GHOSt NON-GEOSTATIONARY SATELLITE SYSTEM

ATTACHMENT B

Technical Annex to Supplement Schedule S

A.1 SCOPE AND PURPOSE

This Attachment contains the information required by Sections 25.114 and 25.122 and other sections of the Federal Communications Commission's ("Commission" or "FCC") Part 25 rules that cannot be fully captured by the Schedule S software.

A.2 OVERALL DESCRIPTION OF SYSTEM FACILITIES, OPERATIONS AND SERVICES

Orbital Sidekick, Inc. ("OSK") requests authority to launch and operate a six-satellite hyperspectral imaging non-geostationary orbit ("NGSO") constellation in Low Earth Orbit ("LEO"), known as Global Hyperspectral Observation Satellite ("GHOSt"). The GHOSt constellation combines advanced space-based sensing with robust data analysis and machine learning methods.

A.2.a Orbital Configuration

The GHOSt mission will involve deploying a remote sensing constellation of small satellites with radiofrequency and optical payloads. The satellite constellation will consist of six (6) technically identical satellites launched into a sun-synchronous orbital ("SSO") inclination in LEO. The constellation will consist of three orbital planes, each having two satellites with the orbital parameters given in Table A.2.a-1.

Table A.2.a-1 Orbital parameters of the GHOSt satellite system

Orbital Plane Number	1	2	3
Number of Satellites within the Orbital Plane	2	2	2
Inclination Angle	97.5°		
Orbital Period	5708 seconds		
Apogee	525 km		
Perigee	525 km		
Argument of Perigee	0°		
Active Service Arc	-90° to 90° *		
Right Ascension of the Ascending Node	30°	330°	0°
Initial Phase Angles	<10° between each satellite **		
Local Time of Descending Node	1:30 PM	10:00 AM	10:00 AM

* Although the GHOSt satellites are capable of transmitting throughout their entire orbit, they will only transmit when visible to any one of their Earth stations.

** Given that the satellites are launched two at a time from the same launch vehicle, the initial phase angles will be very small. Over time, the two satellites in a given plane will separate further within their respective orbital planes and eventually be separated by 180°.

The first pair of satellites to be launched—GHOSt-01 and GHOSt-02—will be deployed in orbital plane number 1 in the above table. The second pair of satellites—GHOSt-03 and GHOSt-04—will be in orbital plane number 2 and the final pair of satellites—GHOSt-05 and GHOSt-06—will be in orbital plane number 3.

A.2.b Frequency and Polarization Plan

Each of the six satellites in the GHOSt constellation will operate in UHF-band, S-band, L-band, and Ka-band. Table A.2.b-1 provides the general frequency plan for each of the satellites.

Table A.2.b-1 General frequency bands used by the GHOSt satellite system

Type of Link and Transmission Direction	Frequency Ranges
Earth Exploration-Satellite Service Downlink	25.5-27.0 GHz
Earth Exploration-Satellite Service and TT&C Uplink	2025-2110 MHz
Inter-Satellite Service (Transmit)	1615-1617.5 MHz
Space Operations Service Downlink (TT&C)	400.15-401 MHz
GPS Signals	L1 C/A, L1C, L2C, L2P, L5

For the inter-satellite service in L-band, the GHOSt satellites will transmit to Globalstar satellites, pursuant to an agreement with Globalstar for the provision of inter-satellite data relay service ("IDRS"), but GHOSt will not have the capability to receive communications from the Globalstar satellites. OSK will only use the IDRS in limited, time-sensitive scenarios, *i.e.* to send alerts based on analytics from one or more GHOSt satellites.

The GHOSt satellites will utilize wideband downlink channels (450 MHz) within the 25.5-27.0 GHz Earth exploration satellite service ("EESS") (space-to-Earth) allocation in accordance with the ITU Table of Frequency Allocations, as well as Footnote **US258** in the U.S. Table of Frequency Allocations.[1] The GHOSt satellites will have both service and TT&C uplinks within the 2025-2110 MHz space operations service (Earth-to-space) and EESS (Earth-to-space) allocations in accordance with the ITU Table of Frequency Allocations, as well as Footnote **US347** in the U.S. Table of Frequency Allocations.[2] The GHOSt satellites will have downlinks within the 400.15-

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[1] **US258** In the bands 8025-8400 MHz and 25.5-27 GHz, the Earth exploration-satellite service (space-to-Earth) is allocated on a primary basis for non-Federal use. Authorizations are subject to a case-by-case electromagnetic compatibility analysis.

[2] **US347** In the band 2025-2110 MHz, non-Federal Earth-to-space and space-to-space transmissions may be authorized in the space research and Earth exploration-satellite services subject to such conditions as may be applied on a case-by-case basis. Such transmissions shall not cause harmful

401.0 MHz allocation to the space operations service (space-to-Earth) in accordance with the ITU Table of Frequency Allocations and the U.S. Table of Frequency Allocations. Within the general frequencies provided in Table A.2.b-1, the specific frequencies and polarizations utilized by each of the satellite antenna beams is given in Table A.2.b-2.

Table A.2.b-2 Detailed frequency and polarization plan for the GHOSt satellite system

Beam Name	Center Frequency	Bandwidth	Polarization	Link Type
SCNT	2047.5 MHz	5 MHz	RHCP	Service
SCMD	2055 MHz	300 kHz	RHCP	TT&C
UTLM	400.5 MHz	40 kHz	Linear Rotating[3]	TT&C
LTLM	1616.25 MHz	2.5 MHz	LHCP	Service
KaA	25.725 GHz	450 MHz	RHCP	Service
KaB	26.25 GHz	450 MHz	RHCP	Service
KaC	26.775 GHz	450 MHz	RHCP	Service
KaD	25.725 GHz	450 MHz	LHCP	Service
KaE	26.25 GHz	450 MHz	LHCP	Service
KaF	26.775 GHz	450 MHz	LHCP	Service
KaG	26.8 GHz	86.4 MHz	RHCP	Service
KaH	26.8 GHz	86.4 MHz	LHCP	Service

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interference to Federal and non-Federal stations operating in accordance with the Table of Frequency Allocations.

[3] The polarization of the UTLM beam is linear and, consequently, the terrestrially-received signal polarization rotates in space due to (1) the rotation of the satellite, (2) the rotation of the linearly polarized wave in space due to Faraday rotation, and (3) the motion of the satellite relative to the ground station on any pass. For these reasons, a linear polarization reference (such as horizontal or vertical) cannot be defined for the UHF downlink signal. Instead, the technique used to receive the linear signal is to use a circularly polarized antenna on the Earth to receive the signal and accept the loss due to polarization mismatch.

Only the GHOSt-01 and GHOSt-02 satellites will have the narrower bandwidth KaG and KaH antenna beams. The SCNT, SCMD, UTLM, and LTLM beams will be on each of the six GHOSt satellites. For the beams KaA through KaF, the minimum data rate is 177.89 Mbps and the maximum data rate is 2413.99 Mbps within each of the 450 MHz wide channels dependent upon the modulation and coding scheme selected. The Ka-band channel plan allows for six wideband emissions to share three frequency channels using polarization diversity. Each of the GHOSt satellites is able to transmit two of these wideband emissions at a fixed center frequency and polarization. By using such a scheme with the highest modulation and coding settings, a spectral efficiency of 5.36 bit/Hz is achieved, and a total spectral efficiency when both polarizations are employed of up to 10.72 bits/Hz can be achieved. In a technological context, the GHOSt spacecraft utilize the radio spectrum at the highest efficiency possible, which is another means by which OSK is operating in furtherance of the public interest. Table A.2.b-3 summarizes how the GHOSt spacecraft will utilize the 6-channel plan.

Table A.2.b-3 Ka-band channel utilization by spacecraft

Spacecraft	Transmit type	Channel ID	Polarization	Bandwidth (MHz)	Center frequency
GHOSt-01	Narrowband	DRH	RHCP	86.4	26.8 GHz
	Wideband	CRH	RHCP	450	26.775 GHz
	Wideband	BRH	RHCP	450	26.25 GHz
GHOSt-02	Narrowband	DLH	LHCP	86.4	26.8 GHz
	Wideband	CLH	LHCP	450	26.775 GHz
	Wideband	BLH	LHCP	450	26.25 GHz
GHOSt-03	Wideband	ARH	RHCP	450	25.725 GHz
	Wideband	BRH	RHCP	450	26.25 GHz
GHOSt-04	Wideband	ALH	LHCP	450	25.725 GHz
	Wideband	BLH	LHCP	450	26.25 GHz
GHOSt-05	Wideband	ARH	RHCP	450	25.725 GHz
	Wideband	CRH	RHCP	450	26.775 GHz
GHOSt-06	Wideband	ALH	LHCP	450	25.725 GHz
	Wideband	CLH	LHCP	450	26.775 GHz

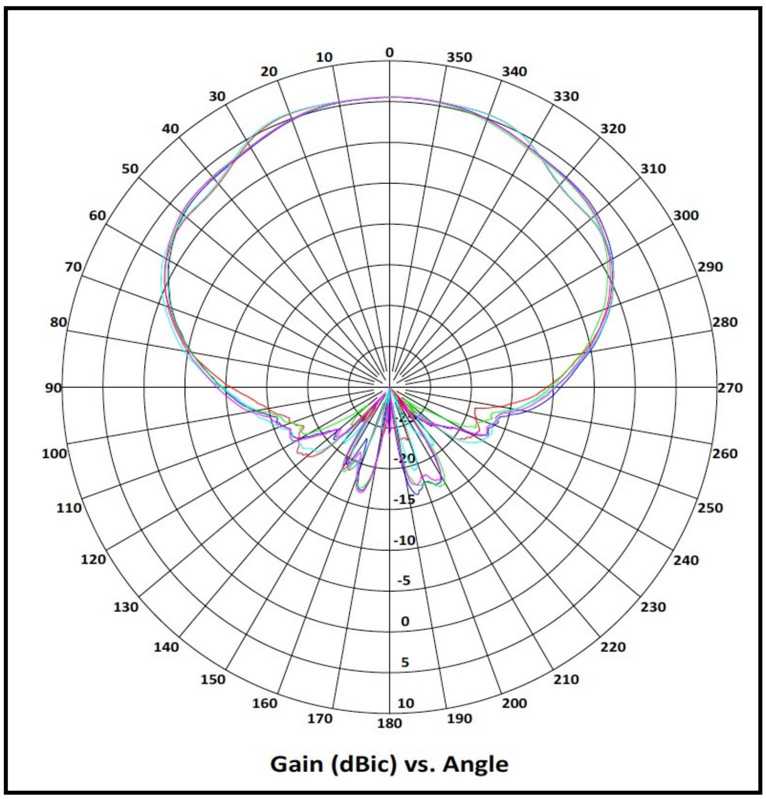
A.2.c Overall Description of Operations

The GHOSt satellites will collect remote sensing data via a hyperspectral optical payload. This collected payload data will be downlinked using Ka-band to earth stations located in Svalbard, Norway and Troll, Antarctica. S-band service uplinks will be from the earth stations located in Svalbard and Troll. S-band TT&C uplinks will be from earth stations located in Tromsø, Norway, and Svalbard. UHF TT&C downlinks will be to earth stations located in Santa Clara, California and Tromsø. As stated previously, the GHOSt satellites will transmit to the Globalstar constellation (space-to-space) in order to provide IDRS to customers for time-sensitive data.

A.3 SATELLITE ANTENNA BEAM TRANSMIT AND RECEIVE GAIN PATTERNS

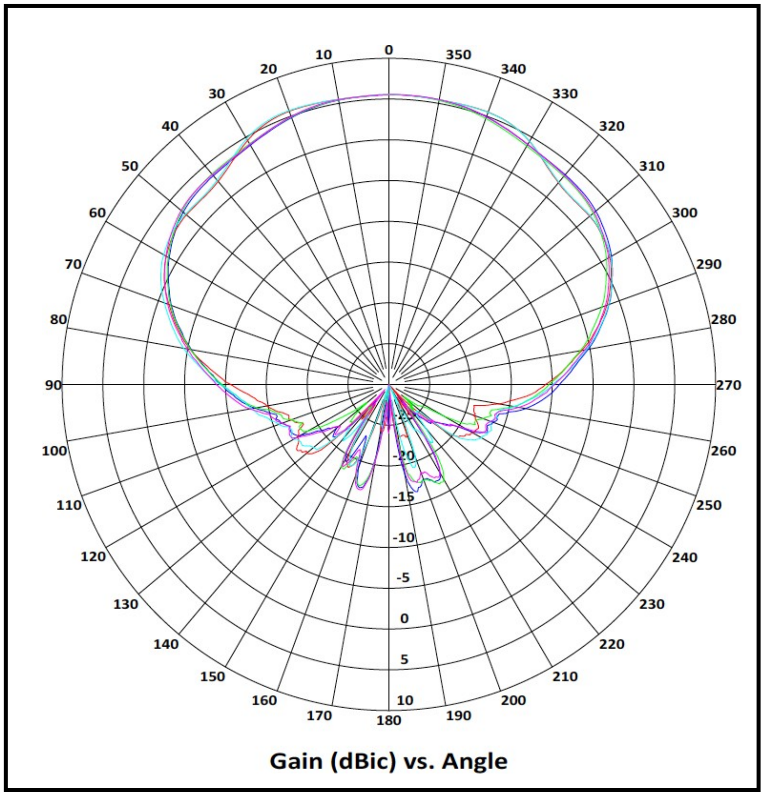
For the uplink service links in S-band (SCNT beam), there is one patch antenna on each of the GHOSt satellites with a peak receive antenna gain of 5.5 dBi. The receive antenna gain pattern is given in Figure A.3-1.

Figure A.3-1 S-Band receive antenna gain pattern (SCNT Beam)



For the uplink TT&C command link in S-band (SCMD beam), there will be two identical receive antennas mounted on each of the GHOSt satellites. The peak receive antenna gain for each antenna is 5.5 dBi and the receive gain pattern for these antennas is given in Figure A.3-2.

Figure A.3-2 S-Band receive antenna gain pattern (SCMD Beam)



There will be two identical UHF-band patch antennas mounted on each of the GHOSt satellites for the downlink transmissions (UTLM Beam). The peak transmit antenna gain for the UTLM beam is 0.19 dBi and the transmit gain patterns for three different elevation/azimuth cuts are given in Figures A.3-3a, A.3-3b, and A.3-3c.

Figure A.3-3a UHF-Band transmit antenna gain pattern, X-Z elevation cut (UTLM Beam)

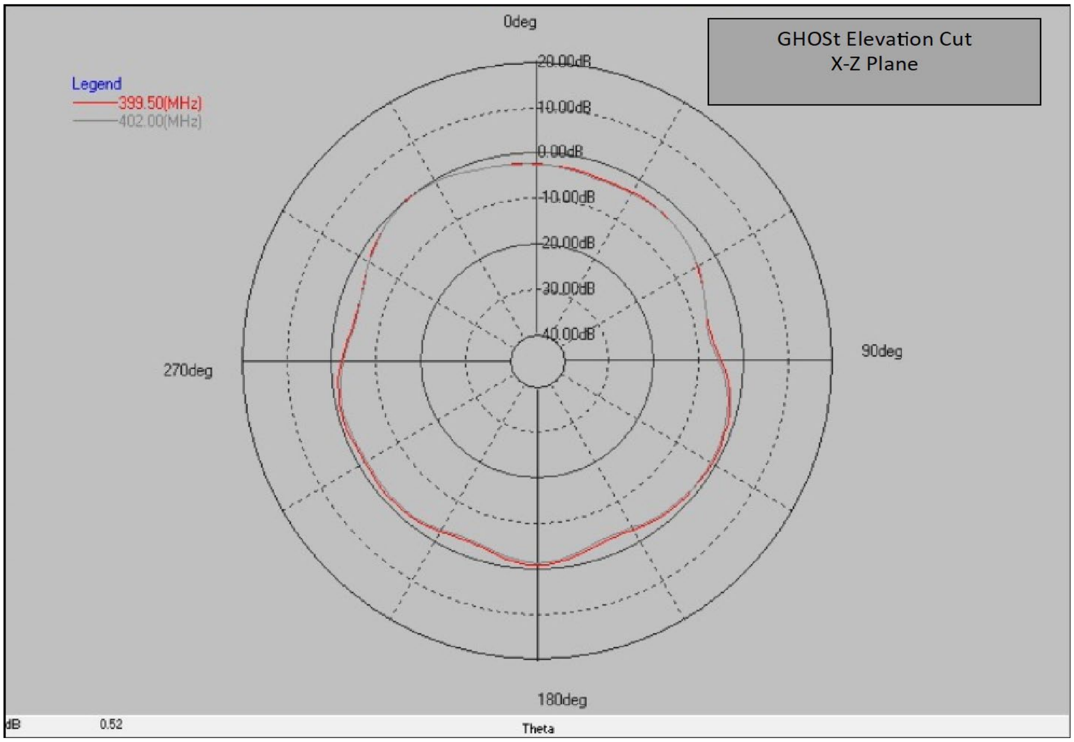


Figure A.3-3b UHF-Band transmit antenna gain pattern, X-Y elevation cut (UTLM Beam)

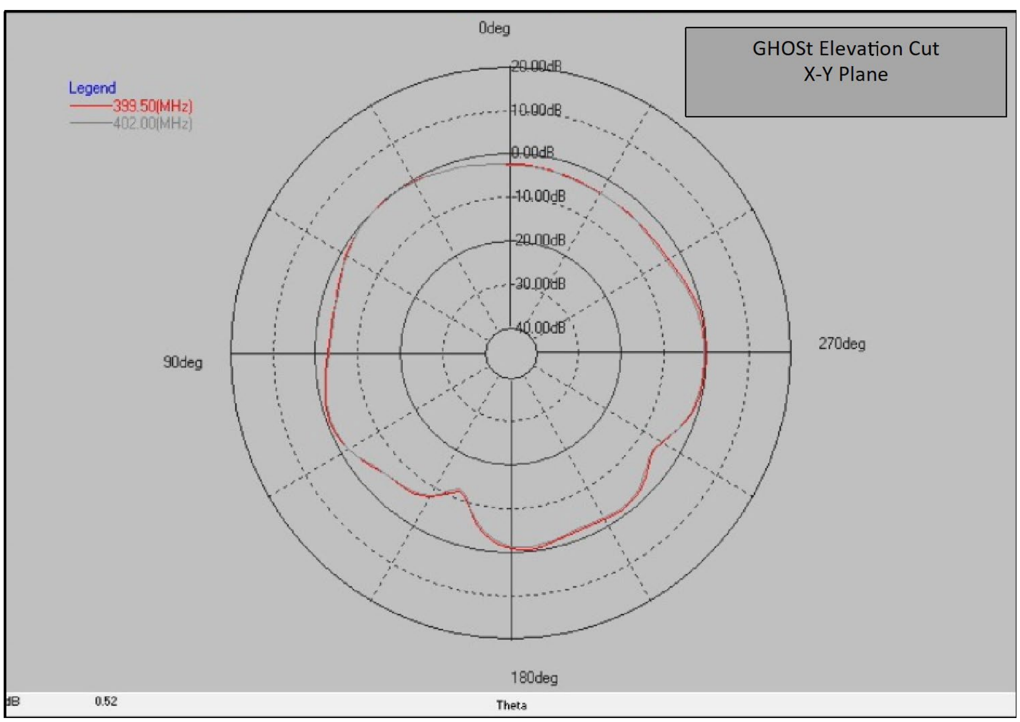
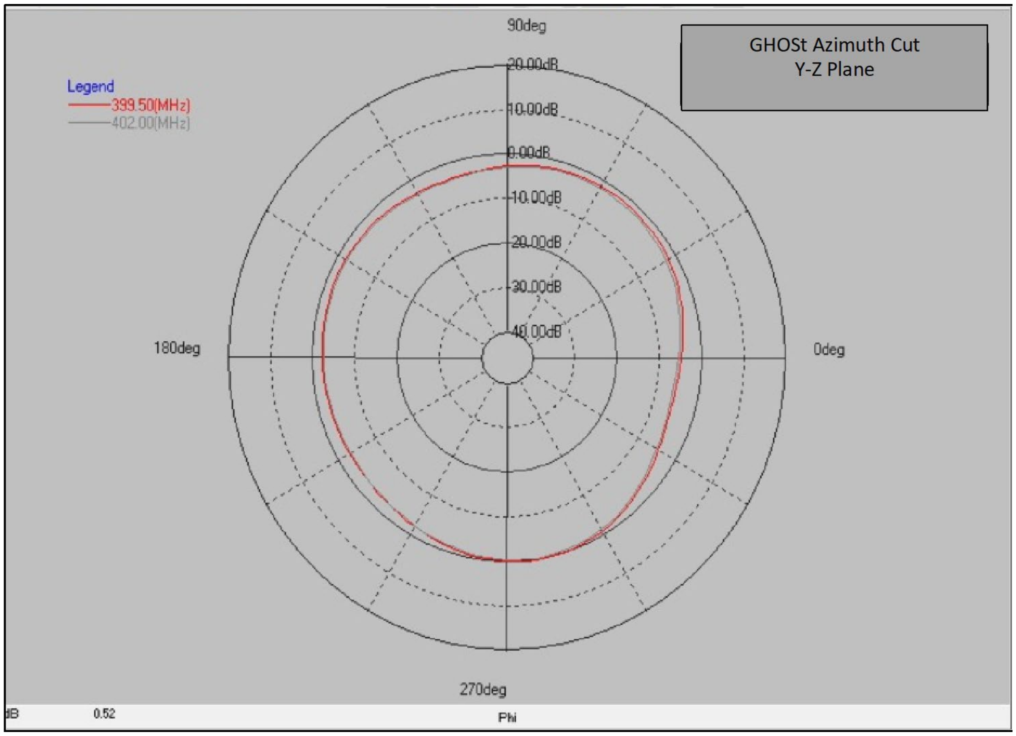
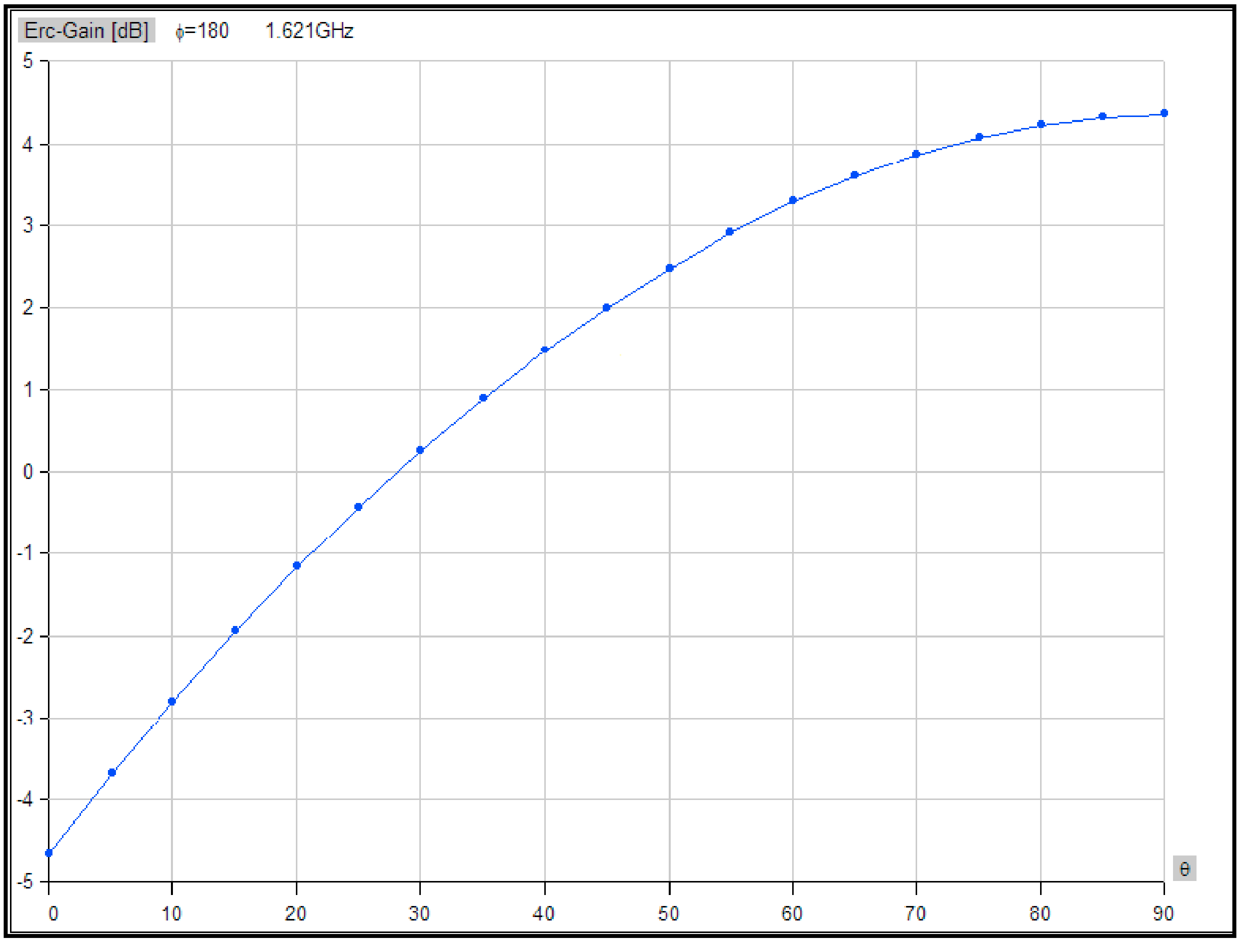


Figure A.3-3c UHF-Band transmit antenna gain pattern, Y-Z azimuth cut (UTLM Beam)



There will be one L-band transmit antenna on each GHOSt satellite for communications with satellites in the Globalstar constellation (LTLM Beam). The peak transmit antenna gain is 4.4 dBi with a 3 dB beamwidth of about 17°. The transmit gain pattern for this antenna is given in Figure A.3-4. This antenna is nominally directed toward zenith during use. The gain toward the Earth would be from -10 dBi to -50 dBi depending on the elevation angle from the Earth toward the satellite. The maximum EIRP toward the surface of the Earth would be -26 dBW.

Figure A.3-4 L-Band transmit antenna gain pattern (LTLM Beam)



There will be two Ka-band transmit antennas mounted on each GHOSt satellite for high-speed, wideband transmission of data to the earth stations located in Svalbard, Norway and Troll, Antarctica (Beams KaA, KaB, KaC, KaD, KaE and KaF). The peak transmit antenna gain of these antennas is 27.4 dBi and the relative transmit gain pattern for these antennas is given in Figures A.3-5a and A.3-5b for RHCP and LHCP, respectively. The multiple lines represent measurements taken at several frequencies from 25.5-27.0 GHz.

Figure A.3-5a Ka-Band transmit antenna gain pattern, RHCP (KaA - KaC Beams)

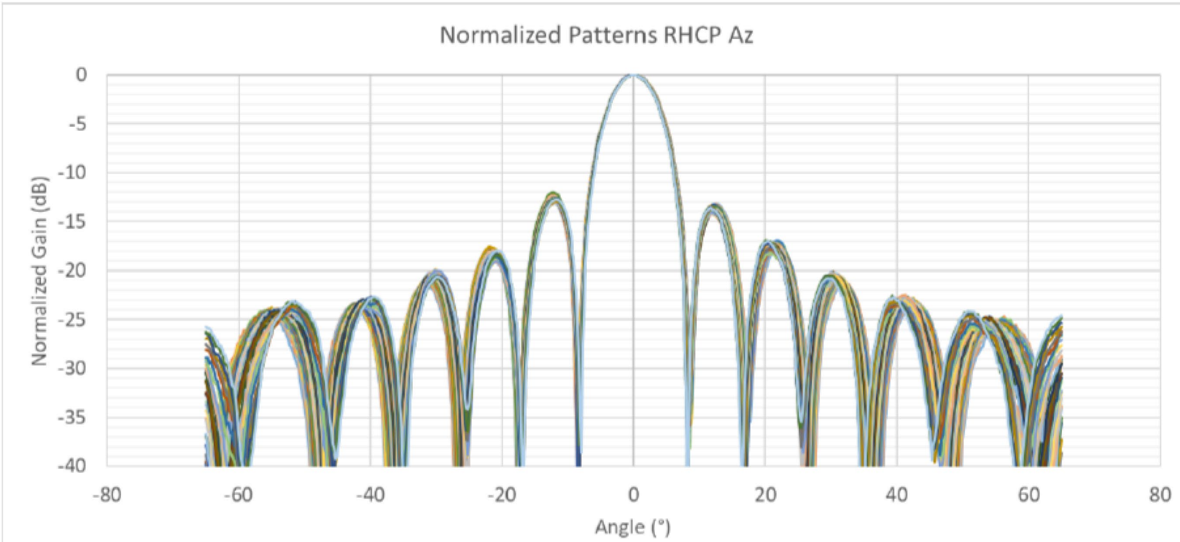
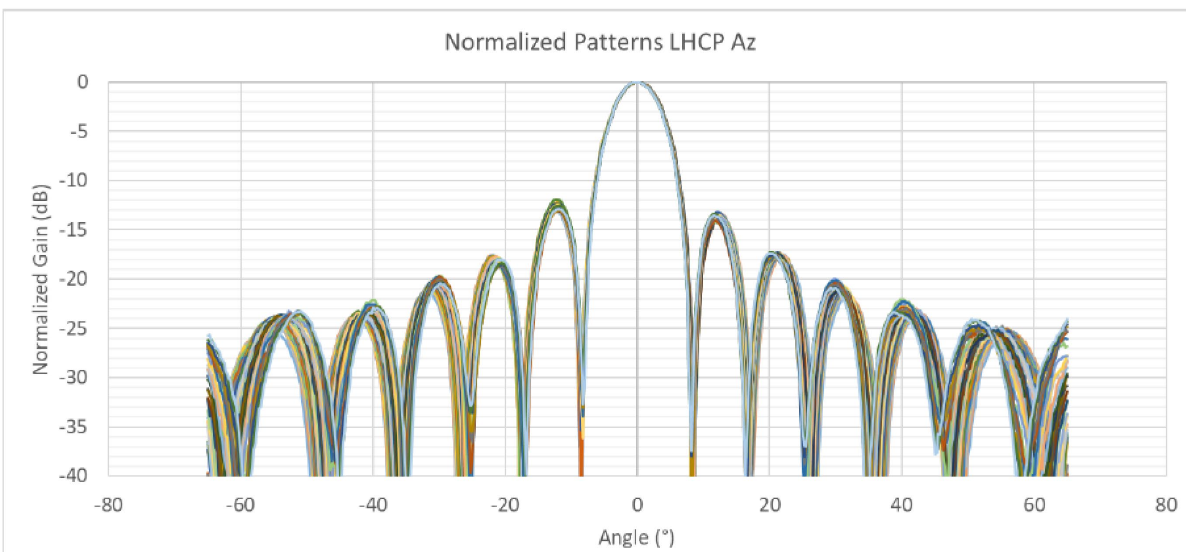
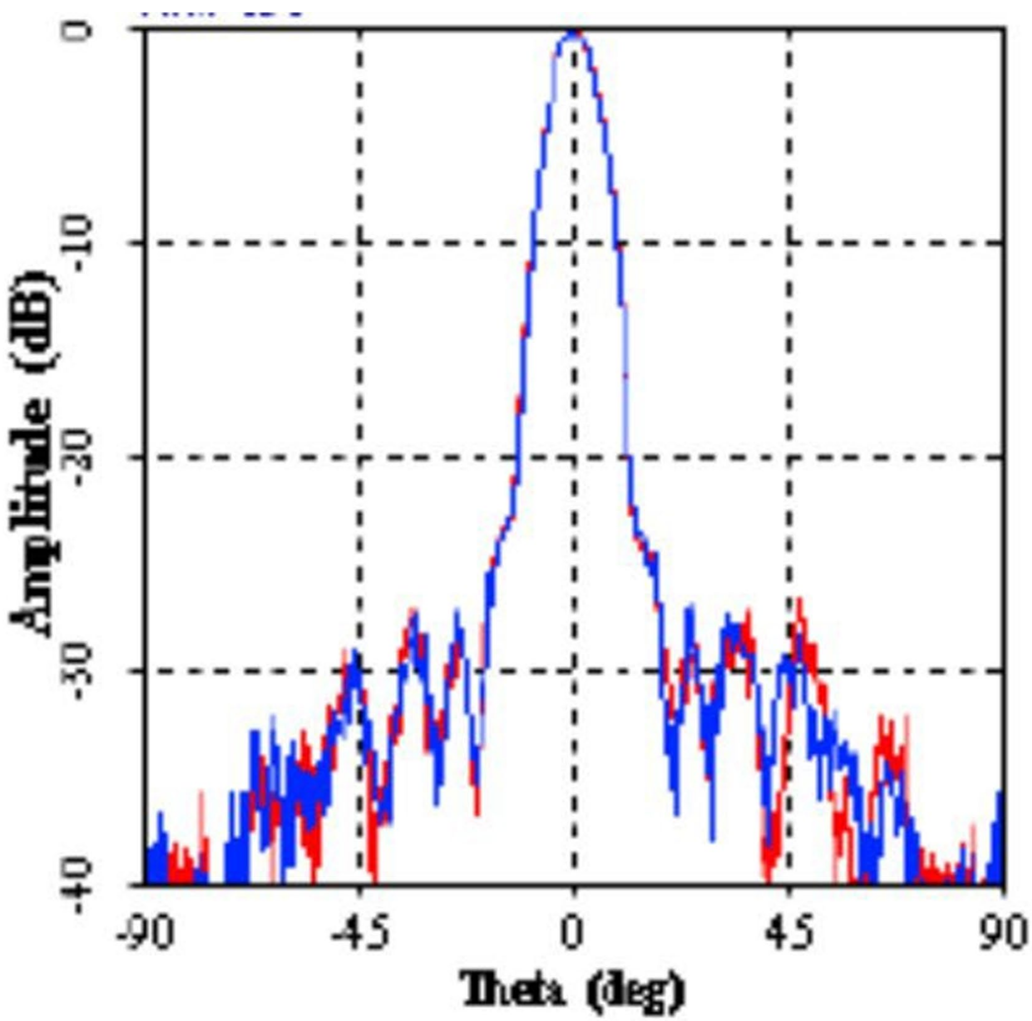


Figure A.3-5b Ka-Band transmit antenna gain pattern, LHCP (KaD - KaF Beams)



In addition to these Ka-band antennas, there will be one additional Ka-band antenna on both the GHOSt-01 and GHOSt-02 satellites, known as a Lens Aided Horn, which has a lower peak gain of 23.5 dBi. The relative transmit gain pattern for this antenna is given in Figure A.3-6.

Figure A.3-6 Ka-Band transmit antenna gain pattern (KaG and KaH Beams)



A.4 EARTH STATION ANTENNA TRANSMIT AND RECEIVE GAIN PATTERNS

The antenna gain patterns for the S-band earth station transmit antennas for both the TT&C and service links can be defined by the following gain envelope pattern, which is identical to the pattern given in Recommendation ITU-R M.694-1:

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

$$G = G_1 \qquad \text{for } \varphi_m \le \varphi < \varphi_r$$

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

$$G = 0 \qquad \text{for } \varphi_b \le \varphi \le 180°$$

where:

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

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

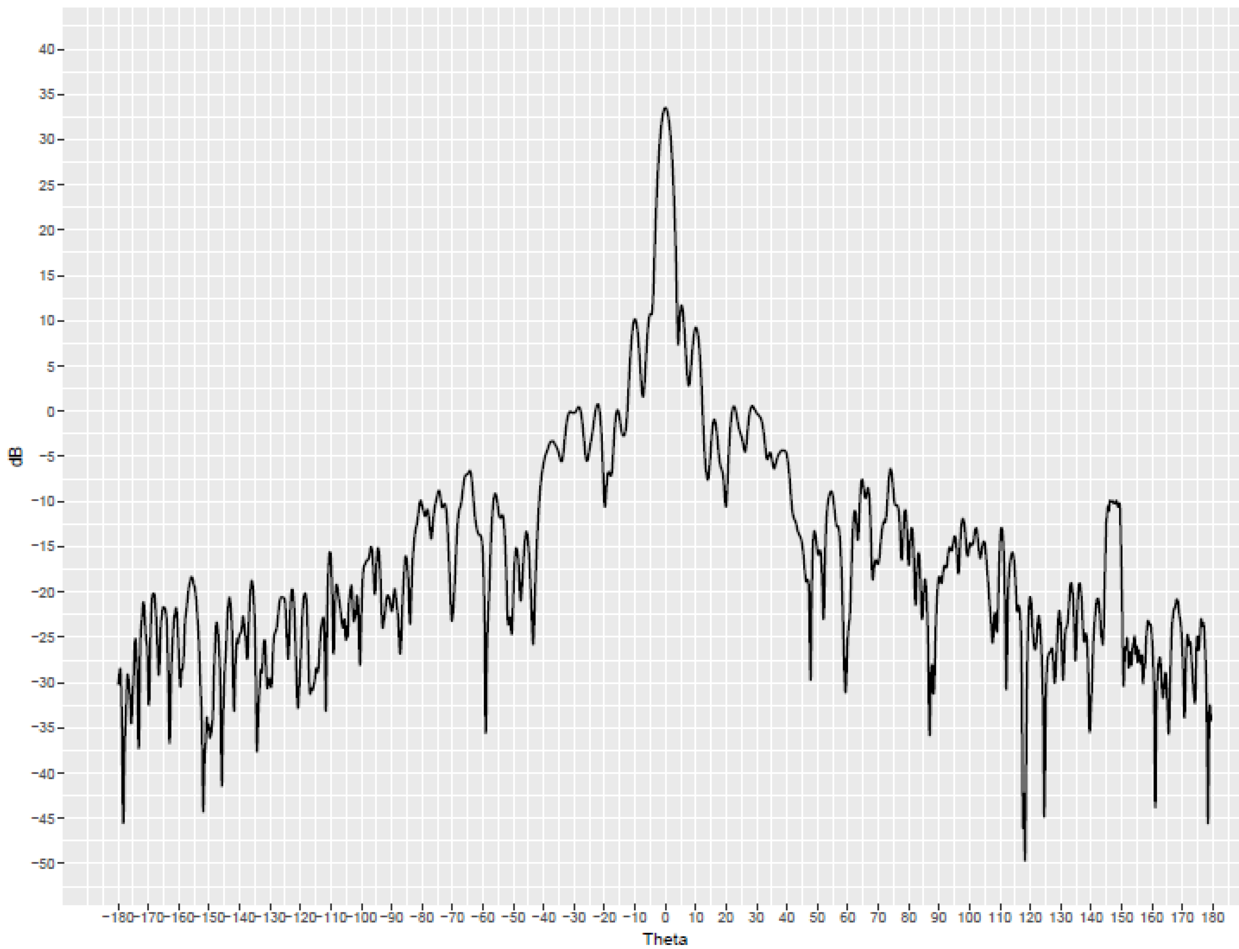
$$\varphi_m = 20\,\lambda/D\,\sqrt{G_{max} - G_1}\,.$$

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

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

For the 1.5 meter antenna located in Tromsø, the maximum transmit gain is 27.5 dBi. For the 3.0 meter antennas located at Svalbard and Troll, the maximum transmit gain is 33.0 dBi. The measured antenna gain pattern for the 3.0 meter antennas is shown in Figure A.4-1.

Figure A.4-1 Svalbard and Troll S-Band measured earth station transmit antenna gain pattern



The UHF receive earth station antenna located in Santa Clara has a peak gain of 21.0 dBi and the relative gain pattern is shown in Figure A.4-2. For the UHF receive earth station antenna located in Tromsø, the peak antenna gain is 20.5 dBi and the relative gain pattern is shown in Figure A.4-3.

Figure A.4-2 Santa Clara earth station receive antenna gain pattern (Relative to peak)

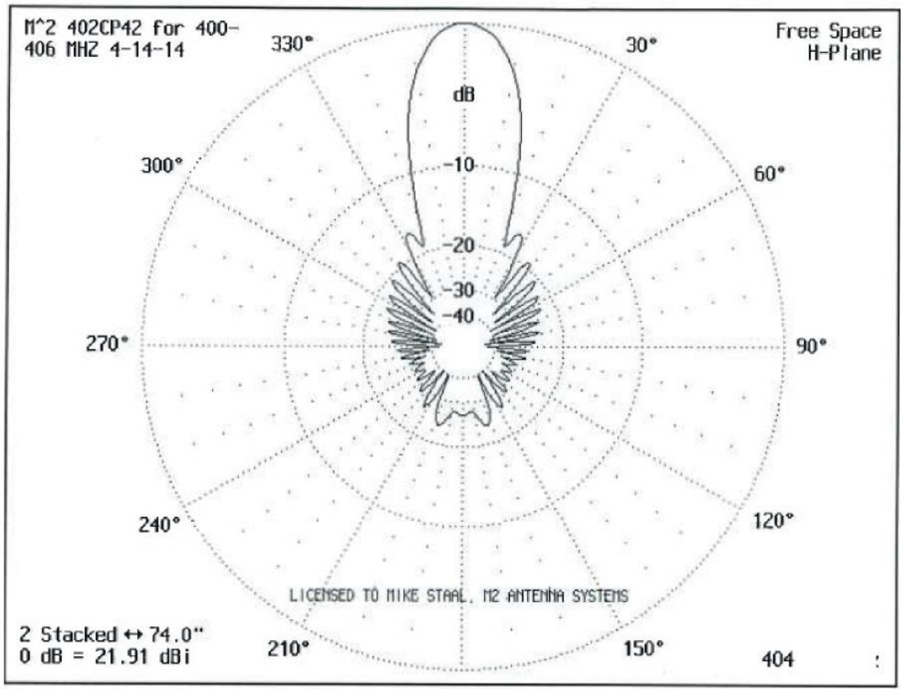
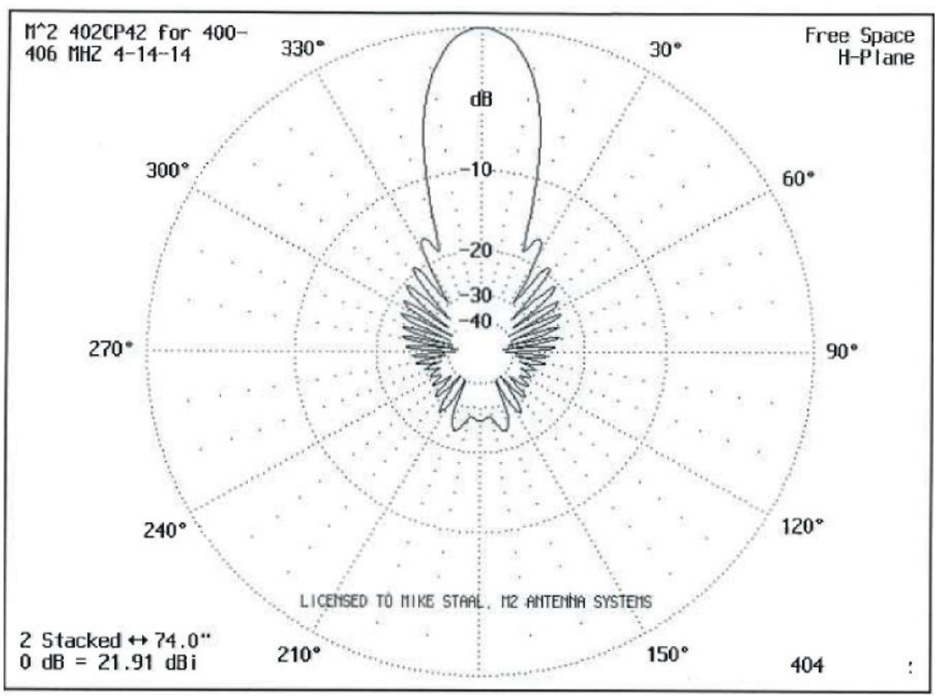
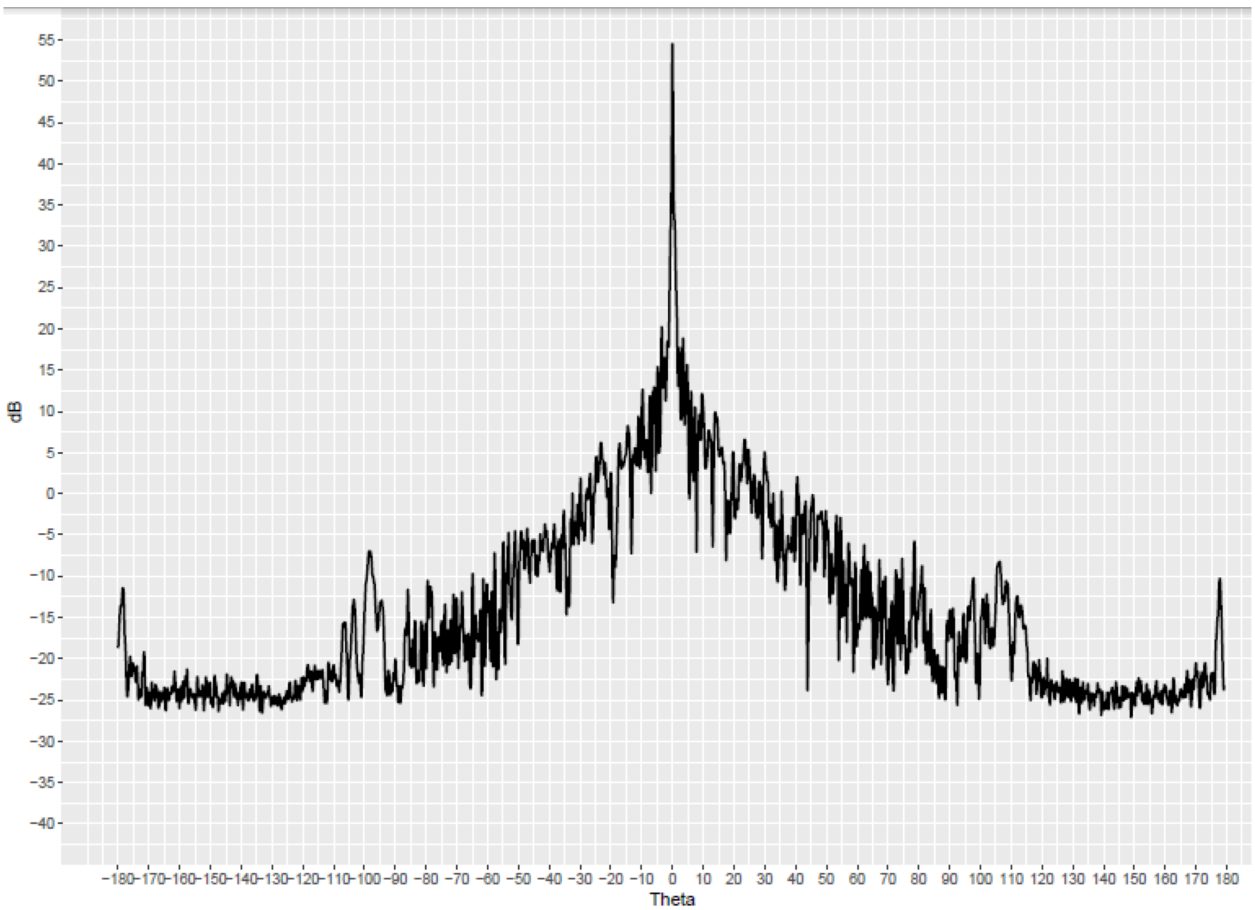


Figure A.4-3 Tromsø earth station receive antenna gain pattern (Relative to peak)



The Ka-band receive earth stations located in Svalbard and Troll will be identical with a maximum receive gain of about 54.4 dBi depending on the specific transmit center frequency. The measured off-axis antenna gain pattern for these antennas is shown in Figure A.4-4.

Figure A.4-4 Ka-Band earth station receive antenna gain pattern



A.5 SATELLITE ANTENNA GAIN CONTOURS

OSK used a map system provided online by Google Earth® to generate the diagrams for the gain contours of each beam on the GHOSt satellites at an orbital altitude of 525 km. 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, California; 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. OSK has also attached the beam contours to its Schedule S as GIMS-readable files, filed concurrently with this application.

The Ka-band transmit antenna gain contours for the KaA through KaF beams and for the KaG and KaH beams when a GHOSt satellite is directly above the Svalbard earth station are shown in Figure A.5-1 and Figure A.5-2, respectively.

Figure A.5-1 KaA through KaF transmit antenna gain contours - Svalbard

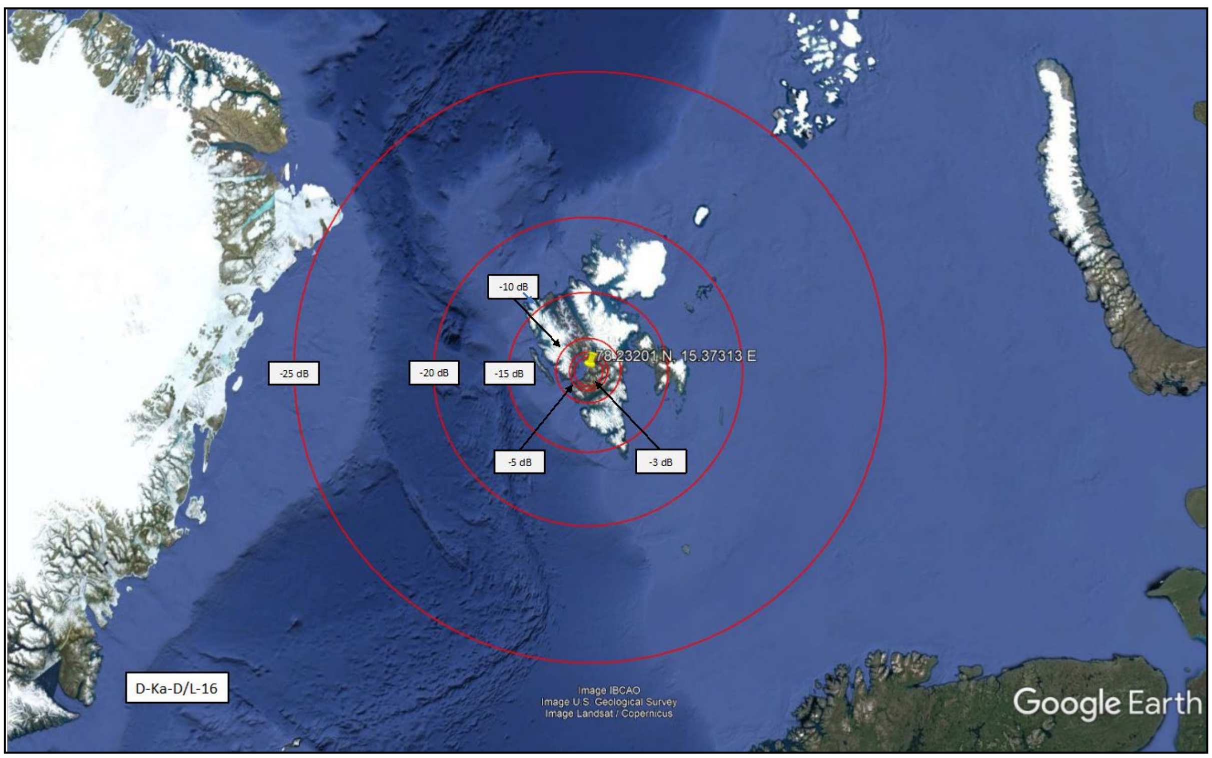
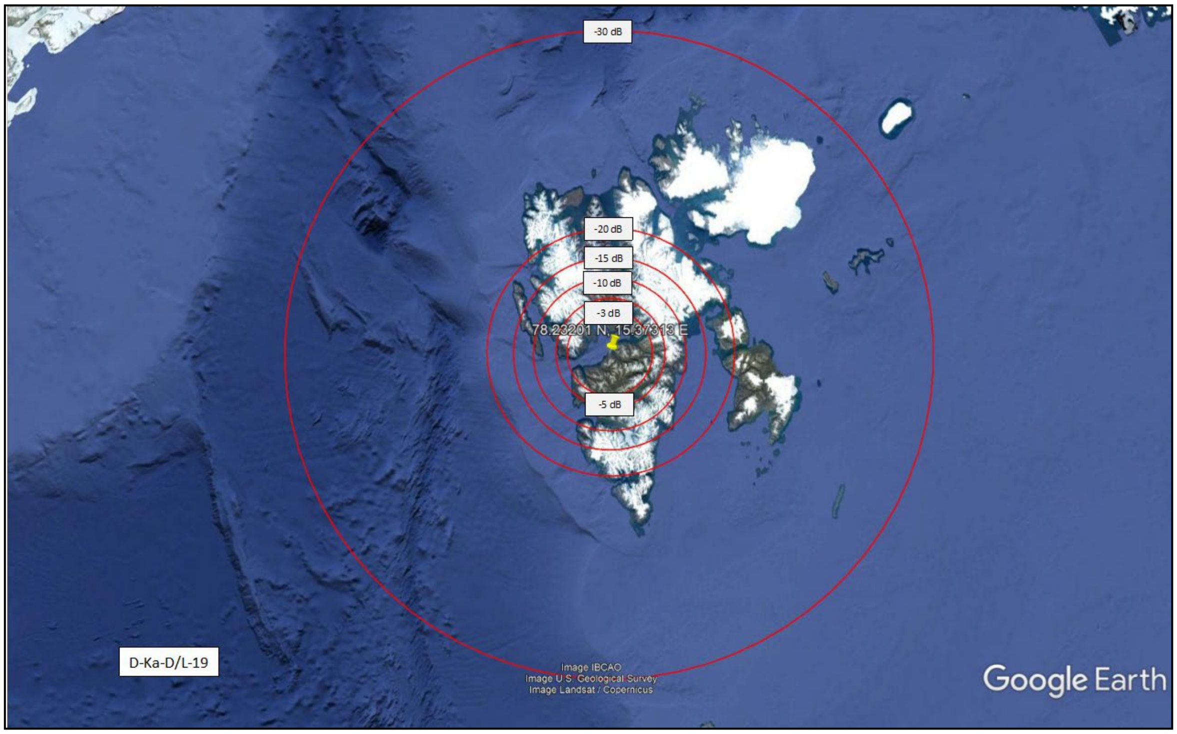


Figure A.5-2 KaG and KaH transmit antenna gain contours - Svalbard



The Ka-band transmit antenna gain contours for the KaA through KaF beams and for the KaG and KaH beams when a GHOSt satellite is directly above the Troll earth station are shown in Figure A.5-3 and Figure A.5-4, respectively.

Figure A.5-3 KaA through KaF transmit antenna gain contours - Troll

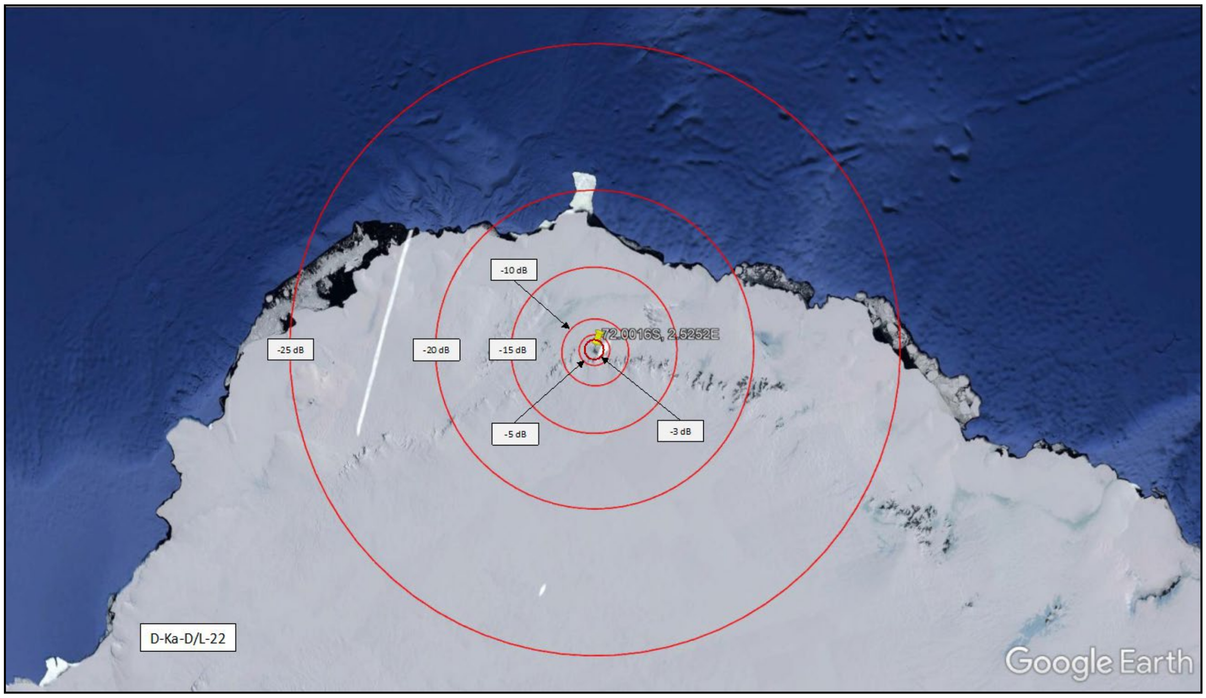
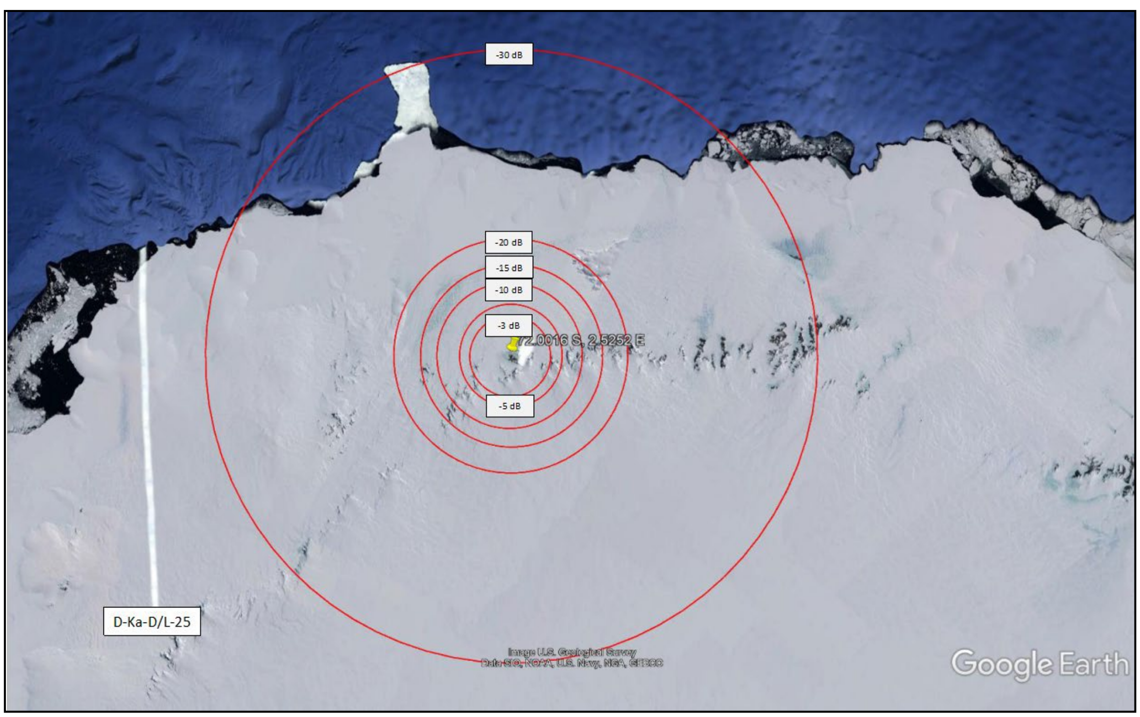


Figure A.5-4 KaG and KaH transmit antenna gain contours - Troll



The S-band receive antenna gain contours for the SCMD beams when a GHOSt satellite is directly above Tromsø and Svalbard are shown in Figure A.5-5 and Figure A.5-6, respectively.

Figure A.5-5 SCMD receive antenna gain contours – Tromsø

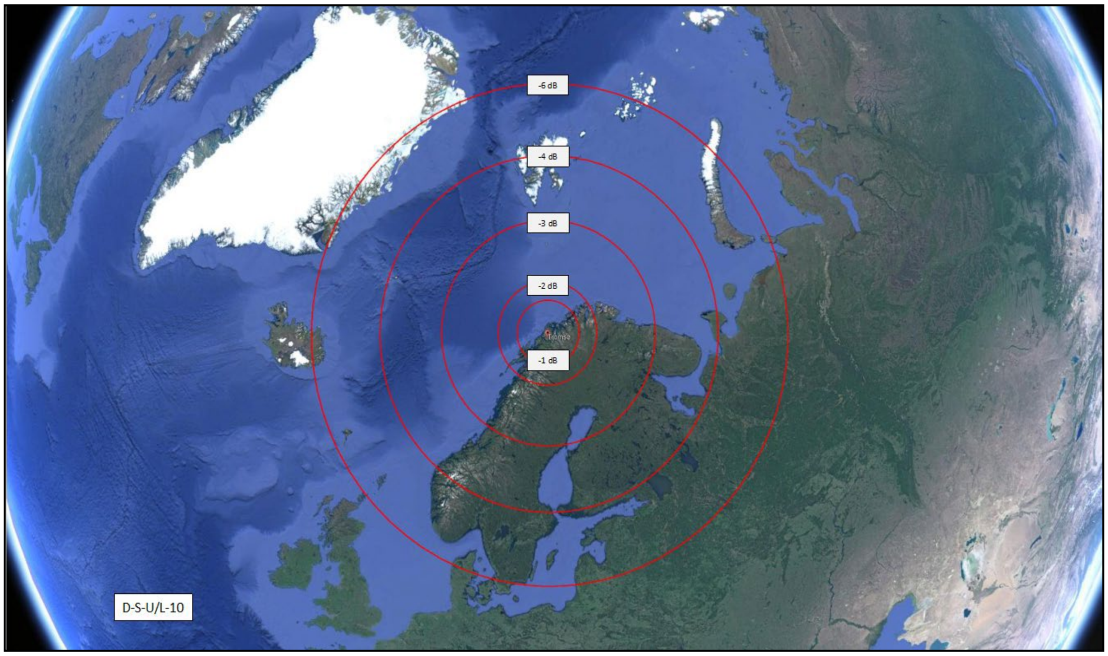
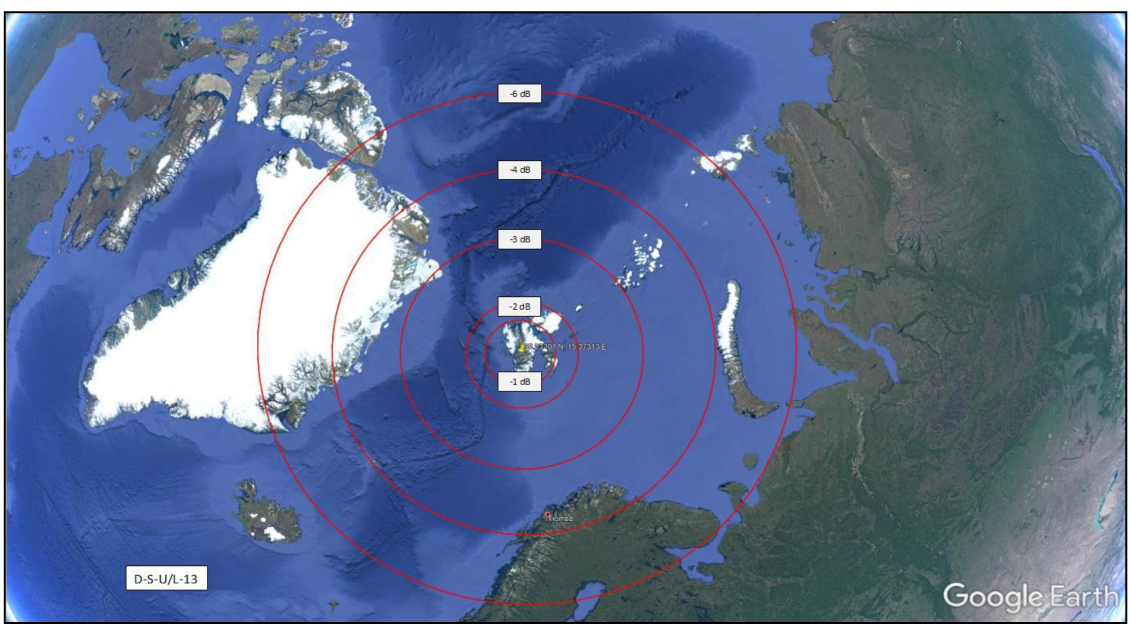


Figure A.5-6 SCMD receive antenna gain contours – Svalbard



The S-band receive antenna gain contours for the SCNT beams when a GHOSt satellite is directly above the Svalbard and Troll earth stations are shown in Figure A.5-7 and A.5-8, respectively.

Figure A.5-7 SCNT receive antenna gain contours – Svalbard

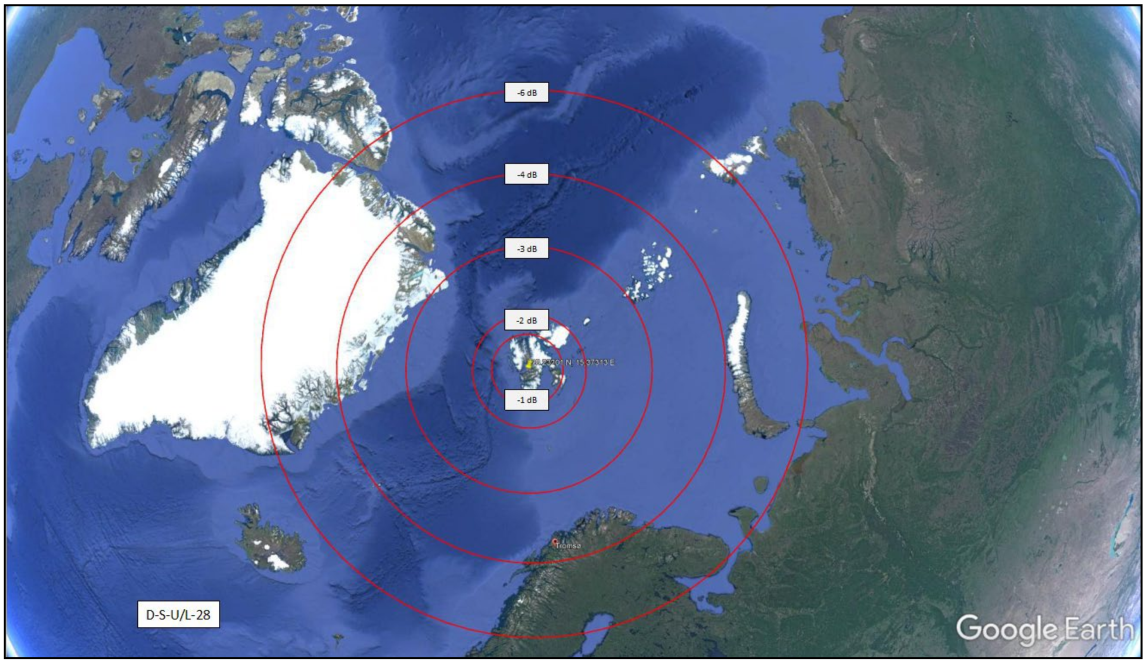
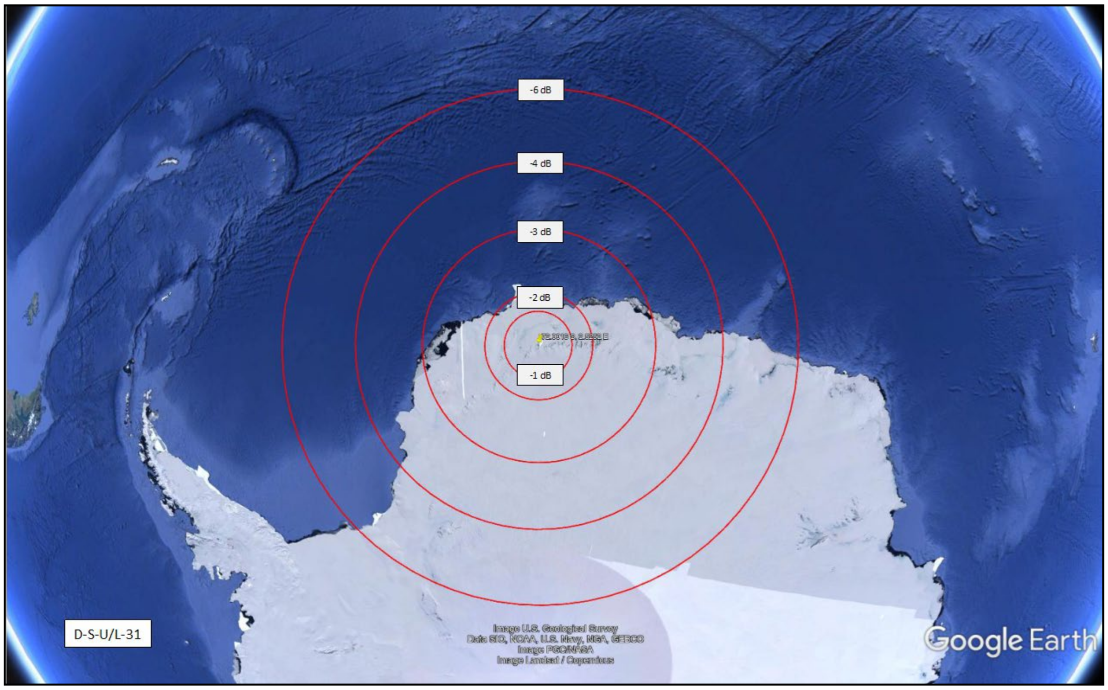


Figure A.5-8 SCNT receive antenna gain contours – Troll



All six satellites in the GHOSt constellation will use the UHF spectrum in the same manner. Each of the satellites will use an omni-direction antenna system with a dipole-like pattern (Figures A.3-3a through A.3-3c show the transmit antenna gain patterns). While the satellites will nominally fly with the peak gain of the antenna directed in the nadir direction, the UHF system must also be capable of being used at times when the spacecraft will have other inertial orientations, including if the spacecraft is 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. During these times, it is insufficient to produce beam contours that show specific gain levels relative to the peak gain when transmitting to the earth station that would be envelope all of the possibilities. Rather, OSK has provided tables that show the maximum and minimum transmit antenna gain values and the resulting maximum and minimum signal levels at the surface of the Earth for various elevation angles during these periods when the satellite is operating within range of the earth stations in Santa Clara and Tromsø. These levels are statistical in nature but, will vary only between a nominal minimum and nominal maximum gain level.

The minimum and maximum signal power levels at the surface of the Earth, are calculated as a function of the elevation angle to a GHOSt satellite from the specific location on the Earth. The maximum and minimum possible isotropic signal power levels are computed using the path loss for a given slant range associated with a particular elevation angle from a location on the Earth to a GHOSt satellite, the input power to the antenna (4 Watts less 1 dB of loss), and the highest and lowest possible transmit antenna gains, as measured during the satellite development program. The maximum transmit EIRP for these downlinks is 5.21 dBW in a 40 kHz bandwidth. Table A.5-1 shows the minimum and maximum isotropic signal power levels at the surface of the Earth for varying satellite off-nadir pointing angles and elevation angles at the earth station.

Table A.5-1 UTLM minimum and maximum isotropic signal levels at the surface of the Earth for varying satellite off-nadir / elevation angles from the Earth

UHF Pattern	Range to G.S.	Range to G.S.	Beam Contour, Off NADIR Angle	Elev. Angle from G.S.	Antenna Gain @ φ Contour		Isotropic Signal Level @ G.S.	
TUMBLE MODE	*D (km):*	*Path Loss (dB):*	η = φ (deg.): *	ε (deg.)	Max.	Min.	Max.	Min.
525 km Orbit	525.00	138.9	0.0	90.0	0.19 dBi	-12.71 dBi	-133.7 dBW	-146.6 dBW
ε=0.0033	527.17	139.0	5.0	84.6	0.19 dBi	-12.71 dBi	-133.7 dBW	-146.6 dBW
	533.78	139.1	10.0	79.2	0.19 dBi	-12.71 dBi	-133.9 dBW	-146.8 dBW
	545.14	139.2	15.0	73.7	0.19 dBi	-12.71 dBi	-134.0 dBW	-146.9 dBW
	561.77	139.5	20.0	68.3	0.19 dBi	-12.71 dBi	-134.3 dBW	-147.2 dBW
	614.78	140.3	30.0	57.2	0.19 dBi	-12.71 dBi	-135.1 dBW	-148.0 dBW
	706.47	141.5	40.0	45.9	0.19 dBi	-12.71 dBi	-136.3 dBW	-149.2 dBW
	871.23	143.3	50.0	34.0	0.19 dBi	-12.71 dBi	-138.1 dBW	-151.0 dBW
	1009.09	144.6	55.0	27.6	0.19 dBi	-12.71 dBi	-139.4 dBW	-152.3 dBW
	1228.81	146.3	60.0	20.4	0.19 dBi	-12.71 dBi	-141.1 dBW	-154.0 dBW
	1707.39	149.2	65.2	10.7	0.19 dBi	-12.71 dBi	-144.0 dBW	-156.9 dBW

A.6 GHOST SATELLITE POWER FLUX DENSITY COMPLIANCE

A.6.a GHOSt Power Flux Density at the Earth's Surface for EESS Operations in the 25.5 – 27.0 GHz band

Section 25.208 of the Commission's rules requires that the power flux density ("PFD") at the Earth's surface produced by emissions form a space station in the EESS in the 25.5-27.0 GHz band, for all conditions and for all methods of modulation, shall 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) 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.

These limits relate to the PFD which would be obtained under assumed free-space propagation conditions. It is noted that these PFD limits are the same as the ones contained in Article 21, Table **21-4** of the ITU Radio Regulations.

For the 450 MHz wideband downlink channels using Beams KaA through KaF, the maximum transmitted EIRP is 33.2 dBW and the maximum transmitted EIRP density is –52.9 dBW/Hz and an EIRP density in any 1 MHz of 7.1 dBW based upon the half-power bandwidth of the signal being 409.1 MHz. Table A.6.a-1 provides the calculations for the maximum PFD at the surface of the Earth for varying elevation angles for Beams KaA through KaF for the operational orbital altitude of 525 km. For the narrowband downlinks using Beams KaG and KaH, the maximum transmitted EIRP is 21.2 dBW in the 86.4 MHz channel and the maximum transmitted EIRP density is -57.4 dBW/Hz and an EIRP density in any 1 MHz of 2.6 dBW based upon the half-power bandwidth of the signal being 72 MHz. Table A.6.a-2 provides the results of the calculations of the maximum PFD at the surface of the Earth for varying elevation angles for Beams KaG and KaH for the operational orbital altitude of 525 km. Figure A.6.a-1 demonstrates the compliance of all of the Ka-band downlink EESS emissions with the limits given in both the Commission's rules (Section 25.208) and Table **21-4** of the ITU Radio Regulations.

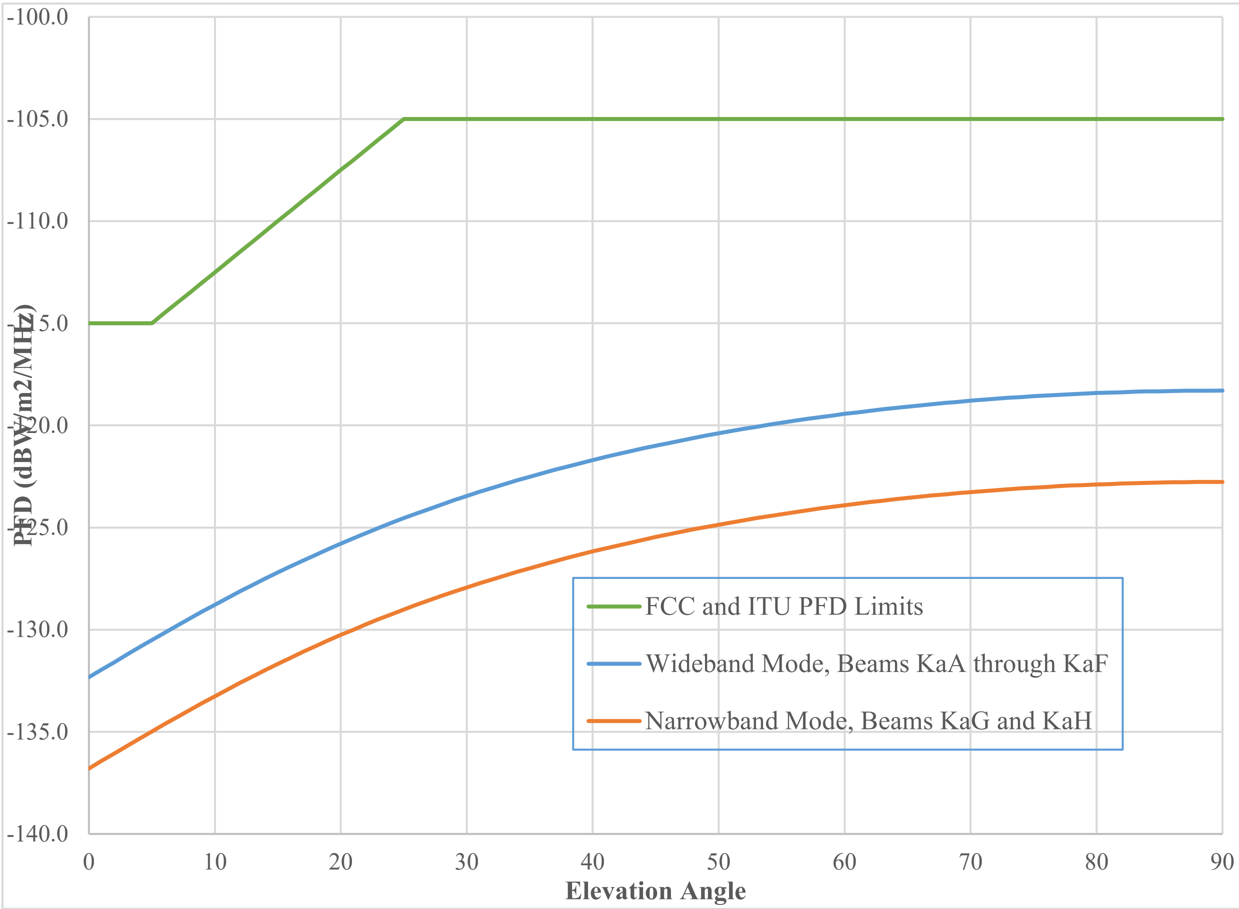
Table A.6.a-1 Maximum PFD at the surface of the Earth for Beams KaA through KaF

Elevation Angle (°)	Distance (km)	PFD (dBW/m²/MHz)
0	2640.6	-132.3
5	2142.6	-130.5
10	1755.9	-128.8
15	1463.3	-127.2
20	1243.7	-125.8
25	1077.9	-124.5
30	951.3	-123.5
35	853.4	-122.5
40	776.8	-121.7
45	716.2	-121.0
50	667.9	-120.4
55	629.4	-119.9
60	598.7	-119.4
65	574.6	-119.1
70	555.9	-118.8
75	542.0	-118.6
80	532.5	-118.4
85	526.9	-118.3
90	525.0	-118.3

Table A.6.a-2 Maximum PFD at the surface of the Earth for Beams KaG and KaH

Elevation Angle (°)	Distance (km)	PFD ($dBW/m^2/MHz$)
0	2640.6	-136.8
5	2142.6	-135.0
10	1755.9	-133.3
15	1463.3	-131.7
20	1243.7	-130.3
25	1077.9	-129.0
30	951.3	-128.0
35	853.4	-127.0
40	776.8	-126.2
45	716.2	-125.5
50	667.9	-124.9
55	629.4	-124.4
60	598.7	-123.9
65	574.6	-123.6
70	555.9	-123.3
75	542.0	-123.1
80	532.5	-122.9
85	526.9	-122.8
90	525.0	-122.8

Figure A.6.a-1 Compliance with FCC and ITU PFD limits Beams KaA through KaH



A.6.b GHOSt PFD at the Earth's Surface for TT&C Operations in the 400.15 – 401MHz band

Appendix 5 of the Radio Regulations contains "trigger" levels for the PFD in the 400.15-401 MHz frequency band from transmitting satellites at the surface of the Earth that govern the need to coordinate with the terrestrial services of an administrations in whose territory these PFD levels are exceeded. Specifically, in the 400.15-401 MHz frequency band, coordination of a space station of the Mobile-Satellite Service (space-to-Earth) with respect to terrestrial services is required only if the PFD produced by the space station exceeds -125 dB(W/(m^2•4 kHz)).

As the UHF downlinks are only transmitted when visible to the GHOSt earth stations, the number of countries on which the "trigger" level could be exceeded will be limited to the countries that are located closest to the earth stations. For the UHF downlinks to the earth station in Santa Clara, this will only be an issue if the "trigger" level is exceeded in Canada or Mexico. For the UHF downlinks to the Tromsø earth station, there is the potential for this level to be exceeded in the countries near Northern Norway (Finland, Sweden, or Russia). The maximum transmitted EIRP of the UTLM beam is 5.21 dBW and the bandwidth of this emission is 40 kHz. At the shortest distance from the satellite to the Earth (525 km at an elevation angle of 90°), the maximum PFD produced by the GHOSt satellites at the surface of the Earth is -130.2 dB(W/(m^2•4 kHz)). This level does not exceed the threshold given in the ITU Radio Regulations and, therefore, no coordination of the UHF downlink will be necessary with the terrestrial stations of the administrations that are nearest to the GHOSt earth stations.

A.6.c GHOSt PFD in the 1615-1617.5 MHz band

There are no applicable PFD limits in the 1615-1617.5 MHz band in the ITU Radio Regulations or the Commission's rules. However, Schedule S requires that PFDs be supplied for any transmitting beam. For Beam LTLM, the PFD values given in Schedule S are those that would occur at the Globalstar orbital altitude for various elevation angles.

A.7 ANALYSIS OF GHOST INTERFERENCE AND SHARING CONSIDERATIONS

In general, the GHOSt constellation will operate in a manner such that current and future operators will not be constrained and the spectrum can be easily shared. Among other factors, the GHOSt satellites will only be transmitting to and receiving from a small number of earth stations and only when a GHOSt satellite is visible to each specific earth station, which occurs for limited periods of time during each orbit.

A.7.a Analysis of GHOSt Interference Potential to Geostationary Data Relay Satellite Systems

This section will address the potential interference to Federal and international Data Relay Satellite ("DRS") systems from the GHOSt satellite downlinks in the 25.5-27.0 GHz band. Radio Regulation **5.536A** states that "earth stations in the Earth exploration-satellite service or in the space research service should be operated taking into account the most recent version of Recommendation ITU-R SA.1862." Recommendation ITU-R SA.1862, "Guidelines for efficient use of the band 25.5-27.0 GHZ by the Earth exploration-satellite service (space-to-Earth) and space research service (space-to-Earth)", specifies a PFD level at any DRS location on the geostationary satellite orbit. Applicable to the GHOSt satellite system is recommends 5, "EESS and SRS satellites in non-geostationary orbits with space-to-Earth satellite links should not produce a PFD greater than -133 dB(W/(m^2•MHz)) at any DRS satellite location on the geostationary orbit. This limit may be exceeded no more than 0.1% of the time for [NGSO] systems with altitudes greater than 1370 km."

Recommendation ITU-R SA.1862 notes that there are two potential geometries where NGSO systems could interfere with a geostationary DRS satellite:

- Case 1: When the victim DRS satellite is directly above one of the satellites in the NGSO system while the satellite is transmitting to its intended earth station. In this case the transmission toward the DRS satellite would be from the backlobe of the NGSO satellite transmit antenna.
- Case 2: When the victim DRS satellite is directly in-line with the NGSO satellite that is transmitting to its intended earth station. This occurs when the NGSO satellite is at very low elevation angles from its intended earth station (near 0°).

The two earth stations receiving signals in this frequency band are located in Svalbard, Norway at 78.23°N and 15.41°E and Troll, Antarctica at 72.0°S and 2.53°E. As the GHOSt satellites will only transmit when visible to these earth stations, there is no situation where Case 1 could occur as the GHOSt satellite would never be transmitting when crossing the Equator or even at lower latitudes.

Case 2 may occur occasionally, for very short periods of time. The geometry is shown in Figures A.7.a-1, A.7.a-2, and A.7.a-3 for the earth station located in Svalbard, which is located in the vicinity of the North Pole. The geometry for passes of the GHOSt satellite over Troll will be similar except the figures would be inverted as the Troll earth station is located in the vicinity of the South Pole.

Figure A.7.a-1 Illumination of the geostationary arc from a transmitting GHOSt satellite as viewed from within the geostationary orbit plane

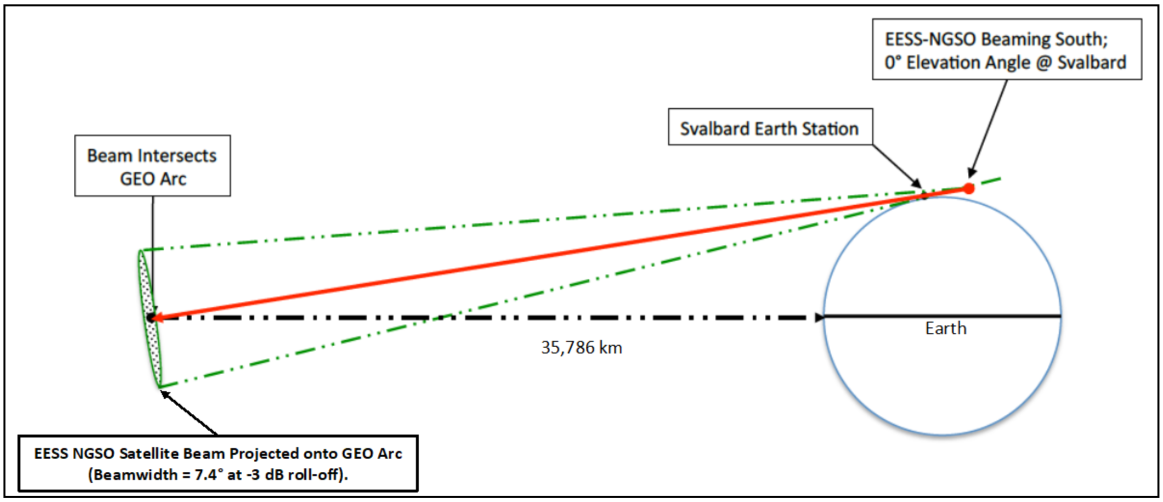


Figure A.7.a-2 Illumination of the geostationary arc from a transmitting GHOSt satellite as viewed from approximately normal to the geostationary orbit plane with the GHOSt satellite beaming due South

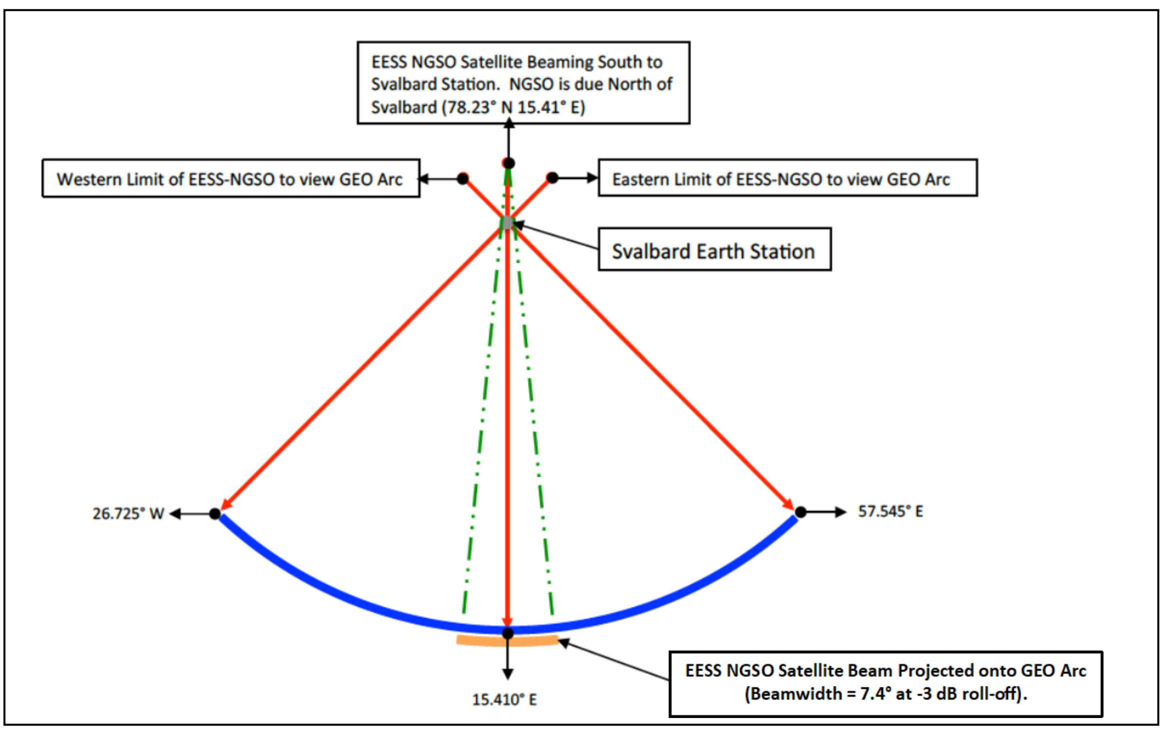
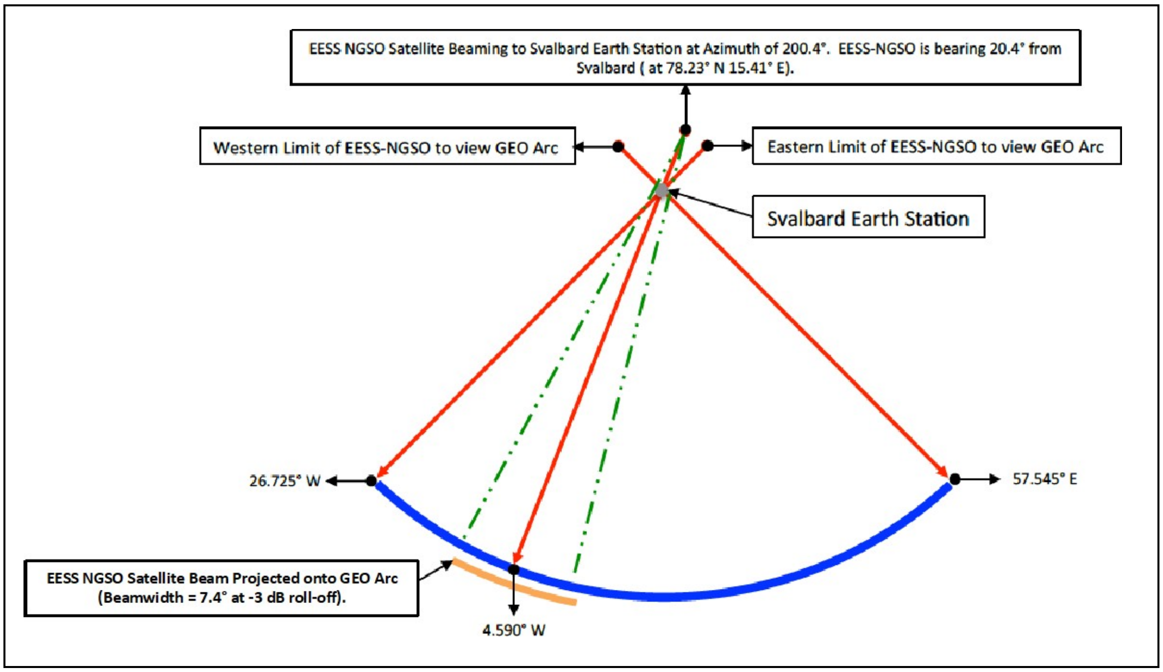


Figure A.7.a-3 Example when the GHOSt satellite is directing its beam to the worst-case azimuth and elevation angle toward the geostationary orbit plane



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, the emissions from a GHOSt satellite will also be directed past Svalbard at grazing angle and will arrive at certain locations on the geostationary arc. This can occur at epochs very near the beginning of a pass and very near the end of the path as the satellite 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 satellite illuminates the geostationary arc at 15.4°E. The beamwidth of a GHOSt spacecraft Ka-band antenna is 7.4° and so the geostationary 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 geostationary arc. At this location of the GHOSt spacecraft (when it is at just 0° elevation angle to Svalbard) a geostationary satellite at 15.4°E would be at an elevation angle from the GHOSt spacecraft of 3.1°. 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 away from the geostationary arc. Within approximately 60 seconds of the acquisition of signal to the loss of signal at Svalbard, the beam will have rolled off by more than 10 dB as seen at the geostationary arc. Hence, the opportunity for this alignment to occur at this geostationary arc location is approximately 2 minutes per day per satellite.

Other GHOSt satellites may be directing their beams at very low elevation angles toward Svalbard but, from other positions than with their satellite antennas beaming due South. These satellites will also see the geostationary arc but, for an even shorter duration. Figure A.7.a-3 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 least 3 dB lower than the peak PFD) from 8.2°W to 0.9°W longitude. The elevation angle to this geostationary arc segment is never more than 2.4° and 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 A.7.a-4 demonstrates that the geostationary arc in 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 satellites are transmitting to the Svalbard earth station. Figure A.7.a-5 provides the same information when the GHOSt satellites are transmitting to the Troll, Antarctica station. In this scenario, when the GHOSt satellite beam is pointed due North from its position south of Troll, the maximum elevation angle will be 9.4° and the geostationary arc can be illuminated from 58.2°W to 63.2°E. Figures A.7.a-4 and A.7.a-5 also show the corresponding PFD levels that would be received at these locations on the geostationary arc.

Figure A.7.a-4 Elevation angles to the geostationary arc and PDF at the geostationary arc from a GHOSt satellite near Svalbard as of function of geostationary arc location

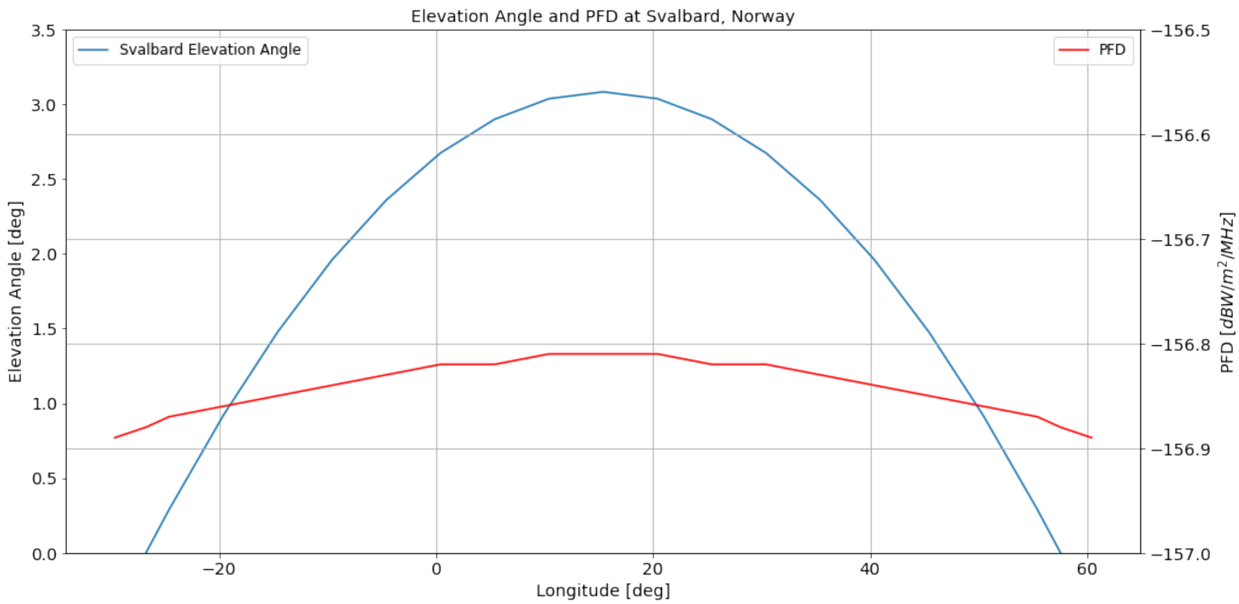
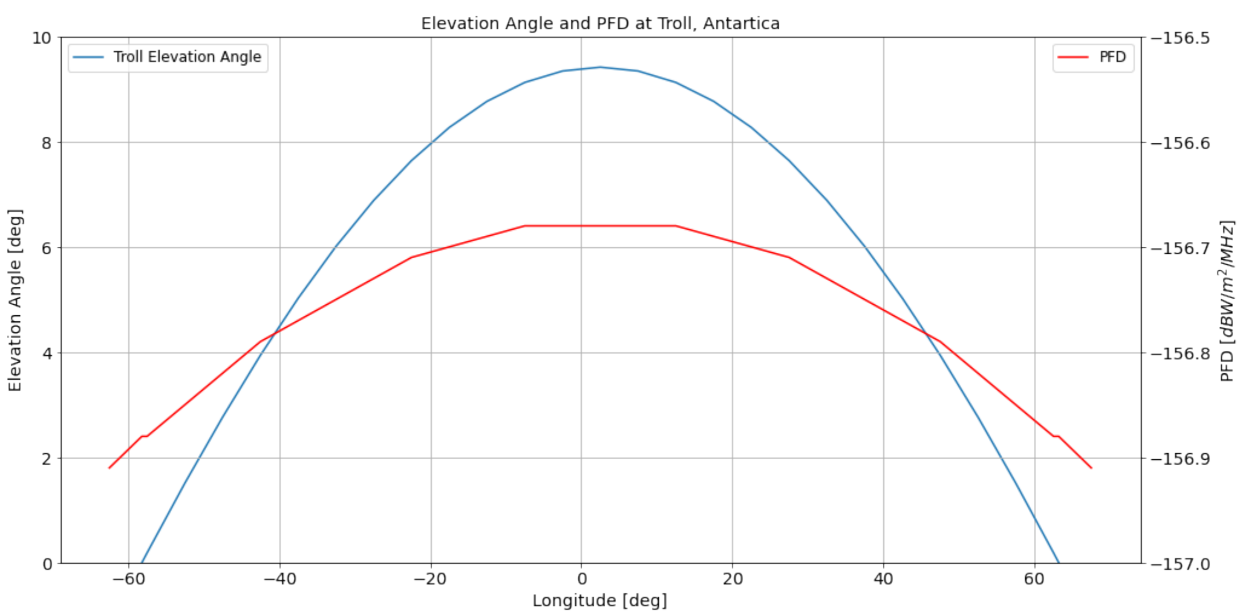


Figure A.7.a-5 Elevation angles to the geostationary arc and PDF levels at the geostationary arc from a GHOSt satellite near Troll as of function of geostationary arc location



As can be seen from the PFD values above, the maximum PFD at the geostationary arc is less than -156.6 dBW/m^2/MHz over the range of longitudes shown in the above figures. This value is significantly less than the PFD value given in ITU-R Recommendation SA.1862, recommends 5 of -133 dBW/m^2/MHz.

A.7.b GHOSt Sharing Considerations with Other Downlinks in the 25.5-27.0 GHz Band

With respect to sharing with other EESS (space-to-Earth) and space research service (space-to-Earth) satellite systems, whether geostationary or NGSO, the limited number of GHOSt earth stations—and their remote locations near the North and South Poles—eliminates the possibility of interference to many of these other satellite networks due to the geographic isolation of the earth stations and the fact that the GHOSt satellites will only transmit when they are visible to the earth stations in Svalbard and Troll. For any geostationary satellites using this band for downlinks, the maximum elevation angle from Svalbard to the geostationary arc is 3.1° and the maximum angle from Troll to the geostationary arc is 9.4° and there is very little chance that earth stations for geostationary satellites would be located at elevation angles less than about 20° and certainly not near the Svalbard and Troll earth station locations.

There are likely to be other NGSO satellite systems that are also using these same or nearby earth stations in this frequency band, so there may be some situations where adjustments in the operating schedules of the different satellites would need to be made during certain passes by the Svalbard and Troll earth stations. These deconflicts will be handled by the operators of these earth stations and the GHOSt satellites. In addition, the Ka-band transmit antennas on the GHOSt satellites have a relatively narrow beamwidth of 7.4° and would illuminate only a small portion of the Earth when transmitting to these earth stations. In the event that there are interference concerns from another operator, OSK will engage in coordination with the operator to ensure that a solution is found where the GHOSt constellation operations will not cause harmful interference to the networks of the other operators. Other operators have successfully coordinated operations in the GHOSt Ka-band range, including Astro Digital (File No. SAT-LOA-20170508-00071).

A.7.c GHOSt Sharing Considerations in the 2025-2110 MHz Frequency Band for TT&C Uplinks

With respect to sharing with other space operations service (Earth-to-space) and EESS (Earth-to-space) satellite systems in the 2054.85-2055.15 MHz and 2045-2050 MHz frequency bands, the limited number of GHOSt earth stations will mitigate the potential of interference to other satellite networks. For the uplinks from the Svalbard, Tromsø, and Troll earth stations, their location at higher latitudes and in remote locations near the North and South Poles eliminate the possibility of interference to many of these other satellite networks due to the geographic isolation of the earth stations and the fact that these earth stations will only transmit when visible to a GHOSt satellite. For any geostationary satellites using this band for uplinks, the maximum elevation angle from Svalbard to the geostationary arc is 3.1°, the maximum angle from Tromsø to the geostationary arc is 11.8°, and the maximum angle from Troll to the geostationary arc is 9.4°. Although it is possible to transmit from earth stations with these low elevation angle to geostationary satellites at these frequencies, it is not likely that there would be many of them in the vicinity of Svalbard, Tromsø, or Troll. There are likely to be other NGSO satellite systems that are also using these same or nearby earth stations in this frequency band, so there may be some situations where adjustments in the operating schedules of the different satellites would need to be made during certain passes by these earth stations. These would be handled by the operators of these earth stations.

With respect to Federal systems, OSK has begun coordinating with NASA and NOAA. In the event that there are other operators for which coordination is necessary, OSK will engage in coordination with the operator to ensure that a solution is found where the GHOSt constellation operations will not cause harmful interference to the networks of the other operators. Similar to the Ka-band coordination discussed above, the bands have previously been coordinated by other commercial operators (*see e.g.*, SAT-LOA-20170508-00071).

A.7.d GHOSt Sharing Considerations with Other Downlinks in the 400.15-401 MHz Band

UHF downlinks are performed using the Tromsø and Santa Clara earth stations. With respect to sharing with other EESS (space-to-Earth) and space research service (space-to-Earth) satellite systems, whether geostationary or NGSO, the limited number of GHOSt earth stations will mitigate the potential of interference to other satellite networks. The Tromsø earth station is located at high latitude and in remote location near the North Pole which eliminates the possibility of interference to many of these other satellite networks due to the geographic isolation of the earth station and the fact that the GHOSt satellites will only transmit when they are visible to the earth station. The Santa Clara earth station has previously been coordinated with other operators in this band (*see e.g.* File No. SAT-LOA-20170508-00071).

A.8 COORDINATION WITH U.S. GOVERNMENT SYSTEMS

Coordination with NOAA and NASA has begun for certain frequency bands and will continue to be pursued until agreements are reached. Several of the frequencies are currently operated based upon on-going agreements with other entities and any further coordination will be addressed as it arises . In the event that there are interference concerns from another operator, OSK will engage in good faith coordination discussions with the operator to achieve a solution whereby the GHOSt constellation operations will not cause harmful interference to the networks of the other operators.

A.9 CESSATION OF EMISSIONS

All downlink transmissions can be turned on and off by ground telecommand, thereby achieving cessation of emissions from the satellite, as required by Section 25.207 of the FCC's rules.

A.10 FREQUENCY TOLERANCE (SECTION 25.202(E))

The frequency tolerance requirements of Section 25.202(e) of the FCC's rules that the carrier frequency of each space station transmitter be maintained within 0.002% of the reference frequency will be met.

A.11 OUT-OF-BAND EMISSIONS (SECTION 25.202(F))

The out-of-band emission limits of Sections 25.202(f)(1), (2) and (3) of the FCC's rules will be met.

A.12 ITU FILINGS

The necessary ITU filings for the six satellite GHOSt constellation have not yet been submitted to the ITU but are in the process of being prepared.

A.13 ORBITAL DEBRIS MITIGATION AND POST-MISSION DISPOSAL

OSK confirms that the GHOSt satellites will not undergo any planned release of debris during their normal operations.[4] All separation and deployment mechanisms, and any other potential source of debris, will be retained by the spacecraft. OSK has assessed the probability of the space stations becoming sources of debris by collision with small debris or meteoroids of less than one centimeter in diameter that could cause loss of control and prevent post-mission disposal. OSK has taken steps to limit the effects of such collisions through shielding, the placement of components, and the use of redundant systems.

OSK has assessed and limited the probability of accidental explosions during and after completion of mission operations through a failure-mode verification analysis.[5] As part of the satellite manufacturing process, OSK has taken steps to ensure that debris generation will not result from the conversion of energy sources on board the satellites into energy that fragments the satellites. All sources of stored energy onboard the spacecraft will have been depleted or safely contained when no longer required for mission operations or post-mission disposal.

OSK has assessed and limited the probability of the space stations becoming a source of debris by collisions with large debris or other operational spacecraft.[6] OSK will work closely with its launch providers to ensure that the satellites are deployed in such a way as to minimize the potential for

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[4] *See* 47 C.F.R. §§ 25.114(d)(14)(i) & 25.122(c)(5).

[5] *See* 47 C.F.R. §§ 25.114(d)(14)(ii) & 25.122(c)(6).

[6] *See* 47 C.F.R. §§ 25.114(d)(14)(iii) & 25.122(c)(7).

in-plane collision. This specifically includes minimizing the potential for collision with crewed spacecraft.

OSK participates in a sharing agreement with the Combined Space Operations Center ("CSpOC") to better coordinate collision avoidance measures and receive conjunction threat reports.[7] OSK satellites carry onboard GPS receivers that provide for precise orbital position determination. OSK also receives from CSpOC updated two-line element sets, or "TLEs," which facilitate the identification and tracking of OSK satellites. CSpOC will be able to contact the OSK satellite operations team, that is accessible 24 hours per day/seven days per week to ensure that OSK can take immediate action to coordinate collision avoidance measures.

The GHOSt-01 through -06 satellites will not maintain inclination angle, apogee, perigee, and right ascension of the ascending node to any specified degrees of accuracy.

OSK's detailed Orbital Debris Assessment Report ("ODAR") is attached as Attachment B.[8] The disclosure of the orbital deployment parameters, orbital plane inclination, and the orbital period to be used can assist third parties in identifying potential problems. This information also lends itself to coordination between OSK and other operators located in similar orbits.[9]

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[7] GHOSt-01 through -06 can each be actively tracked through unique telemetry markers. The GHOSt satellites will also be registered with the 18th Space Control Squadron or successor entity prior to deployment, and OSK will share information regarding the GHOSt satellites' initial deployment, ephemeris, and/or planned maneuvers with the 18th Space Control Squadron or successor entity, other entities that engage in space situational awareness or space traffic management functions, and/or other operators. *See Mitigation of Orbital Debris in the New Space Age*, Report and Order and Further Notice of Proposed Rulemaking, 35 FCC Rcd 4156 at Appendix A (2020) ("Orbital Debris Order").

[8] *See* 47 C.F.R. § 25.114(d)(14)(iv).

[9] Pursuant to the *Orbital Debris Order*, OSK affirms that there are no other applications or grants relating to OSK's proposed operations. *See* Orbital Debris Order at Appendix A; *see also* Legal Narrative at n.2.

CERTIFICATION OF PERSON RESPONSIBLE FOR PREPARING ENGINEERING INFORMATION

I hereby certify that I am the technically qualified person responsible for 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 it is complete and accurate to the best of my knowledge and belief.

/s/

Steven K. Kaltenmark
503 Ridge Road SW
Vienna, VA 22180
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December 17, 2021