Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
O3B LIMITED	)	Call Sign: S2935
	)	
Amendment to Application to Modify U.S. Market Access Grant for the O3b Medium Earth Orbit Satellite System	)	File No. SAT-AMD-20161115-00116

COMMENTS OF SPACE EXPLORATION TECHNOLOGIES CORP.

Space Exploration Technologies Corp. ("SpaceX") hereby comments on the amended application filed by O3b Limited to modify its authorization to serve the U.S. market with its non-geostationary satellite orbit ("NGSO") system providing Fixed-Satellite Service ("FSS"). O3b seeks to modify its existing authorization to, *inter alia*, add Ku and Ka band operations to certain satellites, add 24 new satellites in circular equatorial orbits, and add sixteen new satellites in inclined orbits, each of which would use Ku and Ka band spectrum, as well as other frequencies.[1] While these satellites will use relatively narrow beams, they will be steerable over an extremely large footprint which, taking into account the significant spreading that would occur from O3b's relatively high operational altitudes in mid-Earth orbit ("MEO"), could each cover almost the entirety of North and South America.[2] The use of such a large coverage area, however, will greatly complicate spectrum sharing between NGSO systems in these bands, and reduce spectral efficiency. O3b's equatorial-orbit satellites may cause only

[1] *See Amendment to Application to Modify U.S. Market Access Grant for the O3b Medium Earth Orbit Satellite System*, IBFS File No. SAT-AMD-20161115-00116, at 2 (Nov. 15, 2016).

[2] *See id.* at 9-10.

limited coordination challenges with other NGSO operators, as NGSO systems (including SpaceX) will avoid the GSO arc. But O3b's inclined-orbit satellites will experience frequent and prolonged in-line events with other NGSO systems.

In addition, due to O3b's proposed operational altitude, its uplink beams are likely to cause significant interference to LEO satellites whenever a LEO satellite passes through an O3b earth stations main beam or sidelobe. This would effectively prevent a LEO system with steerable beams (like SpaceX's) from working around the in-line event, forcing the default arrangement of band segmentation. The Commission should ensure that systems at all altitudes under consideration in this processing round will be able to coexist with one another while making efficient use of scarce spectral resources. And, if necessary, the Commission should impose license conditions to ensure that operators have the proper incentives to coordinate fairly and effectively with every other NGSO system.

I. EXTREMELY LARGE COVERAGE AREAS AND HIGH OPERATIONAL ALTITUDES EXACERBATE COEXISTENCE CHALLENGES, IN THE ABSENCE OF REAL-TIME INFORMATION SHARING

When the Commission adopted its current avoidance of in-line interference approach, it anticipated that in-line events would be relatively infrequent.[3] However, due to the very large footprint of O3b's satellites, there will virtually always be at least one, and often more LEO satellites within that footprint, greatly increasing the frequency of apparent in-line events beyond what the Commission anticipated. In fact, such in-line events involving three or more operators may not be uncommon.

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[3] *Establishment of Policies and Service Rules for the Non-Geostationary Satellite Orbit, Fixed Satellite Service in the Ka-Band*, Report and Order, 18 FCC Rcd. 14708, ¶ 19 (2003).

Large coverage area and high altitude increases the number of in-line events that an O3b satellite is likely to experience with other systems, increases the duration of those in-line events, and increases the odds that a given satellite will experience in-line events with multiple operators at one time. Instead of a fleeting event, an in-line event with an O3b satellite will last a significant period of time, during which affected satellites will remain in either a band-splitting or other spectrally inefficient coordination regime. LEO satellites may experience long-duration in-line events with an O3b satellite and a large number of LEO satellites may be affected simultaneously by one single O3b satellite. Both operators will take the burden of long periods of in-line coexistence with O3b satellites, due to its large footprint and high altitude. This will significantly reduce the spectrum available to the O3b system itself and also other systems, especially in cases of in-line events with more than one operator.

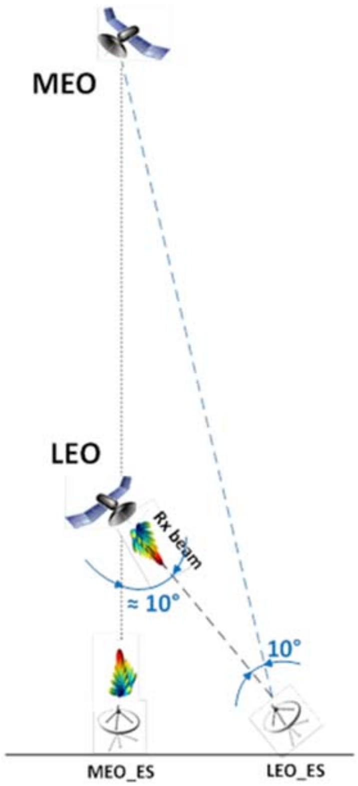
Troublingly, the large majority of these in-line events would, in fact, be "false" in-line events that, unbeknownst to other operators, would not have caused harmful interference. O3b can avoid this and greatly increase spectral efficiency by committing to provide real-time coordination data with other operators that includes the steering angle of each of its beams at a given time. However, in the absence of this information, other operators will be forced to assume that in-line interference is possible at anytime, anywhere within the O3b footprint.

II. Higher-Orbit Systems May Cause Interference to Any LEO Satellite Within or Near Their Beams, Even Outside an In-line Event

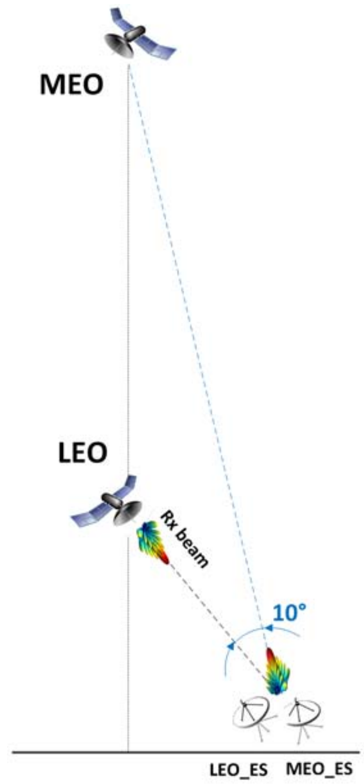
The O3b system, and other systems with high operational altitudes, are likely to cause interference to LEO systems due to the very high power of these systems' earth station uplink beams. For example, in order to communicate with MEO satellites at altitudes of 8,000 km, O3b's uplink beams will transmit at power levels much higher than SpaceX's. With such an extreme power disparity, the O3b uplink beam would likely degrade SpaceX's or any other LEO satellite's ability to receive any uplink signal in the affected band from *any* location on the Earth, whether or not it is near the transmitting O3b earth station. This would essentially prevent a LEO satellite with steerable beams from using that steering capability to avoid an in-line event, forcing both operators to default to band segmentation.

To illustrate this point, consider two in-line scenarios involving the NGSO systems proposed by O3b and SpaceX. As depicted below, in Scenario 1, the SpaceX LEO satellite is in the main beam of the O3b earth station uplink to an O3b MEO satellite.[4] In Scenario 2, the SpaceX and O3b earth stations are essentially collocated while their satellites have an apparent angular separation of 10 degrees.

4 Note that, given the extreme difference between the operating altitudes of the two systems, the separation angle between MEO_ES and LEO_ES from the LEO satellite perspective is essentially the same as the angle between MEO and LEO from the LEO_ES perspective.



Scenario 1



Scenario 2

Using operational parameters from the SpaceX and O3b applications, we can determine the impact (measured as ΔT/T) of these in-line events.

For example, Table 1 below sets forth the analysis of the impact that the uplink beam from an O3b earth station would have on SpaceX in Scenario 1. As this analysis demonstrates, the uplink beam from an O3b earth station would cause a dramatic increase in noise temperature relative to the desired signal at the receive antenna of SpaceX satellites, with ΔT/T of 92,991%, assuming 10 degrees of angular separation.[5]

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[5] For purposes of this analysis, SpaceX used a representative frequency (29 GHz) and a representative orbital altitude for its system (1,110 km), and EIRP values for O3b earth stations taken from O3b's Hawaii earth station (call sign E100088). I/N is calculated using this equation (where k = Boltzmann constant):

$$\frac{I}{N} = EIRP - 10\log(4\pi d^2) - 10\log\left(\frac{4\pi}{\lambda^2}\right) + \frac{G}{T} - 10\log(k)$$

SpaceX SAT Rx antenna gain at nadir [dB]	41.00	
SpaceX SAT Rx antenna G/T at nadir [dB/K]	13.70	*see SpaceX FCC filing*
SpaceX SAT Rx antenna G/T at 10º [dB/K]	-20.30	*32-25log(φ) at 10° separation*
O3B ES EIRP [dBW/40kHz]	50.00	
O3B ES EIRP [dBW/Hz]	3.98	
I/N [dB]	**29.68**	*at 10° separation*
ΔT/T [%]	**92,991%**	*at 10° separation*

Table 1. Impact of O3b Earth Station in Scenario 1

An analysis of Scenario 2 yields similar results, although here it is the sidelobes of the O3b earth station[6] that interfere with the main beam of the SpaceX earth station's uplink transmissions. Table 2 belows show the increase in noise temperature expected in the SpaceX uplink when the separation angle between a SpaceX satellite and an O3b satellite is 10 degrees, from the earth station's point of view.

SpaceX SAT Rx antenna G/T at nadir [dB/K]	13.70	*see SpaceX FCC filing*
O3B ES Diameter D [m]	7.3	*per O3B info for Hawaii ES*
O3B ES Gmax [dB]	64.9	*per O3B info*
O3B ES Gain @ 10º [dB]	7.00	*32-25log(φ), per Rec. ITU-R S.465-6*
O3B ES rejection @ 10º [dB]	57.90	
O3B ES EIRP @ 10º [dBW/40kHz]	-7.90	
O3B ES EIRP @ 10º [dBW/Hz]	-53.92	
I/N [dB]	**5.78**	*at 10° separation*
ΔT/T [%]	**379%**	*at 10° separation*

Table 2. Impact of O3b Earth Station at 10 Degree Separation in Scenario 2

As these tables demonstrate, the high EIRP of the O3b earth stations will make equitable and efficient spectrum sharing difficult or impossible. In Scenario 1, interference is so strong that it would prevent the SpaceX satellite from using its steerable beams to service other users (even outside the area subject to the in-line event) using spectrum shared with O3b, and thus essentially prevents SpaceX from using those

6 For this analysis, SpaceX determined off-axis gain of ViaSat earth stations using the formula 32-25log(ϕ) from Recommendation ITU-R S.465-6, *available at* https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.465-6-201001-I!!PDF-E.pdf.

frequencies anywhere during the in-line event. In Scenario 2, because SpaceX will experience an unacceptable level of interference without a separation angle much larger than 10 degrees, the operators would have to expand the in-line event zone which would negatively impact spectral efficiency and usable capacity for both systems.

Without effective coordination, this pervasive interference will significantly reduce the overall utility of NGSO operations throughout the band. The Commission is currently considering whether to adopt default limits for EIRP density of NGSO uplink transmissions in order to facilitate spectrum sharing among systems,[7] and SpaceX believes that such limits will be critical to equitable coexistence among non-homogeneous NGSO systems. At a minimum, any grant of O3b's application should be conditioned upon compliance with the outcome of that rulemaking proceeding. The Commission should also consider whether it would be appropriate to impose additional conditions to address this potential interference and enhance the potential for efficient spectrum sharing.

The Commission's definition of "in-line interference event" already covers both scenarios discussed above, defining such an event as one where satellites in two or more systems are aligned "with an operating Earth station of **one** of these networks."[8] Thus, under the Commission's rules, and in the absence of another coordination agreement, O3b would be required to split the spectrum with the LEO system when one of its satellites and an LEO satellite were aligned with a transmitting O3b earth station. Band splitting in this situation, however, will be especially burdensome and inefficient, as it

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7 *See Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, 31 FCC Rcd. 13651, ¶¶ 28-30 (2016).

8 47 C.F.R. § 25.261(b) (emphasis added).

could require the LEO system to refrain from using a portion of the spectrum, *even when serving earth stations outside O3b's footprint.* Without effective coordination, this pervasive interference will significantly reduce the overall utility of NGSO operations throughout the band.

III. CONCLUSION

In effect, systems operating at high altitudes and with large coverage areas cause a very large number of in-line events inefficiently splitting spectrum during a large portion of its satellites' time on orbit. Higher-altitude systems such as O3b's compound these challenges by posing an asymmetric interference risk to lower-altitude operators whenever they pass through the main beam or sidelobe of an O3b uplink transmission. The Commission should carefully consider whether the public interest would be served by authorizing systems that are only workable if other, more adaptable systems take a disproportionate burden of sharing, as the compromises required would reduce the overall capacity available to serve consumers, and evaluate how it can foster spectrally efficient coexistence between systems of widely differing altitudes.

Respectfully submitted,

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June 26, 2017

ENGINEERING CERTIFICATION

The undersigned hereby certifies to the Federal Communications Commission as follows:

(i) I am the technically qualified person responsible for the engineering information contained in the foregoing Comments,

(ii) I am familiar with Part 25 of the Commission's Rules, and

(iii) I have either prepared or reviewed the engineering information contained in the foregoing Comments, and it is complete and accurate to the best of my knowledge and belief.

Signed:

/s/ Mihai Albulet

Mihai Albulet, PhD
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SPACE EXPLORATION TECHNOLOGIES CORP.

June 26, 2017

Date

CERTIFICATE OF SERVICE

I hereby certify that, on this 26th day of June, 2017, a copy of the foregoing Comments was served by electronic mail upon:

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