Introduction

The experimental PolarCube student satellite mission includes 1 satellite and 1 US earth station, employs the 401.340 to 401.390 MHz frequency range for space-to-earth and earth-to-space links and is consistent with the US and International table of frequency allocations. PolarCube will be launched into a 500-km altitude, 61 degree inclination orbit and will operate from a single ground station located at the University of Colorado at Boulder. PolarCube's mission will demonstrate a novel method for the collection of meteorological data, and specifically temperature profiling, of Earth's atmosphere. To respond to FCC requirement to demonstrate compliance with an experimental systems obligation to operate on a non-interference basis with other authorized operators in the bands, this report provides a two-part electromagnetic compatibility study with the existing authorized users.

TT&C Frequency usage

The proposed PolarCube frequency was changed in January 2018 to align with the 401-402 MHz band that is allocated for earth to space communications, and further refined within this band in April 2018 a smaller 50kHz bandwidth, in the range of 401.340 to 401.390 MHz, for which no users are shown in the FCC database.

PolarCube can be commanded to stop transmissions if requested by other users of the spectrum.

One other CubeSat system, Spire/Lemur 2-3, has been licensed to use frequencies in the band, indicating acceptability of using the 401-402MHz band for CubeSat use. Additionally, PolarCube's mission is a meteorological based experimental mission. Other users in the larger 401-402 MHz are meteorological based missions and use this band as data downlink. See the note in the introduction referring to coordination with NOAA.

The PolarCube spacecraft uses an omni directional antenna, and a low power (3.9W EIRP) transmitter. The resulting maximum ground Power Flux Density is -130 dBw/m^2/4kHz as seen on the ground at the closest approach; see figure 1. The analysis is based on a 10 degree elevation mask from our ground station (however this is conservative, because we will actually operate at 30 degree minimum elevation). 10 degrees yields in a maximum exclusion radius of 2,300km which would only include the US, Mexico and Canada. A Power Flux Density analysis was completed to understand the observed surface power density. The received PFD will be low, never exceeding -130dBW/m^2/4kHz. The likelihood of PolarCube interference is low.

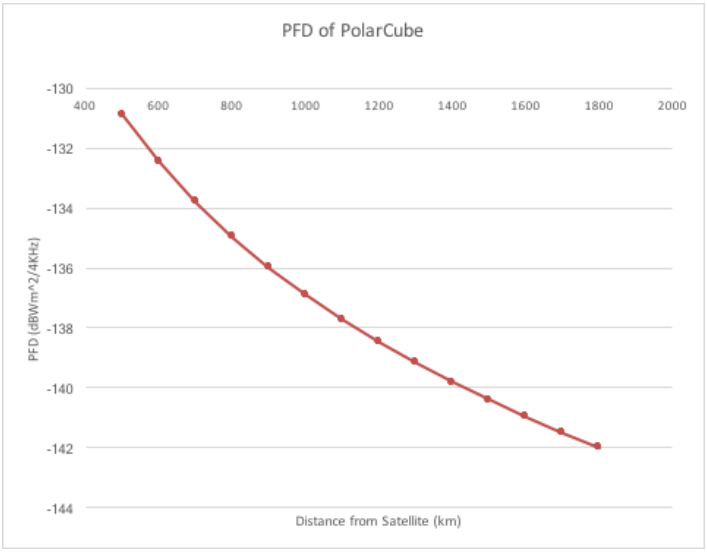

Figure 1: PolarCube PFD

Beaconing

The PolarCube mission will limit international transmissions. During early operations, and for initial tracking purposes, PolarCube will beacon internationally. Short beacons, a few milliseconds, will be transmitted every 15 seconds during the anticipated first week of the mission. Once the satellite tracking is confirmed, the worldwide beacon will be stopped by ground command. Uplink and downlink transmissions from the Ground Station at Boulder, CO, USA will be the normal operations mode during the mission. Uplink transmission will be from Boulder, CO only. Uplink transmissions will be limited and will help to complete the PolarCube mission of Earth Exploration and will specifically aid in acquiring meteorological data.

No non Federal US Operators in this Frequency

From the FCC OET and FCC International Bureau databases, a list of satellite systems using the 401.2 to 401.4 MHz band was collected and shown in Table 1 below. None of these operations have frequency overlap with PolarCube, so no interference by PolarCube is expected.

Search Criteria: Frequency Range = 401.2 MHz through 401.4 MHz, Box Search: Start Coordinates = 24° 33' 18" N 81° 46' 47" W End coordinates=47° 36' 28" N 122° 20' 6" W, Currently Licensed and Pending Facilities

OET Experimental Licensing System Database

Callsign: WI2XSC	**File Number:** 0039-EX-CN-2017	**Licensee:** Blue Origin	**FRN:** 0024940371	**Issue Date:** 02/06/2017	**Expiration:** 02/01/2019	**Radio Service:** XT	**Status:** Granted

Site Address:	**State:** TX	**County:** CULBERSON	**Mobile Coordinates:** 31° 25' 23" N, 104° 45' 26" W

Frequency: 401.20000000 M

Callsign: WI2XWO	**File Number:** 0314-EX-CN-2017	**Licensee:** The Boeing Company	**FRN:** 0001583483	**Issue Date:** 05/25/2017	**Expiration:** 06/01/2019	**Radio Service:** XT	**Status:** Granted

Site Address: White Sands Missile Range Space Harbor	**State:** NM	**Mobile Coordinates:** 32° 57' 0" N, 106° 27' 0" W

Frequency: 401.40000000 - 406.00000000 M

Site Address: White Sands Missile Range	**State:** NM	**Mobile Coordinates:** 33° 38' 24" N, 106° 36' 35" W

Frequency: 401.40000000 - 406.00000000 M

Site Address: Dugway Proving Grounds	**State:** UT	**Mobile Coordinates:** 40° 10' 12" N, 113° 28' 11" W

Frequency: 401.40000000 - 406.00000000 M

Site Address: Edwards Air Force Base	**State:** CA	**Mobile Coordinates:** 34° 57' 0" N, 117° 49' 58" W

Frequency: 401.40000000 - 406.00000000 M

Site Address: Wilcox Playa	**State:** AZ	**Mobile Coordinates:** 32° 8' 24" N, 109° 50' 59" W

Frequency: 401.40000000 - 406.00000000 M

Table 1: FCC Experimental Licenses

International Operators in This Frequency

From the ITU Space Network Systems Online (SNS), a list of satellite systems using the 401.340 to 401.390 MHz frequency range is shown in the below table. For each satellite system, the table indicates the administrative jurisdiction, service areas, frequencies and an assessment of the impact of PolarCube operation on the system.

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The following table details the limited impact PolarCube may have on users in the band.

ADM/ORG	ITU ID No	Satellite Name	BR IFIC ID	Center Freq (MHz)	Min Freq (MHz)	Max Freq (MHz)	Bandwidth (kHz)	Status	Assessment of Impact
CAN	108540431	JC2SAT	2640	402	401	403	2000	N/A	On hold indefinitely. No impact.
CAN	113540650	GHGSAT-D	2773	402	401	403	2000	Active	Coordinated. No Impact.
CAN	117545422	MULTUS	2863	401.075	400.15	402	1850	Active	Inuvik Canada based ground station beyond our ground station area of operation. No Impact.
USA	104500107	MRO	2584	397.5	390	405	15000	Operational	Note 1
USA	108540735	OSTM	2682	401.25	400.25	402.25	1000	Operational	DORIS instrument, uses 401 as an auxiliary frequency.
USA	108500627	MSL	2750	402.5	395	410	15000	Inactive	Note 1
USA	113540399	INSIGHT	2764	397.5	390	405	15000	Active	Note 1
USA	114500041	INSIGHT	2807	401.5856	400.5606	402.6106	2050	Active	Note 1
USA	115545100	MARCO	2823	39.75	390	405	15000	Active	Note 1
USA	115500163	USPOJOAQUE	2829	401.512	401.046	401.979	933	N/A	Not active. No Impact.
USA	107540739	NPOESS	2831	402	401	403	2000	Inactive	Inactive, No impact.
USA	116545103	MARS 2020	2831	397.5	390	405	15000	Pending Launch	Note 1
USA	113540648	USASAT-30F	2788	401.5	401	402	1000	Almost all operational (constellation)	Ground station operation out of Fairbanks, Alaska, beyond our ground station area of operation. No impact.,

Note 1: The Mars mission uses highly directional ground based antennas and PolarCube will transit quickly if at all, across these highly directional antennas, in roughly 4 seconds maximum. Other users in this band present a more frequent beam crossing occurrence.

Table 2: List of Satellite Systems in the ITU SNS, transmitting 401.340 to 401.390 MHz MHz with USA, CAN or MEX ADM/ORG.

NOAA

NOAA conducts operations of the GOES system in the range of 401 to 402 MHz. Carmelo Rivera at NOAA was contacted, and an analysis of compatibility with NOAA operations, was provided. Per a letter he forwarded July 26 2018 from Fred Mistichelli, NESDIS (See Appendix 1):

"Regarding PolarCube, the interference power from the downlink to the Boulder ground station never exceeds the short-term interference criteria (-186.3 dBW/100 Hz). Additionally, regarding the PolarCube uplink, if the CONOPS are arranged so that Earth-to-space transmissions are only conducted when the elevation angle to the cubesat is in the range of 30 – 90 degrees, then the short-term interference criteria is not exceeded."

PolarCube agrees to limit the elevation of the ground station to a minimum of 30 degrees, to be consistent with NOAA requirements.

Conclusion

The experimental satellite and US earth station pose no risk of creating harmful interference with any known system.

Appendix 1

Email from NOAA on Interference Mitigation

-------- Original Message --------
Subject: Fwd: Consideration of University Cubesats interference mitigation methods
Date: Thu, 26 Jul 2018 10:06:58 -0400
From: Carmelo Rivera - NOAA Federal <carmelo.rivera@noaa.gov>
To: mlmiller@sterksolutions.com

---------- Forwarded message ----------
From: **Alfredo Mistichelli - NOAA Federal** <alfredo.mistichelli@noaa.gov>
Date: Mon, Jul 23, 2018 at 1:30 PM
Subject: Consideration of University Cubesats interference mitigation methods
To: Carmelo Rivera - NOAA Federal <carmelo.rivera@noaa.gov>

Carmelo,
NESDIS provided analysis results to on 6/18 which showed potential for harmful interference from the University Cubesats to the GOES DCS system.
On 6/22, DoC/NOAA provided interference mitigation techniques which the University Cubesats operators had developed in order to avoid harmful interference to GOES DCS. These mitigation techniques included the following:

- § CONOPS can be arranged so that only one transmitter is operating at a time
- § CONOPS can be further arranged so that the cubesats would only transmit once they are far enough from the GOES receiver so that the interference criteria are not exceeded
- § The ground stations located in Virginia (Charlottesville, Blacksburg, and Norfolk) can be constrained so that they do not transmit when any GOES receiver is in the ground station's antenna beam

Analysis Results
Our analyses show that, in the cases of the UVA/VT/ODU cubesats' uplinks/downlinks, the interference power at the GOES satellites is always in violation of the draft revised criteria of the ITU-R Recommendation SA.1163 short-term criteria, regardless of the geometry between the GOES satellite and the cubesat/corresponding cubesat ground station. In other words, any time the UVA/VT/ODU cubesats are transmitting to their ground station, or their ground station is transmitting to them, the interference power within the GOES satellite receiver is greater than or equal to -186.3 dBW/100 Hz. Since the interference power is always greater than the criteria threshold, the interference mitigation solution comes down to the percentage of time that the interference power threshold is exceeded. The short-term criteria states that the interference power to exceed I = -186.3 dBW/100 Hz for no more than 0.1% of time.

The table below provides the total uplink/downlink transmission time per day, which was provided to DoC/NOAA by Mike Miller via email on 6/7/2018. The 4th and 6th rows contain the calculated total minutes of transmission per day for both the uplinks and downlinks. Additionally, within each cell in that row, in parentheses, is what that total transmission time would equal, in terms of percentage of one day. In each of the eight cases in the table, the percentage of time is greater than 0.1%.

	PolarCube	UVA	VT	ODU
Avg. passes per day	6	2	2	2
Avg. minutes of transmission per pass for uplink	0.3	1.6	1.6	1.6
Total minutes of transmission per day for uplink	1.8 (0.125%)	3.2 (0.22%)	3.2 (0.22%)	3.2 (0.22%)
Avg. minutes of transmission per pass for downlink	8.3	6.6	6.6	6.6
Total minutes of transmission per day for downlink	49.8 (3.5%)	13.2 (0.92%)	13.2 (0.92%)	13.2 (0.92%)

Regarding PolarCube, the interference power from the downlink to the Boulder ground station never exceeds the short-term interference criteria (-186.3 dBW/100 Hz). Additionally, regarding the PolarCube uplink, if the CONOPS are arranged so that Earth-to-space transmissions are only conducted when the elevation angle to the cubesat is in the range of 30 – 90 degrees, then the short-term interference criteria is not exceeded.

Conclusion

Therefore, in addition to what was already proposed by Mike Miller, in order to avoid harmful interference to GOES DCS:

- **§ The UVA/VT/ODU University Cubesat networks must arrange the CONOPS of each cubesat network so that the total uplink/downlink transmission time combined does not exceed 0.1% of a given period of time (1 day, 1 month, etc.)**
- **§ The PolarCube uplink must only be active when the elevation angle to the cubesat is in the 30 – 90 degrees range**

Recommend these Universities consider obtaining Amateur Satellite License for use of appropriate Amateur bands.

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Regards,
Fred Mistichelli
Electronics Engineer
US Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)
National Environmental Satellite, Data and Information Service (NESDIS)
Office of Chief Information Officer
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