# TECHNICAL ANNEX

# I. GHOSt SATELLITE SYSTEM ANTENNA PATTERNS

The antenna patterns for the GHOSt 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**

**GHOSt-01 - GHOSt-06 All Spacecraft**

| *Pattern No.:* | *Antenna:* | *Purpose:* | *Emission Category:* | *Antenna Type:* | *Frequency:* | *Peak Gain:* | *Polarization:* | |
|---|---|---|---|---|---|---|---|---|
| C-UHF-TX-GH-1 | UHF TX | TLM TX-ADV | T&C | Dipole- Like | 400.500 MHz | 2.1 dBi | Linear | Rotating |
| C-UHF-TX-GH-2 | UHF TX | TLM TX-TRV | | Dipole- Like | 400.500 MHz | 2.1 dBi | Linear | Rotating |
| C-S-RX-GH-1 | S-band RX | COMMAND | | Patch | 2056.0 MHz | 5.5 dBi | Circular | RHCP |
| C-L-TX-GH-3 | L-band TX | G* RTN TLM | ISDL-TLM | Patch | 1618 MHz | 4.4 dBi | Circular | RHCP |
| C-Ka-TX-GH-M1 | Ka-band TX | H. S. Data (Mode 1) | Service Downlink | Horn Array | 25.5-27.0 GHz | 26.8 dBi | Circular | LHCP or RHCP |
| C-Ka-TX-GH-M2 | Ka-band TX | H. S. Data (Mode 2) | | Lens Aided Horn | 26.800 GHz | 23.5 dBi | Circular | LHCP or RHCP |
| C-S-RX-GH-M1 | S-band RX | H.S. Data Control | Service Uplink | Patch | 2047.5 MHz | 5.5 dBi | Circular | RHCP |

**Table C-2: Ground Station Antenna Patterns**

**GHOSt-01 - GHOSt-06 All Earth Stations**

| *Pattern No.:* | *Antenna:* | *Purpose:* | *Emission Category:* | *Antenna Type:* | *Frequency:* | *Peak Gain:* | *Polarization:* | | *Stn. Location:* | *Latitude:* | *Longitude:* | *Alt. (above MSL):* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C-UHF-RX-GS-1 | UHF RX | TLM | T&C | 2 X-Pole Yagi System | 400.5 | 21.0 dBi | Circular | RHCP/LHCP | Santa Clara, CA | 37°22'48"N | 121°57'40"W | 11 m |
| C-UHF-RX-GS-2 | UHF RX | TLM | | 2 X-Pole Yagi System | 400.5 | 20.5 dBi | Circular | RHCP/LHCP | Tromsø, NOR | 69°39'44"N | 18°56'27"E | 95 m |
| C-S-TX-GS-3 | S-band TX | CMD | | 1.5 m Parabola | 2056.0 MHz | 27.5 dBi | Circular | RHCP/LHCP | Tromsø, NOR | 69°39'44"N | 18°56'27"E | 95 m |
| C-S-TX-GS-4 | S-band TX | CMD | | 2.8 m Parabola | 2056.0 MHz | 33.0 dBi | Circular | RHCP/LHCP | Svalbard, NOR | 78°13'55"N | 15°22'23"E | 479 m |
| C-Ka-RX-GS-5 | Ka-band RX | H.S. Data | Service Downlink | 2.8 m Parabola | 26.800 GHz | 55.3 dBi | Circular | RHCP/LHCP | Svalbard, NOR | 78°13'55"N | 15°22'23"E | 479 m |
| C-Ka-TX-GS-6 | Ka-band RX | H.S. Data | | 2.8 m Parabola | 25.5-27.0 GHz | 57.0 dBi | Circular | LHCP/RHCP | Troll, Antarctica | 72°00'5.9" | 2°31'30.8"E | 1336 m |
| C-S-TX-GS-7 | S-band TX | H.S. Data Control | Service Uplink | 2.8 m Parabola | 2047.5 MHz | 33.0 dBi | Circular | RHCP/LHCP | Troll, Antarctica | 72°00'5.9" | 2°31'30.8"E | 1336 m |
| C-S-TX-GS-8 | S-band TX | H.S. Data Control | Service Uplink | 2.8 m Parabola | 2047.5 MHz | 33.0 dBi | Circular | RHCP/LHCP | Svalbard, NOR | 78°13'55"N | 15°22'23"E | 479 m |

## Space Station Antenna Patterns:

The spacecraft antenna patterns for the GHOSt-01 – GHOST-06 satellites are the same for the two UHF monopoles and S-band and L-band patch antennas and for the high gain Ka-band array horn antennas employed by all six spacecraft. GHOSt-01 and -02, however, do have one additional Ka-band antenna per spacecraft. This antenna, known as a Lens Aided Horn, is used when Ka-band, mode 2, is enabled. This antenna has a slightly lower peak gain, efficiency and a slightly poorer axial ratio. This antenna's performance is presented as Pattern: C-Ka-TX-GH-M2.

While the polarization of all other spacecraft antennas is circular, the polarization of the UHF TX pattern is linear, and consequently, the terrestrially received signal polarization 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 NGSO orbits 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 (such as horizontal or vertical) 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 the signal and accept at least a 3 dB loss in C/N on the far end of the link, accordingly.

The Globalstar patch antenna (using an L-band transmit frequency) is located on the +Z surfaces of the GHOSt satellites. Hence the patterns are directed upward away from the Earth.

There are two pairs of S-band patch antennas oriented with their boresight directions aligned with the +Y and –Y axes. Two receive patches on opposite side of the satellite are CMD antennas (using 2056 MHz) and two patches, also on opposite sides are for the HSD control link (using 2047.5 MHz). Both pairs are then fed in-phase, creating a near-omnidirectional antenna pattern. The individual patterns of these antennas are presented in this attachment.

## Antenna Patterns C-UHF-TX-GH-1 and C-UHF-RX-GH-2

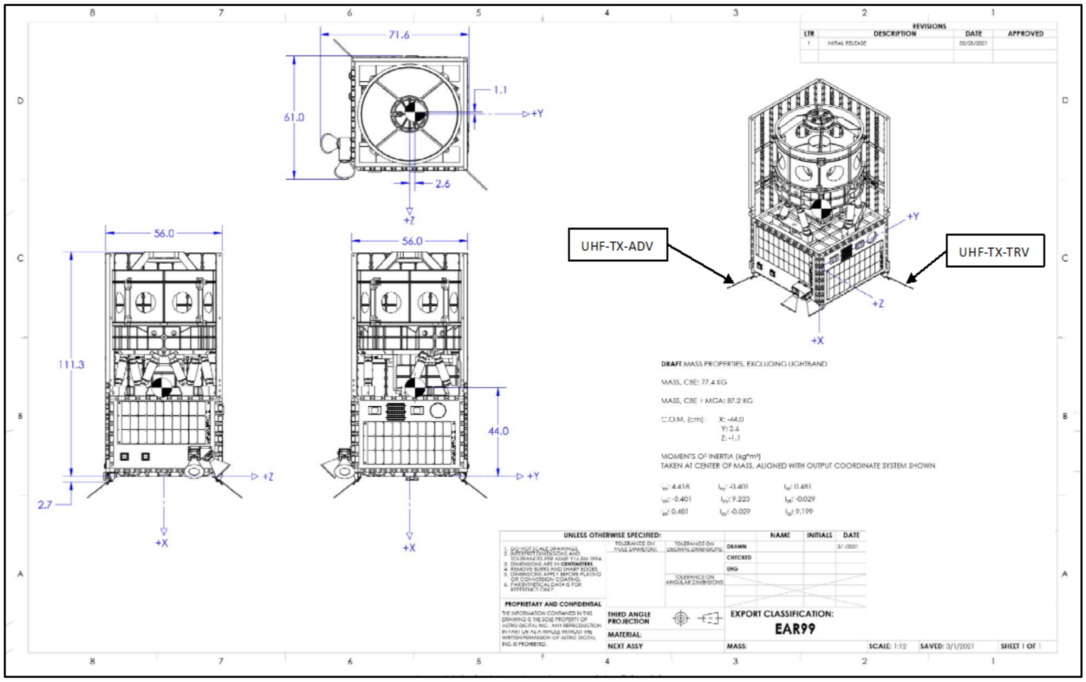


**Figure C-UHF-TX-GH-1/2 A:** Reference Coordinate System for GHOSt-01-06

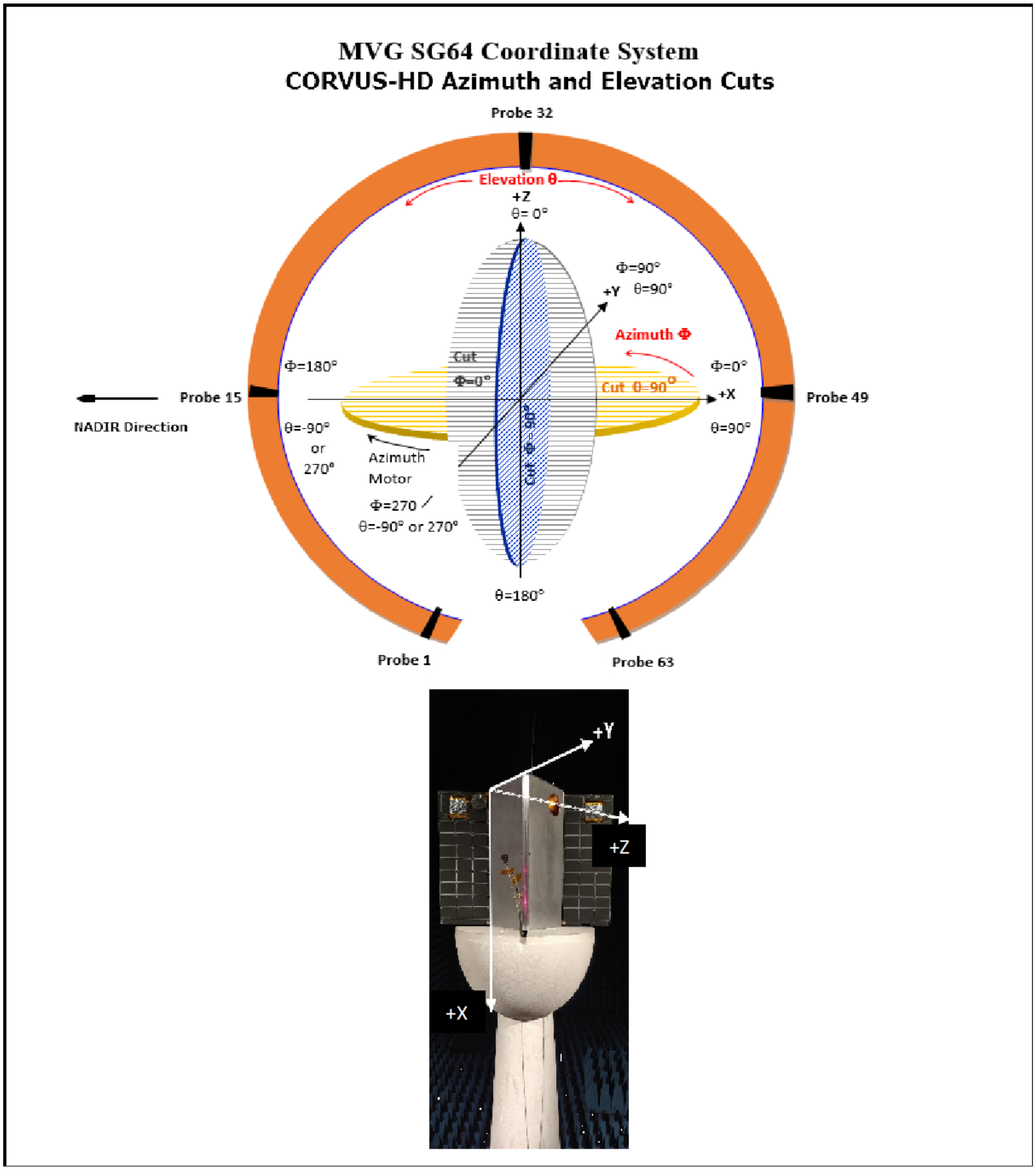
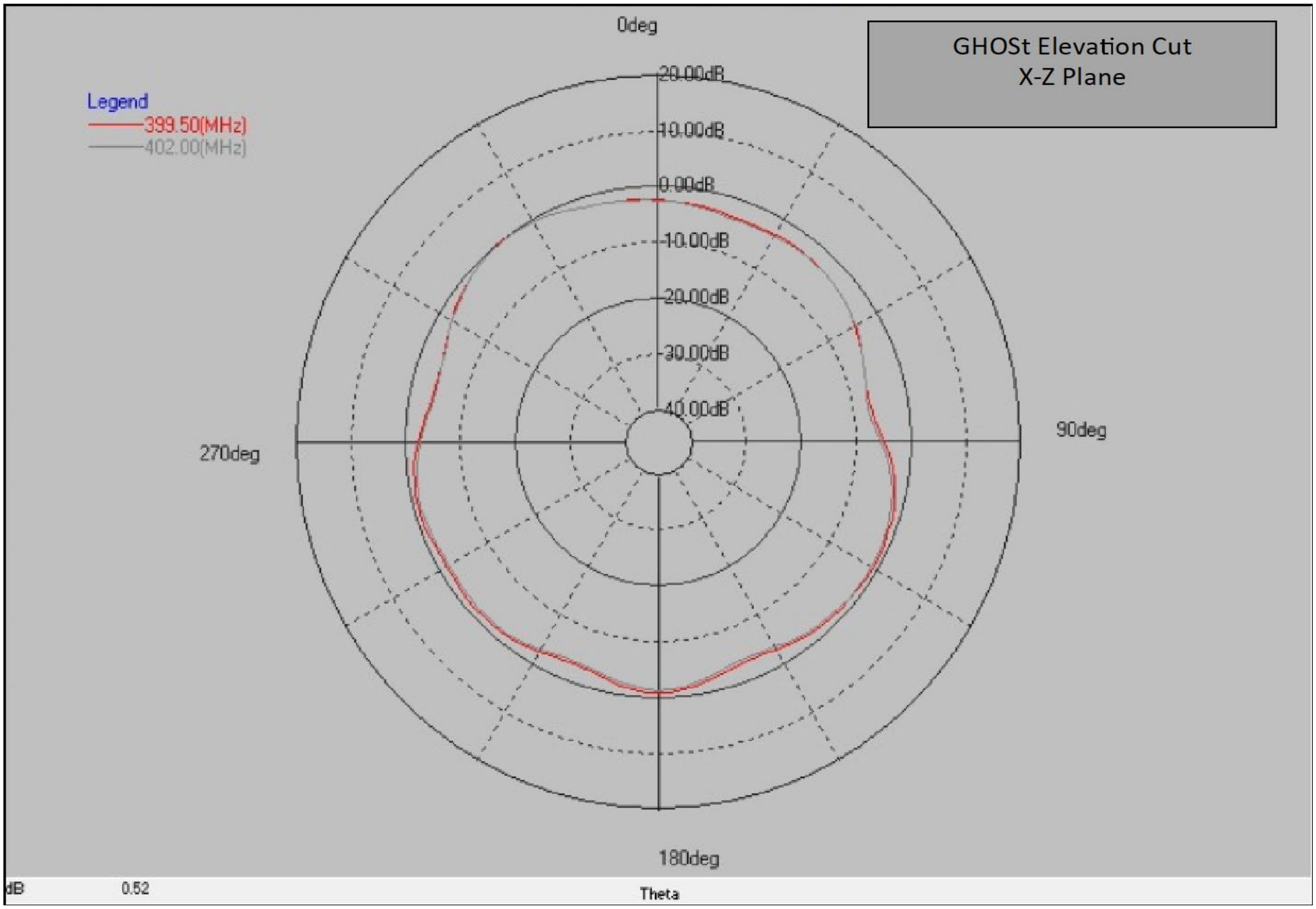
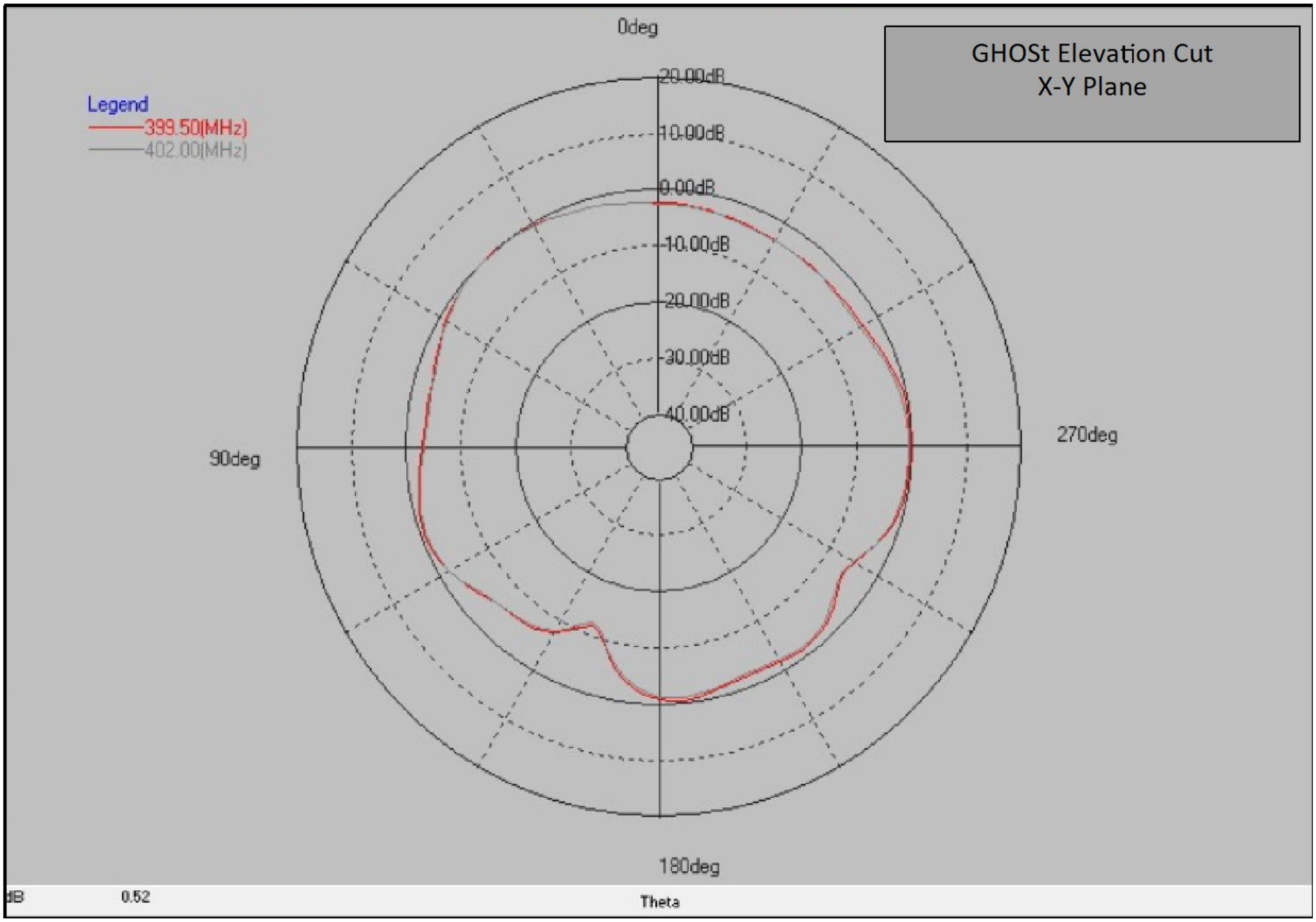


**Figure C-UHF-TX-GH-1/2 B:** Measurement Coordinate System for GHOSt-01-06



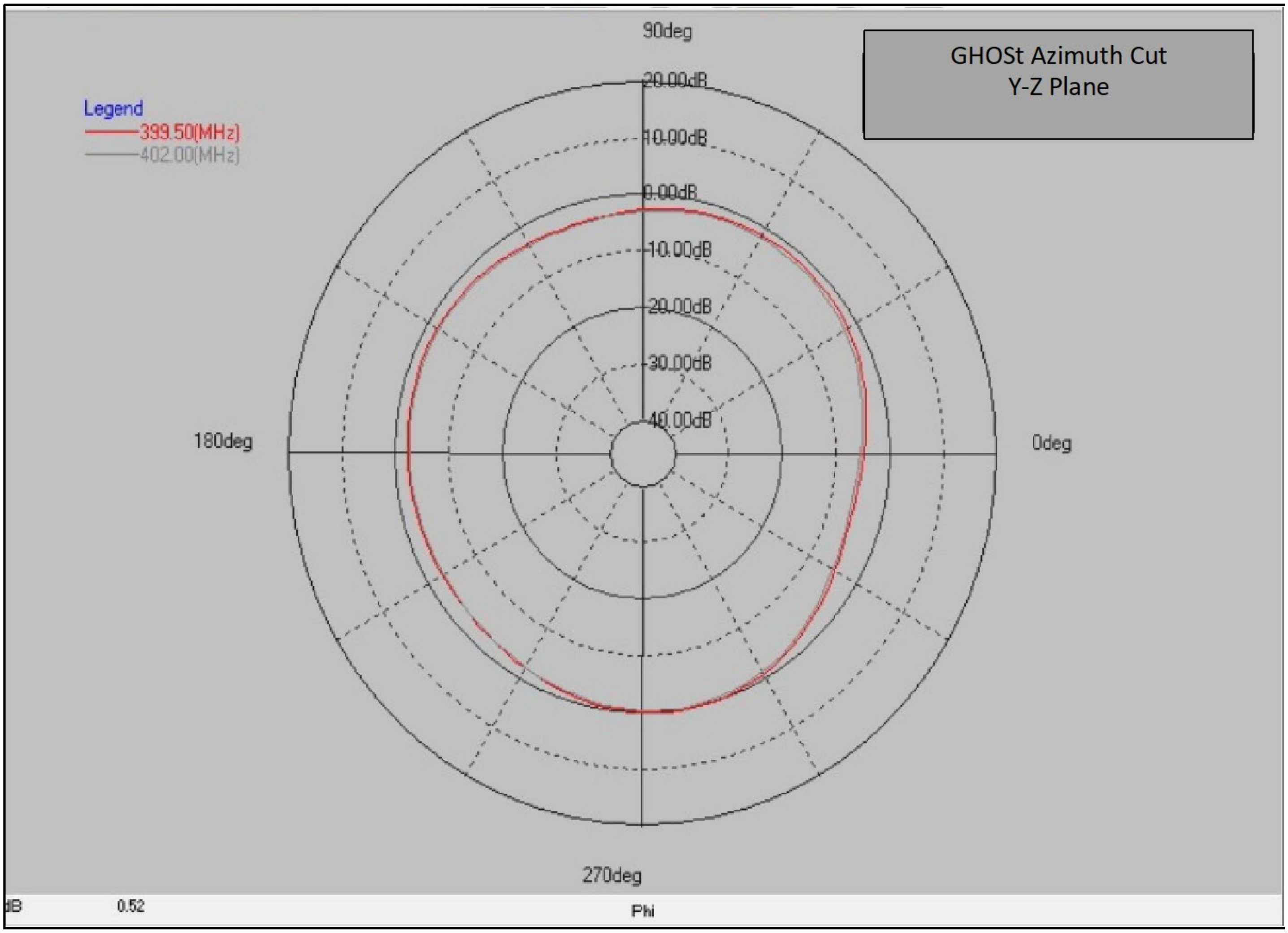
Theta (θ)

**<u>Figure C-UHF-TX-GH-1/2 C</u>:** GHOSt Elevation Cut; X-Z Plane



Theta (θ)

**Figure C-UHF-TX-GH-1/2 D**: GHOSt Elevation Cut; X-Y Plane



Phi (φ)

**Figure C-UHF-TX-GH-1/2 E:** GHOSt Azimuth Cut; Y-Z Plane

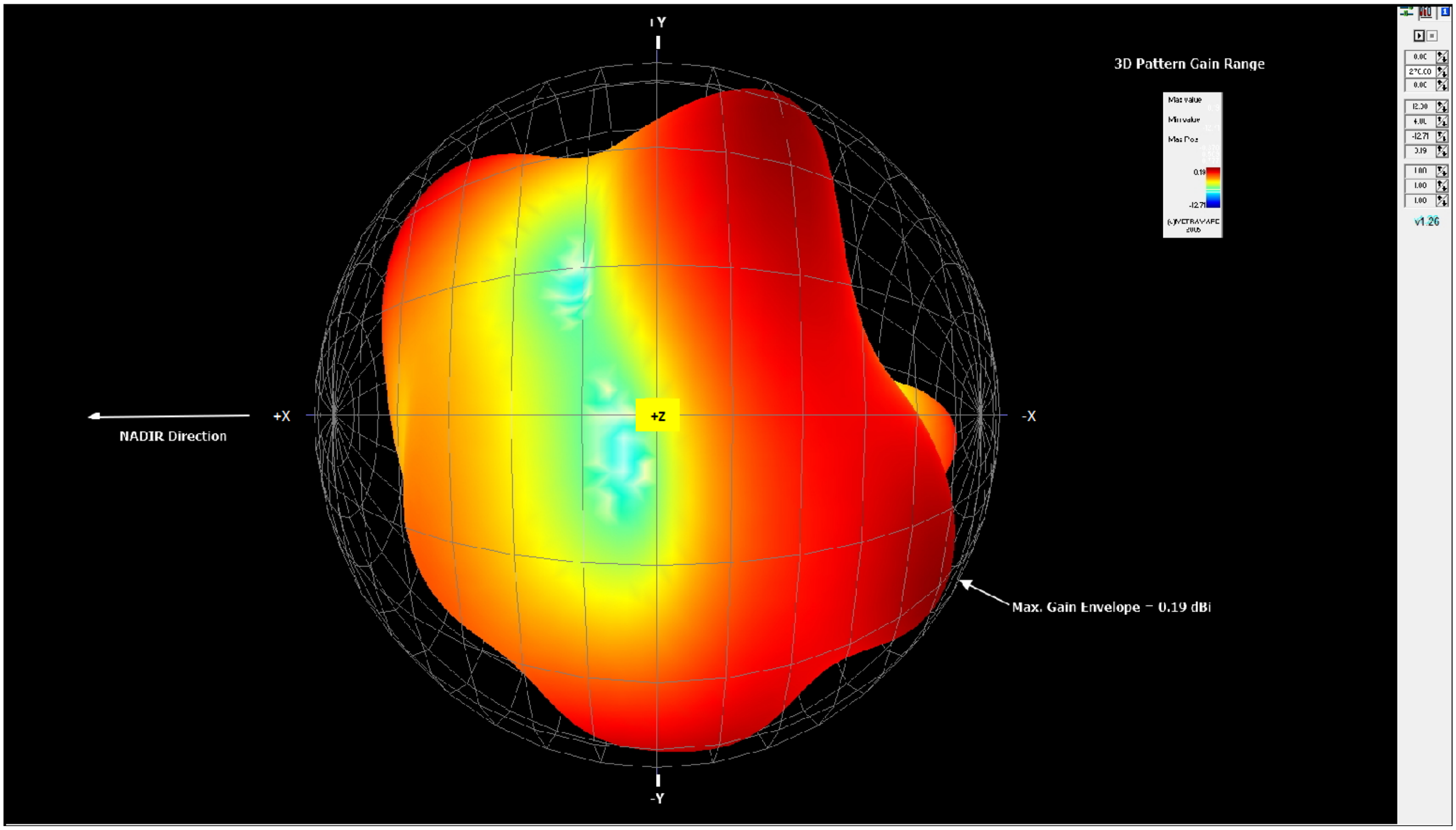


**Figure C-UHF-TX-GH-1/2 F:** 3D Pattern Plot; +Z View

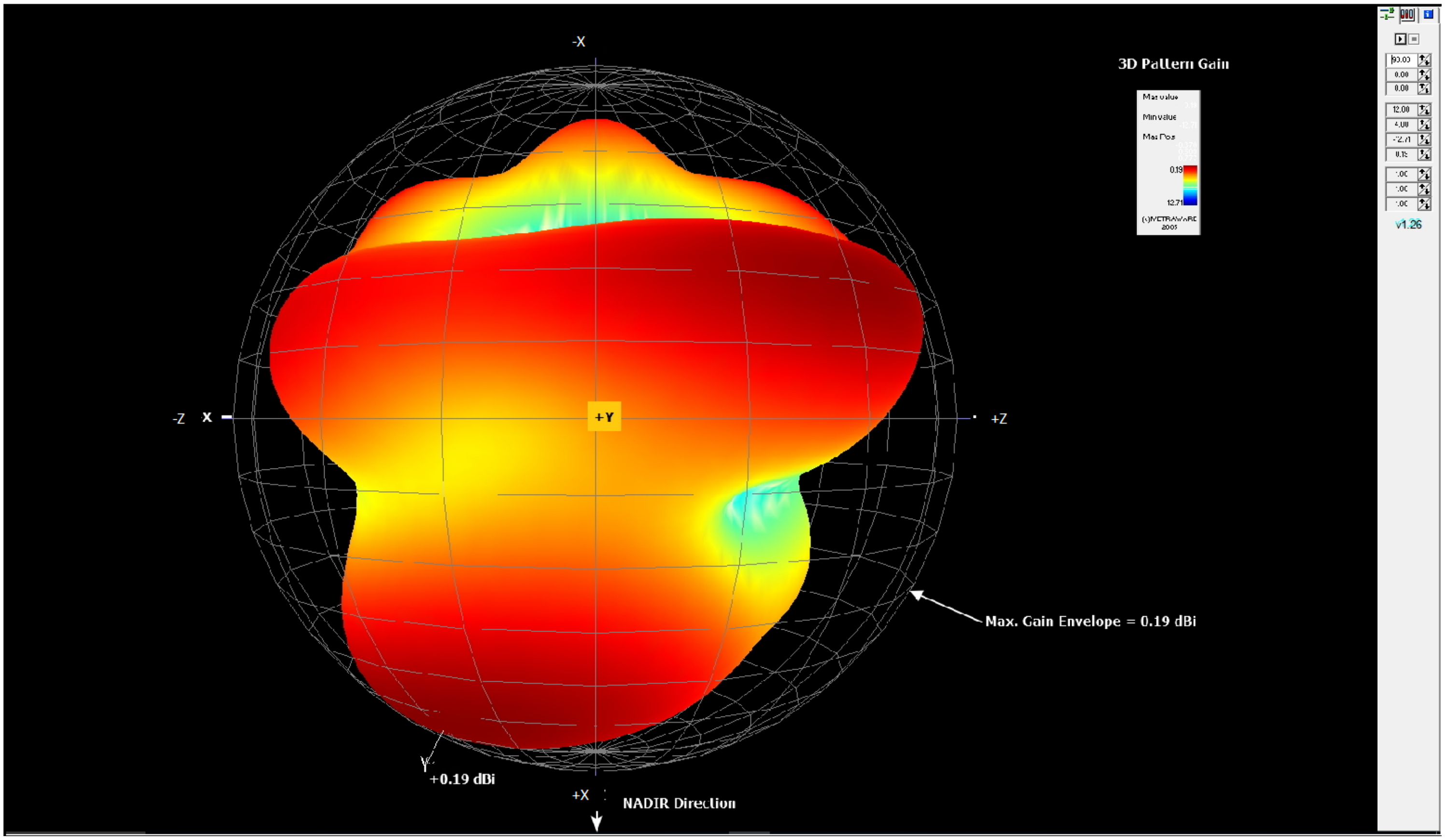


**Figure C-UHF-TX-GH-1/2 G:** 3D Pattern Plot; +Y View

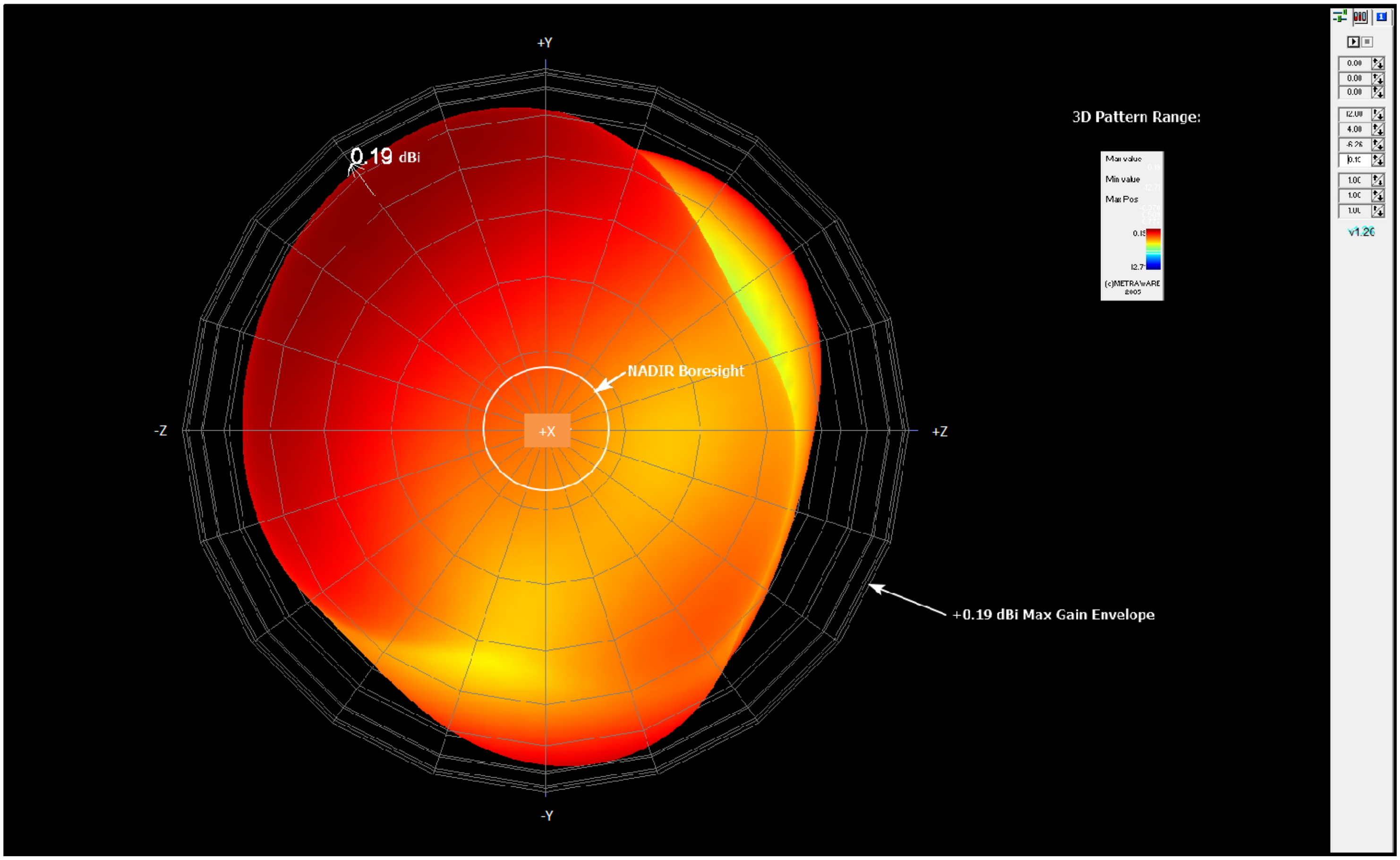
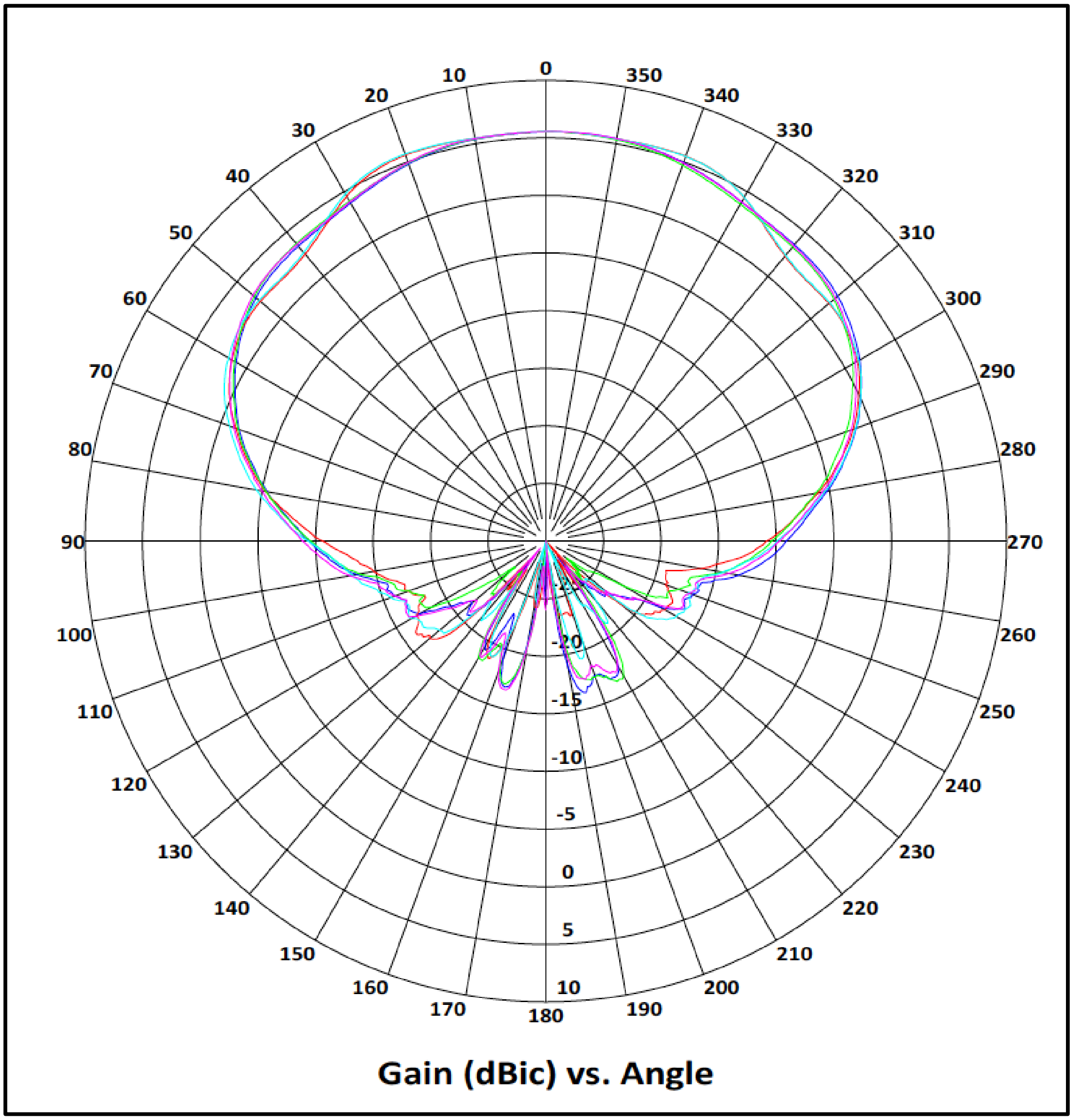


**Figure C-UHF-TX-GH-1/2 G:** 3D Pattern Plot; +X View

## Antenna Pattern C-S-RX-GH-1 (S-band CMD Receive Patch, x 2)



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

<u>NOTE</u>: Flight Antennas will be re-manufactured for a center frequency of 2056 MHz, RHCP. Gain performance will be as per this data set.

Antennas mounted to +Y and –Y surfaces of S/C.

**<u>Figure C-S-RX-GH-1/2 A:</u>** Command Patch Ant. Pattern

## Antenna Pattern: C-L-TX-GH-3 (L-band Transmit Patch)

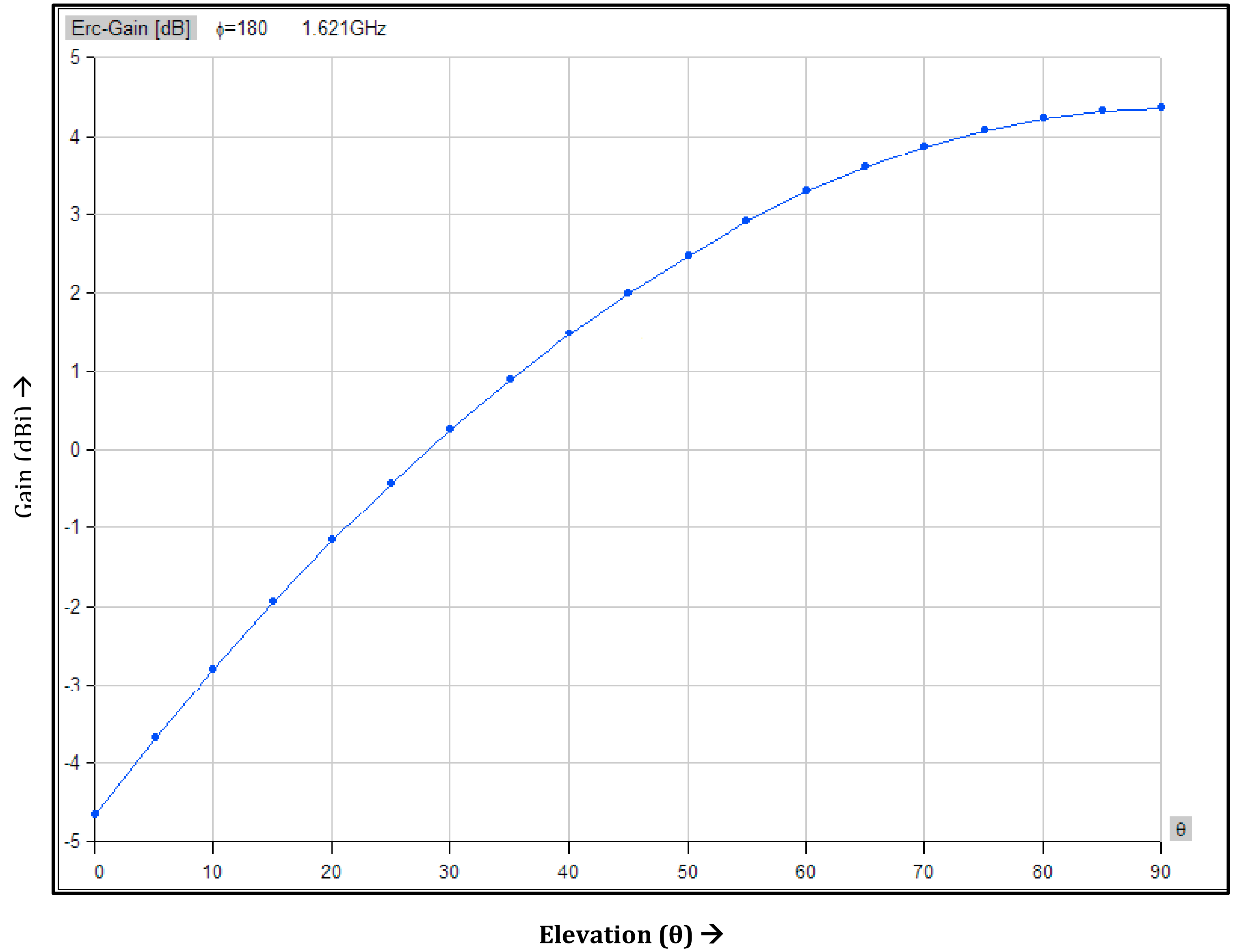
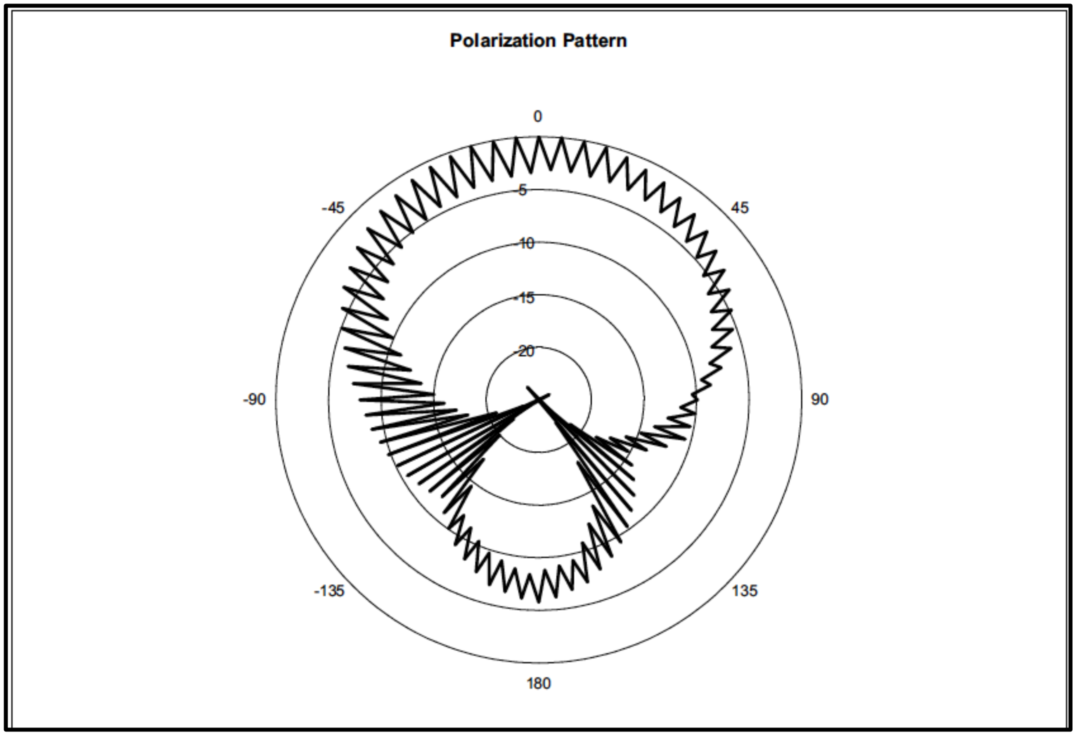


**Figure C-L-TX-GH-3 A**: Antenna Pattern C-L-TX-6B (Globalstar ISDL Transmit Patch)

NOTE: Flight Antennas will be re-manufactured for a center frequency of 1617 MHz, RHCP. Gain performance will be as per this data set.

Antennas mounted to +Y and –Y surfaces of S/C.

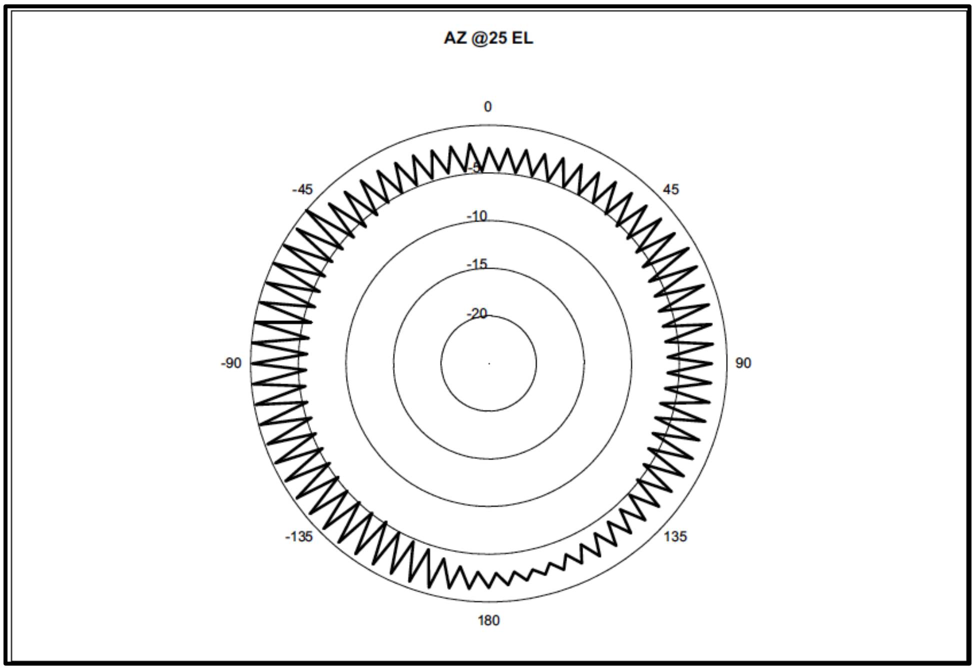
**Gain and Axial Ratio vs. Elevation (θ)**



↑ * Ref. Gain 0.0 = 4.5 dBi

**Max. Gain Toward +Z or –Z**

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

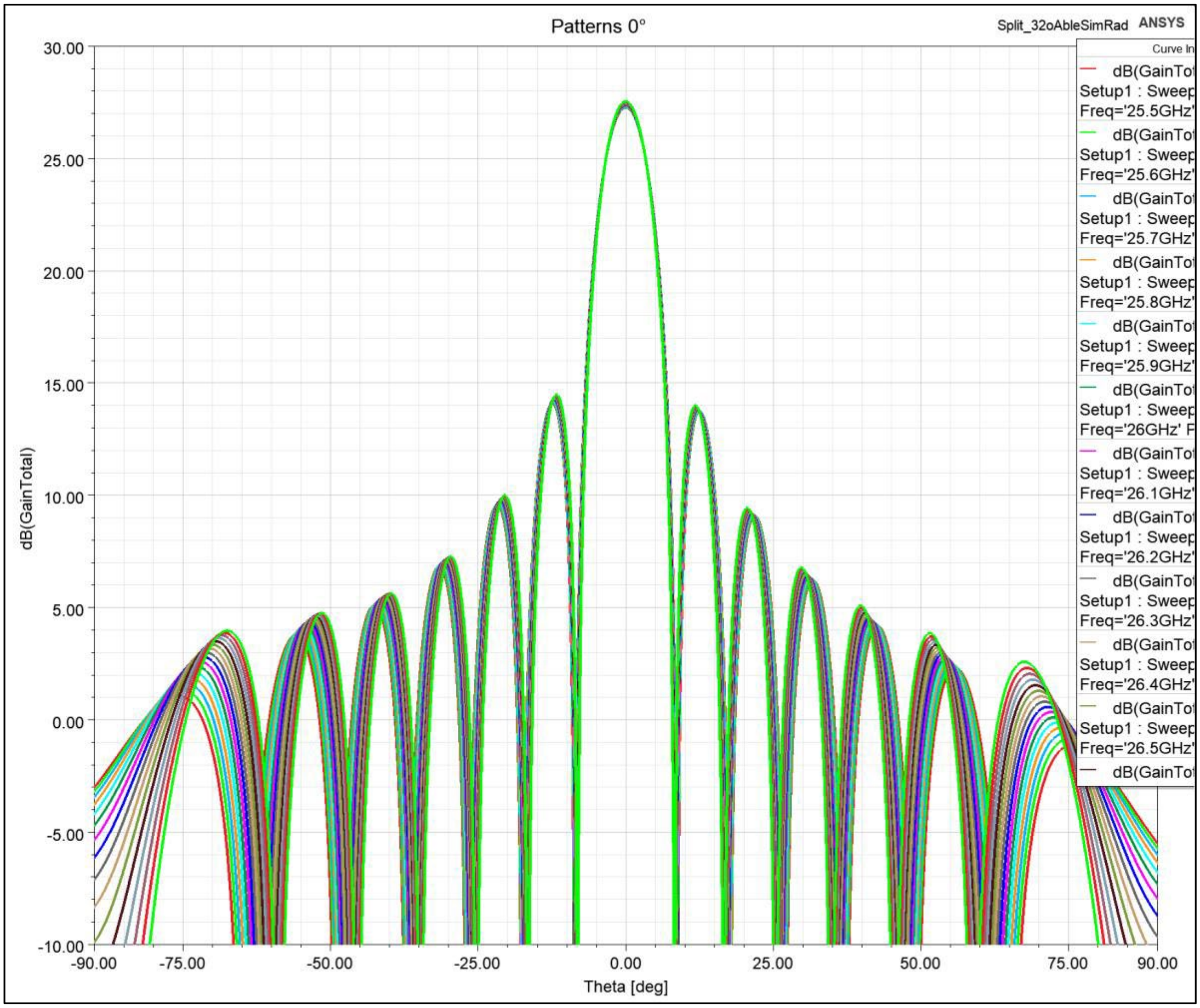


* Ref. Gain 0.0 = 2.5 dBi

**<u>Figure C-L-TX-GH-3 B</u>:** Axial Ratio (Globalstar ISDL Transmit Patch)

# Antenna Pattern: C-Ka-TX-GH-M1 (H.S. Data Antenna – Mode 1)

(Cut: φ = 0°)

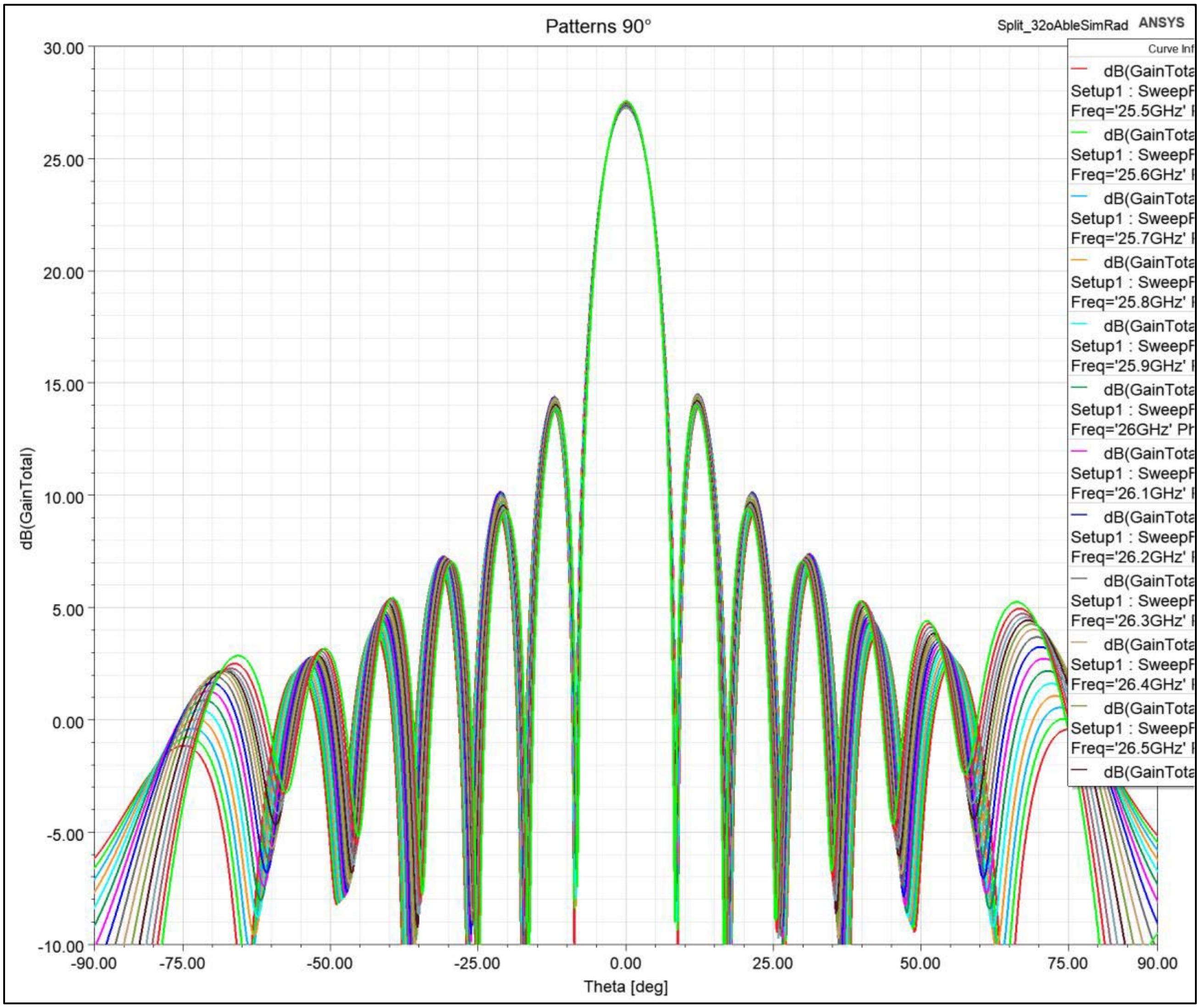


| | | |
|---|---|---|
| **Frequency:** | 26.25 | GHz |
| **Polarization:** | RHCP | |
| **Peak Gain:** | 26.8 | dB |
| **1st Null:** | 8 | deg |
| **2nd Null:** | 16.5 | deg |
| **Beamwidth:** | 3.58 | +/- deg |
| | 7.16 | deg |
| **SLL:** | 13.3 | dB |

Directivity: 27.5 dBi

**<u>Figure C-Ka-TX-GH-M1 A</u>:** High Gain Ka-band Antenna Directivity ((Cut: φ = 0°)

(Cut: φ = 90°)



<u>NOTE</u>: Flight Antennas will be manufactured for maximum gain at a center frequency of 26.25 GHz, RHCP or LHCP (selectable in orbit). Gain and directivity performance will be as per this data set.

Antennas mounted on +Z surface of the spacecraft.

**<u>Figure C-Ka-TX-GH-M1 B</u>:** High Gain Ka-band Antenna Directivity ((Cut: φ =90°)

## Antenna Pattern: C-Ka-TX-GH-M2 (H.S. Data Antenna – Mode 2)

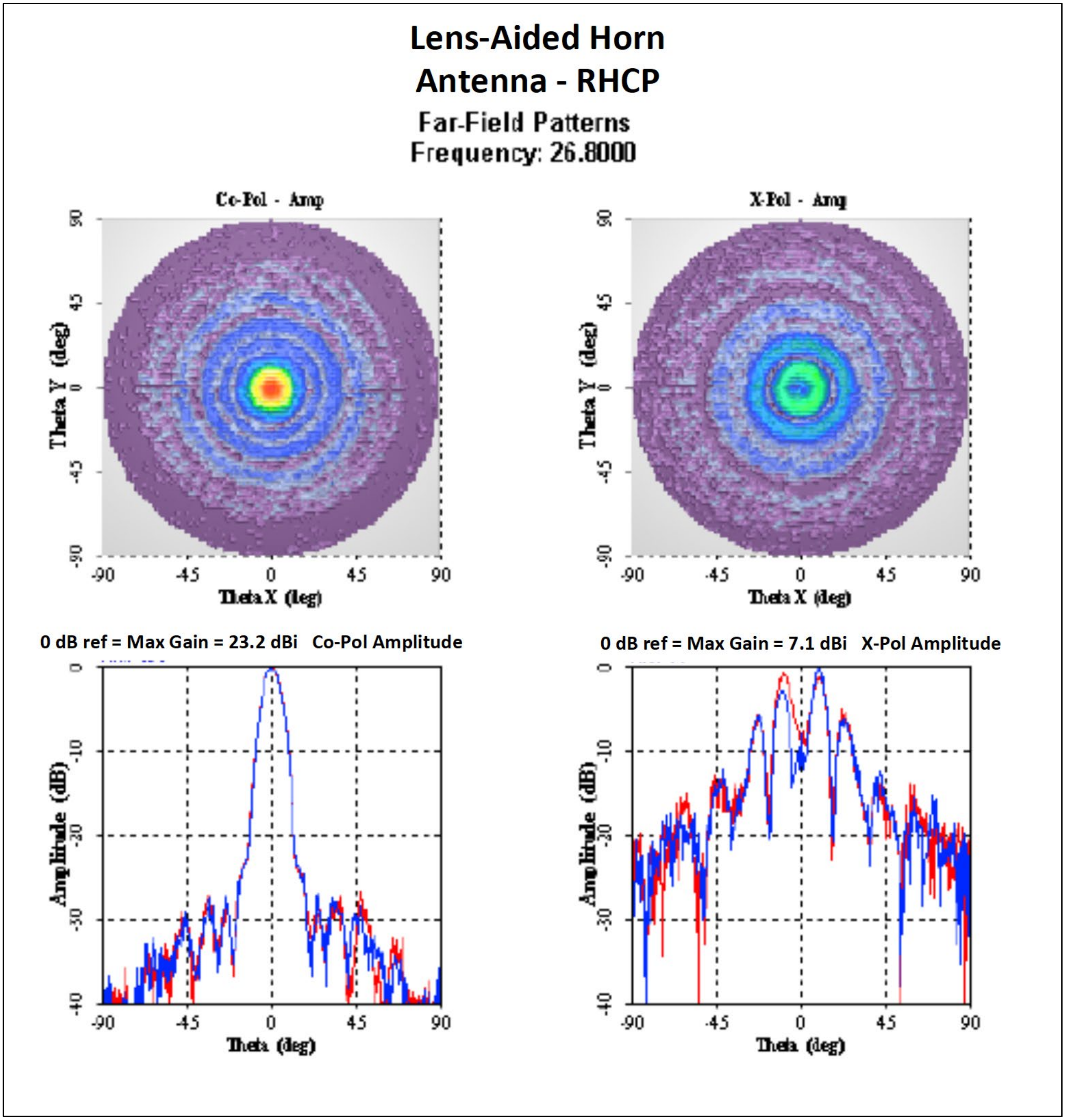
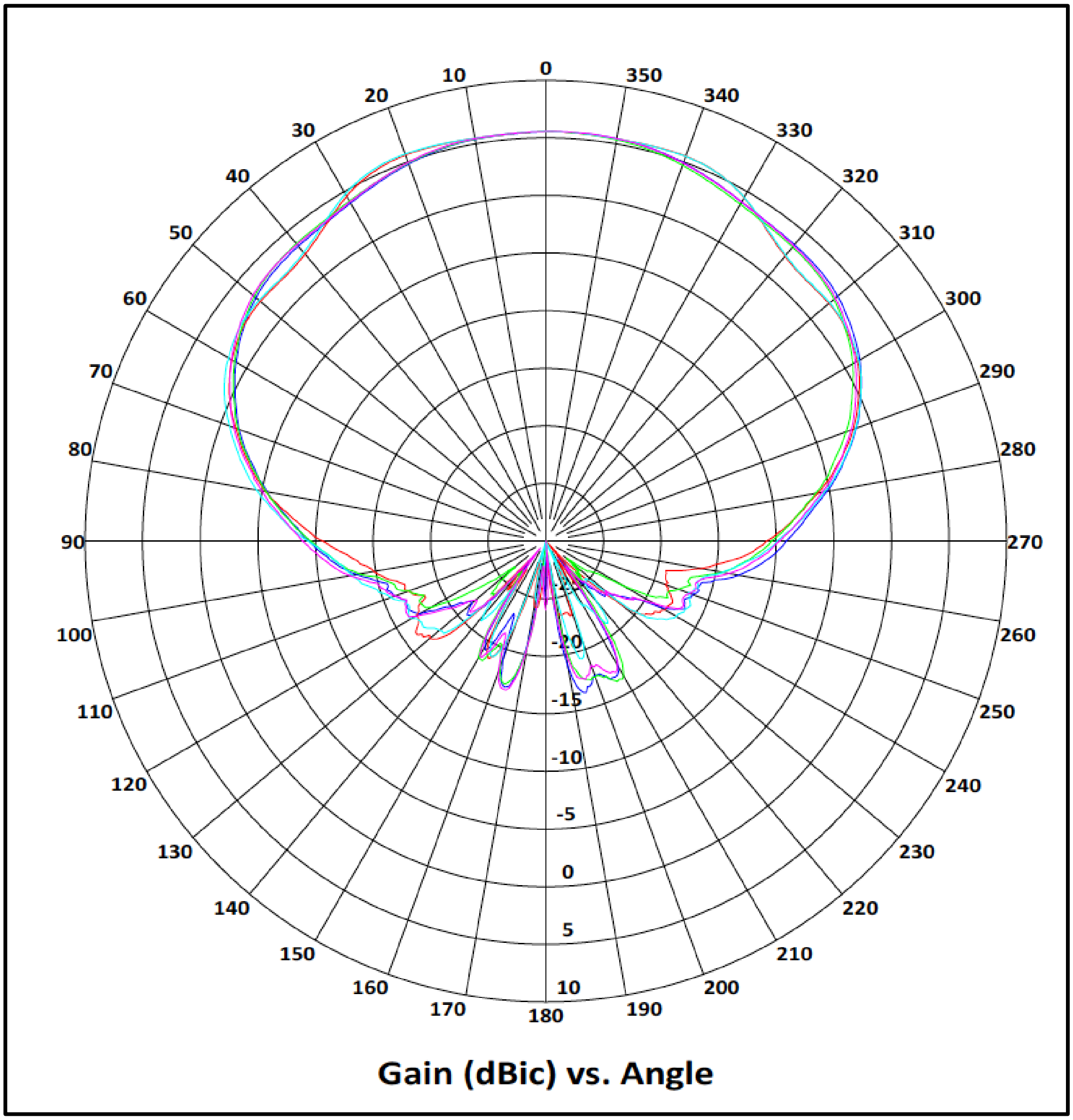


**Figure C-Ka-TX-GH-M2**: High Gain Lens Aided Horn Antenna Gain (Mode 2) – Mounted on +Y Surface

## Antenna Pattern C-S-RX-GH-M1 (S-band Receive, H.S. Data Control Patch x 2)



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

**Figure C-S-RX-GH-M1 A:** H.S. Data Control Patch

NOTE: Flight Antennas will be re-manufactured for a center frequency of 2047.5 MHz, RHCP. Gain performance will be as per this data set.

Antennas (2) mounted on +Z surface of S/C.

# EARTH STATION ANTENNA PATTERNS

**(See Table C-2)**

## Earth Station Antenna Pattern C-UHF-RX-GS-1 (Santa Clara, CA, USA)

The Astro Digital US, Inc. ("Astro Digital") earth station, supporting the GHOSt-01 thru -06 mission at Santa Clara, CA utilizes one UHF antenna array comprised of two phased individual Yagi antennas. The system operates in full-duplex mode such that the UHF antennas works in the TLM receive mode while the S-band antenna works in the uplink transmit CMD mode. The antennas are held in position relative to one another by a single cross-mast. An Az-El rotator positioned at the center of the cross-mast, points the antenna system. The characteristics of each Yagi antenna are given in Table C-3, and the characteristics of the overall antenna array are given in Table C-4. The antenna patterns of the array are provided in Figures C-UHF-RX-GS-1 A and C-UHF-RX-GS-1 B. We note that the 1x2 arrangement of the antenna array produces an elliptical beam pattern as described below with the narrower cut in the azimuth direction.

**Table C-3: Single UHF Yagi Characteristics**

| Parameter | Value |
|---|---|
| Manufacturer: | $M^2$ Antenna Systems, Inc. |
| Model: | 402CP42 |
| Frequency Range: | 399.5 – 408.0 MHz[1] |
| Gain: | 18.7 dBi |
| Beamwidth: | 23.0° |
| Front-to-Back Ratio: | 16.2 dB |
| Axial Ratio: | 1.5 dB |
| Polarization: | RHCP/LHCP |
| Feed Type: | Folded Dipole |
| Feed Impedance: | 50 Ohms (Unbalanced) |
| Maximum VSWR: | 1.5:1 |
| Boom Length: | 245" (6.22 m) |
| Max. Element Length: | 14.5" (0.368 m) |
| Turning Radius: | 148" (3.76 m) |

**Table C-4: Two UHF Yagi Array Characteristics**

| Parameter | Value |
|---|---|
| Frequency Range: | 399.5 – 408.0 MHz |
| Receive Gain: | 20.5 to 21.0 dBi |
| TX & RX Half Power Beamwidth: | 12° (Azimuth) X 23° (Elevation) |
| Polarization: | RHCP/LHCP |
| First Side lobe Attenuation: | -13 to -16 dBr |

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[1] This value only reflects the antenna capability. OSK's specifically-requested channels are listed in this application. See Schedule S.

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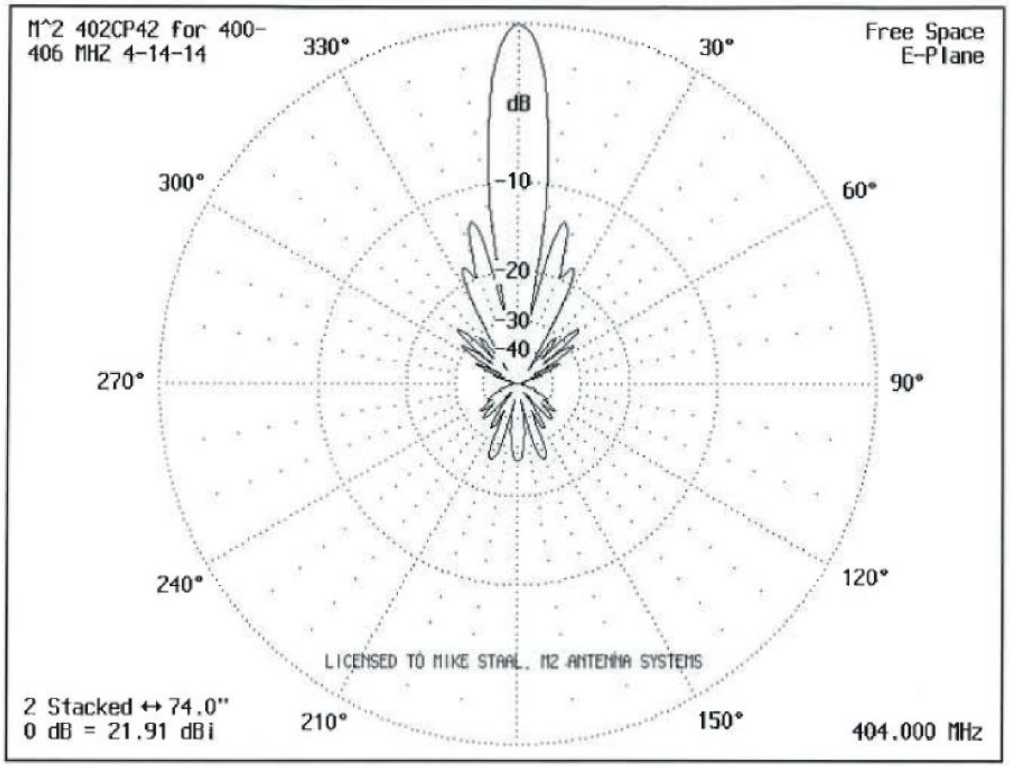

**Figure C-UHF-TX-GS-1 A:** Santa Clara E. S. UHF Yagi Array –Azimuth Pattern

*** Corrected & Calibrated Reference Gain 0.0 = 21.0 dBi; RHCP or LHCP**

*

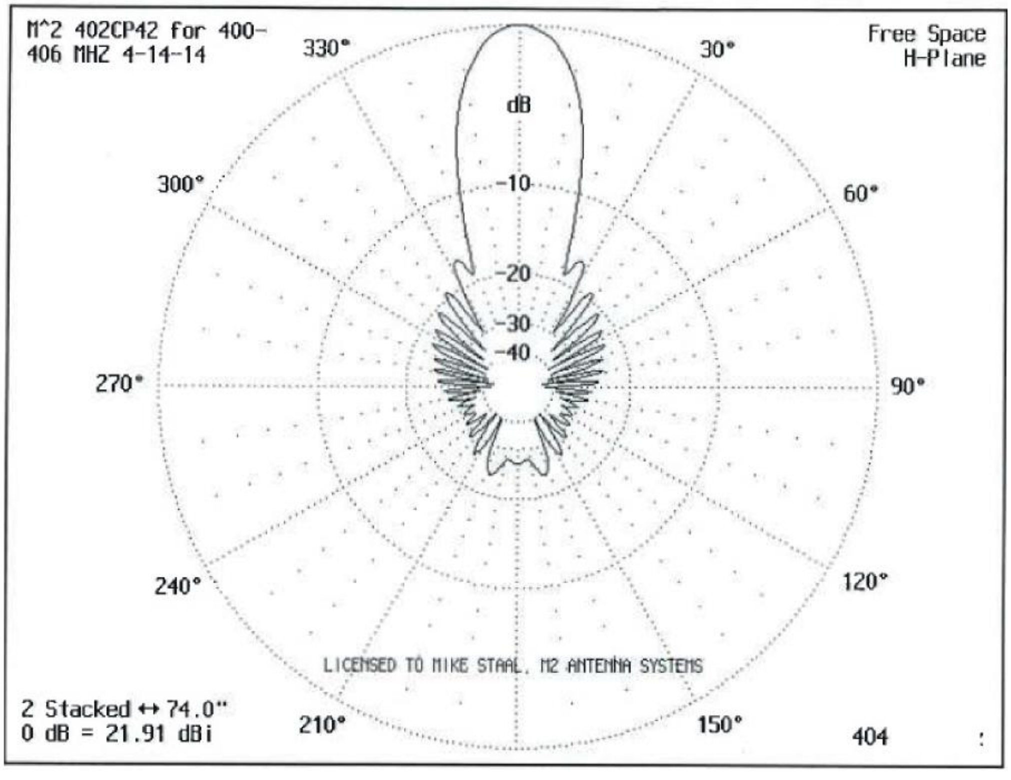

**Figure C-UHF-TX-GS-1 B:** Santa Clara E.S. UHF Yagi Array – Elevation Pattern

## Earth Station UHF Antenna Pattern C-UHF-RX-GS-2 (Tromsø)

The Kongsberg Satellite Services (KSAT) earth station, supporting the GHOSt-01 thru -06 mission at Tromsø, Norway, also utilizes one UHF antenna array comprised of two phased individual Yagi antennas. The system operates in full-duplex mode such that the UHF antennas works in the TLM receive mode while the S-band antenna works in the uplink transmit CMD mode. The antennas are held in position relative to one another by a single cross-mast. An Az-El rotator positioned at the center of the cross-mast, points the antenna system. The characteristics of each Yagi antenna are given in Table C-5, and the characteristics of the overall antenna array are given in Table C-6. The antenna patterns of the array are provided in Figures C-UHF-RX-GS-2 A and C-UHF-RX-GS-2 B. We note that the 1x2 arrangement of the antenna array produces an elliptical beam pattern as described below with the narrower cut in the azimuth direction.

**Table C-5: Single UHF Yagi Characteristics**

| Parameter | Value |
|---|---|
| Manufacturer: | M$^2$ Antenna Systems, Inc. |
| Model: | 402CP42 |
| Frequency Range: | 399.5 – 408.0 MHz[2] |
| Gain: | 18.7 dBi |
| Beamwidth: | 23.0° |
| Front-to-Back Ratio: | 16.2 dB |
| Axial Ratio: | 1.5 dB |
| Polarization: | RHCP/LHCP |
| Feed Type: | Folded Dipole |
| Feed Impedance: | 50 Ohms (Unbalanced) |
| Maximum VSWR: | 1.5:1 |
| Boom Length: | 245” (6.22 m) |
| Max. Element Length: | 14.5” (0.368 m) |
| Turning Radius: | 148” (3.76 m) |

**Table C-6: Two UHF Yagi Array Characteristics**

| Parameter | Value |
|---|---|
| Frequency Range: | 399.5 – 408.0 MHz |
| Receive Gain: | 20.5 to 21.0 dBi |
| TX & RX Half Power Beamwidth: | 12° (Azimuth) X 23° (Elevation) |
| Polarization: | RHCP/LHCP |
| First Side lobe Attenuation: | -13 to -16 dBr |

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[2] This value only reflects the antenna capability. OSK’s specifically-requested channels are listed in this application. See Schedule S.

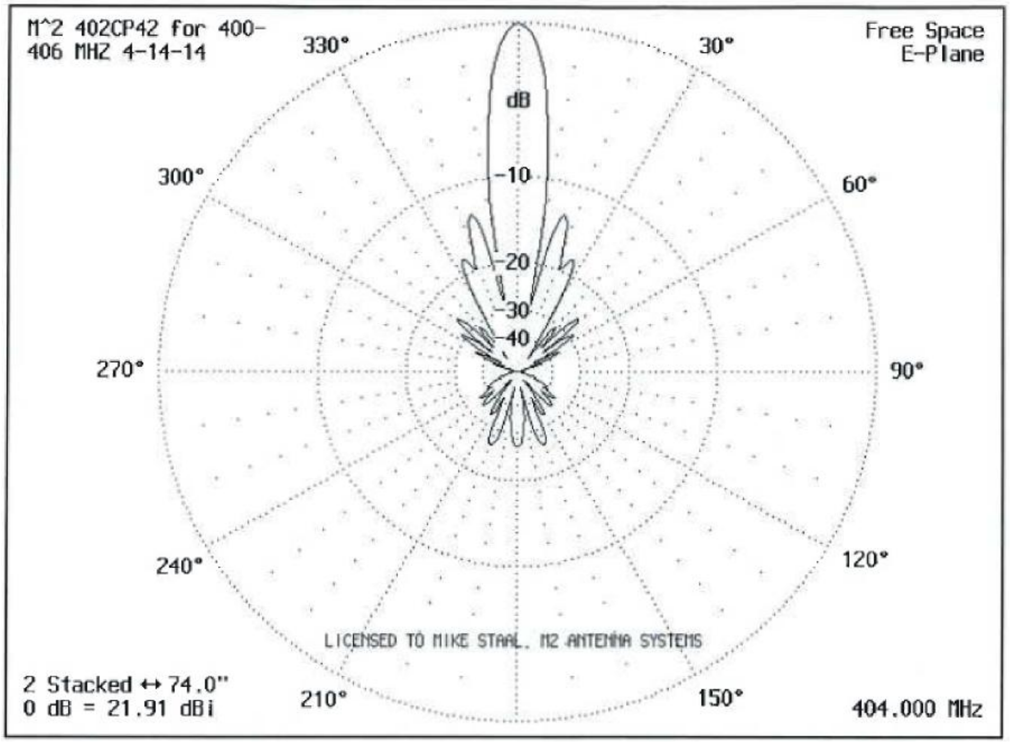

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**Figure C-UHF-TX-GS-2 A:** Tromsø E. S. UHF Yagi Array –Azimuth Pattern

*** Corrected & Calibrated Reference Gain 0.0 = 20.5 dBi;  RHCP or LHCP**

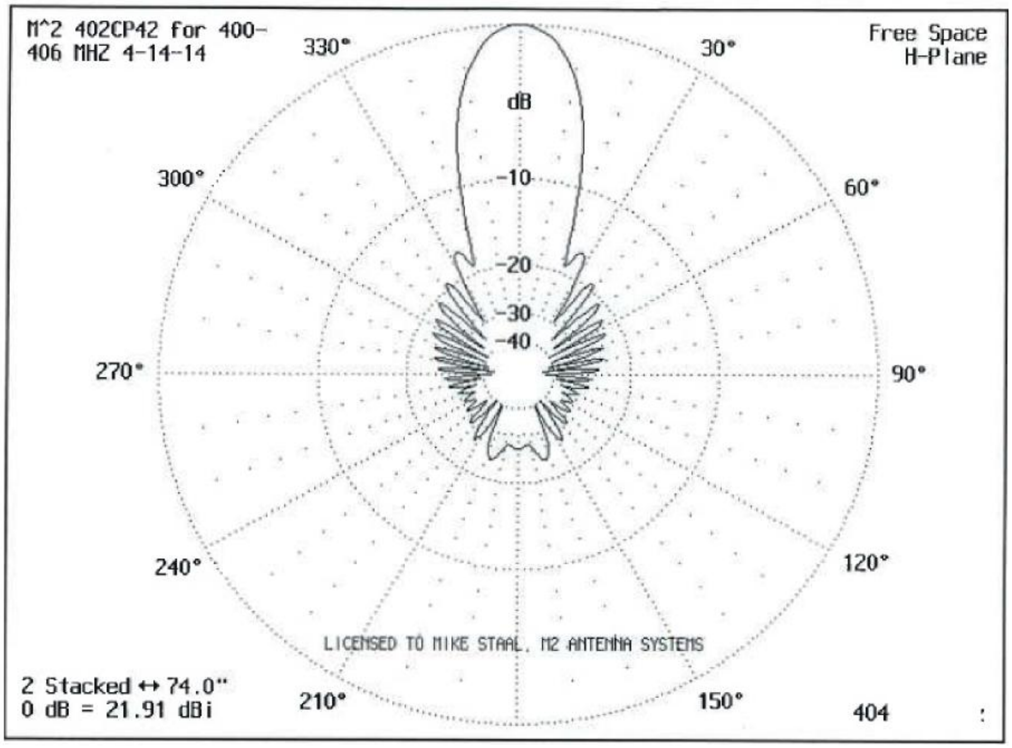

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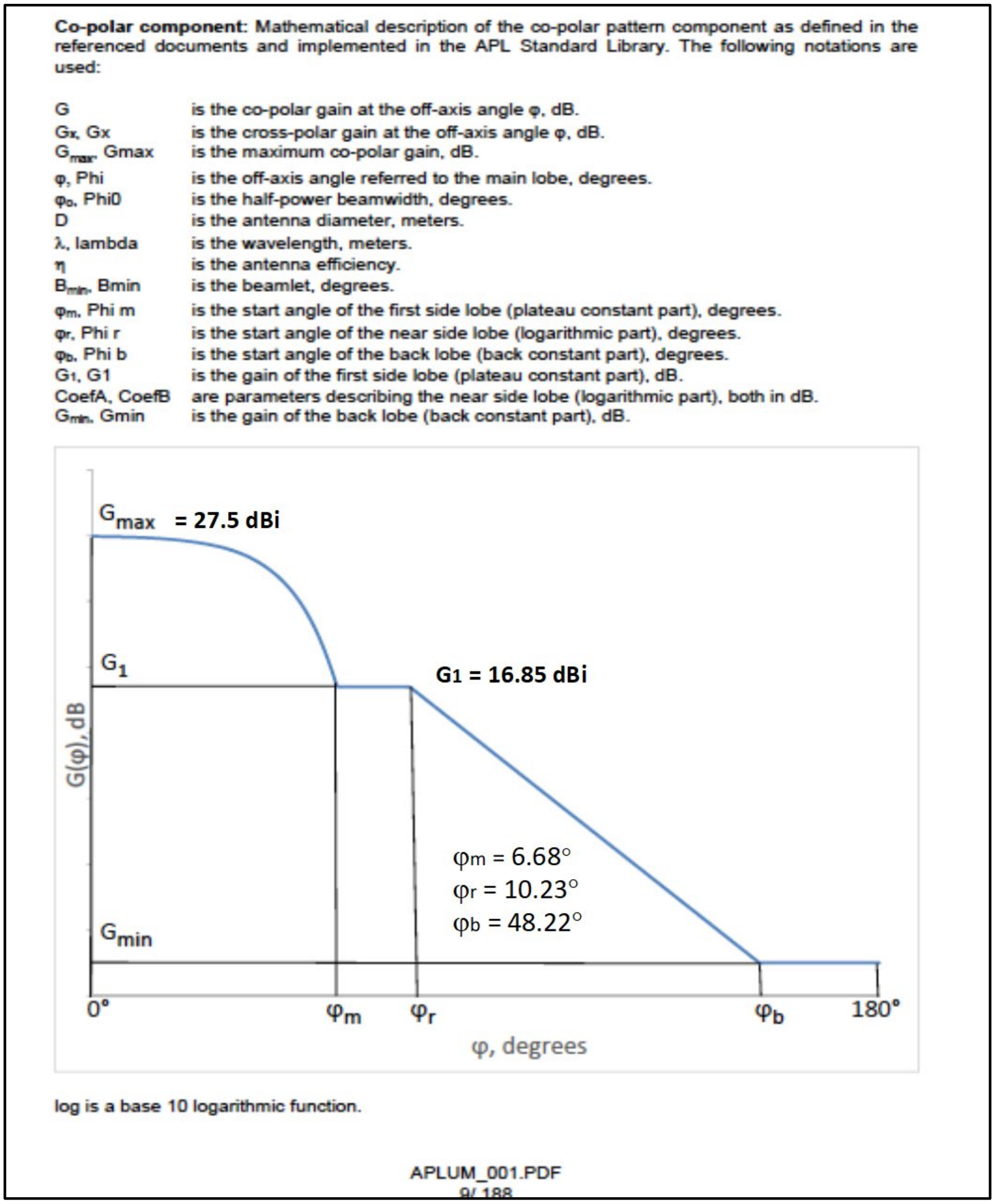
**Figure C-UHF-TX-GS-2 B:** Tromsø E. S. UHF Yagi Array –Elevation Pattern

# Antenna Pattern C-S-TX-GS-3 (1.5 m Parabolic Dish @ Tromsø)

This 2056.000 MHz Command Antenna has been modeled using a mathematical description given by the ITU Antenna Patterns Reference Manual.[3] 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-3 A: 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. |
| $\varphi_0$, 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. |
| $\varphi_m$, Phi m | is the start angle of the first side lobe (plateau constant part), degrees. |
| $\varphi_r$, Phi r | is the start angle of the near side lobe (logarithmic part), degrees. |
| $\varphi_b$, 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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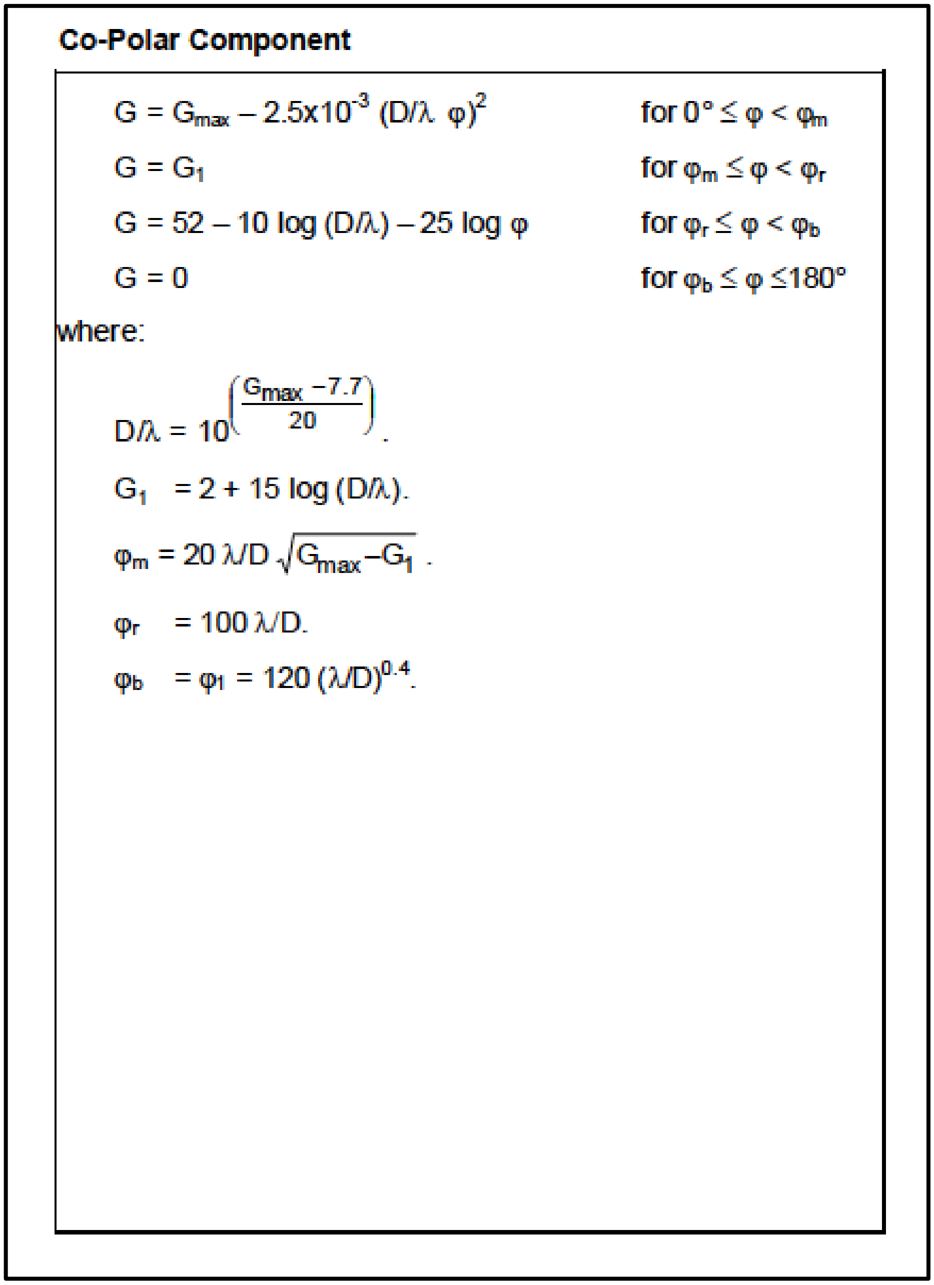
[3] T. Filipova, <u>Antenna Patterns Reference Manual</u>, Ref: APL-UM-001, Ver. 1.1.19, 2016-04-21, p 9 & 22.

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-3 B: APEREC005V01 Gain & Angle Formulas**



**Co-Polar Component**

$G = G_{max} - 2.5\times10^{-3}\,(D/\lambda\ \varphi)^2$ 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:

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

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

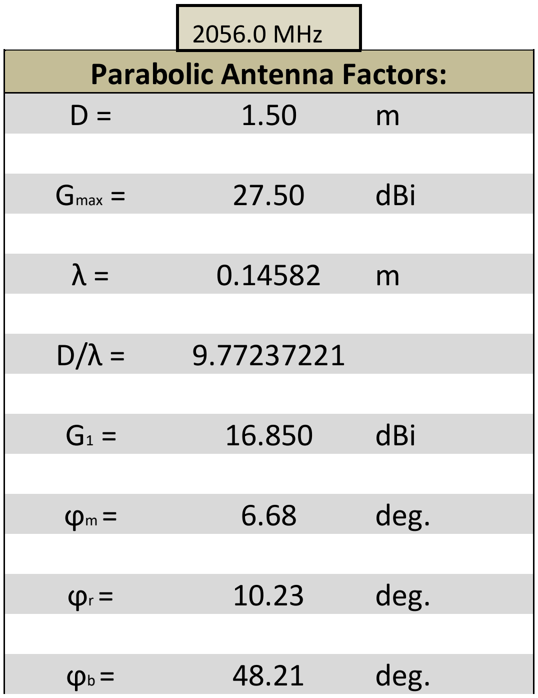
$$\varphi_m = 20\,\lambda/D\sqrt{G_{max}-G_1}\ .$$

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

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

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

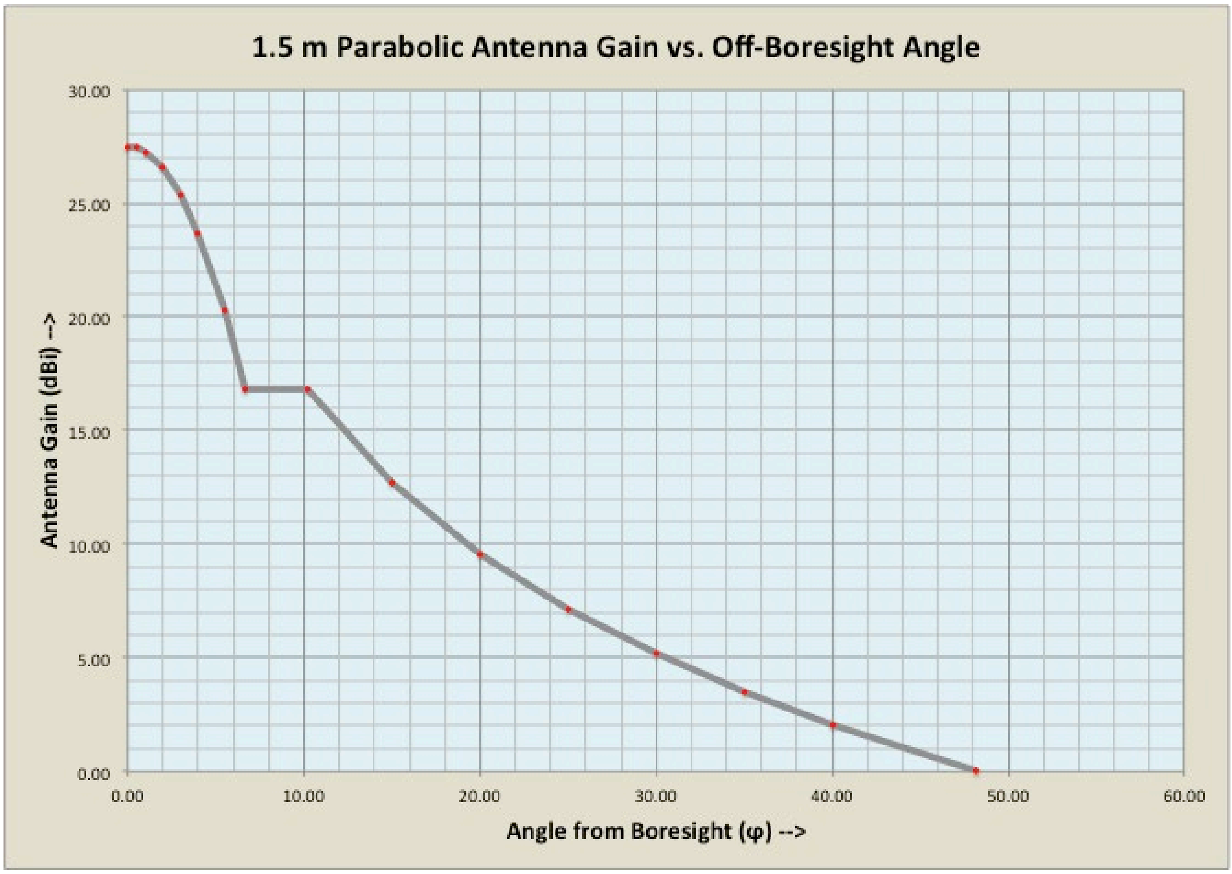
**<u>Table C-S-TX-GS-3 C:</u> S-band Antenna Characteristics**



2056.0 MHz

| Parabolic Antenna Factors: | | |
|---|---|---|
| D = | 1.50 | m |
| $G_{max}$ = | 27.50 | dBi |
| λ = | 0.14582 | m |
| D/λ = | 9.77237221 | |
| $G_1$ = | 16.850 | dBi |
| $\varphi_m$ = | 6.68 | deg. |
| $\varphi_r$ = | 10.23 | deg. |
| $\varphi_b$ = | 48.21 | deg. |

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



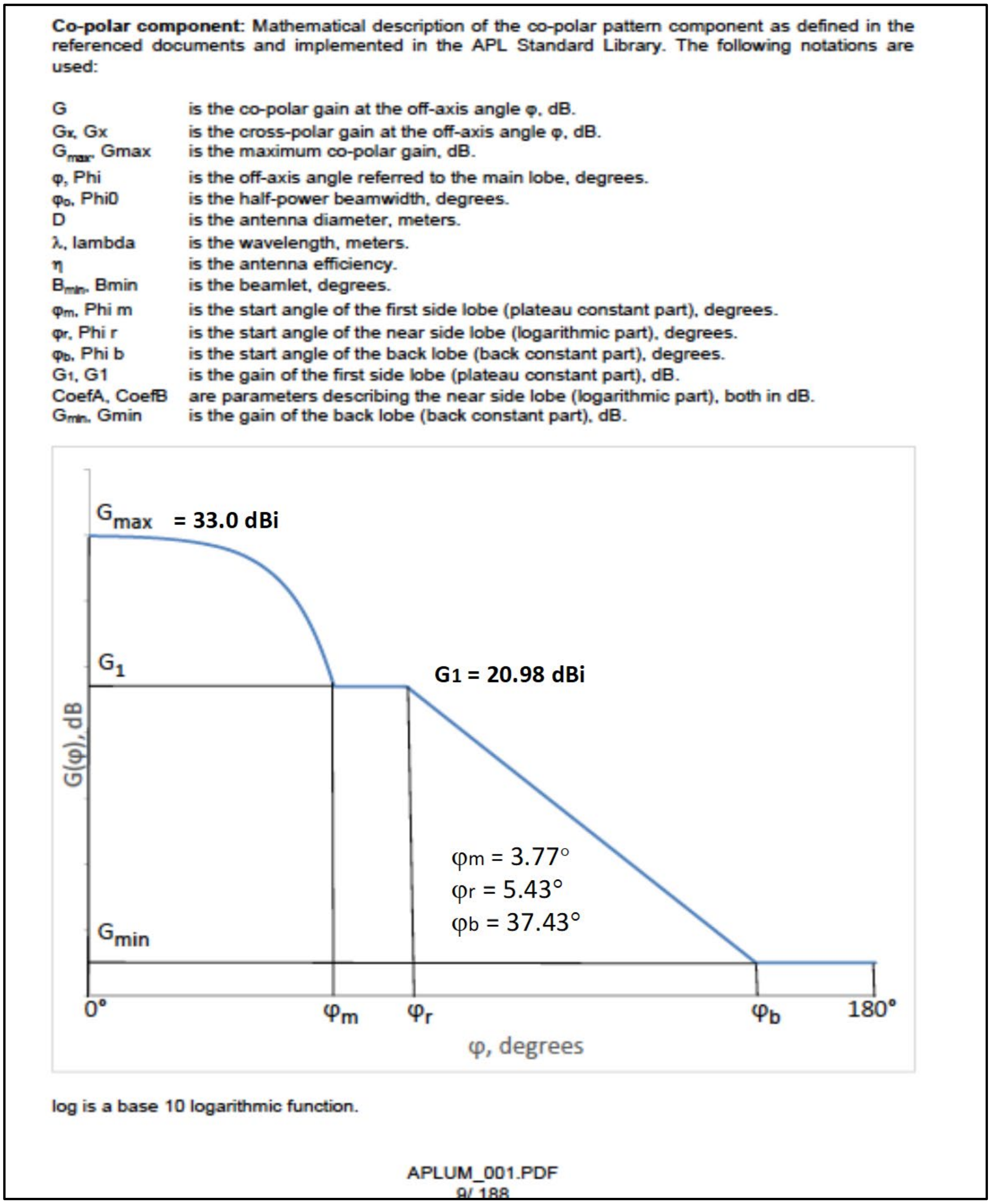
<u>Figure C-S-TX-GS-3</u>: **Antenna Gain Profile vs. Angle from Boresight - (1.5 m Parabolic Dish Antenna)**

## Antenna Pattern C-S-TX-GS-4 (2.8 m Parabolic Dish @ Svalbard)

This 2056.000 MHz Command Antenna has been modeled using a mathematical description given by the ITU Antenna Patterns Reference Manual. 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-4 A: 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. |
| $\varphi_0$, 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. |
| $\varphi_m$, Phi m | is the start angle of the first side lobe (plateau constant part), degrees. |
| $\varphi_r$, Phi r | is the start angle of the near side lobe (logarithmic part), degrees. |
| $\varphi_b$, 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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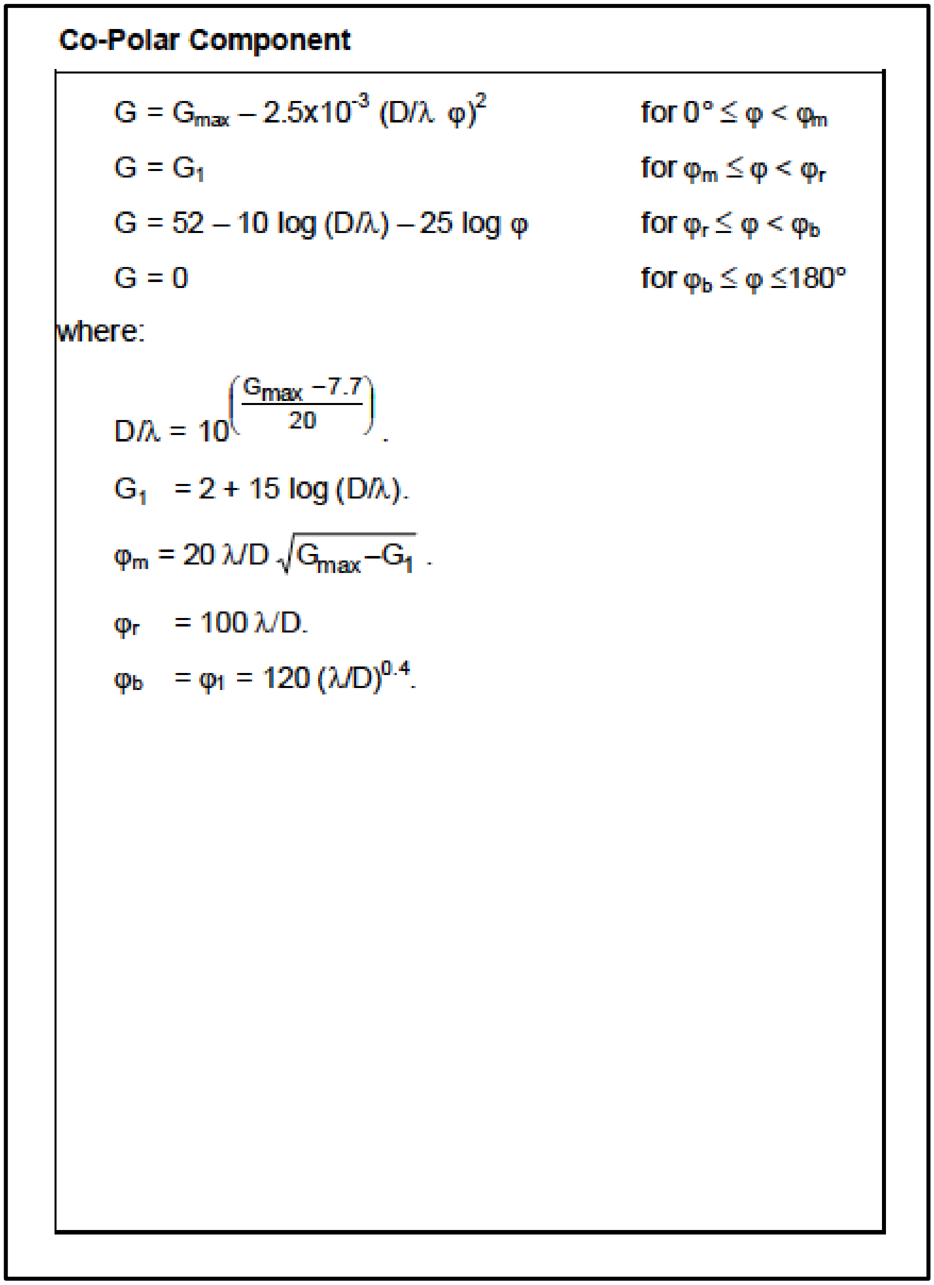
The equations given by the referenced document for the gain and boresight angle behavior of the antenna is further specified as follows:

**Table C-S-TX-GS-4 B: APEREC005V01 Gain & Angle Formulas**



**Co-Polar Component**

$G = G_{max} - 2.5\text{x}10^{-3}\ (D/\lambda\ \varphi)^2$ 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:

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

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

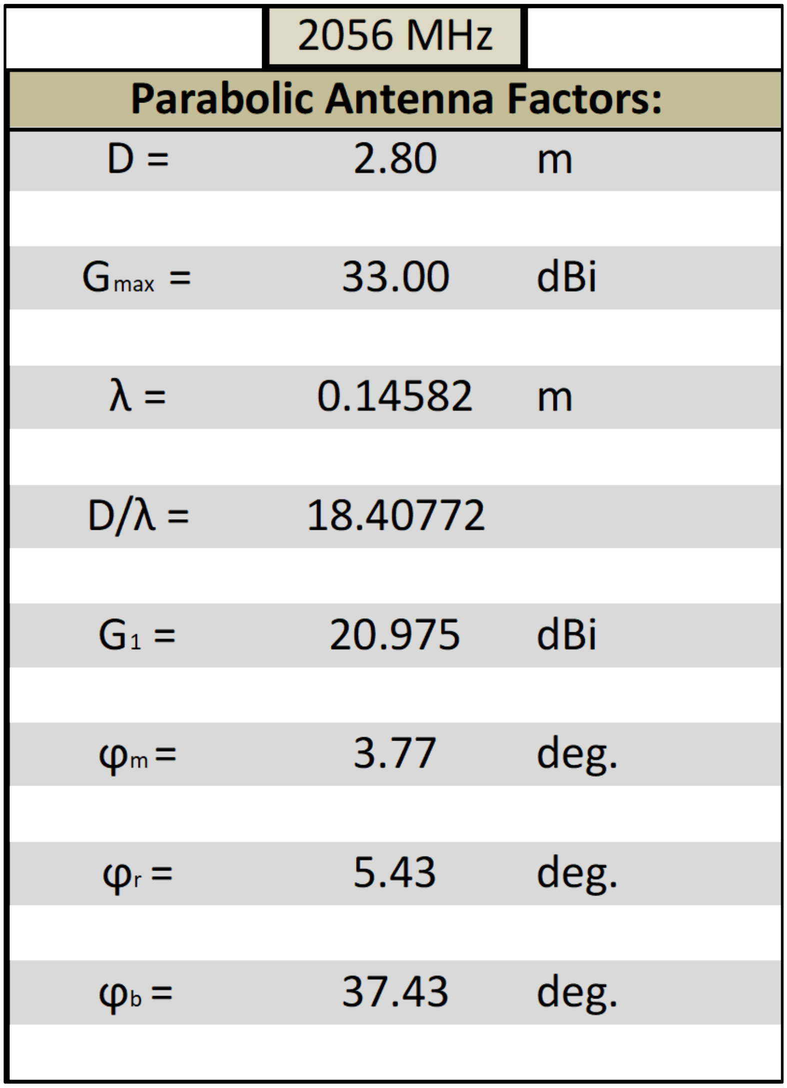
$$\varphi_m = 20\ \lambda/D \sqrt{G_{max} - G_1}\ .$$

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

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

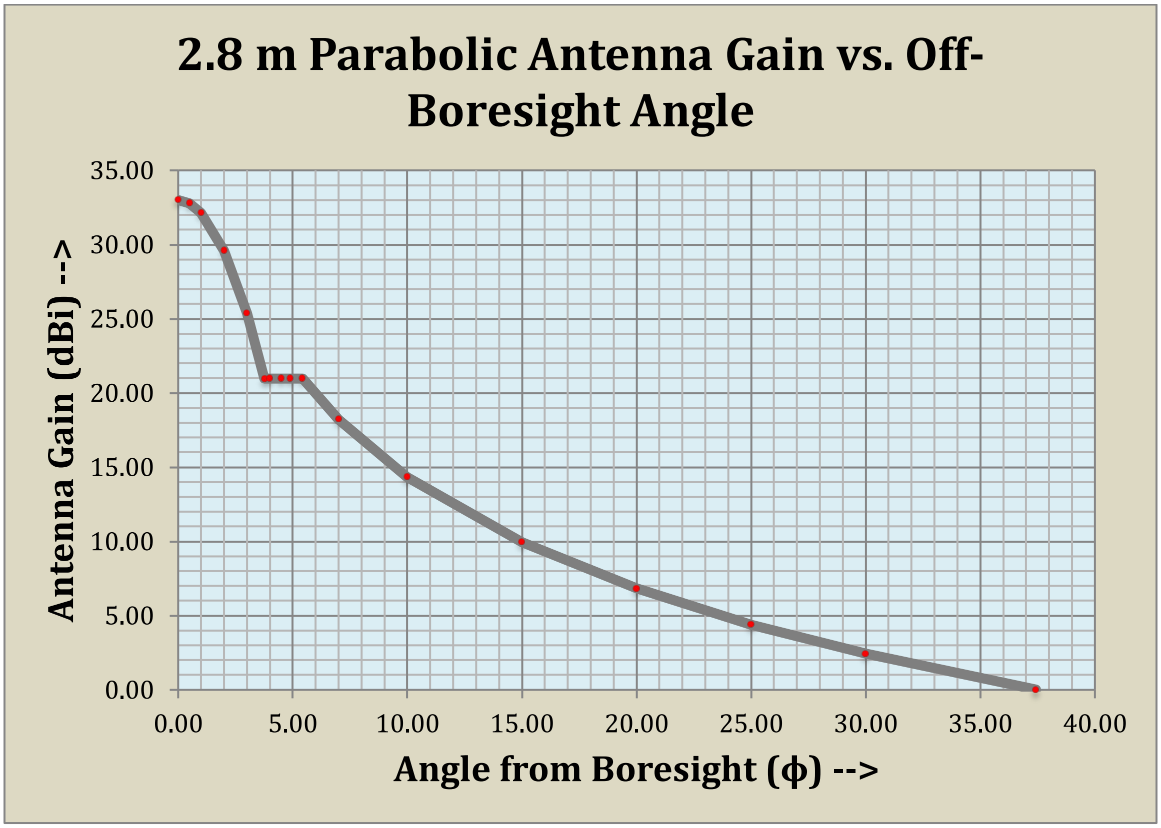
Calculations yield the following characteristics for this S-band command antenna at Svalbard:

**<u>Table C-S-TX-GS-4 C:</u> S-band Antenna Characteristics**



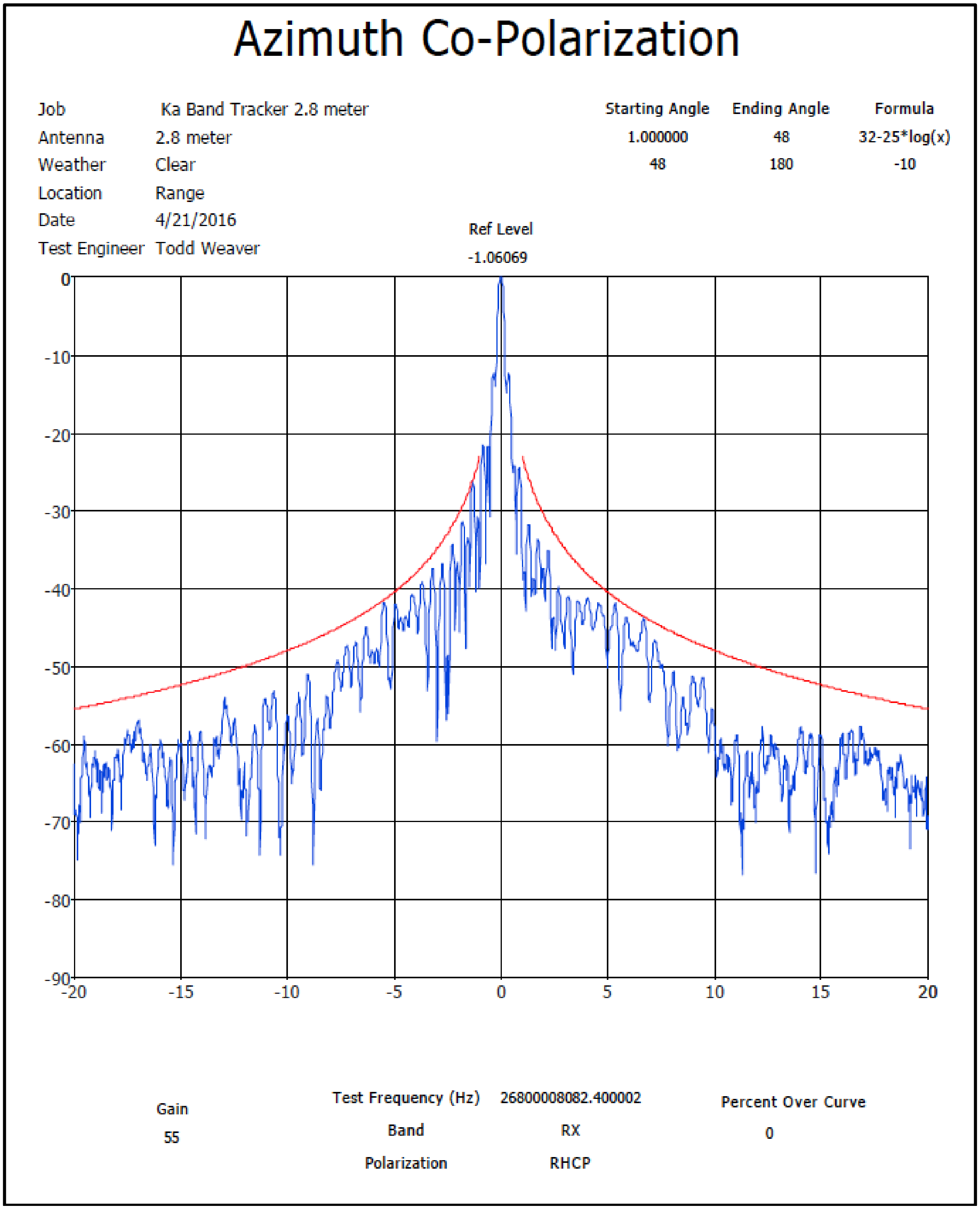
| | 2056 MHz | |
|---|---|---|
| **Parabolic Antenna Factors:** | | |
| $D =$ | 2.80 | m |
| $G_{max} =$ | 33.00 | dBi |
| $\lambda =$ | 0.14582 | m |
| $D/\lambda =$ | 18.40772 | |
| $G_1 =$ | 20.975 | dBi |
| $\varphi_m =$ | 3.77 | deg. |
| $\varphi_r =$ | 5.43 | deg. |
| $\varphi_b =$ | 37.43 | deg. |

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-4</u>: Antenna Gain Profile vs. Angle from Boresight - (2.8 m Parabolic Dish Antenna)**

# Antenna Pattern for C-Ka-RX-GS-5 and C-Ka-RX-GS-6 -(2.8 m Parabolic Reflector Antenna at Svalbard & Troll)



Azimuth Co-Polarization

| | |
|---|---|
| Job | Ka Band Tracker 2.8 meter |
| Antenna | 2.8 meter |
| Weather | Clear |
| Location | Range |
| Date | 4/21/2016 |
| Test Engineer | Todd Weaver |

| Starting Angle | Ending Angle | Formula |
|---|---|---|
| 1.000000 | 48 | 32-25*log(x) |
| 48 | 180 | -10 |

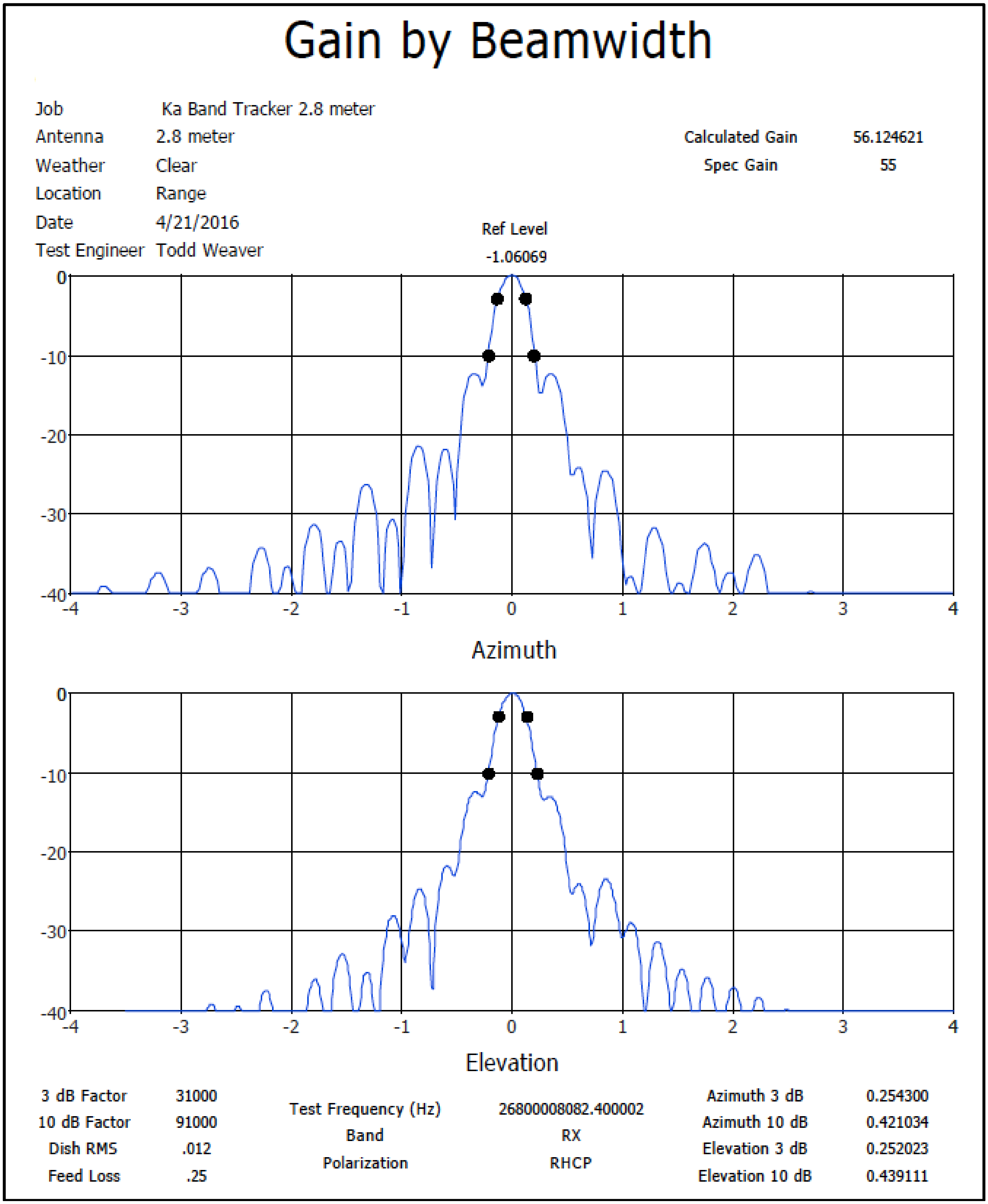
Ref Level
-1.06069

Gain
55

Test Frequency (Hz) 26800008082.400002
Band RX
Polarization RHCP

Percent Over Curve
0

**<u>Figure C-Ka-RX-GS-5/6 A:</u> Antenna Pattern (2.8 m Parabolic Dish)**



Gain by Beamwidth

| | |
|---|---|
| Job | Ka Band Tracker 2.8 meter |
| Antenna | 2.8 meter |
| Weather | Clear |
| Location | Range |
| Date | 4/21/2016 |
| Test Engineer | Todd Weaver |

| | |
|---|---|
| Calculated Gain | 56.124621 |
| Spec Gain | 55 |

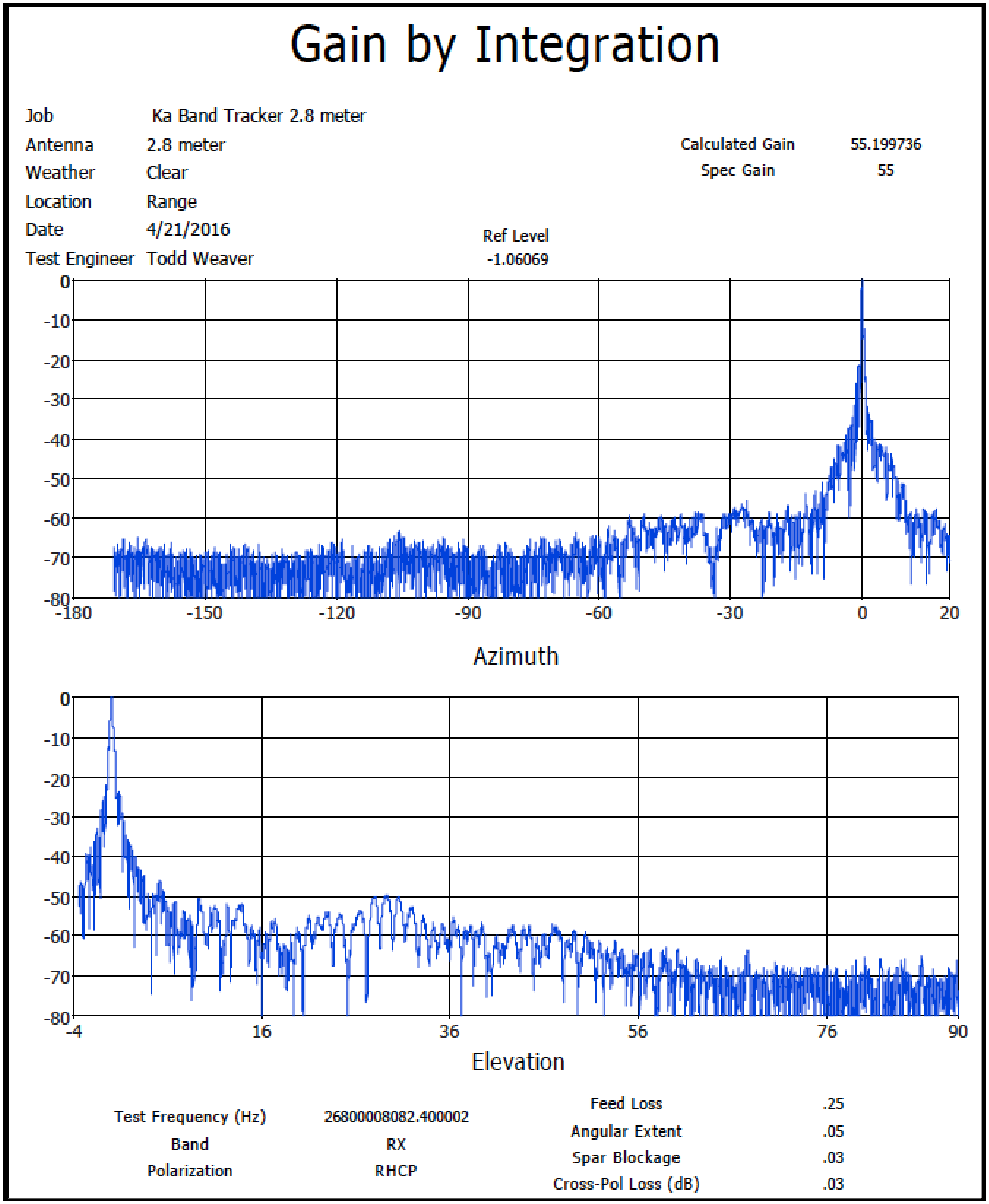
Ref Level
-1.06069

| | |
|---|---|
| 3 dB Factor | 31000 |
| 10 dB Factor | 91000 |
| Dish RMS | .012 |
| Feed Loss | .25 |

| | |
|---|---|
| Test Frequency (Hz) | 26800008082.400002 |
| Band | RX |
| Polarization | RHCP |

| | |
|---|---|
| Azimuth 3 dB | 0.254300 |
| Azimuth 10 dB | 0.421034 |
| Elevation 3 dB | 0.252023 |
| Elevation 10 dB | 0.439111 |

**Figure C-Ka-RX-GS-5/6 B:** Antenna Pattern (2.8 m Parabolic Dish)



Gain by Integration

Job Ka Band Tracker 2.8 meter
Antenna 2.8 meter
Weather Clear
Location Range
Date 4/21/2016
Test Engineer Todd Weaver

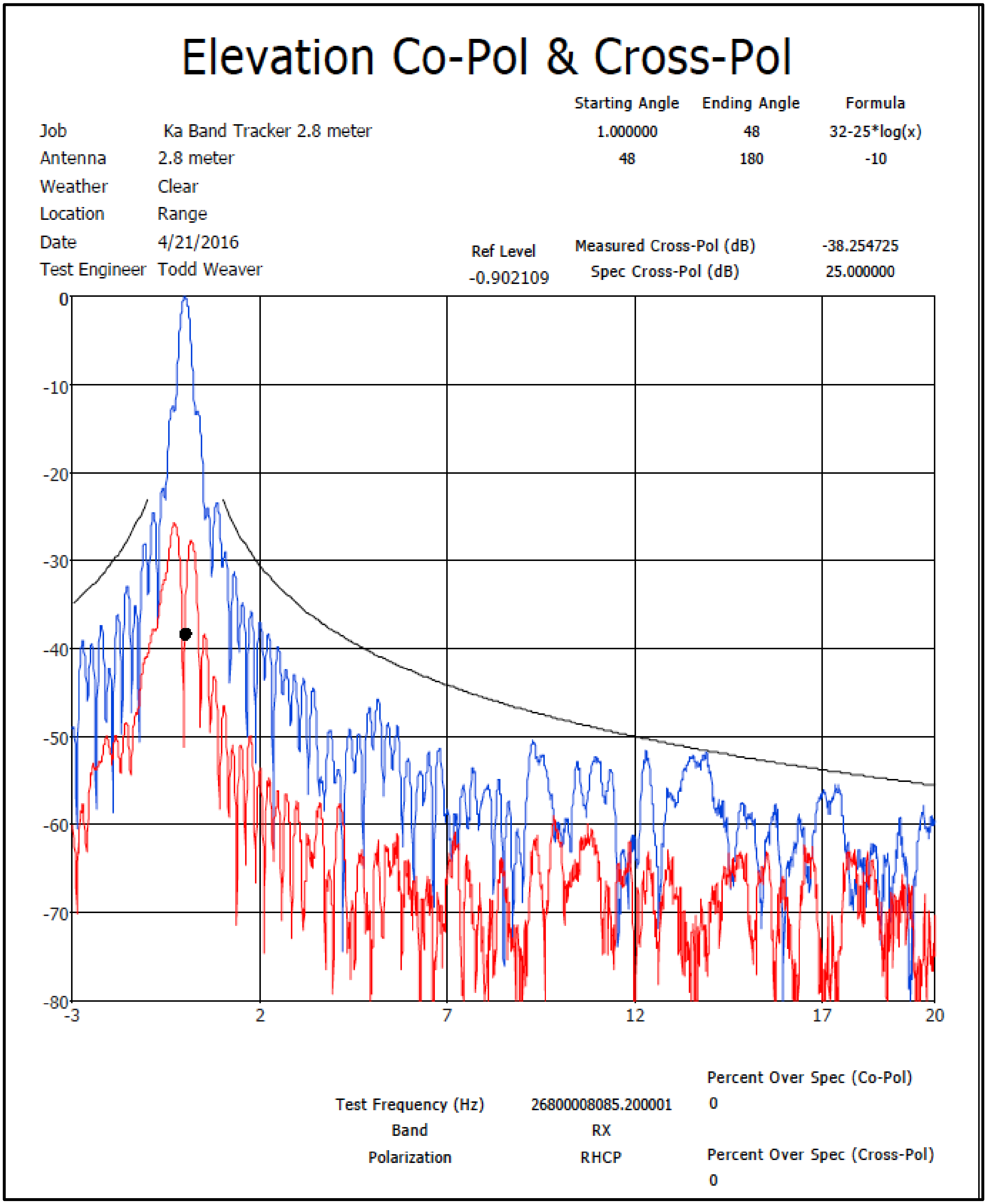
Calculated Gain 55.199736
Spec Gain 55

Ref Level -1.06069

Test Frequency (Hz) 26800008082.400002
Band RX
Polarization RHCP

Feed Loss .25
Angular Extent .05
Spar Blockage .03
Cross-Pol Loss (dB) .03

**<u>Figure C-Ka-RX-GS-5/6 C:</u> Antenna Pattern (2.8 m Parabolic Dish)**



Elevation Co-Pol & Cross-Pol

| Starting Angle | Ending Angle | Formula |
|---|---|---|
| 1.000000 | 48 | 32-25*log(x) |
| 48 | 180 | -10 |

Job Ka Band Tracker 2.8 meter
Antenna 2.8 meter
Weather Clear
Location Range
Date 4/21/2016
Test Engineer Todd Weaver

Ref Level -0.902109

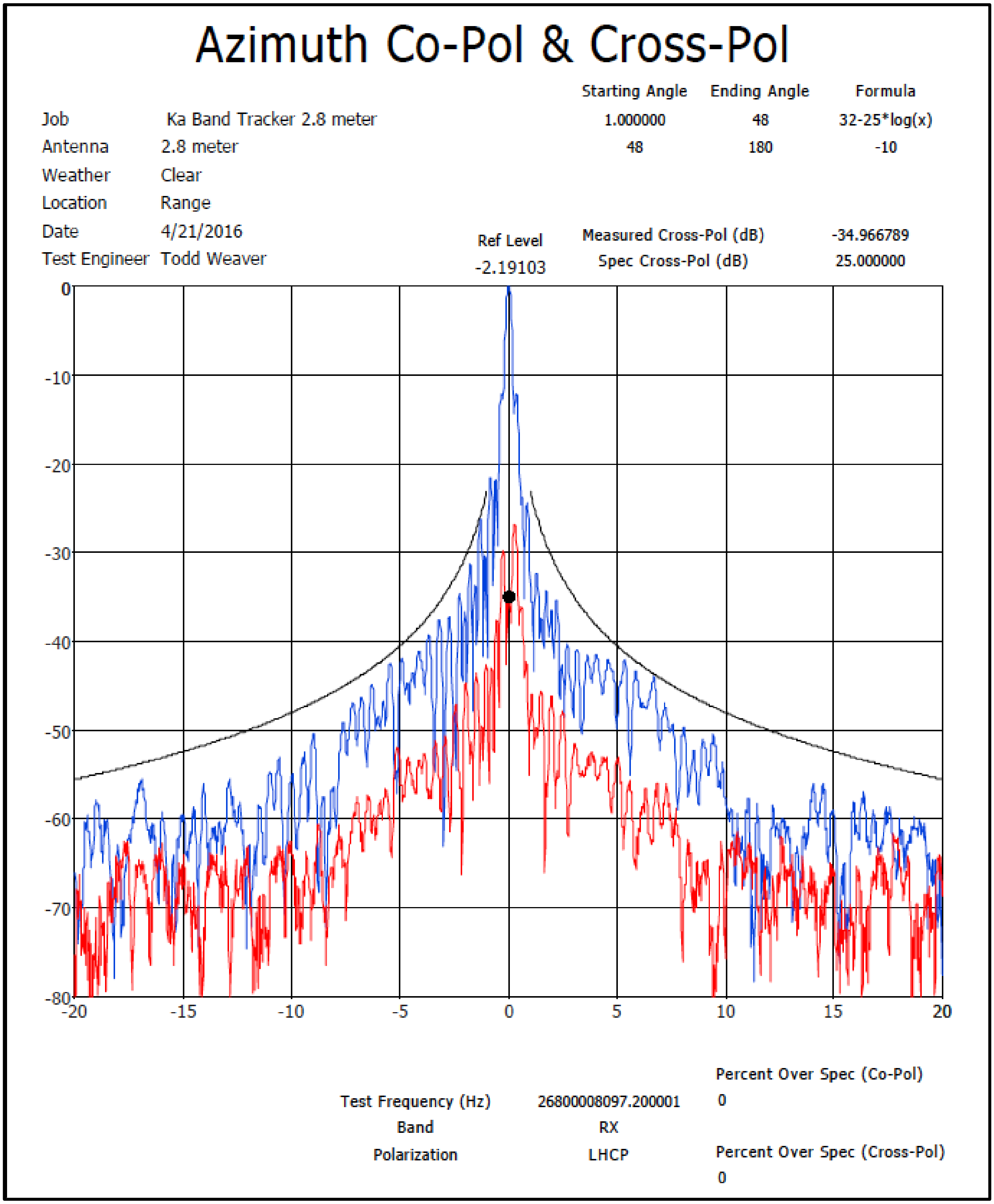
Measured Cross-Pol (dB) -38.254725
Spec Cross-Pol (dB) 25.000000

Test Frequency (Hz) 26800008085.200001
Band RX
Polarization RHCP

Percent Over Spec (Co-Pol) 0

Percent Over Spec (Cross-Pol) 0

**<u>Figure C-Ka-RX-GS-5/6 D:</u> Antenna Pattern (2.8 m Parabolic Dish)**



Azimuth Co-Pol & Cross-Pol

Job Ka Band Tracker 2.8 meter
Antenna 2.8 meter
Weather Clear
Location Range
Date 4/21/2016
Test Engineer Todd Weaver

| Starting Angle | Ending Angle | Formula |
|---|---|---|
| 1.000000 | 48 | 32-25*log(x) |
| 48 | 180 | -10 |

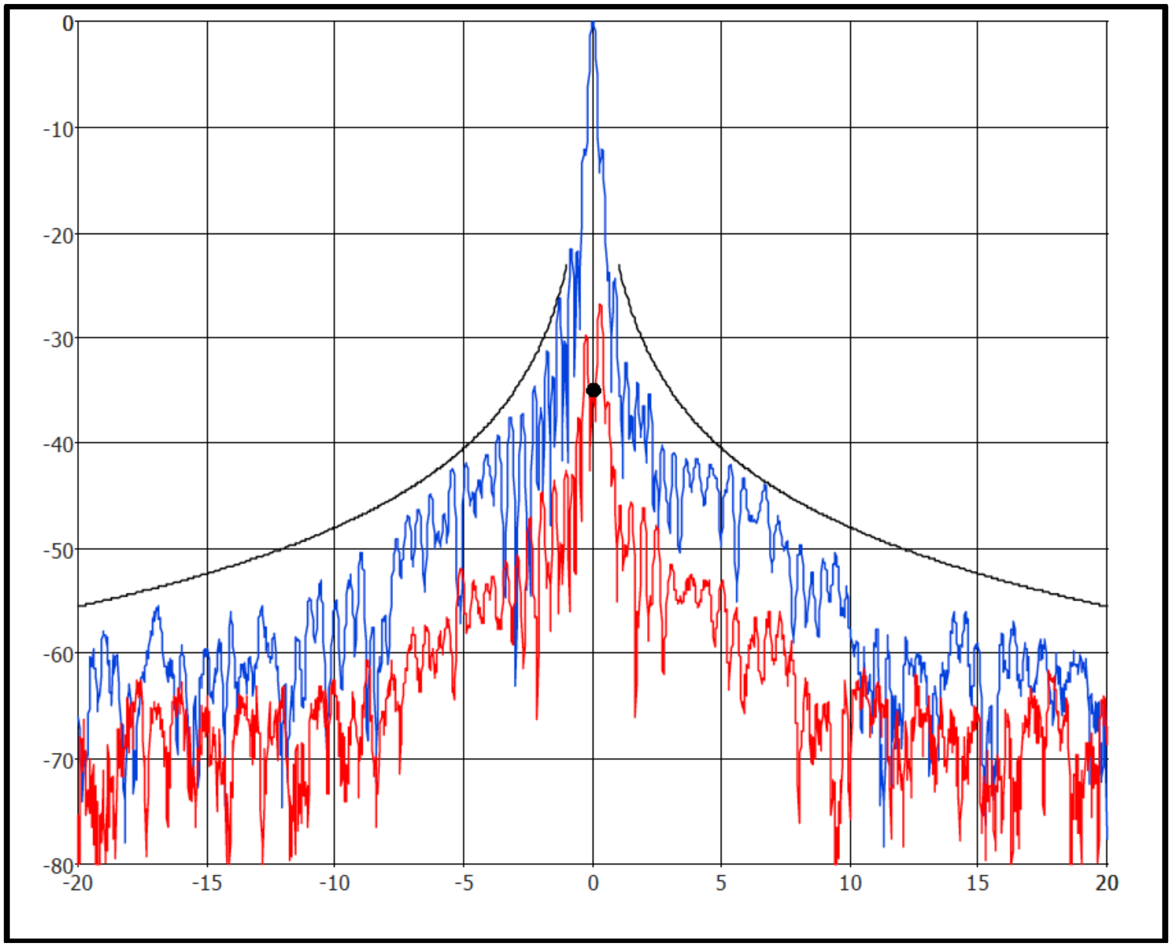
Ref Level -2.19103

Measured Cross-Pol (dB) -34.966789
Spec Cross-Pol (dB) 25.000000

Test Frequency (Hz) 26800008097.200001
Band RX
Polarization LHCP

Percent Over Spec (Co-Pol) 0
Percent Over Spec (Cross-Pol) 0

**<u>Figure C-Ka-RX-GS-5/6 E</u>: Antenna Pattern (2.8 m Parabolic Dish)**



**<u>Figure C-Ka-RX-GS-5/6 F</u>: Antenna Pattern (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

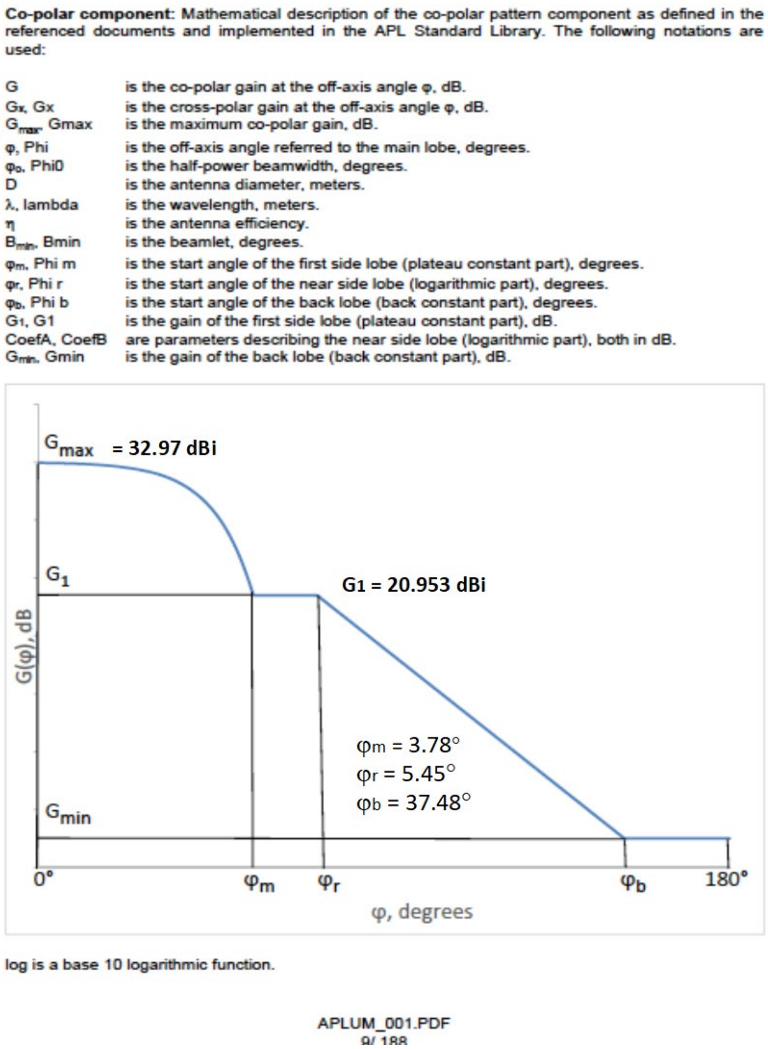
Reference Equation for Gain Envelope: $G = 32 - 25\log(\theta)$
where $\theta$ is offset angle from antenna boresight

## Antenna Pattern C-S-TX-GS-7 and C-S-TX-GS-8 (2.8 m S-Band H.S. Data Control Link; Parabolic Dish Antennas at Svalbard and Troll)

The 2047.500 MHz Antenna, employed for the H.S.D. Control (ACM and LPR adjustments) has been modeled using a mathematical description given by the ITU Antenna Patterns Reference Manual. Specifically Reference Antenna APEREC005V01 is utilized.

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

### <u>Table C-S-TX-GS-7/8 A</u>: 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. |
| $\varphi_0$, 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. |
| $\varphi_m$, Phi m | is the start angle of the first side lobe (plateau constant part), degrees. |
| $\varphi_r$, Phi r | is the start angle of the near side lobe (logarithmic part), degrees. |
| $\varphi_b$, 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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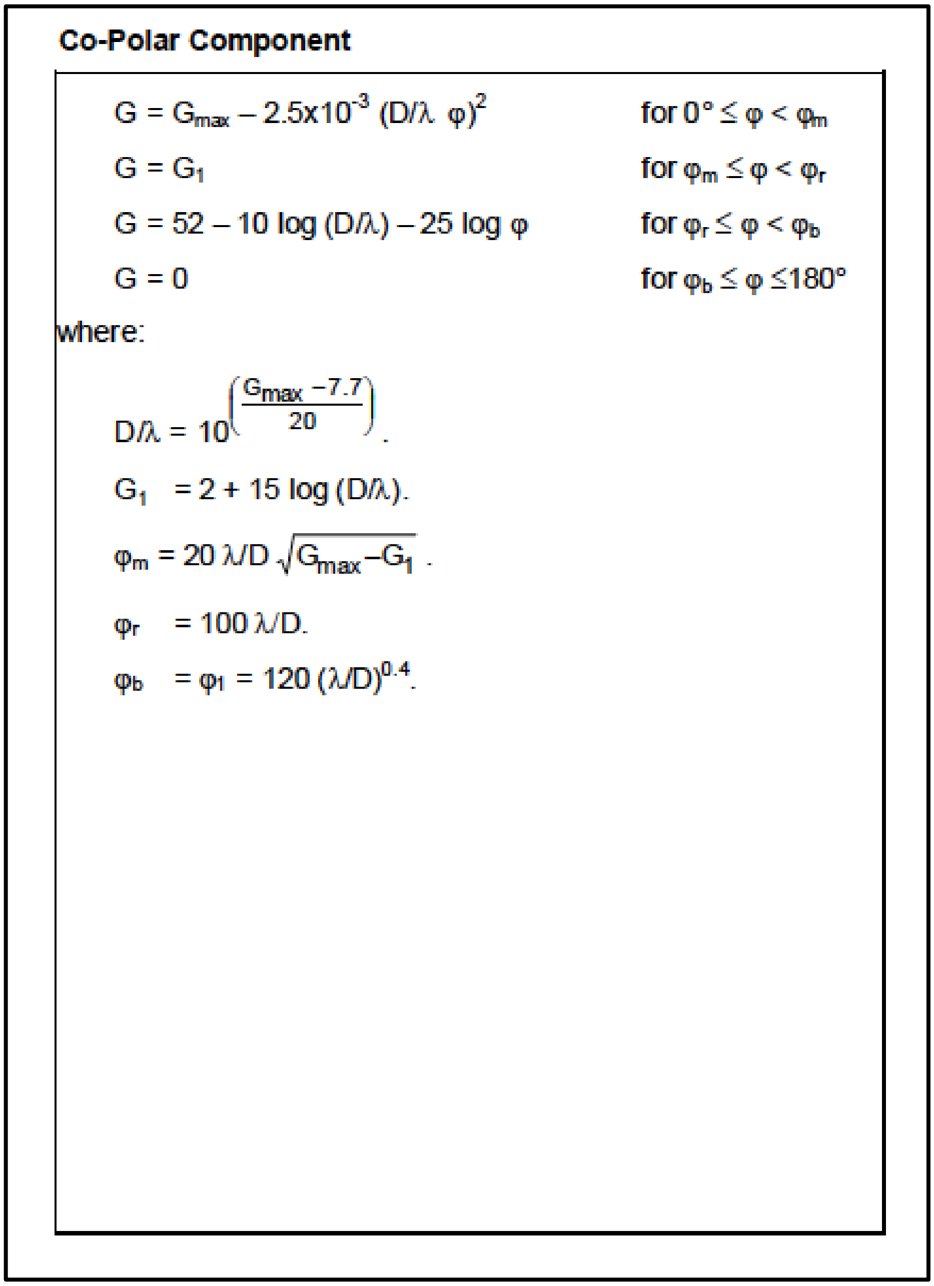
The equations given by the referenced document for the gain and boresight angle behavior of the antenna is further specified as follows:

### <u>Table C-S-TX-GS-7/8 B</u>: APEREC005V01 Gain & Angle Formulas



**Co-Polar Component**

$G = G_{max} - 2.5\times10^{-3} (D/\lambda\ \varphi)^2$ for $0° \le \varphi < \varphi_m$

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

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

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

where:

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

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

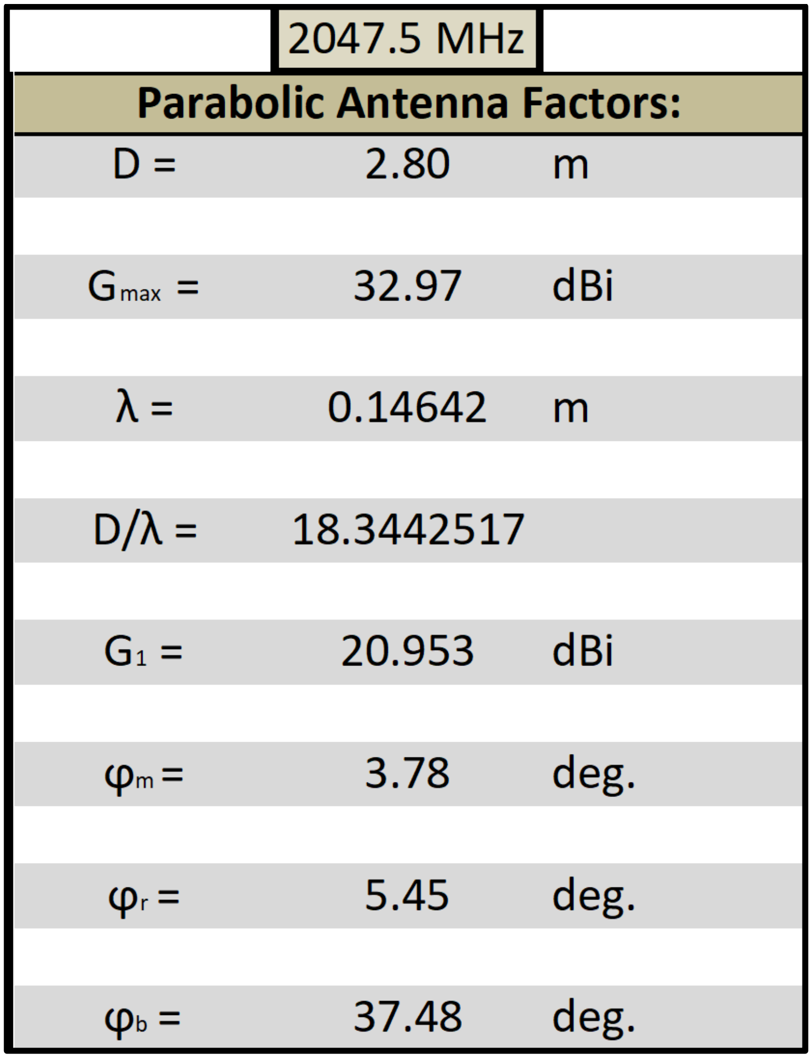
$\varphi_m = 20\ \lambda/D \sqrt{G_{max} - G_1}$ .

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

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

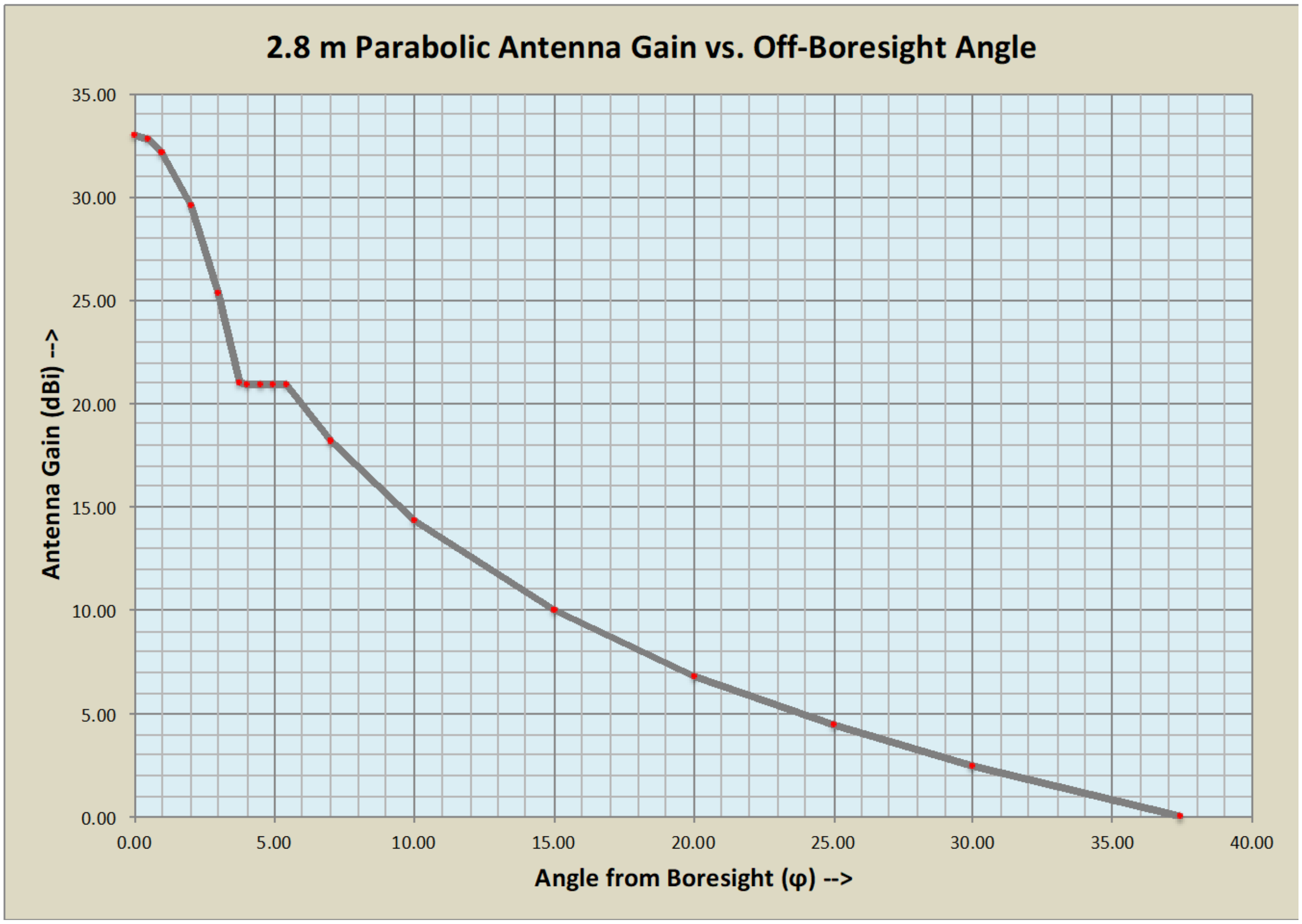
Calculations yield the following characteristics for the S-band H.S.D Control antenna:

**<u>Table C-S-TX-GS-7/8 C</u>: S-band Antenna Characteristics**



| | 2047.5 MHz | |
|---|---|---|
| **Parabolic Antenna Factors:** | | |
| D = | 2.80 | m |
| $G_{max}$ = | 32.97 | dBi |
| λ = | 0.14642 | m |
| D/λ = | 18.3442517 | |
| $G_1$ = | 20.953 | dBi |
| $\varphi_m$ = | 3.78 | deg. |
| $\varphi_r$ = | 5.45 | deg. |
| $\varphi_b$ = | 37.48 | deg. |

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-7/8 D</u>: Antenna Gain vs. Angle from Boresight – (2.8 m Parabolic Dish Antenna)**

## II. GHOSt SATELLITE ANTENNA BEAM CONTOURS

This Attachment provides a "paper version" of the beam antenna contours for each GHOSt satellite in the initial constellation. *We are filing ITU-required GTX format file attachments in our Schedule-S submission, as well.*

Table D-1 summarizes the provided beam contour plots for each transmit and receive beam for the space segment of the system. There are five (5) types of patterns: 1) Beam Gain Roll-Off Contours (relative gain); 2) Beam Absolute Gain Contours; 3) Beam Isotropic Power Levels; 4) Beam EIRP Contours; and 5) Beam G/T Contours, as applicable to each satellite and Earth station. The UHF Transmitter Antenna system uses a tabular format to present the radiated EIRP and signal power data.

**Table D-1: Satellite Beam Antenna Contours and Tables Summary:**

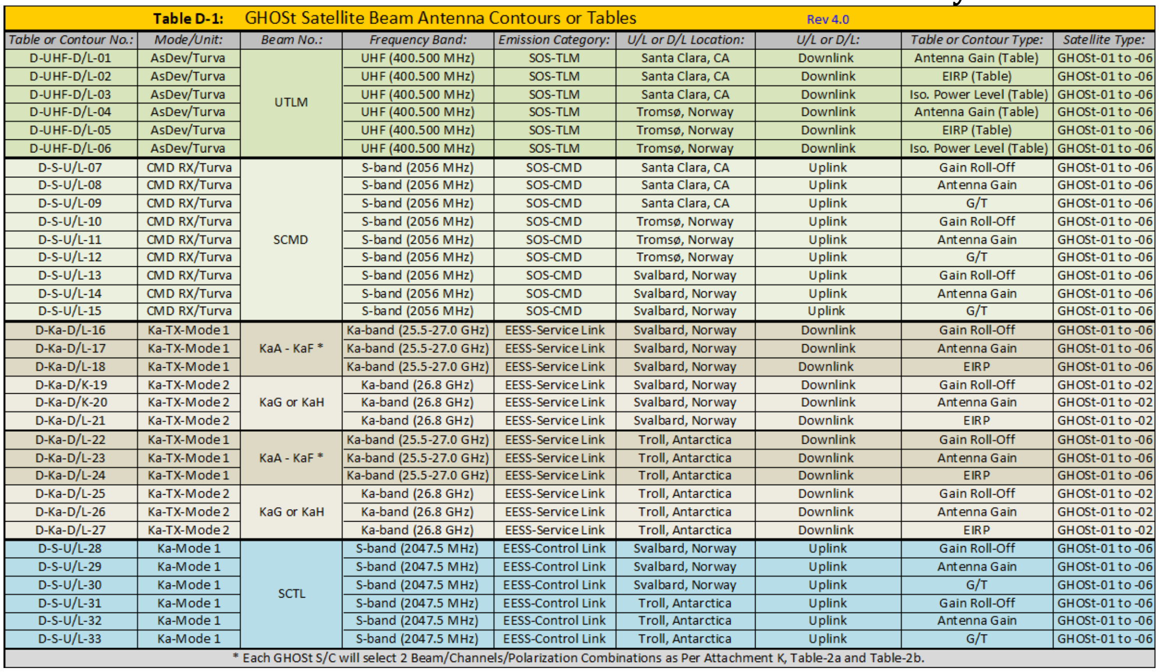


**Table D-1:** GHOSt Satellite Beam Antenna Contours or Tables Rev 4.0

| *Table or Contour No.:* | *Mode/Unit:* | *Beam No.:* | *Frequency Band:* | *Emission Category:* | *U/L or D/L Location:* | *U/L or D/L:* | *Table or Contour Type:* | *Satellite Type:* |
|---|---|---|---|---|---|---|---|---|
| D-UHF-D/L-01 | AsDev/Turva | UTLM | UHF (400.500 MHz) | SOS-TLM | Santa Clara, CA | Downlink | Antenna Gain (Table) | GHOSt-01 to -06 |
| D-UHF-D/L-02 | AsDev/Turva | | UHF (400.500 MHz) | SOS-TLM | Santa Clara, CA | Downlink | EIRP (Table) | GHOSt-01 to -06 |
| D-UHF-D/L-03 | AsDev/Turva | | UHF (400.500 MHz) | SOS-TLM | Santa Clara, CA | Downlink | Iso. Power Level (Table) | GHOSt-01 to -06 |
| D-UHF-D/L-04 | AsDev/Turva | | UHF (400.500 MHz) | SOS-TLM | Tromsø, Norway | Downlink | Antenna Gain (Table) | GHOSt-01 to -06 |
| D-UHF-D/L-05 | AsDev/Turva | | UHF (400.500 MHz) | SOS-TLM | Tromsø, Norway | Downlink | EIRP (Table) | GHOSt-01 to -06 |
| D-UHF-D/L-06 | AsDev/Turva | | UHF (400.500 MHz) | SOS-TLM | Tromsø, Norway | Downlink | Iso. Power Level (Table) | GHOSt-01 to -06 |
| D-S-U/L-07 | CMD RX/Turva | SCMD | S-band (2056 MHz) | SOS-CMD | Santa Clara, CA | Uplink | Gain Roll-Off | GHOSt-01 to -06 |
| D-S-U/L-08 | CMD RX/Turva | | S-band (2056 MHz) | SOS-CMD | Santa Clara, CA | Uplink | Antenna Gain | GHOSt-01 to -06 |
| D-S-U/L-09 | CMD RX/Turva | | S-band (2056 MHz) | SOS-CMD | Santa Clara, CA | Uplink | G/T | GHOSt-01 to -06 |
| D-S-U/L-10 | CMD RX/Turva | | S-band (2056 MHz) | SOS-CMD | Tromsø, Norway | Uplink | Gain Roll-Off | GHOSt-01 to -06 |
| D-S-U/L-11 | CMD RX/Turva | | S-band (2056 MHz) | SOS-CMD | Tromsø, Norway | Uplink | Antenna Gain | GHOSt-01 to -06 |
| D-S-U/L-12 | CMD RX/Turva | | S-band (2056 MHz) | SOS-CMD | Tromsø, Norway | Uplink | G/T | GHOSt-01 to -06 |
| D-S-U/L-13 | CMD RX/Turva | | S-band (2056 MHz) | SOS-CMD | Svalbard, Norway | Uplink | Gain Roll-Off | GHOSt-01 to -06 |
| D-S-U/L-14 | CMD RX/Turva | | S-band (2056 MHz) | SOS-CMD | Svalbard, Norway | Uplink | Antenna Gain | GHOSt-01 to -06 |
| D-S-U/L-15 | CMD RX/Turva | | S-band (2056 MHz) | SOS-CMD | Svalbard, Norway | Uplink | G/T | GHOSt-01 to -06 |
| D-Ka-D/L-16 | Ka-TX-Mode 1 | KaA - KaF * | Ka-band (25.5-27.0 GHz) | EESS-Service Link | Svalbard, Norway | Downlink | Gain Roll-Off | GHOSt-01 to -06 |
| D-Ka-D/L-17 | Ka-TX-Mode 1 | | Ka-band (25.5-27.0 GHz) | EESS-Service Link | Svalbard, Norway | Downlink | Antenna Gain | GHOSt-01 to -06 |
| D-Ka-D/L-18 | Ka-TX-Mode 1 | | Ka-band (25.5-27.0 GHz) | EESS-Service Link | Svalbard, Norway | Downlink | EIRP | GHOSt-01 to -06 |
| D-Ka-D/K-19 | Ka-TX-Mode 2 | KaG or KaH | Ka-band (26.8 GHz) | EESS-Service Link | Svalbard, Norway | Downlink | Gain Roll-Off | GHOSt-01 to -02 |
| D-Ka-D/K-20 | Ka-TX-Mode 2 | | Ka-band (26.8 GHz) | EESS-Service Link | Svalbard, Norway | Downlink | Antenna Gain | GHOSt-01 to -02 |
| D-Ka-D/L-21 | Ka-TX-Mode 2 | | Ka-band (26.8 GHz) | EESS-Service Link | Svalbard, Norway | Downlink | EIRP | GHOSt-01 to -02 |
| D-Ka-D/L-22 | Ka-TX-Mode 1 | KaA - KaF * | Ka-band (25.5-27.0 GHz) | EESS-Service Link | Troll, Antarctica | Downlink | Gain Roll-Off | GHOSt-01 to -06 |
| D-Ka-D/L-23 | Ka-TX-Mode 1 | | Ka-band (25.5-27.0 GHz) | EESS-Service Link | Troll, Antarctica | Downlink | Antenna Gain | GHOSt-01 to -06 |
| D-Ka-D/L-24 | Ka-TX-Mode 1 | | Ka-band (25.5-27.0 GHz) | EESS-Service Link | Troll, Antarctica | Downlink | EIRP | GHOSt-01 to -06 |
| D-Ka-D/L-25 | Ka-TX-Mode 2 | KaG or KaH | Ka-band (26.8 GHz) | EESS-Service Link | Troll, Antarctica | Downlink | Gain Roll-Off | GHOSt-01 to -02 |
| D-Ka-D/L-26 | Ka-TX-Mode 2 | | Ka-band (26.8 GHz) | EESS-Service Link | Troll, Antarctica | Downlink | Antenna Gain | GHOSt-01 to -02 |
| D-Ka-D/L-27 | Ka-TX-Mode 2 | | Ka-band (26.8 GHz) | EESS-Service Link | Troll, Antarctica | Downlink | EIRP | GHOSt-01 to -02 |
| D-S-U/L-28 | Ka-Mode 1 | SCTL | S-band (2047.5 MHz) | EESS-Control Link | Svalbard, Norway | Uplink | Gain Roll-Off | GHOSt-01 to -06 |
| D-S-U/L-29 | Ka-Mode 1 | | S-band (2047.5 MHz) | EESS-Control Link | Svalbard, Norway | Uplink | Antenna Gain | GHOSt-01 to -06 |
| D-S-U/L-30 | Ka-Mode 1 | | S-band (2047.5 MHz) | EESS-Control Link | Svalbard, Norway | Uplink | G/T | GHOSt-01 to -06 |
| D-S-U/L-31 | Ka-Mode 1 | | S-band (2047.5 MHz) | EESS-Control Link | Troll, Antarctica | Uplink | Gain Roll-Off | GHOSt-01 to -06 |
| D-S-U/L-32 | Ka-Mode 1 | | S-band (2047.5 MHz) | EESS-Control Link | Troll, Antarctica | Uplink | Antenna Gain | GHOSt-01 to -06 |
| D-S-U/L-33 | Ka-Mode 1 | | S-band (2047.5 MHz) | EESS-Control Link | Troll, Antarctica | Uplink | G/T | GHOSt-01 to -06 |

* Each GHOSt S/C will select 2 Beam/Channels/Polarization Combinations as Per Attachment K, Table-2a and Table-2b.

OSK used a map system provided on-line by Google Earth® to generate the diagrams for the beam contours included below.[4] This map application provides tools for calculating ground surface distances directly on the graphic. Off-boresight angles for each antenna roll-off value were converted to ground surface distances for the four target locations (the Earth stations at Santa Clara, CA; Svalbard, Norway; Tromsø, Norway; and Troll, Antarctica) and the contours were generated using the surface distance measuring feature of Google Earth for each map. Roll-off contour rings were then constructed at suitable angles from boresight for each antenna case using surface distance graphics. Roll-off

---

[4] OSK has also attached the beam contours as GIMS-readable files to its Schedule S technical exhibit, filed concurrently with this application. The serialized numbers in the figures below correspond to the same figure numbers in the Schedule-S GIMS-readable attachments.

values were then converted to EIRP or G/T contours, as appropriate for TX or RX beams respectively. An orbit height of 525 km was used for each satellite in making the contours. We used the average height of the 6 satellites to generate the contours and we assume the spacecraft is at its zenith position relative to the Earth station.

## D.1: Detailed Method Used for Preparing Ka-band Transmit Beam Contour Plots

As the Ka-band antennas have the highest gain of all the GHOSt RF system antennas and the transmission systems in both Mode 1 and Mode 2 have an EIRP in excess of 20 dBW, special care was taken to make these plots. We consulted ITU Reference Publication APL-UM-001, Ver. 1.1.19 (2016-04-21) in an effort to identify a suitable ITU class spacecraft antenna that could be used to mathematically define our Ka-band transmit antenna systems. This specific method was not successful. However, we were able to identify a ship Earth station antenna, which did resemble the pattern of our two types of transmitting horn antennas used on both GHOSt-01 and -02. GHOST-03 thru -06 will use the first of these antennas only (shown here as MODE-1) . Although the original ITU-referenced antenna was used at L-band as an Earth station antenna and our system employs Ka-band spacecraft antennas, the D/λ and roll-off behavior for the two antennas was found to be very similar.

First we “digitized” the data from our measured analog roll-off data from the supplying vendors. We then adjusted coefficients for the selected antenna, taken from ITU-R APL-UM-001. The selected antenna has the name: APEREC005V01. After adjusting the coefficients we developed the following relationships:

Equation Fit for GHOSt Ka-band Antenna Pattern: MODE 1

$G = G_{max} - 2.75E\text{-}3\square( D/\lambda\square\ \varphi)^{\wedge}2$ [dBi] for $0° \leq \varphi < \varphi_m$

$G = G_1 = 15\log(D/\lambda)$ [dBi] = 14.7 dBi for $\varphi_m \leq \varphi < \varphi_r$

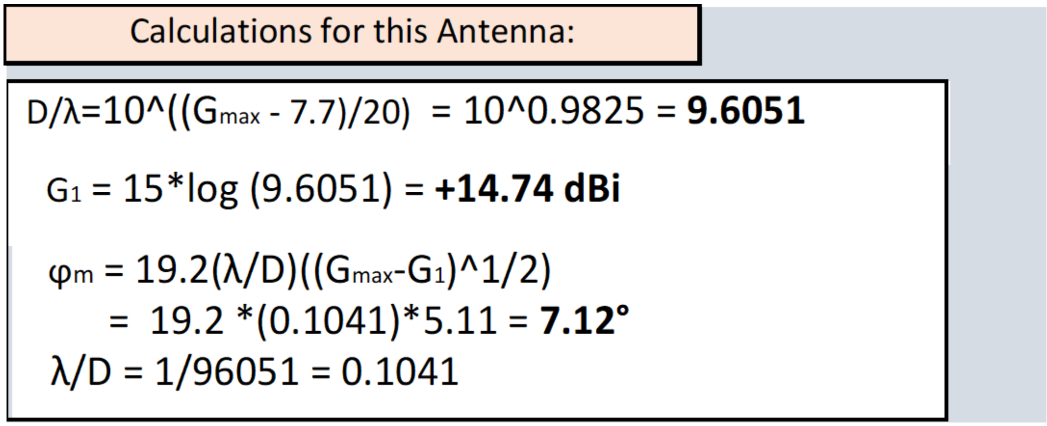
$\varphi_m = 19.2(\lambda/D)(G_{max} - G_1)^{\wedge}/1/2$ [degrees] = 7.1°

$\varphi_r = 113.8(\lambda/D) = 11.8°$ [degrees]

$G = 51.5 - 10\log(D/\lambda) - 23\log(\varphi)$ [degrees] for $\varphi_r \leq \varphi < \varphi_b$

$\varphi_b = 48.5°$ [degrees]

**Figure D-1: Equations Expressing MODE-1 Ka-Band Horn Antenna Pattern**



Calculations for this Antenna:

$D/\lambda = 10\text{^}((G_{max} - 7.7)/20) = 10\text{^}0.9825 = \mathbf{9.6051}$

$G_1 = 15 * \log(9.6051) = \mathbf{+14.74\ dBi}$

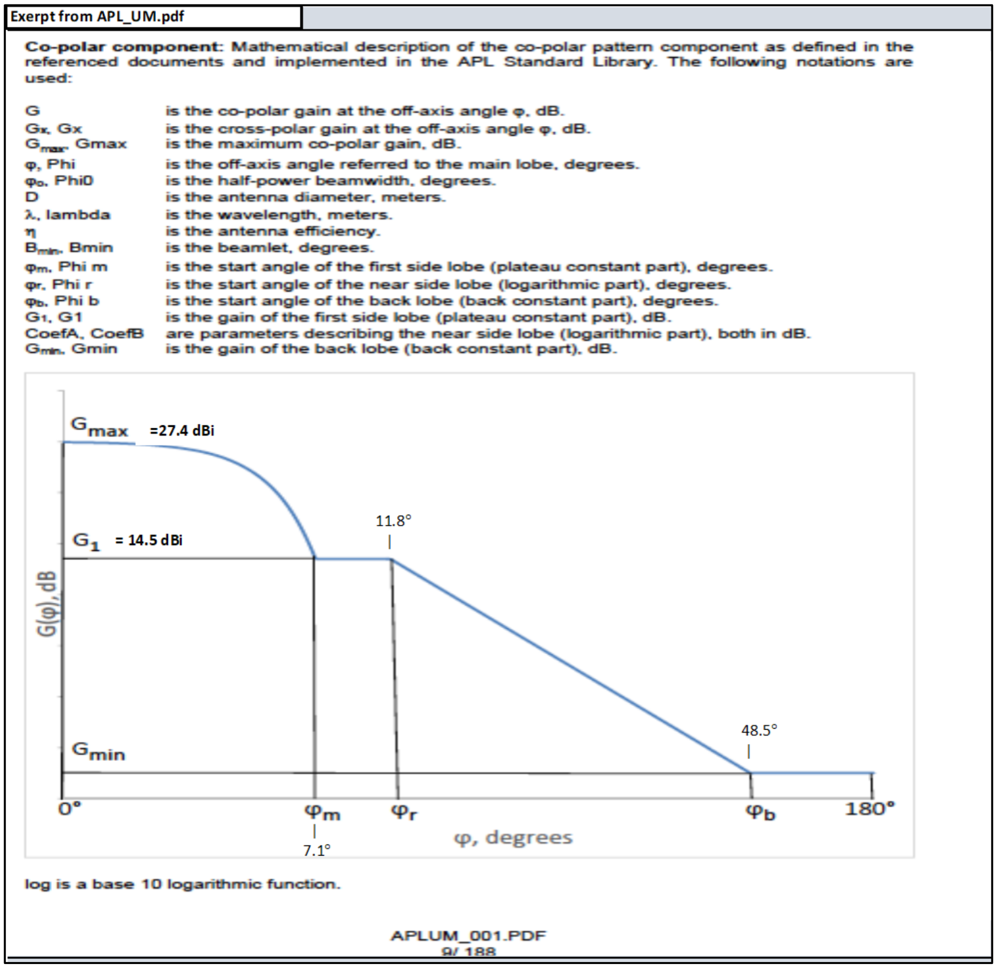
$\varphi_m = 19.2(\lambda/D)((G_{max} - G_1)\text{^}1/2)$

$= 19.2 * (0.1041) * 5.11 = \mathbf{7.12°}$

$\lambda/D = 1/96051 = 0.1041$

Figure D-2: Specific Calculations for Mode-1 Antenna

Where gain and angle parameters are as defined in the following excerpt from ITU Reference Publication APL-UM-001, annotated for the Mode-1 case:



Exerpt from APL_UM.pdf

**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. |
| $\varphi_0$, 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. |
| $\varphi_m$, Phi m | is the start angle of the first side lobe (plateau constant part), degrees. |
| $\varphi_r$, Phi r | is the start angle of the near side lobe (logarithmic part), degrees. |
| $\varphi_b$, 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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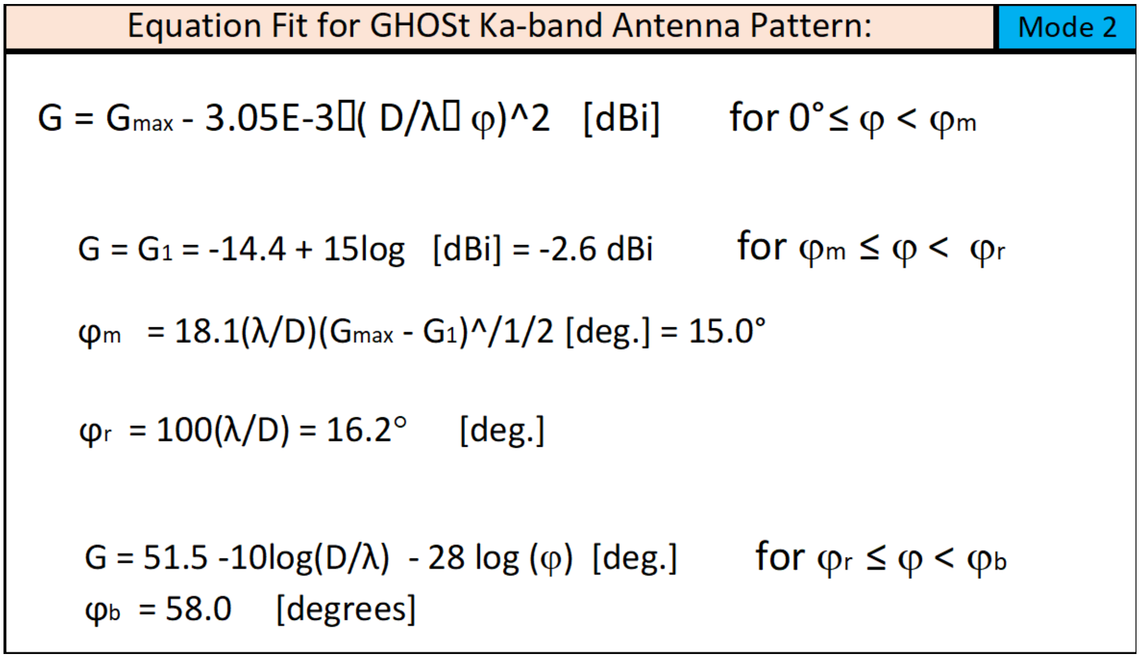
Figure D-3: Mathematical Description of Co-polar Antenna Patterns Mode-1



Equation Fit for GHOSt Ka-band Antenna Pattern: Mode 2

$G = G_{max} - 3.05E\text{-}3\square( D/\lambda\square\ \varphi)\text{^}2$ [dBi] for $0° \leq \varphi < \varphi_m$

$G = G_1 = -14.4 + 15\log$ [dBi] = -2.6 dBi for $\varphi_m \leq \varphi < \varphi_r$

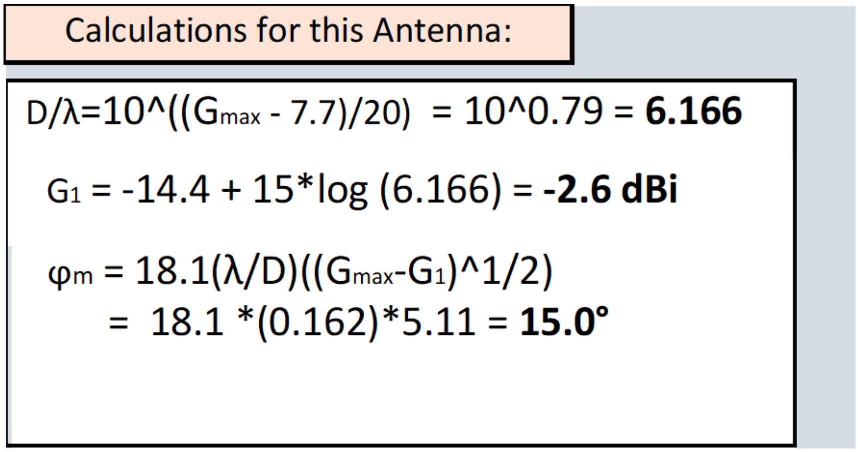
$\varphi_m = 18.1(\lambda/D)(G_{max} - G_1)\text{^}/1/2$ [deg.] = 15.0°

$\varphi_r = 100(\lambda/D) = 16.2°$ [deg.]

$G = 51.5 - 10\log(D/\lambda) - 28\log(\varphi)$ [deg.] for $\varphi_r \leq \varphi < \varphi_b$

$\varphi_b = 58.0$ [degrees]

**Figure D-4: Equations Expressing MODE-2 Ka-Band Horn Antenna Pattern**



Calculations for this Antenna:

$D/\lambda = 10\text{^}((G_{max} - 7.7)/20) = 10\text{^}0.79 =$ **6.166**

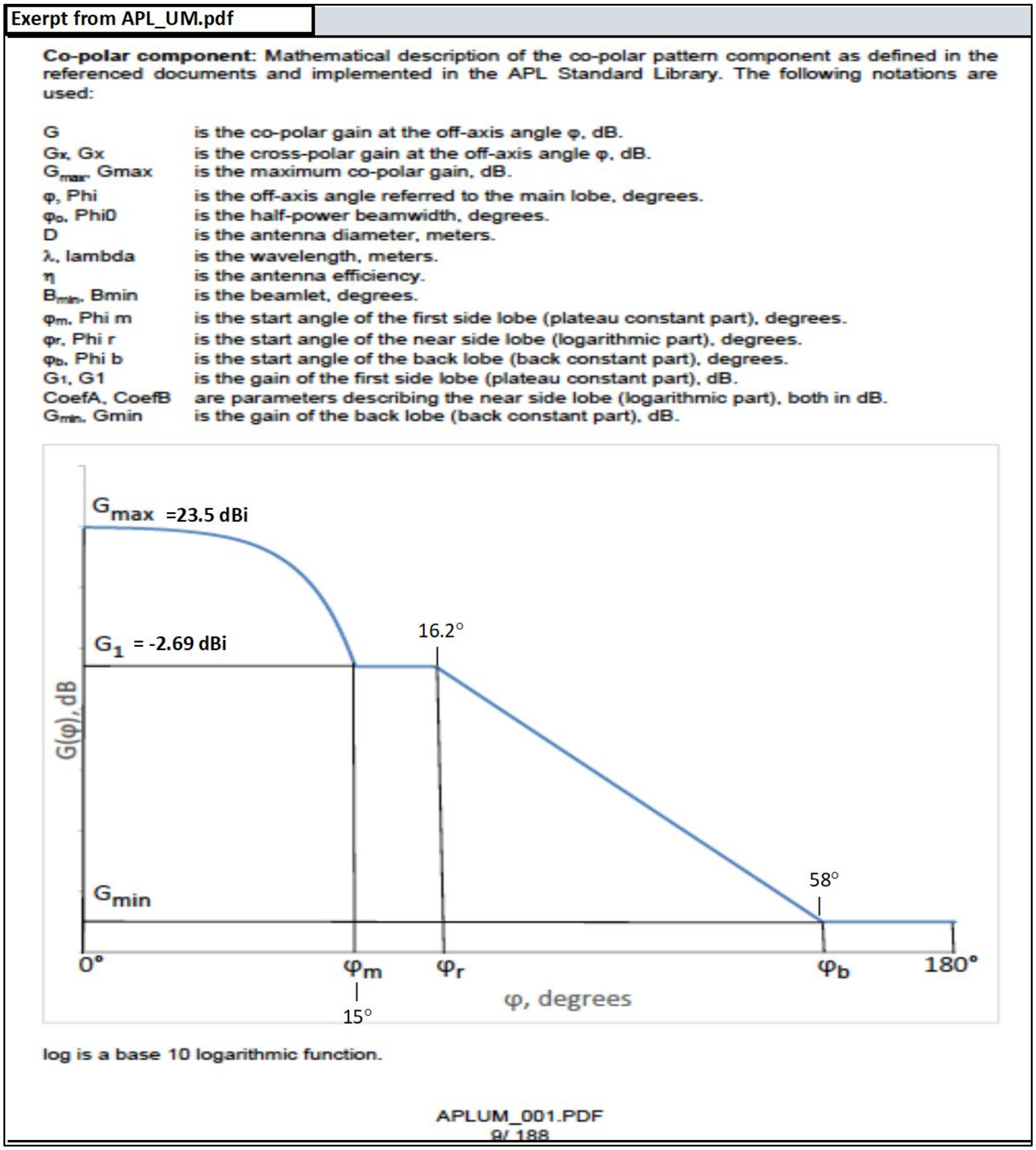
$G_1 = -14.4 + 15 * \log(6.166) =$ **-2.6 dBi**

$\varphi_m = 18.1(\lambda/D)((G_{max} - G_1)\text{^}1/2)$

$= 18.1 * (0.162) * 5.11 =$ **15.0°**

**Figure D-5: Specific Calculations for Mode-2 Antenna**

Where, once again, the gain and angle parameters are as defined in the following excerpt from ITU Reference Publication APL-UM-001 (annotated for the Mode-2 case):



**Exerpt from APL_UM.pdf**

**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. |
| $\varphi_0$, 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. |
| $\varphi_m$, Phi m | is the start angle of the first side lobe (plateau constant part), degrees. |
| $\varphi_r$, Phi r | is the start angle of the near side lobe (logarithmic part), degrees. |
| $\varphi_b$, 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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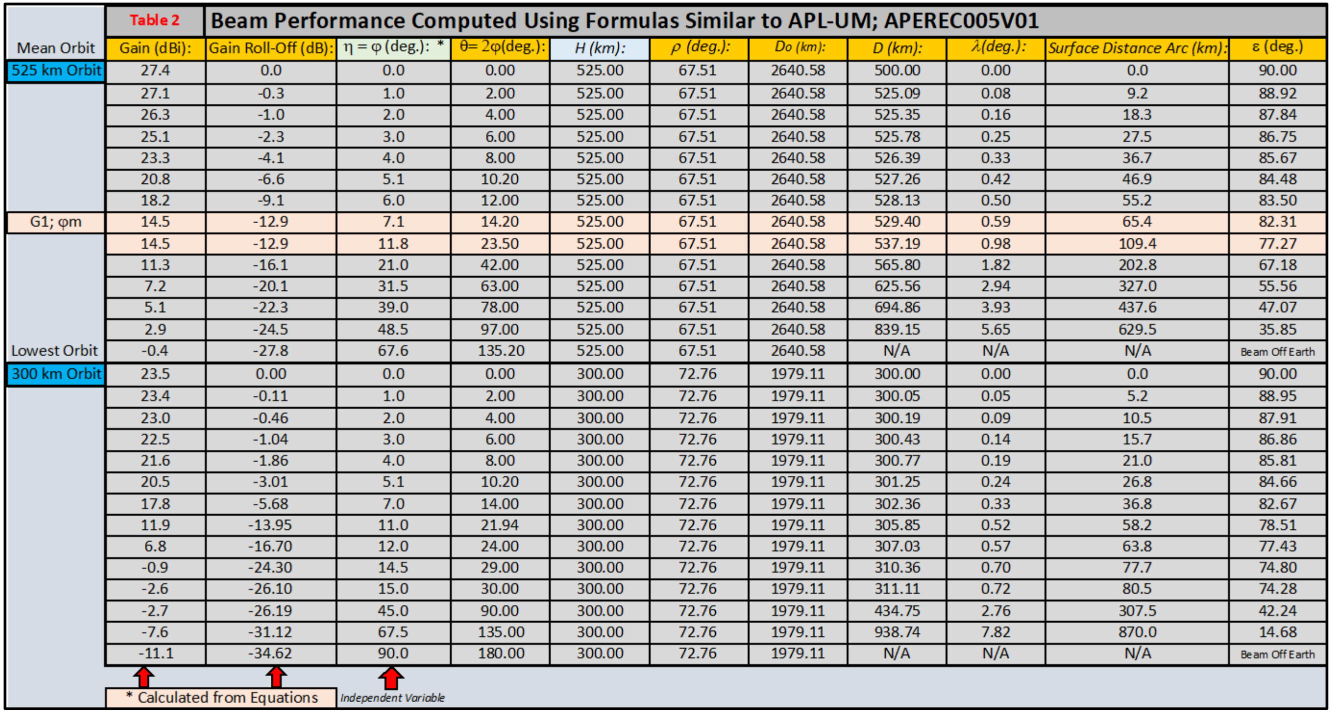
Figure D-6: Mathematical Description of Co-polar Antenna Patterns Mode-2

Table D-2 was then created to allow beam radii to be generated using a conversion from off-boresight angle to ground surface distance along the curvature of the arc of the Earth. The depiction of the quantities used and calculated are provided in Figure D-7. From this table a plot of Gain Roll-Off vs. Surface Arc Distance was prepared; then the beam contours could be constructed.

## Table D-2: Ka-band Computed Beam Envelope (Mode-1)

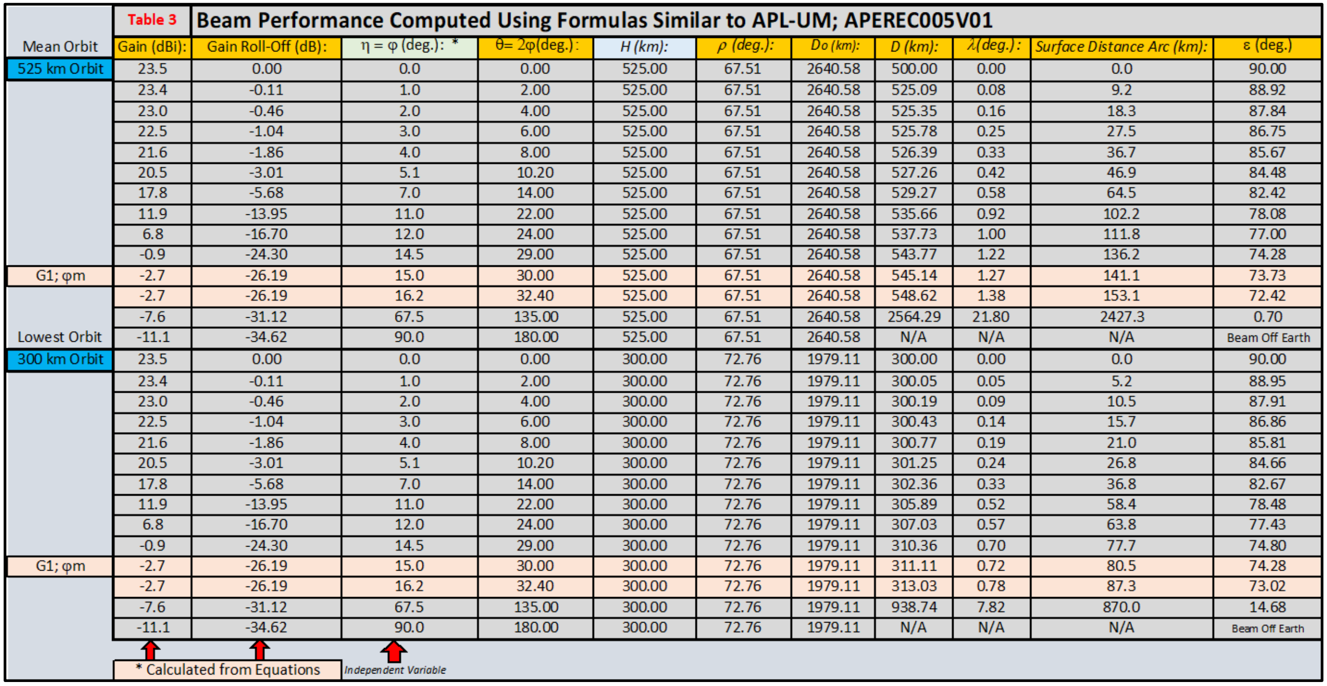


| | Table 2 | Beam Performance Computed Using Formulas Similar to APL-UM; APEREC005V01 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Orbit | Gain (dBi): | Gain Roll-Off (dB): | $\eta = \varphi$ (deg.): * | $\theta = 2\varphi$(deg.): | $H$ (km): | $\rho$ (deg.): | $D_o$ (km): | $D$ (km): | $\lambda$(deg.): | Surface Distance Arc (km): | $\varepsilon$ (deg.) |
| 525 km Orbit | 27.4 | 0.0 | 0.0 | 0.00 | 525.00 | 67.51 | 2640.58 | 500.00 | 0.00 | 0.0 | 90.00 |
| | 27.1 | -0.3 | 1.0 | 2.00 | 525.00 | 67.51 | 2640.58 | 525.09 | 0.08 | 9.2 | 88.92 |
| | 26.3 | -1.0 | 2.0 | 4.00 | 525.00 | 67.51 | 2640.58 | 525.35 | 0.16 | 18.3 | 87.84 |
| | 25.1 | -2.3 | 3.0 | 6.00 | 525.00 | 67.51 | 2640.58 | 525.78 | 0.25 | 27.5 | 86.75 |
| | 23.3 | -4.1 | 4.0 | 8.00 | 525.00 | 67.51 | 2640.58 | 526.39 | 0.33 | 36.7 | 85.67 |
| | 20.8 | -6.6 | 5.1 | 10.20 | 525.00 | 67.51 | 2640.58 | 527.26 | 0.42 | 46.9 | 84.48 |
| | 18.2 | -9.1 | 6.0 | 12.00 | 525.00 | 67.51 | 2640.58 | 528.13 | 0.50 | 55.2 | 83.50 |
| $G_1$; $\varphi_m$ | 14.5 | -12.9 | 7.1 | 14.20 | 525.00 | 67.51 | 2640.58 | 529.40 | 0.59 | 65.4 | 82.31 |
| | 14.5 | -12.9 | 11.8 | 23.50 | 525.00 | 67.51 | 2640.58 | 537.19 | 0.98 | 109.4 | 77.27 |
| | 11.3 | -16.1 | 21.0 | 42.00 | 525.00 | 67.51 | 2640.58 | 565.80 | 1.82 | 202.8 | 67.18 |
| | 7.2 | -20.1 | 31.5 | 63.00 | 525.00 | 67.51 | 2640.58 | 625.56 | 2.94 | 327.0 | 55.56 |
| | 5.1 | -22.3 | 39.0 | 78.00 | 525.00 | 67.51 | 2640.58 | 694.86 | 3.93 | 437.6 | 47.07 |
| | 2.9 | -24.5 | 48.5 | 97.00 | 525.00 | 67.51 | 2640.58 | 839.15 | 5.65 | 629.5 | 35.85 |
| Lowest Orbit | -0.4 | -27.8 | 67.6 | 135.20 | 525.00 | 67.51 | 2640.58 | N/A | N/A | N/A | Beam Off Earth |
| 300 km Orbit | 23.5 | 0.00 | 0.0 | 0.00 | 300.00 | 72.76 | 1979.11 | 300.00 | 0.00 | 0.0 | 90.00 |
| | 23.4 | -0.11 | 1.0 | 2.00 | 300.00 | 72.76 | 1979.11 | 300.05 | 0.05 | 5.2 | 88.95 |
| | 23.0 | -0.46 | 2.0 | 4.00 | 300.00 | 72.76 | 1979.11 | 300.19 | 0.09 | 10.5 | 87.91 |
| | 22.5 | -1.04 | 3.0 | 6.00 | 300.00 | 72.76 | 1979.11 | 300.43 | 0.14 | 15.7 | 86.86 |
| | 21.6 | -1.86 | 4.0 | 8.00 | 300.00 | 72.76 | 1979.11 | 300.77 | 0.19 | 21.0 | 85.81 |
| | 20.5 | -3.01 | 5.1 | 10.20 | 300.00 | 72.76 | 1979.11 | 301.25 | 0.24 | 26.8 | 84.66 |
| | 17.8 | -5.68 | 7.0 | 14.00 | 300.00 | 72.76 | 1979.11 | 302.36 | 0.33 | 36.8 | 82.67 |
| | 11.9 | -13.95 | 11.0 | 21.94 | 300.00 | 72.76 | 1979.11 | 305.85 | 0.52 | 58.2 | 78.51 |
| | 6.8 | -16.70 | 12.0 | 24.00 | 300.00 | 72.76 | 1979.11 | 307.03 | 0.57 | 63.8 | 77.43 |
| | -0.9 | -24.30 | 14.5 | 29.00 | 300.00 | 72.76 | 1979.11 | 310.36 | 0.70 | 77.7 | 74.80 |
| | -2.6 | -26.10 | 15.0 | 30.00 | 300.00 | 72.76 | 1979.11 | 311.11 | 0.72 | 80.5 | 74.28 |
| | -2.7 | -26.19 | 45.0 | 90.00 | 300.00 | 72.76 | 1979.11 | 434.75 | 2.76 | 307.5 | 42.24 |
| | -7.6 | -31.12 | 67.5 | 135.00 | 300.00 | 72.76 | 1979.11 | 938.74 | 7.82 | 870.0 | 14.68 |
| | -11.1 | -34.62 | 90.0 | 180.00 | 300.00 | 72.76 | 1979.11 | N/A | N/A | N/A | Beam Off Earth |

* Calculated from Equations

Independent Variable

## Table D-3: Ka-band Computed Beam Envelope (Mode-2)



| | Table 3 | Beam Performance Computed Using Formulas Similar to APL-UM; APEREC005V01 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Orbit | Gain (dBi): | Gain Roll-Off (dB): | $\eta = \varphi$ (deg.): * | $\theta = 2\varphi$(deg.): | $H$ (km): | $\rho$ (deg.): | $D_o$ (km): | $D$ (km): | $\lambda$(deg.): | Surface Distance Arc (km): | $\varepsilon$ (deg.) |
| 525 km Orbit | 23.5 | 0.00 | 0.0 | 0.00 | 525.00 | 67.51 | 2640.58 | 500.00 | 0.00 | 0.0 | 90.00 |
| | 23.4 | -0.11 | 1.0 | 2.00 | 525.00 | 67.51 | 2640.58 | 525.09 | 0.08 | 9.2 | 88.92 |
| | 23.0 | -0.46 | 2.0 | 4.00 | 525.00 | 67.51 | 2640.58 | 525.35 | 0.16 | 18.3 | 87.84 |
| | 22.5 | -1.04 | 3.0 | 6.00 | 525.00 | 67.51 | 2640.58 | 525.78 | 0.25 | 27.5 | 86.75 |
| | 21.6 | -1.86 | 4.0 | 8.00 | 525.00 | 67.51 | 2640.58 | 526.39 | 0.33 | 36.7 | 85.67 |
| | 20.5 | -3.01 | 5.1 | 10.20 | 525.00 | 67.51 | 2640.58 | 527.26 | 0.42 | 46.9 | 84.48 |
| | 17.8 | -5.68 | 7.0 | 14.00 | 525.00 | 67.51 | 2640.58 | 529.27 | 0.58 | 64.5 | 82.42 |
| | 11.9 | -13.95 | 11.0 | 22.00 | 525.00 | 67.51 | 2640.58 | 535.66 | 0.92 | 102.2 | 78.08 |
| | 6.8 | -16.70 | 12.0 | 24.00 | 525.00 | 67.51 | 2640.58 | 537.73 | 1.00 | 111.8 | 77.00 |
| | -0.9 | -24.30 | 14.5 | 29.00 | 525.00 | 67.51 | 2640.58 | 543.77 | 1.22 | 136.2 | 74.28 |
| $G_1$; $\varphi_m$ | -2.7 | -26.19 | 15.0 | 30.00 | 525.00 | 67.51 | 2640.58 | 545.14 | 1.27 | 141.1 | 73.73 |
| | -2.7 | -26.19 | 16.2 | 32.40 | 525.00 | 67.51 | 2640.58 | 548.62 | 1.38 | 153.1 | 72.42 |
| | -7.6 | -31.12 | 67.5 | 135.00 | 525.00 | 67.51 | 2640.58 | 2564.29 | 21.80 | 2427.3 | 0.70 |
| Lowest Orbit | -11.1 | -34.62 | 90.0 | 180.00 | 525.00 | 67.51 | 2640.58 | N/A | N/A | N/A | Beam Off Earth |
| 300 km Orbit | 23.5 | 0.00 | 0.0 | 0.00 | 300.00 | 72.76 | 1979.11 | 300.00 | 0.00 | 0.0 | 90.00 |
| | 23.4 | -0.11 | 1.0 | 2.00 | 300.00 | 72.76 | 1979.11 | 300.05 | 0.05 | 5.2 | 88.95 |
| | 23.0 | -0.46 | 2.0 | 4.00 | 300.00 | 72.76 | 1979.11 | 300.19 | 0.09 | 10.5 | 87.91 |
| | 22.5 | -1.04 | 3.0 | 6.00 | 300.00 | 72.76 | 1979.11 | 300.43 | 0.14 | 15.7 | 86.86 |
| | 21.6 | -1.86 | 4.0 | 8.00 | 300.00 | 72.76 | 1979.11 | 300.77 | 0.19 | 21.0 | 85.81 |
| | 20.5 | -3.01 | 5.1 | 10.20 | 300.00 | 72.76 | 1979.11 | 301.25 | 0.24 | 26.8 | 84.66 |
| | 17.8 | -5.68 | 7.0 | 14.00 | 300.00 | 72.76 | 1979.11 | 302.36 | 0.33 | 36.8 | 82.67 |
| | 11.9 | -13.95 | 11.0 | 22.00 | 300.00 | 72.76 | 1979.11 | 305.89 | 0.52 | 58.4 | 78.48 |
| | 6.8 | -16.70 | 12.0 | 24.00 | 300.00 | 72.76 | 1979.11 | 307.03 | 0.57 | 63.8 | 77.43 |
| | -0.9 | -24.30 | 14.5 | 29.00 | 300.00 | 72.76 | 1979.11 | 310.36 | 0.70 | 77.7 | 74.80 |
| $G_1$; $\varphi_m$ | -2.7 | -26.19 | 15.0 | 30.00 | 300.00 | 72.76 | 1979.11 | 311.11 | 0.72 | 80.5 | 74.28 |
| | -2.7 | -26.19 | 16.2 | 32.40 | 300.00 | 72.76 | 1979.11 | 313.03 | 0.78 | 87.3 | 73.02 |
| | -7.6 | -31.12 | 67.5 | 135.00 | 300.00 | 72.76 | 1979.11 | 938.74 | 7.82 | 870.0 | 14.68 |
| | -11.1 | -34.62 | 90.0 | 180.00 | 300.00 | 72.76 | 1979.11 | N/A | N/A | N/A | Beam Off Earth |

* Calculated from Equations

Independent Variable

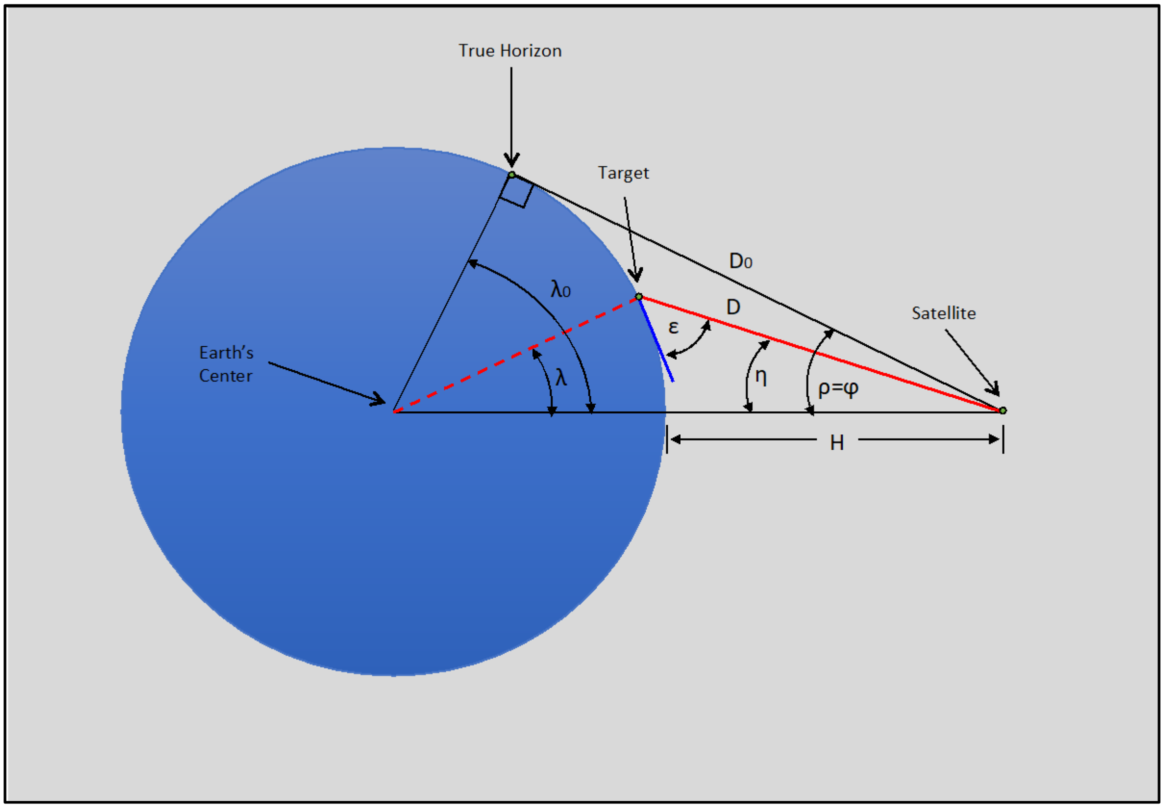


**Figure D-7: NGSO Orbit Geometry; Key Calculations and Parameters**

We believe this representation of our Ka-band satellite antenna pattern will be useful as a means of working within the ITU environment. Further, this approach minimizes measurement errors by smoothing out the vendor-supplied pattern information.

## D.2 Detailed Method Used for Generating S-band Receive Beam Information

The S-band command patch antennas and the S-band HSD Control patch antenna are "in-between cases." The boresight gain is larger than for the UHF antennas but, much lower than the Ka-band antennas. The patterns are symmetric and well-formed and have good axial ratio performance. There is no corresponding antenna in the ITU Ref. Puplication APL-UM-001. Thus, measured performance roll-off data was used. Table D-4 gives provides the calculation converting the off-axis measurements to Earth Surface Arc distance, using the same calculation scheme as per Figure D-7. The results for the patch antennas are presented in Table D-4 and these were used, in turn, to generate the corresponding beam contours at the appropriate Earth station locations.

**Table D-4: S-band Computed Beam Envelope (CMD and Mode 1 Control)**

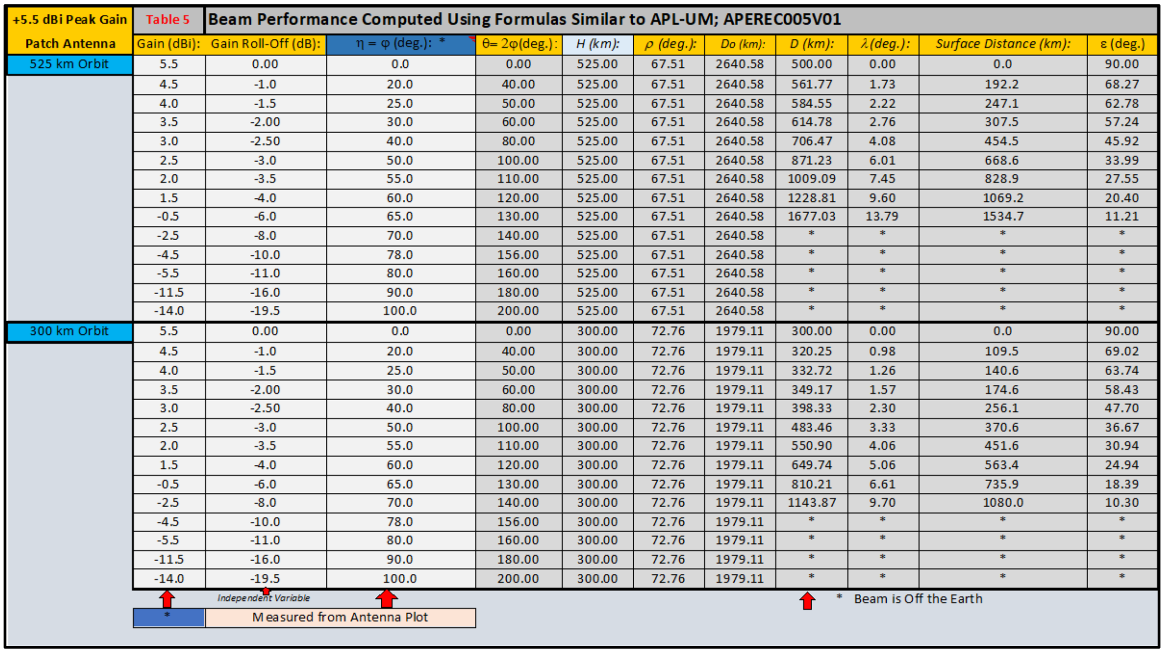


Table 5 **Beam Performance Computed Using Formulas Similar to APL-UM; APEREC005V01**

| **+5.5 dBi Peak Gain Patch Antenna** | Gain (dBi): | Gain Roll-Off (dB): | η = φ (deg.): * | θ= 2φ(deg.): | *H (km):* | *ρ (deg.):* | *$D_o$ (km):* | *D (km):* | *λ (deg.):* | *Surface Distance (km):* | ε (deg.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 525 km Orbit | 5.5 | 0.00 | 0.0 | 0.00 | 525.00 | 67.51 | 2640.58 | 500.00 | 0.00 | 0.0 | 90.00 |
| | 4.5 | -1.0 | 20.0 | 40.00 | 525.00 | 67.51 | 2640.58 | 561.77 | 1.73 | 192.2 | 68.27 |
| | 4.0 | -1.5 | 25.0 | 50.00 | 525.00 | 67.51 | 2640.58 | 584.55 | 2.22 | 247.1 | 62.78 |
| | 3.5 | -2.00 | 30.0 | 60.00 | 525.00 | 67.51 | 2640.58 | 614.78 | 2.76 | 307.5 | 57.24 |
| | 3.0 | -2.50 | 40.0 | 80.00 | 525.00 | 67.51 | 2640.58 | 706.47 | 4.08 | 454.5 | 45.92 |
| | 2.5 | -3.0 | 50.0 | 100.00 | 525.00 | 67.51 | 2640.58 | 871.23 | 6.01 | 668.6 | 33.99 |
| | 2.0 | -3.5 | 55.0 | 110.00 | 525.00 | 67.51 | 2640.58 | 1009.09 | 7.45 | 828.9 | 27.55 |
| | 1.5 | -4.0 | 60.0 | 120.00 | 525.00 | 67.51 | 2640.58 | 1228.81 | 9.60 | 1069.2 | 20.40 |
| | -0.5 | -6.0 | 65.0 | 130.00 | 525.00 | 67.51 | 2640.58 | 1677.03 | 13.79 | 1534.7 | 11.21 |
| | -2.5 | -8.0 | 70.0 | 140.00 | 525.00 | 67.51 | 2640.58 | * | * | * | * |
| | -4.5 | -10.0 | 78.0 | 156.00 | 525.00 | 67.51 | 2640.58 | * | * | * | * |
| | -5.5 | -11.0 | 80.0 | 160.00 | 525.00 | 67.51 | 2640.58 | * | * | * | * |
| | -11.5 | -16.0 | 90.0 | 180.00 | 525.00 | 67.51 | 2640.58 | * | * | * | * |
| | -14.0 | -19.5 | 100.0 | 200.00 | 525.00 | 67.51 | 2640.58 | * | * | * | * |
| 300 km Orbit | 5.5 | 0.00 | 0.0 | 0.00 | 300.00 | 72.76 | 1979.11 | 300.00 | 0.00 | 0.0 | 90.00 |
| | 4.5 | -1.0 | 20.0 | 40.00 | 300.00 | 72.76 | 1979.11 | 320.25 | 0.98 | 109.5 | 69.02 |
| | 4.0 | -1.5 | 25.0 | 50.00 | 300.00 | 72.76 | 1979.11 | 332.72 | 1.26 | 140.6 | 63.74 |
| | 3.5 | -2.00 | 30.0 | 60.00 | 300.00 | 72.76 | 1979.11 | 349.17 | 1.57 | 174.6 | 58.43 |
| | 3.0 | -2.50 | 40.0 | 80.00 | 300.00 | 72.76 | 1979.11 | 398.33 | 2.30 | 256.1 | 47.70 |
| | 2.5 | -3.0 | 50.0 | 100.00 | 300.00 | 72.76 | 1979.11 | 483.46 | 3.33 | 370.6 | 36.67 |
| | 2.0 | -3.5 | 55.0 | 110.00 | 300.00 | 72.76 | 1979.11 | 550.90 | 4.06 | 451.6 | 30.94 |
| | 1.5 | -4.0 | 60.0 | 120.00 | 300.00 | 72.76 | 1979.11 | 649.74 | 5.06 | 563.4 | 24.94 |
| | -0.5 | -6.0 | 65.0 | 130.00 | 300.00 | 72.76 | 1979.11 | 810.21 | 6.61 | 735.9 | 18.39 |
| | -2.5 | -8.0 | 70.0 | 140.00 | 300.00 | 72.76 | 1979.11 | 1143.87 | 9.70 | 1080.0 | 10.30 |
| | -4.5 | -10.0 | 78.0 | 156.00 | 300.00 | 72.76 | 1979.11 | * | * | * | * |
| | -5.5 | -11.0 | 80.0 | 160.00 | 300.00 | 72.76 | 1979.11 | * | * | * | * |
| | -11.5 | -16.0 | 90.0 | 180.00 | 300.00 | 72.76 | 1979.11 | * | * | * | * |
| | -14.0 | -19.5 | 100.0 | 200.00 | 300.00 | 72.76 | 1979.11 | * | * | * | * |

*Independent Variable*

* Measured from Antenna Plot

* Beam is Off the Earth

## D.3 Detailed Method Used for Generating UHF Transmit Beam Information

All six satellites in the initial GHOSt program will use the UHF spectrum in the same manner. That is, the satellites will all use an omni-direction antenna system having a dipole-like pattern. The antennas will be linearly polarized. While this system will nominally fly with one surface of the satellite directed to the NADIR direction, this system must be used at times when the spacecraft will have other inertial orientations and could even be tumbling and not under attitude control. As such, the system must operate satisfactorily during times when there is motion about any axis of the GHOSt satellites (-01 through -06). As there are certainly times when the system must operate with good performance during periods of uncontrolled attitude, it is inappropriate to produce beam contours that show specific levels or EIRP or G/T as would be the case for a GEO beam projection on the Earth. Rather, we have chosen to provide tables that show what the maximum and minimum EIRP and G/T values will be during periods when the satellite is operating within range of Santa Clara, CA and Tromsø, Norway (that is, when in-range of the command/control Earth stations). These levels are statistical in nature but, will vary only between a nominal minimum and nominal maximum EIRP and G/T.

We also present a table showing what the TX isotropic signal power level could be, which arrives from the spacecraft to an arbitrary Earth station (victim) location depending on the instantaneous elevation angle to that same spacecraft from the victim's antenna. In this case, the victim site is receiving this level of interference from the GHOSt spacecraft. Once again, the maximum and minimum possible isotropic signal power levels are computed and are based on:

- Path loss for a given slant range associated with a particular elevation angle to the Earth Station.

- Excess Path Loss, which includes primarily polarization losses as well as atmospheric and ionospheric losses. This value was fixed at -5.5 dB.

- The highest possible UHF antenna gain and the lowest possible UHF antenna gain measured for the UHF antenna system (this value is the same for the GHOSt-01 through GHOSt-06 satellites). These values were measured during the satellite development program.

The approach taken in this application is the most appropriate way of presenting the signal performance of our T&C telemetry downlink system in a simple manner, since:

1) During periods when the satellites could be tumbling, the signal level can only be bounded by the maximum and minimum EIRP value in any arbitrary direction.

2) At any instant in time, a victim station's location and angular orientation to the satellite antenna (where interference could be sourced) cannot be known.

3) At any location on the Earth, even if the satellite's motion were controlled, the amplitude of the signal would vary at a rate and by a scalar amplitude determined by the effect known as Faraday rotation.

We note here again, that unlike all other RF systems in the GHOSt network, the satellite UHF transmitter is linearly polarized. This further increases the amplitude variations possible to a victim station.

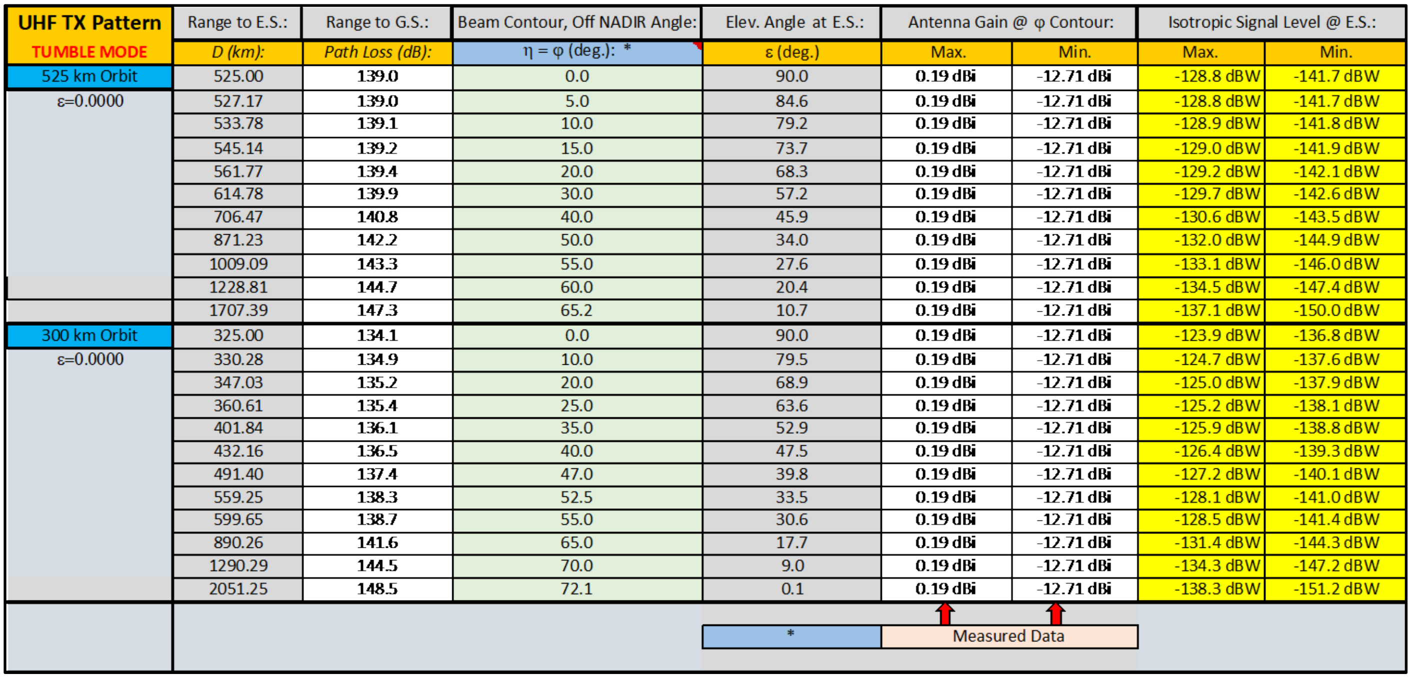
**Table D-UHF-D/L-01: GHOSt UHF Transmit Beam (circa. Santa Clara, CA) – Gain**

| Antenna Operating Frequency: | Maximum Gain in Tumble Mode: | Minimum Gain in Tumble Mode: |
|---|---|---|
| 400.5 MHz | +0.19 dBi | -12.7 dBi |

**Table D-UHF-D/L-02: GHOSt UHF Transmit Beam (circa. Santa Clara, CA) – EIRP**

| Antenna Operating Frequency: | Maximum EIRP in Tumble Mode: | Minimum EIRP in Tumble Mode: |
|---|---|---|
| 400.5 MHz | +4.7 dBW | -8.2 dBW |

**Table D-UHF-D/L-03: GHOSt UHF Transmit Isotropic Power Level* @ Victim Earth Station - (Circa. Santa Clara, CA)**



| **UHF TX Pattern** | Range to E.S.: | Range to G.S.: | Beam Contour, Off NADIR Angle: | Elev. Angle at E.S.: | Antenna Gain @ φ Contour: | | Isotropic Signal Level @ E.S.: | |
|---|---|---|---|---|---|---|---|---|
| **TUMBLE MODE** | *D (km):* | *Path Loss (dB):* | η = φ (deg.): * | ε (deg.) | Max. | Min. | Max. | Min. |
| 525 km Orbit | 525.00 | 139.0 | 0.0 | 90.0 | 0.19 dBi | -12.71 dBi | -128.8 dBW | -141.7 dBW |
| ε=0.0000 | 527.17 | 139.0 | 5.0 | 84.6 | 0.19 dBi | -12.71 dBi | -128.8 dBW | -141.7 dBW |
| | 533.78 | 139.1 | 10.0 | 79.2 | 0.19 dBi | -12.71 dBi | -128.9 dBW | -141.8 dBW |
| | 545.14 | 139.2 | 15.0 | 73.7 | 0.19 dBi | -12.71 dBi | -129.0 dBW | -141.9 dBW |
| | 561.77 | 139.4 | 20.0 | 68.3 | 0.19 dBi | -12.71 dBi | -129.2 dBW | -142.1 dBW |
| | 614.78 | 139.9 | 30.0 | 57.2 | 0.19 dBi | -12.71 dBi | -129.7 dBW | -142.6 dBW |
| | 706.47 | 140.8 | 40.0 | 45.9 | 0.19 dBi | -12.71 dBi | -130.6 dBW | -143.5 dBW |
| | 871.23 | 142.2 | 50.0 | 34.0 | 0.19 dBi | -12.71 dBi | -132.0 dBW | -144.9 dBW |
| | 1009.09 | 143.3 | 55.0 | 27.6 | 0.19 dBi | -12.71 dBi | -133.1 dBW | -146.0 dBW |
| | 1228.81 | 144.7 | 60.0 | 20.4 | 0.19 dBi | -12.71 dBi | -134.5 dBW | -147.4 dBW |
| | 1707.39 | 147.3 | 65.2 | 10.7 | 0.19 dBi | -12.71 dBi | -137.1 dBW | -150.0 dBW |
| 300 km Orbit | 325.00 | 134.1 | 0.0 | 90.0 | 0.19 dBi | -12.71 dBi | -123.9 dBW | -136.8 dBW |
| ε=0.0000 | 330.28 | 134.9 | 10.0 | 79.5 | 0.19 dBi | -12.71 dBi | -124.7 dBW | -137.6 dBW |
| | 347.03 | 135.2 | 20.0 | 68.9 | 0.19 dBi | -12.71 dBi | -125.0 dBW | -137.9 dBW |
| | 360.61 | 135.4 | 25.0 | 63.6 | 0.19 dBi | -12.71 dBi | -125.2 dBW | -138.1 dBW |
| | 401.84 | 136.1 | 35.0 | 52.9 | 0.19 dBi | -12.71 dBi | -125.9 dBW | -138.8 dBW |
| | 432.16 | 136.5 | 40.0 | 47.5 | 0.19 dBi | -12.71 dBi | -126.4 dBW | -139.3 dBW |
| | 491.40 | 137.4 | 47.0 | 39.8 | 0.19 dBi | -12.71 dBi | -127.2 dBW | -140.1 dBW |
| | 559.25 | 138.3 | 52.5 | 33.5 | 0.19 dBi | -12.71 dBi | -128.1 dBW | -141.0 dBW |
| | 599.65 | 138.7 | 55.0 | 30.6 | 0.19 dBi | -12.71 dBi | -128.5 dBW | -141.4 dBW |
| | 890.26 | 141.6 | 65.0 | 17.7 | 0.19 dBi | -12.71 dBi | -131.4 dBW | -144.3 dBW |
| | 1290.29 | 144.5 | 70.0 | 9.0 | 0.19 dBi | -12.71 dBi | -134.3 dBW | -147.2 dBW |
| | 2051.25 | 148.5 | 72.1 | 0.1 | 0.19 dBi | -12.71 dBi | -138.3 dBW | -151.2 dBW |
| | | | | * | Measured Data | | | |

* NOTE: Isotropic signal level measured in a 40 kHz bandwidth.

### Table D-UHF-D/L-04: GHOSt UHF Transmit Beam (circa. Tromsø, Norway) – Gain

See Table D-UHF-D/L-01. Same values.

### Table D-UHF-D/L-05: GHOSt UHF Transmit Beam (circa. Tromsø, Norway) – EIRP

See Table D-UHF-D/L-02. Same values.

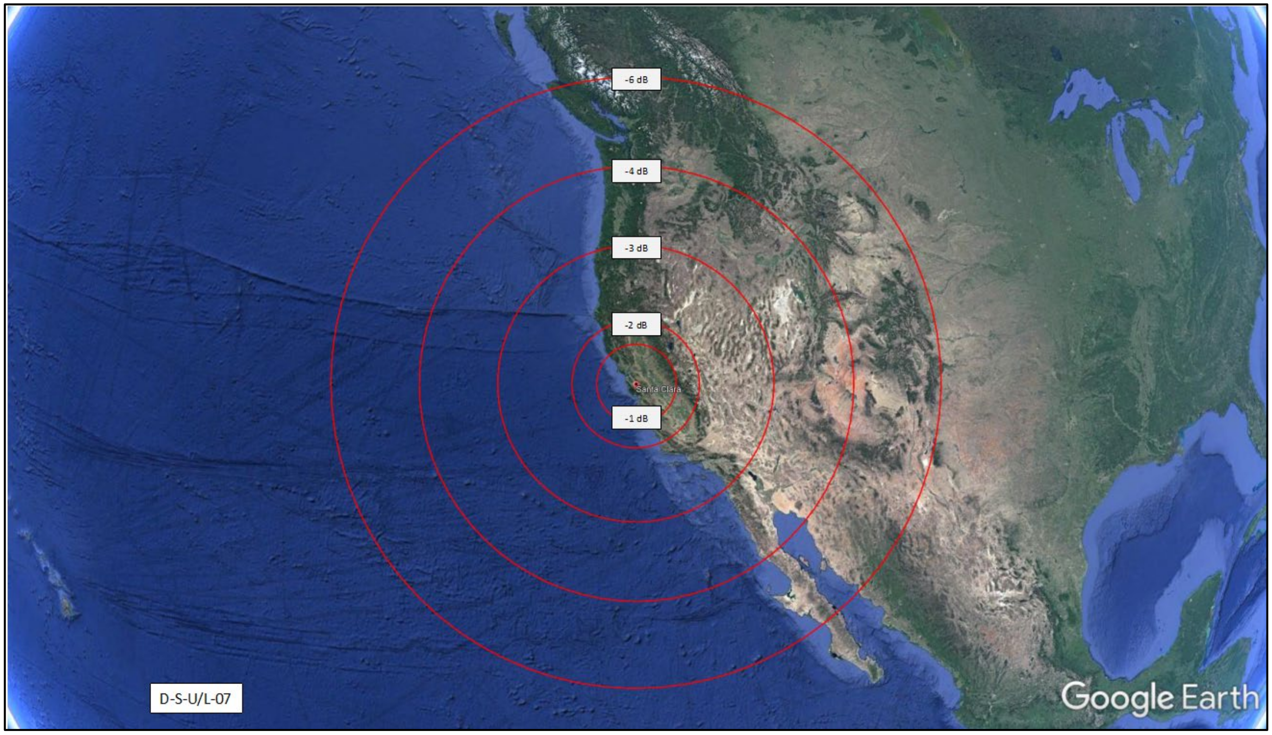
### Table D-UHF-D/L-06: GHOSt UHF Transmit Isotropic Power Level @ Victim Earth Station – (circa. Tromsø, Norway)

See Table D-UHF-D/L-03. Same values.

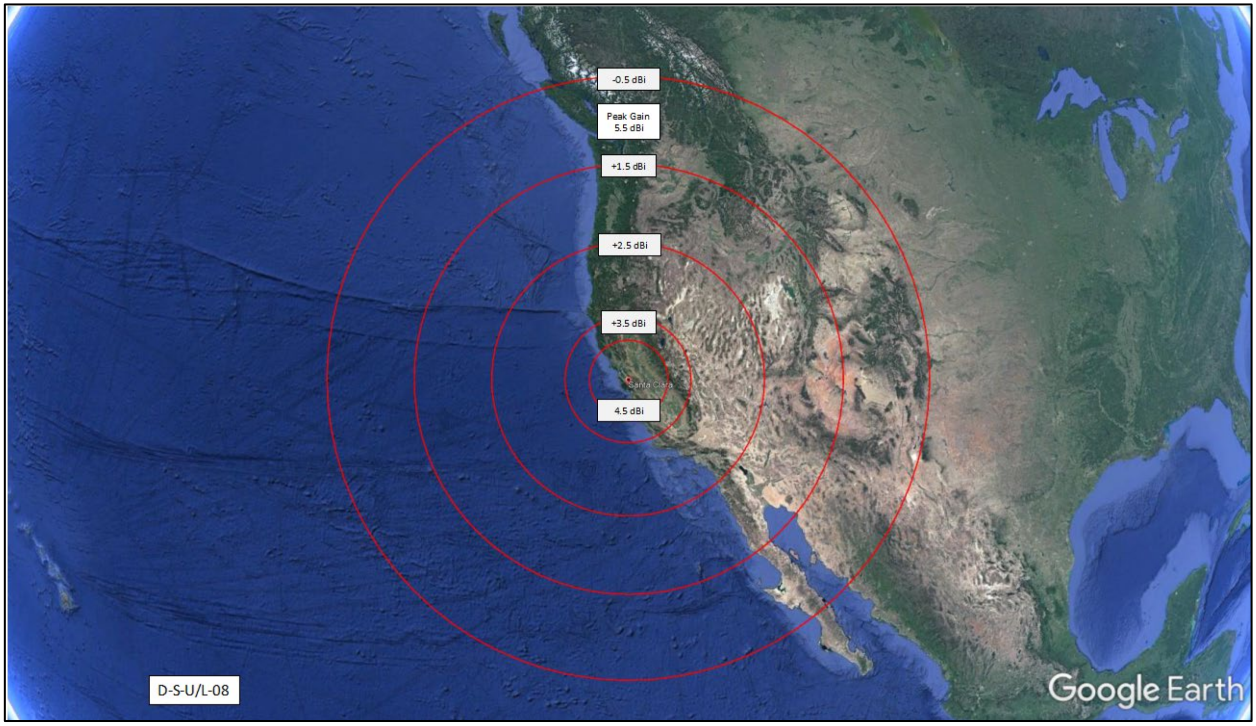
## Ka-band Downlink & S-band Uplink BEAM Contours

## - D-S-U/L-05 Through D-S-U/L-33 -

### Beam Contour D-S-U/L-07: GHOSt; S-band CMD RX Beam; Santa Clara, CA – Gain Roll-Off (dB)

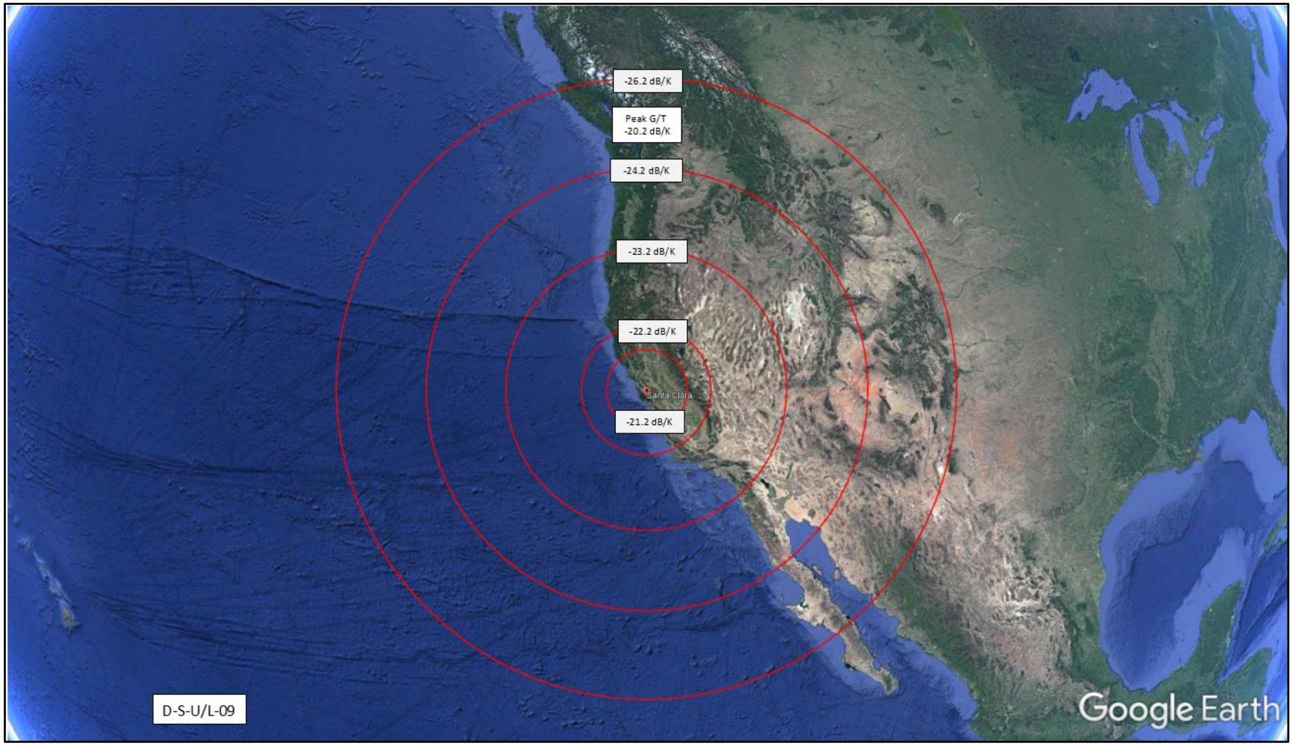


### Beam Contour D-S-U/L-08: GHOSt; S-band CMD RX Beam; Santa Clara, CA – Antenna Gain (dBi)

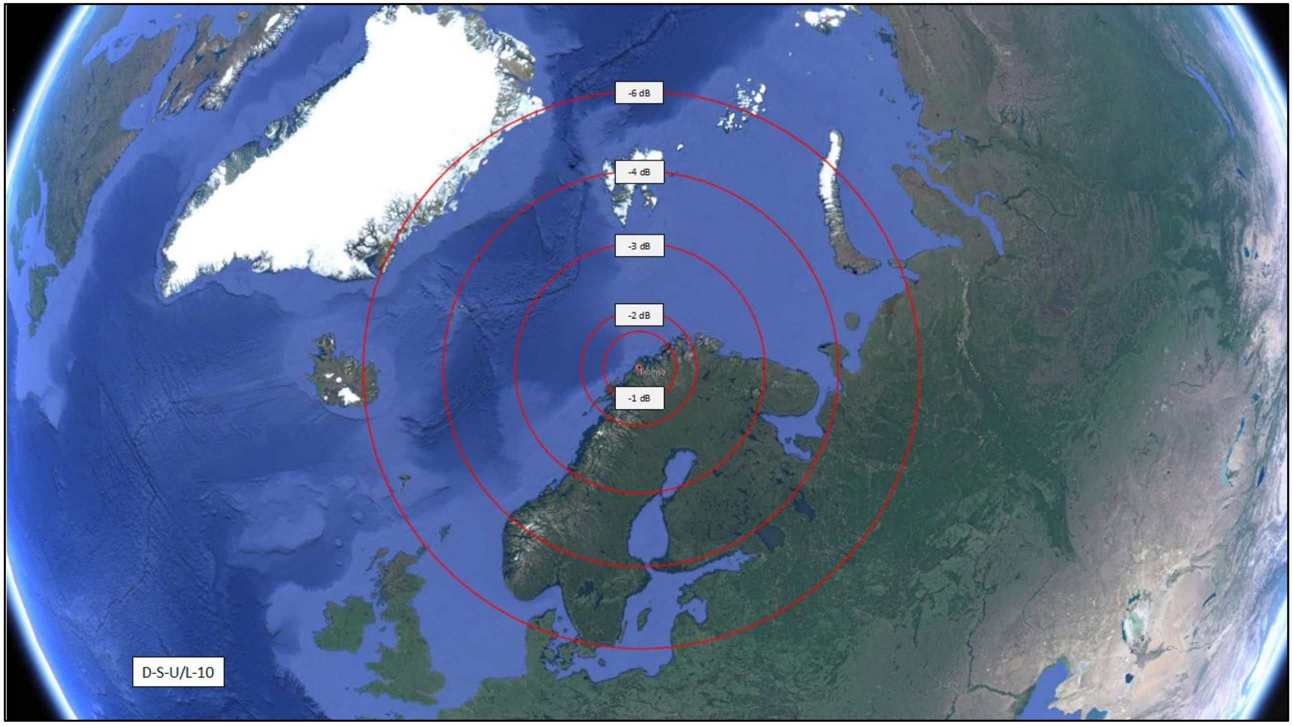


### Beam Contour D-S-U/L-09: GHOSt; S-band CMD RX Beam; Santa Clara, CA

**– Figure of Merit (G/T) (dB/K)**

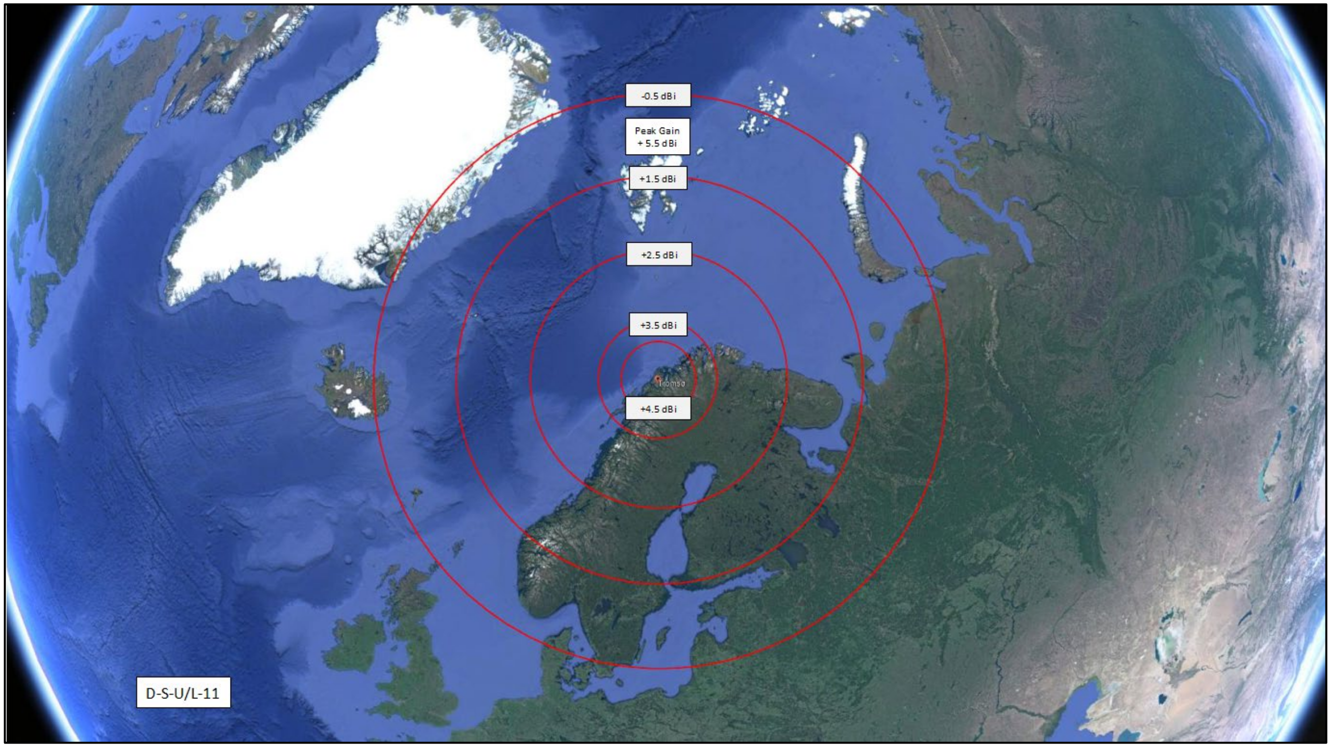


**Beam Contour D-S-U/L-10: GHOSt S-band CMD RX Beam; Tromsø, Norway - Gain Roll-Off (dB)**

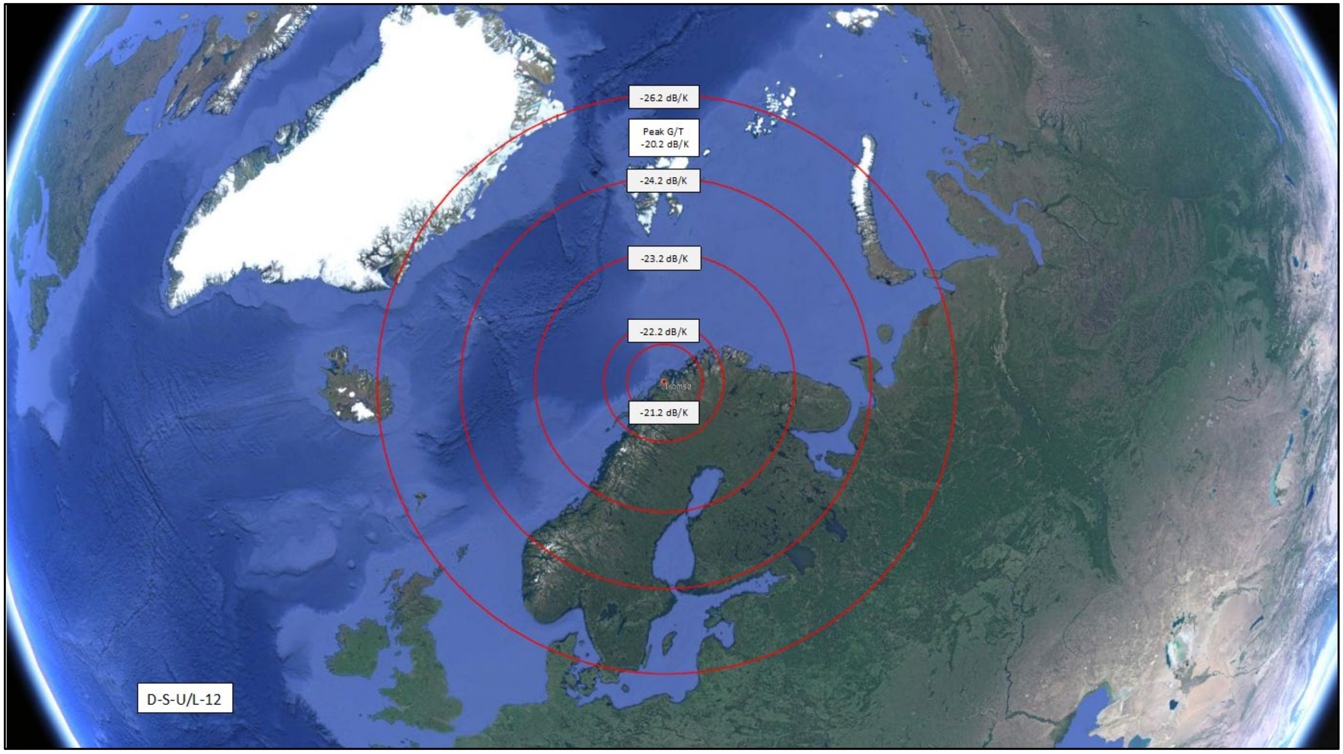


**Beam Contour D-S-U/L-11: GHOSt S-band CMD RX Beam; Tromsø, Norway**

**- Antenna Gain (dBi)**

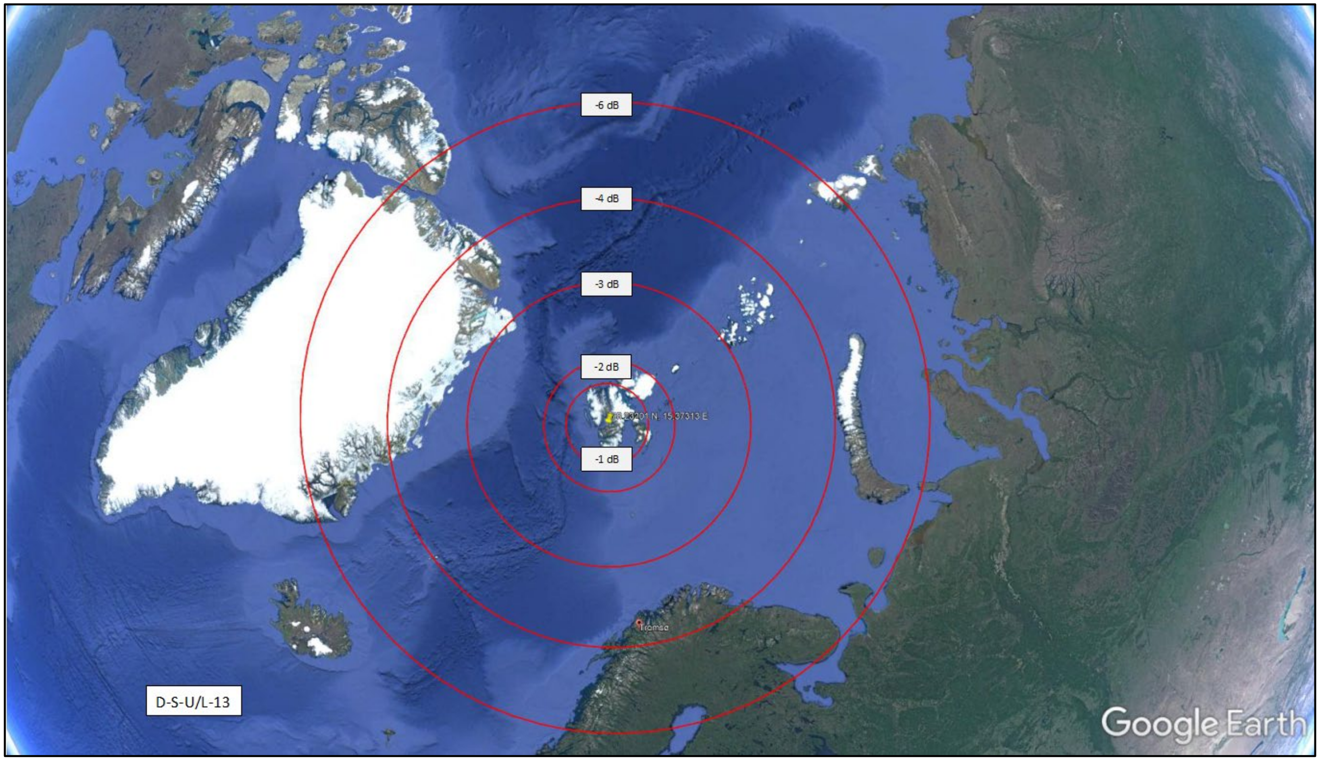


**Beam Contour D-S-U/L-12: GHOSt, S-band Transmit Beam; Tromsø, Norway – Figure of Merit (G/T) (dB/K)**

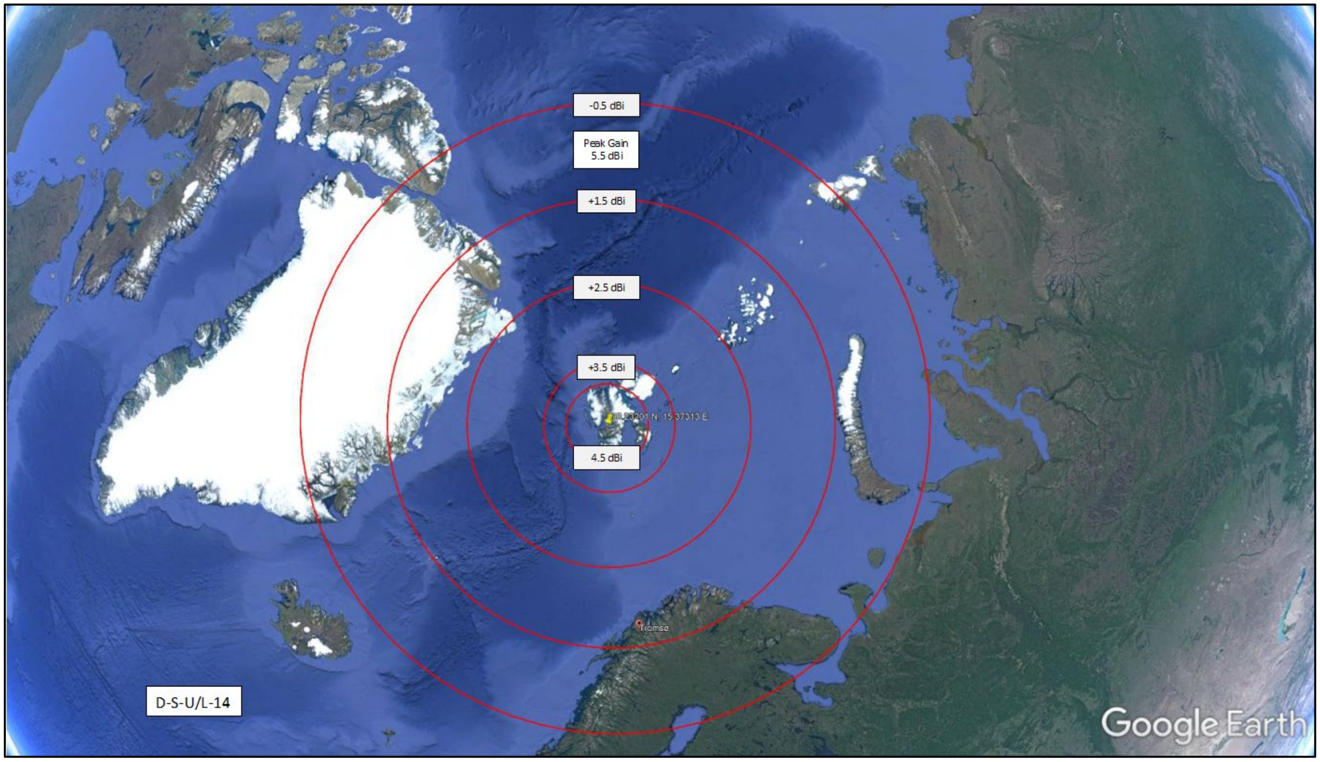


**Beam Contour D-S-U/L-13: GHOSt S-band CMD RX Beam; Svalbard, Norway**

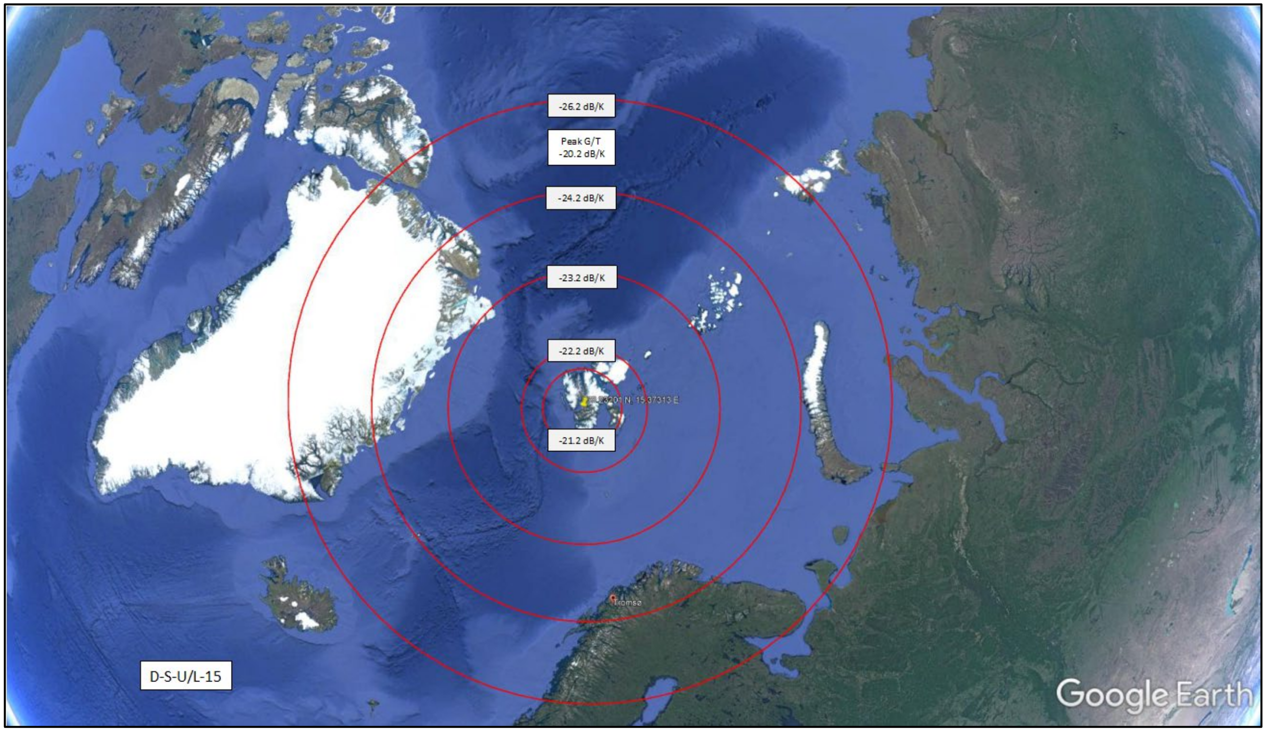
## - Gain Roll-Off (dB)



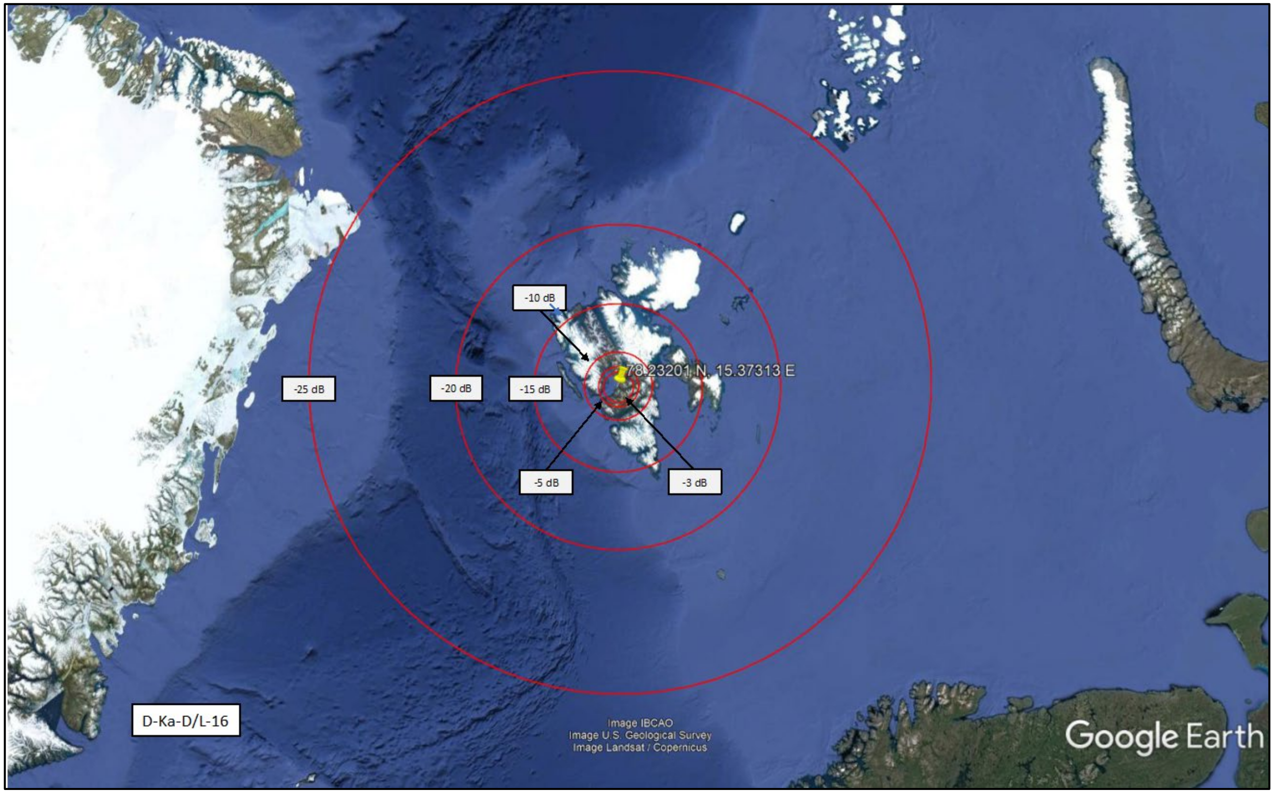
## Beam Contour D-S-U/L-14: GHOSt S-band CMD RX Beam; Svalbard, Norway - Antenna Gain (dBi)



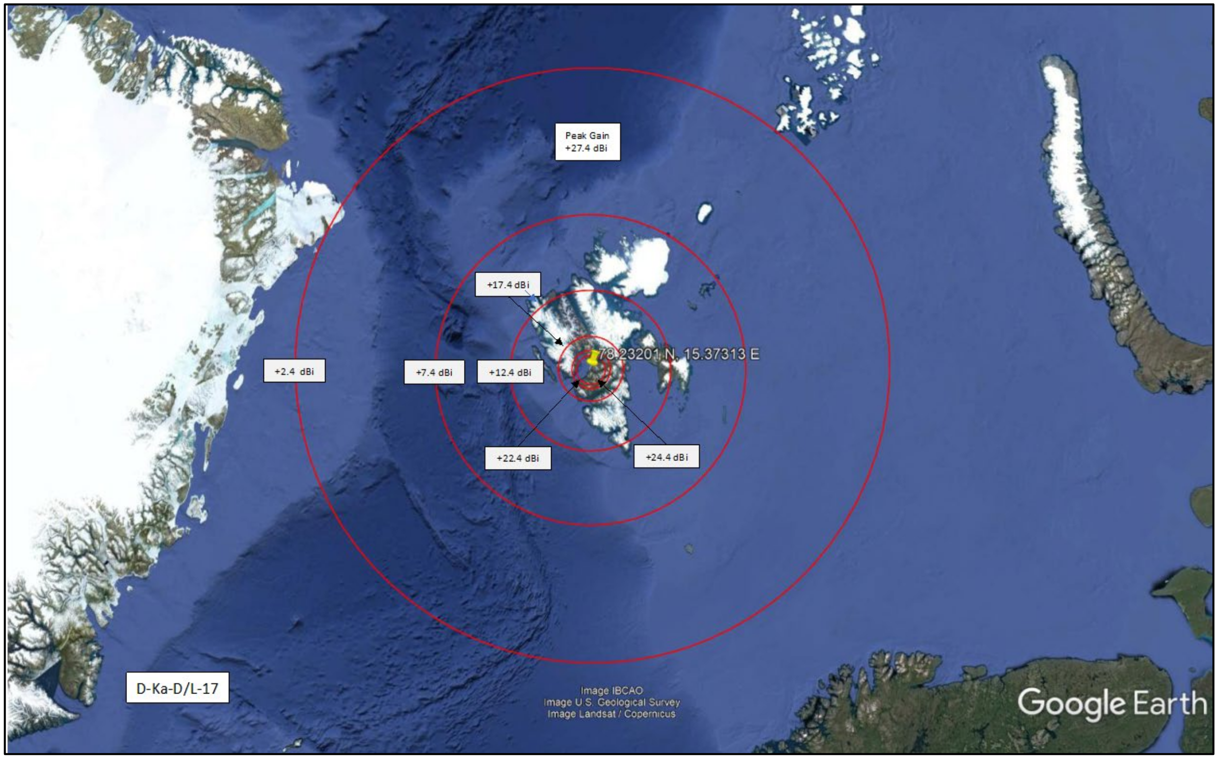
## Beam Contour D-S-U/L-15: GHOSt, S-band Transmit Beam; Svalbard, Norway – Figure of Merit (G/T) (dB/K)



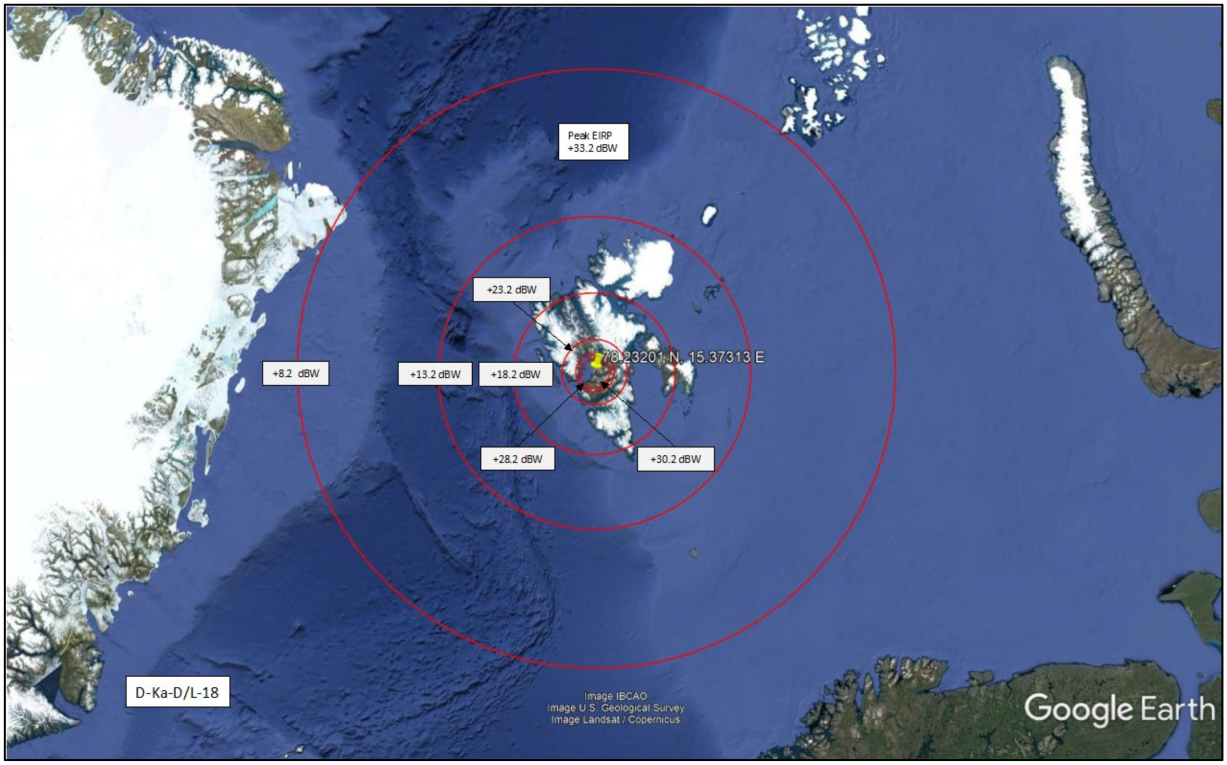
## Beam Contour D-Ka-D/L-16: GHOSt Ka-band TX Beam, Mode-1; Svalbard, Norway – Gain Roll-Off (dB)



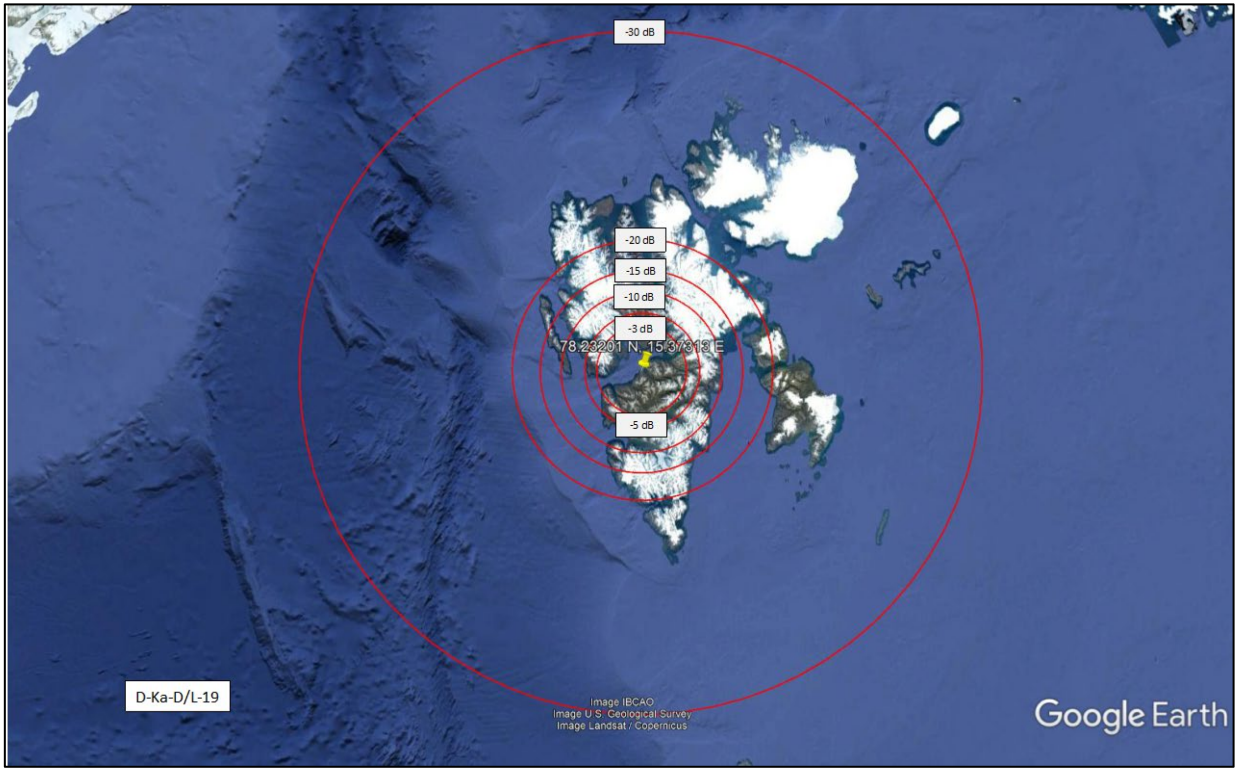
## Beam Contour D-Ka-D/L-17: GHOSt Ka-band TX Beam, Mode-1; Svalbard, Norway – Antenna Gain (dBi)



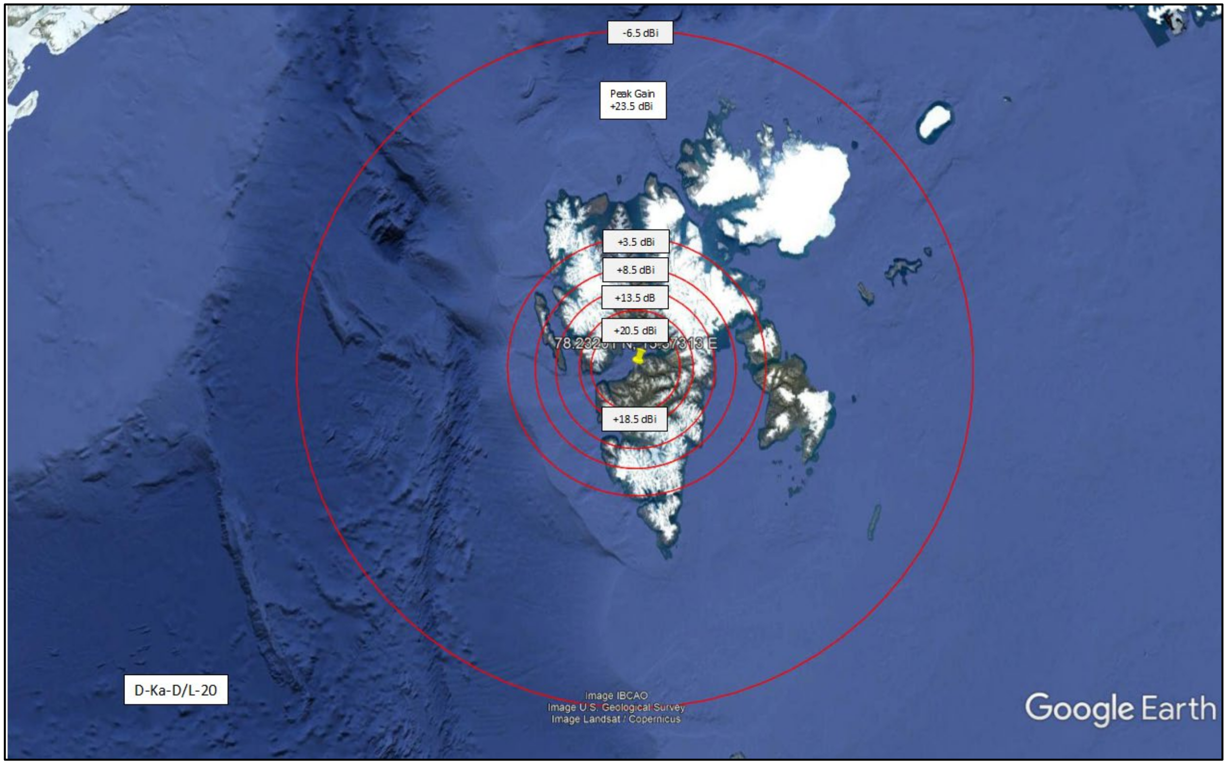
## Beam Contour D-Ka-D/L-18: GHOSt Ka-band TX Beam, Mode-1; Svalbard, Norway – EIRP (dBW)



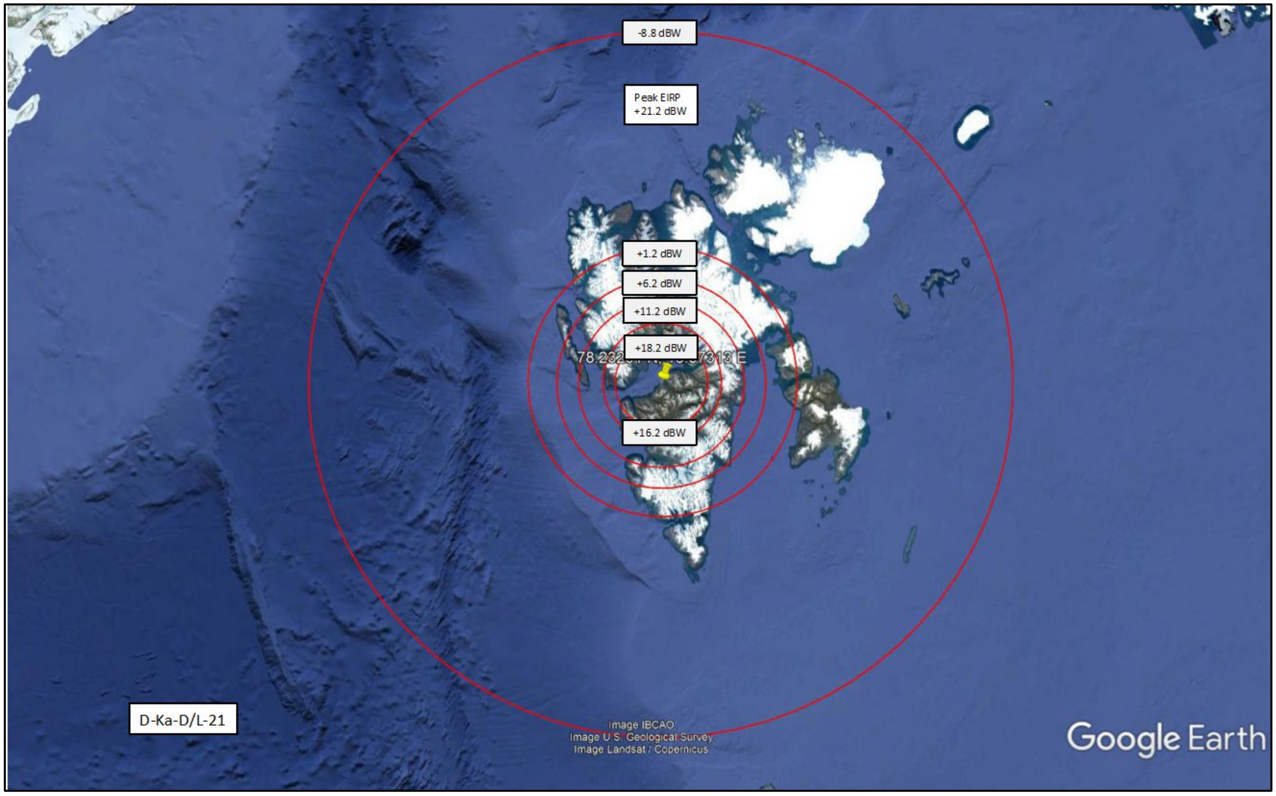
### Beam Contour D-Ka-D/L-19: GHOSt Ka-band TX Beam, Mode-2; Svalbard, Norway – Gain Roll-Off (dB)



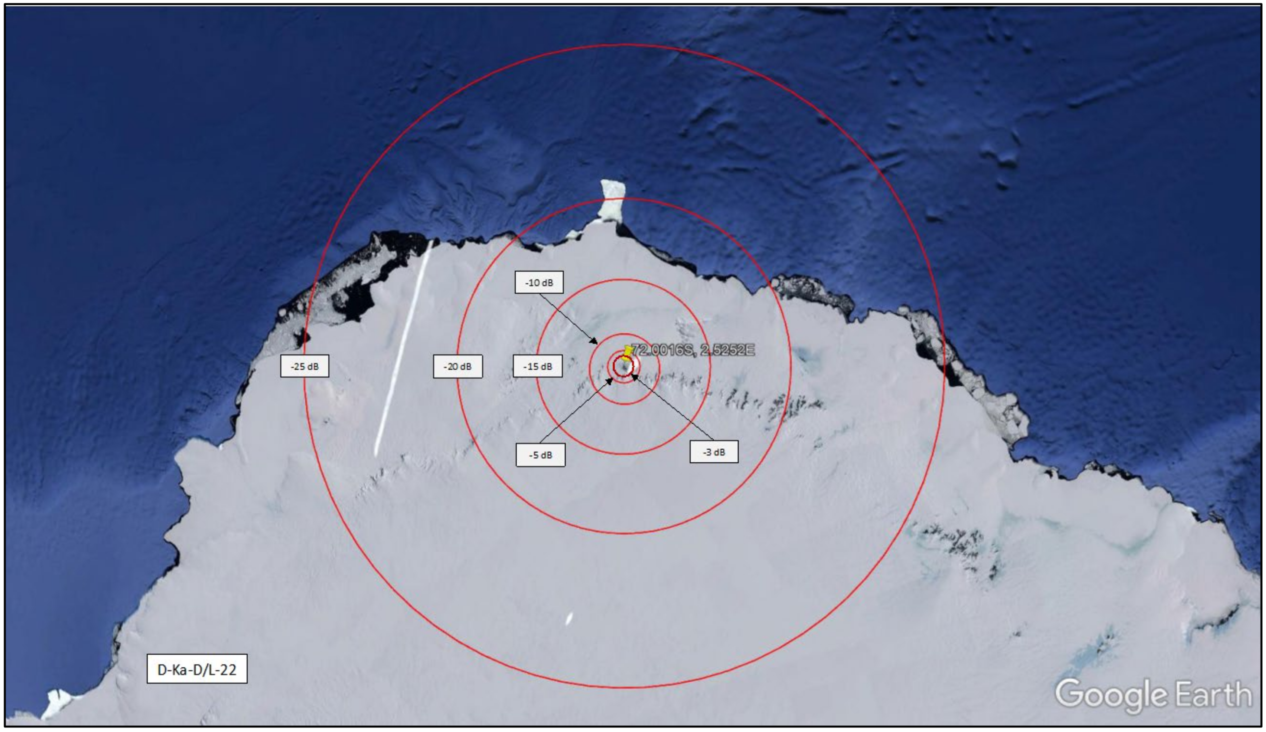
### Beam Contour D-Ka-D/L-20: GHOSt Ka-band TX Beam, Mode-2; Svalbard, Norway – Antenna Gain (dBi)



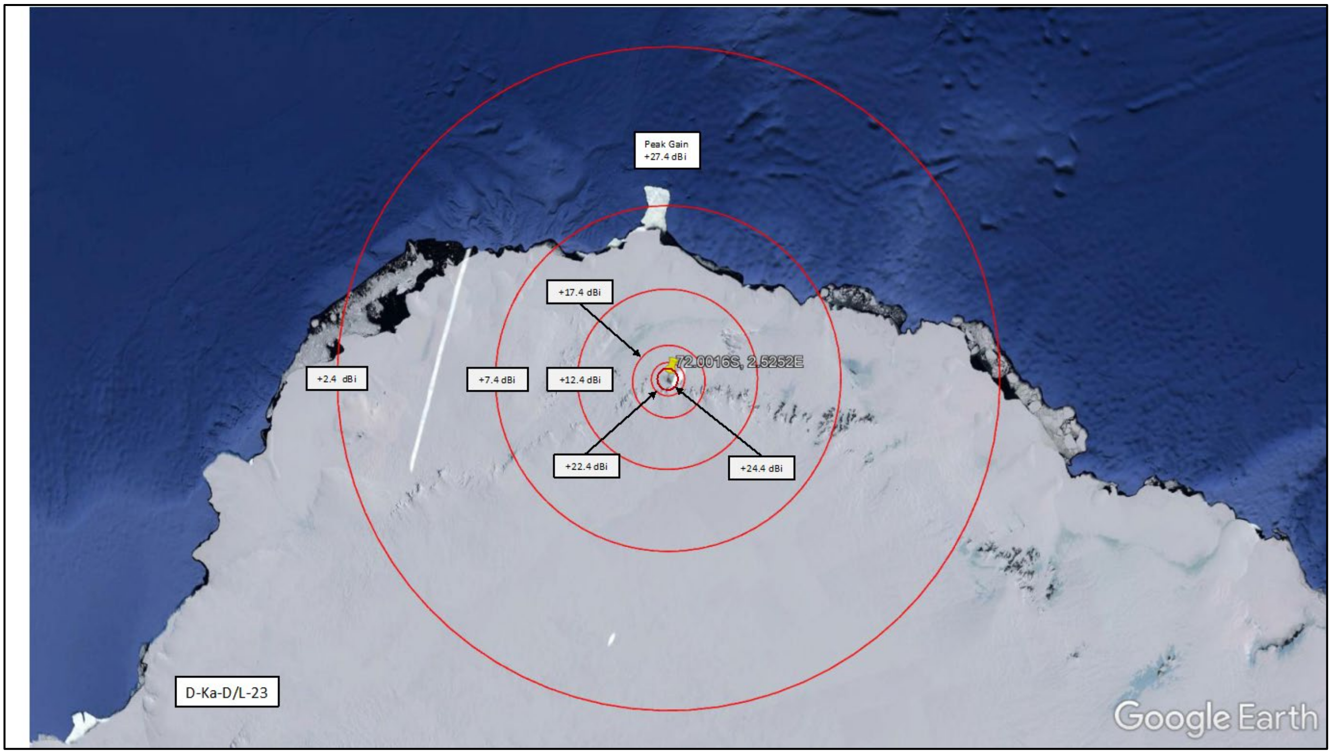
**Beam Contour D-Ka-D/L-21: GHOSt Ka-band TX Beam, Mode-2; Svalbard, Norway – EIRP (dBW)**



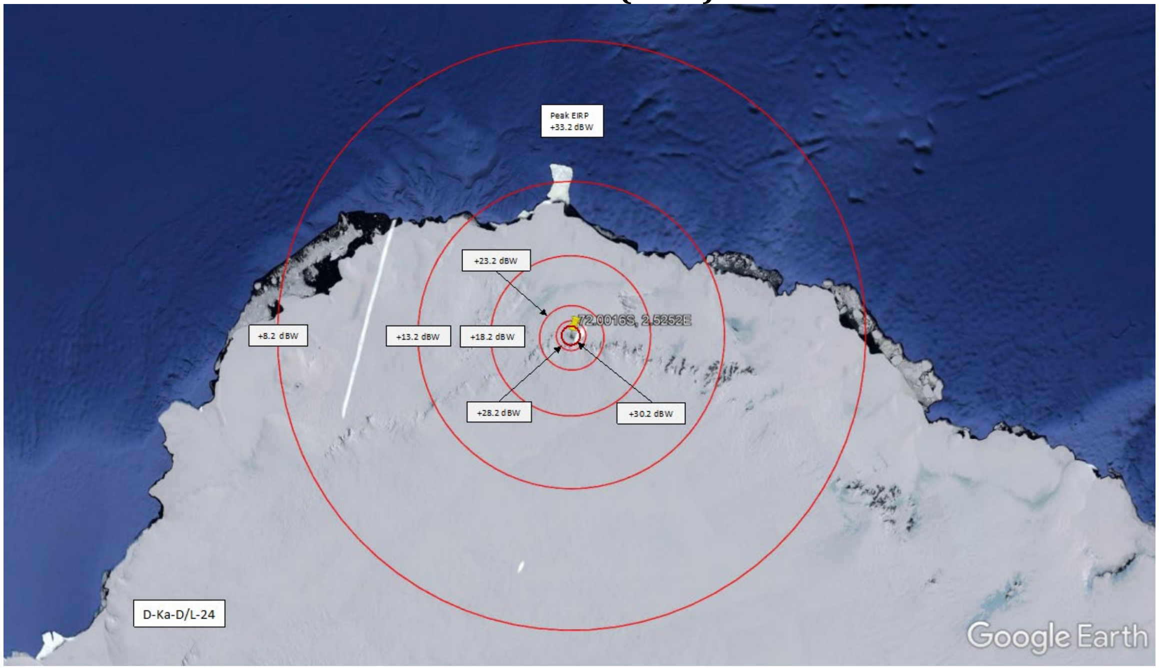
**Beam Contour D-Ka-D/L-22: GHOSt Ka-band TX Beam, Mode-1; Troll, Antarctica – Gain Roll-Off (dB)**



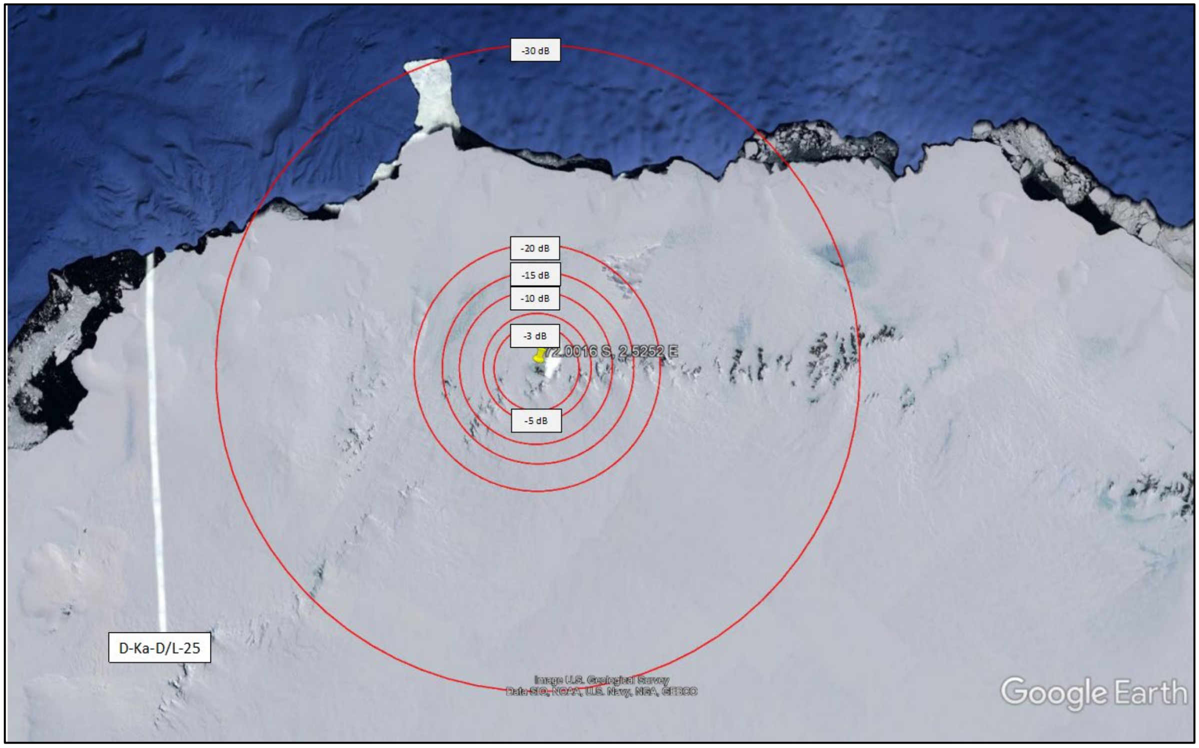
## Beam Contour D-Ka-D/L-23: GHOSt Ka-band TX Beam, Mode-1; Troll, Antarctica – Antenna Gain (dBi)



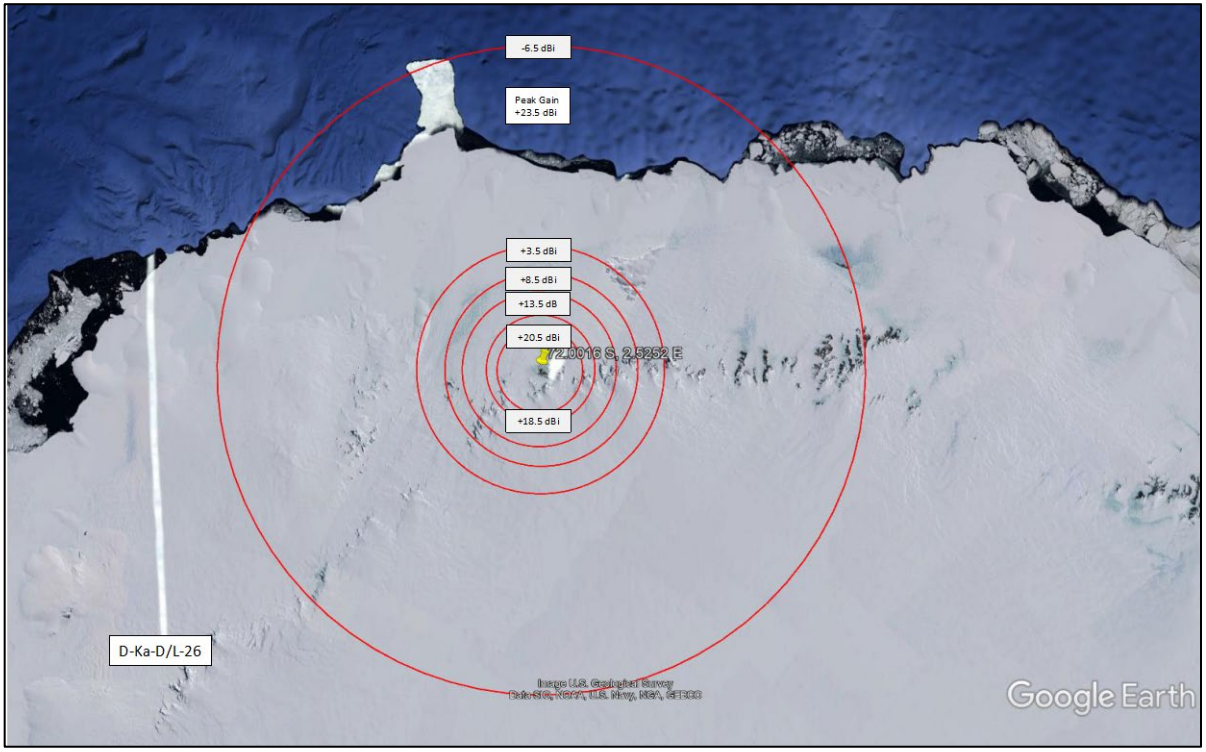
## Beam Contour D-Ka-D/L-24: GHOSt Ka-band TX Beam, Mode-1; Troll, Antarctica – EIRP (dBW)



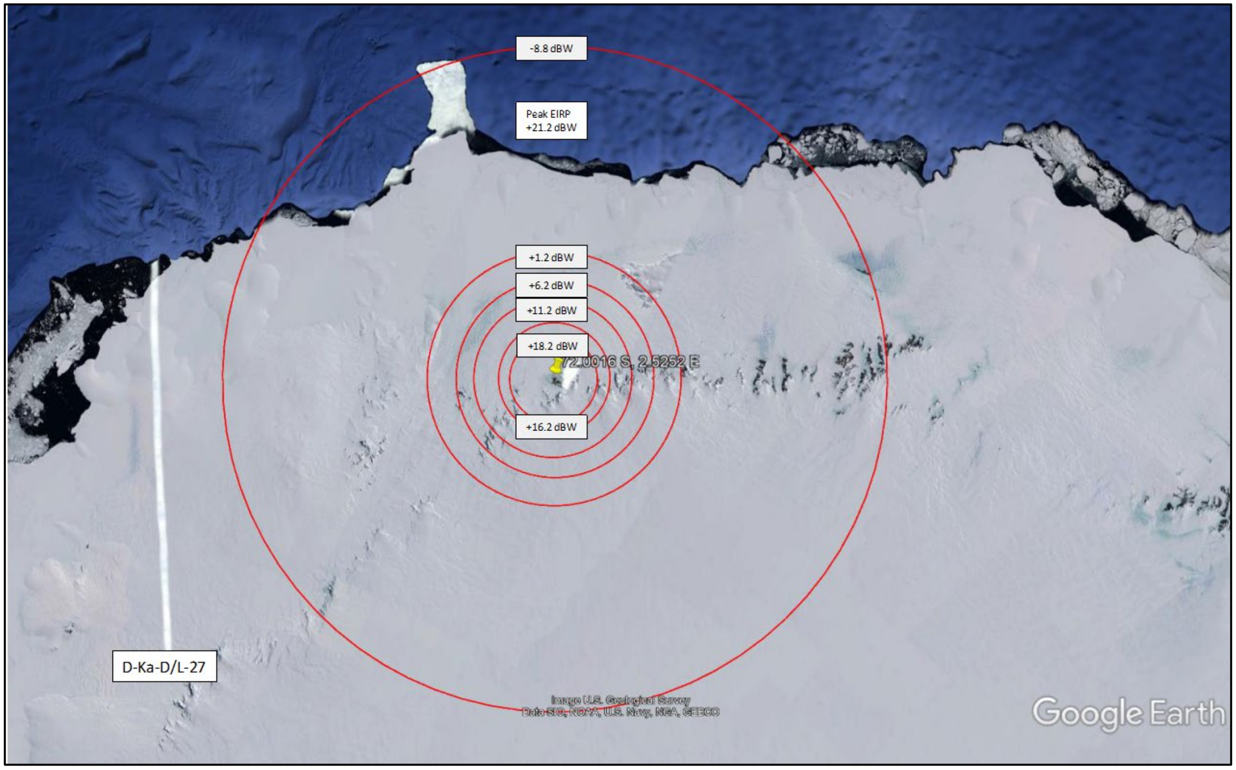
## Beam Contour D-Ka-D/L-25: GHOSt Ka-band TX Beam, Mode-2; Troll, Antarctica – Gain Roll-Off (dB)



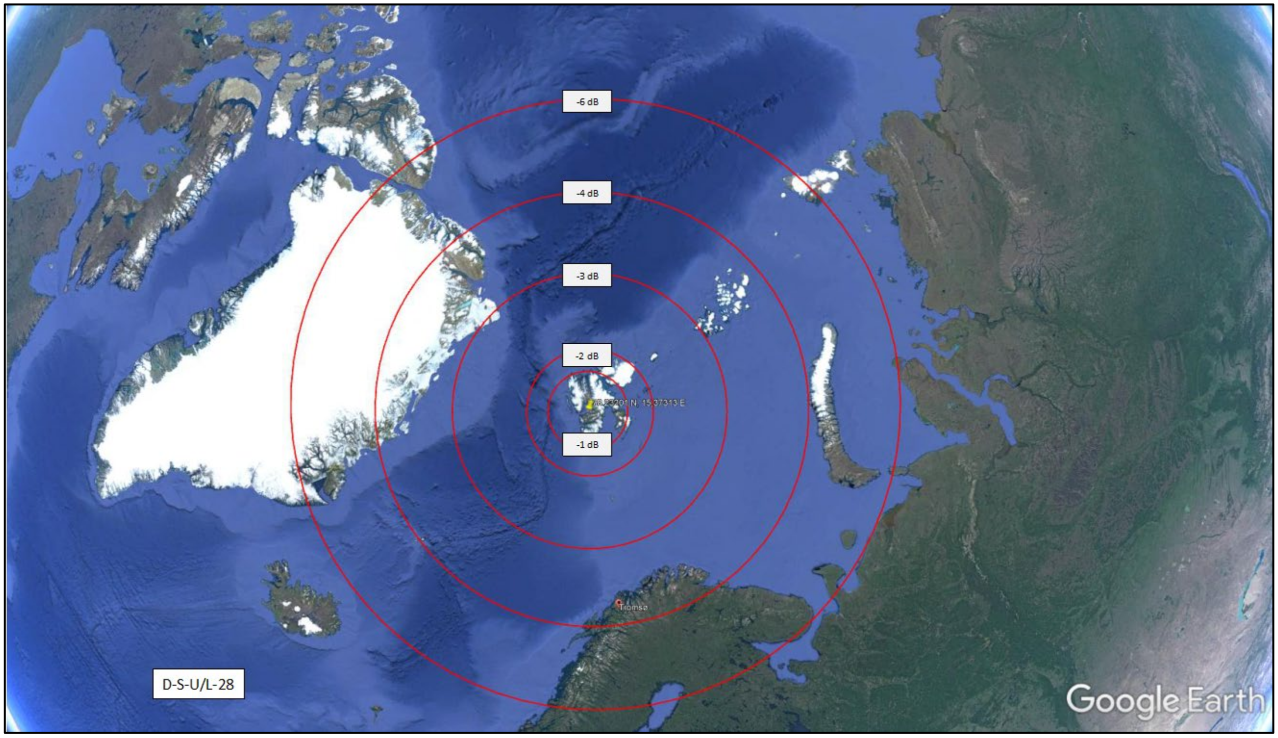
## Beam Contour D-Ka-D/L-26: GHOSt Ka-band TX Beam, Mode-2; Troll, Antarctica – Antenna Gain (dBi)



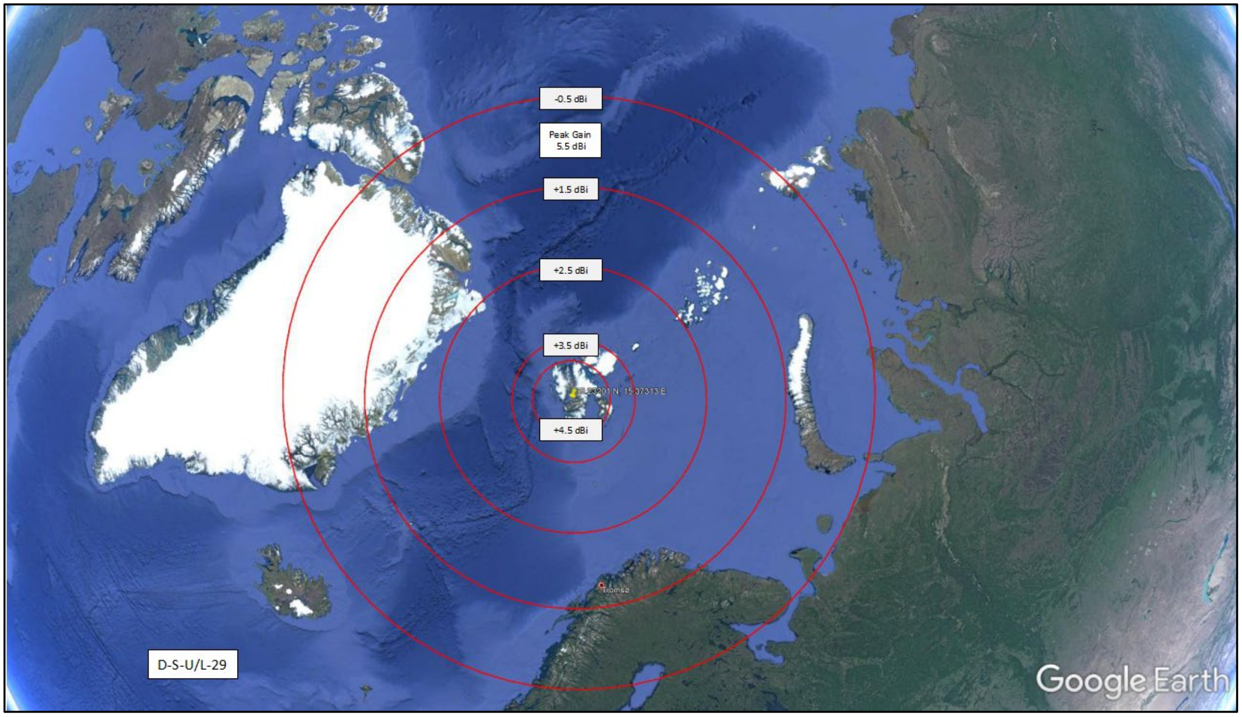
## Beam Contour D-Ka-D/L-27: GHOSt Ka-band TX Beam, Mode-2; Troll, Antarctica – EIRP (dBW)



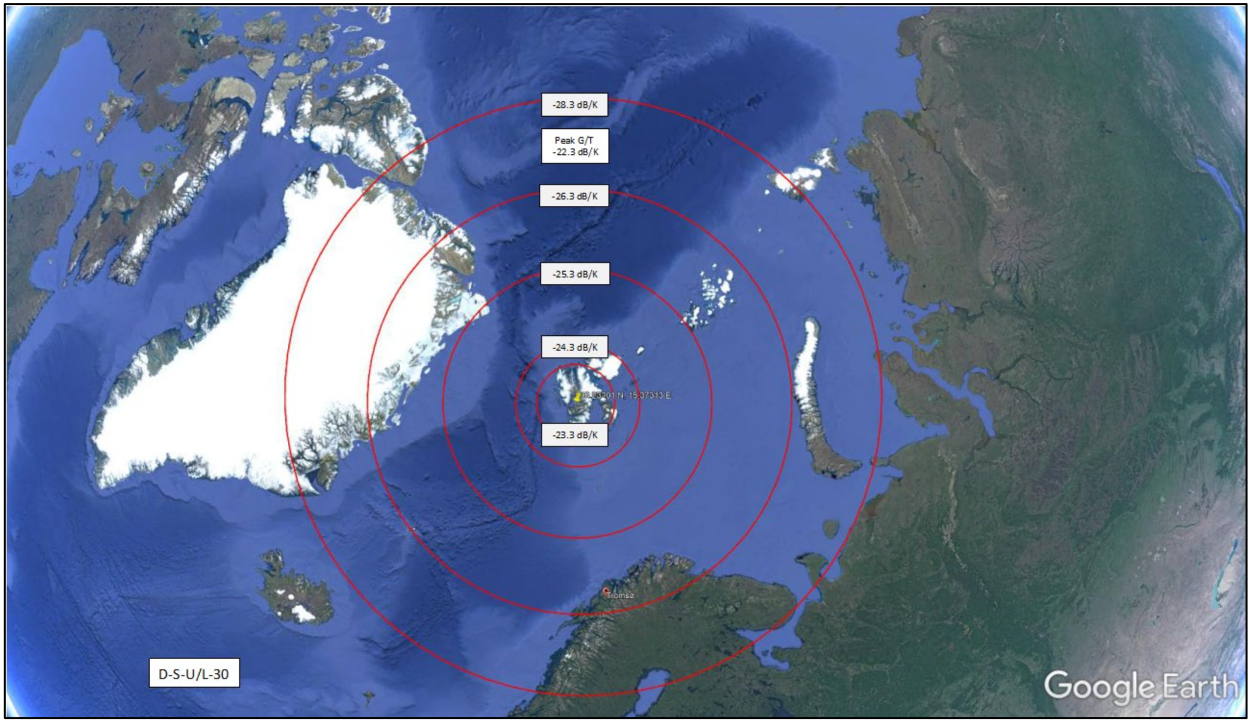
## Beam Contour D-S-U/L-28: GHOSt; S-band Control RX Beam; Svalbard, Norway – Gain Roll-Off (dB)



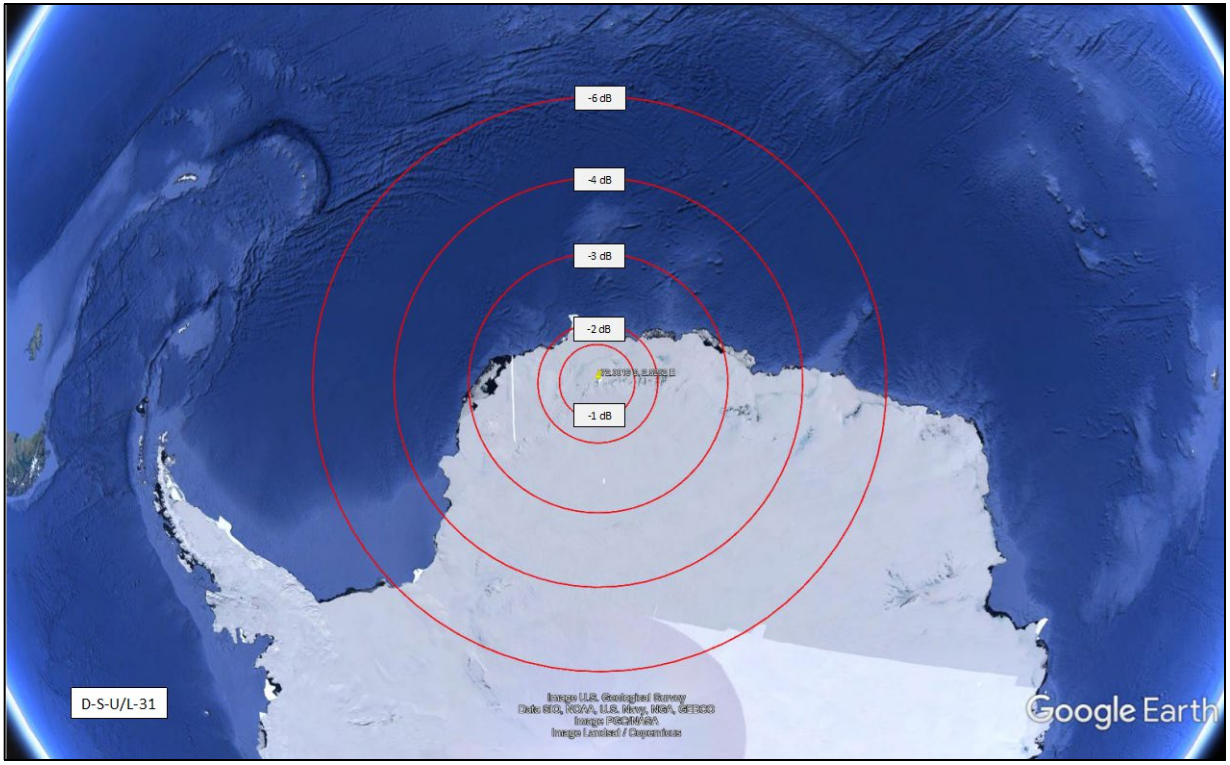
## Beam Contour D-S-U/L-29: GHOSt; S-band Control RX Beam; Svalbard, Norway – Antenna Gain (dBi)



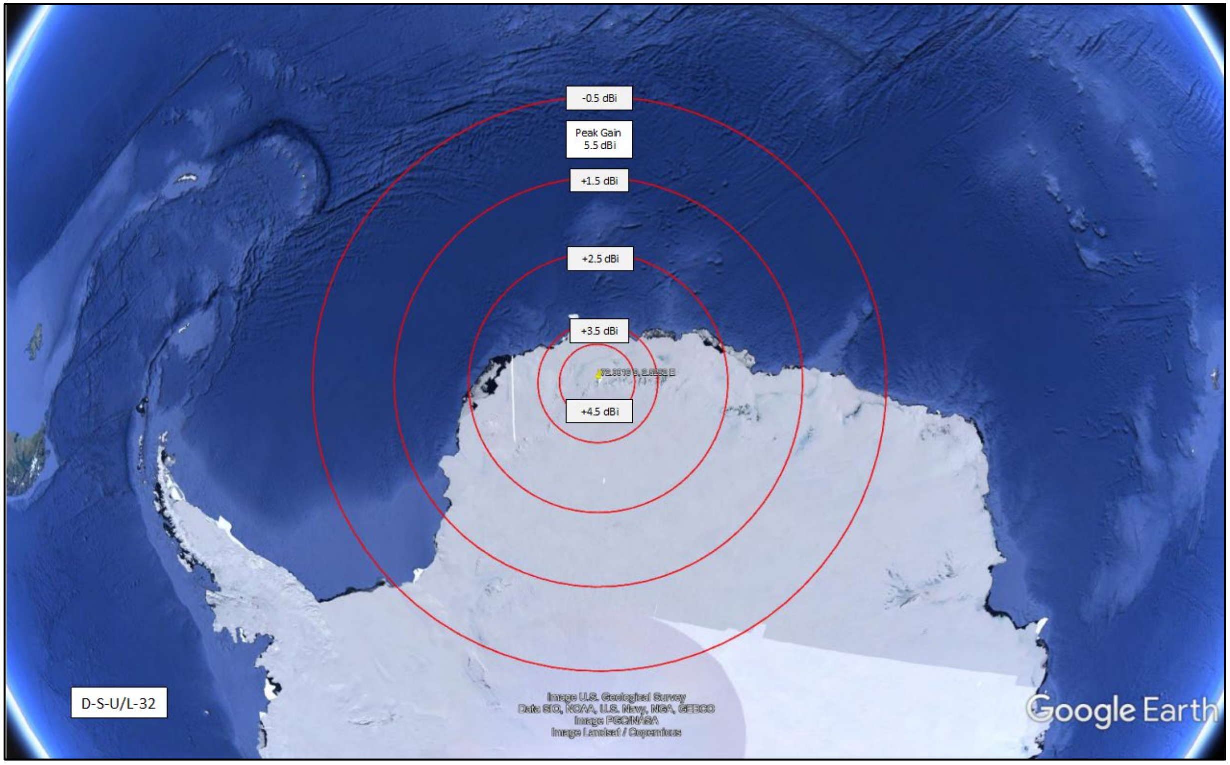
## Beam Contour D-S-U/L-30: GHOSt; S-band Control RX Beam; Svalbard, Norway – Figure of Merit (G/T) (dB/K)



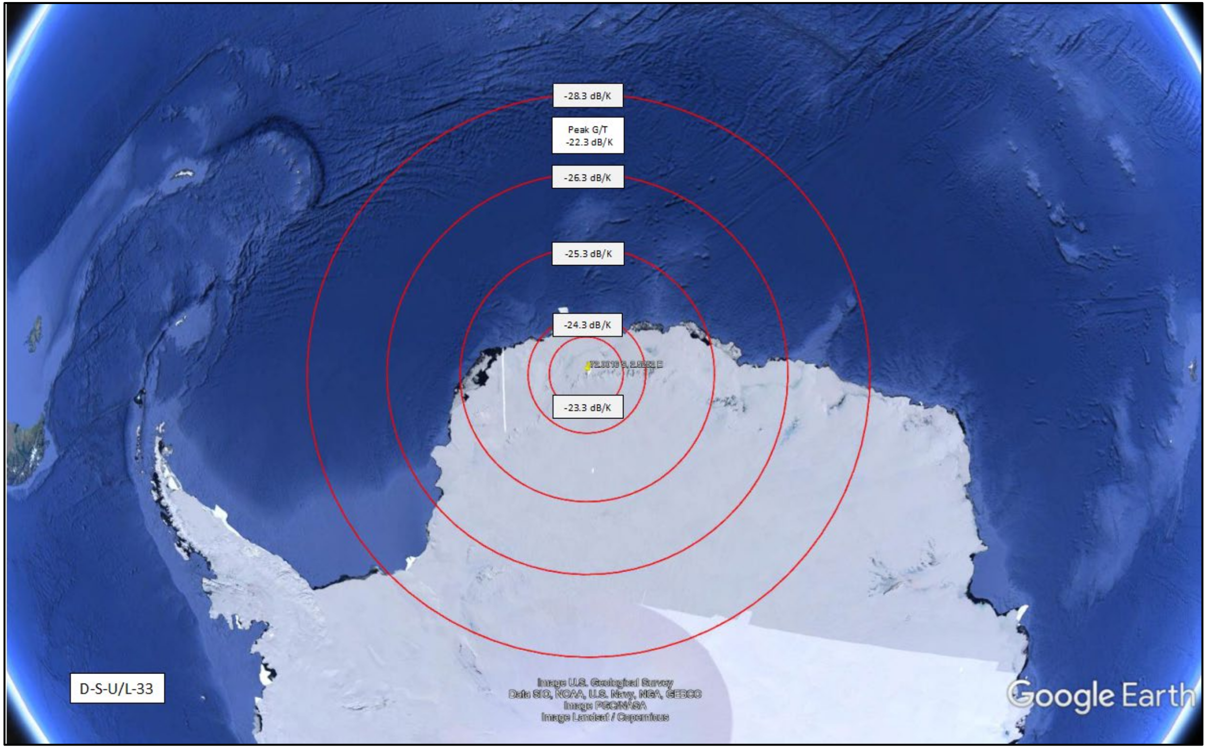
## Beam Contour D-S-U/L-31: GHOSt; S-band Control RX Beam; Troll Antarctica – Gain Roll-Off (dB)



## Beam Contour D-S-U/L-32: GHOSt; S-band Control RX Beam; Troll Antarctica – Antenna Gain (dBi)



## Beam Contour D-S-U/L-33: GHOSt; S-band Control RX Beam; Troll Antarctica – Figure of Merit (G/T) (dB/K)



## III. Ka-Band Band Plan for the Preliminary GHOSt Satellite Constellation and Details of Channel Assignments within the Band 25.5 – 27.0 GHz for the Space-to-Earth Links

In order to complete Schedule S of our Form 312 submission, it is necessary to identify the frequency plan for the service frequencies (i.e., the frequency channels) proposed to be used by the GHOSt system to downlink our hyper-spectral imaging data.

As described in our Legal Narrative, the GHOST spacecraft will utilize wideband downlink channels within the 25.5-27.0 GHz EESS frequency band, in accordance with U.S. domestic footnote US-258. The first two spacecraft (GHOSt-01 and -02) will carry one additional narrower-band mode, which is based on a heritage Astro Digital Ka-band transmitter design. The modes of this service link radio system, which also includes an S-band control link receiver, discussed elsewhere, are summarized in Table 1:

**Table 1: Ka-band Service Link Modes and Option Settings**

| XCVR Mode: | Options: | Bandwidth: | Symbol Rate: | Data Rate: (Minimum) | Data Rate: (Maximum) |
|---|---|---|---|---|---|
| 1 | a | 450 MHz | 409.09 Msps | 177.89 Mbps | 2413.99 Mbps |
| | b | 337.5 MHz | 306.82 Msps | 133.42 Mbps | 1810.49 Mbps |
| | c | 225 MHz | 204.55 Msps | 88.94 Mbps | 1206.99 Mbps |
| | d | 112.5 MHz | 102.27 Msps | 44.47Mbps | 603.50 Mbps |
| 2 | N/A | 86.4 MHz | 72.00 Msps | 35.30 Mbps | 320.62 Mbps |

The proposed (and more, generalized, long-term) Ka-band operational plans for our system are provided in Figure 1 and Figure 2. We note that the channel plan allows for six (6) wideband emissions to share three (3) frequency channels using polarization diversity. Using such a scheme, we are able to achieve a total spectral efficiency (when both polarizations are employed) of up to 10.72 bits/Hz when we are using Mode 1a and at the highest "MODCOD" (modulation and coding) setting. In a technological context, our spacecraft utilize the radio spectrum at the highest efficiency possible. This is another means by which OSK is further operating consistent with the pubic interest.

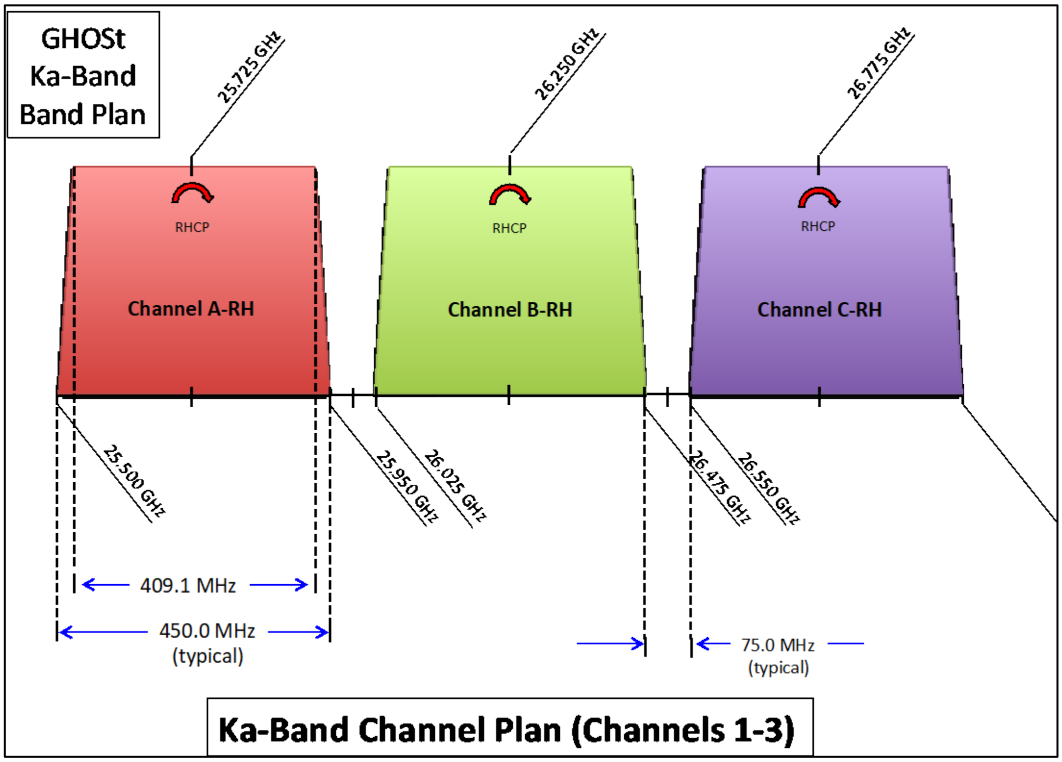


Figure 1: GHOSt Long-Term Ka-Band Channel Plan for Channels 1 Through 3

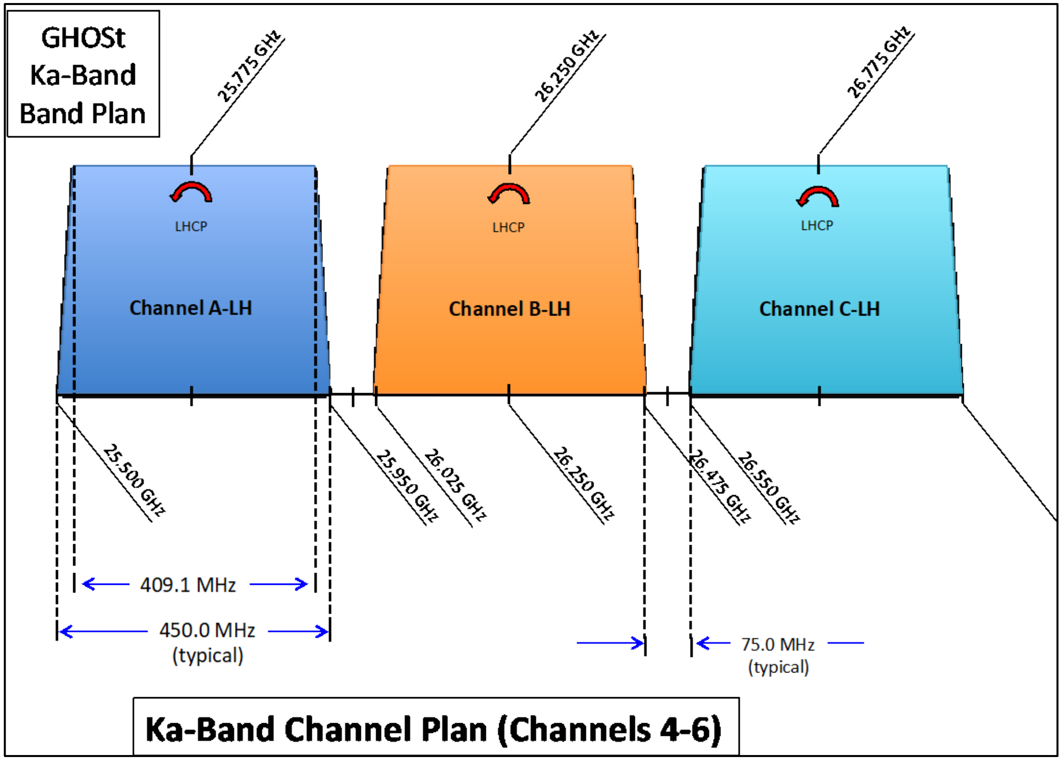


Figure 2: GHOSt Long-Term Ka-Band Channel Plan for Channels 4 Through 6

Six spacecraft, including 12 total transmitters will occupy the above band plan. Each channel/polarization combination will be used twice among the six spacecraft. Tables 2 and 3 and Figures 3 through 8 of this exhibit summarize how the six (6) GHOSt spacecraft will utilize the 6-channel plan being established for this program.

**Table 2a: GHOST Launch #1 Channel Utilization**

| Spacecraft: (Launch): | TX Type: | Channel No.: | Polarization: | BW: | Channel Bottom Frequency: | Channel Center Frequency: | Channel Top Frequency: |
|---|---|---|---|---|---|---|---|
| GHOSt-01<br>(Launch #1) | Gen-3<br>Narrow Band | D-RH<br>(mode 2) | RHCP | 86.4 | 26.7568 GHz | 26.800 GHz | 26.8432 GHz |
| | Gen-4<br>Wide Band | C-RH<br>(mode 1) | RHCP | 450 | 26.550 GHz | 25.725 GHz | 27.000 GHz |
| | Gen-4<br>Wide Band | B-HR<br>(mode 1) | RHCP | 450 | 26.025 GHz | 26.250 GHz | 26.475 GHz |
| GHOSt-02<br>(Launch #1) | Gen-3<br>Narrow Band | D-LH<br>(mode 2) | LHCP | 86.4 | 26.7568 GHz | 26.800 GHz | 26.8432 GHz |
| | Gen-4<br>Wide Band | C-LH<br>(mode 1) | LHCP | 450 | 26.550 GHz | 25.725 GHz | 27.000 GHz |
| | Gen-4<br>Wide Band | B-LH | LHCP | 450 | 26.025 GHz | 26.250 GHz | 26.475 GHz |

**Table 2b: GHOST Launches #2 and #3 Channel Utilization**

| Spacecraft: (Launch): | TX Type: | Channel No.: | Polarization: | BW: | Channel Bottom Frequency: | Channel Center Frequency: | Channel Top Frequency: |
|---|---|---|---|---|---|---|---|
| GHOSt-01<br>(Launch #1) | Gen-3<br>Narrow Band | D-RH<br>(mode 2) | RHCP | 86.4 | 26.7568 GHz | 26.800 GHz | 26.8432 GHz |
| | Gen-4<br>Wide Band | C-RH<br>(mode 1) | RHCP | 450 | 26.550 GHz | 25.725 GHz | 27.000 GHz |
| | Gen-4<br>Wide Band | B-HR<br>(mode 1) | RHCP | 450 | 26.025 GHz | 26.250 GHz | 26.475 GHz |
| GHOSt-02<br>(Launch #1) | Gen-3<br>Narrow Band | D-LH<br>(mode 2) | LHCP | 86.4 | 26.7568 GHz | 26.800 GHz | 26.8432 GHz |
| | Gen-4<br>Wide Band | C-LH<br>(mode 1) | LHCP | 450 | 26.550 GHz | 25.725 GHz | 27.000 GHz |
| | Gen-4<br>Wide Band | B-LH | LHCP | 450 | 26.025 GHz | 26.250 GHz | 26.475 GHz |

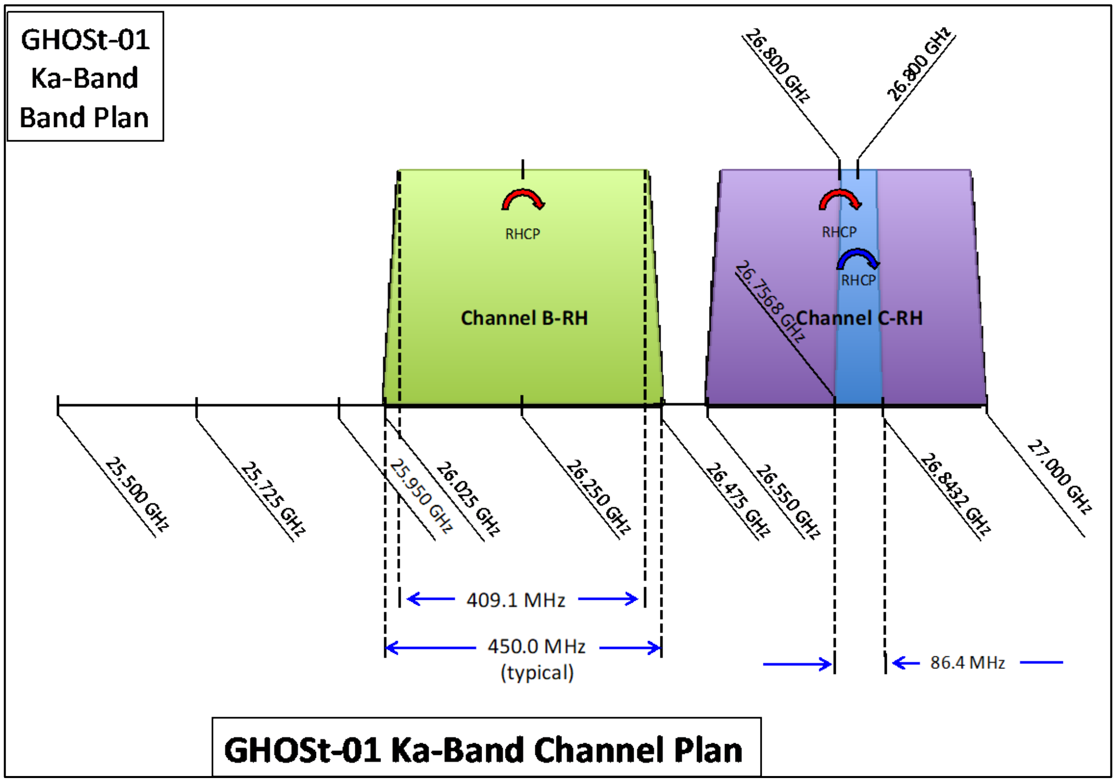


Figure 3: GHOSt-01 Ka-Band Channel Plan

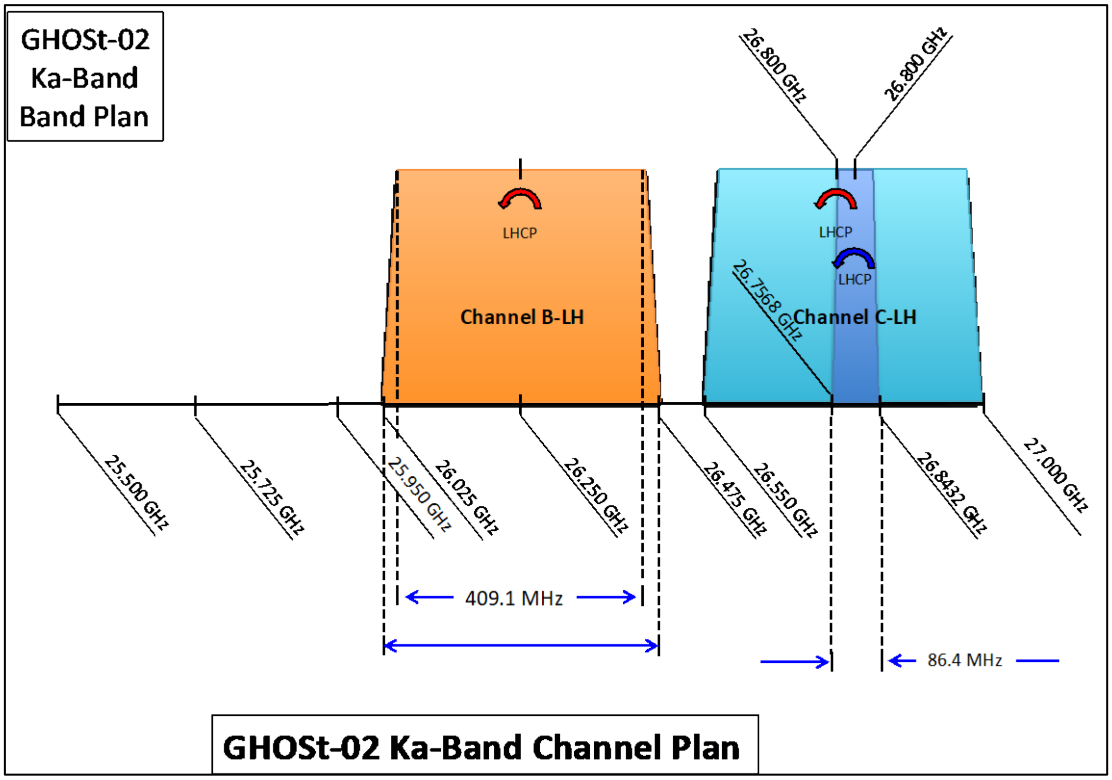


Figure 4: GHOSt-02 Ka-Band Channel Plan

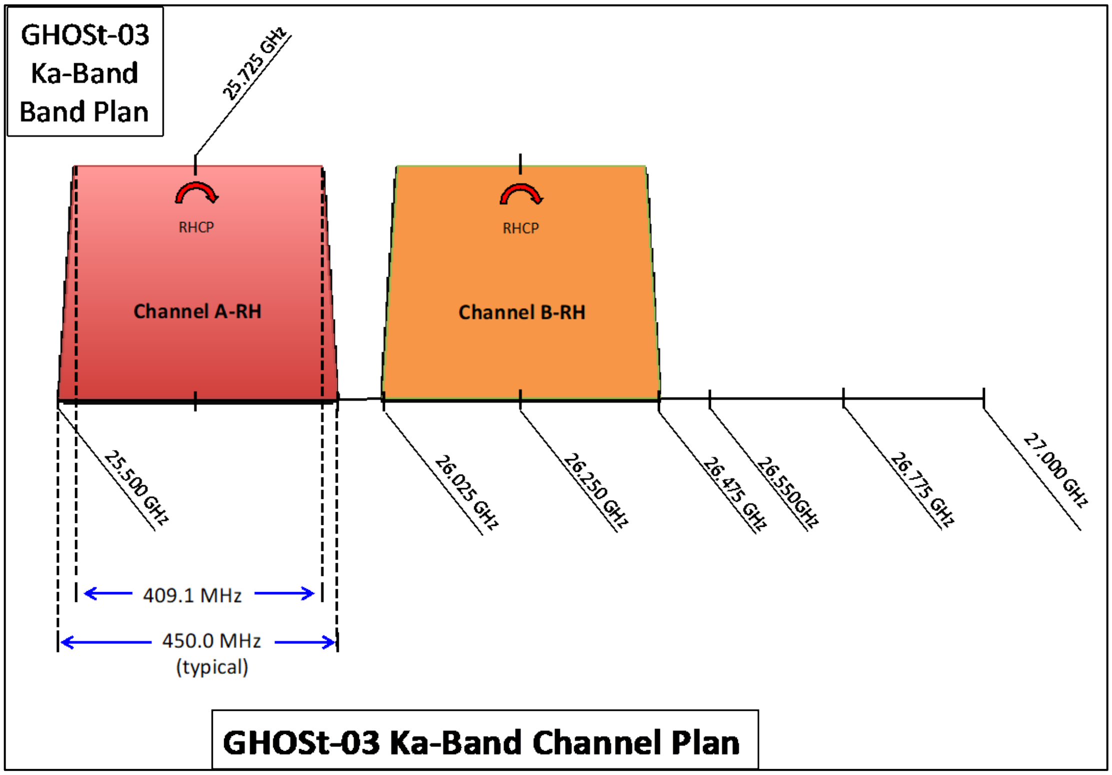


**Figure 5: GHOSt-03 Ka-Band Channel Plan**

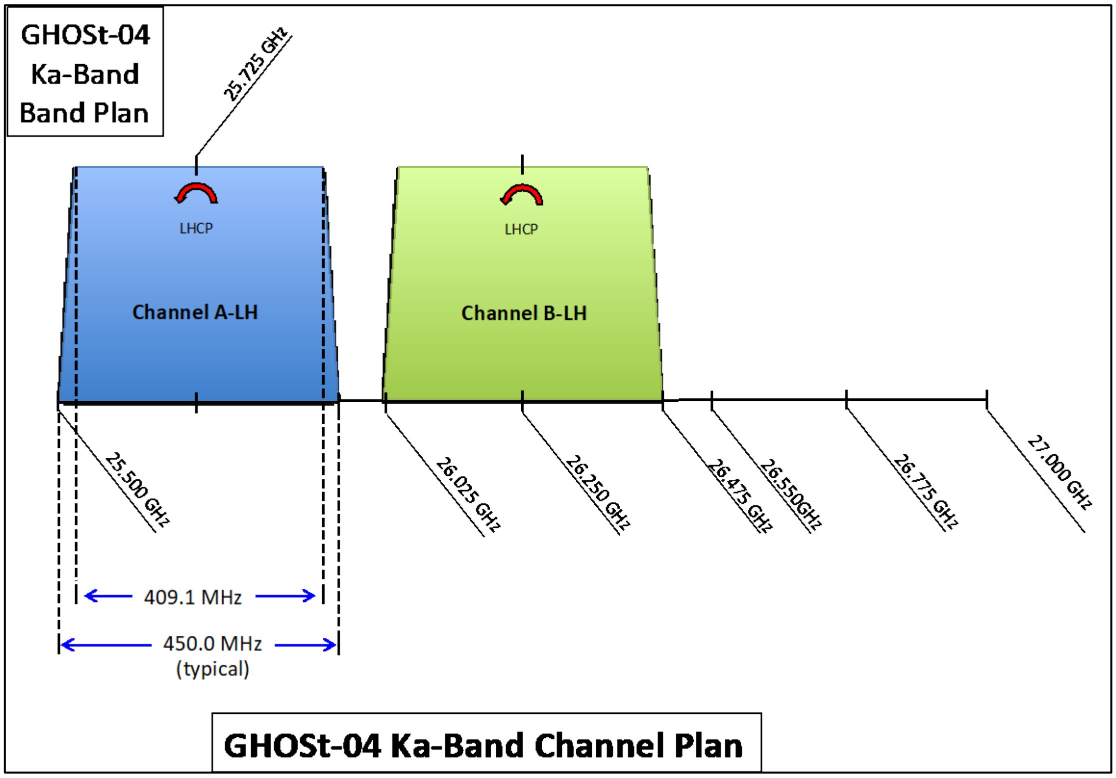


**Figure 6: GHOST-04 Ka-Band Channel Plan**

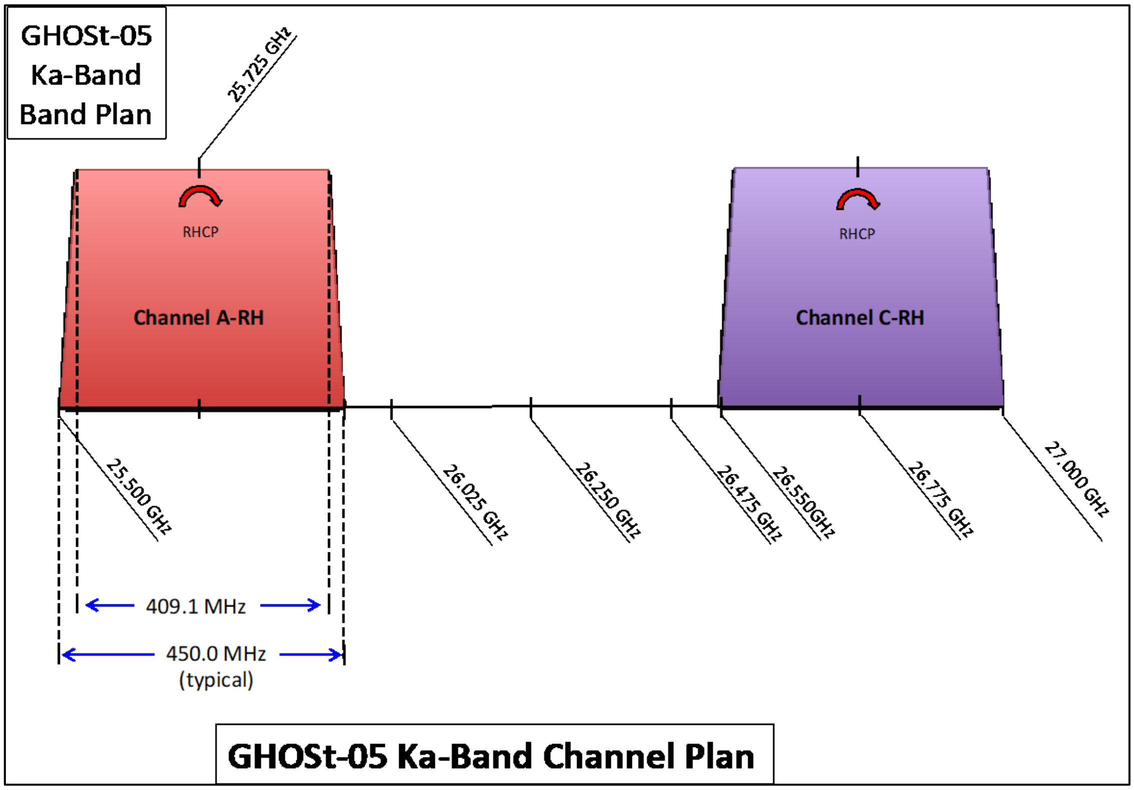


Figure 7: GHOSt-05 Ka-Band Channel Plan

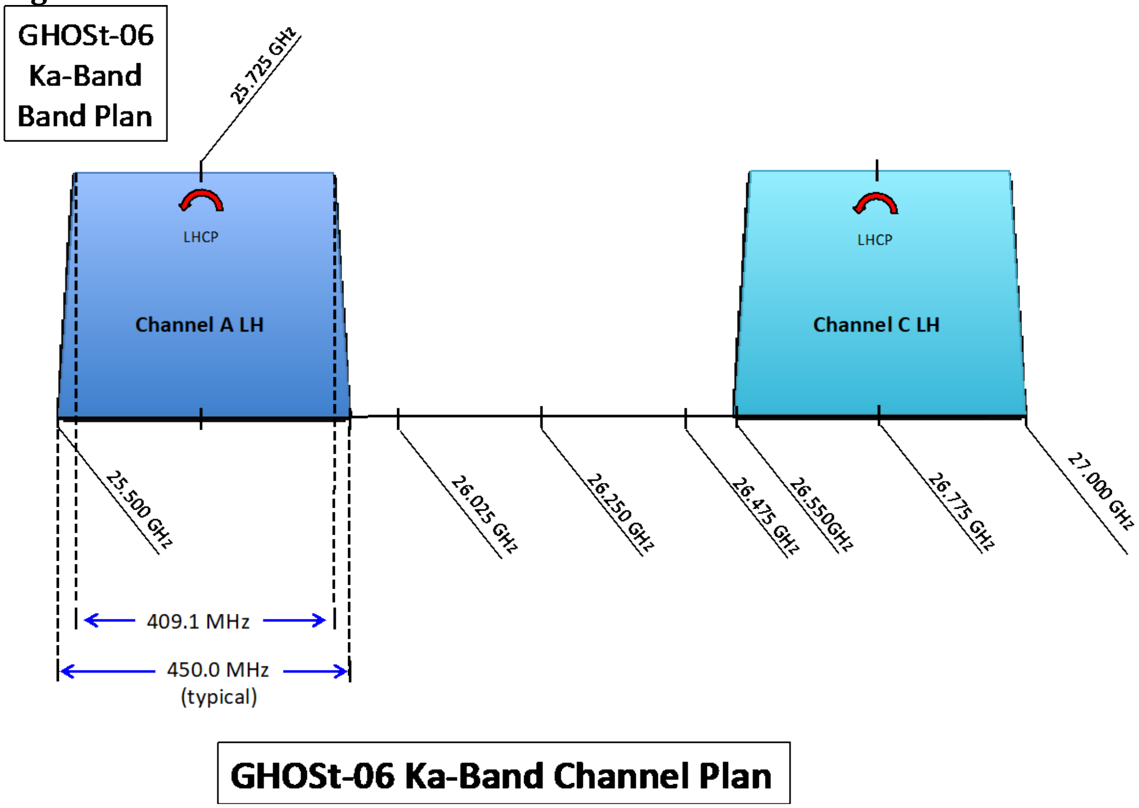


Figure 8: GHOSt-06 Ka-Band Channel Plan

*Alternative Operating Modes for Ka-Band*: The Ka-band Transceiver, operating in Mode 2 has a maximum EIRP of 23.5 dBW, however, the power output of the transmitter can be adjusted downward in small increments (less than 1 dB per step). This is the only significant adjustment that can be made to the transceiver in Mode 2. Also, in Mode 2 the S-band receiver portion of the sub-system is not operating, and therefore we do not anticipate operating the transmitter in ACM (adaptive coding mode). As such, this is a more primitive mode of operation.

The Ka-band Transceiver, operating in Mode 1 (a thru d) has a maximum EIRP of 33.2 dBW and can be adjusted downward in power output and in frequency to any of the channels given in Tables 1 and 2. Further, the bandwidth setting of the modulator system can adjust the bandwidth in four settings, namely, 450 MHz, 337.5, 225 MHz and 112.5 MHz. These are operating options a, b, c and d respectively. While the lower bandwidth settings are available, the primary intended operating bandwidth for the GHOST program is 450 MHz. During Mode 1, the S-band receiver is available as discussed elsewhere in this application.

## IV. POWER FLUX DENSITY CALCULATIONS FROM A GHOSt SPACECRAFT TO GLOBALSTAR ORBIT

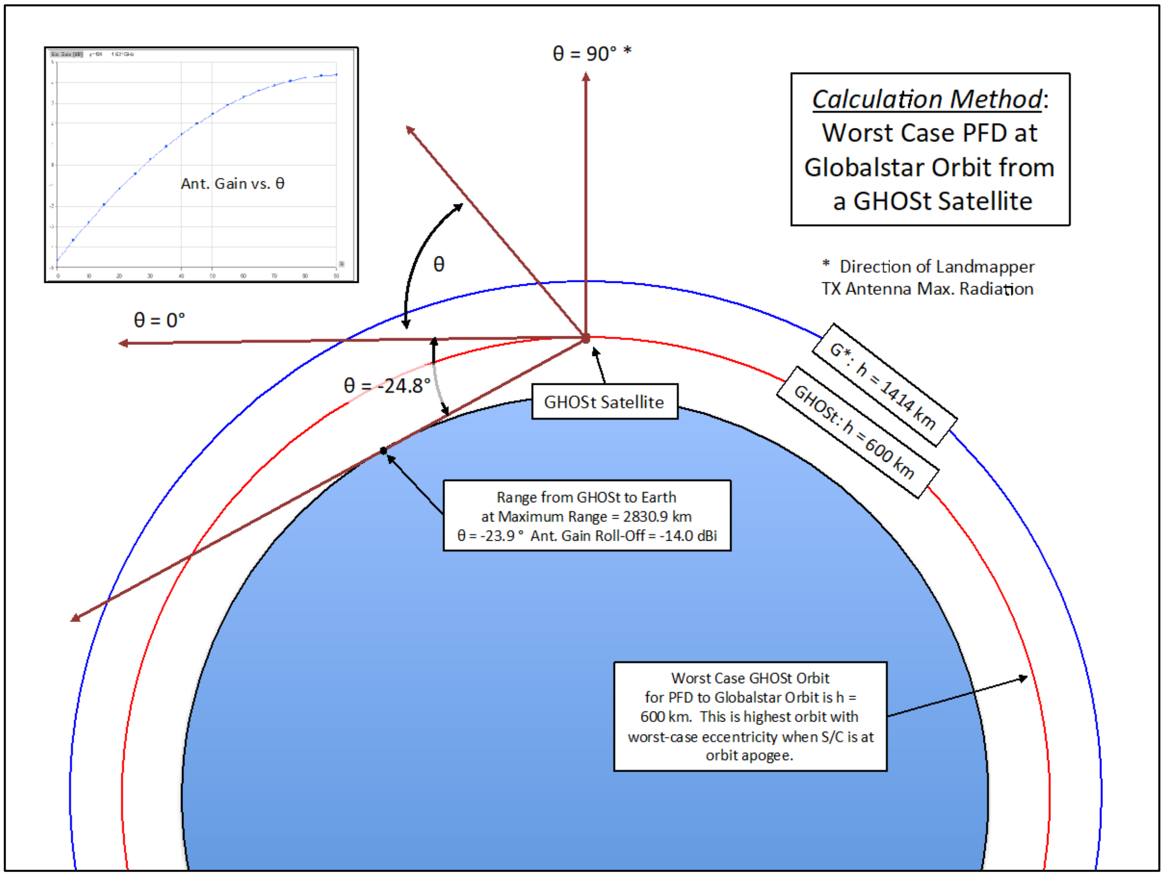
In order to complete Schedule S of our Form 312 submission it was necessary to compute PFD levels for the transmit beam from a GHOSt satellite to the Globalstar Constellation orbit, as contained in that submission. We understand, however, that normally this PFD would be associated with an Earth Station transmitting to a satellite. In this case, however, the geometry is different. It is a link from a GHOSt NGSO satellite to a Globalstar NGSO satellite.

In order to explain our PFD results it is important to define a coordinate system so that the power flux computations can be interpreted. The geometry and a reference 2D coordinate system are defined here in Figure G-1.

We note that the worst-case PFD would be from the highest altitude possible orbit for GHOSt. That orbit is a 525 km sun-synchronous orbit and the highest PFD would occur at the apogee of that orbit. This highest instant altitude is 600 km. We assume that GHOSt is NADIR-looking but, is making use of its ZENITH-mounted patch antenna to transmit to Globalstar. The antenna roll-off of this antenna away from zenith is given by the antenna pattern if Figure G-2. We note that this antenna's gain is defined as a function of off-point angle θ; measured as zero at the GHOSt satellite horizon. This will yield a maximum PFD from GHOSt toward Zenith at θ = 90°.

In addition, a single case PFD was calculated for the direction where the Globalstar transmit beam from GHOSt intersects the Earth. This occurs at a negative angle of θ: θ = -23.9°. At the point where GHOSt's Globalstar beam intersects the Earth the range from the satellite to a station at this location would be 2831 km and the Globalstar patch antenna will have rolled-off to -14.0 dBi net gain.

The calculated PFD levels along the Globalstar orbit arc and for the one case calculated for the PFD to an Earth station at 0° elevation is given in Table G-1.



*Calculation Method*: Worst Case PFD at Globalstar Orbit from a GHOSt Satellite

* Direction of Landmapper TX Antenna Max. Radiation

Range from GHOSt to Earth at Maximum Range = 2830.9 km θ = -23.9 ° Ant. Gain Roll-Off = -14.0 dBi

Worst Case GHOSt Orbit for PFD to Globalstar Orbit is h = 600 km. This is highest orbit with worst-case eccentricity when S/C is at orbit apogee.

**Figure G-1: GHOSt-to-Globalstar Geometry**

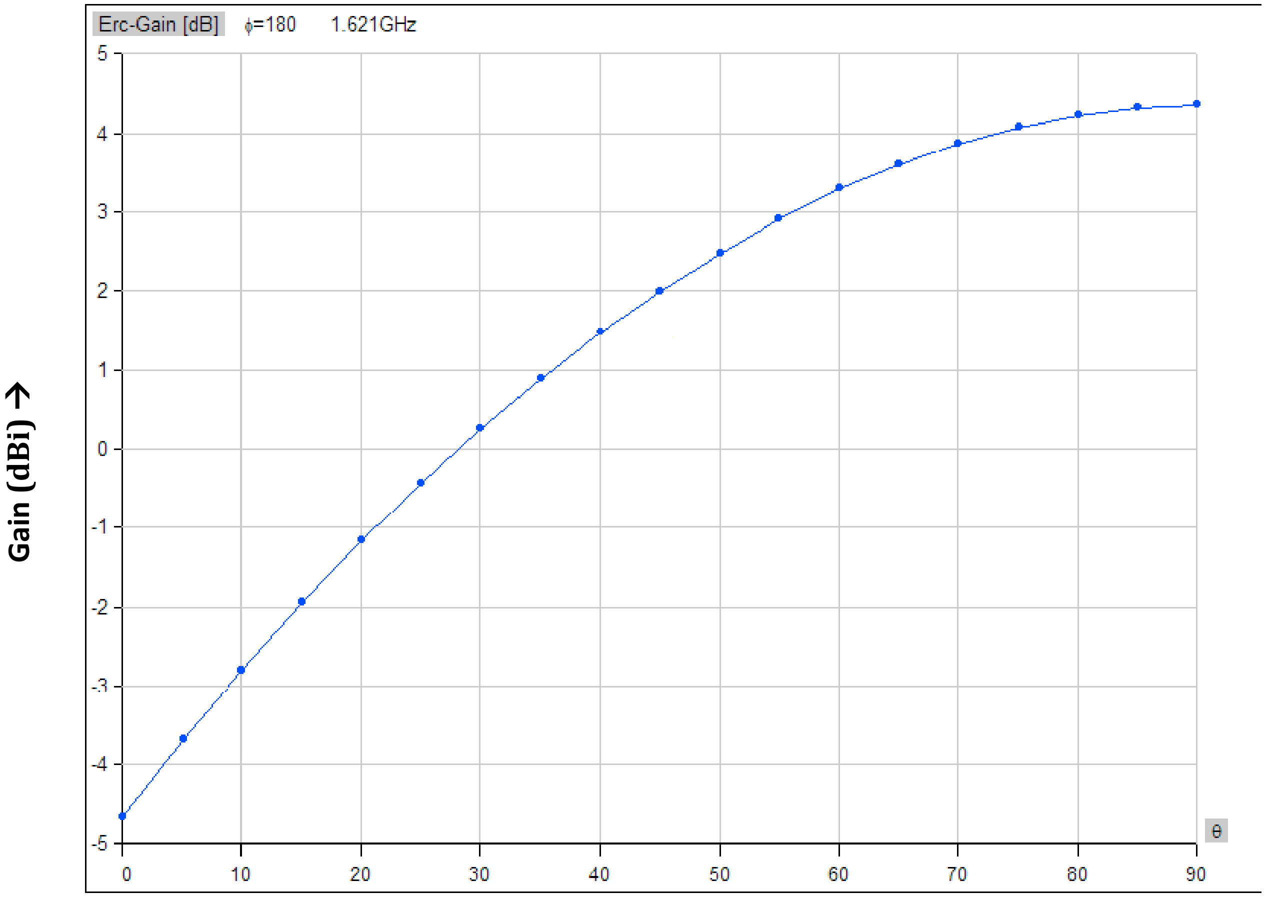
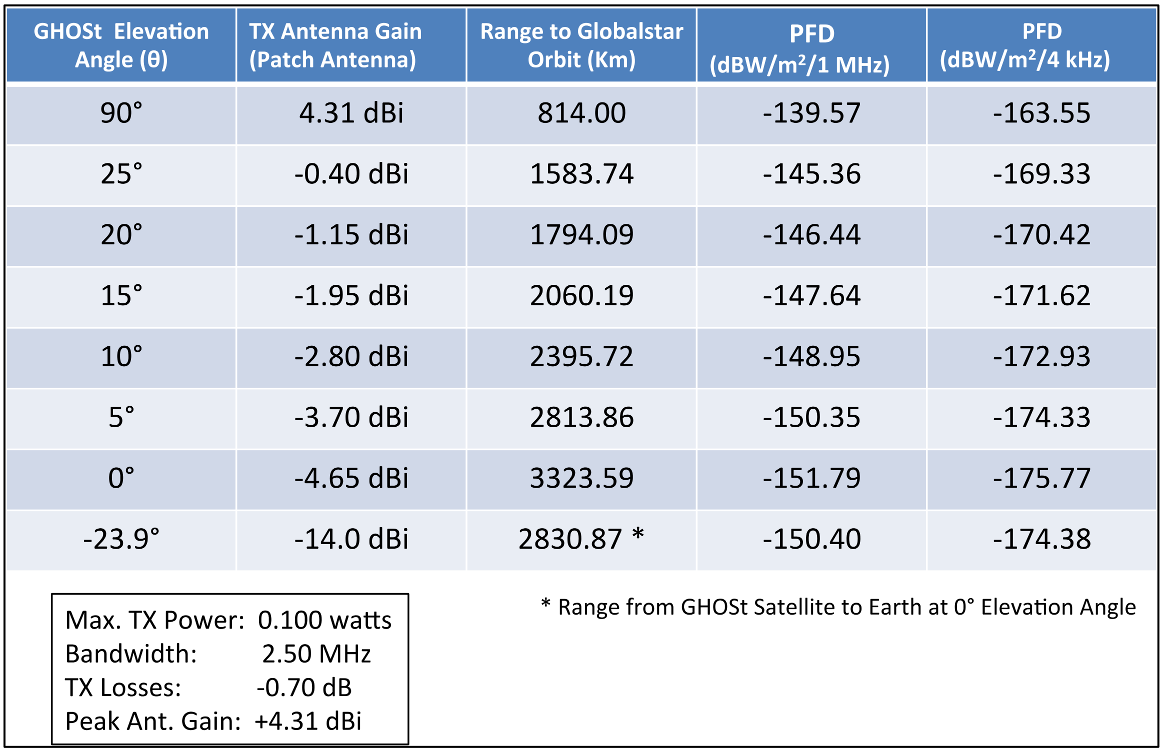


**Figure G-2: GHOSt PatchAntenna Transmit Gain (dBi) vs. Angle θ (°)**

## Table G-1: GHOSt-to-Globalstar Orbit PFD



| GHOSt Elevation Angle (θ) | TX Antenna Gain (Patch Antenna) | Range to Globalstar Orbit (Km) | PFD (dBW/m²/1 MHz) | PFD (dBW/m²/4 kHz) |
|---|---|---|---|---|
| 90° | 4.31 dBi | 814.00 | -139.57 | -163.55 |
| 25° | -0.40 dBi | 1583.74 | -145.36 | -169.33 |
| 20° | -1.15 dBi | 1794.09 | -146.44 | -170.42 |
| 15° | -1.95 dBi | 2060.19 | -147.64 | -171.62 |
| 10° | -2.80 dBi | 2395.72 | -148.95 | -172.93 |
| 5° | -3.70 dBi | 2813.86 | -150.35 | -174.33 |
| 0° | -4.65 dBi | 3323.59 | -151.79 | -175.77 |
| -23.9° | -14.0 dBi | 2830.87 * | -150.40 | -174.38 |

| | |
|---|---|
| Max. TX Power: | 0.100 watts |
| Bandwidth: | 2.50 MHz |
| TX Losses: | -0.70 dB |
| Peak Ant. Gain: | +4.31 dBi |

* Range from GHOSt Satellite to Earth at 0° Elevation Angle

## V. ANALYSIS OF GHOSt CONSTELLATION INTERFERENCE POTENTIAL TO FEDERAL AND INTERNATIONAL DRS GEO SATELLITE SYSTEMS

This analysis focuses on the interference potential from the GHOSt Hyper-spectral Imaging Constellation system to domestic and international data relay satellites (like TDRSS) located in geostationary orbit. The ITU has addressed interference limits from NGSO EESS systems to DRS GEO systems in ITU-R Recommendation SA.1862. Adherence to this recommendation is made compulsory by ITU FN 5.536A. Specifically, *Recommends 5* of SA.1862 establishes a PFD limit for NGSOs operating in the EESS to DRS systems in geostationary orbit. This recommendation establishes a limit of -133 dBW/m$^2$/1 MHz of bandwidth while using the band 25.5-27.0 GHz. We will, therefore utilize this limit as the basis for our analysis.

**I. Geometric Analysis**: SA.1862 notes that there are two potential geometries where NGSO systems could interfere, under co-channel conditions, with a GEO DRS system. These are:

*Case 1.*) When the victim GEO system is directly above the NGSO system and the NGSO system is transmitting to it's intended Earth station, and the NGSO radiating antenna back-lobe is projected toward the GEO system.

and,

*Case 2.*) When the victim GEO system is directly in-line with the NGSO station and the receiving Earth station. Under these circumstances, the NGSO satellite is at very low elevation angles (near 0 degrees) and has begun its downlink transmission to its intended Earth Station. This geometry is shown in Figures E-1a, E-1b, and E-1c of this analysis. The example shown in these figures is for the Svalbard, Norway station, located in the vicinity of the North Pole of the Earth. The geometry for passes from our satellites to Troll, Antarctica is similar to the situation at Svalbard, however, the graphics in the figures would be inverted. In the interest of clarity and simplicity, the same figures for Troll are not presented here.

Orbital Sidekick has investigated these two orbit geometries. Our two Earth stations for receiving signals in the band 25.5-27.0 GHz are at Svalbard, Norway, situated at 78.23° N and 15.41° E, and Troll, Antarctica, at 72.00° S and 2.53° E. From these locations the satellite-to-satellite geometry can never satisfy condition a.) above. As our primary Earth stations are nearly at the Earth's poles, there is no practical geometry where one of the GHOSt satellites could view the GEO arc in such a way that the victim GEO system would be behind the GHOSt satellite such that the back lobe from the NGSO satellite antenna could be projected toward the GEO arc. Hence, Case a.) is not applicable for the GHOSt system, which only turns ON its Ka-band transmitter when it is very nearly in view of Svalbard or Troll (and hence in the vicinity of one of the poles of the Earth).

Case b.) from SA.1862, however, can and will occur for very short periods of time on some orbits. This geometry can be visualized using the following figures.

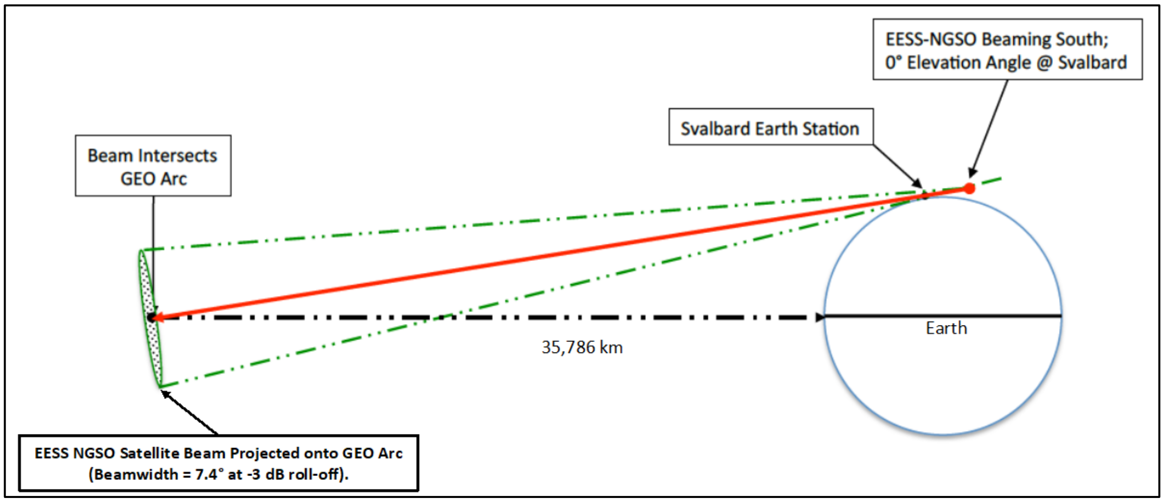


**Figure E-1a. : Case 2.) Illumination of the GEO Arc from a Transmitting Landmapper Spacecraft (Viewed from within Geostationary Orbit Plane)**

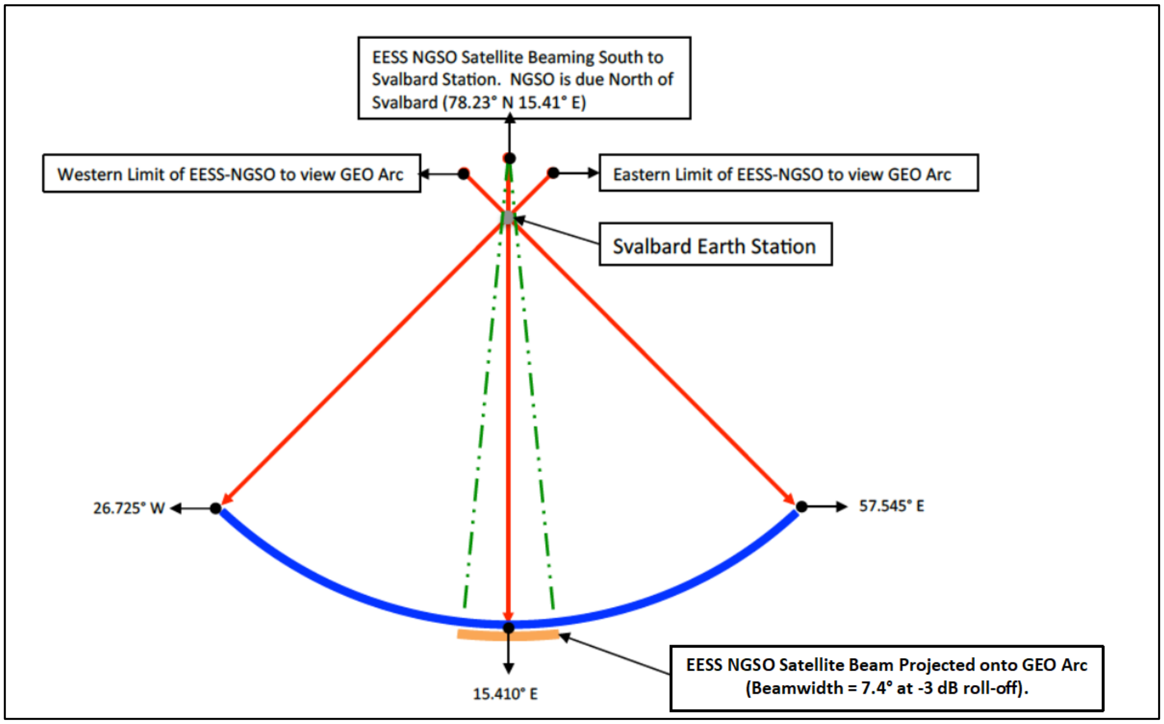


**Figure E-1b. : Case 2.) Illumination of the GEO Arc from a Transmitting GHOSt Spacecraft (View approximately Normal to GEO Plane; NGSO beaming due South)**

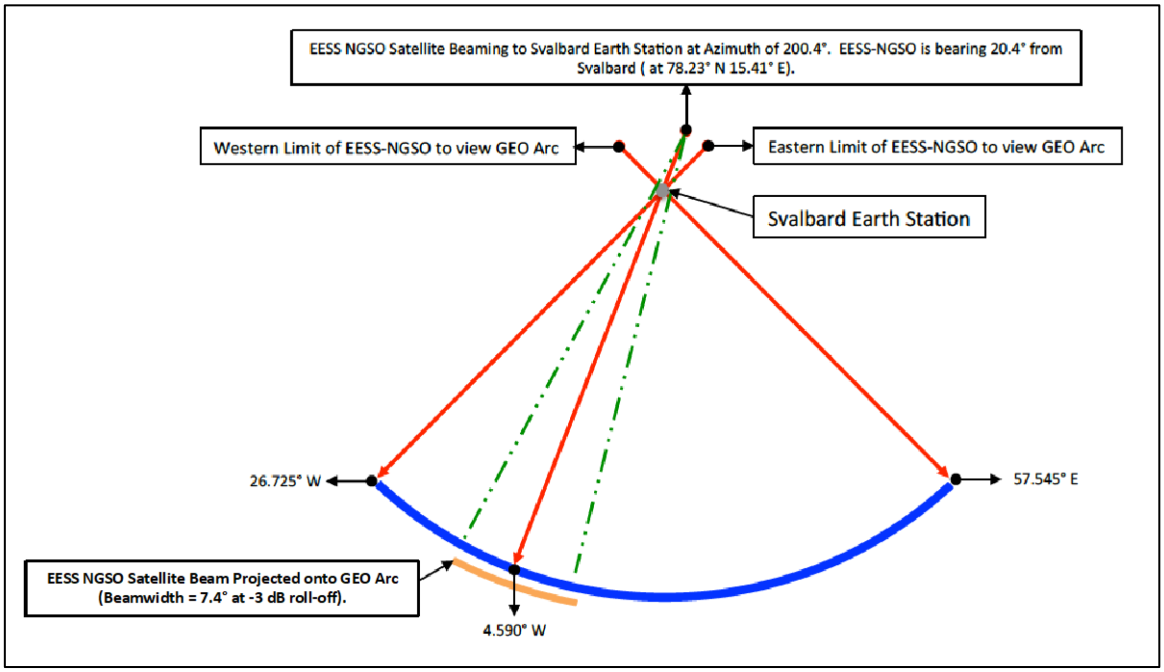
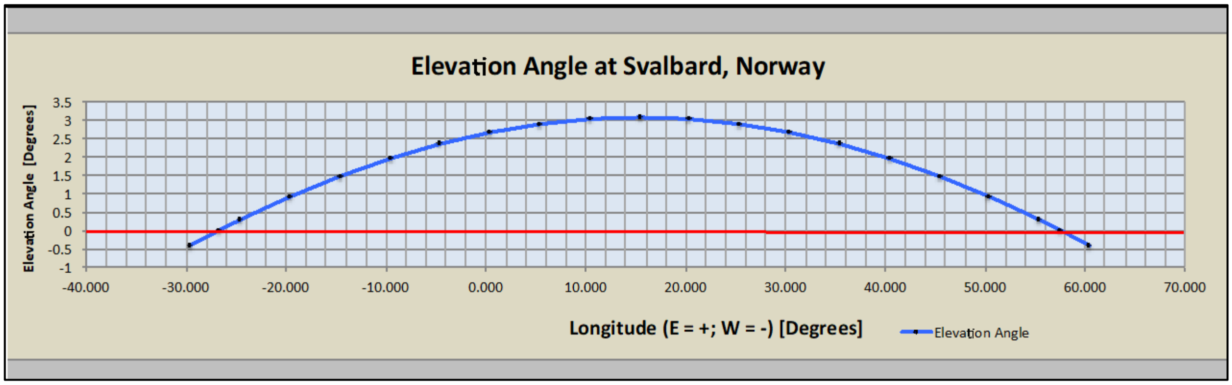


**Figure E-1c.: Case 2) Example when, During a GHOSt Satellite Pass, the Satellite is Directing its Beam to an Azimuth Value of 200.4°. The NGSO Beam illuminates the GEO Arc at 4.6° W ± 3.7°. Elevation angle at this time is 2.4°.**

What can be observed from these three figures is that during times when a GHOSt satellite is beaming nearly South and is at very low elevation angles relative to Svalbard station, RF energy from a GHOSt satellite, will also be directed past Svalbard at grazing angle and will arrive at the GEO arc. This can occur at epochs very near the beginning of a pass and very near the end, as the spacecraft is rising or setting at Svalbard. During the geometric case where a spacecraft is due North of Svalbard, the narrow directed beam from the GHOSt spacecraft not only illuminates Svalbard but, passes on to the GEO arc and illuminates the Arc, centered at 15.4°E. The beamwidth of a GHOSt Ka-band spacecraft antenna is 7.4° and so the GEO arc will be illuminated at this time and condition, from 11.7° E to 19.1° E. These are the two locations on the arc where the PFD from the GHOSt system will be 3 dB below the peak value which will occur at 15.4° E on the GEO Arc. At this particular location for the GHOSt spacecraft (when it is at just 0° elevation angle to Svalbard) a GEO satellite at 15.4° E would be at an elevation angle from the GHOSt spacecraft of 3.1 °. This is the highest elevation angle ever seen by a GHOSt directing its beam toward the arc. As this satellite rises above the horizon at Svalbard the satellite beam (as it tracks the Earth station target) will be directed downward, and further and further away from the arc. Within approximately 60 seconds of AOS (acquisition of signal) or LOS (loss of signal) at Svalbard, the beam will have rolled off by more than 10 dB as seen at the GEO arc. Hence, the opportunity for this alignment to occur at this GEO arc location is approximately 2 minutes per day per satellite and will occur when, 1.) the GHOSt transmitter is ON and 2.) if the victim GEO system has its receive beam directed toward Svalbard and 3.) if there is a co-channel use condition existing, 4.) if the GHOSt transmitter uses the same polarization as the victim GEO system.

Other GHOSt satellites may be directing their beams at very low elevation angles toward Svalbard but, from other positions other than with their satellite antennas beaming due South. These satellites will also see the GEO arc but, for an even shorter duration. Figure E-1c shows an example of a GHOSt satellite beaming south at an Azimuth bearing of 200.4°. Using the same calculation method, this GHOSt satellite will illuminate the arc (at -3 dB or higher w.r.t. to peak PFD) from 8.2° W to 0.9° W longitude. However, the elevation angle to this GEO arc segment is never more than 2.4°. Hence, it will be visible in this narrow elevation gap for only about 80 seconds per satellite per day (two orbits at 40 seconds per event).

Figure E-2a demonstrates that the GEO arc using this Case 2) geometry can be illuminated by GHOSt satellites over the portion of the arc that extends from 26.7° W to 57.5° E when the satellite transmitter is switched on for Svalbard. These conditions exist for up to about 1 minute per day per satellite within any given 7.4 degree sector of the GEO arc segment just identified. Figure E-2b provides the same information for the Case 2) geometry but, when the GHOSt satellite is transmitting to the Troll, Antarctica station. In this scenario, when the satellite beams due North (0.0° Azimuth) from its position south of Troll, the maximum elevation angle will be 9.4° and the GEO arc can be illuminated, briefly and periodically, from 58.2° W to 63.2° E. The durations of illumination associated with the Troll station are very similar to those at Svalbard and the arguments and geometry constraints are the same.



**<u>Figure E-2a</u>: Elevation Angle to GEO Arc from a GHOSt Spacecraft near Svalbard as a Function of GEO Arc Location**

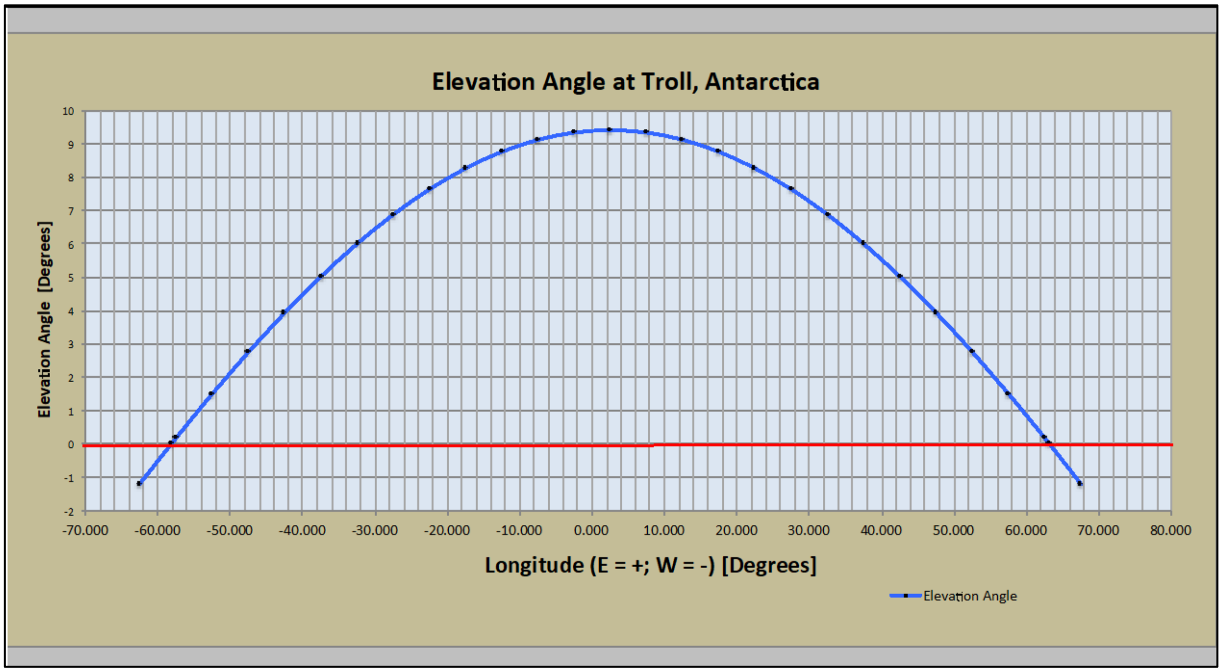


**Figure E-2b**: **Elevation Angle to GEO Arc from a GHOSt Spacecraft near Troll as a Function of GEO Arc Location**

## II. Power Flux Density Analysis:

**A. Range Calculation:** The lowest altitude orbit ever occupied by satellites in the GHOSt system, when in operation, will be 300 km. This orbit condition will exist briefly at the end of the lifetime of any GHOSt satellite. This orbit will produce a slightly worst-case lower bound range distance and, therefore, a slightly higher PFD value at the GEO arc. During the time when the GHOSt satellites are in the position where they can illuminate the GEO arc at highest elevation angle, the Range to the satellite is approximately:

$$R_{SR} \approx R_{GEO} + R_{NGSO}$$

**Where:**

**$R_{SR}$ = Total Slant Range to GEO Arc Position**

**$R_{GEO}$ = Range from Position on GEO Arc to the Earth Station**

**$R_{NGSO}$ = Range from Earth Station to GHOSt Spacecraft at 0°** [5]

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[5] Spacecraft is in sun-synchronous orbit at an altitude of 300 km.

The range $R_{SR}$ can be calculated by routine formulas given in the literature. [6] The range $R_{NGSO}$ is a constant for the 300 km circular orbit and, at 0° elevation angle, is equal to 1979 km.

## B. Power Flux Density (PFD) Calculation:

The PFD value for the range $R_{SR}$ can be given by:

$$\mathbf{PFD[W/m^2/MHz] = EIRP\ (dBW)\ -71\ -20log_{10}\ (R_{SR})\ -10log_{10}(BW/10E+6)}$$

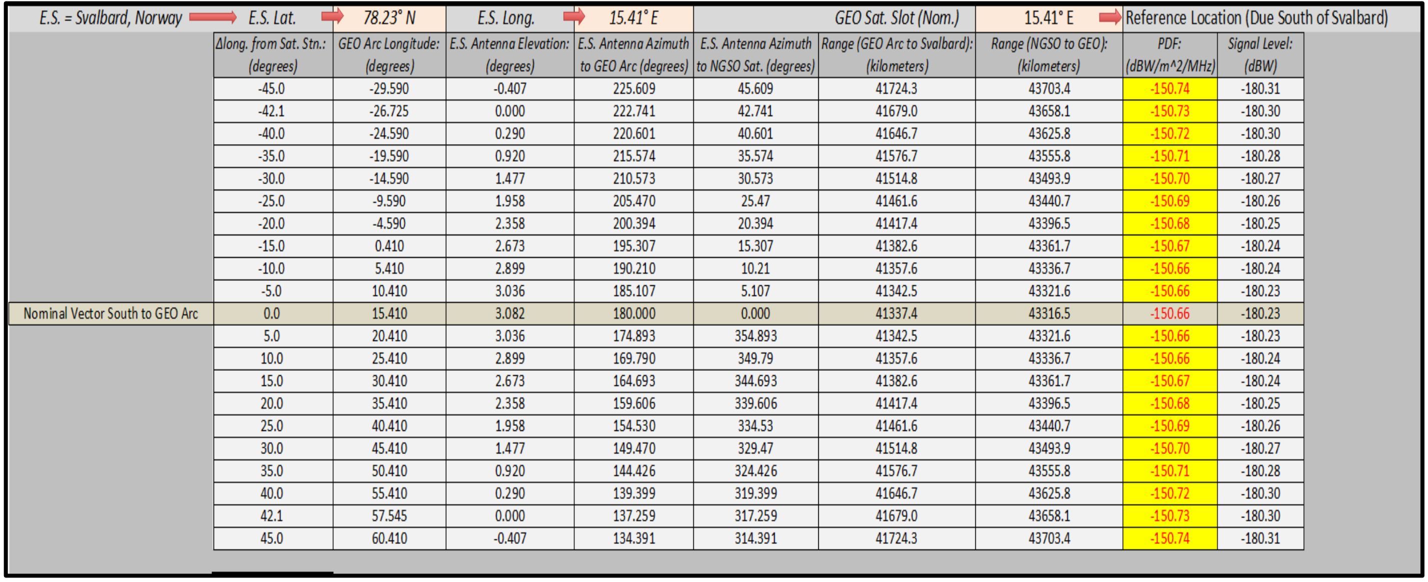
**Where:**

**EIRP = The effective isotopic radiated power.) = 33.2 dBW (worst case).**

**BW = The symbol rate bandwidth of the Ka-band TX emission = 102,270,000 Hz (worst case).**

The PFD received at the GEO arc can then be calculated as a function of position along the arc. These values, along with other important parameters associated with this interference case, are summarized in Table E-1a and E-1b for Svalbard, Norway and Tables E-1c and E-1d for Troll, Antarctica.

### Table E-1a.: PFD at the GEO Arc from a GHOSt S/C at 0° El. Angle Radiating Toward Svalbard, Norway



| E.S. = Svalbard, Norway → | E.S. Lat. → | 78.23° N | E.S. Long. → | 15.41° E | | GEO Sat. Slot (Nom.) | 15.41° E → | Reference Location (Due South of Svalbard) | |
|---|---|---|---|---|---|---|---|---|---|
| | Δlong. from Sat. Stn.: (degrees) | GEO Arc Longitude: (degrees) | E.S. Antenna Elevation: (degrees) | E.S. Antenna Azimuth to GEO Arc (degrees) | E.S. Antenna Azimuth to NGSO Sat. (degrees) | Range (GEO Arc to Svalbard): (kilometers) | Range (NGSO to GEO): (kilometers) | PDF: (dBW/m^2/MHz) | Signal Level: (dBW) |
| | -45.0 | -29.590 | -0.407 | 225.609 | 45.609 | 41724.3 | 43703.4 | -150.74 | -180.31 |
| | -42.1 | -26.725 | 0.000 | 222.741 | 42.741 | 41679.0 | 43658.1 | -150.73 | -180.30 |
| | -40.0 | -24.590 | 0.290 | 220.601 | 40.601 | 41646.7 | 43625.8 | -150.72 | -180.30 |
| | -35.0 | -19.590 | 0.920 | 215.574 | 35.574 | 41576.7 | 43555.8 | -150.71 | -180.28 |
| | -30.0 | -14.590 | 1.477 | 210.573 | 30.573 | 41514.8 | 43493.9 | -150.70 | -180.27 |
| | -25.0 | -9.590 | 1.958 | 205.470 | 25.47 | 41461.6 | 43440.7 | -150.69 | -180.26 |
| | -20.0 | -4.590 | 2.358 | 200.394 | 20.394 | 41417.4 | 43396.5 | -150.68 | -180.25 |
| | -15.0 | 0.410 | 2.673 | 195.307 | 15.307 | 41382.6 | 43361.7 | -150.67 | -180.24 |
| | -10.0 | 5.410 | 2.899 | 190.210 | 10.21 | 41357.6 | 43336.7 | -150.66 | -180.24 |
| | -5.0 | 10.410 | 3.036 | 185.107 | 5.107 | 41342.5 | 43321.6 | -150.66 | -180.23 |
| Nominal Vector South to GEO Arc | 0.0 | 15.410 | 3.082 | 180.000 | 0.000 | 41337.4 | 43316.5 | -150.66 | -180.23 |
| | 5.0 | 20.410 | 3.036 | 174.893 | 354.893 | 41342.5 | 43321.6 | -150.66 | -180.23 |
| | 10.0 | 25.410 | 2.899 | 169.790 | 349.79 | 41357.6 | 43336.7 | -150.66 | -180.24 |
| | 15.0 | 30.410 | 2.673 | 164.693 | 344.693 | 41382.6 | 43361.7 | -150.67 | -180.24 |
| | 20.0 | 35.410 | 2.358 | 159.606 | 339.606 | 41417.4 | 43396.5 | -150.68 | -180.25 |
| | 25.0 | 40.410 | 1.958 | 154.530 | 334.53 | 41461.6 | 43440.7 | -150.69 | -180.26 |
| | 30.0 | 45.410 | 1.477 | 149.470 | 329.47 | 41514.8 | 43493.9 | -150.70 | -180.27 |
| | 35.0 | 50.410 | 0.920 | 144.426 | 324.426 | 41576.7 | 43555.8 | -150.71 | -180.28 |
| | 40.0 | 55.410 | 0.290 | 139.399 | 319.399 | 41646.7 | 43625.8 | -150.72 | -180.30 |
| | 42.1 | 57.545 | 0.000 | 137.259 | 317.259 | 41679.0 | 43658.1 | -150.73 | -180.30 |
| | 45.0 | 60.410 | -0.407 | 134.391 | 314.391 | 41724.3 | 43703.4 | -150.74 | -180.31 |

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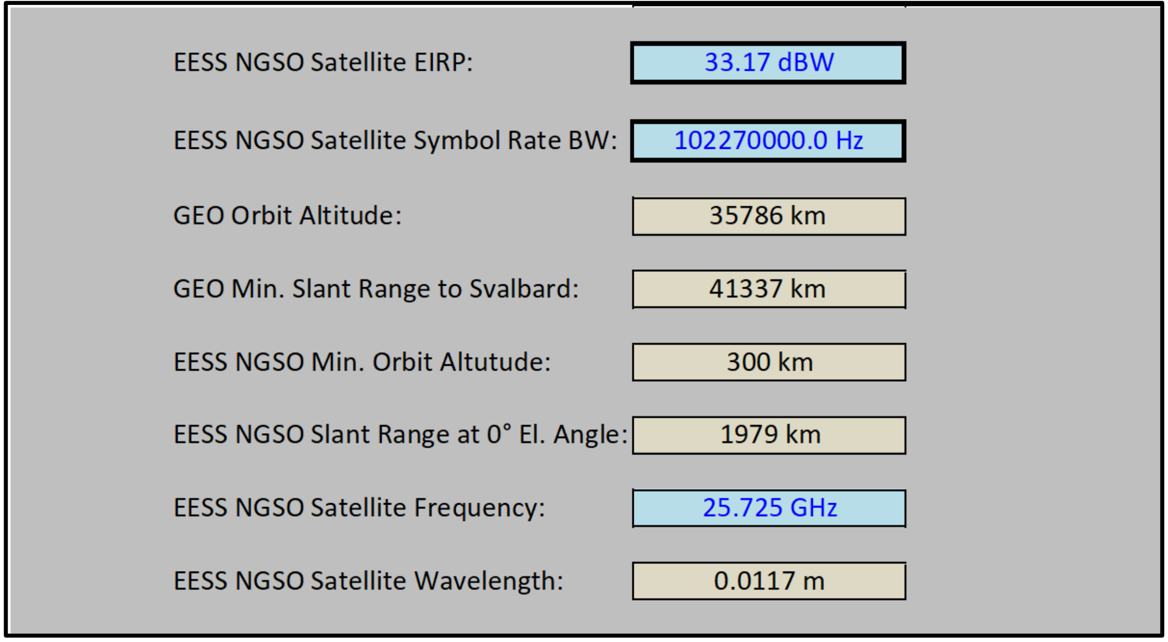
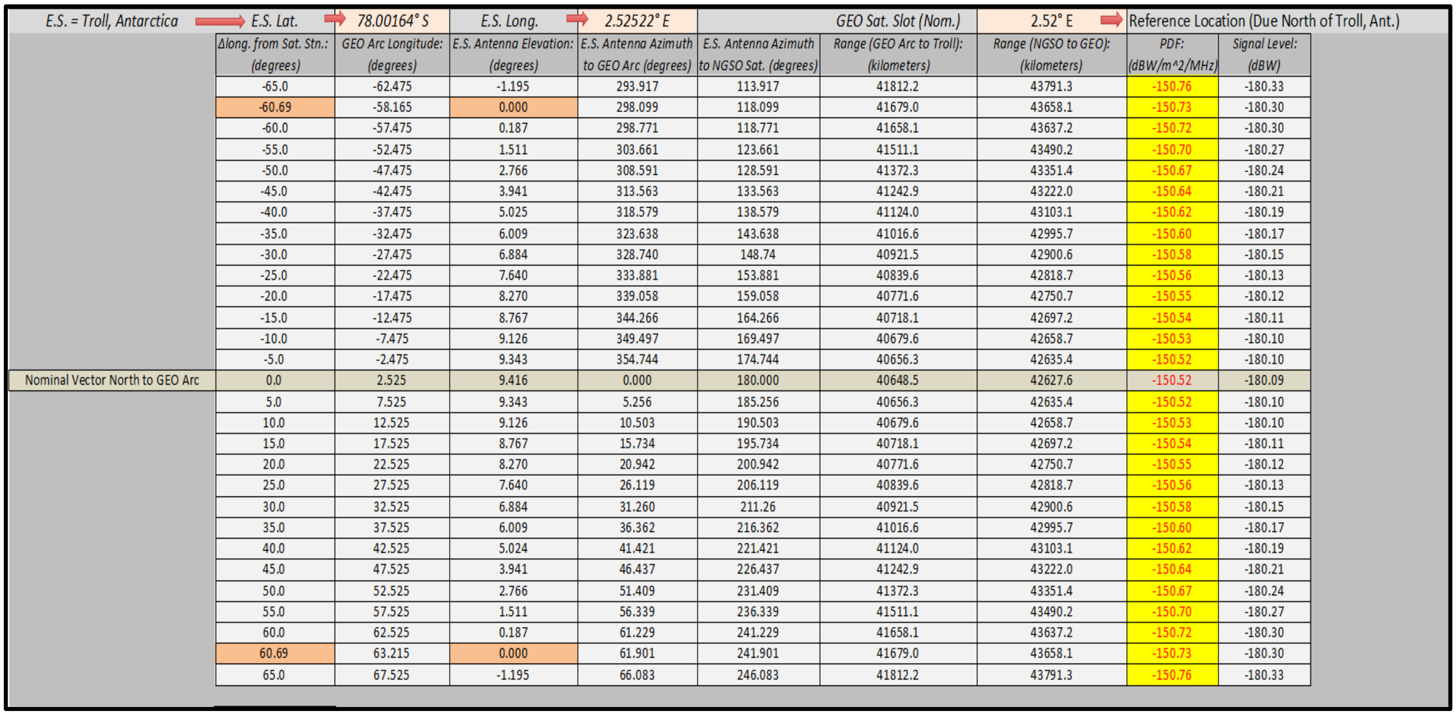
[6] Morgan, W.L. and Gordon, G.D., Principles of Communications Satellites, John Wiley & Sons, Inc., 1993, Chapter 2 and pp.140-143.

**Table E-1b. : PFD and Isotropic Power Level Calculation Critical Parameters for a GHOSt S/C Radiating Toward Svalbard**



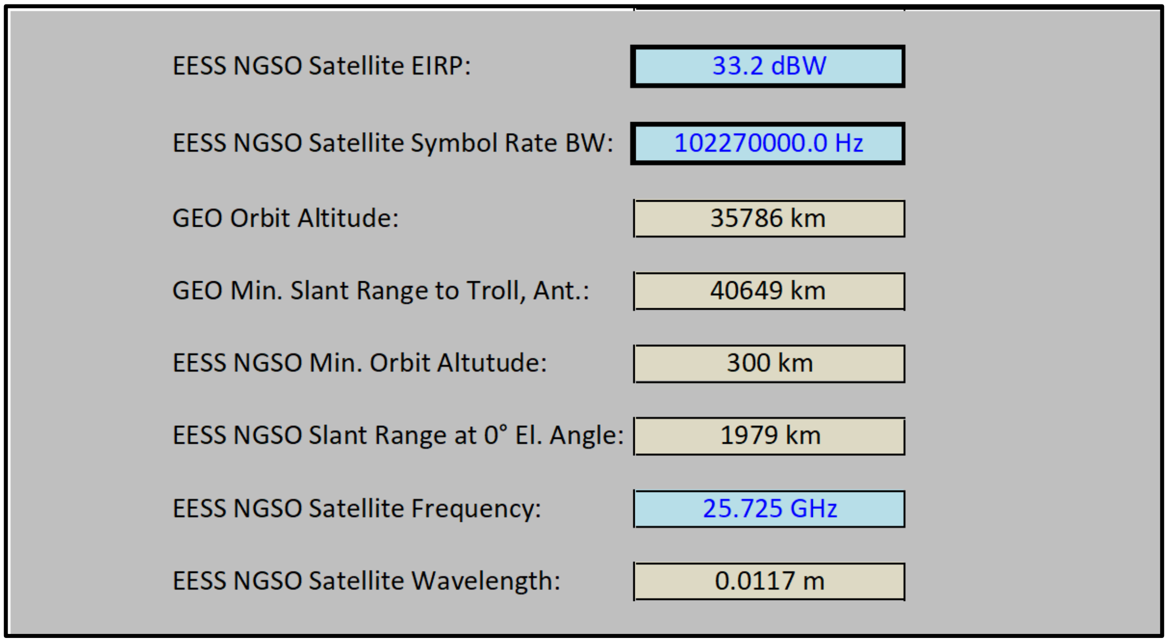
| | |
|---|---|
| EESS NGSO Satellite EIRP: | 33.17 dBW |
| EESS NGSO Satellite Symbol Rate BW: | 102270000.0 Hz |
| GEO Orbit Altitude: | 35786 km |
| GEO Min. Slant Range to Svalbard: | 41337 km |
| EESS NGSO Min. Orbit Altutude: | 300 km |
| EESS NGSO Slant Range at 0° El. Angle: | 1979 km |
| EESS NGSO Satellite Frequency: | 25.725 GHz |
| EESS NGSO Satellite Wavelength: | 0.0117 m |

**Table E-1c.: PFD at the GEO Arc from a GHOSt S/C at 0° El. Angle Radiating Toward Troll, Antarctica**



| E.S. = Troll, Antarctica | E.S. Lat. | 78.00164° S | E.S. Long. | 2.52522° E | GEO Sat. Slot (Nom.) | | 2.52° E | Reference Location (Due North of Troll, Ant.) | |
|---|---|---|---|---|---|---|---|---|---|
| | Δlong. from Sat. Stn.: (degrees) | GEO Arc Longitude: (degrees) | E.S. Antenna Elevation: (degrees) | E.S. Antenna Azimuth to GEO Arc (degrees) | E.S. Antenna Azimuth to NGSO Sat. (degrees) | Range (GEO Arc to Troll): (kilometers) | Range (NGSO to GEO): (kilometers) | PDF: (dBW/m^2/MHz) | Signal Level: (dBW) |
| | -65.0 | -62.475 | -1.195 | 293.917 | 113.917 | 41812.2 | 43791.3 | -150.76 | -180.33 |
| | -60.69 | -58.165 | 0.000 | 298.099 | 118.099 | 41679.0 | 43658.1 | -150.73 | -180.30 |
| | -60.0 | -57.475 | 0.187 | 298.771 | 118.771 | 41658.1 | 43637.2 | -150.72 | -180.30 |
| | -55.0 | -52.475 | 1.511 | 303.661 | 123.661 | 41511.1 | 43490.2 | -150.70 | -180.27 |
| | -50.0 | -47.475 | 2.766 | 308.591 | 128.591 | 41372.3 | 43351.4 | -150.67 | -180.24 |
| | -45.0 | -42.475 | 3.941 | 313.563 | 133.563 | 41242.9 | 43222.0 | -150.64 | -180.21 |
| | -40.0 | -37.475 | 5.025 | 318.579 | 138.579 | 41124.0 | 43103.1 | -150.62 | -180.19 |
| | -35.0 | -32.475 | 6.009 | 323.638 | 143.638 | 41016.6 | 42995.7 | -150.60 | -180.17 |
| | -30.0 | -27.475 | 6.884 | 328.740 | 148.74 | 40921.5 | 42900.6 | -150.58 | -180.15 |
| | -25.0 | -22.475 | 7.640 | 333.881 | 153.881 | 40839.6 | 42818.7 | -150.56 | -180.13 |
| | -20.0 | -17.475 | 8.270 | 339.058 | 159.058 | 40771.6 | 42750.7 | -150.55 | -180.12 |
| | -15.0 | -12.475 | 8.767 | 344.266 | 164.266 | 40718.1 | 42697.2 | -150.54 | -180.11 |
| | -10.0 | -7.475 | 9.126 | 349.497 | 169.497 | 40679.6 | 42658.7 | -150.53 | -180.10 |
| | -5.0 | -2.475 | 9.343 | 354.744 | 174.744 | 40656.3 | 42635.4 | -150.52 | -180.10 |
| Nominal Vector North to GEO Arc | 0.0 | 2.525 | 9.416 | 0.000 | 180.000 | 40648.5 | 42627.6 | -150.52 | -180.09 |
| | 5.0 | 7.525 | 9.343 | 5.256 | 185.256 | 40656.3 | 42635.4 | -150.52 | -180.10 |
| | 10.0 | 12.525 | 9.126 | 10.503 | 190.503 | 40679.6 | 42658.7 | -150.53 | -180.10 |
| | 15.0 | 17.525 | 8.767 | 15.734 | 195.734 | 40718.1 | 42697.2 | -150.54 | -180.11 |
| | 20.0 | 22.525 | 8.270 | 20.942 | 200.942 | 40771.6 | 42750.7 | -150.55 | -180.12 |
| | 25.0 | 27.525 | 7.640 | 26.119 | 206.119 | 40839.6 | 42818.7 | -150.56 | -180.13 |
| | 30.0 | 32.525 | 6.884 | 31.260 | 211.26 | 40921.5 | 42900.6 | -150.58 | -180.15 |
| | 35.0 | 37.525 | 6.009 | 36.362 | 216.362 | 41016.6 | 42995.7 | -150.60 | -180.17 |
| | 40.0 | 42.525 | 5.024 | 41.421 | 221.421 | 41124.0 | 43103.1 | -150.62 | -180.19 |
| | 45.0 | 47.525 | 3.941 | 46.437 | 226.437 | 41242.9 | 43222.0 | -150.64 | -180.21 |
| | 50.0 | 52.525 | 2.766 | 51.409 | 231.409 | 41372.3 | 43351.4 | -150.67 | -180.24 |
| | 55.0 | 57.525 | 1.511 | 56.339 | 236.339 | 41511.1 | 43490.2 | -150.70 | -180.27 |
| | 60.0 | 62.525 | 0.187 | 61.229 | 241.229 | 41658.1 | 43637.2 | -150.72 | -180.30 |
| | 60.69 | 63.215 | 0.000 | 61.901 | 241.901 | 41679.0 | 43658.1 | -150.73 | -180.30 |
| | 65.0 | 67.525 | -1.195 | 66.083 | 246.083 | 41812.2 | 43791.3 | -150.76 | -180.33 |

## Table E-1b. : PFD and Isotropic Power Level Calculation Critical Parameters for a GHOSt S/C Radiating Toward Svalbard



| | |
|---|---|
| EESS NGSO Satellite EIRP: | 33.2 dBW |
| EESS NGSO Satellite Symbol Rate BW: | 102270000.0 Hz |
| GEO Orbit Altitude: | 35786 km |
| GEO Min. Slant Range to Troll, Ant.: | 40649 km |
| EESS NGSO Min. Orbit Altutude: | 300 km |
| EESS NGSO Slant Range at 0° El. Angle: | 1979 km |
| EESS NGSO Satellite Frequency: | 25.725 GHz |
| EESS NGSO Satellite Wavelength: | 0.0117 m |

It can be seen from Table E-1a and E-1c the PDF from a GHOSt satellite to the GEO arc is approximately constant at a worst-case value of **-150.5 dBW/m²/MHz.** The allowable PFD limit in accordance with ITU-R Recommendation SA.1862, *Recommends 5*, is -133 dBW/m$^2$/MHz. Therefore, the GHOSt system complies with SA.1862, which allows a higher PFD level, even on a sustained basis.

Given that the *Recommends 5* limitation on PFD is met, the percentage of time when GHOSt might exceed the allowable PFD limit is *not* applicable. We emphasize , however, that the amount of time that any single satellite in Case 2) sees the GEO arc within any 7.5° sector along the GEO arc, is almost exactly 0.1% of the time, based on using a NGSO EESS 300 km orbit. For a 525 km orbit this percentage would be slightly larger. Hence, EVEN IF the PFD level of SA.1862 were not met, we could easily make very small adjustments in our operating schedule to comply with *any reasonable EPFD* Recommendation in the future.

As a final note, satellite PFD analysis does not normally allow for the inclusion of excess path loss resulting from meteorological factors in such a calculation. We understand that this inclusion would not be in the spirit of a worst-case analysis. However, in this circumstance, considering the frequency of our downlink (in the 25.5-27.0 GHz band) and the geometry involved in Case 2), whereby there is a grazing incidence path past the edge of the Earth from NGSO to GEO, it must be noted that this interference signal vector to the victim GEO satellite passes **twice** through the Earth's atmosphere along it's path from the NGSO to the GEO victim system. We present here what the excess path loss would be at two frequencies just above and below our proposed downlink frequency. This particular loss parameter is **only** the *gaseous absorption* component of the excess path loss for one transition of the atmosphere. Rain and cloud attenuation and other atmospheric effects are additional losses but, in this instance, we would not consider such contributions, as they are statistical parameters. We have taken this data from a long-standing and well known reference source and it is based on in-orbit measured data from NASA telecommunications program experiments at 20 and 30 GHz.[7] Presented here is the dry atmospheric case, which is applicable at the Svalbard Earth station. See Figure E-3.

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[7] Ippolito, L.J.Jr., Radiowave Propagation in Satellite Communications, Van Norstrand Reinhold Co., 1986, Chapters 3 and 7.

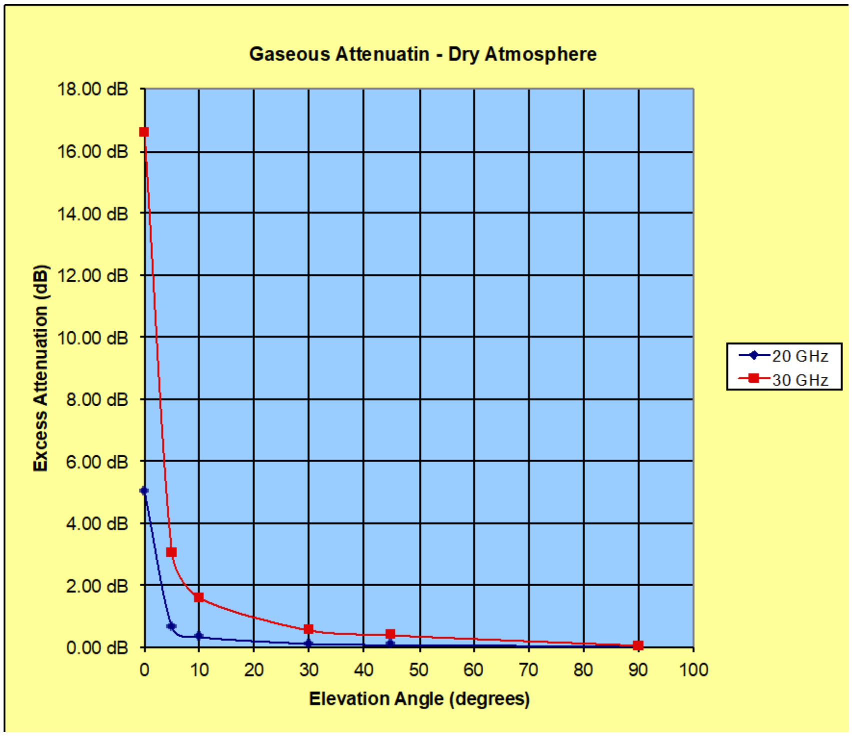
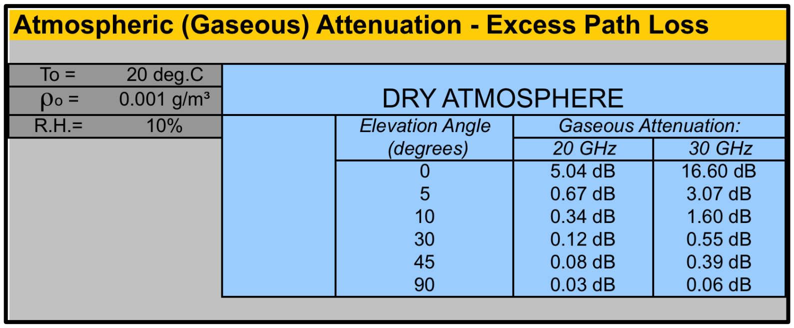


**Figure E-3: Gaseous Absorption at Low Elevation Angles at 20 and 30 GHz**



**Atmospheric (Gaseous) Attenuation - Excess Path Loss**

| | |
|---|---|
| To = | 20 deg.C |
| $\rho_o$ = | 0.001 g/m³ |
| R.H.= | 10% |

DRY ATMOSPHERE

| *Elevation Angle (degrees)* | *Gaseous Attenuation:* | |
|---|---|---|
| | *20 GHz* | *30 GHz* |
| 0 | 5.04 dB | 16.60 dB |
| 5 | 0.67 dB | 3.07 dB |
| 10 | 0.34 dB | 1.60 dB |
| 30 | 0.12 dB | 0.55 dB |
| 45 | 0.08 dB | 0.39 dB |
| 90 | 0.03 dB | 0.06 dB |

**Figure E-3 (Continued)**

From this data, it is evident that considerable excess path loss (as high as 30 dB) would exist during portions of the time while the signal transitions the lower atmosphere **twice** along the path from NGSO to GEO. While it is understood that typically, such excess path loss is not considered, OSK believes that the non-statistical portion of this excess path loss (the atmospheric absorption component) should be included and is a legitimate loss factor, in such a PDF analysis.

This excess path loss argument and justification, however, need not be included in our analysis, in order for OSK to be found compliant with ITU-R SA.1862. It is simply noted that even a conservative estimate of the PFD levels in this case, should include this specific excess path loss component.   And, this loss will further reduce the PFD received by any victim satellite on the GEO arc.

## VI. GHOSt SATELLITE SYSTEM PFD AT THE EARTH'S SURFACE FOR EESS OPERATIONS IN THE 25.5-27 GHZ BAND

### L.1 Power Flux Density Calculations

Section 25.208 of the Commission's rules require that power flux density at the Earth's surface produced by emissions from a space station in the Earth Exploration Satellite Service in the band 25.5-27.0 GHz, for all conditions and for all methods of modulation to not exceed the following values:

- -115 dB(W/m$^2$) in any 1 MHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;
- -115 + 0.5(δ -5) dB(W/m$^2$) in any 1 MHz band for angles of arrival (δ measured in degrees) between 5 and 25 degrees above the horizontal plane;
- -105 dB(W/m$^2$) in any 1 MHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

where δ is the angle between the boresight of the victim antenna and the horizontal plane. The PFD in a reference bandwidth of 1.0 MHz may be calculated using the relationship:

$$PFD\ [dB(W/m^2/1\ MHz)] = EIRP(dBW) - 71.0 - 20\log_{10}(D) - 10\log_{10}(BW)$$

Where:

- EIRP is the maximum EIRP of the transmission, in dBW = 33.2 dBW
- D is the distance in km between the satellite and the victim antenna (or surface area of interest)
- BW is the symbol bandwidth of the transmission, in MHz

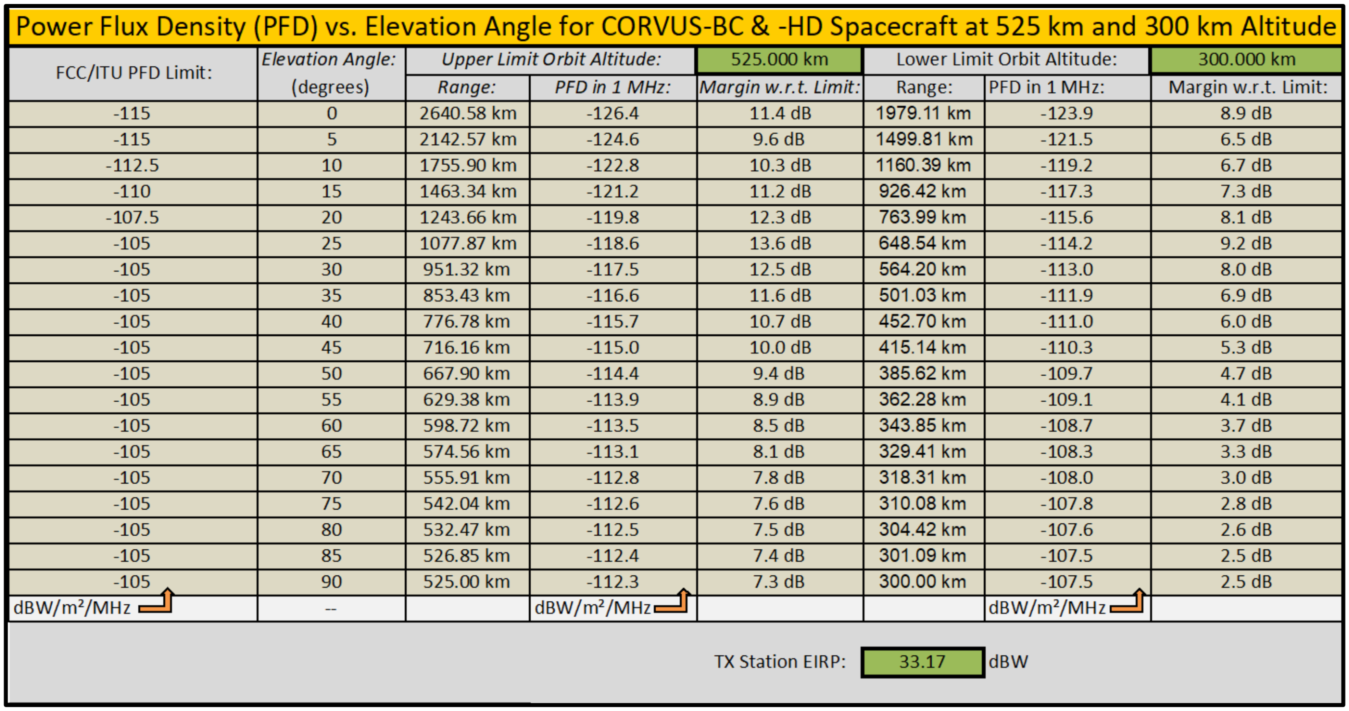
These limits refer to the PFD that would be obtained under assumed free-space propagation conditions only (no excess path loss of any kind is assumed). This corresponds to worst-case conditions for our system as excess path loss at Ka-band mmW frequencies for space systems never approaches zero under any practical link conditions, at any elevation angle. Figure 3 and Table 3 below provide calculations for the worst-case scenario for PFD on the Earth's surface for all 6 GHOSt satellites in the initial constellation and considers both Mode 1 and Mode 2 in the 25.5-27.0 GHz band, as a function of elevation angle. Two conditions are presented:

a). Case 1: For any of the six GHOSt spacecraft at 525 km circular orbit altitude (average starting [beginning of life] altitude for any member of the constellation). Mode 1 at Ka-band is the worst-case satellite mode for GHOSt -01 and -02.

b). Case 2: For any of the six GHOSt spacecraft at 300 km circular orbit altitude (lowest end-of-life altitude currently envisioned for the operation of any member of the constellation). Mode 1 at Ka-band is the worst-case satellite mode for GHOSt -01 and -02.

We note that our Ka-band TX, operating at any frequency within the 25.50 to 27.00 GHz, may be adjusted in output power, by ground control, from the maximum power level of just under 4.0 watts (as was used to calculate the PFD values given in Table 3) to levels as much as 20 dB below this level (or a transmit power equal to 10 mW). Hence it is always possible for our system to reduce emission EIRP in order to satisfy regulatory PFD requirements, regardless of spacecraft altitude or, otherwise, in order to deal with practical interference problems that could possibly arise. We have computed the PFDs at both altitudes assuming the narrowest bandwidth of the Type 1 transmitter. This -3 dB bandwidth is equal to 102.270 MHz and the channel occupied is calculated to be 112.5 MHz using a 10% Nyquist Roll-off of the emission.

**Table 3: PFD vs. Elevation Angle for CORVUS-BC and –HD Spacecraft**



Power Flux Density (PFD) vs. Elevation Angle for CORVUS-BC & -HD Spacecraft at 525 km and 300 km Altitude

| FCC/ITU PFD Limit: | *Elevation Angle:* | *Upper Limit Orbit Altitude:* | | 525.000 km | Lower Limit Orbit Altitude: | | 300.000 km |
|---|---|---|---|---|---|---|---|
| | (degrees) | *Range:* | *PFD in 1 MHz:* | *Margin w.r.t. Limit:* | Range: | PFD in 1 MHz: | Margin w.r.t. Limit: |
| -115 | 0 | 2640.58 km | -126.4 | 11.4 dB | 1979.11 km | -123.9 | 8.9 dB |
| -115 | 5 | 2142.57 km | -124.6 | 9.6 dB | 1499.81 km | -121.5 | 6.5 dB |
| -112.5 | 10 | 1755.90 km | -122.8 | 10.3 dB | 1160.39 km | -119.2 | 6.7 dB |
| -110 | 15 | 1463.34 km | -121.2 | 11.2 dB | 926.42 km | -117.3 | 7.3 dB |
| -107.5 | 20 | 1243.66 km | -119.8 | 12.3 dB | 763.99 km | -115.6 | 8.1 dB |
| -105 | 25 | 1077.87 km | -118.6 | 13.6 dB | 648.54 km | -114.2 | 9.2 dB |
| -105 | 30 | 951.32 km | -117.5 | 12.5 dB | 564.20 km | -113.0 | 8.0 dB |
| -105 | 35 | 853.43 km | -116.6 | 11.6 dB | 501.03 km | -111.9 | 6.9 dB |
| -105 | 40 | 776.78 km | -115.7 | 10.7 dB | 452.70 km | -111.0 | 6.0 dB |
| -105 | 45 | 716.16 km | -115.0 | 10.0 dB | 415.14 km | -110.3 | 5.3 dB |
| -105 | 50 | 667.90 km | -114.4 | 9.4 dB | 385.62 km | -109.7 | 4.7 dB |
| -105 | 55 | 629.38 km | -113.9 | 8.9 dB | 362.28 km | -109.1 | 4.1 dB |
| -105 | 60 | 598.72 km | -113.5 | 8.5 dB | 343.85 km | -108.7 | 3.7 dB |
| -105 | 65 | 574.56 km | -113.1 | 8.1 dB | 329.41 km | -108.3 | 3.3 dB |
| -105 | 70 | 555.91 km | -112.8 | 7.8 dB | 318.31 km | -108.0 | 3.0 dB |
| -105 | 75 | 542.04 km | -112.6 | 7.6 dB | 310.08 km | -107.8 | 2.8 dB |
| -105 | 80 | 532.47 km | -112.5 | 7.5 dB | 304.42 km | -107.6 | 2.6 dB |
| -105 | 85 | 526.85 km | -112.4 | 7.4 dB | 301.09 km | -107.5 | 2.5 dB |
| -105 | 90 | 525.00 km | -112.3 | 7.3 dB | 300.00 km | -107.5 | 2.5 dB |
| dBW/m$^2$/MHz | -- | | dBW/m$^2$/MHz | | | dBW/m$^2$/MHz | |

TX Station EIRP: 33.17 dBW

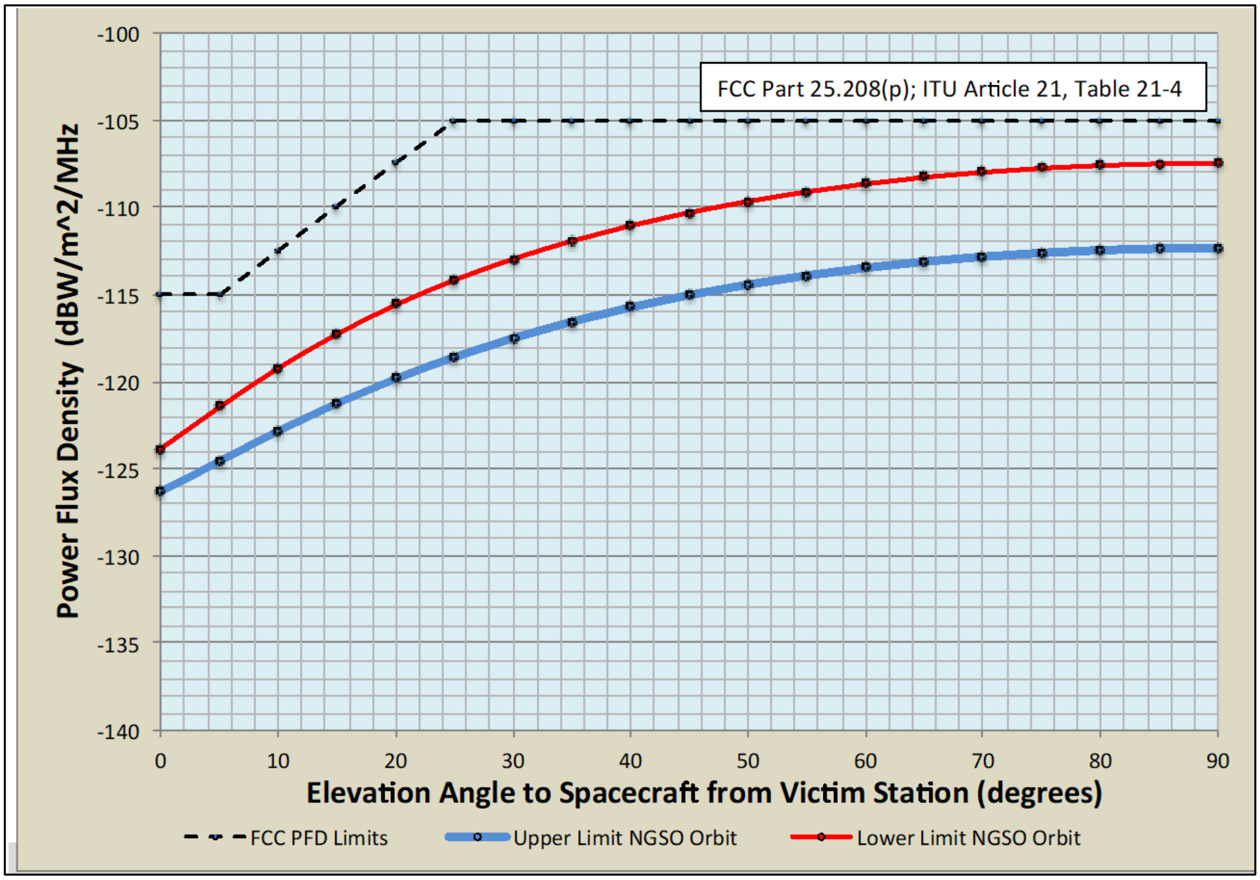


**Figure 3: PFD vs. Elevation Angle for Upper and Lower Limit CORVUS Spacecraft**

It can be seen that a reasonable margin exists between our worst-case achieved PFD levels vs. those limits imposed by 25.208(p) such that, as long as our spacecraft are not operated below 300 km altitude, the PFD limits imposed will not be exceeded. Hence this control capability and the effective (time averaged) EPFD are not essential considerations to the discussion of these PFD limitations. Figure 3 demonstrates this even more clearly.

We note that it is our intention to operate the Ka-band system at a full bandwidth of 450 MHz (409.09 MHz = -3 dB bandwidth). Hence the PFD at the Earth's surface, expected even at 300 km altitude and 90° elevation angle will be, nominally, 6 dB less that those values given in Table 3 and Figure 3 above.

Consequently, under worst-case conditions, when one of the six GHOSt spacecraft might be at 90° elevation angle with respect to a victim receiving station, the PFD received by the victim receiver would be less than:

a.) -112.3 dB(W/$m^{2)}$/MHz for satellites in a 525 km circular SSO

b.) -107.5 dB(W/$m^{2}$/MHz for satellites in a 300 km circular SSO

As can be seen, the PFD level will decrease with an increase in bandwidth and is well within FCC/ITU limit requirements under all worst-case conditions.

# Technical Certification

I, Pete Friedhoff, hereby certify that I am the technically qualified person responsible for the preparation of the engineering information contained in this application, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application, and that the technical information is complete and accurate to the best of my knowledge and belief.

*/s/ Pete Friedhoff*
Pete Friedhoff
Director, Space Systems
Orbital Sidekick, Inc.
pete@orbitalsidekick.com

Dated: May 20, 2021