ATHENA NGSO SATELLITE

EXHIBIT 1

Technical Information to Supplement Form 442 and Application Narrative

A.1 Scope and Purpose

This exhibit supplements FCC Form 442 and contains the technical information referenced in the application narrative that is required by Parts 5 and 25 of the Commission's rules.

A.2 Radio Frequency Plan (§25.114(c)(4))

The Athena satellite will have two E-band uplinks and two E-band downlinks. The downlink emissions are nominally centered at 72 GHz and 75 GHz and the uplink emissions are nominally centered at 82 GHz and 85 GHz[1]. The bandwidth for both the uplinks and downlinks is 2.1852 GHz. The TT&C uplink will be conducted at 2082 MHz with an occupied bandwidth of 1.5 MHz. The TT&C downlink will be conducted at 8496.25 MHz with an occupied bandwidth of 2.3 MHz. Table A.2-1 shows the frequency ranges to be used by the Athena satellite.

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[1] There is the possibility that mild tuning may be performed from the planned 72, 75, 82 and 85 GHz centered carriers (*e.g.*, 74.8 and 82.2 GHz may be used for example to mitigate any potential, mild "inter-channel interference" due to spectral regrowth issues and limited transmit-to-receive isolation). In addition, a limited number of tests, estimated at one to two dozen, may be performed with continuous wave (CW), unmodulated carriers as far out as the band edges (i.e., 71-76 GHz and 81-82 GHz) to measure the atmospheric attenuation characteristics. Any mild tuning or atmospheric measurement testing would maintain compliance with NTIA Redbook requirements for the licensed carriers.

Table A.2-1: Frequency Bands Used by the Athena non-GSO Satellite

Type of Link and Transmission Direction	Frequency Ranges
E-band Uplink	80.9074 – 83.0926 GHz 83.9074 – 86.0926 GHz
E-band Downlink	70.9074 – 73.0926 GHz 73.9074 – 76.0926 GHz
TT&C Uplink	2081.25 – 2082.75 MHz
TT&C Downlink	8494.75 – 8497.75 MHz

The E-band uplink and E-band downlink will use both right-hand circular polarization and left-hand circular polarization. The TT&C uplink and TT&C downlink will use right-hand circular polarization.

A.3 Non-GSO Orbital Characteristics (§25.114(c)(6))

The Athena experiment will consist of one non-GSO satellite operating in a circular sun-synchronous orbit at an altitude of 500 to 550 km. Table A.3-1 gives the other relevant orbital parameters for the Athena satellite.

Table A.3-1: Athena Satellite Characteristics

Number of Orbital Planes	1
Satellites Per Orbital Plane	1
Inclination of the Orbital Plane	97.4° for 500 km case 97.6° for 550 km case
Orbital Period	5677 seconds (1 hour, 34.6 minutes) for 500 km case 5730 seconds (1 hour, 35.5 minutes) for 550 km case
Apogee	500 – 550 km
Perigee	500 – 550 km
Active Service Arc	When visible to the earth stations at minimum elevation angles of 5° - 30° (See Section A.4 for further explanation)
Local Time of Descending Node	10:30 AM

It is noted that additional orbital parameters, such as the argument of perigee and the initial phase angle of the satellite, are not applicable to a one-satellite non-GSO system in a circular orbit. The right ascension of the ascending node (RAAN) is dependent upon the specific launch date. The RAAN will change by 0.9856° per day in order to keep up with the 360° Earth rotation around the sun in 365.25 days.

A.4 Frequency Bands and Coverage Areas (§25.114(c)(7))

As stated in Section A.2, the E-band downlinks will be in the 70.9074-76.0926 GHz frequency ranges and the E-band uplinks will be in the 80.9074-86.0926 GHz frequency ranges. During nominal operations, the satellite will only transmit and receive in the E-band when it is at an elevation angle greater than or equal to 30° from one of the earth stations located in the Los Angeles/Ventura county area. However, there may be some experiments in which the satellite will transmit and receive in the E-band when it is at a minimum elevation angle of 10°.

TT&C will be performed in the 2081.25-2082.75 MHz frequency band for the uplink and the 8494.75-8497.75 MHz band for the downlink. For TT&C, the satellite will only transmit and receive when it is at an elevation angle greater than or equal to 5° from the Mojave, Brewster and

Albuquerque earth stations. Figures A.4-1 and A.4-2 show the coverage areas for the TT&C links based on these minimum elevation angles. The spacecraft will only transmit and receive when it is within the yellow circles on the figures. The grid shows 15° lines for both latitude and longitude.

Figure A.4-1: Global View of Athena Satellite TT&C Coverage Area

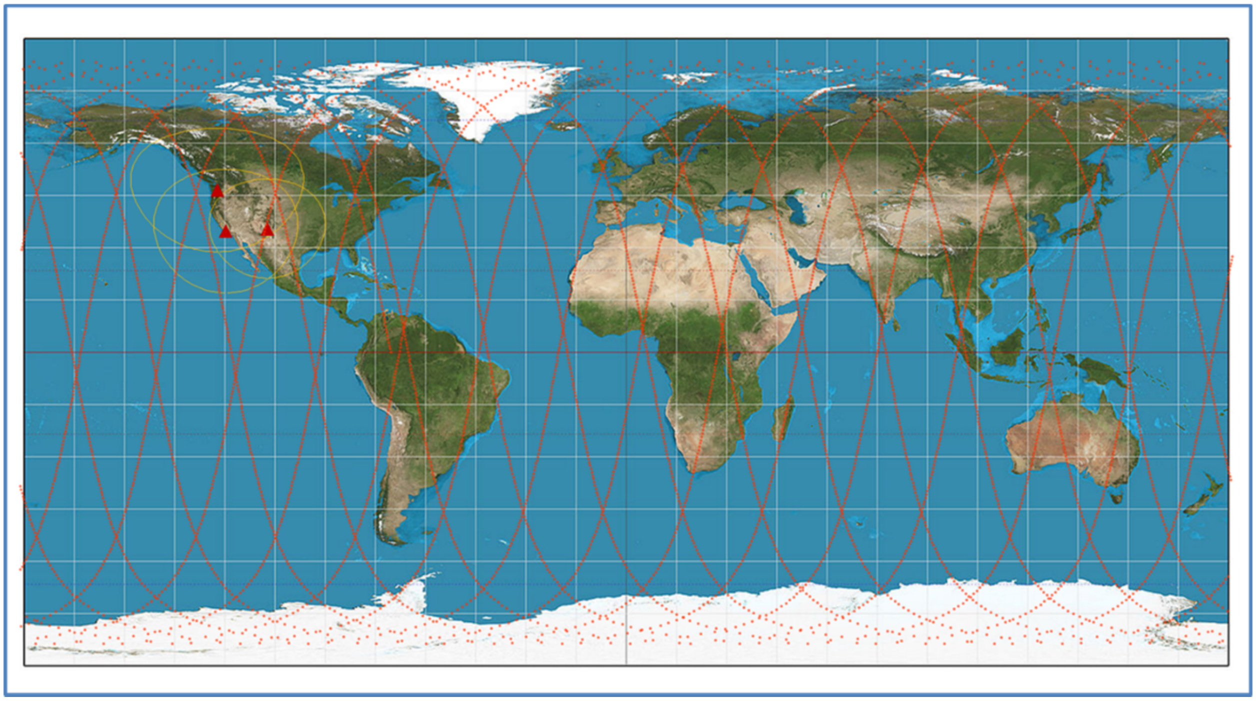


Figure A.4-2: Zoom View of Athena Satellite TT&C Coverage Area

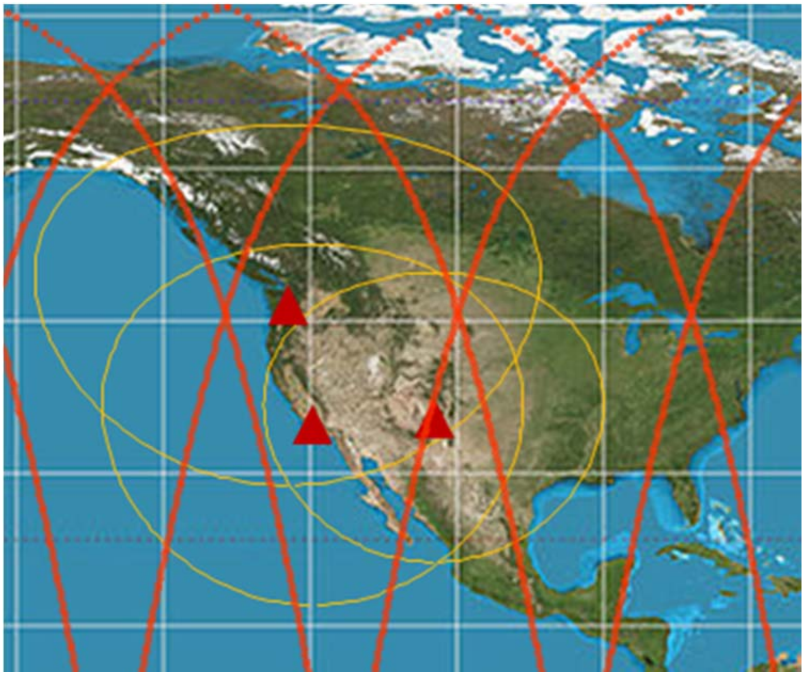


Figure A.4-3 and Figure A.4-4 show the coverage areas of the Athena satellite E-band for minimum elevation angles of 30° and 10°, respectively. The spacecraft will only transmit and receive when it is within the green circles on the figures. The grid shows 15° lines for both latitude and longitude.

Figure A.4-3: View of Athena Satellite E-Band Coverage Area for 30° Minimum Elevation Angle

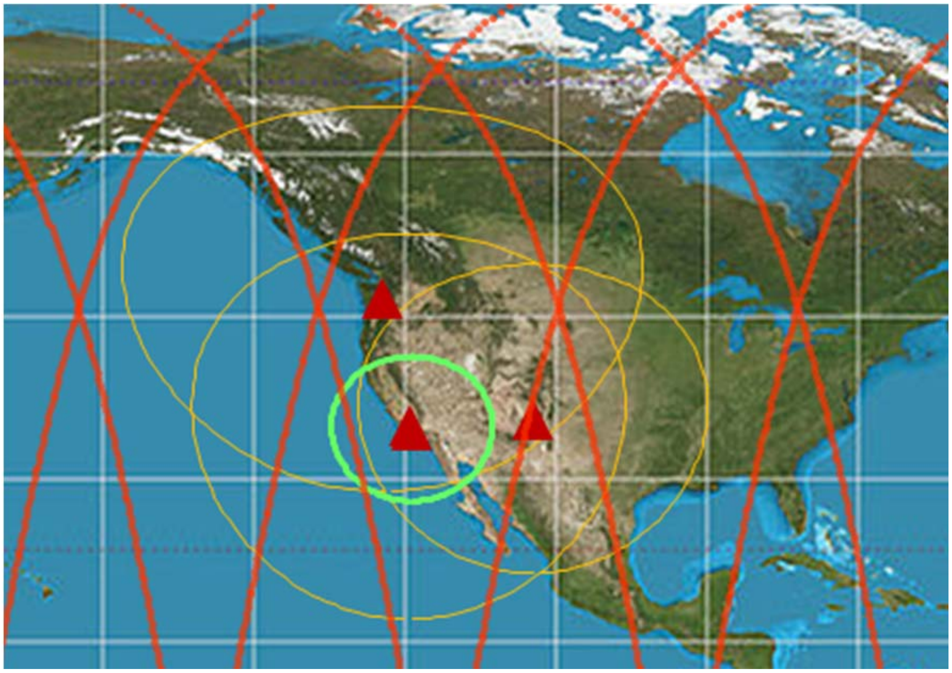
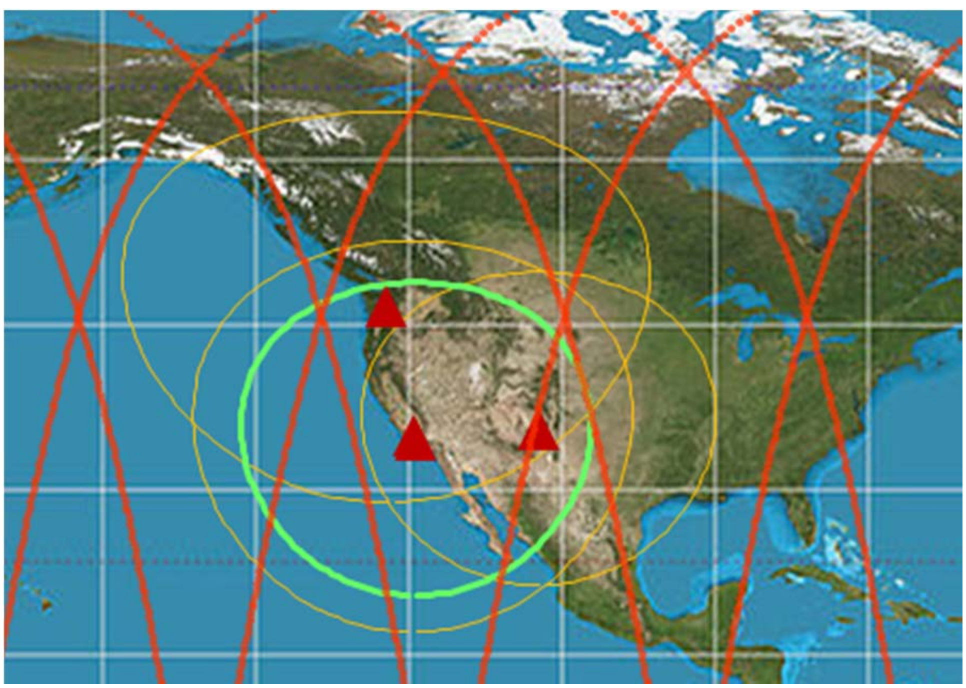


Figure A.4-4: View of Athena Satellite E-Band Coverage Area for 10° Minimum Elevation Angle



A.5 Calculated Maximum Power Flux Density Levels (§25.114(c)(8))

The Athena satellite's TT&C downlink operations in part of the 8025-8500 MHz band comply with the ITU Power Flux Density ("PFD") limits applicable to that band. Table A.5-1 shows the ITU PFD limits in the band.

Table A.5-1: ITU Power Flux Density Limits in the 8025 – 8500 MHz Band

Frequency range	PFD Limit in dB(W/m^2) for angles of arrival (δ) above the horizontal plane			Reference bandwidth
	0°-5°	5°-25°	25°-90°	
8025 – 8500 MHz	-150	$-150 + 0.5(\delta - 5)$	−140	4 kHz

The Athena satellite TT&C downlink has a maximum transmit EIRP of 3.64 dBW and a bandwidth of 2.3 MHz. Table A.5-2 shows the maximum PFD at the surface of the earth produced by this emission assuming an orbital altitude of 500 km, which would result in the highest PFD levels.

Table A.5-2: Maximum Athena PFD in the 8025 – 8500 MHz Band

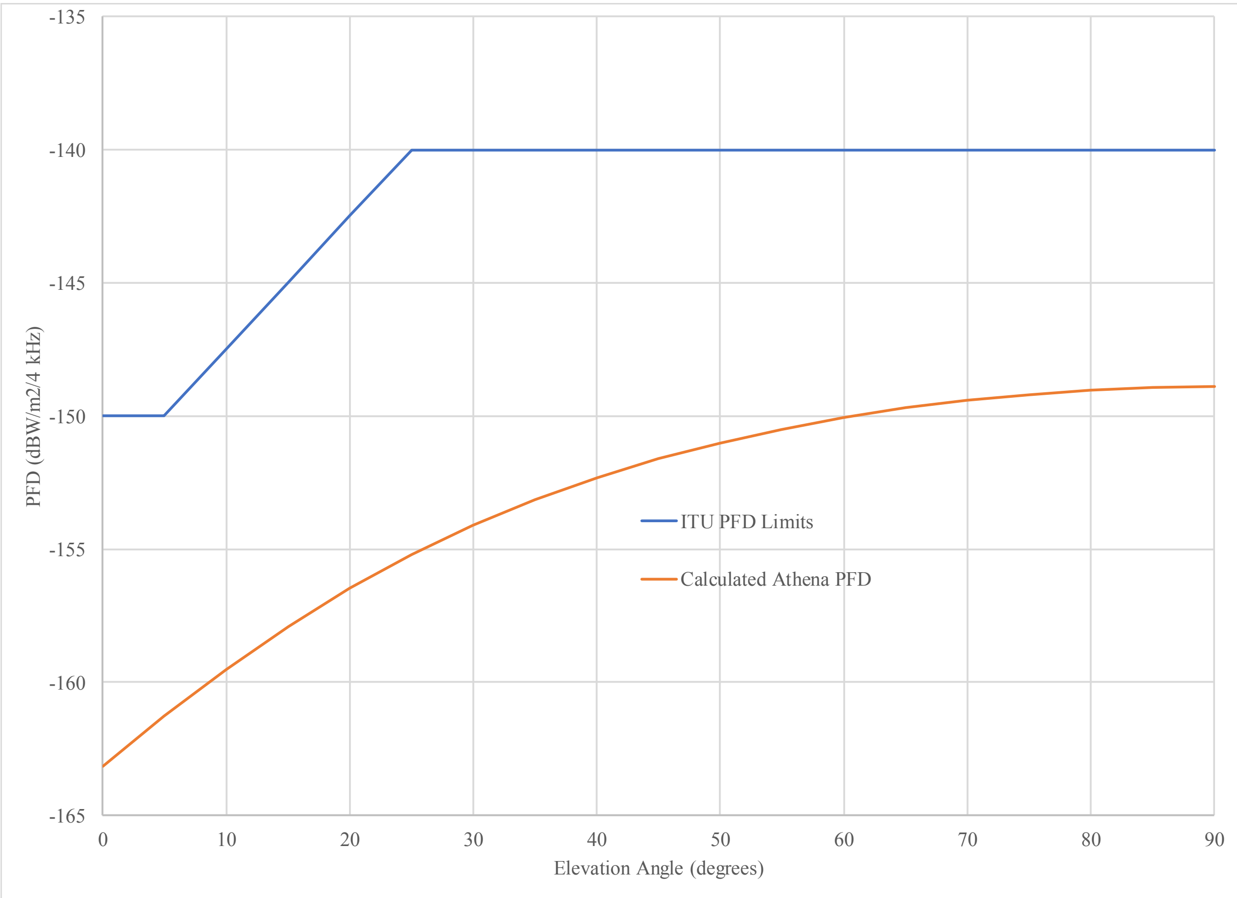
Maximum EIRP (dBW)	3.64
Bandwidth (MHz)	2.3
EIRP Density (dBW/4 kHz)	-23.94
Minimum Distance (km)	500
Maximum PFD (dBW/m^2/4 kHz)	-148.96

Table A.5-3 shows the calculated maximum PFD levels at the surface of the Earth for elevation angles from 5° to 90° along with the margin and demonstrates that the ITU PFD Limit in the 8025-8500 MHz band is met. Figure A.5-1 shows the graphical comparison of the Athena maximum PFD levels to the ITU PFD limits.

Table A.5-3: X-Band TT&C Downlink Compliance with ITU PFD Limits in the 8025-8500 MHz Band

Elevation Angle (°)	ITU PFD Limit (dBW/m^2 / 4kHz)	PFD with Peak Antenna Gain (dBW/m^2 / 4kHz)	Margin to ITU PFD Limit (dB)
5	-150.00	-160.78	**10.78**
10	-147.50	-159.31	**11.81**
15	-145.00	-157.70	**12.70**
20	-142.50	-156.26	**13.76**
25	-140.00	-155.00	**15.00**
30	-140.00	-153.91	**13.91**
35	-140.00	-152.95	**12.95**
40	-140.00	-152.13	**12.13**
45	-140.00	-151.65	**11.65**
50	-140.00	-151.04	**11.04**
55	-140.00	-150.52	**10.52**
60	-140.00	-150.09	**10.09**
65	-140.00	-149.73	**9.73**
70	-140.00	-149.44	**9.44**
75	-140.00	-149.22	**9.22**
80	-140.00	-149.06	**9.06**
85	-140.00	-148.97	**8.97**
90	-140.00	-148.96	**8.96**

Figure A.5-1: PFD Levels from the Athena TT&C Downlink compared with ITU Limits



There are no ITU or FCC PFD limits in the 71-76 GHz band. In this band, the Athena satellite has a maximum transmitted EIRP of 44.3 dBW and a bandwidth of 2.1852 GHz. Table A.5-4 shows the maximum PFD at the surface of the earth produced by this emission. Table A.5-5 shows the calculated maximum PFD levels for elevation angles from 10° to 90°.

Table A.5-4: Maximum Athena Satellite PFD at the Surface of the Earth in the 71 - 76 GHz Band

Maximum EIRP (dBW)	44.3
Bandwidth (GHz)	2.1852
EIRP Density (dBW/4 kHz)	-113.07
Minimum Distance (km)	500
Maximum PFD (dBW/m^2/4 kHz)	-138.05

Table A.5-5: Maximum Athena PFD in the 71 - 76 GHz Band at Various Elevation Angles

Elevation Angle (°)	PFD with Peak Antenna Gain (dBW/m2/4 kHz)
10	-148.65
15	-147.04
20	-145.60
25	-144.34
30	-143.24
35	-142.29
40	-141.47
45	-140.76
50	-140.15
55	-139.63
60	-139.19
65	-138.83
70	-138.54
75	-138.32
80	-138.17
85	-138.08
90	-138.05

5.a X-Band TT&C Compliance with Deep Space Protection Limits

According to the ITU Radio Regulations, the 8400-8450 MHz band is allocated to the Space Research Service in the space-to-Earth direction and the use of the band is limited to satellites that are orbiting in deep space. Recommendation ITU-R SA.1157-1 ("Protection criteria for deep-space research") gives the maximum allowable interference power into deep-space receiving earth stations and the interference protection criteria for deep-space earth stations in the 8400-8425 GHz frequency band. The following is an excerpt from the ITU-R Recommendation:

Recommendation ITU-R SA.1157-1 TABLE 4

Maximum allowable interference power to earth-station receivers

Band (GHz)	**Receiver noise spectral density (dB(W/Hz))**	**Maximum CW interference power (dBW)**	**Maximum noise-like interference power spectral density (dB(W/Hz))**
2.29-2.30	–216.6	–221.6	–222.5
8.40-8.45.	–215.0	–220.0	–220.9
12.75-13.25	–214.6	–219.6	–220.5
31.8-32.3	–211.4	–216.4	–217.3

Protection criteria for deep-space earth-station receivers

Table 5 gives the maximum allowable interference that will not cause more than the acceptable degradation of earth-station receiver performance. These values are the protection criteria for a deep-space earth-station receiver at the receiver input terminals: greater interference is harmful. Also shown is the corresponding power spectral flux-density at the aperture of a 70 m diameter reflector antenna. The antenna has approximately 70% area efficiency for the lower bands and 40% at 32 GHz.

Recommendation ITU-R SA.1157-1 TABLE 5

Interference protection for deep-space earth-stations

Band (GHz)	**Maximum allowable interference power spectral density (dB(W/Hz))**	**Maximum allowable interference power spectral flux-density (dB(W/m^2 · Hz))**
2.29-2.30	–222.5	–257.0
8.40-8.45	–220.9	–255.1
12.75-13.25	–220.5	–254.3
31.8-32.3	–217.3	–249.3

To protect earth-station receivers, the power spectral density of noise-like interference, or the total power of CW interference, should not be greater than the amount shown in Table 5.

The Athena satellite X-band telemetry carrier is centered at a frequency of 8496.25 MHz. Tests were performed to determine the interference levels that would be received at a deep-space earth station operating in the 8400-8450 MHz band. Table A.5.a-1 shows the maximum power level at the surface of the earth under clear-sky conditions at the Athena satellite TT&C center frequency.

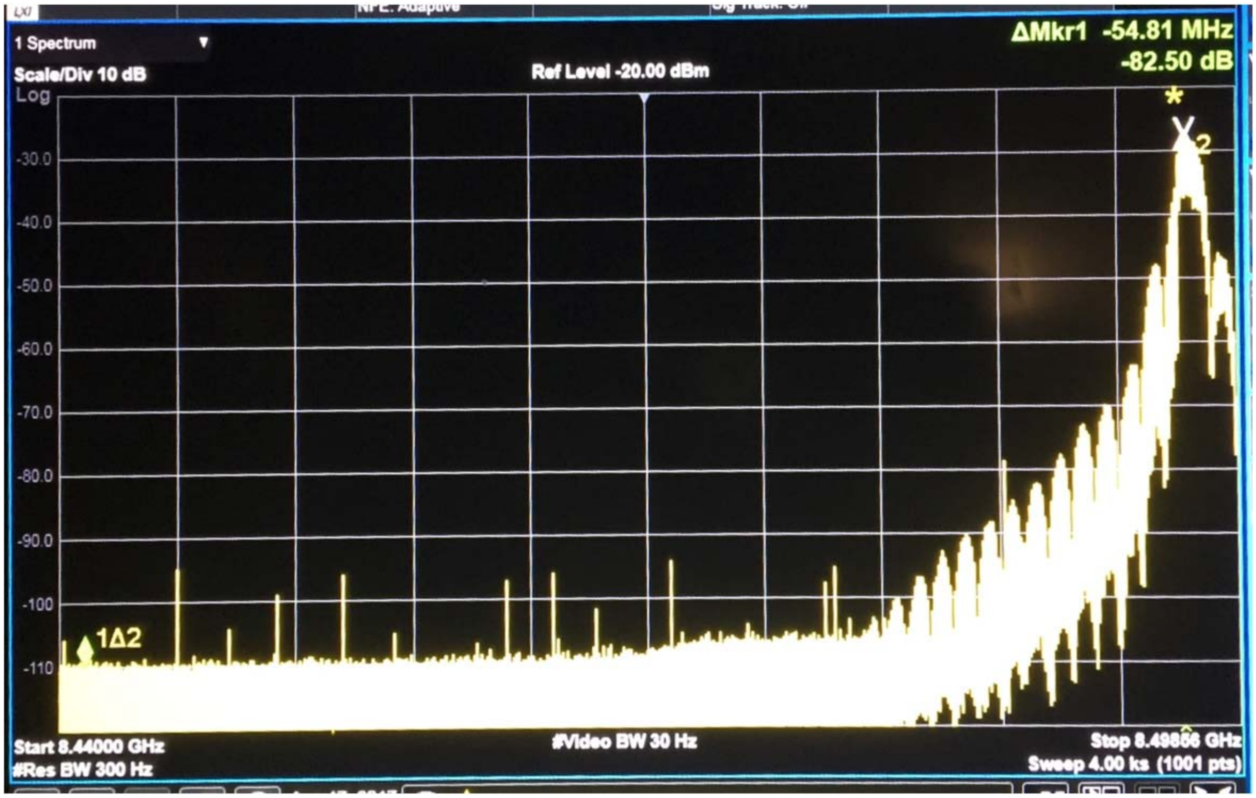
Table A.5.a-1: Maximum Power Level at the Surface of the Earth at TT&C Center Frequency

Telemetry (Downlink) Budget

Parameter	**5 deg El** (Peak)	**10 deg El** (Peak)	**45 deg El** (Peak)	**90 deg El** (Peak)	**Unit**
Frequency	8.49625	8.49625	8.49625	8.49625	GHz
Altitude	500	500	500	500	km
Elevation Angle	5	10	45	90	deg
Slant Range	2077.96	1695.09	683.09	500.00	km
Range Factor	137.34	135.58	127.68	124.97	dB
Aperture Factor	40.03	40.03	40.03	40.03	dB
Path Loss	-177.38	-175.61	-167.72	-165.01	dB
Atmospheric Loss	-0.6	-0.3	-0.07	-0.05	dB
Tx Power	2.5	2.5	2.5	2.5	W
in dBW	3.98	3.98	3.98	3.98	dBW
S/C Antenna Gain	5.5	5.5	5.5	5.5	dBi
Tx Loss	-5.84	-5.84	-5.84	-5.84	dB
Transmit EIRP	3.64	3.64	3.64	3.64	dBW
Transmit EIRP (W)	2.31	2.31	2.31	2.31	W
Pol Loss	0	0	0	0	dB
Power at E/S	-174.34	-172.27	-164.15	-161.42	dBW

Figure A.5.a-1 shows the test data for the X-band TT&C spurious emissions spectrum down to 8.44 GHz.

Figure A.5.a-1: X-band Telemetry Spurious Emissions Spectrum



As shown in Table A.5.a-1, the power level at the Earth's surface at 8496.25 MHz is -164.1 dBW. The CW interference level roll-off from the modulated spectrum peak at the edge of the deep-space band (8450 MHz) is 67 dBc. Thus, the maximum CW interference power in the deep-space band is -228.4 dBW, which is 8.4 dB below the maximum CW interference power given in Table 4 of ITU Recommendation SA.1157-1. The peak PFD at the Earth's surface of the Athena satellite X-band downlinks is -185.0 dBW/m^2/Hz. The measurements show the test equipment noise floor at -82 dBc, which results in a PFD in the deep-space band of -267 dBW/m^2/Hz, which is 11.9 dBW less than the protection level given in the ITU Recommendation. Similarly, the noise-like interference based on a peak power spectral density of -225.0 dBW/Hz and a noise floor of -82 dBc results in a maximum noise-like interference of -307.0 dBW/Hz, which is 86.1 dB less than the protection values given in the ITU Recommendation. Table A.5.a-2 shows that that Athena satellite X-band downlinks are compliant with the deep-space protection criteria.

Table A.5.a-2: Athena Satellite Compliance with Deep Space Protection Criteria

ITU-R SA.1157 (8.40-8.45 GHz)	ITU Limit	Hardware Test	Margin	Compliant
Max CW interference (power, dBW) Table 4	-220.0	-228.4	8.4	Yes
Noise-like interference (PSD, dBW/Hz) Table 4	-220.9	-307.0	86.1	Yes
Max interference (PSD, dBW/Hz) Table 5	-220.9	-307.0	86.1	Yes
Max interference (PFD, dBW/m2/Hz) Table 5	-255.1	-267.0	11.9	Yes

A.6 Overall Description of System Facilities, Operations and Services (§25.114(d)(1))

The Athena experiment includes one non-GSO satellite operating in the E-band (71-76 GHz for downlink and 81-86 GHz for uplink) communicating with earth stations located in the southwest United States. The TT&C for the satellite will be conducted in the X-band for downlink and S-band for uplink and will use three specific earth stations.

Due to the nature of the non-geostationary orbit, there will be limited time during the orbit that the satellite is visible to one of its earth stations. Additionally, the duration of this visibility will be relatively short. For the E-band communications, the transmissions will be for less than 8 minutes per contact and there will be up to two contacts per day at an elevation angle greater than or equal to 30°, which may increase to four contacts a day for experiments at an angle lower than 30° and greater than or equal to 10°. For the TT&C communications, the transmissions will be less than 10 minutes per contact. There will be up to ten contacts per day for the TT&C downlinks, and up to three contacts per day for the TT&C uplinks. The TT&C coverage areas are shown in Section A.4 of this Exhibit.

Table A.6-1 gives the maximum amount of time (in seconds) the Athena satellite will transmit and receive above a given minimum elevation angle during the longest pass over the TT&C and E-band ground stations.

E-band link "baseline" testing will nominally occur above 30° minimum elevation angles, with the primary goal of demonstrating high rate links up to 4.5 minutes in duration, per contact, to an earth station through a variety of atmospheric conditions, enabling the validation of ITU models. E-band "goal" testing will occur above 20° minimum elevation angles for up to 5.3 minutes to study the effects of additional atmospheric attenuation. E-band "stretch" testing will occur above 10° minimum elevation angles for up to 8.0 minutes to study maximum attenuation effects. Less than six contacts per month are planned to be goal or stretch tests that apply minimum elevation angles less than 30°.

Table A.6-1: Maximum Pass Time (in Seconds) for Different Minimum Elevation Angles

Minimum Elevation Angle	Maximum Pass Time 500 km altitude	Maximum Pass Time 550km altitude	Notes
5 °	552.4	589.6	TT&C: Brewster, Mojave, Albuquerque
10 °	443.0	476.9	E-band (stretch test): LA/Ventura Counties (see A.6.a)
20 °	295.8	322.2	E-band (goal test): LA/Ventura Counties (see A.6.a)
30 °	207.4	227.3	E-band (baseline test): LA/Ventura Counties (see A.6.a)

A.6.a Description of Satellite, including Antenna Patterns for both E-band and TT&C

For the TT&C, there is a single S/X-band transceiver on the satellite with internal transmit signal amplification. The receiver is always ON; the transmitter is only ON when in the field-of-view of the TT&C ground stations above the respective minimum elevation angles. There are two receive S-band patch antennas for command and two transmit X-band patch antennas for telemetry. Both command and telemetry use right-hand circular polarization. The gain patterns for these antennas are given in Figure A.6.a-1 and A.6.a-2. Table A.6.a-1 provides a description of each of the TT&C earth stations.

Figure A.6.a-1 TT&C Satellite Antenna Transmit Pattern

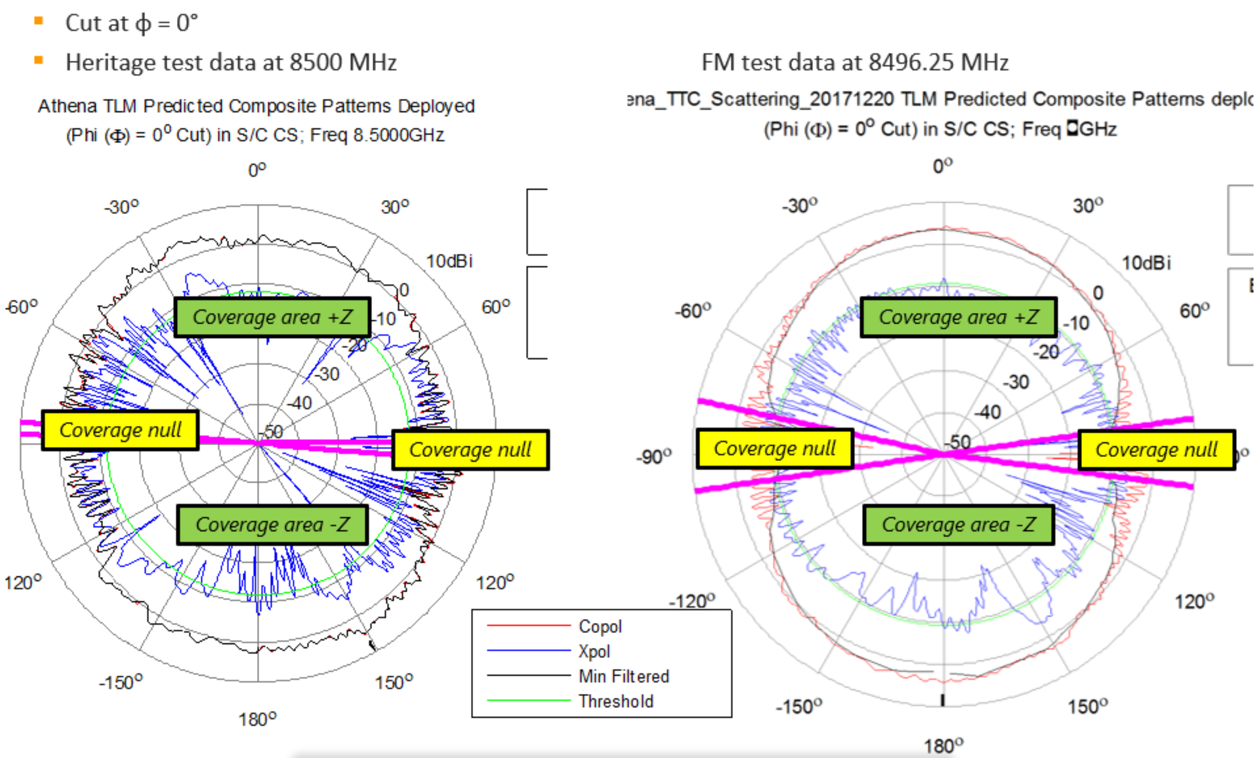


Figure A.6.a-2 TT&C Satellite Antenna Receive Pattern

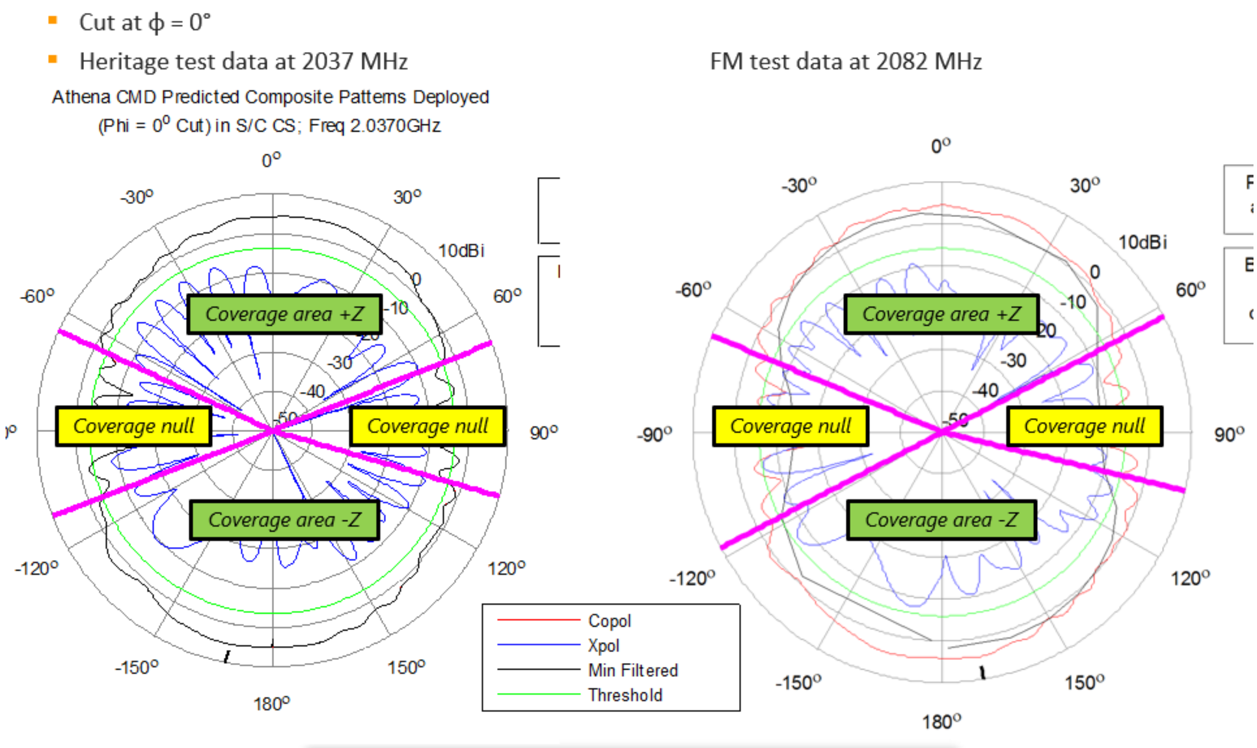
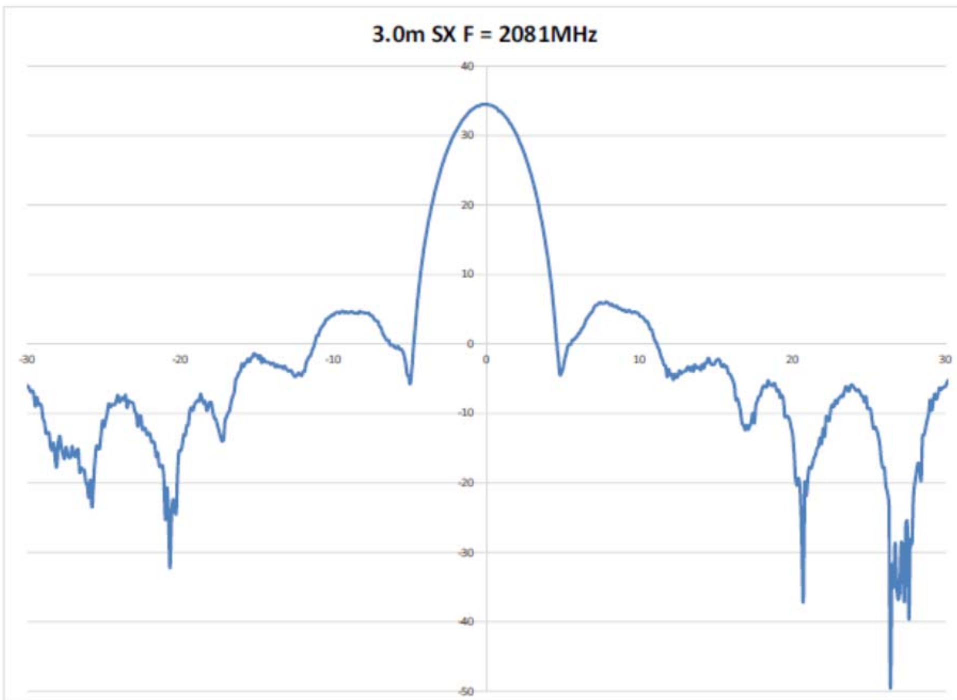


Table A.6.a-1 Description of TT&C Earth Stations

Location	**Mojave, CA**	**Albuquerque, NM**	**Brewster, WA**
Latitude (°N)	35.064	35.054	48.145
Longitude (°E)	-118.162	-106.619	-119.7
Antenna Size	3.0 m (Rx/Tx S-band, Rx X-band)	3.0 m S-band Rx/Tx 4.5m X-band Tx	7.6m (Rx/Tx)
Maximum Uplink EIRP	45 dBW	45 dBW	48 dBW
Earth Station Antenna Maximum Transmit Gain	34 dBi	34 dBi	42.2 dBi
Reference Antenna Pattern	See Figure A.6.a-3	See Figure A.6.a-3	Meets reference radiation pattern set forth in Recommendation ITU-

			R S.465-6.
Polarization	RHCP	RHCP	RHCP
Minimum Elevation Angle	5°	5°	5°
Maximum Pass Length	590 seconds	590 seconds	590 seconds
Maximum Passes Per Day	3 to 4	3 to 4	4 to 5

Figure A.6.a-3 TT&C 3.0 meter Earth Station Antenna Transmit Pattern



The maximum uplink EIRP for the TT&C command link will be 48 dBW for the Brewster earth station and 45 dBW for the Mojave and Albuquerque earth stations. The data rate will be 256 kbps. Right-hand circular polarization will be used for the command signal. Table A.6.a-2 shows the link budget for the command. These link budgets are for an EIRP level of 45 dBW. For the 48 dBW EIRP uplink from the Brewster earth station, the link will close with additional margin.

Table A.6.a-2: TT&C Command Link Budget

Parameter	5 deg El (Peak)	10 deg El (Peak)	45 deg El (Peak)	90 deg El (Peak)	Unit
Frequency	2.082	2.082	2.082	2.082	GHz
Altitude	500	500	500	500	km
Elevation Angle	5	10	45	90	deg
Slant Range	2077.96	1695.09	683.09	500.00	km
Range Factor	137.34	135.58	127.68	124.97	dB
Aperture Factor	27.82	27.82	27.82	27.82	dB
Path Loss	-165.16	-163.40	-155.50	-152.79	dB
Atmospheric Loss	-0.45	-0.23	-0.06	-0.04	dB
E/S Uplink EIRP	45.00	45.00	45.00	45.00	dBW
Pol Loss	0	0	0	0	dB
Uplink Flux Density	-92.34	-90.81	-82.74	-80.01	dBW/m^2
S/C ANT Gain	6.8	6.8	6.8	6.8	dBi
Signal Power at Antenna Hardline Interface	-113.81	-111.83	-103.76	-101.03	dBW
RX Input Loss	-4.62	-4.62	-4.62	-4.62	dB
Signal Power at RX Input	-88.44	-86.45	-78.38	-75.65	dBm
Min Acquire Threshold	-103.00	-103.00	-103.00	-103.00	dBm
Margin without Interference	14.56	16.55	24.62	27.35	dB
C/X Isolation at Antenna	8.00	8.00	8.00	25.00	dB
Interf Gain @ Opposite Antenna	-6.00	-6.00	-6.00	-30.00	dBi
Interf Pwr at Rx Input, Total RSS	-101.11	-99.12	-91.05	-111.84	dBm
Signal Power at Rcvr Input, Interference Degraded	-88.68	-86.69	-78.63	-75.65	dBm
Margin to Threshold, WC Intf Degraded	14.32	16.31	24.37	27.35	dB
Command Rcvr Noise Figure	3.5	3.5	3.5	3.5	dB
Noise Density	-170.48	-170.48	-170.48	-170.48	dBm/Hz
C/No, WC Intf Degraded	81.80	83.79	91.85	94.82	dB-Hz
Eb/No @ 10^{-10} BER	13	13	13	13	dB
Implementation Loss	2	2	2	2	dB
Bit rate	256	256	256	256	kbps
Bit rate BW	54.08	54.08	54.08	54.08	dB-Hz
Required S/No	69.08	69.08	69.08	69.08	dB-Hz
BER Margin	**12.72**	**14.70**	**22.77**	**25.74**	**dB**

The data rate for the telemetry link is 512 kbps with a maximum transmitter output power of 2.5 Watts. The peak antenna gain is 5.5 dBi. Right-hand circular polarization will be used for the telemetry signal. The maximum EIRP after losses is 3.64 dBW. Table A.6.a-3 shows the link budget for the telemetry link. These link budgets are for the Mojave and Albuquerque 3.0 meter earth station antennas. Again, for the Brewster 7.6 meter antenna, the link will close with additional margin due to the higher on-axis gain.

Table A.6.a-3: TT&C Telemetry Link Budget

Parameter	5 deg El (Peak)	10 deg El (Peak)	45 deg El (Peak)	90 deg El (Peak)	Unit
Frequency	8.49625	8.49625	8.49625	8.49625	GHz
Altitude	500	500	500	500	km
Elevation Angle	5	10	45	90	deg
Slant Range	2077.96	1695.09	683.09	500.00	km
Range Factor	137.34	135.58	127.68	124.97	dB
Aperture Factor	40.03	40.03	40.03	40.03	dB
Path Loss	-177.38	-175.61	-167.72	-165.01	dB
Atmospheric Loss	-0.6	-0.3	-0.07	-0.05	dB
Tx Power	2.5	2.5	2.5	2.5	W
in dBW	3.98	3.98	3.98	3.98	dBW
S/C Antenna Gain	5.5	5.5	5.5	5.5	dBi
Tx Loss	-5.84	-5.84	-5.84	-5.84	dB
Transmit EIRP	3.64	3.64	3.64	3.64	dBW
Transmit EIRP (W)	2.31	2.31	2.31	2.31	W
Pol Loss	0	0	0	0	dB
Power at E/S	-174.34	-172.27	-164.15	-161.42	dBW
C/X Isolation at S/C Antenna	5.00	5.00	5.00	8.00	
Interf Gain @ Opposite Antenna	-6.00	-6.00	-6.00	-30.00	dBi
E/S G/T	25	25	25	25	dB/K
Downlink C/No	79.26	81.33	89.45	92.18	dB-Hz
Downlink C/No, Intf Degraded	78.92	80.99	89.12	92.17	dB-Hz
Reqd Eb/No @ 10^{-6} BER	10.5	10.5	10.5	10.5	dB
Coding Gain	5.5	5.5	5.5	5.5	dB
Implementation Loss	2	2	2	2	dB
Bit rate	512	512	512	512	Kbps
Bit rate BW	57.09	57.09	57.09	57.09	dB-Hz
Required S/No	64.09	64.09	64.09	64.09	dB-Hz
Link Margin	**14.83**	**16.90**	**25.02**	**28.08**	**dB**

For the E-band, there is one antenna onboard the spacecraft. This antenna is a parabolic, Axially Displaced Ellipse (ADE) with a diameter of 50 cm. The maximum transmit gain for this antenna is 49.7 dBiC and the maximum receive gain is 50.7 dBiC. Both right-hand circular and left-hand circular polarizations will be used for the uplink and downlink transmissions. The satellite transmit antenna gain patterns are shown in Figures A.6.a-4 and A.6.a-5. The satellite receive antenna gain patterns are shown in Figures A.6.a-6 and A.6.a-7. The uplink transmissions are received at center frequencies of 82 GHz and 85 GHz and the downlink transmissions are sent at center frequencies of 72 GHz and 75 GHz. The occupied bandwidth for these carriers is 2.185 GHz. The satellite will normally only transmit and receive when the elevation angle from the earth station to the satellite is greater than or equal to 30°; however, there are some specific experiments in which the minimum elevation angle will be 10°.

Figure A.6.a-4 Athena E-Band Satellite Antenna Transmit Pattern (RHCP)

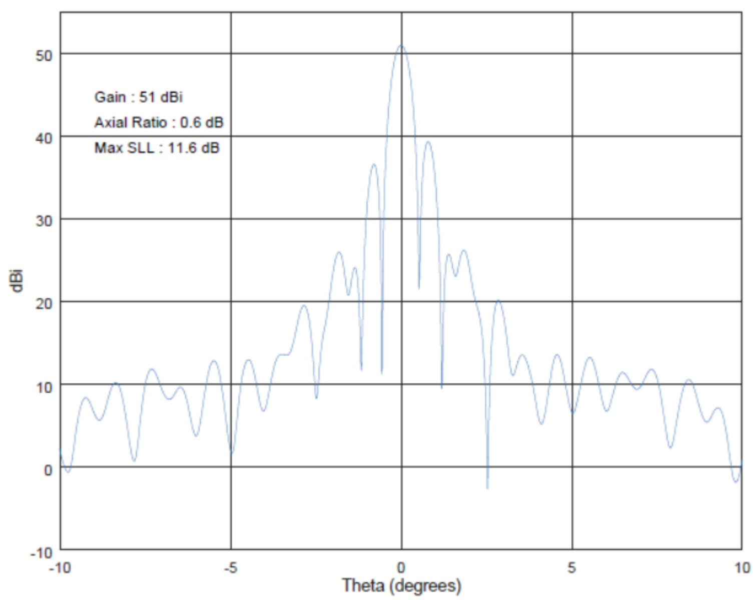


Figure A.6.a-5 Athena E-Band Satellite Antenna Transmit Pattern (LHCP)

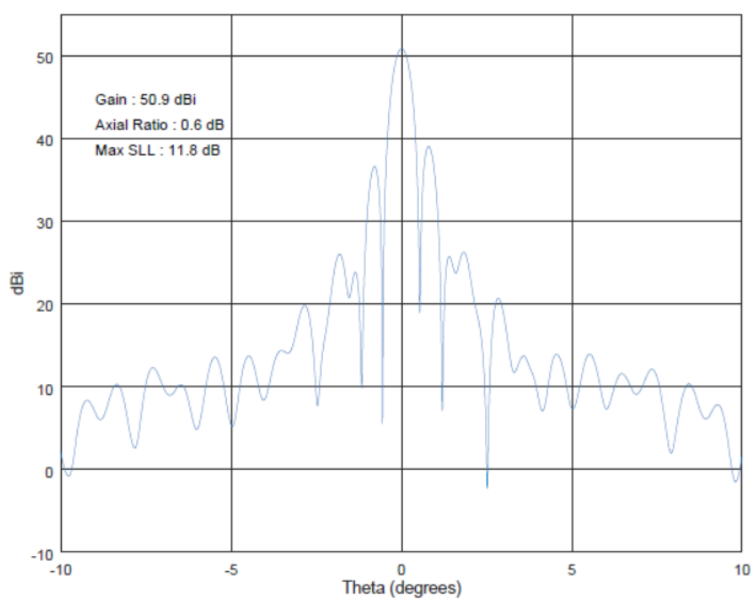


Figure A.6.a-6 Athena E-Band Satellite Antenna Receive Pattern (RHCP)

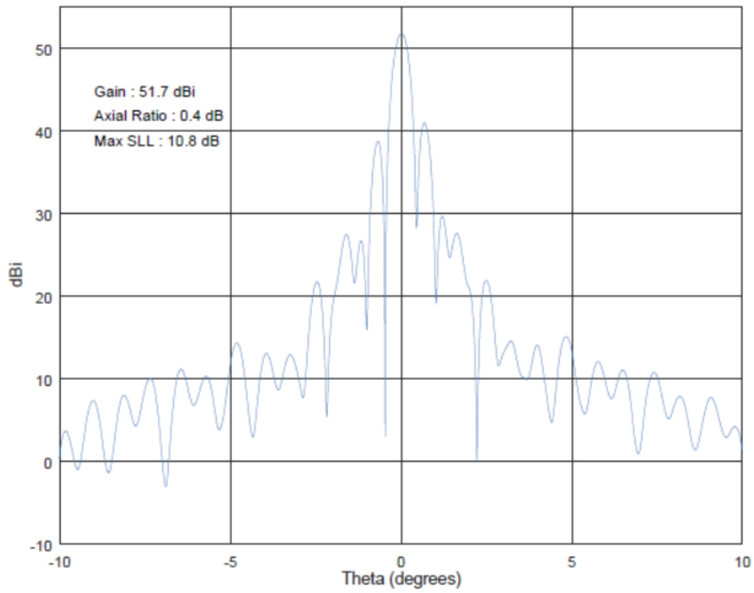
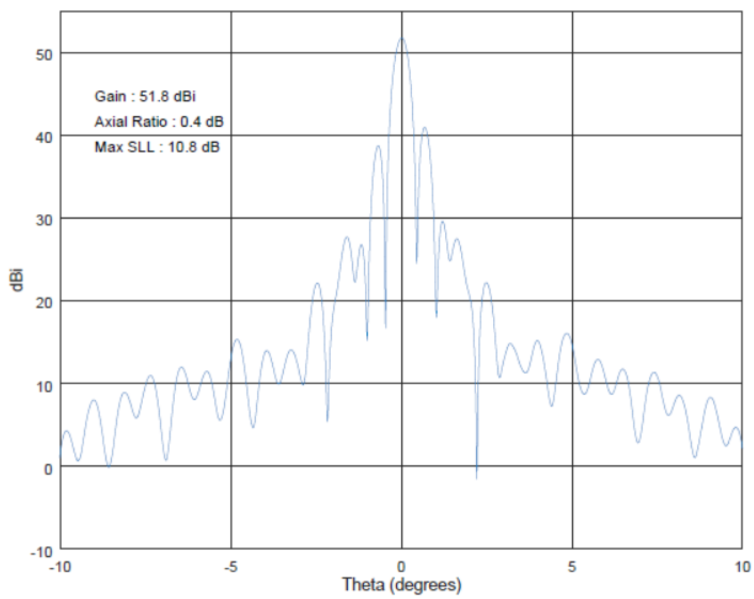


Figure A.6.a-7 Athena E-Band Satellite Antenna Receive Pattern (LHCP)



At the present time, there are three potential E-band earth station locations and two of these will be selected to be used for the Athena satellite in the first half of 2018. Table A.6.a-4 gives the technical parameters and pass information for the E-band earth stations.

Table A.6.a-4: Description of E-Band Earth Stations

Location	**Northridge, California**	**Los Angeles County (Mt. Wilson)**	**Santa Paula, California**
Latitude (°N)	34.224241	34.224889	34.402443
Longitude (°E)	-118.500349	-118.056639	-119.072900
Antenna Size	1.2 m	2.4 m	2.4 m
Maximum Antenna Gain	58.0 dBi	65.8 dBi	65.8 dBi
Reference Antenna Pattern	See Figure A.6.a-8	See Figures A.6.1.a-9 and A.6.a-10	See Figures A.6.1.a-9 and A.6.a-10
Nominal Minimum Elevation Angle	30	30	30
Maximum Pass Length at Nominal Minimum Elevation Angle (and at 10°elevation)	228 (477)	228 (477)	228 (477)
Passes Per Day	Up to 2	Up to 2	Up to 2

Figure A.6.a-8 Earth Station Pattern for 1.2m Ground Antenna at 76 GHz and 86 GHz

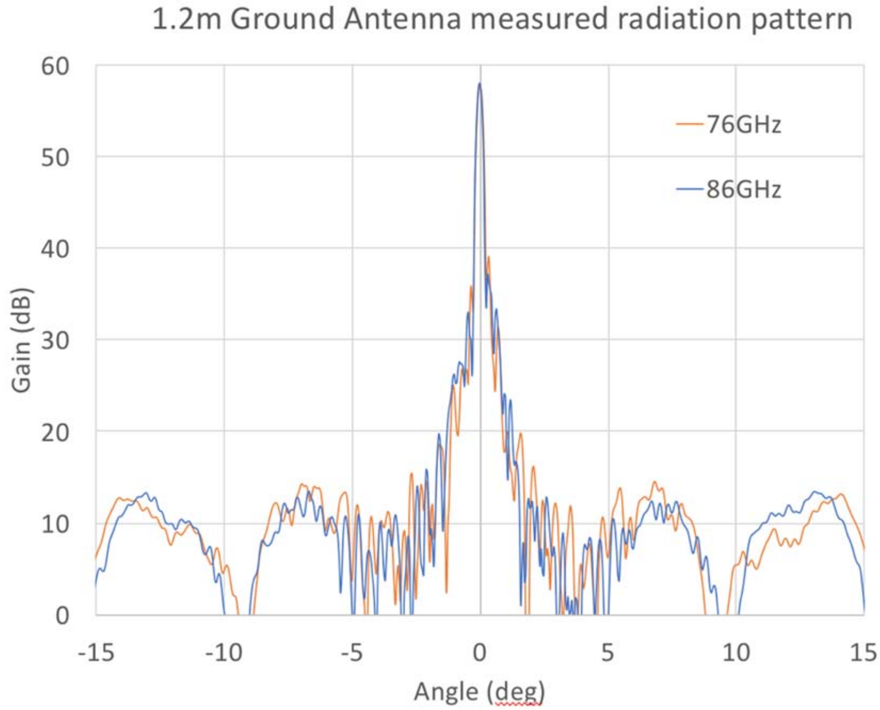


Figure A.6.a-9: LHCP Earth Station Antenna Pattern for 2.4 Meter Antenna at 83 GHz

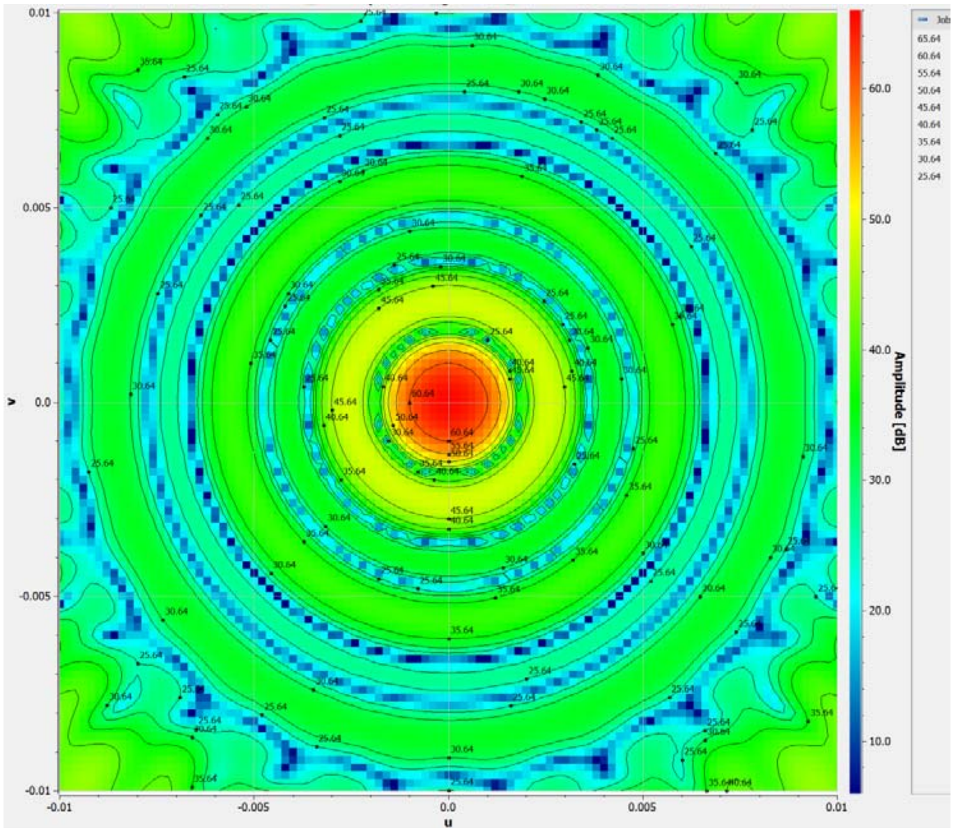
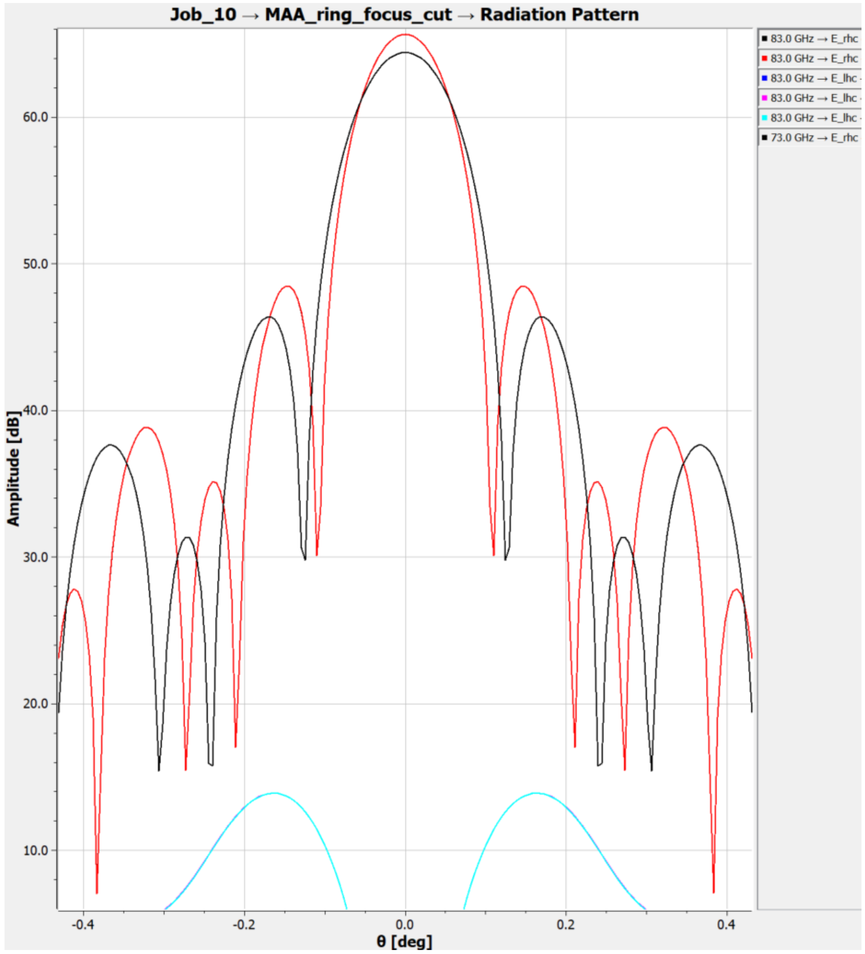


Figure A.6.a-10: LHCP Earth Station Principal Plane Pattern Cuts for 2.4 Meter Antenna at 83 GHz (Peak Gain: 65.8 dBiC)



The baseline link budgets for the E-band uplink and downlink using a 2.4 meter earth station antenna are given in Table A.6.a-5. The baseline link budgets for the E-band uplink and downlink using a 1.2 meter backup earth station antenna are given in Table A.6.a-6. For the uplink, a higher power option for the primary earth station's 2.4 m antenna may be applied at the midpoint of the mission. This higher power uplink would substitute (50W) traveling wavetube amplifiers (TWT) for the existing solid-state earth station power amplifiers as a demonstration of the viability of commercial E-band TWTs for space-based communication systems to drive higher link data rates, which has not previously been publicly demonstrated. The higher power 2.4 m antenna will observe the same general operational principles as the initially deployed antenna (*e.g.*, number of passes, pass duration, elevation angles).

Table A.6.a-5: E-Band Link Budgets using 2.4 meter Earth Station Antenna

Link Parameter	Downlink		Uplink		HP Opt.	
Carrier Frequency	72.0GHz	75.0GHz	82.0GHz	85.0GHz	82.0GHz	85.0GHz
Wavelength	0.0042m	0.0040m	0.0037m	0.0035m	0.0037m	0.0035m
RRC Roll-Off Factor	α=0.37	α=0.37	α=0.37	α=0.37	α=0.37	α=0.37
Symbol Rate	1.595GSps	1.595GSps	1.595GSps	1.595GSps	1.595GSps	1.595GSps
Occupied Bandwidth	2.185GHz	2.185GHz	2.185GHz	2.185GHz	2.185GHz	2.185GHz
Information Rate (/Ch/Pol)	2.65Gbps	2.65Gbps	2.65Gbps	2.65Gbps	7.94Gbps	7.94Gbps
TX Power Amplifier P_{1dB}	30.0dBm	30.0dBm	33.0dBm	33.0dBm	47.0dBm	47.0dBm
Output Back-Off (OBO)	3.8dB	3.8dB	3.8dB	3.8dB	7.5dB	7.5dB
Post PA Losses	1.55dB	1.55dB	1.55dB	1.55dB	1.55dB	1.55dB
Transmitted Power P_{Out}	24.6dBm	24.6dBm	27.6dBm	27.6dBm	37.9dBm	37.9dBm
Transmit Antenna Aperture	0.50m	0.50m	2.40m	2.40m	2.40m	2.40m
Half-power beamwidth	0.583°	0.560°	0.107°	0.103°	0.107°	0.103°
Transmit Aperture Efficiency	60%	60%	84%	84%	84%	84%
Transmit Antenna Gain	49.3dBi	49.7dBi	65.5dBi	65.8dBi	65.5dBi	65.8dBi
EIRP	73.9dBm	74.3dBm	93.1dBm	93.4dBm	103.4dBm	103.8dBm
Transmit Antenna Pointing Loss	0.50dB	0.50dB	0.50dB	0.50dB	0.50dB	0.50dB
Radome Loss	0.00dB	0.00dB	1.07dB	1.09dB	1.07dB	1.09dB
Link Distance Slant Range	909km	909km	909km	909km	909km	909km
Free Space Loss	188.8dB	189.1dB	189.9dB	190.2dB	189.9dB	190.2dB
Propagation Loss	8.60dB	8.60dB	5.5dB	5.5dB	5.5dB	5.5dB
Total Path Loss (Less Radomes)	197.4dB	197.7dB	195.4dB	195.7dB	195.4dB	195.7dB
Radome Loss	1.25dB	1.17dB	0.00dB	0.00dB	0.0dB	0.0dB
Received Power at Antenna	-125.2dBm	-125.1dBm	-103.8dBm	-103.8dBm	-93.5dBm	-93.5dBm
Receive Antenna Aperture	2.40m	2.40m	0.50m	0.50m	0.50m	0.50m
Receive Antenna Efficiency	84%	84%	60%	60%	60%	60%
Receive Antenna Gain	64.4dBi	64.7dBi	50.4dBi	50.7dBi	50.4dBi	50.7dBi
Receive Antenna Pointing Loss	0.50dB	0.50dB	0.50dB	0.50dB	0.50dB	0.50dB
Feed Loss	0.10dB	0.10dB	0.10dB	0.10dB	0.10dB	0.10dB
Post-Feed Losses	1.55dB	1.55dB	1.45dB	1.45dB	1.45dB	1.45dB
Received Power at LNA Input	-63.0dBm	-62.5dBm	-55.5dBm	-55.2dBm	-45.1dBm	-44.8dBm
Receiver Noise Temperature	438.4K	438.4K	438.4K	438.4K	438.4K	438.4K
System Noise Temperature	697.0K	697.0K	668.0K	668.0K	668.0K	668.0K
Carrier to Noise (C/N)	15.2dB	15.6dB	22.9dB	23.2dB	33.2dB	33.5dB
Carrier to Interference (C/I)	40.0dB	40.0dB	40.0dB	40.0dB	40.0dB	40.0dB
Antenna Cross-Pol Isolation	35.0dB	35.0dB	35.0dB	35.0dB	35.0dB	35.0dB
C/(N+I)	15.1dB	15.6dB	22.5dB	22.8dB	30.5dB	30.6dB
Link margin (dB)	**5.9dB**	**6.4dB**	**13.3dB**	**13.6dB**	**8.2dB**	**8.3dB**
Total information rate (Gb/s)	**10.59Gbps**	**10.59Gbps**	**10.59Gbps**	**10.59Gbps**	**31.77Gbps**	**31.77Gbps**

Table A.6.a-6: E-Band Link Budgets for using 1.2 meter Backup Earth Station Antenna

Link Parameter	Downlink		Uplink		HP Opt.	
Carrier Frequency	72.0GHz	75.0GHz	82.0GHz	85.0GHz	82.0GHz	85.0GHz
Wavelength	0.0042m	0.0040m	0.0037m	0.0035m	0.0037m	0.0035m
RRC Roll-Off Factor	α=0.37	α=0.37	α=0.37	α=0.37	α=0.37	α=0.37
Symbol Rate	1.595GSps	1.595GSps	1.595GSps	1.595GSps	1.595GSps	1.595GSps
Occupied Bandwidth	2.185GHz	2.185GHz	2.185GHz	2.185GHz	2.185GHz	2.185GHz
Information Rate (/Ch/Pol)	2.65Gbps	2.65Gbps	2.65Gbps	2.65Gbps	7.94Gbps	7.94Gbps
TX Power Amplifier P_{1dB}	30.0dBm	30.0dBm	33.0dBm	33.0dBm	47.0dBm	47.0dBm
Output Back-Off (OBO)	3.8dB	3.8dB	3.8dB	3.8dB	7.5dB	7.5dB
Post PA Losses	1.55dB	1.55dB	1.55dB	1.55dB	1.55dB	1.55dB
Transmitted Power P_{Out}	24.6dBm	24.6dBm	27.6dBm	27.6dBm	37.9dBm	37.9dBm
Transmit Antenna Aperture	0.50m	0.50m	1.20m	1.20m	1.20m	1.20m
Half-power beamwidth	0.583°	0.560°	0.213°	0.206°	0.213°	0.206°
Transmit Aperture Efficiency	60%	60%	55%	55%	55%	55%
Transmit Antenna Gain	49.3dBi	49.7dBi	57.7dBi	58.0dBi	57.7dBi	58.0dBi
EIRP	73.9dBm	74.3dBm	85.3dBm	85.6dBm	95.6dBm	95.9dBm
Transmit Antenna Pointing Loss	0.50dB	0.50dB	0.50dB	0.50dB	0.50dB	0.50dB
Radome Loss	0.00dB	0.00dB	1.07dB	1.09dB	1.07dB	1.09dB
Link Distance Slant Range	909km	909km	909km	909km	909km	909km
Free Space Loss	188.8dB	189.1dB	189.9dB	190.2dB	189.9dB	190.2dB
Propagation Loss	8.60dB	8.60dB	5.5dB	5.5dB	5.5dB	5.5dB
Total Path Loss (Less Radomes)	197.4dB	197.7dB	195.4dB	195.7dB	195.4dB	195.7dB
Radome Loss	1.25dB	1.17dB	0.00dB	0.00dB	0.0dB	0.0dB
Received Power at Antenna	-125.2dBm	-125.1dBm	-111.7dBm	-111.7dBm	-101.4dBm	-101.4dBm
Receive Antenna Aperture	1.20m	1.20m	0.50m	0.50m	0.50m	0.50m
Receive Antenna Efficiency	55%	55%	60%	60%	60%	60%
Receive Antenna Gain	56.5dBi	56.9dBi	50.4dBi	50.7dBi	50.4dBi	50.7dBi
Receive Antenna Pointing Loss	0.50dB	0.50dB	0.50dB	0.50dB	0.50dB	0.50dB
Feed Loss	0.10dB	0.10dB	0.10dB	0.10dB	0.10dB	0.10dB
Post-Feed Losses	1.55dB	1.55dB	1.45dB	1.45dB	1.45dB	1.45dB
Received Power at LNA Input	-70.8dBm	-70.4dBm	-63.3dBm	-63.0dBm	-53.0dBm	-52.7dBm
Receiver Noise Temperature	438.4K	438.4K	438.4K	438.4K	438.4K	438.4K
System Noise Temperature	697.0K	697.0K	668.0K	668.0K	668.0K	668.0K
Carrier to Noise (C/N)	7.3dB	7.8dB	15.0dB	15.3dB	25.4dB	25.7dB
Carrier to Interference (C/I)	40.0dB	40.0dB	40.0dB	40.0dB	40.0dB	40.0dB
Antenna Cross-Pol Isolation	35.0dB	35.0dB	35.0dB	35.0dB	35.0dB	35.0dB
C/(N+I)	7.3dB	7.8dB	15.0dB	15.3dB	24.8dB	25.0dB
Link margin (dB)	**-1.9dB**	**-1.4dB**	**5.8dB**	**6.1dB**	**2.5dB**	**2.7dB**
Total information rate (Gb/s)	**10.59Gbps**	**10.59Gbps**	**10.59Gbps**	**10.59Gbps**	**31.77Gbps**	**31.77Gbps**

[redacted]

A.7 The Complete Program of Research and Experimentation Proposed, Including a Description of Equipment and Theory of Operation (Form 442 – Question 7a, §5.63(c)(1))

Space Systems/Loral ("SSL") is the manufacturer of the Athena satellite. The satellite consists of an SSL 100 bus customized to accommodate the Athena payload. Spacecraft mass is 150 kg and volume approximately 0.33 cubic meters. The spacecraft bus is a three-axis stabilized bus providing attitude control, power and communication channels to the payload. To support payload activities, the bus will steer the spacecraft body towards a ground station, maintain pointing throughout the payload operations, and provide the necessary power for the payload to operate. During that entire time, the spacecraft will be in contact with the ground providing telemetry and responding to commands. After payload activities are completed, the spacecraft will return to a Sun pointing attitude that will allow its batteries to recharge in preparation for the subsequent payload activity. Power is nominally only provided to the payload during predetermined and commanded payload pass opportunities that align with contacts to the ground stations noted in Table A.6.a-4. In addition, as the spacecraft passes in view of TT&C ground stations noted in Table A.6.a-1 (outside of payload activities), it will download stored telemetry to the ground as well as provide uplink opportunities for commands and uploads in preparation of subsequent payload activities. Table A.7-1 and Table A.7-2 give the equipment characteristics for the TT&C receiver and TT&C transmitter, respectively.

Table A.7-1 TT+C Receiver Characteristics

Parameter	Value
Signal Level Range	≤ –100 dBm to ≥ –47 dBm
Signal Sweep Range	f_R ±90 kHz
Acquisition Threshold	≤ –100 dBm at 1 kHz/s, 5 kHz/s ≤ –90 dBm at 1 kHz/s, 5 kHz/s, 10 kHz/s
RF Carrier Frequency	2082 MHz
Data Rate	256 kbps
Modulation	BPSK modulation on carrier
Command Threshold with BER of 10-6)	≤ –100 dBm at RF input
Command Signal Level	≤ –100 dBm to ≥ –47 dBm at RF input

Table A.7-2 TT+C Transmitter Characteristics

- **SPECIFICATION TABLE**
- **Box Level**
  - **Baseband Data**
    - BPSK
    - Bn = 1.024 MHz
  - **Input Frequency (IF)** — **2280 MHz**
  - **Input RF Power** — **-8 dBm**
  - **S to X Gain** — **45 dB**
  - **DC consumption** — **< 42W goal for Transceiver, 28W for UPC_PA**
- **LO Section**
  - **Frequency** — **6216.25 MHz**
  - **Mixer Drive Level** — **15 dBm**
- **CONVERTER SECTION**
  - **Spurious Suppression**
    - For Fc to Bn/2 — Attenuation mask = 0
    - For Bn/2-2.5 Bn — Attenuation mask = 40*log(2*fd/Bn)+8 dB
    - For >2.5*Bn — >-60dBc
- **UPC section DC consumption** — **2.9 W**
- **RF OUTPUT**
  - **Frequency** — **8496.25 MHz**
  - **Power** — **37 dBm**
  - **Spurious Suppression**
    - For Fc to Bn/2 — Attenuation mask = 0
    - For Bn/2-2.5 Bn — Attenuation mask = 40*log(2*fd/Bn)+8 dB
    - For >2.5*Bn — >-60dBc
- **RF Section DC power** — **~ 20W**

The E-band transceivers on the satellite and at the ground station are both of the direct-conversion I/Q modulation type (i.e., baseband signals are modulated/demodulated directly onto/from the E-band carriers via I/Q mixers). After modulation on the carriers, each transmit channel is routed through individual gain stages and power amplifiers before being combined and diplexed through the transceiver multiplexer. The receive paths are identical, but in reverse, and instead of power amplifiers, low noise amplification is utilized between the antenna port and the demodulator. The primary differences between the transceiver on the spacecraft and that in the ground station are (1) the transmit and receive bands are swapped and (2) there are higher-power amplifiers on the ground for the uplink signals. Key specification parameters at the air interfaces for these transceivers are provided in Table A.7-3.

Table A.7-3 E-band Transmitter Details

Key Performance Parameter	Specification	Comment
Carrier Frequencies	Downlink: 72 & 75GHz Uplink: 82 & 85GHz	
Maximum Transmitter RF Output Power	Downlink: +24.6 dBm Uplink: +27.6 dBm Uplink HP Option: 37.9 dBm	As mentioned above and indicated in Tables A.6.a-5 and A.6.a-6, an optional 50W (+47 dBm) TWTA may be used late in the mission for the uplink.
Maximum Transmit EIRP	Downlink: 74.3 dBm Uplink: 93.4 dBm Uplink HP Option: 103.8 dBm	
Carrier Frequency Accuracy	≤±4ppm/Temperature ≤±1ppm/1st year, ≤±5ppm/10 years	
Carrier Phase Noise 1MHz Offset: Integrated over 1-50MHz offset:	≤-95dBc/Hz ≤-38dBc	Applies to both transmit carrier and receive local oscillator signal (at E-band)
RF Modulation	I/Q Modulation	QPSK, 8APSK, 16QAM, 32QAM & 64QAM
Pre-Mod RRC Roll-Off	0.37 nominal	
Data Symbol Rate	1.595 GSps	

A.8 Cessation of Emissions (§25.207)

The satellite transmissions can be turned on and off by ground telecommand, thereby causing cessation of emissions from the satellite, as required by §25.207 of the Commission's rules. For the payload, the spacecraft simply cuts the power supply to the payload modules, inhibiting any transmission of emissions; this is true for any time that the system is not executing a payload contact to a ground station noted in A.6.a-4. For the TT&C chain, although the receiver part of the transceiver is always expected to be on (when battery charge exceeds a certain state-of-charge) in order to receive commands, the transmitter chain is commandable and can be turned off to prevent any transmission of emissions.

The spacecraft power distribution unit has "end of mission" switches that inhibit charging of the battery, causing a slow decay of the state of charge until ultimate passivation. The end of mission switches are commandable (both ways), and the effect of closing the switches is slow enough to allow reversal in case of inadvertent commanding.