

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) File No. ____-EX-PL-2015
Experimental Non-Geostationary)
Low Earth Orbit Satellites)

NARRATIVE EXHIBIT

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Tyvak Nano-Satellite Systems Inc. (“Tyvak”) provides nano-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 five-year authority for ground testing, launch, and operation of several experimental non-geostationary (“NGSO”) low earth orbit (“LEO”) CubeSat satellites. Tyvak’s program will include a series of identical satellites, including operating up to six CubeSats at one time. The RF communications links for these satellites will be two-way telemetry monitoring, tracking, and command (“TT&C”) transmissions in the 400 MHz UHF range and space-to-Earth downlink transmissions in the 8 GHz X-band.¹

¹ Tyvak has previously received experimental authorization for similar CubeSats without the X-band downlink capability. ELS File No. 0194-EX-PL-2014, Call Sign WH2XDU (Granted Oct. 31, 2014). This application is for a series of substantially similar satellites utilizing X-band transmitters.

I. NARRATIVE INFORMATION REQUIRED BY FCC FORM 442

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

Through its CubeSat program, Tyvak validates the technologies needed to support spacecraft rendezvous, proximity operations, docking (“RPOD”), servicing, formation flight, and 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. Throughout the course of its experimental program, Tyvak may develop and launch approximately a dozen individual CubeSats, with up to six in operation at one time.

The satellites 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 other locations. TT&C for the satellites will be carried out by Tyvak via a two-way link in the UHF band between 399.9-400.05 MHz. Additionally, there will be a payload communications capability that is separate from the TT&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.

Prior to launch, Tyvak will conduct developmental testing of satellite components, including its transmitters and receivers, at its Irvine, California facilities. Post launch, the satellites are intended to be short-lived, with an expected lifespan of 9 to 12 months on-orbit, 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 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

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.

For the payload downlink, the 8025-8400 MHz X-band was chosen because many of the satellites 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 8. Justification of the Need for a Five-Year Experimental License Term

Under Section 5.71 of the Commission's rules, the regular license period for stations in the Experimental Radio Service is either two or five years.² An applicant desiring to apply for a five-year license must provide justification for its need for a license of that duration.

Grant of a full five year experimental license is well justified by the long timeline and significant potential for delays and schedule changes inherent in space operations. As illustrated in Table 10, below, the CubeSat System Major Milestones require that experimental authorization be secured prior to fabrication and RF testing that begins more than nineteen months before launch, and experimental authorization must extend through on-orbit experimental operations and decommission, at least nine months after launch. Indeed, frequency

² 47 C.F.R. § 5.71.

authorization must be secured before equipment specifications can be finalized and prior to construction or testing, let alone actually carrying out the experimental mission. Due to the need for continuity of operations at all times from development through decommissioning, a shorter term with the possibility of renewal mid-mission would be inappropriate and authorization should be granted for the requested five-year term.

As further explained in Section II below, grant of the requested license term will not adversely impact any other spectrum users, and is critical to provide the long-term assurance necessary to support the extended development and mission cycle inherent in cutting-edge space research.

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

Each of the CubeSats has capabilities for TT&C and payload downlink. TT&C on all spacecraft is carried out in the UHF band between 399.9-400.05 MHz. Payload downlink is carried out through X-band transmitters that transmit 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.

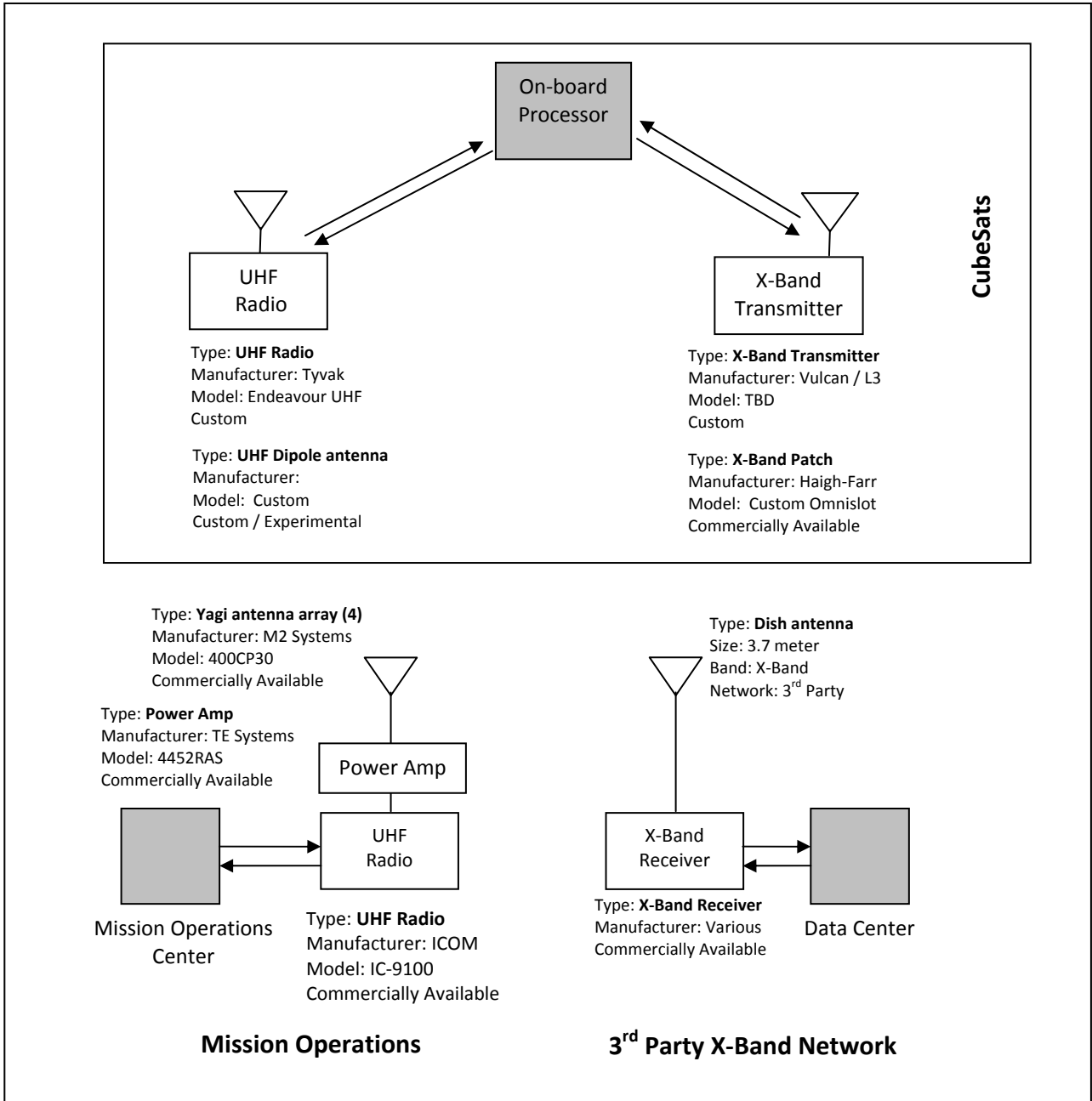


Figure 1: CubeSat System Communications Components

The transmitting components aboard the CubeSats 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. Each vehicle

possesses a UHF system for vehicle command and telemetry retrieval and an X-band system for payload data download. All Tyvak satellites will use the same spectrum.

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 each satellite individually through the use of different 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.

The payload downlink X-band system may use either a customized system from L3 Communications or Vulcan Wireless and interfaces to the main spacecraft computer. A 10mbps 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. The radios will support commonly used BPSK and OQPSK waveforms.

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 transmits the call sign in every packet

transmitted as part of its frame header. The frame header is not encoded or encrypted. 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 CubeSats are low earth orbit (“LEO”) satellites in a sun-synchronous orbital with an orbit period of approximately 1.6 hours. The satellites 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 satellites. 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.

Because the CubeSats are NGSO satellites, the range of antenna azimuth and elevation will vary based on the relative motion of the satellites 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 developmental testing at Tyvak's Irvine, CA facility beginning in October of 2015. Testing for the UHF TT&C link and the X-band payload link will be conducted in carrier current (*i.e.*, closed-loop) configuration and will produce only unintentional emissions. Under the Commission's rules, unintentional radiators operating in the frequency range between 9 kHz to 30 MHz must comply with the radiated emission limits for intentional radiators as provided in 47 C.F.R. § 15.209.³ As Tyvak's test program may marginally exceed these limits, Tyvak seeks herein experimental authority for emissions in the appropriate ranges at the Tyvak facility.

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 CubeSats' 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 CubeSats require 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 CubeSats 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

³ 47 C.F.R. § 15.109(e).

that the Commission has proposed to authorize 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.⁴ Therefore, Tyvak’s proposed operation of its experimental satellites in 50 kHz of the 399.9-400.05 MHz frequency band will not cause harmful interference to any authorized spectrum user.

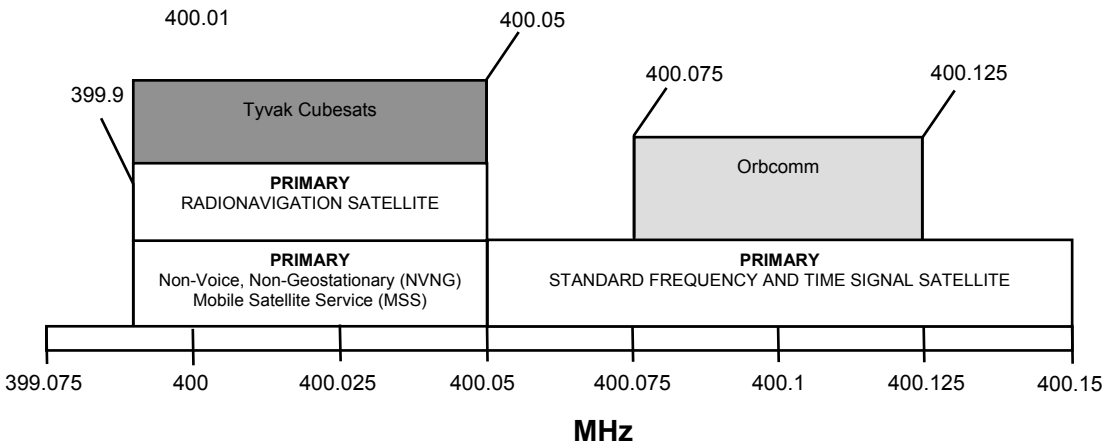


Figure 2: CubeSats Spectrum Diagram (UHF)

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 was also allocated internationally on a primary basis to the Radionavigation Satellite Service (“RNSS”) until January 1, 2015.⁵ 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

⁴ 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).

⁵ See 47 C.F.R. § 2.106 n.5.224B.

available for use by Little LEO MSS networks.⁶ 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 band.⁷ 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.⁸ 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 was 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 1996.⁹

⁶ 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).

⁷ 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).

⁸ See *id.* at 9121.

⁹ 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>.

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 CubeSats have 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 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 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 show 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 Communications Space-to-Ground 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 Communications Parameters

X-Band Communications System

The CubeSats' 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 UHF Earth station at the Irvine MOC or Tyvak-affiliated UHF stations at other locations will issue commands in the UHF-band to trigger

the satellite to transmit payload data in the X-band when over an X-Band Earth station. The Tyvak-affiliated Earth stations will relay received communications frames to the Irvine MOC over a Virtual Private Network (“VPN”).

CubeSat Communications Parameters	Value
Emission Designator	1M50G1D
Service	Digital Data
Band	8025-8400 MHz
Requested Bandwidth	15MHz
Modulation	QPSK
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 5: Tyvak CubeSat X-Band Communications Parameters

The CubeSats will communicate with the MOC, other UHF ground stations, and X-band ground stations only when they are within line-of-sight of the Earth stations and have received a communication from the Earth station directing the spacecraft to initiate transmissions. As a consequence, the spacecraft will utilize the 399.9-400.05 MHz and 8025-8400 MHz band only when in contact with specified Earth stations and 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 harmful 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 harmful interference to other low-altitude satellite networks.

Sharing With Geostationary Satellite Networks: The Tyvak network is highly unlikely to cause harmful interference to 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 Cubesats 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 CubeSats are intended to operate in LEO with the orbit parameters shown in Table 6. Each satellite will have an orbit period of roughly 1.6 hours with typical ground access times of five to seven minutes per pass. The orbit parameters are presented in the following table:

Parameter	Units	Value
Orbit Period	hrs	1.6 hrs
Orbit Altitude	km	620 km (circular)
Inclination	deg	97.9 degrees

Table 7: CubeSat Orbit Parameters

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

The space vehicles are nano-class satellites (< 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 are 3U or 6U in size, which means each

CubeSat will have the dimensions of approximately 30×10×10 centimeters or 30 x 20 x 10cm. The CubeSat dispenser limits the total vehicle mass of a 3U or 6U CubeSat to less than 6 kilograms and 10kg respectively. The CubeSat vehicles have been designed primarily as a single-string system using commercial off-the-shelf parts with a mission lifetime of less than one year on-orbit. The mass budget is identical for each satellite and is provided in the following table:

Component / Subsystem	Mass [g] 3U	Mass [g] 6U
Payload	1400	5000
Spacecraft (Subtotal)	4300	4300
Structure	300	600
Electrical Power System	1500	2500
ADCS	400	400
C&DH	100	100
Communication	500	1000
Thermal	100	100
TOTAL	4300	9700

Table 8: CubeSat Mass Budget per Element

For power generation, each space vehicle is equipped with body-mounted and deployed 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. The EOL power budget is provided in the following table:

Component / Subsystem	EOL Power [mW] Orbit Averaged (3U)	EOL Power [mW] Orbit Averaged (6U)
Payload	3500	8500
Spacecraft (Subtotal)	10000	10000
Propulsion System	140	140
ADCS	5000	5000
C&DH	600	600
Communication	3500	5500
Thermal	400	400
TOTAL	13500	20500

Table 9: Power Budget per Space Vehicle

Section 25.114(c)(12) Schedule

The project timeline and major milestones for the launch and operation of the CubeSat system 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
Fabrication and RF closed loop testing	July 2015-Nov 2015	ToL - 8 to 14 months
Delivery for Launch Integration	December 2015	ToL - 3 months
Pre-launch testing of transmitting components	January 2016	ToL - 2 months
Launch	March 2016	ToL + 0
Release from launch adapter	March 2016	ToL + 0hr 30min
On-orbit check	March 2016	ToL + 24 hours
Start of experiments	April 2016	ToL + 4 weeks
Decommissioning	April 2017	ToL + 12 months
Re-entry	March 2033	ToL + 17 year

Table 10: CubeSat System Major Milestones

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

The Tyvak CubeSats provide a platform for on-orbit testing of advanced maneuvering, proximity operations, and sensor technologies. The onboard systems on each space vehicle provide nominal attitude, electrical power, data storage, and command function for a set of mission payloads. The space vehicles communicate 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 several additional Earth stations operated by Tyvak affiliates at sites in North Pole, Alaska; Bozeman, Montana; and Columbia, Maryland. X-band receive Earth stations will be located at other locations 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.¹⁰ 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.

¹⁰ TT&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 and securely transmitted to the MOC via a VPN over the Internet.

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.

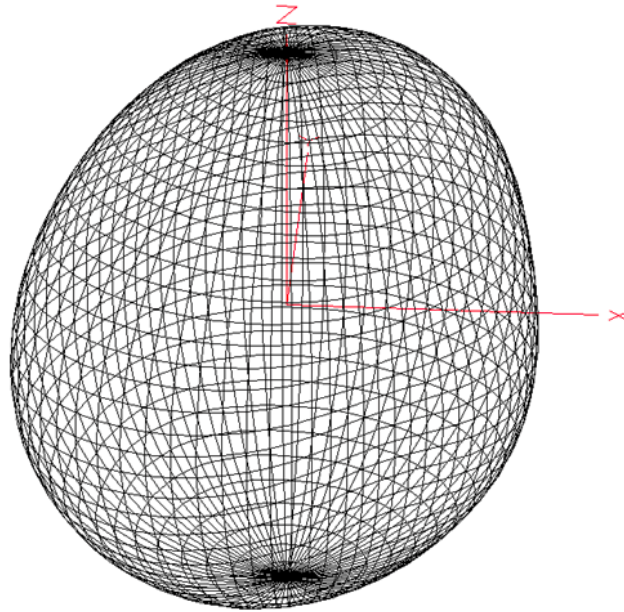


Figure 3: CubeSat L-Dipole UHF Antenna Gain Plot

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.

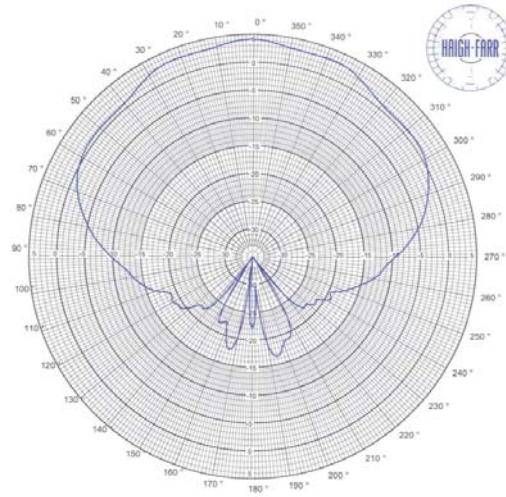


Figure 4: CubeSat X-band Antenna Gain Plot

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 CubeSats have 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 of the satellites 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), 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 1.3×10^{-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 $\sim 0.15 \text{ m}^2$) 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 620 km, the space vehicle is anticipated to re-enter the atmosphere within 17 year based on lifetime prediction simulations for the current mission epoch (*i.e.*, launch in CY2015).

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

The vehicles possess 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), the probability of the CubeSats 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 4×10^{-6}). Although the vehicles do possess propulsive capability for proximity operations demonstration, station keeping, and deorbit, no maneuvers to avoid in-orbit collisions are planned for or anticipated.

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 satellites is within 17 years of mission completion based on its mission orbit, vehicle mass, geometry and mission epoch (*i.e.*, launch in CY2016). 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 five-year experimental authority to launch and operate a fleet of NGSO LEO satellites, 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 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 and the 8025-8400 MHz portion of the X-band allocated for EESS downlink 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.