Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Tyvak Nano-Satellite Systems Inc.	)	
	)	
Application for Authority for Ground	)	
Testing, Launch, and Operation of an	)	File No. ____-EX-PL-2016
Experimental Non-Geostationary	)	
Low Earth Orbit Satellite	)	

NARRATIVE EXHIBIT

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NARRATIVE EXHIBIT

Tyvak Nano-Satellite Systems Inc. ("Tyvak") uses nano-satellite and CubeSat space vehicles to conduct tests of satellite components and for other scientific purposes. With this Application, Tyvak requests two-year authority for ground testing, launch, and operation of a single experimental non-geostationary ("NGSO") low earth orbit ("LEO") CubeSat satellite. The RF communications links for the satellite will be two-way telemetry monitoring, tracking, and command ("TT&C") transmissions and payload data download in the 400 MHz UHF[1] range.

I. NARRATIVE INFORMATION REQUIRED BY FCC FORM 442

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

Tyvak proposes to use a single CubeSat to validate the development of atmospheric sensors and methods, including taking periodic passive magnetometer readings, using the Earth's magnetic field for active vehicle torqueing, and demonstrating a passive Radio Occultation ("RO") GPS instrument to collect atmospheric data. The satellite will adhere to a

[1] Tyvak has previously received experimental authorization for similar CubeSats. ELS File No. 0194-EX-PL-2014, Call Sign WH2XDU (Granted Oct. 31, 2014).

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 satellite will be fabricated, tested, launched, and operated by Tyvak using its Mission Operations Center ("MOC") in Irvine, California. TT&C for the satellite will be carried out by Tyvak via a two-way link in the UHF band between 399.9-400.05 MHz.

Prior to launch, Tyvak will conduct developmental testing of satellite components, including its transmitters and receivers, at its Irvine, California facilities. Post launch, the satellite on-orbit operations are expected to take 9 to 12 months, which will permit adequate time to demonstrate the systems under investigation.

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

The primary purpose of the program is to perform an in orbit test of a Radio Occultation ("RO") GPS instrument. 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.

In addition, on-orbit data provides validation that future systems will operate successfully on-orbit. 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 risk reduction for future satellite programs.

Question 6C. Showing that Existing Communications Facilities are Inadequate

Currently, there are no comparable communications facilities to support the operation of the CubeSat system for any of the required operations.

For the TT&C communications link in the 399.9-400.05 MHz UHF band, as discussed in a later section of this Application, Tyvak is unaware of any currently authorized use of the UHF band between 399.9-400.05 MHz in the United States or other countries other than those currently affiliated with Tyvak. Thus, there are no suitable existing facilities.

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

The satellite has capabilities only for UHF TT&C and payload downlink. Both TT&C and payload downlink are carried out in the UHF band between 399.9-400.05 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.

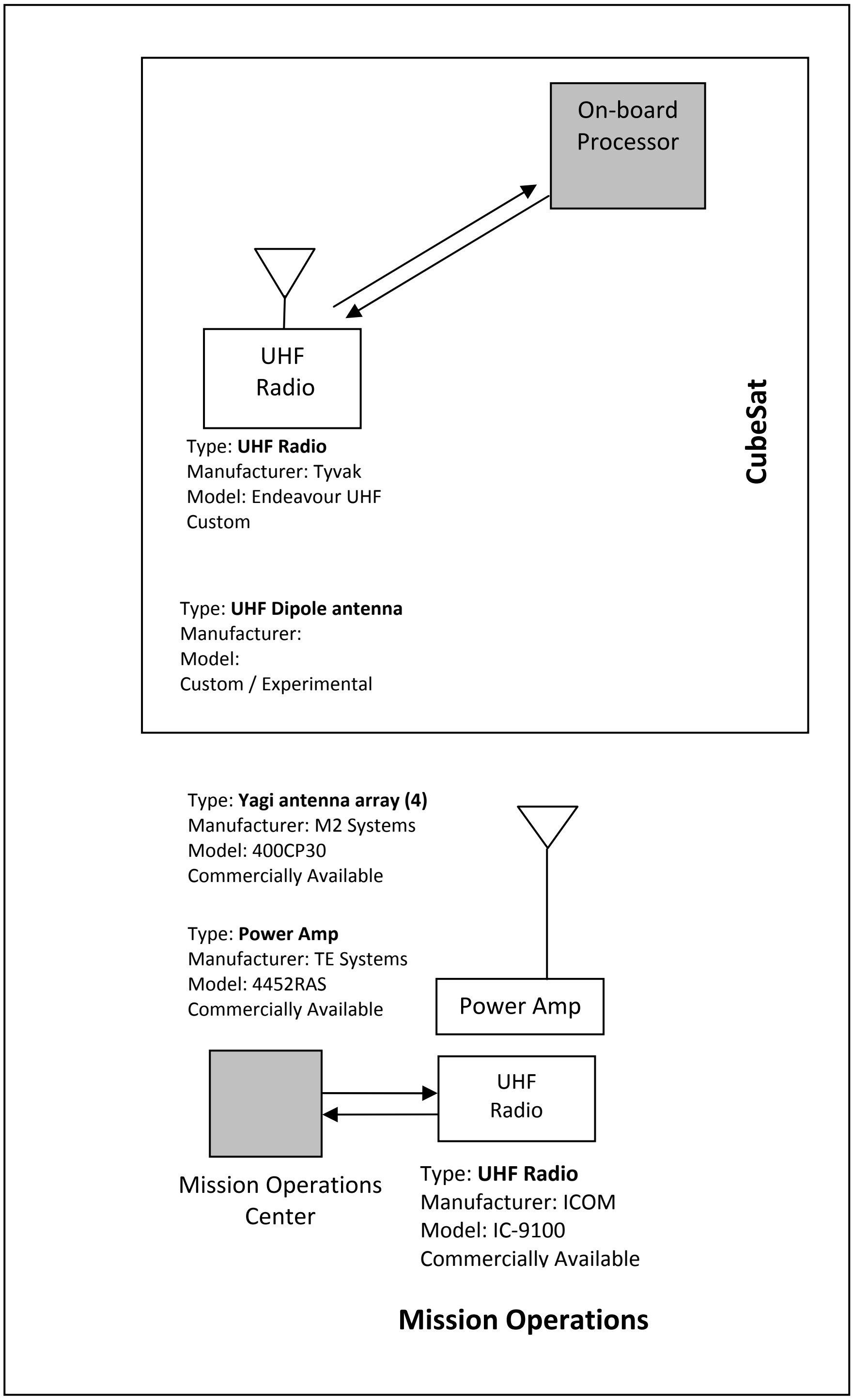

Figure 1: CubeSat System Communications Components

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

The TT&C communications system uses a Tyvak-developed UHF radio derived from commercially-available UHF communications systems. The radio operates at 9,600 baud using GMSK. The UHF system will use a custom designed half-wave dipole antenna.

The TT&C ground segment can address the satellite individually through the use of spacecraft-specific message destination addresses, authentication counts, and/or encryption keys using the same frequency allocation. The transmitting component located at the Irvine Earth station is controlled by dedicated Microsoft Windows workstations. The workstations are used for antenna pointing control, Doppler frequency shift corrections, and data processing for transmission. The antenna (manufacturer/model: M2 Antenna Systems, Inc./400CP30) and radio (manufacturer/model: ICOM/IC-9100) are commercially available, off-the-shelf units, which will be modified with additional hardware to function at the requested frequencies.

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 space component will transmit the call sign in every packet transmitted as part of its frame header. The frame header is not encoded or encrypted.

Question 4: Antenna Registration Form; Operation of Directional Antenna

The satellite is a low earth orbit ("LEO") spacecraft in a sun-synchronous orbital with an orbit period of approximately 1.6 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 seven 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.

Due to the satellite's NGSO orbit, the range of antenna azimuth and elevation will vary based on the relative motion of the satellite with respect to the ground station. It will also differ for each satellite pass. The Earth station will only transmit above a 10 degree elevation angle. Consequently, the range of antenna elevation angles for all satellite passes will be between 10 and 170 degrees. The azimuth can vary between 0 degrees and 360 degrees. Earth station software will be used to control the antenna azimuth and elevation rotors for antenna pointing and limit the range of permissible elevation angles. In addition, the software will be used to predict satellite contact times and antenna pointing angles to support Earth station planning and operations.

In addition to on-orbit operations, the satellite components will undergo occasional ground tests up until launch. Testing for the UHF TT&C link will be conducted in carrier current (*i.e.*, closed-loop) configuration and will not produce any measurable emissions.

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

A. Radio Frequency Plan

UHF Communications System

The CubeSat's UHF communications system will operate using half-duplex communications within the 399.9-400.05 MHz frequency band for telecommand (*i.e.*, earth-to-space) and telemetry (*i.e.*, space-to-earth) communications. Although the CubeSat requires only 50 kHz of spectrum bandwidth, Tyvak requests herein authority to operate within the entire 399.9-400.05 MHz frequency band for the mission to facilitate design flexibility.

The following diagram shows the proposed spectrum use of the CubeSat and ground stations and also shows authorized spectrum uses in adjacent bands, such as the use by the Orbcomm Little LEO MSS network of the 400.075-400.125 MHz band as a beacon frequency. As explained below, the 399.9-400.05 MHz frequency band does not appear to be used by any authorized government or non-government operator in the United States. Tyvak acknowledges that the Commission has authorized operation of a federal Mobile Satellite System in the 399.99-400.05 MHz portion of this fallow band, however, any Tyvak transmissions related to this mission will be completed well before any Federal operations in the band commence.[2] Therefore, Tyvak's proposed operation of its experimental satellite in 50 kHz of the 399.9-400.05 MHz frequency band will not cause harmful interference to any authorized spectrum user.

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[2] *See Federal Space Station Use of the 399.0-400.05 MHz Band*, *ET Docket No. 13-115*, Notice of Proposed Rulemaking, FCC 13-65, ¶ 63 (2013).

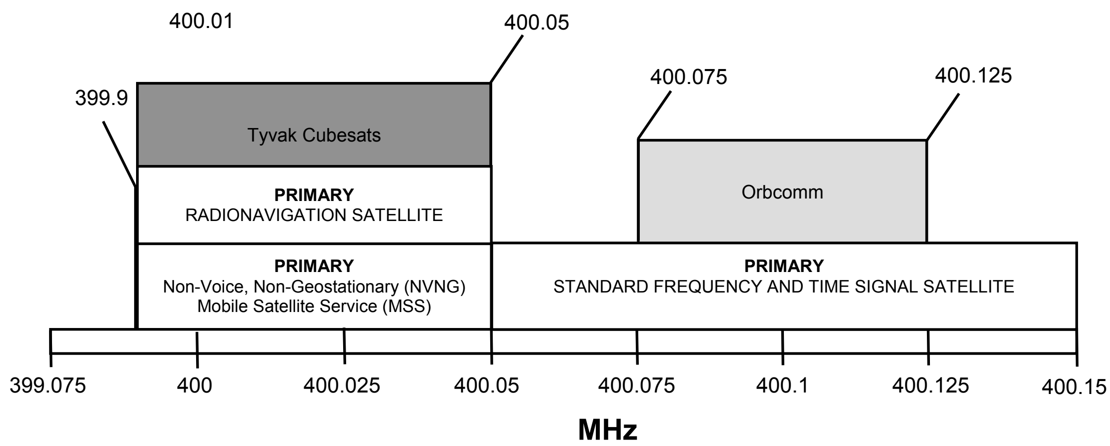

Figure 2: CubeSat Spectrum Diagram **(UHF)**

The 399.9-400.05 MHz frequency band is allocated internationally on a primary basis to the Mobile Satellite Service ("MSS") (earth-to-space). The 399.9-400.05 MHz frequency band is also allocated internationally on a primary basis to the Radionavigation Satellite Service ("RNSS") until January 1, 2015.[3] In the United States, the 399.9-400.05 MHz frequency band is allocated to the MSS and RNSS services for both government and non-government use.

During the 1995 World Radiocommunication Conference ("WRC-95"), the International Telecommunication Union ("ITU") allocated the 399.9-400.05 MHz band for the Little LEO MSS service. The Commission subsequently designated the 399.9-400.05 MHz band as available for use by Little LEO MSS networks.[4] None of the applicants for Little LEO MSS licenses in the United States, however, requested authority to operate in the 399.9-400.05 MHz

[3] *See* 47 C.F.R. § 2.106 n.5.224B.

[4] *See Amendment of Section 2.106 of the Commission's Rules to Allocate Spectrum to the Fixed-Satellite Service and the Mobile-Satellite Service for Low-Earth Orbit Satellites*, Report and Order, 8 FCC Rcd 1812 (1993); 47 C.F.R. §§ 2.106 n.US320 & 25.202(a)(3). Although the Commission originally included the 399.9-400.05 MHz band in footnote US320, reference to the 399.9-400.05 MHz band was inadvertently deleted from US320 during a Commission effort to consolidate footnotes. The Commission corrected the error, reincorporating the reference to the 399.9-400.05 MHz band in footnote US320. *See Amendment of Parts 2, 25, and 73 of the Commission's Rules to Implement Decisions from the World Radiocommunication Conference (Geneva, 2003) (WRC-03) Concerning Frequency Bands Between 5900 kHz and 27.5 GHz and to Otherwise Update the Rules in this Frequency Range*, Report and Order, 20 FCC Rcd 6570, 6625 (2005).

band.[5] Therefore, the Commission refrained from adopting service rules for Little LEO MSS networks operating in the 399.9-400.05 MHz band and did not issue any licenses to Little LEO MSS networks authorizing them to operate in the band.[6] Tyvak is unaware of any Little LEO MSS network operating anywhere in the world (and particularly not in the United States) that uses the 399.9-400.05 MHz band.

The 399.9-400.05 MHz frequency band is also allocated internationally on a primary basis to RNSS until January 1, 2015. The 399.9-400.05 MHz frequency band was previously used by the U.S. Department of Defense for its TRANSIT-SAT RNSS system, which was a polar orbiting satellite network that was primarily used for commercial and government maritime navigation. The TRANSIT-SAT network, however, was decommissioned in December 1996.[7]

It does not appear that the United States government or commercial operators are using the 399.9-400.05 MHz frequency band for any other RNSS service. As a consequence, the 399.9-400.05 MHz frequency band appears to be fallow of any authorized use in the United States. Therefore, the short term operation of Tyvak's experimental CubeSats will not result in harmful interference to any authorized spectrum user.

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

Despite the absence of any authorized spectrum users in the 399.9-400.05 MHz band, the satellite's communications system has been designed to include several precautions to prevent harmful interference to other services from space-to-Earth transmissions. First, as noted above,

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[5] *See Amendment of Part 25 of the Commission's Rules to Establish Rules and Policies Pertaining to the Second Processing Round of the Non-Voice, Non-Geostationary Mobile Satellite Service*, Report and Order, 13 FCC Rcd 9111, 9120-21 (1997).

[6] *See id.* at 9121.

[7] *See Federal Long-Range Spectrum Plan,* Working Group 7 of the NTIA Spectrum Planning Subcommittee (Sept. 2000), available at http://www.ntia.doc.gov/osmhome/LRSP/LRSP5a.htm.

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 or has on-board GPS confirmation that it is above the designated ground station.

Second, the satellite uplink and downlink will use the same 50 kHz bandwidth in half-duplex mode to send digital data using standard GMSK modulation with maximum data rates up to 9,600 baud. The spacecraft transceiver uses a packet-based (non-continuous) communications, which allows command reception between transmissions of packets to provide the ability to command the satellite to cease space-to-Earth transmission operations in a timely manner, if required.

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 tables.

CubeSat Communications Parameters	**Value**
Emission Designator	40K9G1D
Service	Digital Data
Center Frequency	400.03 MHz
Requested Bandwidth (includes Doppler)	50 kHz
Modulation	GMSK
Data Rate	9,600 bps
Polarization	Linear
Antenna Type	Dipole
Antenna Gain	+2 dBi (Max)
RF Power Output	2W
Line/Misc Losses	-2dB
EIRP	1.0 dBW

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

Earth Station Communications Parameters	Value
Emission Designator	40K9G1D
Service	Digital Data
Center Frequency	400.03 MHz
Requested Bandwidth (includes Doppler)	50 kHz
Modulation	GMSK
Data Rate	9,600 bps
Polarization	Linear (H, V) or Circular
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 Ground-to-Space Communications Parameters

B. Orbital Locations

The spacecraft will operate in LEO with the orbit parameters shown in Table 3, with an orbit period of roughly 1.6 hours and typical ground access times of five to seven minutes per pass.

Parameter	Units	Value
Orbit Period	hrs	1.6 hrs
Orbit Altitude	km	610 km (circular)
Inclination	deg	97.8 degrees

Table 3: CubeSat Orbit Parameters

C. Physical Characteristics of Satellite

The satellite 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. This satellite is 6U in size, meaning that it will have the dimensions of approximately 30 x 20 x 10 centimeters. The CubeSat dispenser limits the total vehicle mass of a 6U CubeSat to less than 10kg respectively. The mass budget is identical for each satellite and is provided in the following table:

Component / Subsystem	Mass [g] 6U
Payload	5000
Spacecraft (Subtotal)	4700
Structure	1100
Electrical Power System	2000
ADCS	400
C&DH	100
Communication	1000
Thermal	100
TOTAL	7300

Table 4: CubeSat Mass Budget per Element

For power generation, the satellite is equipped with body-mounted GaAs solar cells that generate approximately 16 watts of power during a typical orbit. Because of the short operational lifetime of the satellite (*i.e.*, less than a year), 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. For operations, the Payload is only powered for a portion of the total orbit. The EOL power budget is provided in the following table:

Component / Subsystem	EOL Power [mW] Orbit Averaged (6U)
Payload	8500
Spacecraft (Subtotal)	11500
ADCS	5000
C&DH	600
Communication	5500
Thermal	400
TOTAL	20000

Table 5: CubeSat Power Budget

D. Estimated Operational Lifetime

The project timeline and major milestones for the launch and operation of the spacecraft are provided in the following table. The dates are approximate and contingent upon the exact launch date ("Time of Launch" or "ToL"), orbit parameters, and unforeseen events during on-orbit operations.

Milestone	Date	Notes
Delivery for Launch Integration	Jun 2016	ToL - 3 months
Pre-launch testing of transmitting components	July 2016	ToL - 2 months
Launch	Sept 2016	ToL + 0
Release from launch adapter	Sept 2016	ToL + 0hr 30min
On-orbit check	Sept 2016	ToL + 24 hours
Start of experiments	October 2016	ToL + 4 weeks
Decommissioning	Sept 2017	ToL + 12 months
Re-entry	June 2037	ToL + 20.8 year

Table 6: CubeSat System Major Milestones

E. General Description of Overall System Facilities, Operations and Services

The CubeSat provides a platform for on-orbit testing of advanced 3-axis control software and hardware, sensor technologies, and RO GPS collection system. The systems onboard the satellite provide nominal attitude, electrical power, data storage, and command function for the RO GPS payload. The satellite communicates with the Earth stations through a low-rate (9.6 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 an additional Earth stations operated by Tyvak in Tromsø, Norway. The Tromsø location is identical to the Irvine MOC location in terms of hardware configuration and operation. The

Tromsø location is operated by the Irvine MOC and will not store any TT&C or payload data locally.

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.[8] The workstations will serve as the primary interface with the ground controllers and will be used for data processing, antenna/radio control, and engineering analysis. The mission data archive server will archive command and telemetry data to support mission operations, status, troubleshooting, and post-mission assessment.

F. 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.

[8] TT&C data and payload data will be received directly from the spacecraft via UHF link and securely transmitted to the MOC via a VPN over the Internet.

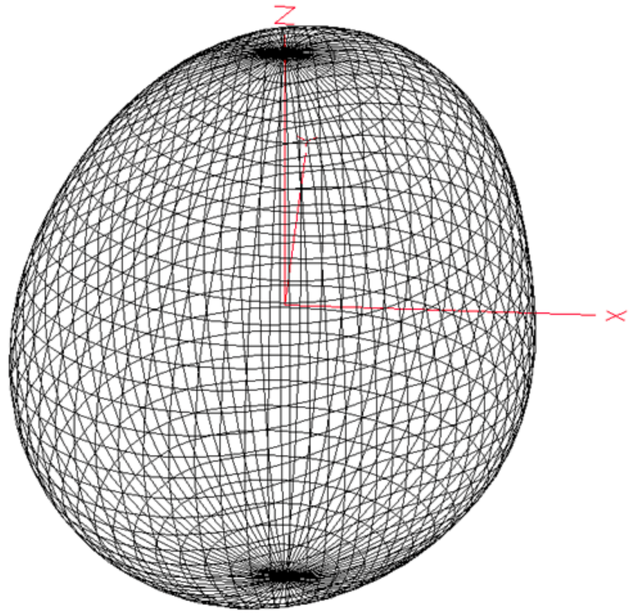

Figure 3: CubeSat L-Dipole UHF Antenna Gain Plot

G. Orbital Debris Mitigation

The CubeSat spacecraft will mitigate orbital debris by the following means. An Orbital Debris Assessment Report ("ODAR") / End of Mission Plan ("EOMP") for the spacecraft is provided as an attachment to this application.

1. *Limiting the amount of debris released and the probability of the satellite becoming a source of debris by collisions with small debris*

In order to limit the amount of debris generated during normal operations, the satellite 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 each satellite is a monolithic cubic structure (*i.e.*, 30cm x 20cm x 10cm). Based on an orbital debris model (ref. NASA DAS v2), 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 ~ 0.07684 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 orbit of 610 km, the space vehicle is anticipated to re-enter the atmosphere within 20.75 year based on lifetime prediction simulations for the current mission epoch (*i.e.*, launch in Q32016).

2. *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.

3. *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), 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.

4. *Post-mission disposal plans for the space station at end of life*

The post-mission disposal plan for the CubeSat 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 vehicle. Anticipated atmospheric re-entry of the satellite is within 20.75 years of mission completion based on its mission orbit, vehicle mass, geometry and mission epoch (*i.e.*, launch in Q32016). 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 two-year experimental authority to launch and operate the proposed NGSO LEO satellite, which will permit Tyvak to test and validate a Radio Occultation ("RO") GPS instrument. Tyvak's experiment will not cause harmful interference to any licensed service. Tyvak will conduct its experiment using the vacant 399.9-400.05 MHz UHF band. 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.