TECHNICAL APPENDIX

1 INTRODUCTION

This Technical Appendix to the Space Logistics, LLC ("Space Logistics") application for authority to launch and operate the MEV-2 spacecraft provides information in response to Section 25.114(d) of the Commission's rules and to support the application.

2 CONTACT INFORMATION

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3 GENERAL DESCRIPTION OF MEV-2 SYSTEM

MEV-2 is a mission extension vehicle ("MEV"), which has the capability to service in-orbit geosynchronous satellites by cooperatively docking with a satellite client vehicle ("CV") and performing the station keeping and attitude control functions for the CV as a combined vehicle stack ("CVS"). For MEV-2's initial mission, Space Logistics has contracted with Intelsat Satellite LLC ("Intelsat") to provide life extension service to the Intelsat 1002 ("IS-1002") spacecraft, operating the satellites as a CVS.

Specifically, MEV-2 is capable of performing the following services:

- Inclination reduction;
- Long-term station keeping and attitude control of customer satellites;
- Relocation of customer satellites to different orbital slots or to different orbits;
- Relocation of customer satellites into the graveyard orbit; and
- Performance of inspections of customer satellites.

By enhancing in-orbit flexibility and options for geosynchronous orbit ("GSO") satellite operators, Space Logistics will be able to assist those operators in maximizing the value of their in-orbit assets and allow them to better respond to customer demand. Consistent with Space Logistics' operating philosophy, the company at all times will conduct operations in a responsible, transparent, and cooperative manner, as discussed in the accompanying Narrative and this Technical Appendix.[1]

The MEV-2 system consists of the space segment (all aspects of the spacecraft and associated design) and the ground segment (all ground-based services and hardware – including test equipment, mission operations centers ("MOCs"), transportation and launch site). Both segments are described below.

3.1 Space Segment

The MEV-2 spacecraft is nearly identical in design to MEV-1 and leverages extensive heritage from Northrop Grumman Innovation System's ("NGIS'") GEOStar product line of communications satellites, as well as the Cygnus spacecraft, which delivers cargo to the International Space Station ("ISS").[2] The 3-axis stabilized MEV-2 spacecraft bus is designed for an in-orbit service lifetime of 15 years at or near GSO. A brief description of each subsystem is given in the following sections.

3.1.1 Tracking, Telemetry and Commanding ("TT&C")

MEV-2 will have only TT&C communications capability. Specifically, MEV-2 will have a single Ku-band transmitter (11450 – 12250 MHz space-to-Earth) and two C-band transmitters (3700 – 4200 MHz space-to-Earth), each of which is tunable in 100 kHz increments.

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[1] *See* Narrative at 13-16.

[2] *See* Narrative at 4.

This transmission flexibility is necessary to minimize interference and facilitate coordination with the CV and adjacent satellite operators. All three systems are circular polarized and can be switched between Right-Hand Circular Polarization ("RHCP") and Left-Hand Circular Polarization ("LHCP"). To the extent the TT&C transmissions are considered part of the service provided by MEV-2, such transmissions are provided on a non-common carrier basis.[3]

The uplink communication consists of command and ranging data for MEV-2. The downlink communication for MEV-2 consists of ranging data, state-of-health telemetry information, and imaging data during Rendezvous, Proximity Operations and Docking ("RPOD") operations. The C-band telemetry system has the capability to operate in three different bandwidths or modes depending on the mission phase and operational requirements, as outlined in Table 3-1. The Ku-band telemetry system operates only in low-rate mode. The command uplink has a bandwidth of 1 MHz.

Downlink Telemetry Mode	**Bandwidth**	**Data Rate**
Low rate (C-band, Ku-band) – drift, RPOD, and servicing operations	200 kHz	4.8 kbps
Medium rate (C-band) – pre-rendezvous operations	400 kHz	18 kbps
High rate (C-band) – RPOD operations	2 MHz	1 Mbps

Table 3-1. Bandwidths for each MEV-2 telemetry mode.

3.1.2 Fault Management ("FM")

The mission class for MEV-2 is Single-Fault Tolerant ("SFT") rendezvous and docking with additional redundancy to address joint operations safety considerations. Safety

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[3] *See* 47 C.F.R. § 25.114(c)(11).

considerations are focused on effects to entities other than MEV-2, such as the CV or other resident space objects ("RSOs"). MEV-2 is required to be SFT to catastrophic and critical hazardous mishaps as defined by systems safety. Specific FM and safety design considerations are applied to each phase of the MEV-2 mission, from pre-launch to decommission, to address the distinct activities and constraints.

3.1.3 Guidance, Navigation, and Control ("GNC")

The GNC subsystem is fully redundant and cross-strapped to provide the fault tolerant, on-board functions of maintaining the attitude/pointing control, momentum control, and orbit/position control during all phases of the mission. These functions utilize a number of sensors including star trackers, sun sensors, attitude rate sensors, a specialized set of RPOD sensors (described in more detail below), and data provided from ground command. The on-board GNC flight software processes these sensor data and ground commanded inputs to command actuators and establish the desired attitude, orbit, and relative position/attitude to the CV. MEV-2's actuators include: momentum wheels, chemical propulsion (hydrazine) thrusters, and steerable electric propulsion (xenon) thrusters.

3.1.4 Electric Power Subsystem ("EPS")

The MEV-2 EPS is fully redundant and cross-strapped to provide the fault tolerant power needed during all phases of the mission including during eclipse or other periods when external power is not available. The vehicle is powered by two 5 kilowatt flat-panel solar arrays and two 110 amp-hour lithium-ion batteries. Battery charge control is managed autonomously by fault-tolerant hardware and flight software running on the flight computer.

3.1.5 Command and Data Handling ("CDH")

The CDH processes ground and internal commands and distributes them to appropriate fight avionics systems for execution. The CDH also collects, stores, and downlinks telemetry data to the ground. The CDH avionics is fully redundant and cross-strapped to provide the fault tolerant command and control functions for MEV-2, leveraging heritage radiation-hardened processors. The command and telemetry streams are protected through a unique spacecraft identifier and National Security Agency-approved AES-256 encryption.

3.1.6 Propulsion

MEV-2 has both electric propulsion ("EP") and chemical propulsion ("CP") capability, using Xenon and Hydrazine as propellants, respectively. The CP and EP propulsion systems are fully redundant and cross-strapped, providing fault-tolerant attitude and orbit control. The EP subsystem uses hall current thrusters ("HCTs") to perform most of the mission's delta-V maneuvers including station keeping. The CP subsystem is used for relative position and attitude control during the final phases of the RPOD when greater agility and control authority is required than the EP subsystem can provide.

3.1.7 Thermal Control Subsystem ("TCS")

The TCS uses passive and active thermal management strategies to maintain the spacecraft hardware within allowable temperature limits. The system consists of radiators and heat pipes for thermal distribution and control. In addition, heaters are also used to keep the components from exceeding their lower allowable temperatures. Heaters are controlled by flight software and thermostats.

3.1.8 Rendezvous, Proximity Operations and Docking Subsystem

The RPOD subsystem consists of the sensors, electronics, algorithms, and mechanisms required for detecting and tracking the CV during rendezvous and proximity operations, sensing the relative position and attitude of the CV, and mechanically docking to and releasing the CV. The sensing hardware includes:

- A visible stereo camera suite with both narrow field of view (“FOV”) and wide FOV to provide far-range and near-range relative position and attitude data;
- A long wavelength infrared stereo camera suite with both narrow FOV and wide FOV to provide far-range and near-range relative position and attitude data;
- A LIDAR with two active sensing modes that provide bearing and range measurement and/or full relative attitude and position;
- Image processing (on-board and ground-based); and
- Illumination for near-range visual wavelength cameras.

The docking mechanisms include a retractable capture mechanism and stanchions. The capture mechanism is designed to interface with the CV’s liquid apogee engine (“LAE”) nozzle that is located on the zenith deck of the CV. This mechanism is designed to be compatible with a large variety of LAE engines used in the industry. The stanchions on MEV-2 provide the mechanical interface with the CV launch vehicle interface adapter ring. These stanchions are designed to work with most of the standard launch adaptor ring sizes.

During the docking phase, the capture mechanism is extended into the LAE and expands once it is beyond the throat of the engine; this creates a soft capture. The capture mechanism is then retracted to pull the stanchions against the launch adaptor ring creating a hard dock. After successful docking, the combined MEV and CV stack is referred to as the CVS. A simulation of the docking process can be found at https://www.youtube.com/watch?v=ZQsVDTsAMxQ.

3.1.9 Station keeping

MEV-2 will maintain the CVS within a station-keeping box of ± 0.05° N-S and ± 0.05° E-W consistent with the Commission's rules.[4] The antenna axis attitude of MEV-2 can be maintained within a value of 0.06° with respect to roll and pitch and 0.1° with respect to yaw.

3.2 Ground Segment

The MEV-2 ground segment supports the operation of MEV-2 during all phases of the mission. The ground segment consists of the MEV-2 primary and backup MOC for controlling MEV-2, ground stations, and networks providing the radiofrequency communications links to MEV-2 from the primary and backup MEV-2 MOCs and the network connectivity and communications links between the MEV-2 MOCs and the CV MOC(s).[5]

The MEV-2 MOC will be located in Dulles, VA at the NGIS operations facility, co-located with other mission operation centers, including the Cygnus and the GEOStar orbit-raising and on-orbit support centers. The MEV-2 backup MOC will be located at NGIS' Gilbert, AZ facility to provide geographic diversity, avoiding common weather events or power grid issues.

During orbit raising, in-orbit testing ("IOT"), and drifting, MEV-2 will utilize a leased global network of C-band and Ku-band TT&C earth stations networked to the MEV-2 MOC. During RPOD and CVS operations, MEV-2 will use the CV's primary and redundant TT&C

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[4] *See* 47 C.F.R. §§ 25.114(c)(5), 25.210(j).

[5] The backup MOCs are for emergency operations in case the primary MOCs are unavailable.

stations and ground antennas with redundant communication links between the TT&C stations and the MEV-2 MOC.

A dedicated communications link will be established between the MEV-2 MOC and the CV MOC during joint operations and CVS servicing to support coordination of activities and safety of both spacecraft. This link will be used to share critical state of health telemetry of both vehicles and coordinate orbit and maneuver data.

3.3 Concept of Operations

After the launch service insertion of MEV-2 into the geosynchronous transfer orbit (“GTO”), MEV-2 will perform various orbit-raising maneuvers to reach the GSO arc. This orbit-raising period is expected to last approximately 150 days. Space Logistics will conduct most of the MEV-2 IOT during this orbit-raising period. After MEV-2 orbit raising, MEV-2 will use its RPOD system to reliably and safely rendezvous and dock with the IS-1002 satellite.

The RPOD phase of the mission begins several days in advance of the docking event with the initial phasing maneuvers of both MEV-2 and the CV. These maneuvers are performed to align the rendezvous capture box and lighting conditions desired for the final stages of the RPOD operations and to avoid other RSOs that may be in proximity. Initial orbital-phasing maneuvers are performed based on ground measured orbit parameters. As MEV-2 approaches within the station-keeping box of the CV, the RPOD sensors begin to track the CV and provide additional relative position data that is used to control the relative position between the two satellites. MEV-2 will use a safe trajectory design that prevents the potential for collision with the CV due to over- or under-performance of maneuvers, until the final R-bar (*i.e.*, the radial vector between the center of the earth and the CV) approach is initiated from close proximity to the CV.

During the final R-bar approach, MEV-2 autonomously maneuvers from one ground commanded waypoint to the next using its on-board sensors and navigation flight software. MEV-2 holds at each waypoint until authorized by ground command to proceed to the next waypoint. MEV-2 will slowly approach the CV from the aft end along the R-bar, ultimately stopping within the capture hold box immediately behind the CV. At this point, following coordination with the CV MOC, the final authorization from the ground is given for MEV-2 to initiate docking. Upon receiving this authorization, the MEV-2 RPOD capture mechanism is extended and achieves soft capture of the CV LAE. Then the mechanism retracts pulling MEV-2 and the CV together to establish a hard docking with MEV-2's stanchions against the CV launch adaptor ring. A pre-loaded tension is applied on the capture mechanism to firmly secure the docking.

Once docking is completed, MEV-2 will maintain the attitude and orbit control of the CVS, as directed by Intelsat pursuant to the contractual agreement between the parties. Operational control of MEV-2 is maintained throughout this process, including post docking, by Space Logistics at the MEV-2 MOC.

After the rendezvous and docking is completed, Space Logistics anticipates that MEV-2 will operate as a CVS with IS-1002 for at least five years. After completion of that service, MEV-2 will undock from the IS-1002, leaving it to continue operation or be decommissioned by Intelsat. Prior to the expiration of its contractual arrangement with Intelsat and undocking with

IS-1002, Space Logistics will seek FCC approval, as well as any other applicable regulatory approvals, to relocate MEV-2 and perform its next mission.[6]

4 RADIO FREQUENCIES, POLARIZATION, AND LINK BUDGETS

4.1 Radio Frequencies and Polarization Plan

Table 4-1 provides the tunable frequency range for the TT&C system. The center frequency of the command and telemetry communications links can be any frequency (subject to the bandwidth of the transmission) within the tunable frequency range in increments of the 100 kHz tuning resolution. MEV-2 is capable of ceasing radio emissions, as required.[7]

	Command - Uplink		Telemetry - Downlink	
	Tunable Frequency Range (MHz)	Polarization	Tunable Frequency Range (MHz)	Polarization
C-Band	5925 – 6425	LHCP or RHCP	3700 – 4200	LHCP or RHCP
Ku-Band	13750 – 14500	LHCP or RHCP	11450 – 12250	LHCP or RHCP

Table 4-1. MEV-2 TT&C Tunable Frequency Ranges and Polarizations.

For the avoidance of doubt, selectable center frequencies for the C-band channel may be calculated as:

$$\text{C-band Uplink Center Frequency (MHz)} = 5925 + 0.1*n_1$$

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[6] If the client satellite operator for future missions is foreign-licensed, then the Commission and foreign administrators may need to exchange letters of understanding regarding the operations of the CVS, consistent with the Commission's practice regarding the use of shared orbital assets. *See, e.g.*, Stamp Grant, *Intelsat License LLC*, Call Sign S2801, File No. SAT-A/O-20091208-00141 (granted June 4, 2012); *PanAmSat Licensee Corp.*, Order and Authorization, 18 FCC Rcd. 19680, 19685-88 (Sat. Div. 2003).

[7] *See* 47 C.F.R. § 25.207.

C-band Downlink Center Frequency (MHz) = 3700 + 0.1*n_2

Where n_1 and n_2 are integers from 0 to 5000, inclusive.

Similarly, the selectable center frequencies for the Ku-band channel may be calculated as:

Ku-band Uplink Center Frequency (MHz) = 13750 + 0.1*m_1

Ku-band Downlink Center Frequency (MHz) = 11450 + 0.1*m_2

Where m_1 is an integer from 0 to 7500 (inclusive) and m_2 is an integer from 0 to 8000 (inclusive).

Space Logistics will coordinate with Intelsat and operate on a subset of the frequencies authorized to and coordinated for IS-1002. Specifically, Space Logistics and Intelsat have coordinated the use of the following frequencies: 3944.5 MHz and 3955.5 MHz (space-to-Earth) and 6170.0 MHz and 6180.0 MHz (Earth-to-space). Depending on operational needs, the parties may revise the coordinated frequencies in the future, and accordingly, Space Logistics requests that it be allowed to operate within the full range of the requested frequencies bands as coordinated with Intelsat. Space Logistics accepts that its license will be conditioned on a requirement to operate within frequencies and technical parameters authorized to IS-1002.

Space Logistics understands that MEV-2's operations in the 11.45-11.70 GHz, 12.20-12.25 GHz, and 13.75-14.0 GHz frequencies may be subject to certain limitations and obligations, which Space Logistics accepts and will fulfill. Provided below is a table identifying the relevant frequency bands and potentially applicable limitations and obligations.

Frequency Band	**Limitations and Obligations**
11.45-11.70 GHz space-to-Earth	• Use of this band is subject to 47 C.F.R. § 2.106, US211, which urges applicants to take all practicable steps to protect radio astronomy observations in the adjacent bands from harmful interference, consistent with footnote 47 C.F.R. § 2.106, US74.

	• Operations in this band are limited to international-only services. 47 C.F.R. § 2.106, NG 52.
12.20-12.25 GHz space-to-Earth	• FSS operations in the 12.2-12.25 GHz band are limited to ITU Regions 1 and 3. 47 C.F.R. § 2.106. • Space stations shall not cause harmful interference to, or claim protection from, broadcasting-satellite service stations operating in accordance with the ITU Regions 1 and 3 plans in ITU Radio Regulations Appendix 30. 47 C.F.R. § 2.106 n. 5.487.

13.75-14.00 GHz Earth-to-space	• Receiving FSS space stations must not claim protection from radiolocation transmitting stations operating in accordance with the U.S. Table of Frequency Allocations. 47 C.F.R. § 2.106, US356. • Any earth station in the U.S.[8] communicating with MEV-2 in the 13.75-13.80 GHz (Earth-to-space) band is required to coordinate with the Frequency Assignment Subcommittee of the Interdepartment Radio Advisory Committee of the National Telecommunications and Information Administration to minimize interference to NASA's Tracking and Data Relay Satellite System, including manned space flight. 47 C.F.R. § 2.106, US337. • Operations of any earth station in the U.S. communicating with MEV-2 in the 13.75-14.00 GHz (Earth-to-space) band must comply with 47 C.F.R. § 2.106, US356, which specifies a mandatory minimum antenna diameter of 4.5 m and a minimum EIRP of 68 dBW and a maximum EIRP of 85 dBW for any emission. Operations of any earth station located outside the U.S. communicating with MEV-2 in the 13.75-14.00 GHz (Earth-to-space) band must be consistent with No. 5.502 to the ITU Radio Regulations, which allows a minimum antenna diameter of 1.2 m for earth stations and specifies that the power flux-density produced by an earth station in a FSS GSO network with an antenna diameter smaller than 4.5 m shall not exceed: ○ -115 dB(W/(m^2 • 10 MHz)) for more than 1% of the time produced at 36 m above sea level at the low water mark, as officially recognized by the coastal State; ○ -115 dB(W/(m^2 • 10 MHz)) for more than 1% of the time produced 3 m above ground at the border of the territory of an administration deploying or planning to deploy land mobile radars in this band, unless prior agreement has been obtained. For those earth stations located outside the U.S. having an antenna diameter 4.5 m or greater, the EIRP of any emission should be at least 68 dBW and should not exceed 85 dBW. • Operations of any earth station in the U.S. communicating with MEV-2 in the 13.77-13.78 GHz (Earth-to-space) frequency band must comply with 47 C.F.R. § 2.106, US357, which specifies that the maximum EIRP density of emissions not exceed 71 dBW in any 6 MHz band within that band. Operations of any earth station located outside the U.S. communicating with MEV-2 in the 13.77-13.78 GHz (Earth-to-space) frequency band must comply with No. 5.503 of the ITU Radio Regulations, which specifies a required maximum EIRP density of emissions varying with the diameter of the antenna: ○ 4.7D + 28 dB (W/40 kHz), where D is the FSS earth station antenna diameter equal to or greater than 1.2 m and less than 4.5 m; ○ 49.2 + 20 log (D/4.5) dB(W/40 kHz), where D is the FSS earth station antenna equal to or greater than 4.5 m and less than 31.9 m; ○ 66.2 dB(W/40 kHz) for any FSS earth station for antenna diameters equal to or greater than 31.9 m; or ○ 56.2 dB(W/4 kHz) for narrow-band emissions (less than 40 kHz) from any FSS earth station having an antenna diameter of 4.5 m or greater.

Table 4-2. Limitations and Obligations on Use of Certain Frequencies.

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[8] All references to the U.S. in this table include U.S. possessions.

4.2 Emission Compliance

The carrier frequency of each transmitter for MEV-2 shall be maintained within 0.002% of the reference frequency.[9] All emissions from MEV-2 shall meet the out-of-band emission limits specified in the Commission's rules.[10]

4.3 Coverage Areas

The respective coverage areas for the C-band and Ku-band TT&C beams for MEV-2 will encompass the entire portion of the visible Earth from the MEV-2 operating location.[11]

5 LINK BUDGETS

5.1.1 C-Band Link Budgets

The C-band link budgets for the commanding and ranging uplink and the telemetry and ranging downlink are provided in Annex A. Both uplink and downlink budgets show positive margin.

5.1.2 Ku-Band Link Budgets

The Ku-band link budgets for the commanding and ranging uplink and the telemetry and ranging downlink are provided in Annex B. Both uplink and downlink budgets show positive margin.

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[9] *See* 47 C.F.R. § 25.202(e).

[10] *See* 47 C.F.R. § 25.202(f).

[11] *See* 47 C.F.R. § 25.114(c)(7).

6 ANTENNA CHARACTERISTICS

MEV-2 will only receive command beams from the ground stations. Therefore, pursuant to Section 25.114(c)(4)(v) of the FCC's rules,[12] Space Logistics has specified the command beam peak flux density at the command threshold in Annex C. Space Logistics meets the EIRP and EIRP density limits specified in 47 C.F.R. § 25.140(a)(3)(i)-(ii), as demonstrated in Annex D.

7 ANTENNA GAIN CONTOURS

Both the TT&C C-band and Ku-band telemetry antennas for MEV-2 provide ±17° beam width from GSO orbit. The Earth's diameter occupies roughly ±8 degrees within that beam width. Therefore, the entire portion of the Earth visible from the MEV-2 operating location is encompassed within the C-band and Ku-band coverage areas of the MEV-2 TT&C beams. The gain contours of the TT&C telemetry downlink antenna vary by less than 8 dB across the surface of the Earth. Accordingly, the gain at 8 dB below the peak falls beyond the edge of the Earth. Therefore, pursuant to Section 25.114(c)(4)(vi)(A) of the FCC's rules,[13] contours for these beams are not required to be provided and the associated GXT files have not been included in Schedule S.

8 POWER FLUX DENSITY

The maximum PFD levels for MEV-2's transmissions were calculated for both the C-band and Ku-band TT&C downlink bands indicated in Table 3-1. The results are provided in

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[12] *See* 47 C.F.R. § 25.114(c)(4)(v).

[13] *See* 47 C.F.R. § 25.114(c)(4)(vi)(A).

Schedule S and show that the downlink PFD levels of MEV-2's TT&C do not exceed the limits specified in Section 25.208 of the Commission's rules.[14]

9 INTERFERENCE ANALYSIS

9.1 Interference Analysis for Space Stations within Two Degrees of MEV-2

Intelsat has coordinated the operations of IS-1002 with adjacent satellites, including those within two degrees of the 1°W orbital location. Space Logistics certifies that it will operate within the frequencies and technical parameters coordinated by Intelsat and authorized to IS-1002 at the 1°W orbital location. Accordingly, MEV-2 operations will conform to the FCC's two-degree spacing requirements.[15]

The table below provides the MEV-2 TT&C uplink and downlink power levels.

	Frequency (MHz)	MEV-2 Level (dBW/Hz)
Downlink (space to earth)	3700-4200	-34
Downlink (space to earth)	11450-11700	-38
Downlink (space to earth)	11700 -12250	Not applicable[16]
Uplink (earth to space)	5925-6425	-52
Uplink (earth to space)	13750-13950	-60
Uplink (earth to space)	13950-14250	-60
Uplink (earth to space)	14250-14500	-60

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[14] *See* 47 C.F.R. § 25.208.

[15] *See* 47 C.F.R. § 25.140(a)(2).

[16] IS-1002 is not authorized to operate in this frequency band, and accordingly, MEV-2 will not operate in this frequency band at this orbital location.

Table 9-1. MEV-2 TT&C Power Levels.

Space Logistics and Intelsat have tentatively agreed on the use of the following frequencies for TT&C: 3944.5 MHz and 3955.5 MHz (space-to-Earth) and 6170.0 MHz and 6180.0 MHz (Earth-to-space). Depending on operational needs, the parties may revise the coordinated frequencies in the future.

9.2 Band Edge Interference

TT&C signals shall be transmitted within the frequency bands specified in Table 4-1. Such transmissions shall cause no greater interference and require no greater protection than the communications traffic authorized for IS-1002 at its operational orbital location.[17] Alternatively, the TT&C signals shall be coordinated with operators of co-frequency space stations at orbital locations within six degrees of the assigned orbital location.[18]

10 ORBITAL LOCATION REQUESTED

As discussed in the Narrative, after testing and docking with IS-1002 at the GSO orbit, MEV-2 and IS-1002 will dock and operate as a CVS at 1° W longitude. Space Logistics accepts that its license will be conditioned on a requirement to operate within frequencies and technical parameters authorized to IS-1002 at this orbital location.

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[17] *See* 47 C.F.R. § 25.202(g).

[18] *See* 47 C.F.R. § 25.140.

11 ORBITAL DEBRIS MITIGATION PLAN

11.1 MEV Flight Safety

Space Logistics has established a Systems Safety Program Plan (“SSPP”) for the identification, evaluation, mitigation, and tracking of all potential hazards associated with the MEV-2 mission. The SSPP defines an MEV Safety Review Process (“SRP”), which outlines the exact procedures for executing the mitigation and tracking of identified potential hazards. The SRP is a general NGIS practice that Space Logistics has tailored specifically to the MEV program. All potential hazards are categorized by mission phase, including flight operations covering activities after launch and separation. Detailed analyses for each potential hazard in applicable flight operations are documented in the Flight Safety Data Package (“FSDP”). Orbital debris generation is a subcategory under the FSDP.

MEV-2 is designed such that no debris is generated as a result of normal operations. This design leaves four primary sources for potentially generating debris from the MEV-2 mission including:

1) Accidental explosions from internal or external sources;
2) Collision during non-RPOD operations;
3) RPOD operations; and
4) End-of-life decommissioning.

Space Logistics leverages four key mitigation layers that address these sources of debris generation, each applying to a unique set of mitigation strategies. The mitigation layers for these debris generation sources include: spacecraft design, autonomous fault protection, the ground segment, and mission operations including trajectory design. Figure 11-1 illustrates how these mitigations are layered to prevent the generation of orbital debris during the MEV-2 mission. The layers progressively involve mission operators to fully mitigate the potential generation of orbital debris.

In the first layer, the spacecraft hardware is designed such that nominal operating conditions do not generate orbital debris. This layer has the least amount of operator intervention since the spacecraft hardware cannot be modified once in orbit. The next layer consists of the MEV-2 on-board fault protection, which can autonomously identify, isolate, and recover from potential safety issues. In the next layer, the ground segment provides for operator interaction with and configuration of MEV-2 and provides for coordination between the MEV-2 MOC and the CV MOC. The ground systems in the MEV-2 MOCs also actively monitor available spacecraft telemetry and issue alarms to alert the operator and enable ground intervention if necessary. The final layer is mission operations including trajectory design. Mission operations establishes and executes MEV-2 operating sequences including trajectories, which are designed passively safe to protect against collisions with the CV and other tracked RSOs. This layer involves significant mission operator involvement and active coordination with other GSO spacecraft operators.

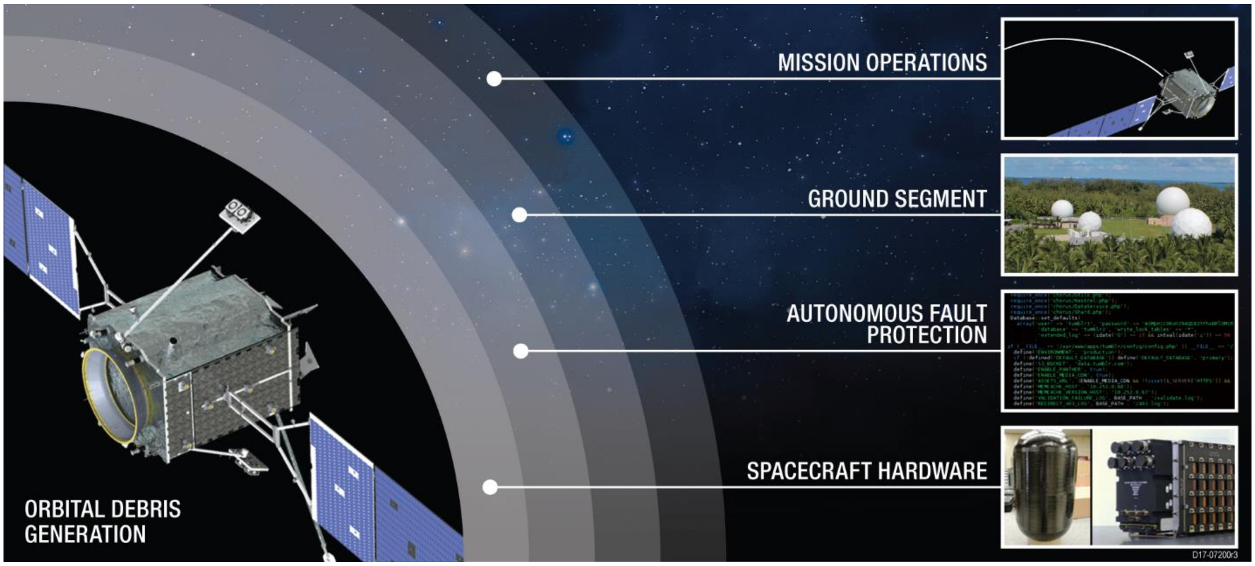

Figure 11-1. The MEV-2 mission layers mitigations to protect against orbital debris generation.

In addressing each of the possible sources of orbital debris generation, the strategies employed within each of the layers discussed above will be identified and elaborated.

11.2 Mitigation Against Accidental Explosion Events

Mitigation Layer: Spacecraft Design

Space Logistics has assessed the probability of accidental explosions caused by either internal or external sources during and after completion of mission operations.[19] MEV-2 is designed in a manner to minimize the potential for such explosions. Propellant tanks and thrusters are isolated using redundant valves, and electrical power systems are shielded in accordance with standard industry practices. Pressure regulators are redundant, providing an extra safeguard to overpressurizing and bursting the tanks.

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[19] 47 C.F.R. § 25.114(d)(14)(ii).

The propulsion subsystem component construction, preflight verification (through both proof testing and analysis), and quality standards have been designed to ensure a very low risk of leakage or over-pressurization with a potential to cause explosions.

The batteries are designed with sufficient factors of safety to prevent any accidental explosions due to over pressurization. On-board systems manage the charging and discharging of the batteries to ensure that these factors of safety are maintained. At the end of life, the batteries can also be remotely discharged from the ground.

Space Logistics has designed MEV-2 to contain the majority of energy-storage components within the central cylinder, including the propellant storage tanks. This design provides the highest level of protection against collisions with micrometeoroids or other space debris.

Mitigation Layer: Autonomous Fault Protection Design

The MEV-2 autonomous fault protection is designed to continuously monitor subsystem conditions during mission operations which could lead to over-pressurization of the propellant tanks or stressing the batteries. The primary cause of propellant or battery explosion is over-pressurization due to high temperature and/or overcharging. Additionally, there are autonomous responses for voltage spikes in the battery cells that could lead to a failure or potential explosion.

Mitigation Layer: Ground Segment Design

In addition to the on-board autonomous fault protection of the subsystems, the spacecraft transmits state of health information for all subsystems including telemetry for propulsion tank pressures and temperatures, as well as battery pressures, temperatures, and cell voltages.

All of these telemetry points are monitored by the ground software with autonomous limit checking. Out-of-limit conditions are flagged on the MOC displays with a prominent alert and require operator acknowledgement. Conditions detected by limit or other signatures in the ground systems can also initiate activities such as alerting off-console support engineers.

Mitigation Layer: Mission Operations

Mission Operations employs flight rule constraints to avoid potentially hazardous conditions, trends subsystems data to actively avoid risks leading to a hazardous condition, and re-actively responds to ground system alerts. At the completion of the mission and upon disposal of the spacecraft, Space Logistics will ensure the removal of all stored energy on the spacecraft by depleting all propellant tanks, venting all pressurized systems, and leaving the batteries in a permanently discharged state.

11.3 Mitigation Against Collisions with Other GSO Satellites and Tracked RSOs (non-RPOD)

Mitigation Layer: Mission Operations and Trajectory Design

Space Logistics will take standard measures to ensure that MEV-2 will not collide with other RSOs. This includes the utilization of both commercial and U.S. government orbit determination services (such as the Space Data Association and the Combined Space Operations Center) to coordinate MEV-2 mission planning and trajectory design.

11.4 Rendezvous, Proximity Operations and Docking

RPOD is a unique feature of the MEV-2 mission compared to other vehicles operating in the GSO arc. MEV-2 is designed to approach and dock cooperatively with another satellite. This mission activity introduces debris-generating risks which Space Logistics has diligently mitigated through a layered approach based on heritage rendezvous and proximity operations and berthing operations of the Cygnus system with the manned ISS. Space Logistics has also engaged with National Aeronautics and Space Administration ("NASA") through a Collaboration for Commercial Space Capabilities Space Act Agreement to receive lessons learned from rendezvous, proximity, docking, and berthing missions dating back to the Gemini program in the 1960s. Through this agreement the company has been and continues to receive recommendations and commentary on the RPOD design, testing, and concept of operation from NASA experts. The docking is the most safety critical phase of the mission and there will be both manual ground-based and autonomous on-board elements to preclude and detect failures and respond appropriately.

Mitigation Layer: Spacecraft Design

Redundant RPOD sensors onboard MEV-2 provide visual imaging and telemetry that are used both onboard and on the ground to determine relative position and attitude between MEV-2 and the CV. During RPOD, MEV-2 provides high data rate telemetry of these sensors to support ground-based monitoring and authorization to proceed. MEV-2's capture mechanism is designed to minimize contact forces to prevent unwanted relative dynamic motion between MEV-2 and the CV. The mechanical docking components are designed to operate safely by use of design margins (mechanical and electro-mechanical). Design elements have also been included to address any electrical charge potential between MEV-2 and the CV which could result in damaging Electro-Static Discharge ("ESD") events. Full six-degree of freedom control is implemented on MEV-2 using the chemical propulsion system, in conjunction with momentum wheels providing additional margins on control authority needed for the proximity operations.

Mitigation Layer: Autonomous Fault Protection

At any point during RPOD, the MEV-2 can autonomously detect anomalies either in MEV-2 itself, or the relative position and orientation with the CV and take appropriate action from recovering from the fault to aborting the approach and causing a retreat to a safe orbit.

Mitigation Layer: Ground Segment

The MEV-2 ground segment is designed to provide redundancy during mission operations. The primary MEV-2 MOC is located in Dulles, VA while the backup MOC is located in Gilbert, AZ. This provides enough geographical separation to isolate the two MOCs from common weather hazards and other contingencies that may occur. Additionally, the TT&C ground stations utilize multiple redundant and diverse ground networks for added reliability.

During the RPO&D phase, both the MEV-2 MOC and the CV MOC are connected through a continuous, real-time interface to ensure critical data is passed between operators of the two spacecraft. Autonomous telemetry monitors continuously check for events and alarms, while an independent ground-based system correlates relative position and attitude information using telemetered RPOD sensor data from MEV-2. Mission operators are provided both graphical and tabular data displays to provide full situational awareness.

Mitigation Layer: Mission Operations and Trajectory Design

Well before launch of MEV-2, nominal and contingency procedures will be developed for all identified practicable scenarios. These procedures will be executed on simulators and the actual spacecraft when feasible. Space Logistics will conduct multiple rehearsals for both nominal and contingency mission scenarios to further train the operations staff and test all software and ground systems under flight like conditions. During the mission, critical operations such as the RPOD phase are fully staffed by a team of experts with a wealth of mission operations and technical experience.

During RPOD, mission operations are performed collaboratively with the CV MOC. At each proximity operation waypoint mentioned above, both Space Logistics and the CV operators must provide authorizations to proceed to continue to the next waypoint. During the docking phase, MEV-2 operators utilize the CV as a viable control to help prevent the vehicles from colliding under some fault scenarios.[20] The ground operators can also send retreat, scrub, or abort commands to MEV-2 if an anomalous condition is detected in either MEV-2 or the CV. MEV-2 is designed to safely and autonomously retreat and depart (if necessary) from the defined keep-out zones around the CV following an autonomous or ground-initiated scrub or abort.

Space Logistics uses a robust trajectory design to minimize risk of collision as MEV-2 approaches the CV during the RPOD phase. This trajectory ensures that the natural motion orbit of MEV-2 does not intersect the CV including over and under thrust performance or failure to execute a maneuver during all but the very final RPOD maneuver which has additional safety procedures incorporated to prevent collision.

The final approach trajectory is designed to minimize any chances of impacts that could generate orbital debris. During this final approach, the relative speed is decreased from 30 mm/s to about 1 mm/s just before MEV-2 enters the capture box directly behind the CV. At this speed, the potential for debris generation caused by an unintended impact has been assessed to be very

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[20] *See also* Narrative at 13-16 (discussing Space Logistics' cooperative, transparent, and responsible operating philosophy).

low. As an added layer of protection during this phase, MEV-2 approaches the capture box in such a way as to allow dual fault tolerance to credible scenarios of loss of control of MEV-2 by enabling time for the CV mission operators to perform a collision-avoidance maneuver if they determine MEV-2 is unable to respond.

11.5 Post-Mission Disposal

Mitigation Layer: Trajectory Design

Space Logistics plans to reserve sufficient fuel and power to dispose of MEV-2 at the end of its mission-capable life at a planned minimum altitude of 300 kilometers (perigee) above the GSO arc.[21] The proposed disposal orbit altitude complies with the altitude resulting from application of the Inter-Agency Space Debris Coordination Committee ("IADC") formula based on the following calculation:

36,021 km + (1000 × C_R × A/m) = 36,061.0 km, or 275.0 km above the GSO arc (35,786 km), where

A, Area of the satellite (average aspect area) is: 40.7 m^2
m, Mass of the spacecraft is: 1525 kg
C_R (solar radiation pressure coefficient) is: 1.5

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[21] 47 C.F.R. § 25.283(a); *see also* Inter-Agency Space Debris Coordination Committee, IADC Space Debris Mitigation Guidelines, § 5.3 (2007); *Mitigation of Orbital Debris*, Second Report and Order, 19 FCC Rcd. 11567, 11578 ¶ 21 (2004).

Accordingly, MEV-2's planned disposal orbit complies with the FCC's rules.[22]

Mitigation Layer: Mission Operations and Trajectory Design

After MEV-2 reaches its final disposal orbit, all on-board sources of stored energy will be depleted, all batteries will be left in a permanent discharge state, and the transmitters will be shut off.[23] The solar arrays will also be skewed away from the sun to minimize power generation.[24]

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[22] *See* 47 C.F.R. § 25.283(a).

[23] *See* 47 C.F.R. §§ 25.283(c), 25.114(d)(14)(ii).

[24] *Id*.

Technical Certification

I, Ronald Capozzi, hereby certify, under penalty of perjury, that I am the person responsible for supervising the preparation of the engineering information contained in the technical portions of the foregoing application and the related attachments, that I am familiar with Part 25 of the Commission's rules, and that the technical information is complete and accurate to the best of my knowledge and belief.

/s/ Ronald Capozzi
Ronald Capozzi
Program Director
Space Logistics, LLC

Dated: December 10, 2019

Annex A: C-band Link Budgets

C-Band Uplink Command/Ranging Budget	Units	HEMI (±75°)	HEMI (±17°)	HEMI (±75°)
		Transfer	On Station	Safe Mode
Ground Station EIRP, Min	dBW	88	85	85
S/C Altitude [GEO + 350 km]	km	65,000	36,136	36,136
Ground Station Elevation Angle	deg	5	5	5
Resulting Range	km	70539	41,481	41,481
Free Space Spreading Loss	dBm^2	167.96	163.35	163.35
CMD Uplink Flux Density, Min	dBW/m^2	-79.96	-78.35	-78.35
Isotropic Aperture	dB-m^2	-37.6	-37.6	-37.6
Antenna Edge of Coverage [Gain]	dBi	-5.0	7.0	-5.0
Antenna Losses	dB	0.0	0.0	0.0
EP Plume interference	dB	-0.4	-0.4	-0.4
Atmospheric Loss	dB	-0.2	-0.2	-0.2
Rain Fade [budgeted] 99% Availability	dB	-0.1	-0.1	-0.1
Polarization Loss	dB	0	0.0	0
Net Antenna Edge of Coverage Gain	dBi	-5.7	6.3	-5.7
Received CMD Power @ Antenna Output	dBm	-93.27	-79.66	-91.66
Hemi Coaxial Cable	dB	-1.89	-1.89	-1.89
Polarization Switch	dB	-0.25	-0.25	-0.25
Coaxial Cable	dB	-0.44	-0.44	-0.44
Hybrid Coupler	dB	-3.50	-3.50	-3.50
Coaxial Cable	dB	-0.30	-0.30	-0.30
Bandpass Filter	dB	-0.50	-0.50	-0.50
Coaxial Cable	dB	-0.27	-0.27	-0.27
Total CMD Input Loss	dB	-7.16	-7.16	-7.16
Command				
Input Level to Command Receiver Without Multipath	dBm	-100.43	-86.82	-98.82
Command Receiver CMD Threshold	dBm	-112	-112	-112
Command Margin Without Multipath	**dB**	+11.57	+25.18	+13.18
Multipath Loss [budgeted]	dB	-2.00	-1.00	-2.00
Input Level to Command Receiver With Multipath	dBm	-102.43	-87.82	-100.82
Command Margin =	**dB**	**+9.57**	**+24.18**	**+11.18**
Ranging				
Input Level to Command Receiver Without Multipath	dBm	-100.43	-86.82	-98.82
Command Receiver Ranging Threshold	dBm	-109	-109	-109
Ranging Margin Without Multipath	**dB**	+8.57	+22.18	+10.18
Multipath Loss [budgeted]	dB	-2.00	-1.00	-2.00
Input Level to Command Receiver With Multipath	dBm	-102.43	-87.82	-100.82
Ranging Margin =	**dB**	**+6.57**	**+21.18**	**+8.18**

C-Band Downlink - Low Data Rate Telemetry and Ranging Budget	Units	HEMI (±75°)	HEMI (±17°)	HEMI (±75°)
		Transfer	On-Station	Safe Mode
Telemetry Transmitter Output Power [30 Watts, EOL]	dBW	15.19	14.77	14.77
RF Coaxial Cable	dB	-0.22	-0.22	-0.22
Isolator	dB	-0.25	-0.25	-0.25
RF Coaxial Cable	dB	-0.24	-0.24	-0.24
Transmit Band Pass Filter	dB	-0.50	-0.50	-0.50
RF Coaxial Cable	dB	-0.22	-0.22	-0.22
Hybrid Coupler	dB	-3.50	-3.50	-3.50
RF Coaxial Cable	dB	-0.39	-0.39	-0.39
Polarization Switch	dB	-0.25	-0.25	-0.25
HEMI Coaxial Cable	dB	-1.65	-1.65	-1.65
Total TLM Output Loss	dB	-7.22	-7.22	-7.22
Antenna Edge of Coverage [Gain]	dBi	-5.0	7.0	-5.0
Antenna Losses	dB	0	0	0
EIRP Without Multipath	dBW	2.96	14.55	2.55
Multipath Loss [budgeted]	dB	-2.0	-1	-2.0
EIRP with Multipath	dBW	0.96	13.55	0.55
S/C Altitude [GEO + 350 km]	km	65,000	36,136	36,136
Ground Station Elevation Angle	deg	5	5	5
Resulting Range	km	70539	41,481	41,481
Free Space Loss	dB	-201.9	-197.3	-197.3
EP Plume interference	dB	-1.3	-1.3	-1.3
Atmospheric Loss	dB	-0.2	-0.2	-0.2
Rain Fade [budgeted] 99% Availability	dB	-0.1	-0.1	-0.1
Ground Station Polarization Loss	dB	0	0.0	0.0
Ground Station G/T	dB/K	35	32	32
Boltzmanns Constant	dB Hz-K/W	228.6	228.6	228.6
Receive C/No	dB-Hz	61.1	75.3	62.3
With 1 Subcarrier or Ranging:				
Required C/No for PCM Telemetry at 4.8 kb/s	dB-Hz	51.3	51.3	51.3
Telemetry Margin =	**dB**	**+9.76**	**+23.96**	**+10.96**
Required C/No for Ranging	dB-Hz	44.01	44.01	44.01
Ranging Margin =	**dB**	**+17.07**	**+31.27**	**+18.27**
With 2 Subcarriers or 1 Subcarrier + Ranging:				
Required C/No for PCM Telemetry at 4.8 kb/s	dB-Hz	54.3	54.3	54.3
Telemetry Margin =	**dB**	**+6.75**	**+20.95**	**+7.95**
Required C/No for Ranging	dB-Hz	47.11	47.11	47.11
Ranging Margin =	**dB**	**+13.97**	**+28.17**	**+15.17**
With 2 Subcarriers + Ranging:				
Required C/No for PCM Telemetry at 4.8 kb/s	dB-Hz	56.1	56.1	56.1
Telemetry Margin =	**dB**	**+4.98**	**+19.18**	**+6.18**
Required C/No for Ranging	dB-Hz	48.74	48.74	48.74
Ranging Margin =	**dB**	**+12.34**	**+26.54**	**+13.54**

C-Band Downlink - Medium Data Rate Telemetry and Ranging Budget	Units	HEMI (±17°)	HEMI (±75°)
		On-Station	Safe Mode
Telemetry Transmitter Output Power [30 Watts, EOL]	dBW	14.77	14.77
RF Coaxial Cable	dB	-0.22	-0.22
Isolator	dB	-0.25	-0.25
RF Coaxial Cable	dB	-0.24	-0.24
Transmit Band Pass Filter	dB	-0.50	-0.50
RF Coaxial Cable	dB	-0.22	-0.22
Hybrid Coupler	dB	-3.50	-3.50
RF Coaxial Cable	dB	-0.39	-0.39
Polarization Switch	dB	-0.25	-0.25
HEMI Coaxial Cable	dB	-1.65	-1.65
Total TLM Output Loss	dB	-7.22	-7.22
Antenna Edge of Coverage [Gain]	dBi	7.0	-5.0
Antenna Losses	dB	0	0
EIRP Without Multipath	dBW	14.55	2.55
Multipath Loss [budgeted]	dB	-1	-2.0
EIRP with Multipath	dBW	13.55	0.55
S/C Altitude [GEO + 350 km]	km	36,136	36,136
Ground Station Elevation Angle	deg	5	5
Resulting Range	km	41,481	41,481
Free Space Loss	dB	-197.3	-197.3
EP Plume interference	dB	-1.3	-1.3
Atmospheric Loss	dB	-0.2	-0.2
Rain Fade [budgeted] 99% Availability	dB	-0.1	-0.1
Ground Station Polarization Loss	dB	0	0
Ground Station G/T	dB/K	32	32
Boltzmann's Constant	dB Hz-K/W	228.6	228.6
Receive C/No	dB-Hz	75.3	62.3
With 1 Subcarrier or Ranging:			
Required C/No for PCM Telemetry at 18 kb/s	dB-Hz	57.0	57.0
Telemetry Margin =	**dB**	**+18.28**	**+5.28**
Required C/No for Ranging	dB-Hz	44.01	44.01
Ranging Margin =	**dB**	**+31.27**	**+18.27**
With 1 Subcarrier + Ranging:			
Required C/No for PCM Telemetry at 18 kb/s	dB-Hz	60.4	60.4
Telemetry Margin =	**dB**	**+14.88**	**+1.88**
Required C/No for Ranging	dB-Hz	47.11	47.11
Ranging Margin =	**dB**	**+28.17**	**+15.17**

C-Band Downlink - High Data Rate Telemetry Budget	**Units**	**HEMI (±17°)**
HDR Transmitter Output Power, Min	dBW	14.77
TTX Frequency [C-Band]	MHz	4,200
RF Coaxial Cable	dB	-0.22
Isolator	dB	-0.25
RF Coaxial Cable	dB	-0.24
Transmit Band Pass Filter	dB	-0.50
RF Coaxial Cable	dB	-0.22
Hybrid Coupler	dB	-3.50
RF Coaxial Cable	dB	-0.39
Polarization Switch	dB	-0.25
HEMI Coaxial Cable	dB	-1.65
Total TLM Output Loss	dB	-7.22
Antenna Edge of Coverage [Gain]	dBi	7.0
Antenna Losses	dB	0
EIRP Without Multipath	dBW	14.55
Multipath Loss [budgeted]	dB	-1.0
EIRP with Multipath	dBW	13.55
S/C Altitude	km	36,136
Ground Station Elevation Angle	deg	5
Resulting Range	km	41,481
Free Space Loss	dB	-197.3
EP Plume interference	dB	-1.3
Atmospheric Loss	dB	-0.2
Rain Fade 99% Availability	dB	-0.1
Ground Station Polarization Loss	dB	0
Ground Station G/T	dB/K	32.0
Boltzmann's Constant	dB Hz-K/W	228.6
Receive C/No	dB-Hz	75.3
Demodulation Process		
Required Eb/No	dB	10.5
Demodulation Implimentation Loss	dB	1.0
High Data Rate	Mbps	1.0
Required C/No at BPSK Demodulator input	dB-Hz	71.5
Margin =	**dB**	**+3.78**

Annex B: Ku-band Link Budgets

Ku-Band Uplink Command/Ranging Budget	Units	HEMI (±17°)	HEMI (±65°)
		On Station	Safe Mode
Ground Station EIRP, Min	dBW	87	87
S/C Altitude [GEO + 350 km]	km	36,136	36,136
Ground Station Elevation Angle	deg	5	5
Resulting Range	km	41,481	41,481
Free Space Spreading Loss	dBm^2	163.35	163.35
CMD Uplink Flux Density, Min	dBW/m^2	-76.35	-76.35
Isotropic Aperture	dB-m^2	-44.7	-44.7
Antenna Edge of Coverage [Gain]	dBi	7.0	-1.5
Antenna Losses	dB	0.0	0.0
Atmospheric Loss	dB	-0.4	-0.4
Polarization Loss	dB	0.0	0.0
Rain Fade [budgeted] 99% Availability	dB	-0.5	-0.5
Net Antenna Edge of Coverage Gain	dBi	6.1	-2.4
Received CMD Power @ Antenna Output	dBm	-84.93	-93.43
Hemi Coaxial Cable	dB	-2.99	-2.99
Polarization Switch	dB	-0.40	-0.40
RF Coaxial Cable	dB	-0.70	-0.70
Hybrid Coupler	dB	-3.50	-3.50
RF Coaxial Cable	dB	-0.44	-0.44
Bandpass Filter	dB	-0.60	-0.60
RF Coaxial Cable	dB	-0.54	-0.54
Total CMD Input Loss	dB	-9.16	-9.16
Command			
Input Level to Command Receiver Without Multipath	dBm	-94.09	-102.59
Command Receiver CMD Threshold	dBm	-112	-112
Command Margin Without Multipath	**dB**	**+17.91**	**+9.41**
Multipath Loss [budgeted]	dB	-1.00	-2.00
Input Level to Command Receiver With Multipath	dBm	-95.09	-104.59
Command Margin =	**dB**	**+16.91**	**+7.41**
Ranging			
Input Level to Command Receiver Without Multipath	dBm	-94.09	-102.59
Command Receiver RNG Threshold	dBm	-109	-109
Ranging Margin Without Multipath	**dB**	**+14.91**	**+6.41**
Multipath Loss [budgeted]	dB	-1.00	-2.00
Input Level to Command Receiver With Multipath	dBm	-95.09	-104.59
Ranging Margin =	**dB**	**+13.91**	**+4.41**

Ku-Band Downlink - Low Data Rate Telemetry and Ranging Budget	Units	HEMI (±17°)	HEMI (±65°)
		On-Station	Safe Mode
Telemetry Transmitter Output Power [20 watts, EOL]	dBW	13.01	13.01
RF Coaxial Cable	dB	-0.65	-0.65
Transmit Band Pass Filter	dB	-0.50	-0.50
RF Coaxial Cable	dB	-0.40	-0.40
Hybrid Coupler	dB	-3.50	-3.50
RF Coaxial Cable	dB	-0.40	-0.40
Polarization Switch	dB	-0.40	-0.40
HEMI Coaxial Cable	dB	-3.07	-3.07
Total TLM Output Loss	dB	-8.93	-8.93
Antenna Edge of Coverage [Gain]	dBi	7.0	-1.5
Antenna Losses	dB	0	0
EIRP Without Multipath	dBW	11.08	2.58
Multipath Loss [budgeted]	dB	-1.0	-2.0
EIRP with Multipath	dBW	10.08	0.58
S/C Altitude [GEO + 350 km]	km	36,136	36,136
Ground Station Elevation Angle	deg	5	5
Resulting Range	km	41,481	41,481
Free Space Loss	dB	-206.9	-206.9
Atmospheric Loss	dB	-0.4	-0.4
Rain Fade [budgeted] 99% Availability	dB	-0.5	-0.5
Ground Station Polarization Loss	dB	0.0	0
Ground Station G/T	dB/K	37	37
Boltzmanns Constant	dB Hz-K/W	228.6	228.6
Receive C/No	dB-Hz	67.9	58.4
With 1 Subcarrier or Ranging:			
Required C/No for PCM Telemetry at 4.8 kb/s	dB-Hz	51.3	51.3
Telemetry Margin =	**dB**	**+16.55**	**+7.05**
Required C/No for Ranging	dB-Hz	44.01	44.01
Ranging Margin =	**dB**	**+23.86**	**+14.36**
With 2 Subcarriers or 1 Subcarrier + Ranging:			
Required C/No for PCM Telemetry at 4.8 kb/s	dB-Hz	54.3	54.3
Telemetry Margin =	**dB**	**+13.53**	**+4.03**
Required C/No for Ranging	dB-Hz	47.11	47.11
Ranging Margin =	**dB**	**+20.76**	**+11.26**
With 2 Subcarriers + Ranging:			
Required C/No for PCM Telemetry at 4.8 kb/s	dB-Hz	56.1	56.1
Telemetry Margin =	**dB**	**+11.77**	**+2.27**
Required C/No for Ranging	dB-Hz	48.74	48.74
Ranging Margin =	**dB**	**+19.13**	**+9.63**

Annex C: Min/Max Flux Density

C-Band Uplink Min/Max Flux Density	Units	HEMI (±75°)	HEMI (±17°)	HEMI (±75°)
		Transfer	On Station	Safe Mode
Command Receiver Threshold	dBm	-112	-112	-112
Hemi Coaxial Cable	dB	-1.89	-1.89	-1.89
Polarization Switch	dB	-0.25	-0.25	-0.25
Coaxial Cable	dB	-0.44	-0.44	-0.44
Hybrid Coupler	dB	-3.50	-3.50	-3.50
Coaxial Cable	dB	-0.30	-0.30	-0.30
Bandpass Filter	dB	-0.50	-0.50	-0.50
Coaxial Cable	dB	-0.27	-0.27	-0.27
Total CMD Input Loss	dB	-7.16	-7.16	-7.16
Command Signal Required at Antenna Terminal	dBm	-104.84	-104.84	-104.84
Antenna Directivity	dBi	-5.0	7.0	-5.0
Antenna Input Signal Required	dBm	-99.84	-111.84	-99.84
Antenna Input Signal Required	dBW	-129.84	-141.84	-129.84
Maximum Operating Frequency	MHz	6425	6425	6425
Isotropic Aperture	dB-m^2	-37.61	-37.61	-37.61
Minimum Flux Density Required at Satellite	dBW/m^2	-92.23	-104.23	-92.23
Command Receiver Overload Limit	dBm	-40	-40	-40
Hemi Coaxial Cable	dB	-1.89	-1.89	-1.89
Polarization Switch	dB	-0.25	-0.25	-0.25
Coaxial Cable	dB	-0.44	-0.44	-0.44
Hybrid Coupler	dB	-3.50	-3.50	-3.50
Coaxial Cable	dB	-0.30	-0.30	-0.30
Bandpass Filter	dB	-0.50	-0.50	-0.50
Coaxial Cable	dB	-0.27	-0.27	-0.27
Total CMD Input Loss	dB	-7.16	-7.16	-7.16
Command Signal allowed at Antenna Terminal	dBm	-32.84	-32.84	-32.84
Maximum Antenna Directivity	dBi	9.0	9.0	9.0
Antenna Input Signal Allowed (Max)	dBm	-41.84	-41.84	-41.84
Antenna Input Signal Allowed (Max)	dBW	-71.84	-71.84	-71.84
Operating Frequency	MHz	6425	6425	6425
Isotropic Aperture	dB-m^2	-37.61	-37.61	-37.61
Maximum Flux Density Allowed at Satellite	dBW/m^2	-34.23	-34.23	-34.23

Ku-Band Uplink Min/Max Flux Density	Units	HEMI (±65°)	HEMI (±17°)	HEMI (±65°)
		Transfer	On Station	Safe Mode
Command Receiver Threshold	dBm	-112	-112	-112
Hemi Coaxial Cable	dB	-2.99	-2.99	-2.99
Polarization Switch	dB	-0.40	-0.40	-0.40
Coaxial Cable	dB	-0.70	-0.70	-0.70
Hybrid Coupler	dB	-3.50	-3.50	-3.50
Coaxial Cable	dB	-0.44	-0.44	-0.44
Bandpass Filter	dB	-0.60	-0.60	-0.60
Coaxial Cable	dB	-0.54	-0.54	-0.54
Total CMD Input Loss	dB	-9.16	-9.16	-9.16
Command Signal Required at Antenna Terminal	dBm	-102.84	-102.84	-102.84
Antenna Directivity	dBi	-1.5	7.0	-1.5
Antenna Input Signal Required	dBm	-101.34	-109.84	-101.34
Antenna Input Signal Required	dBW	-131.34	-139.84	-131.34
Maximum Operating Frequency	MHz	14525	14525	14525
Isotropic Aperture	dB-m^2	-44.68	-44.68	-44.68
Minimum Flux Density Required at Satellite	dBW/m^2	-86.66	-95.16	-86.66
Command Receiver Overload Limit	dBm	-40	-40	-40
Hemi Coaxial Cable	dB	-2.99	-2.99	-2.99
Polarization Switch	dB	-0.40	-0.40	-0.40
Coaxial Cable	dB	-0.70	-0.70	-0.70
Hybrid Coupler	dB	-3.50	-3.50	-3.50
Coaxial Cable	dB	-0.44	-0.44	-0.44
Bandpass Filter	dB	-0.60	-0.60	-0.60
Coaxial Cable	dB	-0.54	-0.54	-0.54
Total CMD Input Loss	dB	-9.16	-9.16	-9.16
Command Signal allowed at Antenna Terminal	dBm	-30.84	-30.84	-30.84
Maximum Antenna Directivity	dBi	9.0	9.0	9.0
Antenna Input Signal Allowed (Max)	dBm	-39.84	-39.84	-39.84
Antenna Input Signal Allowed (Max)	dBW	-69.84	-69.84	-69.84
Operating Frequency	MHz	14525	14525	14525
Isotropic Aperture	dB-m^2	-44.68	-44.68	-44.68
Maximum Flux Density Allowed at Satellite	dBW/m^2	-25.16	-25.16	-25.16

Annex D: TT&C Maximum EIRP and EIRP Density

C-Band Telemetry/Ranging Budget	Units	HEMI (±17°)	Notes
		On-Station	
Telemetry Transmitter Output Power [32 Watts, BOL]	dBW	15.05	max Po
TTX Port Cable Loss [3 feet]	dB	0.36	min loss
PNA - Hybrid	dB	3.2	min loss
Polarization Switch	dB	0.3	min loss
Transmit Band Pass Filter	dB	0.4	min loss
HEMI Cable Loss [20 feet]	dB	2.0	min loss
Total TLM Output Loss	dB	-6.17	
Antenna Peak Coverage [Gain]	dBi	9.5	max directivity
Antenna Losses	dB	0	
EIRP Without Multipath	dBW	18.39	
Multipath Loss [budgeted)	dB	0.0	zero multipath
Maximum EIRP	**dBW**	**18.39**	
Occupied Bandwidth	kHz	200.00	Tx Bandwidth
EIRP Density	**dBW/Hz**	**-34.62**	

Ku-Band Telemetry/Ranging Budget	Units	HEMI (±17°)	Notes
		On-Station	
Telemetry Transmitter Output Power [23 watts, BOL]	dBW	13.62	max Po
TTX Port Cable Loss [3 feet]	dB	0.66	min loss
PNA - Hybrid	dB	3.2	min loss
Polarization Switch	dB	0.3	min loss
Transmit Band Pass Filter	dB	0.4	min loss
HEMI Cable Loss [20 feet]	dB	3.57	min loss
Total TLM Output Loss	dB	-8.13	
Antenna Edge of Coverage [Gain]	dBi	9.5	max directivity
Antenna Losses	dB	0	
EIRP Without Multipath	dBW	14.99	
Multipath Loss [budgeted)	dB	0.0	zero multipath
Maximum EIRP	**dBW**	**14.99**	
Occupied Bandwidth	kHz	200.00	
EIRP Density	**dBW/Hz**	**-38.03**	