Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
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Tyvak Nano-Satellite Systems Inc.	)	
	)	
Application for Authority for Ground	)	
Testing, Launch, and Operation of	)	File No. XXXX-EX-PL-2018
Experimental Non-Geostationary	)	
Low Earth Orbit Satellites	)	

NARRATIVE EXHIBIT

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NARRATIVE EXHIBIT

Tyvak Nano-Satellite Systems Inc. ("Tyvak") provides nano-satellite, micro-satellite, and CubeSat space vehicle products and services that target advanced state-of-the-art capabilities for government and commercial customers to support operationally and scientifically relevant missions. With this Application, Tyvak requests two-year authority for operation of an experimental non-geostationary ("NGSO") low earth orbit ("LEO") CubeSat satellite referred to as Tyvak-0085. The RF communications link for this satellite will be two-way telemetry monitoring and command ("T&C") transmissions in the 400 MHz UHF range and space-to-Earth downlink transmissions in the 8 GHz X-band range.

I. NARRATIVE INFORMATION REQUIRED BY FCC FORM 442

Question 6A. Description of the Nature of the Research Project Being Conducted

Through the Tyvak-0085 satellite, Tyvak validates the technologies needed to support the development of atmospheric sensors and methods for earth exploration satellite services ("EESS"). The program leverages the inherent relative low costs of CubeSat vehicle manufacture and launch capabilities to perform testing and demonstrations in real-world conditions, as well as flight training.

The satellite will adhere to a design specification co-developed by California State University, San Luis Obispo ("Cal Poly") and Stanford University ("Stanford") referred to as the CubeSat Standard. Additional information regarding the CubeSat Standard can be found at the CubeSat Community website, http://www.CubeSat.org/.

The spacecraft will be fabricated, tested, launched, and operated by Tyvak using its Mission Operations Center ("MOC") in Irvine, California, and using affiliated Earth stations in the Continental United States (CONUS) and internationally. T&C for the satellite will be carried out by Tyvak via a two-way link in the UHF band between 401-402 MHz. Additionally, there will be a payload communications capability that is separate from the T&C communications system to report data gathered on experimental operations. The payload communications system will downlink data from any test instruments to Tyvak-affiliated Earth stations using spectrum in the X-band between 8025-8400 MHz.

The Tyvak-0085 satellite was launched into orbit on January 2018 on a PSLV from Sriharikota, India. Tyvak-0085 is anticipated to be operated on-orbit for approximately 2 years. It is requested through the FCC that ground communication authority for the Tyvak-0085 satellite be granted for CONUS ground stations.

Question 6B. Showing that the Communications Facilities Requested are Necessary for the Research Project

The primary purpose of Tyvak's CubeSat program is to test and demonstrate new satellite capabilities or subsystems. On-orbit operation is the only effective way of collecting functional and performance data in the relevant operational environment, and cannot be adequately substituted by ground testing or computer simulation.

With the proliferation of the CubeSat Standard and the availability of low-cost space access for those adhering to that standard, the cost to test miniature components on-orbit has become relatively inexpensive compared to equivalent ground testing and simulation. This is largely due to the availability of low-cost secondary payload launch options and cost sharing among multiple CubeSat developers.

In addition, on-orbit data provides confidence to customers that future systems will operate successfully on-orbit through maneuvers. The evaluation of hardware and software in an environment similar to that found in space is not easily replicated on Earth. On-orbit component failures are often attributed to unforeseen conditions or coupling of effects that cannot be tested adequately until on-orbit. Consequently, the use of an on-orbit test bed provides significant direct and indirect financial benefits, as well as risk reduction for future satellite programs.

Question 6C. Showing that Existing Communications Facilities are Inadequate

The ground stations that would be used for operations are established for T&C operations within the 401-402 MHz UHF band.

For the payload downlink, the 8025-8400 MHz X-band was chosen because the satellite will be testing Earth sensing hardware and downlinking Earth sensing data. This spectrum band contains an allocation for EESS operations and is thus appropriate for Tyvak's program.

Question 10. Transmitting Equipment to be Installed, Including Manufacturer, Model Number and Whether the Equipment is Experimental in Nature

The CubeSat has capabilities for T&C and payload downlink. T&C on the spacecraft is carried out in the UHF band between 401-402 MHz. Payload downlink is carried out through an

X-band transmitter in the range of 8025-8400 MHz. The following graphic provides an overview of the transmitting and receiving components of each element. The specific model numbers are subject to change based on product availability and system upgrades.

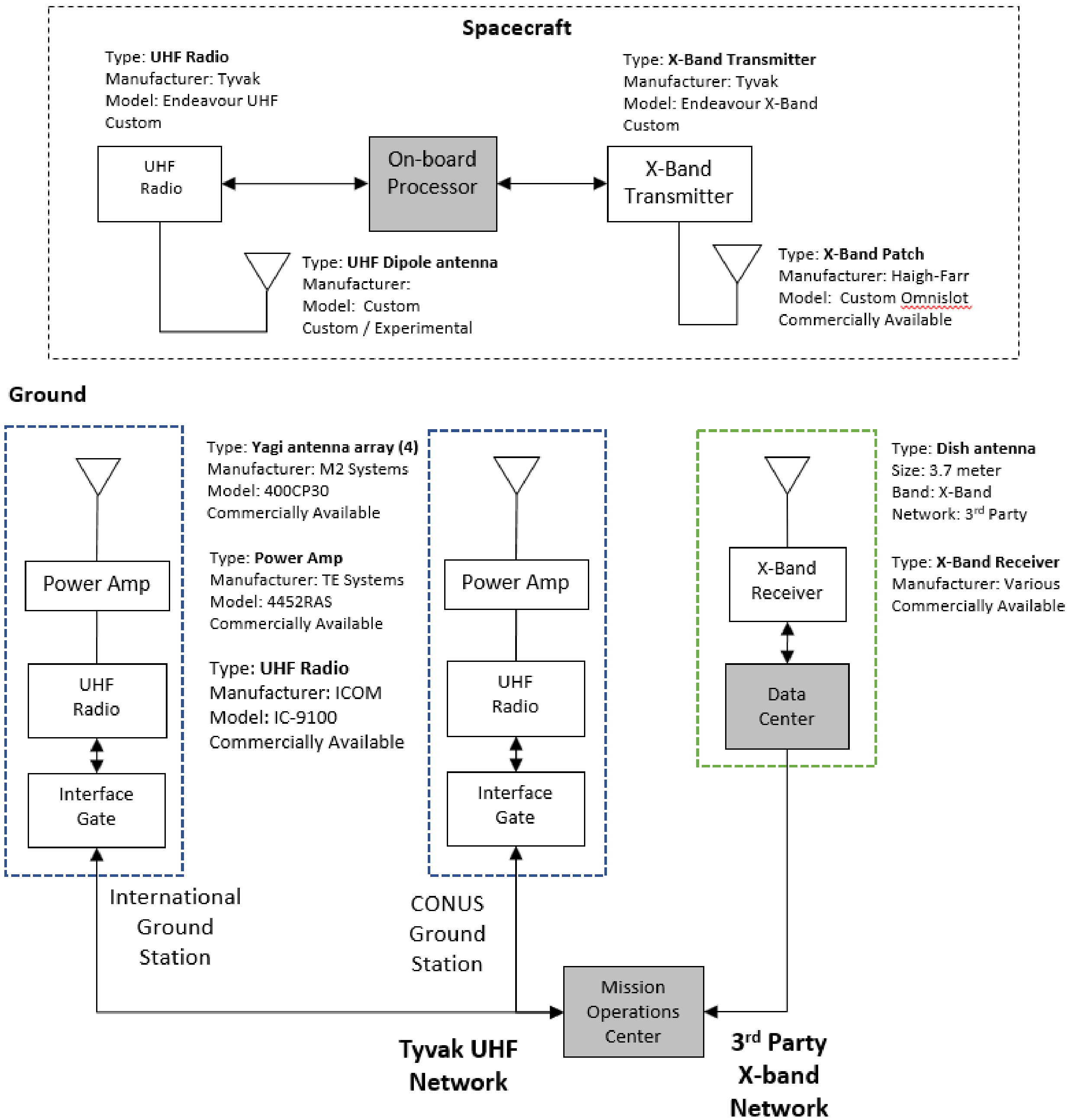

Figure 1: CubeSat System Communications Components

The transmitting components aboard the CubeSat are controlled by a dedicated on-board processor, which processes data for transmission, sends and receives data from the modem, and activates the appropriate radio systems depending on the state of operations. Tyvak-0085 possesses a UHF system for vehicle command and telemetry retrieval and an X-band system for payload data download.

The T&C communications system uses a Tyvak-developed UHF radio derived from commercially-available UHF communications systems. The radio operates at 19,200 baud using GMSK. The UHF system will use a custom designed half-wave dipole antenna.

The payload downlink X-band system utilizes a Tyvak-developed radio derived from commercially-available UHF communications system. X-Band transmissions are completed with blind downlinks and the vehicle does not transmit X-Band unless commanded by the ground to enable the ground station GPS location or via absolute time. A 2 Mbps BPSK data rate is supported between the X-Band patch antenna and a 3.7m dish on the ground with a transmit power of 2W.

Question 11A. Is the Equipment Listed in Item 10 Capable of Station Identification Pursuant to Section 5.115

Each transmitting component of the system is capable of station identification at the end of each complete transmission. The station identification process is incorporated into the mission operations procedure. The ground component will broadcast in clear voice the assigned call sign at the end of each data transmission by ground station operators.

Question 4: Antenna Registration Form; Operation of Directional Antenna

The Tyvak-0085 space vehicle is a low earth orbit ("LEO") satellite in a sun-synchronous orbit with an orbit period of approximately 1.56 hours.. The satellite will pass over the Earth station roughly one to twelve times per day depending on its location with an average access time of five to nine minutes for each Earth station location. The UHF Earth station will use a computer-controlled tracking antenna to point the Earth station's antenna in the direction of the moving satellite. The antenna has a maximum gain of +20.2dBi along the bore-sight of the antenna and a half-power beam-width (*i.e.*, -3dB) of approximately 30 degrees. The antenna array uses four off-the-shelf, Yagi-type antennae developed by M2 Antenna Systems, Inc.

Tyvak-0085 is an NGSO satellite. Thus, the range of antenna azimuth and elevation will vary based on the relative motion of the satellite with respect to the ground station, as well as differ for each satellite pass. The Earth station will transmit at the horizon or a 0-degree elevation angle. Consequently, the range of antenna elevation angles for all satellite passes will be between 0 and 180 degrees. The azimuth can vary between 0 degrees and 360 degrees.

II. RELEVANT INFORMATION ADDRESSED IN SECTION 25.114 OF THE COMMISSION'S RULES

Section 25.114(c)(4)(i) Radio Frequency Plan

UHF Communications System

The CubeSat's UHF communications system will operate using half-duplex communications within the 401-402 MHz frequency band for telecommand (*i.e.*, earth-to-space) and telemetry (*i.e.*, space-to-earth) communications. Tyvak-0085 is performing Earth Exploration technology demonstration and thus the use/categorization of the telecommand (*i.e.*, earth-to-space) communications as earth exploration satellite (earth-to-space) is justified in both the US and international allocation for the 401-402 MHz range. Tyvak-0085 is similarly utilizing UHF for standard vehicle T&C and thus the use/categorization of the telemetry (*i.e.*, space-to-earth) communications as space operation (space-to-earth) is justified in both the US and international allocation for the 401-402 MHz range. The space vehicle UHF communication system is half-duplex and, as such, the center frequency for both telecommand and telemetry are the same.

Space-to-Earth and Earth-to-Space UHF Communications

Tyvak-0085 has been designed to include several precautions to prevent harmful interference to other services from space-to-Earth transmissions. First, as noted above, space-to-Earth satellite transmissions will be controlled from the Earth station and the spacecraft will not transmit until it receives a request from the Earth station.

Second, the satellite uplink and downlink will use the same 28.8 kHz bandwidth in half-duplex mode to send digital data using standard GMSK modulation with maximum data rates up to 19,200 baud.

The satellite transmitter can be adjusted to provide up to two watts of power output when communicating with the Earth station. Transmission power on the Earth station transmitter can be adjusted to provide up to 200 watts of power output. The communications parameters for the UHF communications system for the space-to-Earth and Earth-to-space links are shown in the following table.

CubeSat Communications Parameters	**Value**
Emission Designator	28K8G1D
Service	Digital Data
Center Frequency	401.20 MHz
Requested Bandwidth (includes Doppler)	28.8 kHz
Modulation	GMSK
Data Rate	19,200 bps
Polarization	RHCP
Antenna Type	Dipole
Antenna Gain	0 dBi (Max)
RF Power Output	2W
Line/Misc Losses	-2dB
EIRP	1.0 dBW

Table 1: Tyvak CubeSat UHF Communications Space-to-Ground Parameters

Earth Station Communications Parameters	Value
Emission Designator	28K8G1D
Service	Digital Data
Center Frequency	401.20 MHz
Requested Bandwidth (includes Doppler)	28.8 kHz
Modulation	GMSK
Data Rate	19,200 bps
Polarization	RHCP or LHCP
Antenna Type	Yagi array
Antenna Gain	+20.2 dBi (Max)
RF Power Output	200 W
Line Losses	-3dB
EIRP	40.2 dBW

Table 2: Tyvak Earth Station UHF Communications Parameters

Earth Station	Frequency Range	Geographic Coordinates
San Diego, CA, USA	UHF	32.897°Lat, -117.201°Long
Bardufoss, Norway	UHF	69.05°Lat, 18.48°Long
Benevento, Italy	UHF	41.115°Lat, 14.826°Long
Dead Horse, AK, USA	UHF	70.21°Lat, -148.41°Long

Table 3: Tyvak Earth Stations UHF

X-Band Communications System

The CubeSat's X-band communications system will operate using simplex communications within the 8025-8400 MHz frequency band to downlink recorded payload data to Tyvak-affiliated X-band Earth stations. The Tyvak Irvine MOC will execute commands that are then uplinked through Tyvak-affiliated UHF stations to trigger the satellite to transmit payload data in the X-band when over an X-Band Earth station.

CubeSat Communications Parameters	**Value**
Emission Designator	1M50G1D
Service	Digital Data
Band	8025-8400 MHz
Requested Bandwidth	1.5MHz
Modulation	BPSK
Data Rate	10 Mbps
Polarization	RHCP
Antenna Type	Patch
Antenna Gain	+6 dBic (Max)
RF Power Output	2W
Line Losses	-2dB
EIRP	4 dBW

Table 4: Tyvak CubeSat X-Band Communications Parameters

Earth Station	**Frequency Range**	**Geographic Coordinates**
Svalbard, Norway	X-Band	78.23°Lat, 15.39°Long
Mauritius,	X-Band	-20.17°Lat, 57.52°Long

Table 5: Tyvak Earth Stations X-Band

The CubeSat will communicate with the UHF ground stations and X-band ground stations only when it is within line-of-sight of the Earth stations and has received a communication from the Earth station directing the spacecraft to initiate transmissions. As such, the spacecrafts will utilize the 401-402 MHz and 8025-8400 MHz band only when in contact with specified Earth stations. Potentially conflicting uses of the band in other regions of the world are not relevant to this application.

Spectrum Sharing and Interference Mitigation Techniques

The X-band communications system employs multiple design considerations that make it highly unlikely that harmful interference could result to any other satellite network. These include low-altitude, near-polar orbits and the use of short-duration, narrow bandwidth transmissions.

Sharing With Low Earth Orbit Satellite Networks: The Tyvak network is highly unlikely to cause unacceptable interference to other low-altitude satellite networks. First, transmissions from Tyvak spacecraft will be infrequent and of short duration, triggered only by affirmative command from the Tyvak MOC. Second, conjunction events in which a Tyvak satellite and another low-altitude satellite are relatively close to each other will occur very infrequently. When such rare conjunction events do occur, there will still be no potential for interference unless both satellite systems are transmitting at the same time, which would only happen when a Tyvak-affiliated earth station is in close geographic proximity to the earth station of another network. Given the international allocation for EESS across the entire 8025-8400 MHz band, other NGSO satellites operating in proximity to any Tyvak satellites are highly likely to follow similar interference mitigation procedures as those outlined above, resulting in high confidence that Tyvak operations will not cause unacceptable interference to other low-altitude satellite networks.

Sharing With Geostationary Satellite Networks: The Tyvak network is highly unlikely to cause unacceptable interference with geostationary ("GSO") or other high-altitude satellite networks. The 8025-8400 MHz band is not significantly used by GSO satellite networks. Further, the Tyvak network will utilize the 8025-8400 MHz band only in the space-to-Earth direction, preventing any potential interference toward the geostationary arc. With respect to space-to-Earth transmissions from GSO spacecraft using the 8025-8400 MHz band, these will be protected from harmful interference from the Tyvak satellite transmissions in the same manner as Tyvak will protect space-to-Earth transmissions from low Earth orbit NGSO networks, as discussed above.

Sharing With Fixed Service Networks: The Tyvak network operates in compliance with the ITU power limits specified to protect the Fixed Service operating in the 8025-8400 MHz band. Table 21-4 of ITU Radio Regulation number 21.16 specifies the following PFD limits at the

Earth's surface for emissions from EESS space stations operating in the 8025-8400 MHz band for all conditions and for all methods of modulation.

Frequency band	**Service***	**Limit in dB(W/m^2) for angles of arrival (δ) above the horizontal plane**			**Reference bandwidth**
		0°-5°	**5°-25°**	**25°-90°**	
8 025- 8 500 MHz	Earth exploration-satellite (space-to-Earth)	−150	$-150 + 0.5(\delta - 5)$	−140	4 kHz

When calculated at the minimum anticipated operating orbital altitude for the Tyvak Cubesat of 450 kilometers, the PFD levels at the Earth's surface produced by the Tyvak satellite data and telemetry downlink transmissions will comply with these limits.

Section 25.114(c)(5)(i) Orbital Locations

Tyvak-0085 is planned to operate in LEO with the orbit parameters shown in Table 6. Each satellite will have an orbit period of roughly 1.56 hours with typical ground access times of five to ten minutes per pass. The orbit parameters are presented in the following table:

Parameter	**Units**	**Value**
Orbit Period	hrs	1.56 hrs
Orbit Altitude	km	504 km (circular)
Inclination	deg	97.56 degrees

Table 6: CubeSat Orbit Parameters

Section 25.114(c)(10) Physical Characteristics of Satellites

The space vehicle is a nano-class satellite (< 10 kg), in which each element conforms to the CubeSat Standard. CubeSats can be designed in different sizes as long as they are multiples of the basic CubeSat standard unit, which is 10×10×10 centimeters, generally referred to as a 1U CubeSat, meaning one unit in size. The space vehicles is 6U in size, which means each CubeSat will have the dimensions of approximately 30×20×10 centimeters or 30 x 20 x 10cm. The CubeSat dispenser limits the total vehicle mass of a 6U CubeSat to less than 11 kg respectively. The vehicle has been designed primarily as a single-string system using commercial off-the-shelf parts with a mission lifetime of approximately two years on-orbit. The mass budget is provided in the following table:

Component / Subsystem	**Mass [g] 6U**
Payload	3000
Spacecraft (Subtotal)	7200
Structure	2600
Electrical Power System	1500
ADCS	700
C&DH	300
Communication	2000
Thermal	100
TOTAL	10200

Table 8: Spacecraft Mass Budget per Element

For power generation, Tyvak-0085 is equipped with body-mounted and deployed GaAs solar cells that generate approximately 21 watts of power during a typical orbit. Because of the short operational lifetime of the satellite (*i.e.*, approximately two years), the difference between the beginning-of-life ("BOL") and end-of-life ("EOL") power generation is negligible. To permit operations during eclipse, energy is stored on-board using Li-ion batteries, with power being distributed to subsystems and components through the electrical power subsystem circuitry. The EOL power budget is provided in the following table:

Component / Subsystem	**EOL Power [mW] Orbit Averaged (6U)**
Payload	8500
Spacecraft (Subtotal)	10000
Propulsion System	140
ADCS	5000
C&DH	600
Communication	5500

Thermal	400
TOTAL	20500

Table 9: Power Budget per Space Vehicle

Section 25.114(c)(12) Schedule

Tyvak-0085 will be launched in accordance with the following schedule.

Milestone	Date	Notes
Launch	January 12, 2018	ToL + 0
Release from launch adapter	January 2018	ToL + 0hr 30min
On-orbit check	January 2018	ToL + 24 hours
Start of experiments	February 2018	ToL + 4 weeks
Decommissioning	January 2020	ToL + 24 months
Re-entry	January 2022	ToL + 4 years

Table 10: Major Milestones

Section 25.114(d)(1) General Description of Overall System Facilities, Operations and Services

The Tyvak-0085 space vehicle provides a platform for on-orbit testing of advanced maneuvering, remote sensing, and sensor technologies. The onboard systems provide nominal attitude, electrical power, data storage, and command functionality for a mission payload. The space vehicle communicates with the Earth stations through a low-rate (19.2 kbps) half-duplex communications link operating in the UHF band.

The CubeSat mission will be supported by a UHF Earth station at the Irvine MOC and several additional Earth stations operated by Tyvak affiliates at sites in Deadhorse, Alaska; Bardufoss, Norway; Benevento, Italy; and San Diego, California. X-band Earth stations will be located in Svalbard, Norway; and Mauritius. The X-band Earth stations will be operated under contract by third-party X-band network providers.

The primary responsibilities of the Irvine MOC will be to command the space vehicle to initiate the experiments, recover spacecraft engineering telemetry, and manage the function of the spacecraft. The Earth station equipment comprises a UHF yagi antenna array and UHF transceiver. The MOC will also have vehicle control workstations and a mission data archive server.[1]

Section 25.114(d)(3) Predicted Spacecraft Antenna Gain Contours

The spacecraft UHF antenna is a half wavelength L-dipole antenna, which is essentially omni-directional when mounted on the corner of a CubeSat structure. A simulation of the antenna design is shown in Figure 3.

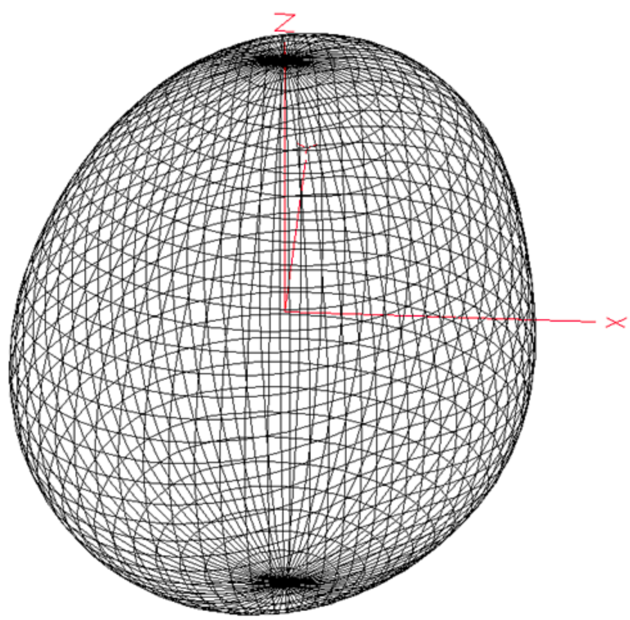

Figure 3: L-Dipole UHF Antenna Gain Plot

[1] T&C data will be received directly from the spacecraft via UHF link; payload data will be downlinked via X-band to third-party Earth stations.

The spacecraft X-band antenna is a microstrip patch antenna possessing a maximum gain perpendicular to the surface normal to the patch. A generalized antenna gain contour plot is provided below representing the X-band patch.

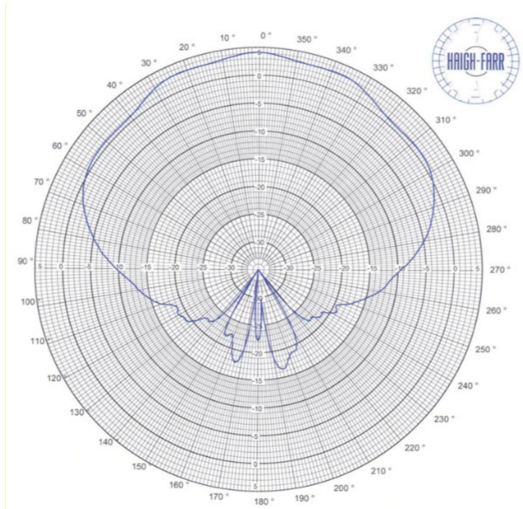

Figure 4: X-band Antenna Gain Plot

Section 25.114(d)(14) Orbital Debris Mitigation

The CubeSat spacecraft will mitigate orbital debris by the following means:

Section 25.114(d)(14)(i) Limiting the amount of debris released during normal operations and the probability of the satellite becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal

In order to limit the amount of debris generated during normal operations, the CubeSat has been designed so that all parts will remain attached to the satellite during launch, ejection, and normal operations. This requirement is intrinsic to all satellites conforming to the CubeSat Standard and compliance is required for launch using the Poly-Picosatellite Orbital Deployer ("P-POD") system.

The basic geometry of the satellite is a monolithic cubic structure (*i.e.*, 30cm x 10cm x 10cm) with two pairs of 30cm x 10cm deployable panels. Based on an orbital debris model (ref. NASA DAS v2.0.2), the probability of a single particle impact with a size of 1 millimeter or larger over the mission lifetime is very low (*i.e.*, roughly 1.3 x 10^{-3}). This low probability of impact for the mission is a result of the small effective area of the space vehicle (*i.e.*, effective area ~ 0.117 m^2) and the relatively short mission duration (*i.e.*, mission life less than one year).

Catastrophic system failure due to orbital debris or micrometeoroid impact will not affect the vehicle's ability to de-orbit within the guidelines for vehicles operating in LEO (*i.e.*, less than 25 years). Based on the mission orbits of 500~505 km, the space vehicle is anticipated to re-enter the atmosphere within 4 years based on lifetime prediction simulations for the current mission epoch.

Section 25.114(d)(14)(ii) Limiting the probability of accidental explosions during and after completion of the mission operations

The vehicle possesses energy storage devices (*i.e.*, Li-ion batteries), which will be left in a nearly discharged state as part of the decommissioning procedure.

Section 25.114(d)(14)(iii) Limiting the probability of the satellite becoming a source of debris by collisions with large debris or other operational space stations

Based on a simple orbital debris model (ref. NASA DAS v2.0.2), the probability of the CubeSat colliding with large debris or other space systems of sizes one centimeter or greater at the mission orbit altitude and inclination is negligible (*i.e.*, roughly $4x10^{-6}$).

The launch provider has instituted deployment procedures in order to place the co-manifested satellites in the launch vehicle into slightly different orbits in order to reduce the risk of collision. One of these procedures is to stagger deployment times.

Section 25.114(d)(14)(iv) Post-mission disposal plans for the space station at end of life

The post-mission disposal plan for the CubeSats includes the transition of all vehicle systems to a dormant state, which includes the cessation of all radio operations (*i.e.*, transmit and receive). Energy storage devices will be held at a minimal charge state at the end of the life of the vehicles. Anticipated atmospheric re-entry of the satellite is within 2 years of mission completion based on the mission orbit, vehicle mass, geometry and mission epoch (*i.e.*, launch in CY2018). No active de-orbit maneuvers are required to meet the 25-year re-entry guidelines.

Re-entry debris and probability of human casualty will be negligible. The materials used on the vehicle include aluminum and PCB material, which have a relatively low melting temperature as compared to other materials such as Ti or stainless steel, and are not expected to survive reentry.

III. CONCLUSION

The Experimental Licensing Branch should grant Tyvak's application for standard two-year experimental authority to launch and operate the Tyvak-0085 NGSO LEO satellite, which will permit Tyvak to demonstrate and evaluate advanced operations and systems for government and non-government customers, adding valuable on-orbit performance data for future CubeSat Standard satellites. Tyvak's operation will not cause harmful interference to any licensed service. Tyvak will operate using the 401-402 MHz UHF band and the 8025-8400 MHz portion of the X-band allocated for EESS operations. Further, the Tyvak operation will meet the Commission's orbital debris mitigation requirements. Therefore, Tyvak's application should be granted at the soonest practicable time.