Agile MicroSat
FCC Form 442 - Mission Narrative
Application for New or Modified Radio Station Under Part 5 of FCC Rules – Experimental Radio Service (Other Than Broadcast)

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REVISION HISTORY

Revision	Description of Change	Author	Date
1.0	Initial draft	D Cousins	7/17/2020

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ACRONYMNS

ADAPT	Active Distributed Aperture Phase Technology
AFLCMC	Air Force Life Cycle Management Center
BCT	Blue Canyon Technologies LLC
CMOS	Complementary Metal Oxide Semiconductor
DPC	Data Processing Center
DSN	Deep Space Network
EROS	Earth Resources Observation Satellite
FEEP	Field Effect Electric Propulsion
FPA	Focal Plane Array
GNC	Guidance, Navigation and Control
GSD	Ground Sample Distance
KSat	Kongsberg Satellite Systems Inc
LTAN	Local Time of Ascending Node
MIT LL	MIT Lincoln Laboratory
MODIS	Moderate Resolution Imaging Spectroradiometer
NIR	Near Infrared
PFD	Power Flux Density
RGB	Red Green Blue
SDRAM	Synchronous Dynamic Random Access Memory
SV	Space Vehicle

1) NARRATIVE STATEMENT

a) INTRODUCTION

Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) researches and develops advanced technologies to meet critical national security needs as a Federally Funded Research and Development Center (FFRDC) operating under a prime contract to the U.S. Air Force. MIT LL applies under FCC Registration No. 0005-1907-31.

MIT LL is developing the Agile MicroSat (AMS) as an Earth Exploration Satellite to research novel Earth remote sensing techniques enabled by satellite agility. AMS will be the first of its kind nanosatellite with suitable agility to make significant orbital maneuvers and reliably operate at low altitude.

b) BACKGROUND

Agility refers to the capability of a spacecraft to reliably maneuver into optimum orbits to make time-sensitive urgent obervations. The Agile Micro Sat is an experimental Earth Exploration Satellite with a level of agility never before attempted by a CubeSat nanaosatellite. One aspect of agility includes the capability to reach and maintain low altitude, thereby providing higher resolution for earth remote sensing than traditional satellite orbits. Another aspect of agility involves maneuvering into a repeating ground track orbit to overpass a given ground site at the same time of day. Both types of agility will allow the AMS spacecraft, and by extension future spacecraft exploiting technology developed in AMS, enhanced methods of earth environmental monitoring. Specific environmental conditions that may benefit include agricultural or ecological stress, coastal and riverine flooding, oil spills, fire smoke plumes, and even harbor and large marine vessel activity.

Spacecraft maneuvers and low altitude operation require that the spacecraft generate and control thrust over sustained periods of time. The AMS spacecraft uses an innovative field effect electric propulsion (FEEP) thruster which has been designed to meet the stringent size and power constraints of a nanosatellite. Control of thrust direction, magnitude, duration and location within the orbit are integrated within the AMS satellite control system. AMS is also implementing both passive and active advanced satellite control techniques to address momentum management during thrusting, atmospheric drag makeup and fault response in low altitude/high drag conditions.

The AMS mission incorporates the following system elements:

- nanosatellite 6U spacecraft bus supplied by Blue Canyon Technologies LLC (BCT);
- electric propulsion thruster supplied by Enpulsion GmhH;
- remote sensing camera and optical beacon payloads developed by MIT LL;
- software defined radio on the spacecraft developed by BCT;
- commercial shared ground stations operated by Kongsberg Satellite Systems (K Sat).

The AMS mission uses the same radio transceiver as:

Applicant:	Space Sciences & Engineering
File No.	0011-EX-CN-2019
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The AMS spacecraft will deploy into a nominal 500 km sun-synchronous low-earth-orbit (LEO) and maneuver through a series of elliptical orbits of decreased perigee and apogee, ultimately reaching and maintaining a very low circular orbit. For mission planning in the 2021-2022 time frame, a minimum final altitude of 275 km is assumed as the lower bound. The final actual orbit altitude limit will depend on the actual geo-solar atmospheric drag conditions encountered during the mission. The AMS mission is planned to last nominal 6 months, after which the spacecraft will rapidly passively re-enter the atmosphere and be completely destroyed.

Within this narrative, RF communications mission analyses are described for both bounding cases: maximum altitude 500km and minimum altitude 275km.

c) GOVERNMENT CONTRACT

The spaceraft is U.S. government property, accountable under U.S. Air Force contract. With regard to Section 4 of FCC Form 442, this frequency authorization application is to be used to fulfill the following government contract:

Government Project:	MIT Lincoln Lab Integrated Systems Line – Agile MicroSat
Agency:	Department of Defense, Under Secretary of Defense for Research and Engineering
Contract Number:	Air Force Contract No. FA8702-15-D-0001
Funding Type:	Applied Research BA-2 (6.2)
Government poc:	Bhupender Singh, AFLCMC/AZS, 781-981-5514, bhupender.singh@ll.mit.edu

2) MISSION DESCRIPTION

a) MISSION EXPECTATIONS

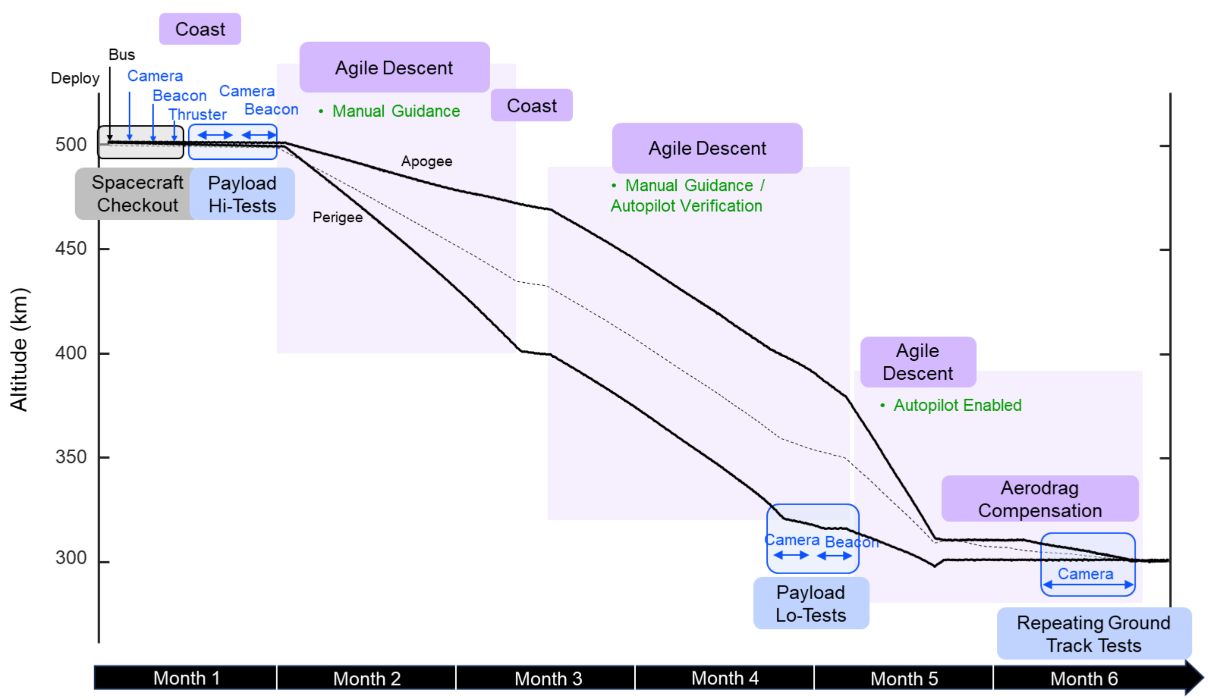


Figure 2.a.1. AMS mission overview and timeline.

Figure 2.a.1 describes the AMS mission timeline. After an initial period of spacecraft checkout, both camera and beacon payloads will be operated to establish baseline performance at the deployment altitude. Subsequently, the spacecraft will operate the thruster to lower its apogee and perigee under different types of maneuver guidance. Once low altitude is achieved and maintained with the thruster, both payloads will be operated to demonstrate benefits of low-atitude spacecraft agility.

Agility success criteria:

- Thrust magnitude at nominal power consumption (0.35 mN at 40W);
- Thrust vector controllable within +/- 15 degree;
- Small number of thruster fault conditions;
- Spacecraft attitude control stability < 1 degree while thrusting;
- Continuous spacecraft momentum management without loss of attitude control;
- Small deviation from actual to targeted orbit altitude (< 3 km);
- Recovery to low-drag mode for commanded spacecraft reset at low altitude.

Payload success criteria

- Camera resolved still imagery collected with nominal image resolution and color balance;
- Properly georegistered image location processed with spacecraft location and attitude knwoledge;
- Short video sequence collected (15 frames obtained within 2.5 second);
- Beacon laser light at nominal 400 mW level;
- Beacon laser light pointed at and received by ADAPT ground terminal;
- Beacon photodiode signal received on-board from ADAPT ground adaptive optics transmitter.

b) THEORY OF OPERATIONS

i) AGILITY

Spacecraft agilty is implemented by the spacecraft executing a schedule of thrust events to reach or maintain a new commanded orbit. Figure 2.b.1 shows a simplified maneuver guidance technique. The thrust event characteristics must properly account for atmospheric drag, which is strongly dependent on spaceraft altitude and attitude and must also be consistent with the spacecraft solar power constraints.

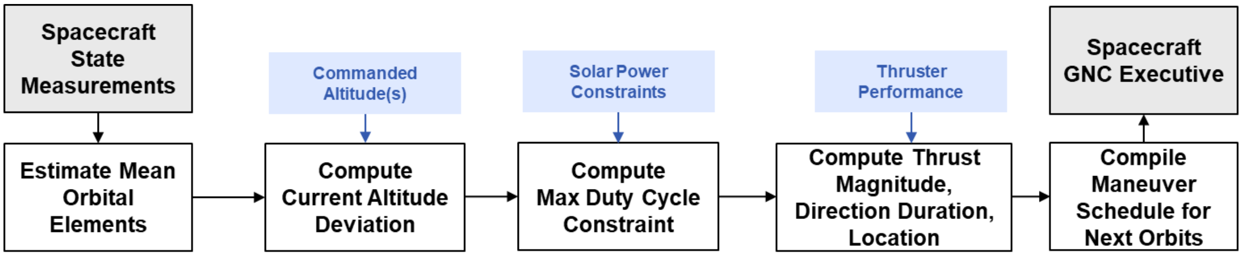


Figure 2.b.1. AMS maneuver guidance technique

The AMS maneuver schedule data can be generated by both ground-based operator computations and on-board by the autopilot software process, as shown by Figure 2.b.2. The mission will step through a series of phases to implement the autopilot derived maneuver schedule into the spacecraft control. In phase 1, maneuvers will be entirely ground-scheduled manual guidance. Phase 2 maneuvers will be ground-scheduled with concurrent ground-based validation of the autopilot.

Phase 3 maneuvers will be controlled solely by the on-board autopilot. In all cases ground-based interrupt may be used to override on-board guidance to assure mission safety.

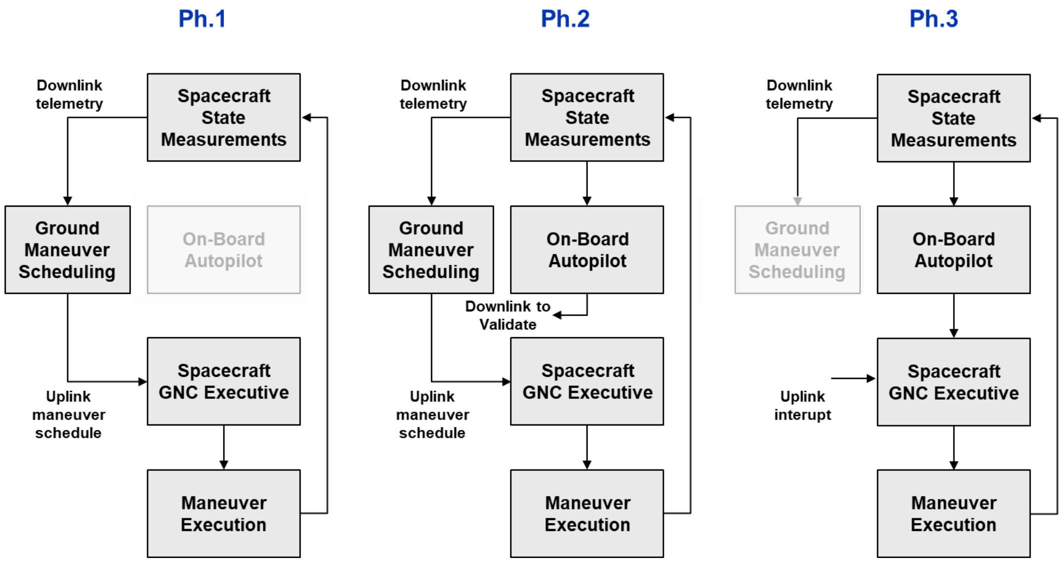
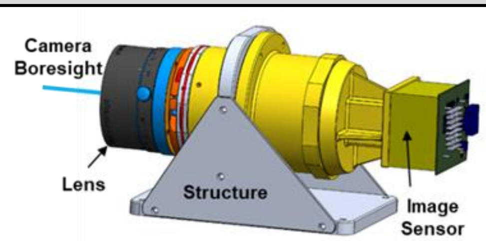


Figure 2.b.2. Phased implementation of spacecraft agility

ii) REMOTE SENSING

The AMS camera payload is a compact visble wavelength color camera. Camera operations involve collection of both still images and short video clips of specific Earth locations as selected and cued in advance by mission operations. Camera optical specifications are described in Table 2.b.1. The camera supports programmable on-board embedded image processing, which can be used to implement image windowing, pixel change detection, data compression, and other processing algorithms. Camera data is time-stamped and stored by the spacecraft for subsequent downlink.

Table 2.b.1. Remote Sensing Camera Specifications



Sensor Model	3D Plus CMOS FPA RGB color, 2048 x 2048 pix. 5.5 um pitch
Lens Model	Schneider Xenon/Emerald 2.9/100-L, f = 100 mm
Wavelength λ	400-1000 nm
Ifov	55 urad
Pixel GSD	15.2 m (30.4 m color demosaic) at 275 km altitude
Image FOV	31.0 km at 275 km altitude

Camera will be used to monitor time-sensitive environmental conditions, such as candidates shown in Figure 2.b.3. Spacecraft agility will enable daily evolving conditions to be revisited.

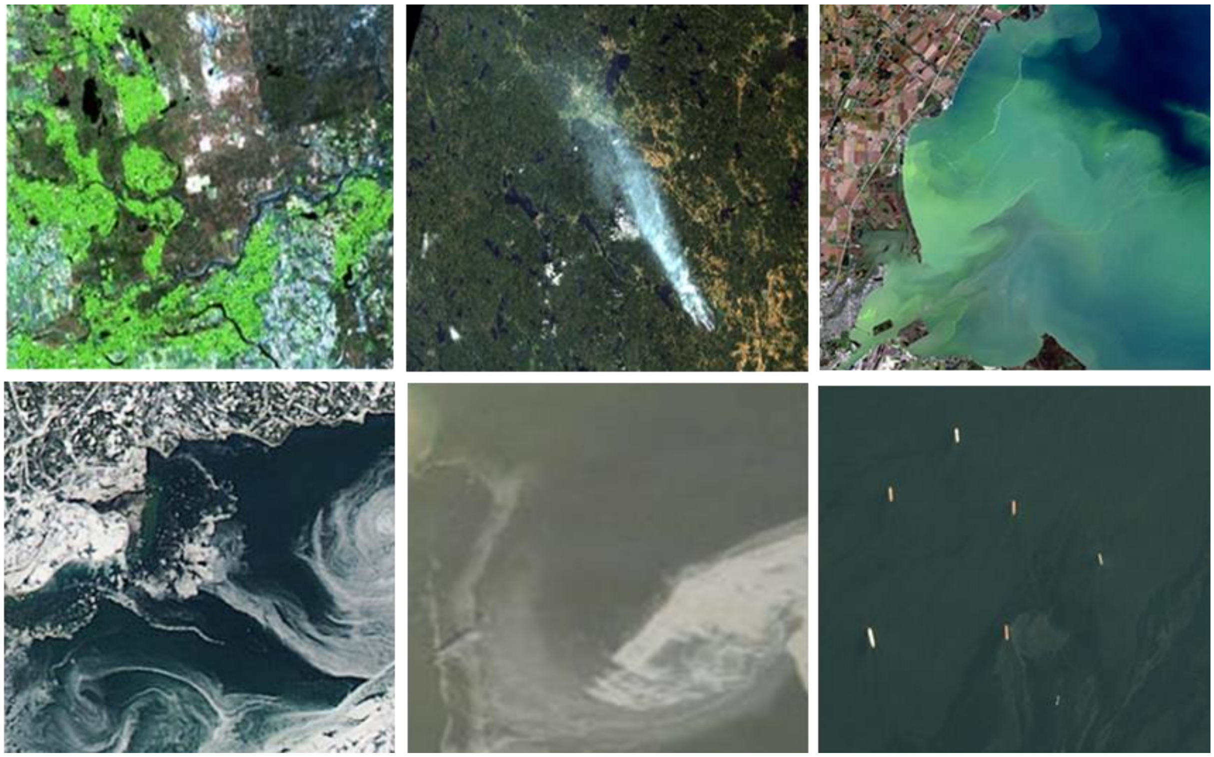


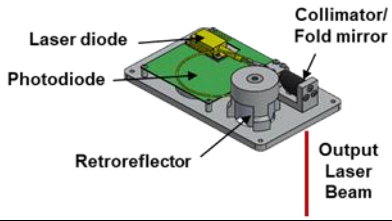
Figure 2.b.3. Examples of candidate remote sensing imagery. Top row, left to right: Crop Damage Assessment, Manitoba, Canada (Courtesy Natural Resources Canada); Forest Fire plume, Vastmanland, Sweden (courtesy NASA Landsat 8); Lake Ecology Algal Bloom, Lake Erie Michigan (courtesy USGS EROS). Bottom Row, left to right: Ice Pack Monitoring, St. Lawrence River, Canada (Courtesy NASA Aqua MODIS sensor); Oil Spill, Gulf of Mexico, Louisiana (Courtesy NASA Terra MODIS); Large Maritime Vessel Monitoring (courtesy Planet Inc, Flock).

The AMS spacecraft and camera will exploit Repeating Ground Track (RGT) orbits. An RGT orbit synchronizes orbital precession with the rotation of the Earth to provide daily overflight of a given location. Traditional missions must plan RGT orbits in advance of mission launch and once implemented, remain in that specific orbit for the duration of the mission. AMS research into on-demand RGT orbits allows mission flexibility to monitor an urgent location which was unknown at the time of launch.

iii) Beacon

The AMS Beacon payload enables the Active Distributed Aperture Phasing Technology (ADAPT) experiment. The ADAPT technique is demonstrating the capability of actively controlling the phase chacteristics of distributed apertures to maximize the transmission of light from a ground site through the atmosphere to a satellite. This capability may improve capabilities for laser communications and space debris removal applications.

Table 2.b.2. ADAPT Optical Beacon Specifications



Model	ADAPT Tx: artificial M_v= -1 to -2 Rx: Photodiode, Retroreflector
Size	13 x 8 x 7 cm^3 ; 0.28 kg
Tx	980 nm diode laser
	Up to 400 mW
	1 deg full angle (17 mrad)
Rx	1064 nm photodiode

During Beacon mission events, the Beacon will be body pointed by the spacecraft at the ADAPT ground site throughout an overpass. During the event the Beacon collimated NIR laser will be activated to provide a phase reference for the ADAPT ground terminal. The Beacon NIR photodiode will be activated to measure the strength of the received ADAPT ground optical signal. Beacon data will be timestamped and stored by the spacecraft for subsequent downlink.

c) SPACECRAFT DESCRIPTION

The AMS spacecraft is a 6U-XL Rail cuebsat configuration developed by Blue Canyon Technologies LLC. Its cubesat body is 14.3 inch length with 77 inch long deployed solar panels. It operates typically in a low-drag balanced configuration with solar panels edge-on and thrust vector aligned with the orbit velocity vector as shown in Figure 2.c.1. The spacecraft radio communication and payload boresights are nominally aligned and can be pointed as needed toward appropriate earth ground sites. The orbit will be sun synchronous with Local Time of Ascending Node (LTAN) at 1000 hours. Orbit altitude will vary from 500 km initially to nominally 275 km at 6 months mission elapsed time.

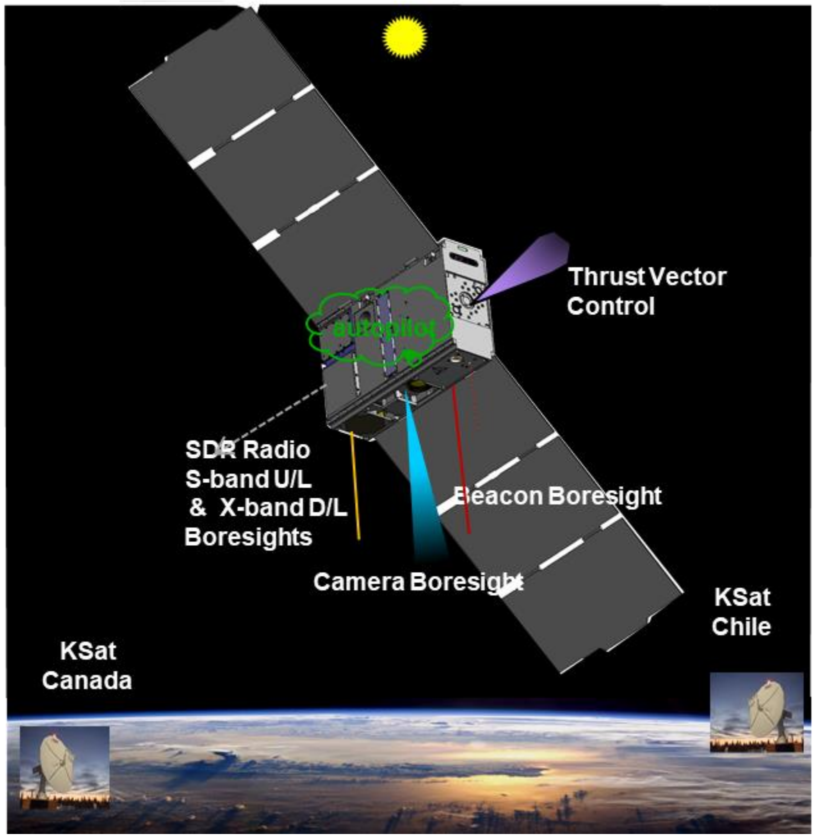


Figure 2.c.1. AMS spacecraft in nominal on-orbit configuration.

Spacecraft communications uses the BCT Software Defined Radio (SDR-X) transceiver for routine mission command uplink and telemetry and data downlink operations. A summary of RF communications specifications are listed in Table 2.c.1.

Table 2.c.1. Mission Communications Specifications					
Spacecraft Radio Model	BCT SDR-X Transceiver				
					
	Frequency Range	**Action Frequency**	**Bandwidth**	**Data Rate**	**Modulation**
Uplink S-band (Earth Exploration Satellite, Earth-to-Space)	2.025 - 2.110 GHz	2.0675 GHz	400 kHz	200 kbps (10 kbps contingency)	BPSK
Downlink X-band (Earth Exploration Satellite, Space-to-Earth)	8.025 - 8.400 GHz	8.2125 GHz	8 MHz	4 Mbps (400 kbps contingency)	OQPSK

AMS spacecraft Downlink X-band transmission characteristics are described by Figure 2.c.2, Table 2.c.2 and in Form 442.

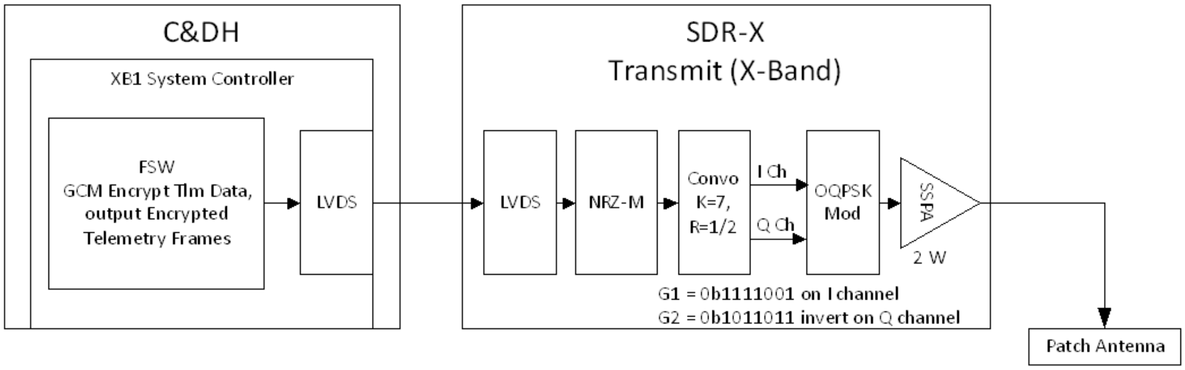


Figure 2.c.2. SDR-X Transmitter Radio Diagram

Table 2.c.2. BCT SDR-X Transmitter Description Non-geostationary	
Action frequency	8.2125 GHz
Maximum output power	2.0 W
EIRP	33 dBm (2 W)
Mean/Peak	Mean
Frequency Tolerance	4 ppm
Emission Designator	5MG1D
Modulating signal	4000000 baud OQPSK
Spurius Emission	< -60 dB

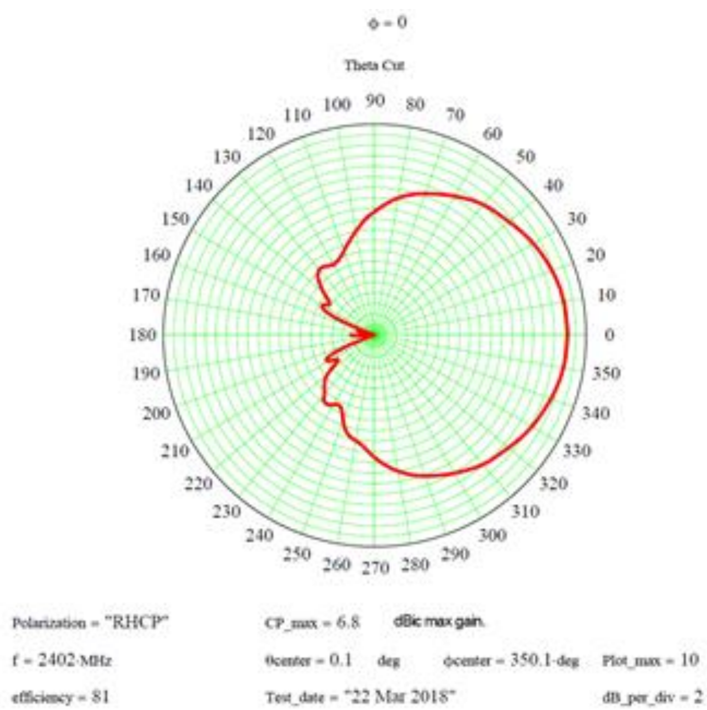


Figure 2.c.3. Nominal Antenna Gain Pattern, Uplink S-band. Plot maximum 10 dBi with 2 dB per division.

The X-band patch antenna is supplied by BCT with Ant Dev Co heritage. It is designed to be RHCP and nearly hemispherical in gain pattern. Gain ranges from nominal peak 6.0 dBi gain at 0 deg, half power points +/- 40 deg, nominal 0 dBi gain at +/- 60 deg with no significant sidelobes.

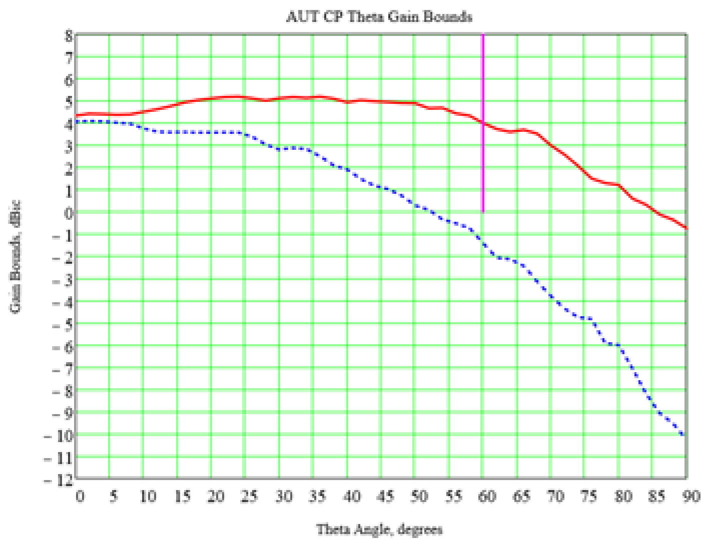


Figure 2.c.4. Nominal Antenna Gain Pattern, Downlink X-band

d) GROUND STATION DESCRIPTION

The AMS mission will utilize Kongsberg Satellite Services for use of selected ground stations within their KSat-Lite network as specified in Table 2.d.1. Mission operations are planned to support 3 passes per day over 2 ground stations. Primary ground sites at Inuvik, Canada and Punta Arena, Chile will be used for routine mission operations. Secondary sites will be used only if primary sites are unavailable. Tertiary site will be restricted to emergency operations if needed.

Table 2.d.1. Ground Station Locations

Site	Name	Mission Status	Latitude (°)	Longitude (°)	Elevation (m)
Inuvik, Canada	KSat Lite	Primary	68.2 N	133.3 W	27
Punta Arenas, Chile	KSat Lite	Primary	52.9 S	70.8 W	186
Tromsø, Norway	KSat Multi	Secondary	69.6 N	19.0 E	106
Hartebeesthoek, South Africa	KSat Lite	Secondary	25.8 S	27.7 E	1543
Awarua, New Zealand	KSat Lite	Tertiary	46.5 S	168.4 E	186

Table 2.d.2. Ground Station Receiver Antenna: Space-to-Earth		
	KSat-Lite	**KSat-Multi**
Antenna Locations	Inuvik, Canada; Punta Arenas, Chile; Hartebeesthoek, South Africa; Awarua, New Zealand	Tromsø, Norway
Diameter (m)	3.7	3.0
Half-power beamwidth (@ 8050 MHz X-Band)	0.4°	0.49°
EIRP @Psat(dBW)	49.4	47.7
Receiving system noise temperature X-band Downlink (K)	95	95
Main Beam Antenna gain X-band (dBi)	47	45.5
Minimum supported elevation range	5	5
Azimuthal range (degrees)	360	360
Polarization	LHCP or RHCP	LHCP or RHCP

Table 2.d.3. Ground Station Transmitter Antenna: Earth-to-Space		
	KSat-Lite	**KSat-Multi**
Antenna Locations	Inuvik, Canada; Punta Arenas, Chile; Hartebeesthoek, South Africa; Awarua, New Zealand;	Tromsø; Norway
Diameter (m)	3.7	3.0
Half-power beamwidth (@ 2250 MHz S-Band)	1.4°	1.76°
Maximum Output Power S-band (W)	25.1	25.1
Minimum Output Power S-band (W)	0	0
EIRP @Psat(dBW)	49.4	47.7
Receiving system noise temperature S-band Uplink (K)	235	235
Maximum isotropic Gain S-band (dBi)	35.4	33.7
Beamwidth S-band (degrees)	1.3	
Minimum supported elevation range	5	5
Azimuthal range (degrees)	360	360
Polarization	LHCP or RHCP	LHCP or RHCP

e) DATA TRANSFER – LINK BUDGET

i) NORMAL OPERATIONS

The SDR-X transceiver only transmits in reply to an authentic uplink command. Under normal operations the spacecraft controls spacecraft attitude so that antenna boresights point at the ground station throughout the overpass. The SDR-X transmitter allows for operational control of the transmitter power levels during all phases of the mission. If anomalies occur to prevent body pointing, the spacecraft can be operated in contingency opertations mode. Contingency operations concentrate RF power in a narrower bandwidth to increase link reliability.

Table 2.e.1 provides the link budget for the Space-to-Earth downlink for communications at full power normal operations for both maximum and minimum operating orbit altitudes.

Table 2.e.1. Space-to-Earth Downlink Budget, Normal Operations

AMS 4.0 Mbps, X-band Downlink Margin Analysis					
Parameter	Symbol	KSAT 3.7m	KSAT 3.7m	Units	Comments/Notes
Spacecraft Orbital Altitude		500	275	km	Input Spacecraft Altitude
Downlink Frequency	f	8.5000	8.5000	GHz	Input Spacecraft Frequency
Wavelength	λ	0.035	0.035	m	λ = c/f
Transmit Power	P_T	2.0	2.0	Watt	Input Transmit RF Output Power
Transmit Power	$P_{T(dB)}$	33.0	33.0	dBm	$P_{T(dB)}$ = 10 log (Pt) + 30
SC Antenna Gain	G_T	5.0	5.0	dBi	Input Spacecraft Antenna Peak Gain: Boresight Pointed
Passive Loss	L_l	-1.5	-1.5	dB	Input Spacecraft Passive RF Loss (Cables + Connectors)
Equivalent Isotropic Radiated Power	EIRP	36.5	36.5	dBm	Spacecraft EIRP = $P_{T(dB)}$ + G_T + L_l
Ground Station Elevation Angle	α	5.0	5.0	deg	Elevation look angle from the ground station to the SC
Slant Range	SR	2077.9	1417.1	km	Calculation of Slant Range to Spacecraft
Free Space Dispersion Loss	L_S	-177.4	-174.1	dB	Calculation of Free Space Dispersion
Total Atmospheric Loss	A_T	-1.0	-1.0	dB	ITU S-band Atmospheric Loss for 99% availability (estimate)
Ground Station G/T	G/T	26.5	26.5	dB/K	Ground Station G/T (KSAT Lite 3.7m)
Total Received Power/T	P_R	-115.4	-112.1	dBm/K	P_R = EIRP + L_S + AR_{Loss} + A_T + G/T
Boltzmann's Constant	k	-198.6	-198.6	dBm/Hz-K	Constant
Total Received Power/kT	$P_{R(dB\text{-}Hz)}$	83.2	86.5	dB-Hz	$P_{R(dB\text{-}Hz)}$ = P_R - k
Data Channel Information					
Data Power/kT	$P_{R(dB\text{-}Hz)}$	83.2	86.5	dB-Hz	= Total Received Power/kT; for suppressed carrier modulation
Information Rate	R	4,000,000	4,000,000	bps	Input Information Data Rate (without FEC)
Information Rate	$R_{(dB\text{-}Hz)}$	66.0	66.0	dB-Hz	= 10 log (R)
Available E_b/N_o	E_b/N_o	17.2	20.5	dB	E_b/N_o = $P_{R(dB\text{-}Hz)}$ - $R_{(dB\text{-}Hz)}$
Required E_b/N_o 10-6 BER	$E_b/N_{o(REQ)}$	10.7	10.7	dB	Theory E_b/N_o for 10^{-6} BER
Implementation Loss	IL	-2.0	-2.0	dB	Estimate of System Distortion Loss
Coding Gain	$FEC_{(Gain)}$	5.7	5.7	dB	Rate 1/2, K=7 Convo Encoding with Soft Decision Decode
Available Margin		**10.2**	**13.5**	**dB**	**Data Channel Margin**

Table 2.e.2. provides the link budget for the Earth-to-Space uplink for normal communications operations for nominal maximum and minimum operating orbit altitudes.

Table 2.e.2. Earth-to-Space Uplink Budget, Normal Operations

AMS: 200 kbps, S-band Uplink Margin Analysis					
Parameter	Symbol	KSAT 3.7m	KSAT 3.7m	Units	Comments/Notes
Spacecraft Orbital Altitude		500	275	km	Input Spacecraft Altitude
Uplink Frequency	f	2.11000	2.11000	GHz	Input Spacecraft Frequency
Wavelength	λ	0.142	0.142	m	λ = c/f
Uplink EIRP	EIRP	74.8	74.8	dBm	Input Ground Station EIRP
Ground Station Elevation Angle	α	5.0	5.0	deg	Input elevation look angle from the ground station to the Spacecraft
Slant Range	SR	2077.9	1417.1	km	Calculation of Slant Range to Spacecraft
Free Space Dispersion Loss	L_S	-165.3	-162.0	dB	Calculation of Free Space Dispersion
Total Atmospheric Loss	A_T	-1.0	-1.0	dB	ITU S-band Atmospheric Loss for 99% availability (estimate)
Passive Loss	L_l	-3.0	-3.0	dB	Input Spacecraft Passive RF Loss
SC Antenna Gain	G_T	5.8	5.8	dBi	Input Spacecraft Antenna Gain: Boresight Pointed
Power at the SC Receiver	P_R	-88.7	-85.4	dBm	Calculated
Minimum Command Channel Power		-97.0	-97.0	dBm	Receiver threshold estimate for 200 kbps, BPSK, BER <1x10-6
Available Command Channel Margin		**8.3**	**11.6**	**dB**	**Data Channel Margin**

CONTINGENCY OPERATIONS

In case of spacecraft control anomalies, contingency operations may be conducted to regain normal full control of the spacecraft. In that situation, both the uplink and downlink data rates are reduced. Tables 2.e.3. and 2.e.4. provide the link budgets for the Space-to-Earth and Earth-to-Space links for normal communications operations respectively.

Table 2.e.3. Space-to-Earth Downlink Budget, Contingency Operations

AMS: 400 kbps, X-band Downlink Margin Analysis					
Parameter	Symbol	KSAT 3.7m	KSAT 3.7m	Units	Comments/Notes
Spacecraft Orbital Altitude		500	275	km	Input Spacecraft Altitude
Downlink Frequency	f	8.5000	8.5000	GHz	Input Spacecraft Frequency
Wavelength	λ	0.035	0.035	m	λ = c/f
Transmit Power	P_T	2.0	2.0	Watt	Input Transmit RF Output Power
Transmit Power	$P_{T(dB)}$	33.0	33.0	dBm	$P_{T(dB)}$ = 10 log (Pt) + 30
SC Antenna Gain	G_T	-4.0	-4.0	dBi	Input Spacecraft Antenna Peak Gain: ~80 degress Off-Pointed
Passive Loss	L_l	-1.5	-1.5	dB	Input Spacecraft Passive RF Loss (includes diplexer)
Equivalent Isotropic Radiated Power	EIRP	27.5	27.5	dBm	Spacecraft EIRP = $P_{T(dB)} + G_T + L_l$
Ground Station Elevation Angle	α	5.0	5.0	deg	Elevation look angle from the ground station to the SC
Slant Range	SR	2077.9	1417.1	km	Calculation of Slant Range to Spacecraft
Free Space Dispersion Loss	L_S	-177.4	-174.1	dB	Calculation of Free Space Dispersion
Total Atmospheric Loss	A_T	-1.0	-1.0	dB	ITU S-band Atmospheric Loss for 99% availability (estimate)
Ground Station G/T	G/T	26.5	26.5	dB/K	Ground Station G/T (estimate)
Total Received Power/T	P_R	-124.4	-121.1	dBm/K	P_R = EIRP + L_S + AR_{Loss} + A_T + G/T
Boltzmann's Constant	k	-198.6	-198.6	dBm/Hz-K	Constant
Total Received Power/kT	$P_{R(dB-Hz)}$	74.2	77.5	dB-Hz	$P_{R(dB-Hz)} = P_R - k$
Data Channel Information					
Data Power/kT	$P_{R(dB-Hz)}$	74.2	77.5	dB-Hz	= Total Received Power/kT; for suppressed carrier modulation
Information Rate	R	400,000	400,000	bps	Input Information Data Rate (without FEC)
Information Rate	$R_{(dB-Hz)}$	56.0	56.0	dB-Hz	= 10 log (R)
Available E_b/N_o	E_b/N_o	18.2	21.5	dB	$E_b/N_o = P_{R(dB-Hz)} - R_{(dB-Hz)}$
Required E_b/N_o 10-6 BER	$E_b/N_{o(REQ)}$	10.7	10.7	dB	Theory E_b/N_o for 10^{-6} BER
Implementation Loss	IL	-2.0	-2.0	dB	Estimate of System Distortion Loss
Coding Gain	$FEC_{(Gain)}$	5.7	5.7	dB	Rate 1/2, K=7 Convo Encoding with Soft Decision Decode
Available Margin		**11.2**	**14.5**	**dB**	**Data Channel Margin**

In contingency operations, transmitter power can be reduced by approximately 8 dB to 25 dBm (0.316 W) and still close the contingency downlink at 5 deg elevation.

Table 2.e.4. Earth-to-Space Uplink Budget, Contingency Operations

AMS: 10 kbps, S-band Uplink Margin Analysis					
Parameter	Symbol	KSAT 3.7m	KSAT 3.7m	Units	Comments/Notes
Spacecraft Orbital Altitude		500	275	km	Input Spacecraft Altitude
Uplink Frequency	f	2.11000	2.11000	GHz	Input Spacecraft Frequency
Wavelength	λ	0.142	0.142	m	λ = c/f
Uplink EIRP	EIRP	74.8	74.8	dBm	Input Ground Station EIRP
Ground Station Elevation Angle	α	5.0	5.0	deg	Input elevation look angle from the ground station to the Spacecraft
Slant Range	SR	2077.9	1417.1	km	Calculation of Slant Range to Spacecraft
Free Space Dispersion Loss	L_S	-165.3	-162.0	dB	Calculation of Free Space Dispersion
Total Atmospheric Loss	A_T	-1.0	-1.0	dB	ITU S-band Atmospheric Loss for 99% availability (estimate)
Passive Loss	L_l	-3.0	-3.0	dB	Input Spacecraft Passive RF Loss
SC Antenna Gain	G_T	-6.0	-6.0	dBi	Input Spacecraft Antenna Gain: ~85 degress Off-Pointed
Power at the SC Receiver	P_R	-100.5	-97.2	dBm	Calculated
Minimum Command Channel Power		-110.0	-110.0	dBm	Receiver threshold estimate for 10 kbps, BPSK, BER <1x10-6
Available Command Channel Margin		**9.5**	**12.8**	**dB**	**Data Channel Margin**

f) POWER LIMIT

The ITU recommends the following limits of Power Flux Density (PFD) from space stations as received at the Earth's surface. These limits relate to the PFD obtained only under free-space path loss conditions and a 4 kHz bandwidth.

Table 2.e.5. ITU PFD Limits at the Earth's Surface					
Frequency band	**Service**	**Limit in dB(W/m2) for angles of arrival (δ) above the horizontal plane**			**Reference bandwidth**
		0°-5°	5°-25°	25°-90°	
8025-8500 MHz	Space research (space-to-Earth)	-150	-150 + 0.5(δ-5)	-140	4 kHz

i) NORMAL OPERATIONS

The PFD profile of the AMS downlink as a function of elevation is shown in Figure 2.f.1 for worst case maximum transmit power (33 dBm) and at minimum orbit altitude (275 km). In this worst case, the PFD profile meets the ITU limit for all elevations in normal operations. The maximum PFD at 90 degree elevation angle is -144.5 dBW/m^2/4kHz. The margin against the ITU limit ranges from 10 dB at 0 ° elevation to 3.5 dB at 90 ° elevation.

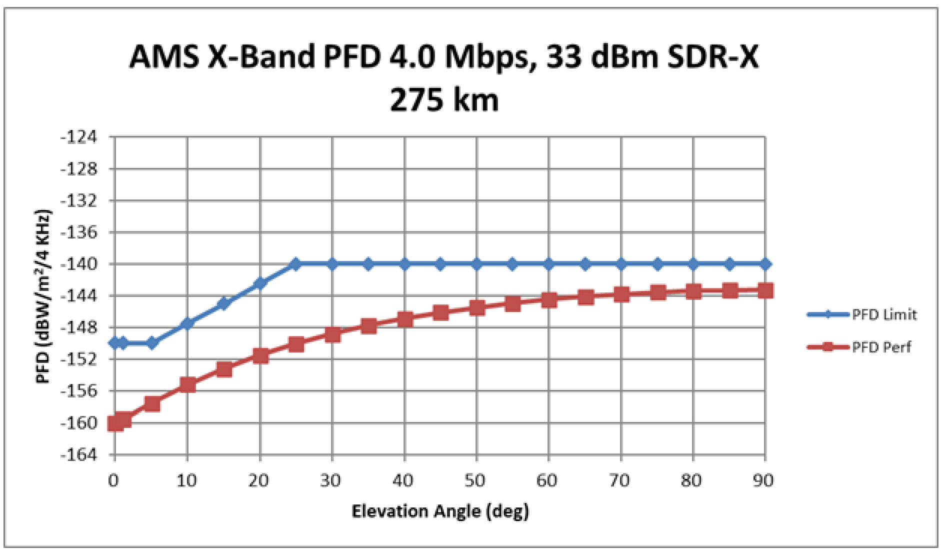


Figure 2.f.1. Downlink Power Flux Density, Normal Operations

ii) CONTINGENCY OPERATIONS

Contingency operations concentrate RF power in a narrower bandwidth to increase link reliability. Figure 2.f.2 shows the PFD assuming power is reduced as described in section 2)e.ii to 25 dBm. In this case, the PFD profile meets the ITU limit for all elevations in contingency operations with the maximum PFD at 90 degree elevation angle of -140.3 dBW/m^2/4kHz.at 90 ° elevation.

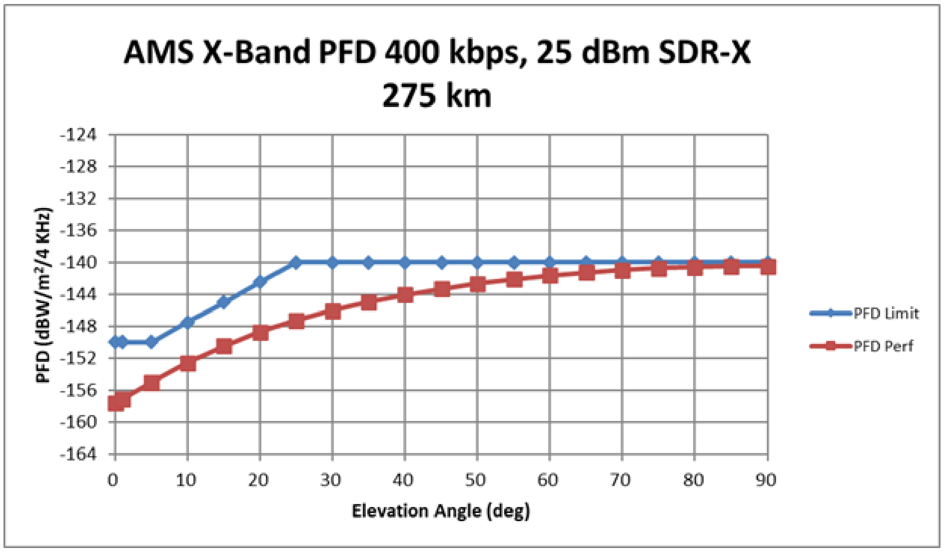


Figure 2.f.2. Downlink Power Flux Density, Contingency Operations

iii) POTENTIAL INTERFERENCE

A simulation of of contacts between AMS and it's ground stations was conducted using the orbital software package Systems Toolkit (STK) from Analytical Graphics, Inc. Results are shown in see Figures 2.f.3 and 2.f.4).

The AMS orbit is analyzed over the range of 500 km to 275 km altitude, with orbit LTAN 100 hours The spacecraft radio is modeled with 40 degree half power cone angle and assumed to be pointed at the mission ground station. The mission ground stations include the primary, secondary and tertiary stations as described in Section 2d). An elevation mask of 5 degrees was imposed at each of the ground stations to account for elevation above the surrounding foliage and structures.

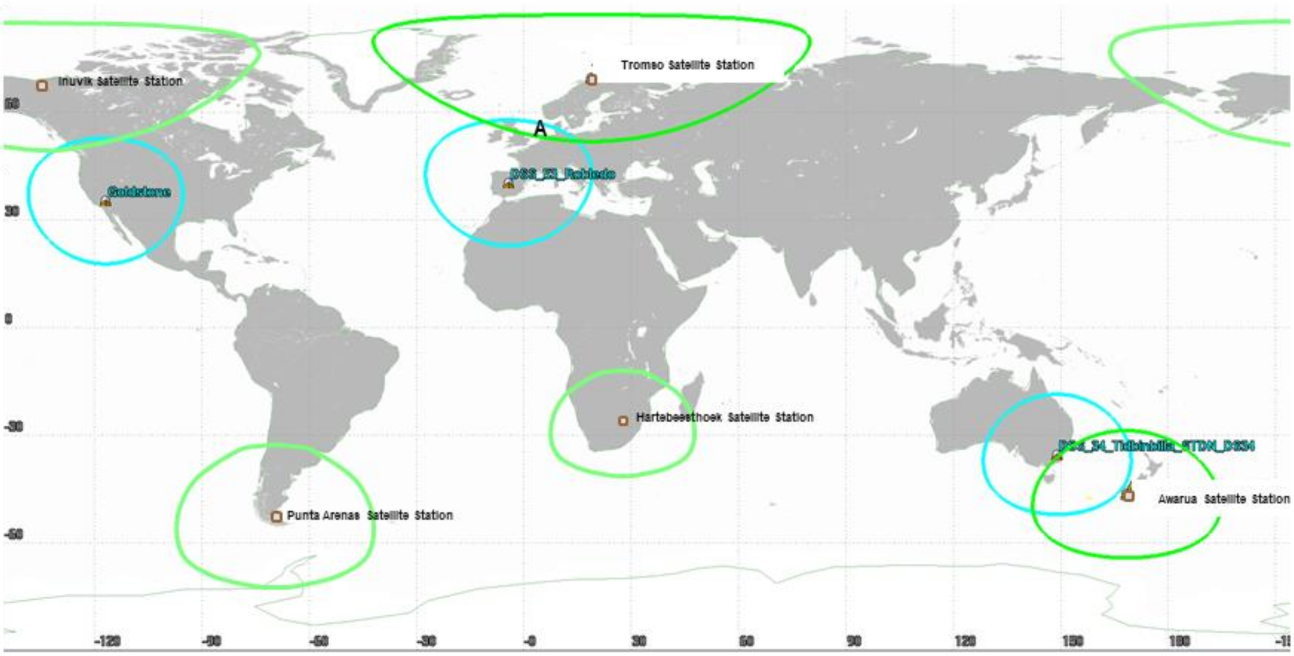


Figure 2.f.3. Transmission footprints from 500 km for contact with mission ground stations.
Sub-satellite footprints for contact with the AMS ground stations (in green) and their potential overlap with DSN stations (in blue). Point "A" indicates location analyzed for potential DSN interference.

Figure 2.f.4. Transmission footprints from 275 km for contact with missin ground stations.
Sub-satellite footprints for contact with the AMS ground stations (in green) and their potential overlap with DSN stations (in blue).

Stations within the Deep Space Network (DSN) at Goldstone CA USA, Madrid-Robledo SP, Canberra-Tidbinbilla AU are included in the analyses. The ITU specifies a maximum allowable interference power spectral flux-density at Earth's surface of -255.1 dB(W/m2·Hz) to protect earth-station receivers in the deep-space research band of 8.40-8.45 GHz.

During normal and contingency operations there is no line-of-sight between the AMS spacecraft and a DSN ground station while the spacecraft is above 5 degree elevation of either primary mission ground stations,. Since AMS downlink tranmissions are only in response to an uplink request, therefore there is no opportunity to generate interference with the DSN stations. AMS satisfies the DSN interference limit during normal operations with the primary mission ground stations.

In a small region, as shown at location "A" in Figure 2.f.3, there is line-of-sight to the DSN Madrid-Robledo DSN site while the spacecraft is within 5 degree elevation of the Tromso mission station. In this worst case, as shown in Figure 2.f.5, the DSN station is at 163 degree angle with respect to transmit boresight. Table 2.e.6 shows that AMS satisfies the DSN interference limit during normal operations with the secondary mission ground stations.

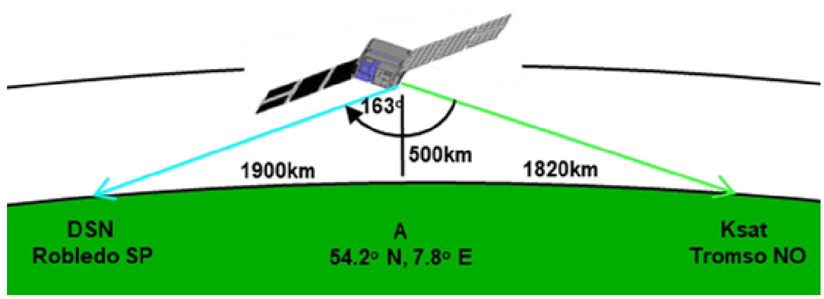


Figure 2.f.5. Potential for interference with Deep Space Network.
AMS sub-satellite position at location "A" while transmitting to KSat Tromso mission ground station.

Table 2.e.6. Potential for Interference with Deep Space Network			
Altitude	500 km	275 km	Max and Min orbit altitude
Maximum in-band transmitter PFD	-144.5 dBW/m2/4kHz	-140.3 dBW/m2/4kHz	Normal Operations, 90 deg
Antenna Pointing Loss	-20 dB	-20 dB	Antenna Gain pattern at 163 deg
Out-of-band Loss	-60 dB	-60 dB	Spurious emission per DD1494
Bandwidth conversion	-36 dB	-36 dB	4 kHz to 1 Hz
Maximum out-of-band interference	-260.5 dBW/m2/Hz	-256.3 dBW/m2/Hz	In 8.40-8.45 GHz DSN band

In emergency cases where neither primary or secondary mission ground stations are available, AMS proposes to operate with a tertiary ground station at Awarua NZ. In this emergency case, analyses indicate there is a two minute window prior to the spacecraft being in range of the Awarua ground station where the radio footprint is within the field of regard of the DSN station at Canberra-Tidbindilla AU. In this rare emergency condition, spacecraft downlink will be restricted to only request transmission when not within the DSN field of regard and thereby abide by the DSN interfence limit by procedure with the tertiary mission ground site.

3) UTILITY OF MISSION DATA

During a ground station overpass, the AMS downlinks accumulated spacecraft and payload data from previous day's orbits while in range of the ground station. The spacecraft downlink is only initiated in response to an uplink command. Some spacecraft telemetry values are available for real-time downlink.

The specific types and instances of mission data selected for downlink will support AMS research for improved satellite agility and corresponding enhancement for remote sensing.

a) AGILITY

Agility enables spaceraft operation at low altitude. For traditional satellite optical remote sensing mssions, low attitude corresponds to smaller sensor apertures or higher resolution for a given aperture. Entirely new remote sensing missions may only be feasible at low altitude, such as LADAR imaging and HF/VHF microwave sounding below some ionosphere layers. AMS will demonstrate the continuous atmospheric drag makeup and automated fault response during high-drag conditions that are fundamentally required for sustained low altitude spacecraft operations.

Agility will be monitored using spacecraft state-of-health telemetry data and flight-software-derived data including on-orbit location, velocity and attiude, and thruster operational data. The specific types of spacecraft data and decimation level will differ depending on the phase of the mission and spaceraft operations.

b) REMOTE SENSING

AMS Camera will provide improved remote sensing benefit by demonstrating the use of on-demand repeating ground track (RGT) orbits. For example, daily observation of widespread flood conditions is critical for disaster response. Figure 3.b.1 shows progression of river flooding conditions separated by several days with consistent illumination conditions. AMS mission analyses indicates that a maneuver over 2.25° longitude shift, can be accomplished in 9.7 days using 117 Ns total impulse. Such a maneuver equates to moiving a RGT orbit from over Boston MA to over New York NY. AMS has total of 5000 Ns total impulse, supporting many similar or larger on-demand RGT maneuvers.

Figure 3.b.1. Example of benefit of repeating ground track orbit used to monitor time-sensitive environmental condtions. Change in River Flood Conditions, Brazos River Texas (Courtesy NASA Earth Observatory).

AMS camera image frame data, together with camera control registers and camera telemetry will be stored onboard and downlinked. With camera operated in SDRAM mode, 15 image frames comprises 125 Mbytes which will require 255 sec to downlink.

c) BEACON

Adaptive optics compensates for atmospheric perturbations on a millisecond basis in order to achieve diffraction-limited imaging on large dish telescopes. The ADAPT experiment is a new adaptive optics technique to extend to an array of optical apertures. The ADAPT capability, if successful, may improve capabilities for laser communications and space debris removal applications by focusing light onto a fast-moving target with a large point-ahead angle.

The beacon payload supports the ADAPT experiment, which is an adaptive optics technique enabling increase in optical transmission through the atmosphere. Beacon transmitter power level data, received power level and beacon telemetry is stored onboard and downlinked. With beacon operated in active mode for 10 minutes, a telemetry message of 1.26 MBytes is generated which will require 2.5 sec to downlink.