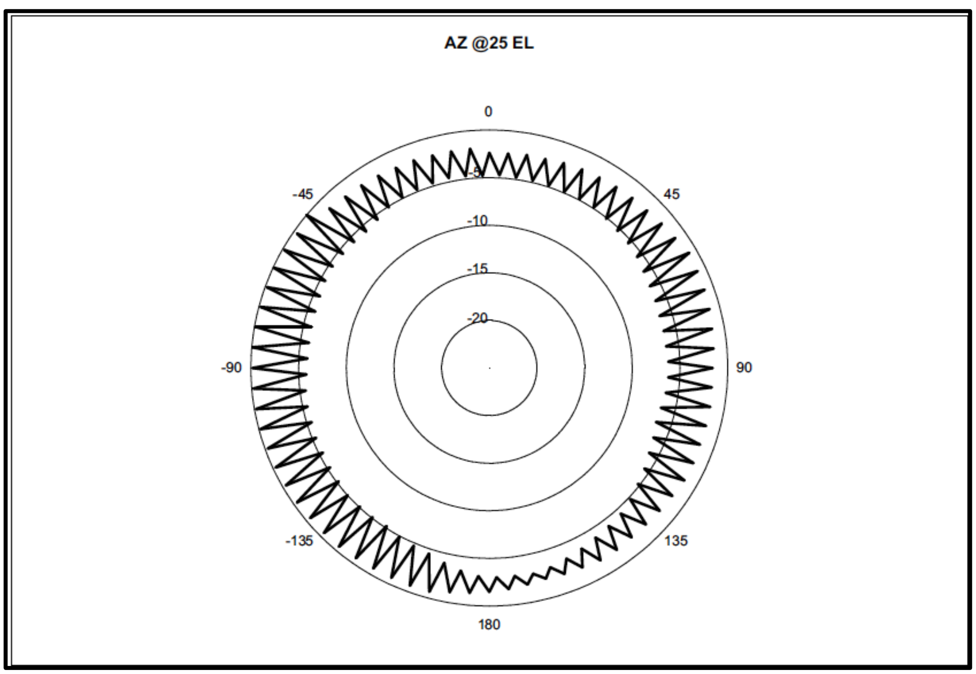
Gain & Axial Ratio vs. Elevation (θ)



+Z

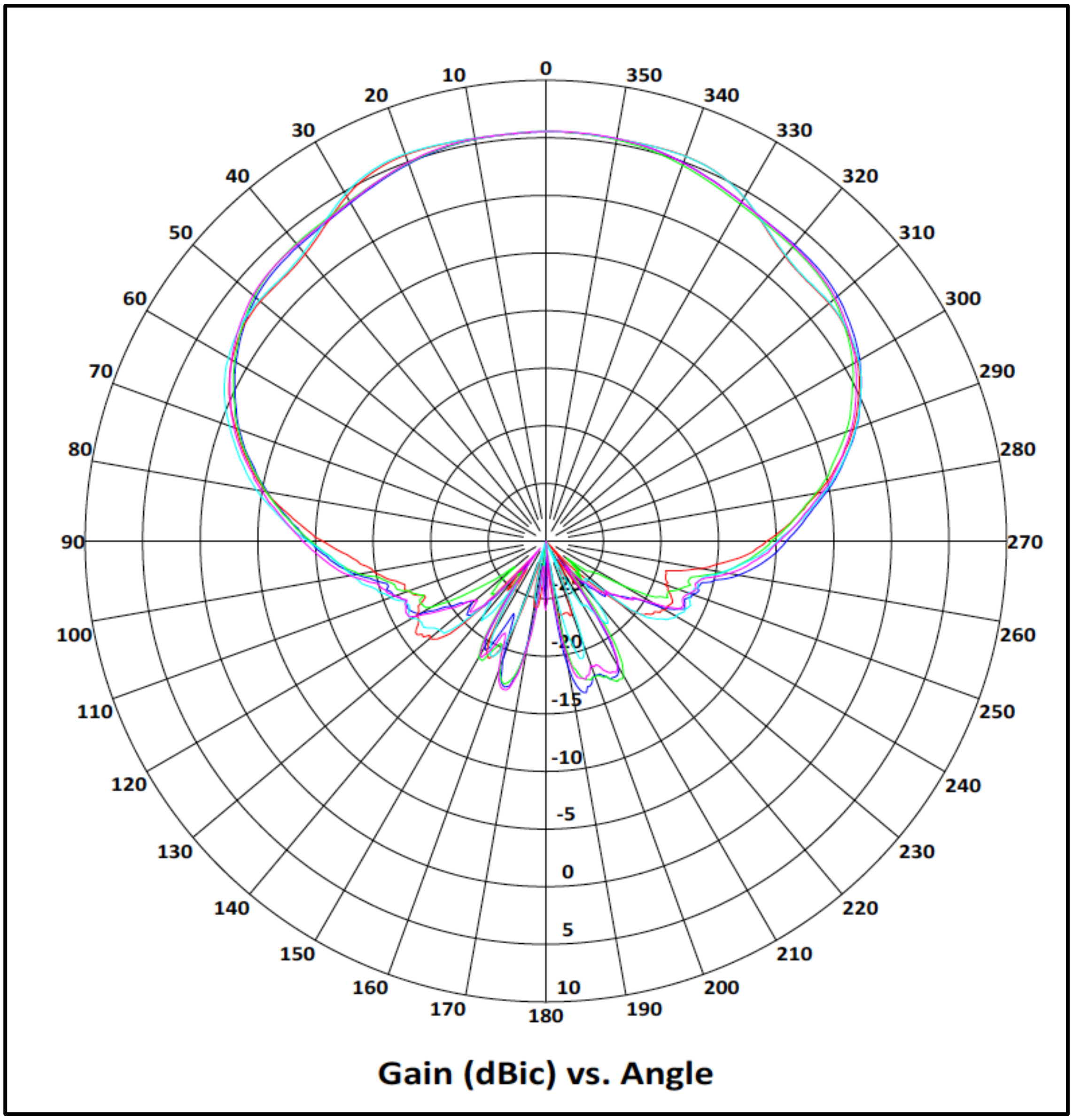
* Ref. Gain 0.0 = 4.5 dBi

Gain and Axial Ratio vs. Azimuth (φ) @ θ = 25°



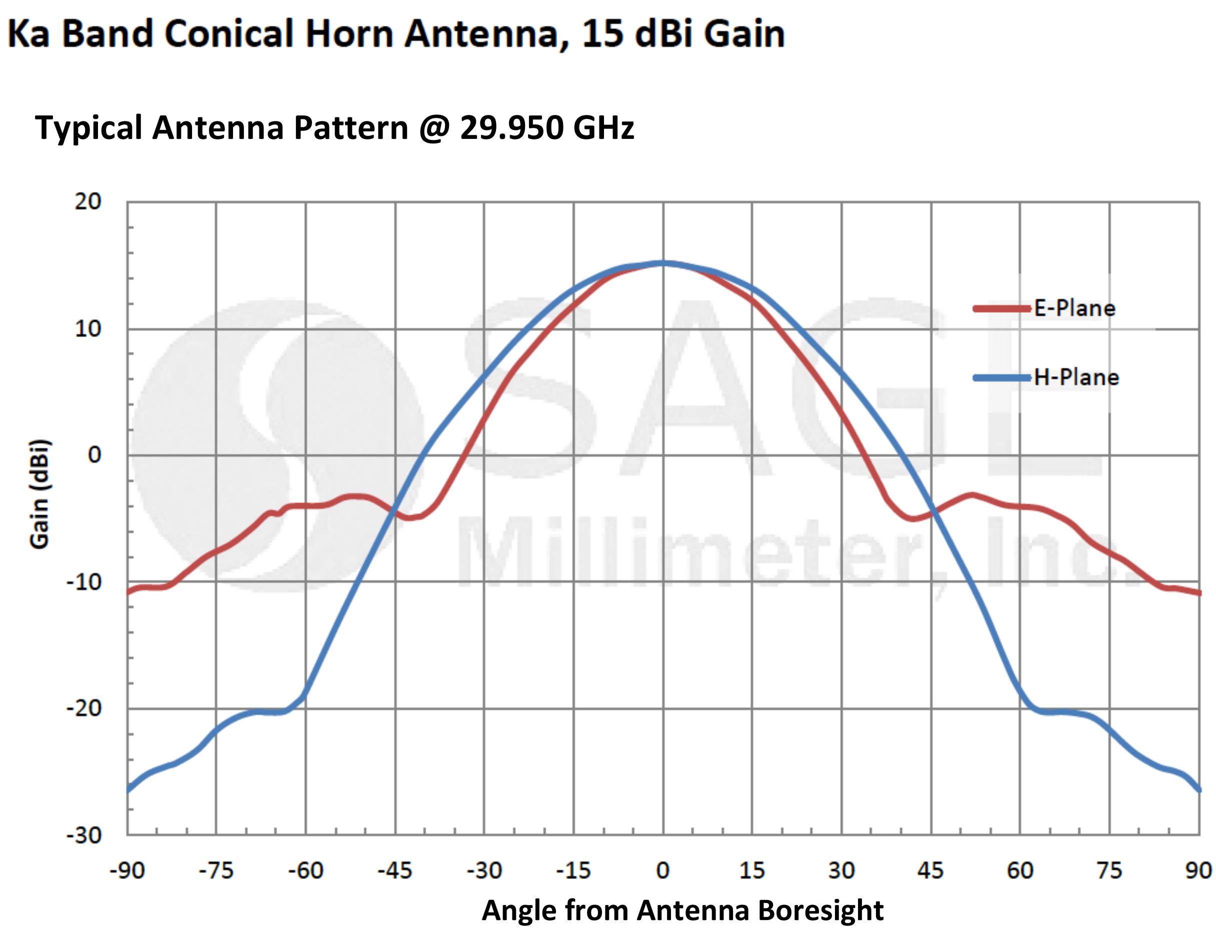
* Ref. Gain 0.0 = 2.5 dBi

Antenna Pattern C-S-RX-8 (S-band CMD Receive Patch)

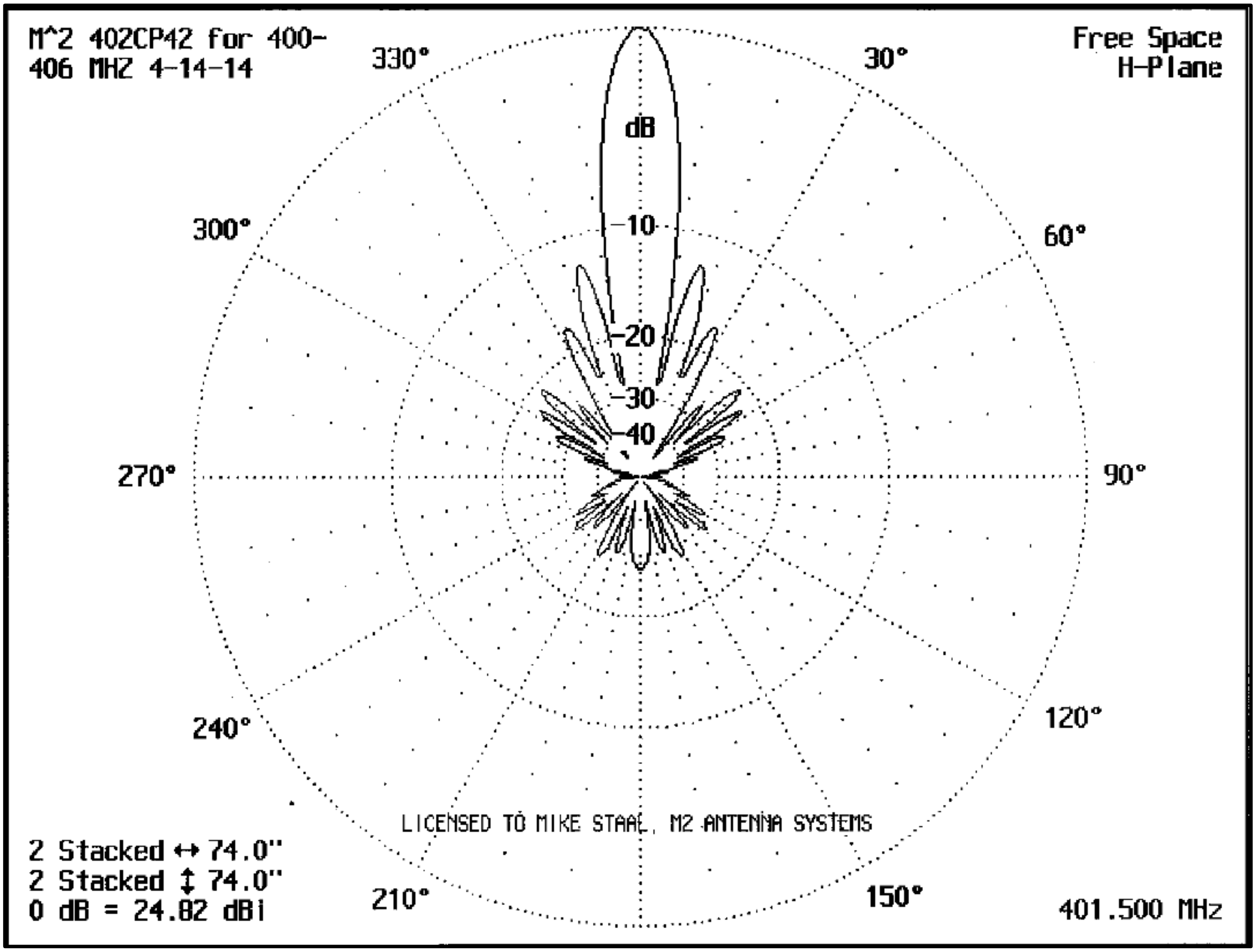


Part Number:	17215
SERIAL NUMBER:	Proto
Frequency:	2.03500 GHz
Polarization:	RHCP
Pattern Cuts: Phi = 0 to 180 Every 45 DEG Theta = VAR	

Antenna Pattern C-Ka-RX-9

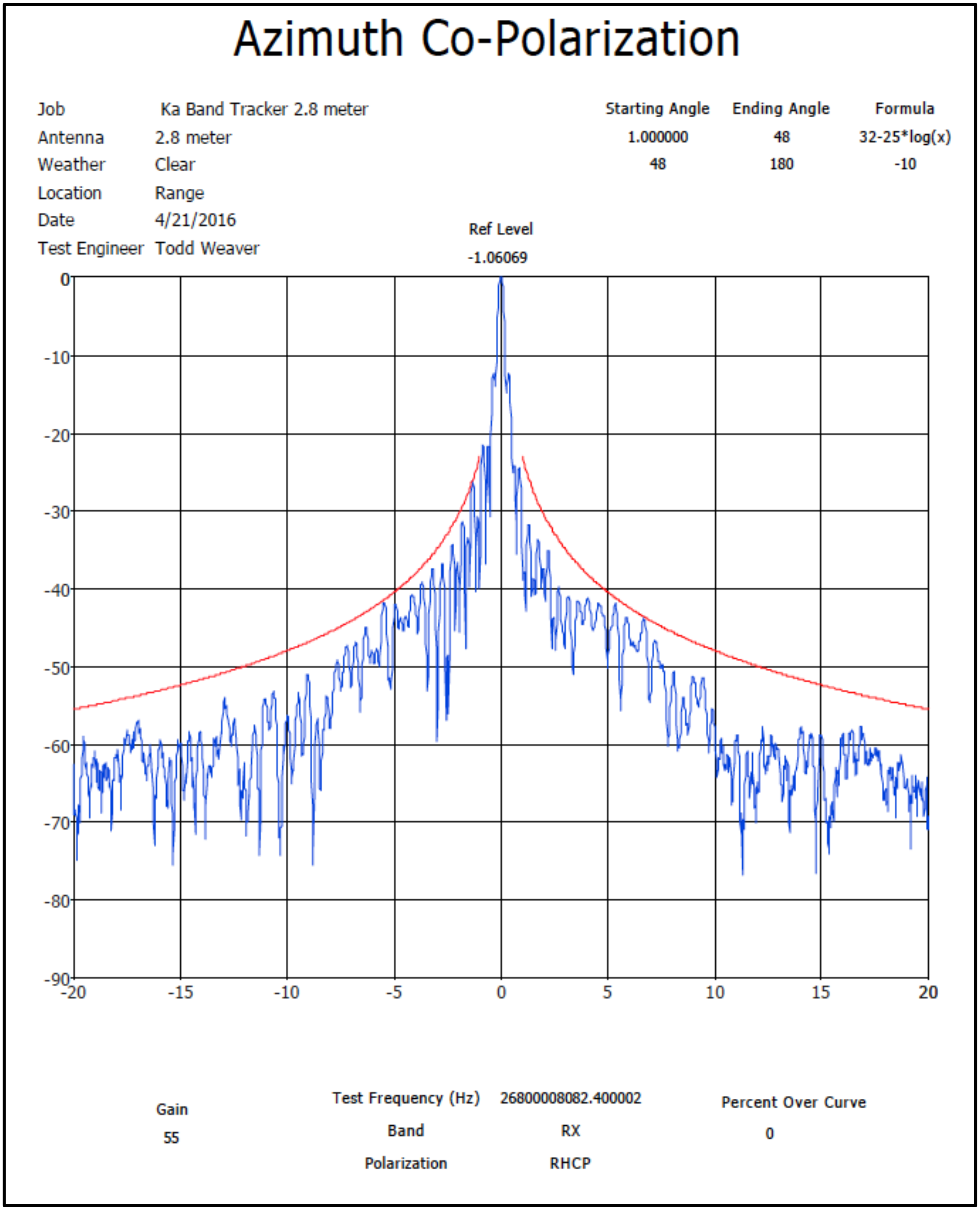


Antenna Patterns C-UHF-TX-GS-10 and C-UHF-RX-GS-11

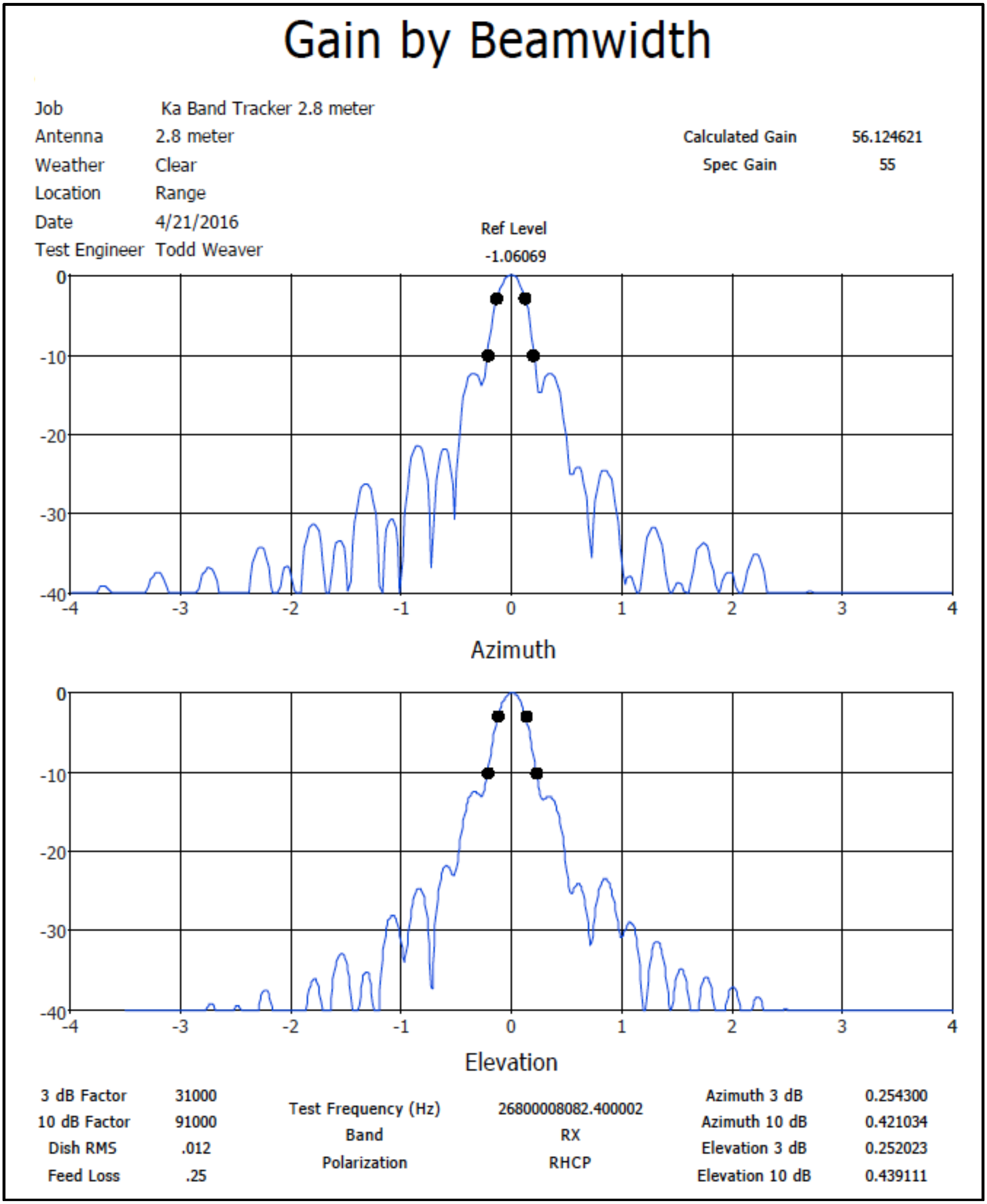


*** Reference Gain 0.0 = 24.8 dBi; RHCP or LHCP**

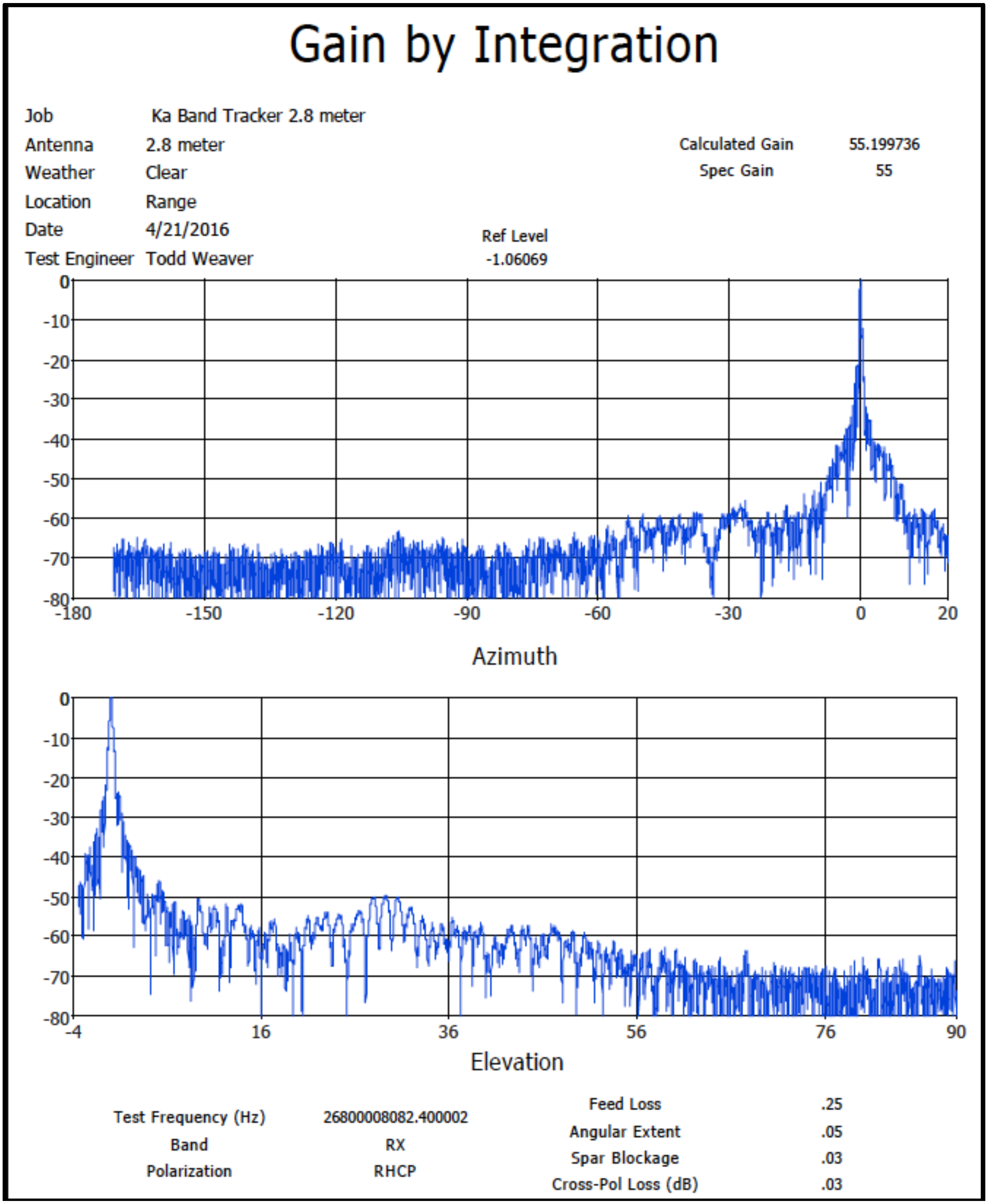
Antenna Pattern C-Ka-RX-GS-12 (2.8 m Parabolic Dish) [1]



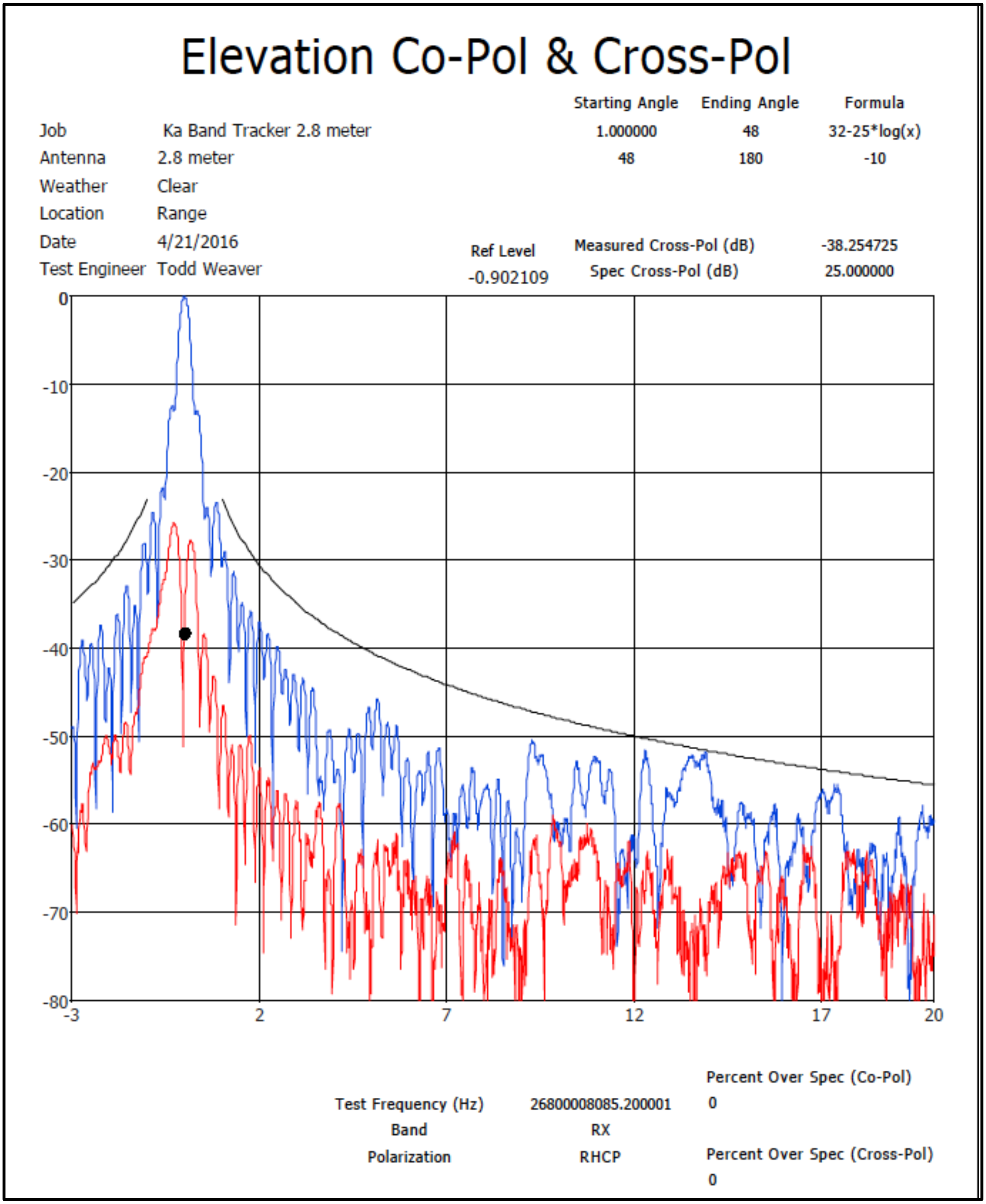
Antenna Pattern C-Ka-RX-GS-12 (2.8 m Parabolic Dish) [2]



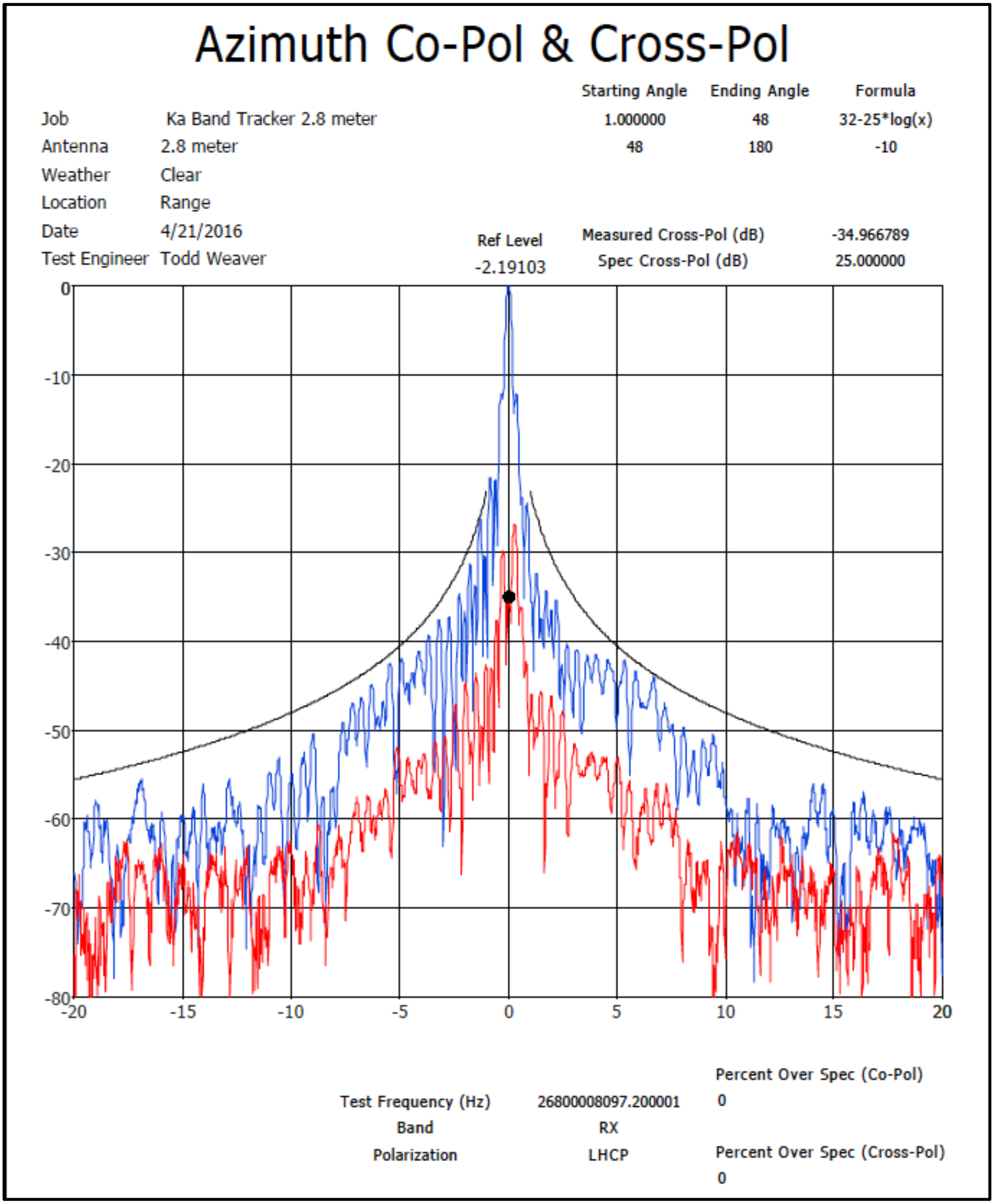
Antenna Pattern C-Ka-RX-GS-12 (2.8 m Parabolic Dish) [3]



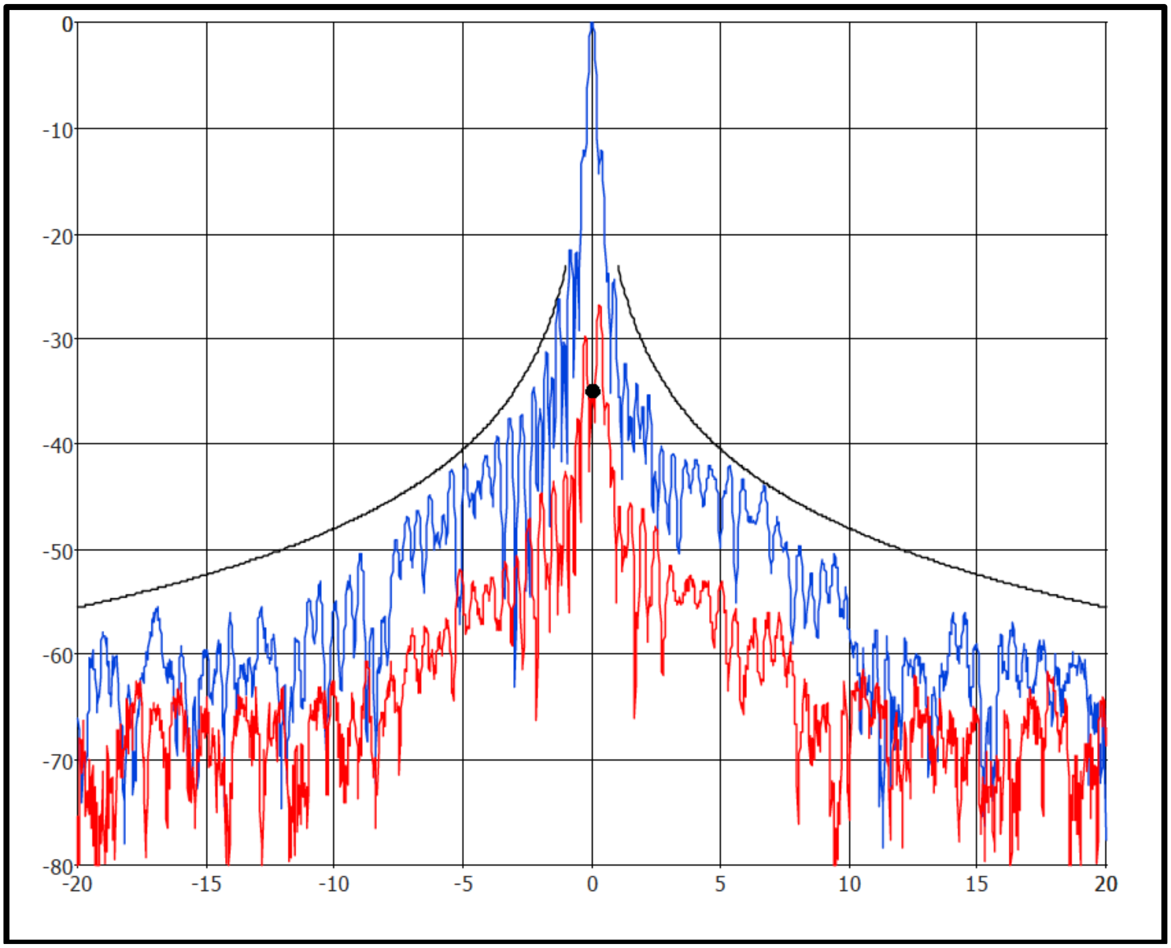
Antenna Pattern C-Ka-RX-GS-12 (2.8 m Parabolic Dish) [4]



Antenna Pattern C-Ka-RX-GS-12 (2.8 m Parabolic Dish) [5]



Antenna Pattern C-Ka-TX-GS-13 (2.8 m Parabolic Dish)



Estimated 2.8 m TX Antenna Performance:

Antenna Peak Gain: 56.7 dBi = 0 Ref.

-3 dB Beamwidth: 0.250 °

Polarization: RHCP

Cross-Polarization Isolation: 27 dB

Reference Equation for Gain Envelope: $G = 32 - 25\log(\theta)$
where θ is offset angle from antenna boresight

Antenna Pattern C-S-TX-GS-14 (1.5 m S-Band Parabolic Dish Antenna)

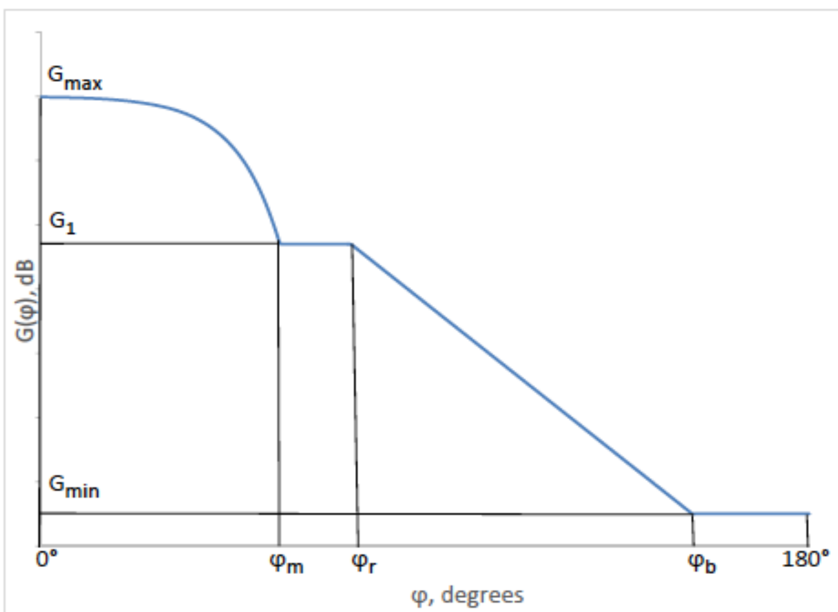
The 2025.600 MHz Command Antenna has been modeled using a mathematical description given by the ITU Antenna Patterns Reference Manual.[1] Specifically Reference Antenna APEREC005V01 is utilized.

The general form for the gain vs. boresight angle used is given in the form:

Table C-S-TX-GS-14A: S-Band Parabolic Antenna General Gain Format

Co-polar component: Mathematical description of the co-polar pattern component as defined in the referenced documents and implemented in the APL Standard Library. The following notations are used:

G	is the co-polar gain at the off-axis angle φ, dB.
G_x, Gx	is the cross-polar gain at the off-axis angle φ, dB.
G_{max}, Gmax	is the maximum co-polar gain, dB.
φ, Phi	is the off-axis angle referred to the main lobe, degrees.
$φ_0$, Phi0	is the half-power beamwidth, degrees.
D	is the antenna diameter, meters.
λ, lambda	is the wavelength, meters.
η	is the antenna efficiency.
B_{min}, Bmin	is the beamlet, degrees.
$φ_m$, Phi m	is the start angle of the first side lobe (plateau constant part), degrees.
$φ_r$, Phi r	is the start angle of the near side lobe (logarithmic part), degrees.
$φ_b$, Phi b	is the start angle of the back lobe (back constant part), degrees.
G_1, G1	is the gain of the first side lobe (plateau constant part), dB.
CoefA, CoefB	are parameters describing the near side lobe (logarithmic part), both in dB.
G_{min}, Gmin	is the gain of the back lobe (back constant part), dB.



log is a base 10 logarithmic function.

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[1] T. Filipova, *Antenna Patterns Reference Manual*, Ref: APL-UM-001, Ver. 1.1.19, 2016-04-21, p 9 & 22.

The equations given by the referenced document for the gain and boresight angle behavior of the antenna is further specified as follows:

Table C-S-TX-GS-14B: APEREC005V01 Gain & Angle Formulas

Co-Polar Component

$G = G_{max} - 2.5 \times 10^{-3} (D/\lambda \ \varphi)^2$ for $0° \leq \varphi < \varphi_m$

$G = G_1$ for $\varphi_m \leq \varphi < \varphi_r$

$G = 52 - 10 \log (D/\lambda) - 25 \log \varphi$ for $\varphi_r \leq \varphi < \varphi_b$

$G = 0$ for $\varphi_b \leq \varphi \leq 180°$

where:

$$D/\lambda = 10^{\left(\frac{G_{max} - 7.7}{20}\right)}.$$

$$G_1 = 2 + 15 \log (D/\lambda).$$

$$\varphi_m = 20 \lambda/D \sqrt{G_{max} - G_1}.$$

$$\varphi_r = 100 \lambda/D.$$

$$\varphi_b = \varphi_1 = 120 (\lambda/D)^{0.4}.$$

Calculations yield the following characteristics for the S-band command antenna:

Table C-S-TX-GS-14C: S-band Antenna Characteristics

Antenna Diameter: 1.50 m

Polarization: RHCP or LHCP

Operating Frequency: 2.025600 GHz

Operating Wavelength: 0.14793 m

$D/\lambda = 9.77237$

Aperture Efficiency = 55.0%

$G_{max} = 27.5$ dBi

-3 dB Beamwidth = 6.91° (two-sided)

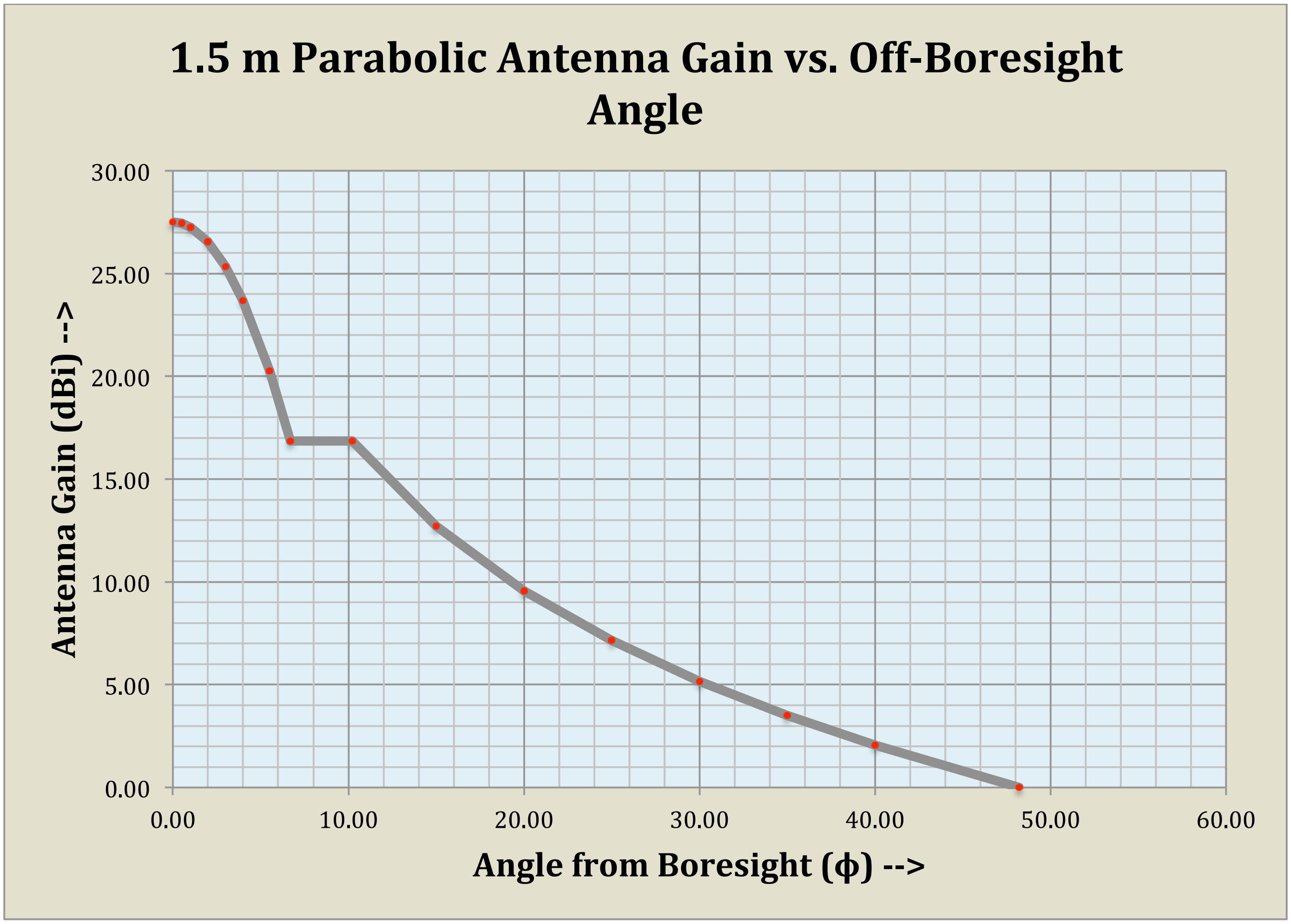
$G_1 = 16.9$ dBi

$\varphi_m = 6.68°$

$\varphi_r = 10.23°$

$\varphi_b = 48.22°$

These equations and the coefficients generated by the reference antenna model produce the following antenna pattern (Gain in dBi vs. off-boresight angle ϕ):



<u>Figure C-S-TX-GS-14</u>: Antenna Gain vs. Angle from Boresight - 1.5 m Parabolic Dish Antenna)