Attachment C – Technical Annex

1. Scope

This Attachment contains additional information regarding the Yet Another Mission (YAM) non-geostationary (NGSO) satellite constellation required by Section 25.114 and other sections of the Part 25 rules that cannot be entered into the Schedule S online submission system.

2. General Description (Section 25.114(d)(1))

The YAM-2 NGSO satellite will be the first in a constellation comprised of 10 micro-satellites hosting various payloads. The YAM satellites will be launched into various orbits based upon available ride-share opportunities.

YAM-2 customer payloads are as follows.

- a cryocooled hyperspectral imager with a ground sampling distance of 35 km[1]
- a hyperspectral imager with a ground sampling distance of 90 km
- an Internet of Things (IoT) payload that transmits in the 400.15-401 MHz band and receives in the 864-925 MHz band[2]
  - TX – Beacon
    - 400.15 – 401 MHz (programmable in this range)
    - 20% TX Duty cycle within 5s frame
    - Turnstile antenna
    - -1.0 dBi antenna gain
    - 5 dBW EIRP
  - RX – Data Collection
    - Channels
      - CH1: 865.7 MHz – 1.4 MHz bandwidth
      - CH2: 868.86 MHz – 1.7 MHz bandwidth
      - CH3: 904.0 MHz – 4.0 MHz bandwidth
      - CH4: 922.0 MHz – 4.0 MHz bandwidth
    - Patch RX Antenna (low gain)
      - 80-degree half power beamwidth
      - 7.1 dBi peak gain
    - Patch Array RX Antenna (high gain)
      - 43-degree half power beamwidth
      - 11.3 dBi peak gain

[1] Loft Orbital is aware of the requirement to obtain a commercial remote sensing license from the National Oceanic and Atmospheric Administration (NOAA) for the operations of imaging sensors and intends to comply with all NOAA regulatory requirements. *See* 15 C.F.R. Part 960.

[2] The International Telecommunication Union (ITU) filing name is F-SAT-NG-8. This payload will be licensed by the French administration, and the customer of this payload may separately request U.S. market access. *See* Narrative at 5-6 n.6.

All YAM satellites will contain the following payloads.

- a software defined radio that receives and processes L-band data signals in the 1535-1559 MHz band from authorized and coordinated Inmarsat plc (Inmarsat) Geostationary (GSO) satellites
- a Globalstar terminal to demonstrate space-to-space communications relayed via the Globalstar constellation in the Globalstar-authorized and assigned frequencies, *i.e.*, 1615.65 MHz/1616.88 MHz and 2489.31 MHz/2490.54 MHz

3. Spacecraft Overview

The YAM satellites will be manufactured and supplied by Blue Canyon Technologies (BCT) and is based on their FlexBus platform. The satellite is 3-axis stabilized, achieves beam steering via body steering of the bus, and does not employ any form of propulsion.

The YAM satellites offer the following common characteristics:

- 5-year operational life
- 3-axis stabilized
- S-band uplink and downlink telemetry, tracking, and command (TT&C)
- X-band downlink mission data
- Software defined radios (SDR)
- Intersatellite communications with the Globalstar constellation

The spacecraft will operate in the frequencies listed below.

Table 1 Frequencies

Usage	Link Direction	Spectrum Range
TT&C Uplink	Uplink (Earth-space)	2025-2110 MHz
TT&C Downlink	Downlink (space-Earth)	2200-2290 MHz
Payload Downlink	Downlink (space-Earth)	8025-8400 MHz
IoT Beacon	Downlink (space-Earth)	400.15–401 MHz
IoT Data Collection	Uplink (Earth-space)	864-925 MHz
L-band Data Signal	Receive (space-space)	1535-1559 MHz
Globalstar – Data	Transmit (space-space)	1613.8-1626.5 MHz (1615.65 MHz/1616.88 MHz center frequencies)
Globalstar – Data	Receive (space-space)	2483.5-2495 MHz (2489.31 MHz/2490.54 MHz center frequencies)

4. Constellation

The YAM constellation will consist of 10 microsatellites in Low Earth Orbit (LEO) deployed between the 425 km to 570 km orbital altitude. The target nominal orbit altitude is 550 km.[3] The actual constellation

[3] The YAM-2 satellite will be deployed between 500 km and 550 km at the discretion of the launch service provider. Loft Orbital has assumed a 550 km deployment orbital altitude for purposes of the orbital debris analysis.

orbital parameters will be defined by available ride-sharing launch opportunities. Most ride-share opportunities to LEO are for sun-synchronous orbit (SSO), and Loft Orbital seeks authority for such deployment opportunities. Other ride share opportunities might also be considered, and Loft Orbital will request the necessary authority for any such deployments at the appropriate time.

Loft Orbital will not seek to launch any satellites to an orbit altitude above 570 km to ensure that each satellite it launches will meet the FCC's 6-year de-orbit requirement for satellites authorized under the FCC's new small satellite streamlined licensing rules.[4] For planning purposes, the constellation data entered into the Schedule S system includes the following orbital planes:

Table 2 Representative Orbital Parameters

Orbit ID	Altitude	Inclination	# SV
1	550	97.7	2
2	525	97.6	2
3	500	97.4	2
4	475	97.3	2
5	450	97.2	1
6	425	97.1	1

5. Telemetry, Tracking and Control (TT&C)

The YAM TT&C sub-system provides for communications during on-station operations, as well as during spacecraft emergencies. S-band telecommand transmissions are received and S-band telemetry communications are transmitted by the spacecraft through patch antennas with near-omni directional patterns during on-station operations and during both transfer orbit and emergency operations.

The S-band telemetry channels have a bandwidth of 2 MHz during normal operations and 200 kHz or 20 kHz during contingency operations. The S-band commanding channels have a bandwidth of 200 kHz during normal operations and 20 kHz or 2 kHz during contingency operations. TT&C operations will be conducted from Kongsberg Satellite Services (KSAT) TT&C sites including: Svalbard, Troll, and others depending upon orbit inclination. The specific S-band telemetry channels and S-band commanding channel have not yet been selected. As those bands are coordinated, Loft Orbital will work with its ground station service provider, KSAT, to minimize spectrum overlap with other customers being served from common locations. Representative channel information is provided below in Table 3 and Table 4.

The TT&C beams have peak gains of 7.4 dBi, and the links are designed for operation down to the -10 dBi contour of the patch antenna. Therefore, pursuant to Section 25.114(c)(4)(vi)(A) of the Commission's rules, contours for these beams are provided in the associated GXT files included in Schedule S.

Each YAM satellite will provide a unique telemetry marker both by selecting unique telemetry channels, in cases where multiple satellites are deployed by the same launch vehicle, and by using a unique satellite identifier within the telemetry signal to assure that each satellite telemetry stream can be unambiguously identified.

Contact details for the control center are provided below:

Address:
Alexander B. Greenberg
Co-Founder and Chief Operating Officer

[4] *See* Attachment A, Narrative § II(A).

715 Bryant Street, Suite 202
San Francisco, CA 94118
Telephone:
410-382-5050

6. Frequency Plan

6.1 S-Band

The following tables list the uplink and downlink S-band channel planned for the YAM constellation. These channels are not finalized and define representative uplink and downlink S-band channels. This information is also provided in the accompanying Schedule S but is included here for completeness.

Table 3 S-Band Downlink Frequency Plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
SD1H	2	2207.5	R
SD2H	2	2212.5	R
SD3H	2	2217.5	R
SD4H	2	2232.5	R
SD5H	2	2242.5	R
SD6H	2	2252.5	R
SD7H	2	2262.5	R
SD8H	2	2272.5	R
SD9H	2	2287.5	R
SD1M	0.2	2207.5	R
SD2M	0.2	2212.5	R
SD3M	0.2	2217.5	R
SD4M	0.2	2232.5	R
SD5M	0.2	2242.5	R
SD6M	0.2	2252.5	R
SD7M	0.2	2262.5	R
SD8M	0.2	2272.5	R
SD9M	0.2	2287.5	R
SD1L	0.02	2207.5	R
SD2L	0.02	2212.5	R
SD3L	0.02	2217.5	R
SD4L	0.02	2232.5	R
SD5L	0.02	2242.5	R
SD6L	0.02	2252.5	R
SD7L	0.02	2262.5	R
SD8L	0.02	2272.5	R
SD9L	0.02	2287.5	R

The YAM constellation requires approximately 4 unique downlink channels to support planned operations. Pending coordination with both NTIA and other domestic and international commercial operators, a subset of channels will be selected. Given guidance from the FCC and NTIA, these channels will most likely be selected from the following subset:

- 2207.5 MHz
- 2212.5 MHz
- 2217.5 MHz
- 2272.5 MHz
- 2287.5 MHz

Table 4 S-Band Uplink Frequency Plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
SU1H	0.2	2030	R
SU2H	0.2	2040	R
SU3H	0.2	2050	R
SU4H	0.2	2060	R
SU5H	0.2	2070	R
SU6H	0.2	2080	R
SU7H	0.2	2090	R
SU8H	0.2	2100	R
SU9H	0.2	2105	R
SU1M	0.02	2030	R
SU2M	0.02	2040	R
SU3M	0.02	2050	R
SU4M	0.02	2060	R
SU5M	0.02	2070	R
SU6M	0.02	2080	R
SU7M	0.02	2090	R
SU8M	0.02	2100	R
SU9M	0.02	2105	R
SU1L	0.002	2030	R
SU2L	0.002	2040	R
SU3L	0.002	2050	R
SU4L	0.002	2060	R
SU5L	0.002	2070	R
SU6L	0.002	2080	R
SU7L	0.002	2090	R
SU8L	0.002	2100	R
SU9L	0.002	2105	R

The fully-deployed YAM constellation will require approximately 4 unique S-band uplink channels to support planned operations. Pending coordination with both NTIA and other domestic and international commercial operators, a subset of channels will be selected.

6.2 X-Band

The following table lists the downlink X-band channel planned for the YAM constellation. This information is also provided in the accompanying Schedule S but is included here for completeness.

Table 5 X-Band Downlink Frequency Plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
XD1L	10	8050	R
XD2L	10	8100	R
XD3L	10	8150	R
XD4L	10	8200	R
XD5L	10	8250	R
XD6L	10	8300	R
XD7L	10	8350	R
XD8L	10	8375	R
XD1M	25	8050	R
XD2M	25	8100	R
XD3M	25	8150	R
XD4M	25	8200	R
XD5M	25	8250	R
XD6M	25	8300	R
XD7M	25	8350	R
XD8M	25	8375	R
XD1H	50	8050	R
XD2H	50	8100	R
XD3H	50	8150	R
XD4H	50	8200	R
XD5H	50	8250	R
XD6H	50	8300	R
XD7H	50	8350	R
XD8H	50	8375	R

6.3 Globalstar Intersatellite Link

The following tables list the S-band space-space receive channels and the L-band space-space transmit channels planned for the YAM constellation. The channels listed in the following two tables reflect the channels used for communications to/from the Globalstar network. This information is also provided in the accompanying Schedule S but is included here for completeness.

Table 6 Globalstar L-Band Space-Space Transmit Frequency Plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
GT01	1.23	1615.65	LHCP
GT02	1.23	1616.88	LHCP

Table 7 Globalstar S-Band Space-Space Receive Frequency Plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
GR01	1.23	2489.31	LHCP
GR02	1.23	2490.54	LHCP

6.4 L-band Data Signals

The following table lists the L-band space-to-space receive channels planned for the YAM constellation. The receive-only payload concurrently receives GPS navigational signals and MSS L-band data signals in the 1535-1559 MHz band from authorized and coordinated Inmarsat satellites. The L-band data signal provides satellite navigation correction data, augmenting the accuracy of Loft Orbital's location assessment.[5]

Table 8 L-Band Data Signal Space-to-Space Receive Frequency Plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
IR01	0.005	1539.9325	RHCP
IR02	0.005	1545.895	RHCP
IR03	0.0025	1539.9525	RHCP
IR04	0.0025	1546.26	RHCP
IR05	0.005	1539.9125	RHCP
IR06	0.005	1545.9275	RHCP
IR07	0.005	1545.9375	RHCP
IR08	0.0025	1539.9625	RHCP
IR09	0.0025	1545.835	RHCP
IR10	0.0025	1545.52	RHCP

[5] *See* Attachment A, Narrative § I(A). The Commission has authorized earth stations licensed in the United States to communicate with Inmarsat satellites in this band. *See, e.g.*, Application of Deere & Company, IBFS File No. SES-LIC-20130422-00340, Exhibit C (filed Mar. 14, 2013); *see also Inmarsat, Inc. Request to Streamline Licensing of L-band Mobile-Satellite Service Terminals Using Inmarsat Satellites as Points of Communication*, Order, IBFS File No. SES-PDR-20080303-00367 (rel. Oct. 21, 2008).

IR11	0.005	1539.9625	RHCP
IR12	0.005	1545.875	RHCP

7. Frequency Tolerance

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

8. Out of Band Emissions

The out-of-band emission limits of Section 25.202(f)(1), (2), and (3) will be met.

9. Frequency Reuse

The YAM constellation does not operate in any frequency bands where Section 25.210(f) applies.

10. 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.

11. ITU Filings

The YAM satellite constellation is associated with the USASAT-30J ITU filing. This ITU filing is being submitted concurrently with this Part 25 FCC filing. The IoT hosted RF payload (operating in the 400.15-401 MHz band and the 864-925 MHz band) is separately authorized by the French Administration.[6]

12. PFD Analysis

A. 2200-2290 MHz

The Commission's rules do not specify a PFD limit in the 2200–2290 MHz band; however, there are PFD limits specified in rule No. 21.16 of the International Telecommunication Union (ITU) Radio Regulations. The maximum PFD levels for the YAM-2 transmissions were calculated for the 2200-2290 MHz band and the results are provided in Schedule S and demonstrate that the downlink power flux density (PFD) levels of the YAM carriers do not exceed the limits specified in rule No. 21.16 of the ITU Radio Regulations.

Figure 1 below illustrates the S-band downlink PFD values in comparison with the ITU PFD limits in No. 21.16. This figure represents the maximum transmitted EIRP when the satellite is at the orbital altitudes of 425 km, 500 km, and 550 km. For satellites at lower orbit altitudes the transmitted RF power is attenuated commensurate with the difference in PFD at Nadir.

[6] *See supra* note 2.

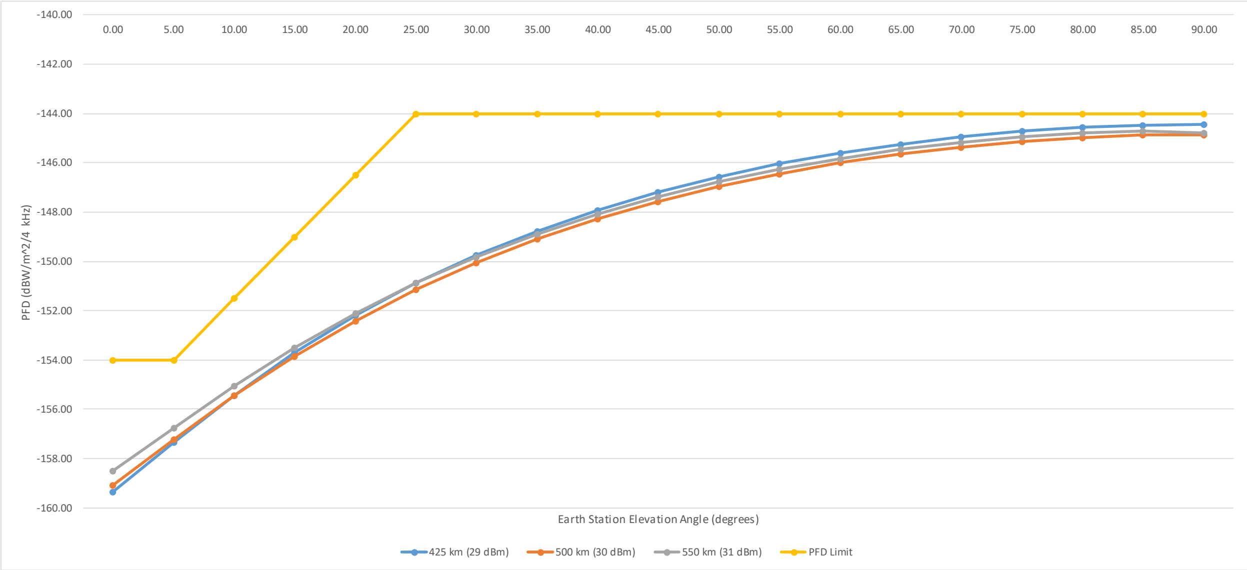

Figure 1 S-band Downlink PFD Analysis

B. 8025-8400 MHz

The Commission's rules do not specify a PFD limit in the 8025–8400 MHz band; however, there are PFD limits specified in rule No. 21.16 of the International Telecommunication Union (ITU) Radio Regulations. The maximum PFD levels for the YAM transmissions were calculated for the 8025–8400 MHz band and the results are provided in Schedule S and demonstrate that the downlink power flux density (PFD) levels of the YAM-2 carriers do not exceed the limits specified in rule No. 21.16 of the ITU Radio Regulations.

Figure 2 below illustrates the X-band downlink PFD values in comparison with the ITU PFD limits in No. 21.16. This figure represents the maximum transmitted EIRP when the satellite is at the orbital altitudes of 425 km, 500 km, and 550 km.

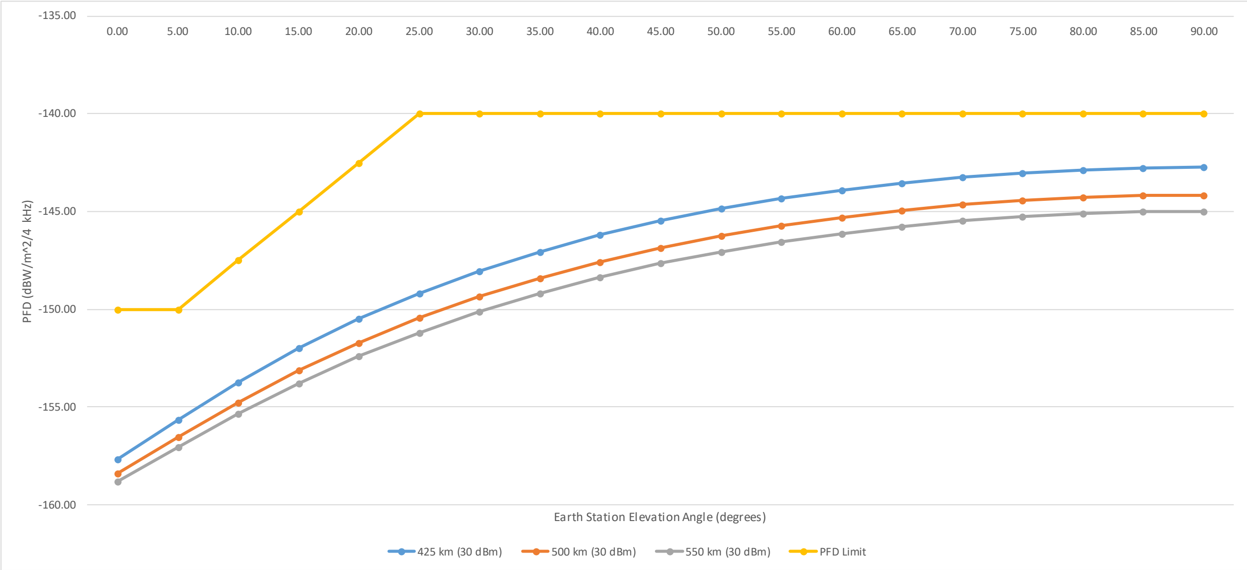

Figure 2 X-band Downlink PFD Analysis

C. 8400-8500 MHz

PFD at the surface of the Earth in the 8400-8450 MHz band ITU-R Recommendation SA-1157 specifies a maximum allowable interference power spectral flux-density level at the earth's surface of -221 dB(W/Hz) to protect ground receivers in the deep-space research band operating in the 8400-8450 MHz frequencies.[7] Loft Orbital uses a combination of baseband digital filtering and hardware radio frequency filtering to achieve the ITU recommended protection for its out-of-band emissions in this frequency band.

13. L-band Interference Analysis

1613.8-1626.5 MHz Frequency Band

Loft Orbital will use a Globalstar terminal to demonstrate space-to-space communications relayed via the Globalstar constellation in the Globalstar-authorized and assigned frequencies, *i.e.*, 1615.65 MHz/1616.88 MHz. Given an emission bandwidth of 1.23 MHz, the top end of this emission is 1617.495 MHz, which provides 280 kHz frequency separation between this emission and the bottom end of the shared Iridium/Globalstar spectrum band: 1617.775-1618.725 MHz.

Loft Orbital's use of the Globalstar modems on its YAM constellation will not cause harmful interference into Iridium for the following reasons:

- Globalstar uses closed-loop power control to manage PFD at its satellite receiver.
- Loft Orbital will only operate in frequencies authorized to Globalstar.
- The Globalstar modem safely meets the international standards governing out-of-channel emissions.

[7] *See* Recommendation ITU-R SA.1157-1 (Protection criteria for deep-space research) (2006).

The FCC has previously approved similar usage of Globalstar modems on NGSO satellites.[8]

14. Link Budgets

Link analysis for YAM-2 was conducted for representative carriers in the S-band uplink, S-band downlink, and X-band downlink bands communicating with a 3.7m KSAT earth station. The results of the link analysis are shown in Exhibit 1.

15. Satellite Antennas

S-band uplink and downlink share a common patch antenna. Antenna pattern cuts for the antenna at the middle of the S-band uplink spectrum, 2050 MHz, and at the middle of the downlink spectrum band, 2250 MHz, are shown in the following two figures. The peak uplink antenna gain is 6 dBi towards Nadir. The peak downlink antenna gain is 7.4 dBi towards Nadir. The S-band uplink and downlink beams are effectively steerable via body steering of the YAM satellites. These beams can be steered to a minimum elevation angle of 5 degrees anywhere within the satellite footprint. The X-band downlink antenna is a fixed-steering patch array with maximum gain of 23 dBi. The antenna pattern for the downlink X-band antenna is illustrated in Figure 5 and a projection of the X-band downlink antenna pattern, pointed towards Nadir, is illustrated in Figure 6. The X-band downlink beam is effectively steerable via body steering of the YAM satellites. This beam can be steered to a minimum elevation angle of 5 degrees anywhere within the satellite footprint. The antenna patterns for the Globalstar space-space link are illustrated in Figure 7 and Figure 8. The Globalstar RX beam is Zenith pointing and has a maximum gain of 5.0 dBi and a 3dB beamwidth of 80 degrees. The Globalstar TX beam is Zenith pointing and has a maximum gain of 4.3 dBi and a 3dB beamwidth of 90 degrees.

The antenna pattern for the reception of the L-band data signals from Inmarsat satellites is illustrated in Figure 9. The L-band data signal RX beam is Zenith pointing and has a maximum gain of 5.0 dBi and a 3dB beamwidth of 80 degrees.

The antenna projections provided in the accompanying Schedule S reflect the beam projection towards Nadir from a NGSO satellite with an orbital altitude of 550 km. Due to limitations in the ITU GIMS software, the beam projections provided are GSO footprints. This approach was taken in order to provide actual GXT contours rather than just images of projected contours which is the only available option for NGSO systems.

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[8] *See, e.g.*, Stamp Grant, Astro Digital U.S., Inc., IBFS File No. SAT-LOA-20170508-00071 at Frequencies and n.4 (granted in part Aug. 1, 2018).

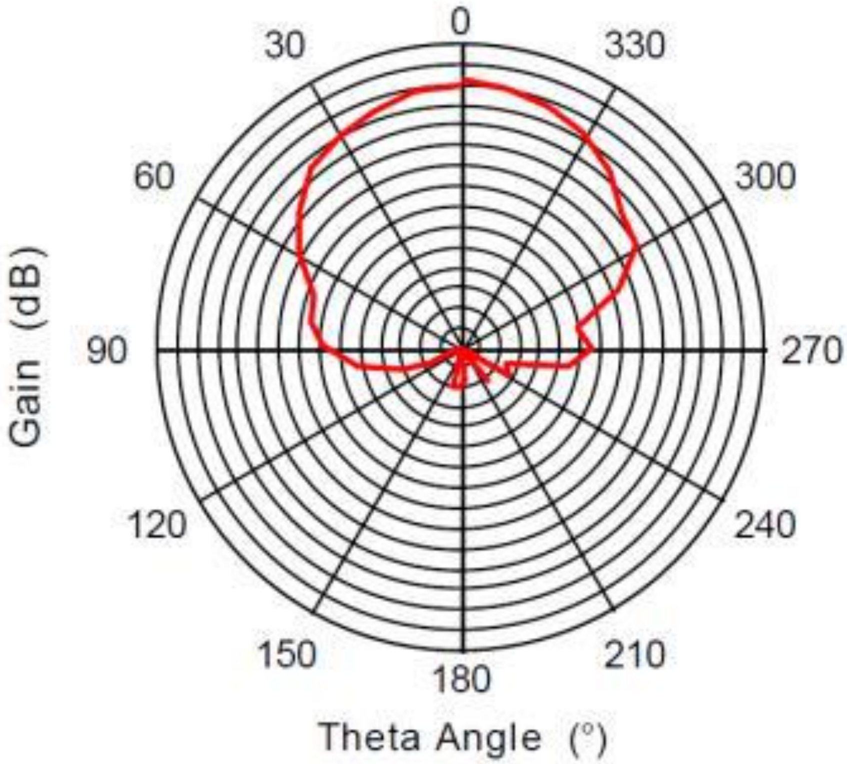

Figure 3 S-band Uplink TT&C - Antenna Pattern

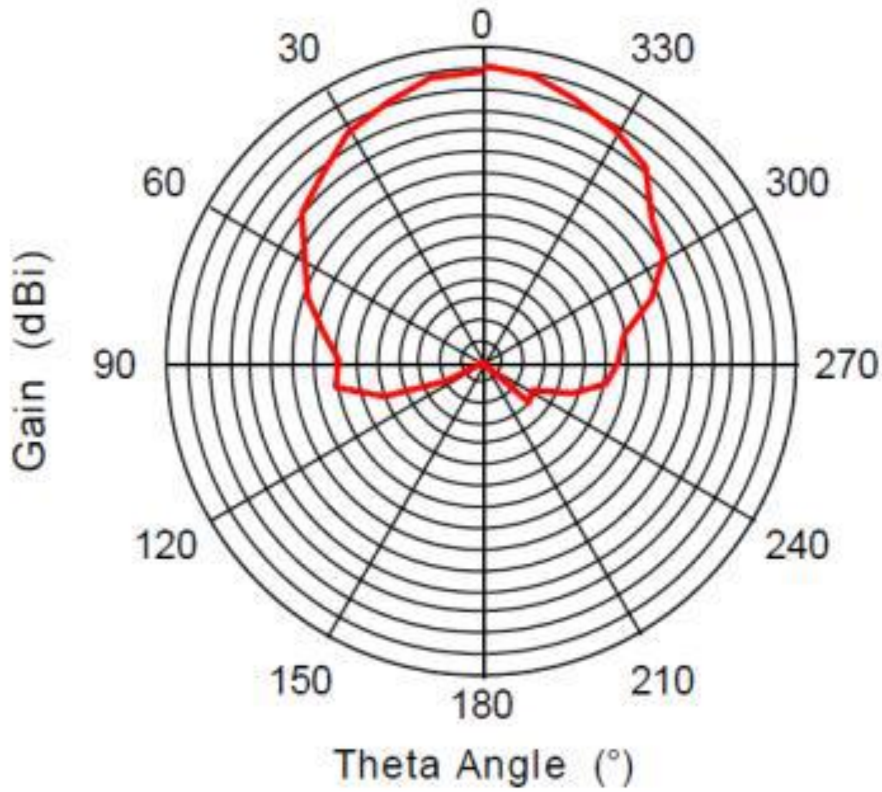

Figure 4 S-band Downlink TT&C - Antenna Pattern

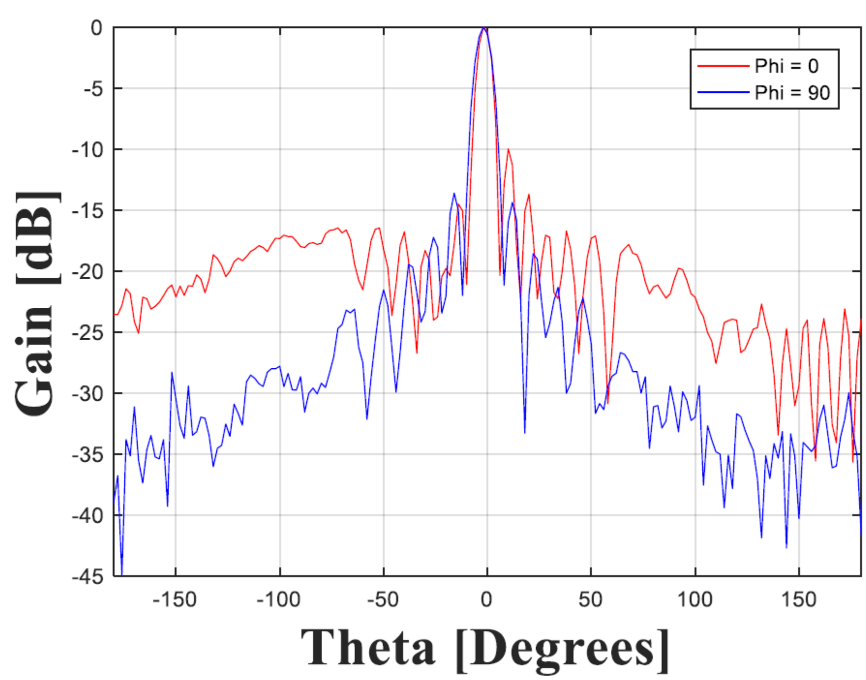

Figure 5 X-band Downlink Mission Data - Antenna Pattern

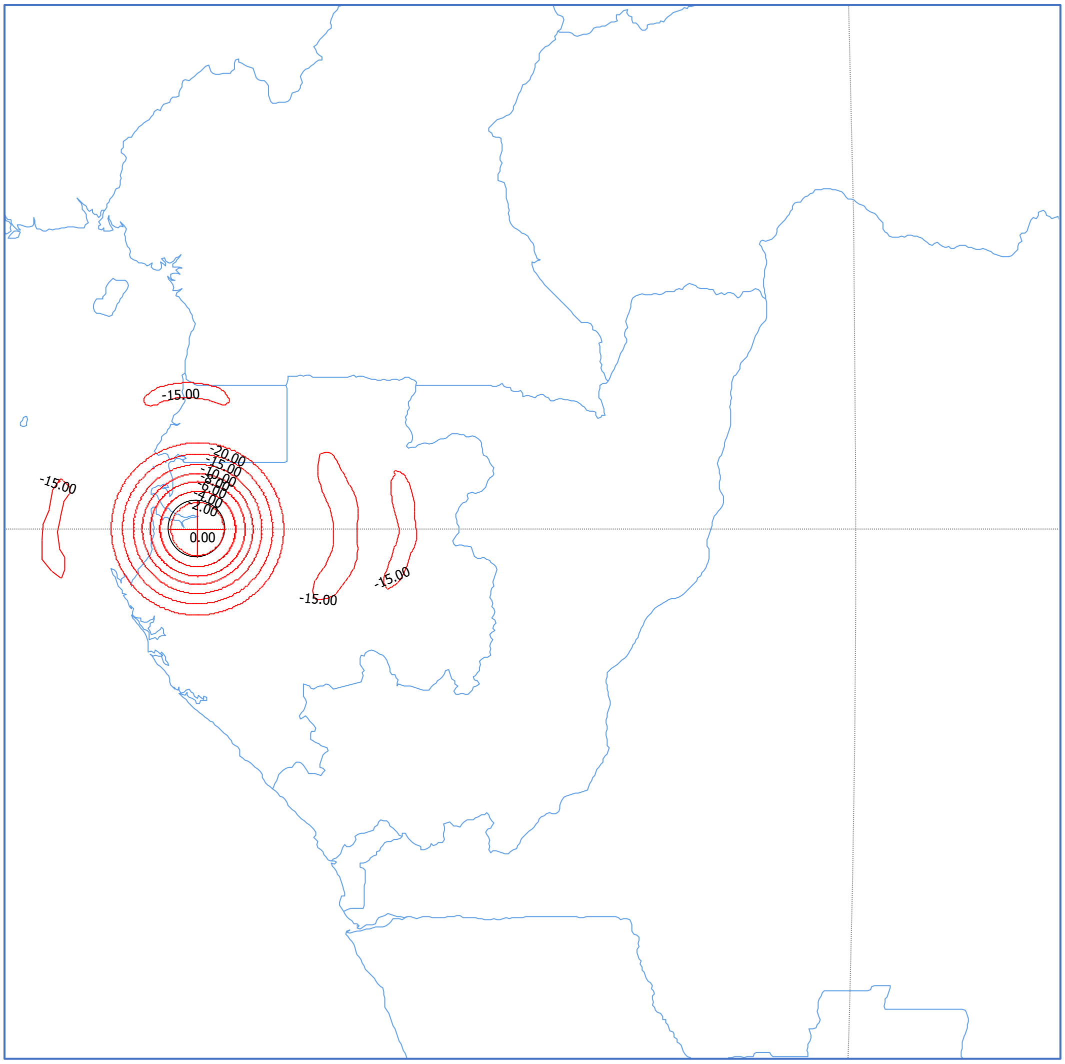

Figure 6 Projection of Nadir X-band Downlink Beam over the West Coast of Africa

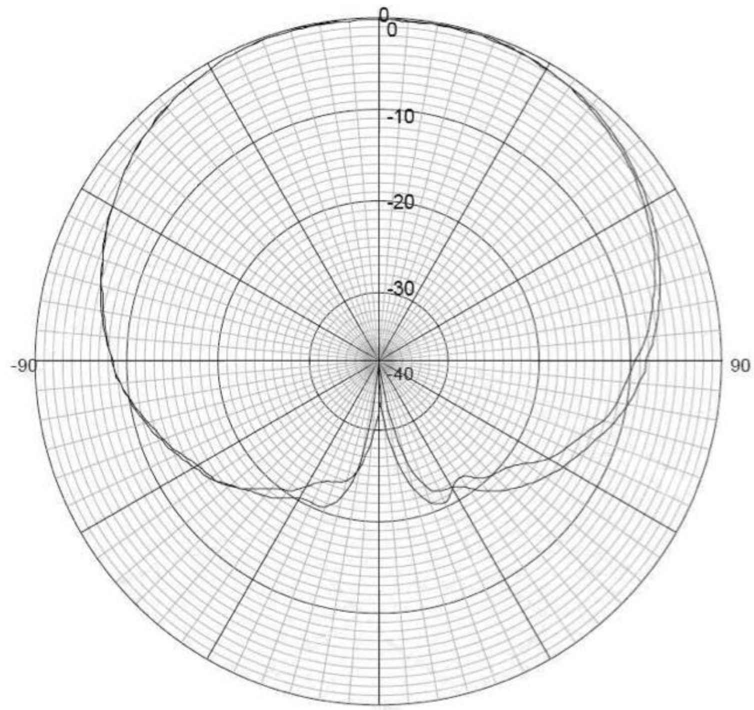

Figure 7 Globalstar Duplex Antenna – L-band Transmit Pattern

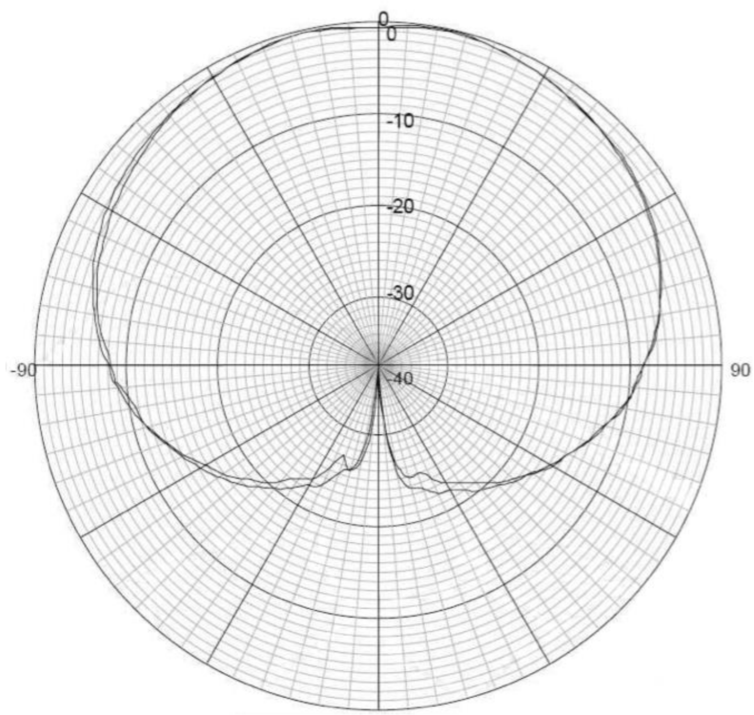

Figure 8 Globalstar Duplex Antenna – S-band Receive Pattern

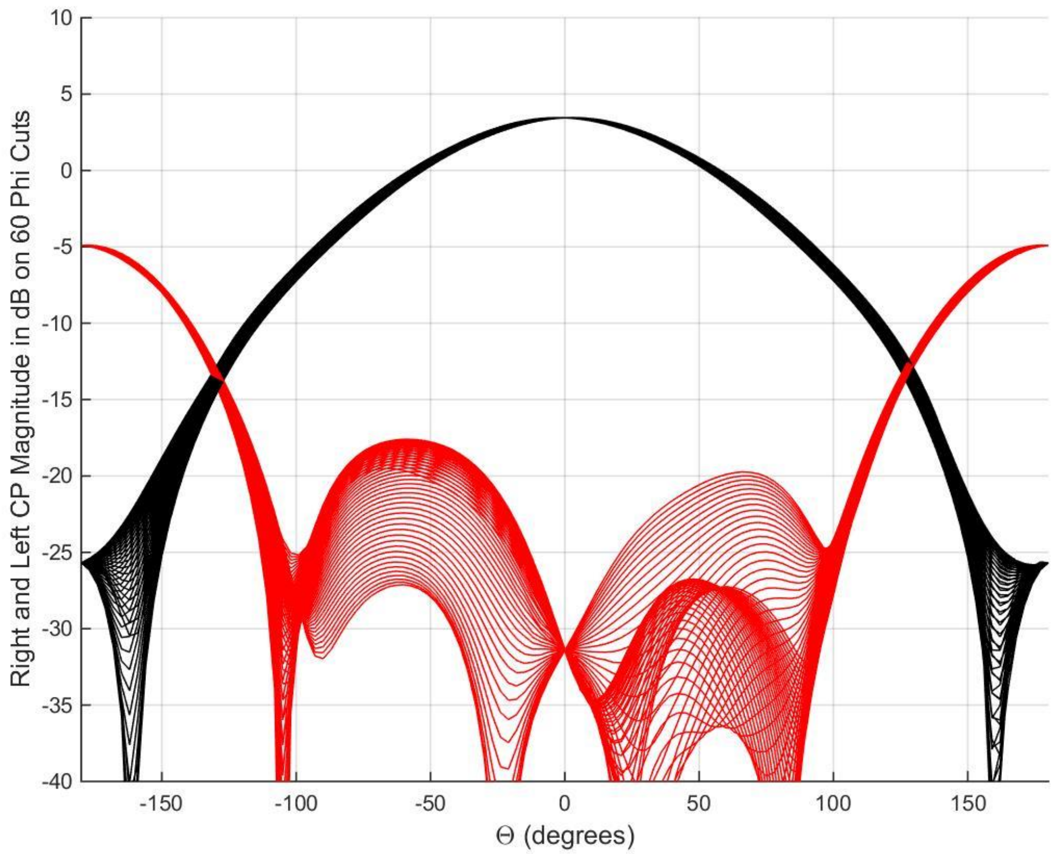

Figure 9 Inmarsat Antenna – L-band Receive Pattern

16. Earth Stations

The Loft Orbital YAM constellation will rely upon the KSAT Lite network of 3.7m Earth Stations for S-band uplink and downlink TT&C communications and X-band downlink payload communications services. The Characteristics of the KSAT Lite network of 3.7m antennas is summarized in Table 9 below.

Table 9 KSAT Antenna Characteristics

	S-band	**X-band**
Reflector Size	3.7m	3.7m
Downlink Band	2200-2290 MHz	8025-8400 MHz
G/T (20-deg elevation)	12.6 dB/K	26.5 dB/K
Polarization	LHCP/RHCP	LHCP/RHCP
Uplink Band	2025-2110 MHz	NA
EIRP	44.8 dBW	NA

Loft Orbital will be using two ground stations in the KSat Lite network, SvalSat and TrollSat.

Table 10 KSAT Earth Station Locations Supporting the YAM Constellation

Name	Type	Country	Coordinates
SvalSat	S band (uplink, downlink) X band (downlink)	Norway (Svalbard)	78.2298° N, 15.3965° E
TrollSat	S band (uplink, downlink) X band (downlink)	Antarctica	72.0167° S, 2.5333° E

17. Orbital Debris Risk Mitigation Plan

Loft Orbital confirms that the YAM satellites will not undergo any planned release of debris during their normal operations.[9] In addition, all separation and deployment mechanisms, and any other potential source of debris, will be retained by the spacecraft. Loft Orbital has also 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. Loft Orbital has taken steps to limit the effects of such collisions through shielding, the placement of components, and the use of redundant systems.

Loft Orbital has assessed and limited the probability of accidental explosions during and after completion of mission operations through a failure-mode verification analysis.[10] As part of the satellite manufacturing process, Loft Orbital 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.

Loft Orbital has assessed and limited the probability of the space stations becoming a source of debris by collisions with large debris or other operational spacecraft.[11] Loft Orbital will work closely with its launch providers to ensure that the satellites are deployed in such a way as to minimize the potential for in-plane collision. This specifically includes minimizing the potential for collision with crewed spacecraft.

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

The YAM-2 satellite will not maintain its inclination angle, apogee, perigee, and right ascension of the ascending node to any specified degrees of accuracy.

Loft Orbital's detailed Orbital Debris Assessment Report is attached as Attachment D.[12] 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 Loft Orbital and other operators located in similar orbits.

[9] See 47 C.F.R. § 25.114(d)(14)(i).
[10] *See* 47 C.F.R. § 25.114(d)(14)(ii).
[11] *See* 47 C.F.R. § 25.114(d)(14)(iii).
[12] *See* 47 C.F.R. § 25.114(d)(14)(iv).

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/

____

David C Morse, Ph.D.
Avaliant, LLC
Bellevue, WA USA
(425) 246-3080

EXHIBIT 1: YAM LINK BUDGETS

Parameter	Symbol	Value	Units	Comments/Notes
Spacecraft Orbital Altitude		550	km	Input Spacecraft Altitude
Uplink Frequency	f	2.110	GHz	Input Spacecraft Frequency
Wavelength	λ	0.142	m	λ = c/f
Uplink EIRP	EIRP	74.8	dBm	Input Ground Station EIRP (KSAT-Lite)
Ground Station Elevation Angle	α	10.0	deg	Input elevation angle from the GS to SC
Slant Range	SR	1816	km	Calculation of Slant Range to SC
Free Space Dispersion Loss	L_S	-164.1	dB	Calculation of Free Space Dispersion
Total Atmospheric Loss	A_T	-1.0	dB	ITU S-band Atmos Loss for 99% availability (est)
SC Antenna Gain	G_T	-3.0	dBi	Input SC Ant Gain Estimate (Broadband Patch +/-55 deg)
Passive Loss	L_l	-2.8	dB	Input SC Passive RF Loss (Cable + Diplexer)
Power at the SC Receiver	P_R	-96.1	dBm	Calculated
Minimum Command Channel Power		-100.0	dBm	Receiver threshold for 100 kbps (BPSK) 1x10-6 BER
Available Margin		**3.9**	**dB**	

Figure 10 S-Band Uplink - Link Budget - Normal Operations

Parameter	Symbol	Value	Units	Comments/Notes
Spacecraft Orbital Altitude		550	km	Input Spacecraft Altitude
Uplink Frequency	f	2.110	GHz	Input Spacecraft Frequency - Placeholder
Wavelength	λ	0.142	m	λ = c/f
Uplink EIRP	EIRP	74.8	dBm	Input Ground Station EIRP (KSAT-Lite)
Ground Station Elevation Angle	α	10.0	deg	Input elevation angle from the GS to SC
Slant Range	SR	1815.6	km	Calculation of Slant Range to SC
Free Space Dispersion Loss	L_S	-164.1	dB	Calculation of Free Space Dispersion
Total Atmospheric Loss	A_T	-1.0	dB	ITU S-band Atmos Loss for 99% availability (est)
SC Antenna Gain	G_T	-10.0	dBi	Input SC Antenna Gain (Broadband Patch +/-85 deg)
Passive Loss	L_l	-2.8	dB	Input SC Passive RF Loss (Cable + Diplexer)
Power at the SC Receiver	P_R	-103.1	dBm	Calculated
Minimum Command Channel Power		-110.0	dBm	Receiver threshold for 20 kbps (BPSK) 1x10-6 BER
Available Margin		**6.9**	**dB**	

Figure 11 S-Band Uplink - Link Budget - Contingency Operations

Parameter	Symbol	Value	Units	Comments/Notes
Spacecraft Orbital Altitude		550	km	Input Spacecraft Altitude
Downlink Frequency	f	2.290	GHz	Input Spacecraft Frequency - Placeholder
Wavelength	λ	0.131	m	λ = c/f
Transmit Power	P_T	2.0	Watt	Input Transmit RF Output Power: 2.0 Watts
Transmit Power	$P_{T(dB)}$	33.0	dBm	$P_{T(dB)}$ = 10 log (Pt) + 30
Passive Loss	L_l	-3.3	dB	Input SC Passive RF Loss (Cable + Diplexer)
SC Antenna Gain	G_T	-5.0	dBi	Input SC Antenna Gain (Broadband Patch +/-70 deg)
Equivalent Isotropic Radiated Power	EIRP	24.7	dBm	Spacecraft EIRP = $P_{T(dB)} + G_T + L_l$
Ground Station Elevation Angle	α	10.0	deg	Input elevation look angle from the GS to SC
Slant Range	SR	1815.6	km	Calculation of Slant Range to SC
Free Space Dispersion Loss	L_S	-164.8	dB	Calculation of Free Space Dispersion
Total Atmospheric Loss	A_T	-1.0	dB	ITU S-band Atmos Loss for 99% availability (est)
Ground Station G/T	G/T	12.6	dB/K	KSAT-Lite Ground Station G/T
Total Received Power/T	P_R	-128.5	dBm/K	$P_R = EIRP + L_S + AR_{Loss} + A_T + G/T$
Boltzmann's Constant	k	-198.6	dBm/Hz-K	Constant
Total Received Power/kT	$P_{R(dB-Hz)}$	70.1	dB-Hz	$P_{R(dB-Hz)} = P_R - k$
Data Channel Information; BPSK				
Data Power/kT	$P_{R(dB-Hz)}$	70.1	dB-Hz	= Total Received Power/kT; suppressed carrier modulation
Information Rate	R	1,000,000	bps	Input Information Data Rate
Information Rate	$R_{(dB-Hz)}$	60.0	dB-Hz	= 10 log (R)
Available E_b/N_o	E_b/N_o	10.1	dB	$E_b/N_o = P_{R(dB-Hz)} - R_{(dB-Hz)}$
Required E_b/N_o 10-6 BER	$E_b/N_{o(REQ)}$	10.5	dB	Theory E_b/N_o for 10^{-6} BER Uncoded (no FEC)
Coding Gain		5.5	dB	Convolutional (7, 1/2) 10^{-6} BER
Implementation Loss	IL	-2.0	dB	Estimate of System Distortion Loss
Available Margin		**3.1**	**dB**	

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Figure 12 S-Band Downlink - Link Budget - Normal Operations

Parameter	Symbol	Value	Units	Comments/Notes
Spacecraft Orbital Altitude		550	km	Input Spacecraft Altitude
Downlink Frequency	f	2.290	GHz	Input Spacecraft Frequency - Placeholder
Wavelength	λ	0.131	m	λ = c/f
Transmit Power	P_T	2.0	Watt	Input Transmit RF Output Power: 2.0 Watts
Transmit Power	$P_{T(dB)}$	33.0	dBm	$P_{T(dB)}$ = 10 log (Pt) + 30
Passive Loss	L_l	-3.3	dB	Input SC Passive RF Loss (Cable + Diplexer)
SC Antenna Gain	G_T	-10.0	dBi	Input SC Antenna Gain (Broadband Patch +/-85 deg)
Equivalent Isotropic Radiated Power	EIRP	19.7	dBm	Spacecraft EIRP = $P_{T(dB)} + G_T + L_l$
Ground Station Elevation Angle	α	10.0	deg	Input elevation look angle from the GS to SC
Slant Range	SR	1815.6	km	Calculation of Slant Range to SC
Free Space Dispersion Loss	L_S	-164.8	dB	Calculation of Free Space Dispersion
Total Atmospheric Loss	A_T	-1.0	dB	ITU S-band Atmos Loss for 99% availability (est)
Ground Station G/T	G/T	12.6	dB/K	KSAT-Lite Ground Station G/T
Total Received Power/T	P_R	-133.5	dBm/K	$P_R = EIRP + L_S + AR_{Loss} + A_T + G/T$
Boltzmann's Constant	k	-198.6	dBm/Hz-K	Constant
Total Received Power/kT	$P_{R(dB\text{-}Hz)}$	65.1	dB-Hz	$P_{R(dB\text{-}Hz)} = P_R - k$
Data Channel Information; BPSK				
Data Power/kT	$P_{R(dB\text{-}Hz)}$	65.1	dB-Hz	= Total Received Power/kT; suppressed carrier modulation
Information Rate	R	100,000	bps	Input Information Data Rate
Information Rate	$R_{(dB\text{-}Hz)}$	50.0	dB-Hz	= 10 log (R)
Available E_b/N_o	E_b/N_o	15.1	dB	$E_b/N_o = P_{R(dB\text{-}Hz)} - R_{(dB\text{-}Hz)}$
Required E_b/N_o 10-6 BER	$E_b/N_{o(REQ)}$	10.5	dB	Theory E_b/N_o for 10^{-6} BER Uncoded (no FEC)
Coding Gain		5.5	dB	Convolutional (7, 1/2) 10^{-6} BER
Implementation Loss	IL	-3.0	dB	Estimate of System Distortion Loss; higher for the lower data rate
Available Margin		**7.1**	**dB**	

Figure 13 S-Band Downlink - Link Budget - Contingency Operations

Parameter	Symbol	Value	Units	Comments/Notes
Spacecraft Orbital Altitude		550	km	Input Spacecraft Altitude
Downlink Frequency	f	8.2	GHz	Input SC Frequency (Earth Observing Freq Allocation)
Wavelength	λ	0.037	m	λ = c/f
Transmit Power	P_T	1.0	Watt	Input Transmit RF Output Power
Transmit Power	$P_{T(dB)}$	30.0	dBm	$P_{T(dB)}$ = 10 log (Pt) + 30
Passive Loss	L_l	-2.0	dB	Input SC Passive RF Loss (cable length 21 inches + test point)
SC Antenna Gain	G_T	23.0	dBi	Input SC Antenna Gain - HGA Patch Array
SC Antenna Pointing Loss	L_P	-0.5	dB	Input SC Pointing Loss - Estimate
Equivalent Isotropic Radiated Power	EIRP	50.5	dBm	Spacecraft EIRP = $P_{T(dB)}$ + G_T + L_l
Ground Station Elevation Angle	α	10.0	deg	Input elevation angle from the GS to SC
Slant Range	SR	1815.6	km	Calculation of Slant Range to SC
Free Space Dispersion Loss	L_S	-175.9	dB	Calculation of Free Space Dispersion
System Axial Ratio Loss	$AR_{LOSS(dB)}$	-0.3	dB	Calculation of System Polarization Loss
Total Atmospheric Loss	A_T	-2.9	dB	ITU X-band Atmos Loss for 99% avail (non-polar location)
Ground Station G/T	G/T	26.5	dB/K	3.7m KSAT-lite antenna
Total Received Power/T	P_R	-102.1	dBm/K	P_R = EIRP + L_S + AR_{Loss} + A_T + G/T
Boltzmann's Constant	k	-198.6	dBm/Hz-K	Constant
Total Received Power/kT	$P_{R(dB\text{-}Hz)}$	96.5	dB-Hz	$P_{R(dB\text{-}Hz)}$ = P_R - k
DVB-S2 8PSK, Rate 5/6, Spectral efficiency = 2.478562 (Data Rate for 41.6 Msps = 103.1 Mbps)				
Data Power/kT	$P_{R(dB\text{-}Hz)}$	96.5	dB-Hz	= Total Received Power/kT; for suppressed carrier mod
DVB-S2 Symbol Rate	R	41,600,000	bps	SDR-X Transmitter Max Symbol Rate = 41.6 Msps
DVB-S2 Symbol Rate	$R_{(dB\text{-}Hz)}$	76.2	dB-Hz	= 10 log (R)
Available E_s/N_o	E_s/N_o	20.3	dB	E_b/N_o = $P_{R(dB\text{-}Hz)}$ - $R_{(dB\text{-}Hz)}$
Required E_s/N_o 10-7 PER	$E_s/N_{o(REQ)}$	9.35	dB	Table 13 of ETSI EN 302 307 V1.2.1, 8PSK 3/4
Implementation Loss	IL	-3.0	dB	Estimate of System Distortion Loss
Available Margin		**8.0**	**dB**	**Data Channel Margin**

Figure 14 X-Band Downlink - Link Budget