Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
O3b Limited	)	File No. SAT-AMD-20220509-_____
	)	Call Sign: S2935
Amendment to Application to Modify	)	
U.S. Market Access Grant for the	)	
O3b NGSO Satellite System	)	

AMENDMENT

O3b Limited ("O3b") hereby amends its pending application to modify its authority to serve the U.S. market using nongeostationary orbit ("NGSO") satellites.[1] O3b submits this amendment ("Amendment") pursuant to Sections 25.116 and 25.137 of the Commission's rules[2] to provide information requested by the Commission.[3] In addition to this narrative, O3b is submitting a Technical Appendix with Annexes and a composite Schedule S describing all authorized and proposed O3b satellites.

O3b certifies that apart from the matters addressed herein, the information supplied in the Modification is unchanged.

Because this Amendment does not increase the potential for interference or seek the use of additional frequencies, it should be deemed a minor amendment that does not affect the processing round status of the Modification. None of the factors listed in Section 25.116(b) that would render an amendment "major" is relevant here. Accordingly, the Modification should continue to be considered as part of the NGSO processing round the International Bureau established on March 24, 2020.[4]

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[1] *See* Modification Application of O3b Limited, Call Sign S2935, IBFS File No. SAT-MOD-20200526-00058 ("Modification"), seeking updates to the authority granted in *O3b Limited*, Order and Declaratory Ruling, 33 FCC Rcd 5508 (2018).

[2] 47 C.F.R. §§ 25.116, 25.137.

[3] *See* Letter from Karl A. Kensinger, Chief, Satellite Division, International Bureau, FCC, to Karis Hastings, Counsel to O3b Limited, File No. SAT-MOD-20200526-00058 (Apr. 8, 2022).

[4] *See Cut-Off Established for Additional NGSO FSS Applications or Petitions for Operations in the 10.7-12.7 GHz, 12.75-13.25 GHz, 13.8-14.5 GHz, 17.7-18.6 GHz, 18.8-20.2 GHz, and 27.5-30 GHz Bands*, Public Notice, DA 20-325 (Mar. 24, 2020).

Please address any questions regarding this matter to the undersigned.

Respectfully submitted,

O3b LIMITED

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May 9, 2022

O3b Amendment
Technical Appendix

This attachment provides information responsive to Commission questions[1] regarding O3b's pending modification application.[2]

> *1) The Schedule S provided includes only information for the 17.8-20.2 GHz and 27.5-30 GHz frequency bands. Please revise the Schedule S to include the technical information for all frequency bands and services for the entire O3b non-geostationary orbit (NGSO) satellite constellation.*

An updated Schedule S is being filed with this Amendment that adds the V-band frequencies authorized in the U.S. Market Access Grant to the 17.7-20.2 GHz and 27.5-30 GHz Ka-band frequencies covered by the Schedule S submitted with the Modification.

O3b provides the following notes with respect to the updated Schedule S:

- While copying the Schedule S using the online FCC Schedule S System, the order of the Orbital Plane information became reversed. The information remains correct, but Orbital Plane 1 from the May-2020 Modification is now Orbital Plane 11; Orbital Plane 2 is now Orbital Plane 10 and so on, as clarified in the table below.

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[1] *See* Letter from Karl A. Kensinger, Chief, Satellite Division, International Bureau, FCC, to Karis Hastings, Counsel to O3b Limited, File No. SAT-MOD-20200526-00058 (Apr. 8, 2022).

[2] *See* Modification Application of O3b Limited, Call Sign S2935, IBFS File No. SAT-MOD-20200526-00058 ("Modification"), seeking updates to the authority granted in *O3b Limited*, Order and Declaratory Ruling, 33 FCC Rcd 5508 (2018) ("U.S. Market Access Grant").

Modification Orbital Plane Identifier	Amendment Orbital Plane Identifier
1	11
2	10
3	9
4	8
5	7
6	6
7	5
8	4
9	3
10	2
11	1

Similarly, the mean anomaly information has also been reordered for all orbital planes. The information is correct but does not appear in the correct order: the mean anomalies should be ordered from low to high. Note that in plane 10 (corresponding to plane 2 of the Modification) there are four spare satellites that are located at nominal mean anomalies of 1, 91, 181 and 271 degrees in longitude.

- The maximum power flux density (PFD) levels for transmit beams VTR1 and VTL1 are shown for faded conditions pursuant to §25.208(r)(2). The corresponding maximum PFD levels under clear-sky conditions would be 12 dB lower than the values shown in the Schedule S.

- Channels VR01, VT01 and VT02 are listed as "service links" but could also be used as "feeder links."

- The VR01 channel has the ability to receive across the entire frequency range of 47.2-51.4 GHz as listed in the Schedule S. However, the associated transmitting earth stations will not transmit in the band 50.2-50.4 GHz in order to protect the passive systems operating in this band.

> *2) For transmit and receive beams, please provide the peak antenna gain values in a Schedule S form in accordance with section 25.114(c)(4)(vi)(B) of the Commission's rules.*

O3b has included peak antenna gain values in the Schedule S based on currently available information for the proposed satellites.[3]

> *3) For satellite-to-satellite operations, please provide the peak antenna gain and 3dB beam width values, in accordance with section 25.114(c)(4)(vi)(B) of the Commission's rules.*

Information responsive to questions 3 and 5 is provided in Annex A, attached.

[3] O3b notes, however, that the rule referred to in this question, Section 25.114(c)(4)(vi)(B), does not explicitly require submission of peak antenna gain values except with respect to satellite-to-satellite links, and O3b is separately providing those values in response to question 3, below. For other beam types, Section 25.114(c)(4)(vi)(B) specifies the submission of gain contours but does not mention a requirement to supply peak antenna gain values, and this is not a mandatory field on the Schedule S. *See also Comprehensive Review of Licensing and Operating Rules for Satellite Services*, IB Docket No. 12-267, Report and Order, 28 FCC Rcd 12403, 12430 (2013) (declining to add a requirement in Section 25.114(c)(4)(ii) to specify peak antenna gain because, as argued by the Satellite Industry Association, "the existing requirement to specify maximum EIRP and the proposed requirement to specify EIRP density obviates any need to specify peak antenna gain") (footnote omitted).

> *4) For command beams, please provide the beam peak flux density at the command threshold, in accordance with section 25.114(c)(4)(v) of the Commission's rules.*

The minimum saturation flux density values provided in Schedule S for the command beams represent the beam peak flux density at the command threshold for each beam. For the beam designated "CMD" the value is -95.0 dBW/m2, and for the other command beams the value is -100.0 dBW/m2.

> *5) O3b states that satellites in Low Earth Orbit (LEO) will use the 27.5-29.1 GHz and 29.5-30 GHz FSS spectrum to transmit to O3b's medium earth orbit (MEO) satellites and to geostationary satellite orbit ("GSO") space stations, and the O3b MEO satellites will use the 17.8-18.6 GHz and 18.8-20.2 GHz FSS and MSS feeder link spectrum to transmit to O3b's LEO satellites. The LEO satellites will receive transmissions in these bands from GSO space stations as well.3 Based on these statements, please provide a list of the GSO space stations O3b intends for these communications, including, if currently available, the ITU satellite name, orbital location and associated licensing administration. In addition to this information, please provide a detailed interference analysis, which demonstrates how O3b's satellite-to-satellite communications in these bands will not cause unacceptable interference to other authorized satellite systems.*

Information re responsive to question 5 is provided in Annex A, attached.

> *6) Please provide the following additional information concerning O3b's plans for orbital debris mitigation and additional supporting material with respect to United Kingdom regulation:*

Information responsive to question 6 is provided in Annex B, attached.

CERTIFICATION OF PERSON RESPONSIBLE FOR PREPARING ENGINEERING INFORMATION

I hereby certify that I am the technically qualified person responsible for preparation of the foregoing engineering information, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information and that it is complete and accurate to the best of my knowledge and belief.

/s/ Frederic Portier

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May 9, 2022

Introduction

O3b's pending Modification seeks authority for additional spacecraft and proposes to conduct satellite-to-satellite operations in Ka-band Fixed-Satellite Service (FSS) and Mobile Satellite Service (MSS) spectrum. O3b proposes to add satellites in Low Earth Orbit (LEO) that will use the 27.5-29.1 GHz and 29.5-30 GHz FSS spectrum to transmit to O3b's medium earth orbit (MEO) satellites and to geostationary satellite orbit (GSO) space stations. O3b also seeks to add MEO satellites that will use the 17.8-18.6 GHz and 18.8-20.2 GHz FSS and MSS feeder link spectrum to transmit to O3b's LEO satellites. The LEO satellites will receive transmissions in these bands from GSO space stations as well.

The following is a list of GSO space stations O3b intends for these communications:

- SES-17, Call Sign S3043
    - Location: 67.1° W.L.
    - ITU filings
        - LUX-G11-49-1
        - LUX-G11-49
    - Licensing Administration: Luxembourg
- AMC-15, Call Sign S2180
    - Location: 105.05° W.L.
    - ITU filings
        - USASAT-31K
    - Licensing Administration: United States

For O3b's satellite-to-satellite operations, the peak antenna gain is 45.2 dBi, and the 3 dB beam width is 0.934 degrees.

The analysis presented in this technical annex demonstrates that O3b's proposed satellite-to-satellite communications will not cause unacceptable interference to other authorized nongeostationary satellite orbit (NGSO) and GSO satellite systems.

The approach and assumptions O3b used reflect ongoing International Telecommunication Union (ITU) work on WRC-23 Agenda Item 1.17. The main reference is Doc 4A/534 from January 2022 (Contribution 534), which contains the guiding principles to ensure that satellite-to-satellite links do not exceed the level of protection specified for GSO and NGSO networks by the ITU Radio Regulations and do not impose additional constraints on existing primary services.

As discussed in Contribution 534, transmissions from NGSO space stations in the space-to-Earth direction using Ka-band FSS spectrum will behave exactly like other emissions directed to the Earth from those FSS space stations in accordance with current regulatory provisions, and therefore the interference environment for terrestrial fixed and mobile stations as well as earth stations of other networks remains unchanged from what is coordinated and notified in accordance with the ITU Radio Regulations. As a consequence, there is no need to study the space-to-Earth case. The results presented in this study only consider the Earth-to-space case.

Study assumptions

The Table below summarizes the configurations of the so-called "user" constellation, the proposed O3b LEO satellites, and the MEO "service provider" system, the O3b MEO satellites.

Table 1: Configuration of the "user" and "service provider" systems considered in the study

	Orbit altitude (km)	Number of planes	Number of satellites per plane	Inclination (deg)
User configuration	507	4	9	97.4
MEO service provider	8062	1	10	0
		4	6	90

The GSO service provider is SES-17, located at 67.1° W.L.

O3b performed dynamic simulations to evaluate the interference level. For purposes of these simulations, an NGSO user space station was considered to be transmitting only when within the cone of coverage of the intended NGSO service provider space station.

The simulation parameters are presented below.

Table 2: Simulation parameters

Parameter	**Value**
Frequency (GHz)	29.985
Duration (days)	5
Time step (seconds)	1
On-ground test location	38° N.L. 77° W.L.
Transmit antenna efficiency	0.6
Transmit antenna pattern	S.580
Transmit antenna size (meters)	0.75
On-ground VSAT Transmit input power spectral density (dBW/Hz)	-65 (user-to-GSO link) -67.5 (user-to-MEO link)
User Transmit antenna input power spectral density (dBW/Hz)	Determined according to the on-ground station input power spectral density to ensure the same power flux density at the wanted receiver, in alignment with Contribution 534

These parameters represent a typical operational configuration that O3b intends to use for satellite-to-satellite transmissions.

At each time step, for each satellite in the constellation, O3b computed the corresponding interference-to-noise ratio (I/N) and selected the highest I/N value. O3b used the resulting data to create complementary cumulative distribution functions (CCDF). The CCDF plots display what percentage of the time steps the I/N was above the specified level on the x-axis. The selection of the worst interferer at every time step, although not representing real-world operations, ensures that the interference envelope presented in the study can never be exceeded.

The table below summarizes the characteristics of a victim GSO network, EUTELSAT 65 WEST A at 65° W.L., adjacent to SES-17. For purposes of the analysis, O3b assumed 2-degree spacing between the two GSO satellites. SES-17 is actually 2.1 degrees away from EUTELSAT 65 WEST A, but this difference does not change the analysis.

Table 3: Characteristics of the victim GSO network studied

Interfered-with GSO network			
Latitude, Longitude, and Altitude (degrees, degrees, kilometers)	0	-65	35 768
Antenna Pattern	S.672 Ls (side-lobe plateau level) = -25		
Antenna Diameter (meters)	2.5		
Antenna Efficiency	0.6		
Noise Temperature (K)	600		

The Table below summarizes the configurations of the authorized Ka-band NGSO systems that O3b studied as potential victims of satellite-to-satellite transmissions originating from the O3b LEO constellation.

Table 4: Ka-band NGSO system configurations

NGSO system	Orbit altitude (km)	Number of planes	Number of satellites per plane	Inclination (deg)
SpaceX	540	72	22	53.2
	550	72	22	53
	560	4	43	97.6
	560	6	58	97.6
	570	36	20	70
OneWeb	1200	18	40	87.9
Telesat	1000	6	12	99.5
	1248	5	9	37.4
Viasat	8200	3	8	87
Space Norway	8102 - perigee 43497 - apogee	1	2	63.4
Theia	809 - perigee 791 - apogee	8	14	98.6

Kuiper	630	34	34	51.9
	590	28	28	33
	610	36	36	42

O3b did not analyze the SpaceLink system because the system will use the 29.5-30.0 GHz band only during emergency recovery situations.

The table below summarizes the operational parameters O3b used to perform its simulation for these NGSO systems, which have been drawn from the systems' FCC applications.

Table 5: Ka-band NGSO system operational parameters

NGSO system	Receive peak gain	Noise temperature (K)	GSO exclusion zone	Minimum elevation angle
SpaceX	38.5	500	18	25
OneWeb	38	440	6	10
Telesat	36.9	1155	4.5	10
Viasat	49.5	550	3	10
Space Norway	35	780	0	10
Theia	36.4	500	6	10
Kuiper	39	460	18	35

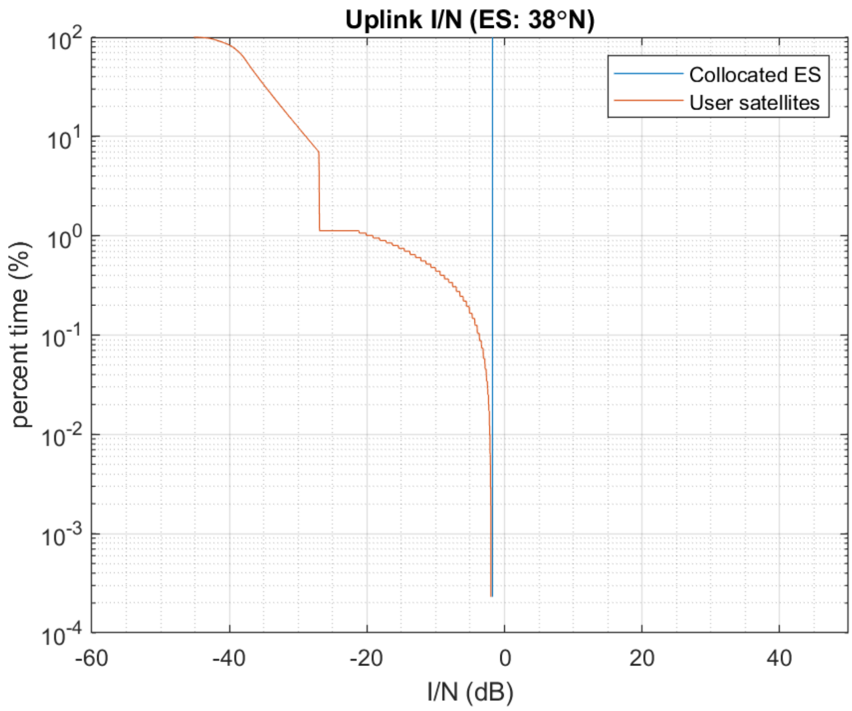
Study results

Interference into authorized GSO and NGSO systems when a GSO is service provider

Interference into authorized GSO networks

The victim GSO is the EUTELSAT 65 WEST A network at 65° W.L. presented in Table 3.

The analysis compares the interference into the victim space station receive antenna originating from a co-located earth station operating in compliance with Section 25.218(i)(1)-(4) of the rules for digital operation in the conventional Ka-band to the interference originating from the user constellation.



The interference originating from the O3b LEO user constellation never exceeds the interference originating from the co-located earth station. Furthermore, the satellite-to-satellite interference reaches the worst-case level only for a very small percentage of time.

Given the nature of this comparative analysis, the outcome can be generalized, and there is no need to conduct similar analyses for other potential GSO victim networks. Moreover, the analysis is emission-insensitive, so increasing the input power spectral density into a specified antenna size would not affect the outcome. Instead, the interference resulting from the proposed satellite-to-satellite transmissions will always be contained within the envelope of the interference from a co-located earth station operating in compliance with Section 25.218(i)(1)-(4) of the rules.

Thus, the proposed O3b satellite-to-satellite links will not cause unacceptable interference to authorized GSO systems.

Interference into authorized NGSO networks

The following figures show the I/N comparative analysis for all NGSO systems presented in Table 4. Because Space Norway's service area starts at 55° N.L., O3b used a test location for the co-located earth station in Alaska (60° N.L., 150° W.L.) and the AMC-15 satellite at 105° W.L. as the GSO service provider for the analysis. O3b used a test earth station location at 38° N.L. and the SES-17 satellite at 67.1° W.L. as the GSO service provider for the analyses with respect to all other NGSO systems.

All plots show that the satellite-to-satellite interference is always contained within the envelope of a co-located earth station, with a significant margin in the majority of cases. As a consequence, this demonstrates that no unacceptable interference will be produced.

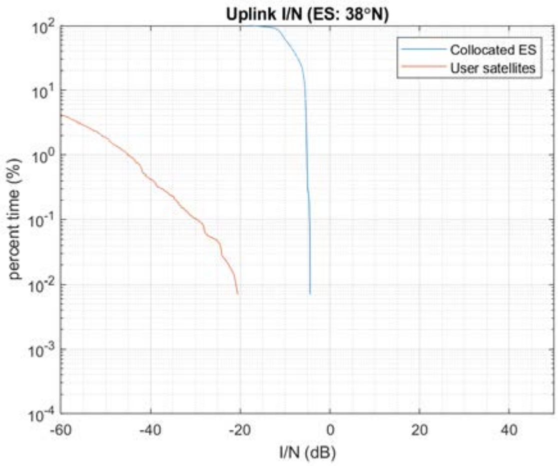


Figure 1: SES-17 service provider, SpaceX victim

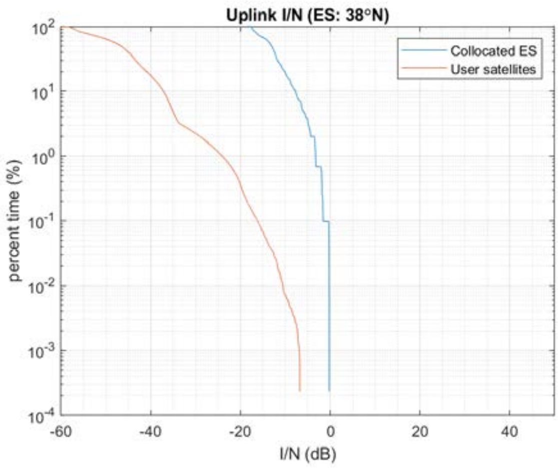


Figure 2: SES-17 service provider, OneWeb victim

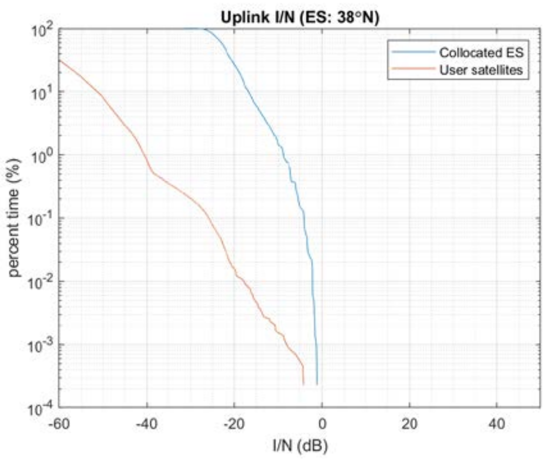


Figure 3: SES-17 service provider, Telesat victim

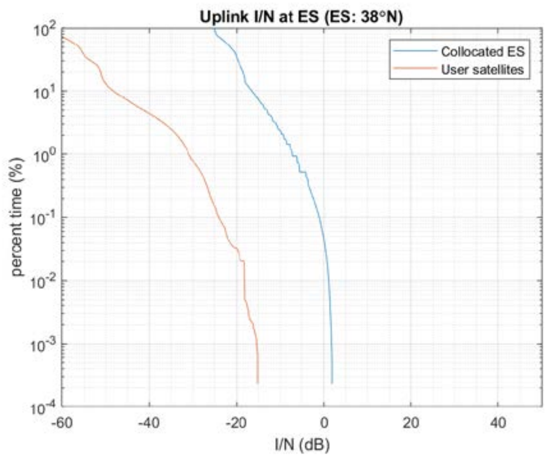


Figure 4: SES-17 service provider, Viasat victim

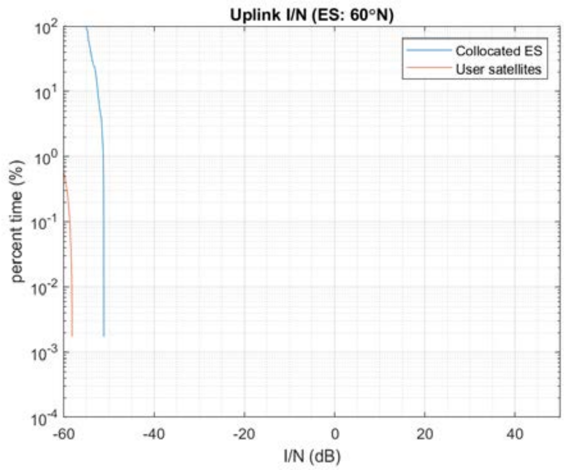


Figure 5: AMC-15 service provider, SpaceNorway victim

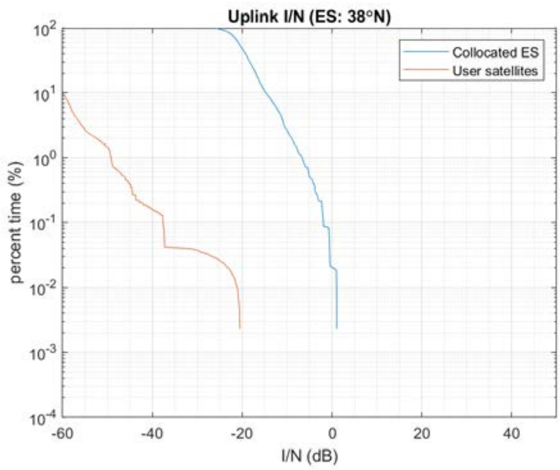


Figure 6: SES-17 service provider, Theia victim

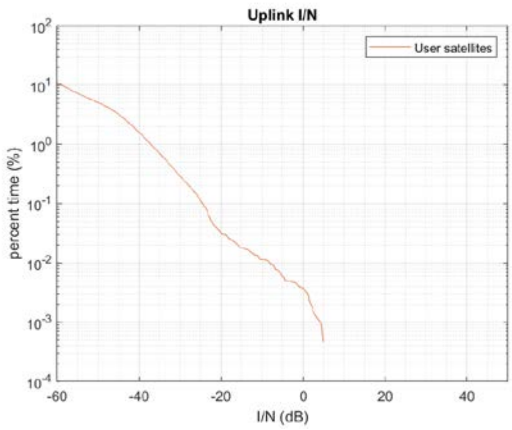


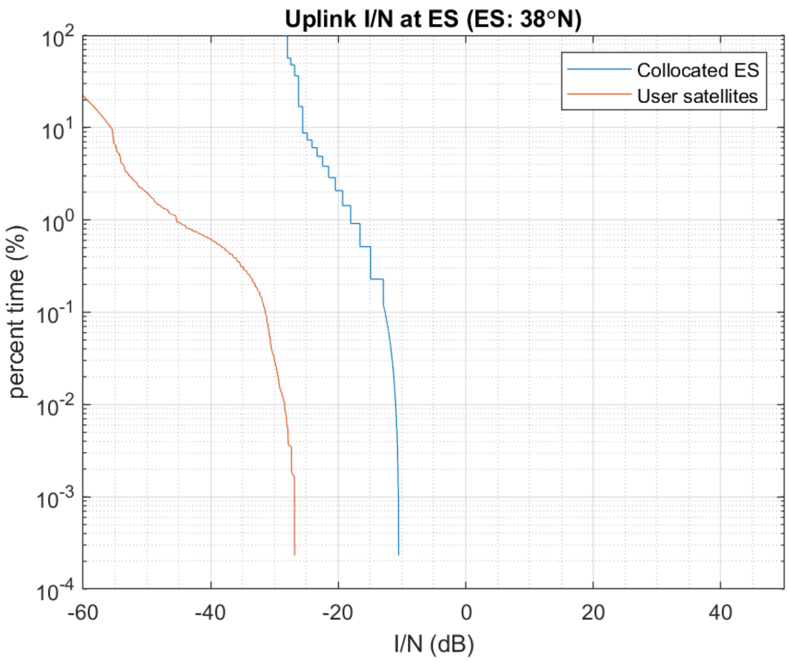
Figure 7: SES-17 service provider, Kuiper victim

Interference into authorized GSO and NGSO systems when O3B MEO fleet is service provider

Interference into authorized GSO networks

The victim GSO is the EUTELSAT 65 WEST A network at 65° W.L. presented in Table 3.

The analysis compares the interference into the victim originating from a co-located earth station to the interference originating from the O3b MEO user constellation.



The interference originating from the user O3b LEO constellation never exceeds the interference originating from a co-located earth station.

Given the nature of this comparative analysis, the outcome can be generalized, and there is no need to conduct similar interference analyses for other potential GSO victim networks. Moreover, the analysis is also emission-insensitive, so increasing the input power spectral density into a specified antenna size would not affect the outcome. Instead, the interference from satellite-to-satellite transmissions will always be contained within the envelope of the interference from a co-located earth station.

Thus, the proposed satellite-to-satellite links will not cause unacceptable interference to authorized GSO systems when the O3b MEO fleet is the service provider.

Interference into authorized NGSO networks

When evaluating potential interference into NGSO systems from an NGSO system satellite-to-satellite link service provider, the I/N analysis described above based on a comparison to a co-located earth station may not be adequate since, in most cases when NGSO earth stations are co-located, operators adopt mitigation techniques to reduce interference into each other to an acceptable level. Instead, O3b focused its analysis on quantifying the interference from the satellite-to-satellite transmissions in absolute terms. Work is still ongoing at the ITU to develop emission limits to apply to satellite-to-satellite transmissions to ensure that no unacceptable interference is caused to other NGSO FSS systems. For purposes of the analysis described in this Annex, O3b used emission values that conform to the latest limits presented to ITU WP4A in May 2022.

The following Figures show the satellite-to-satellite interference into all NGSO systems presented in Table 4. All plots show that an I/N of 0 is exceeded only for a very low percentage of time (0.006% for SpaceX that represents the very worst case of all systems studied). Accordingly, the proposed satellite-to-satellite links will not cause unacceptable interference to other NGSO systems.

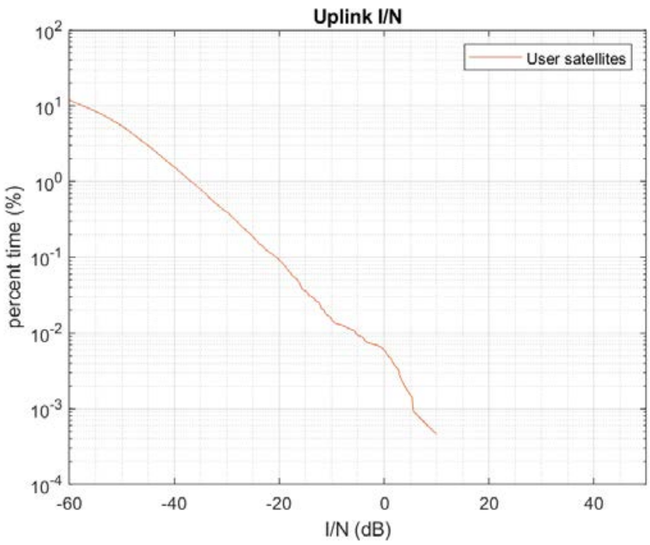


Figure 8: O3B MEO service provider, SpaceX victim

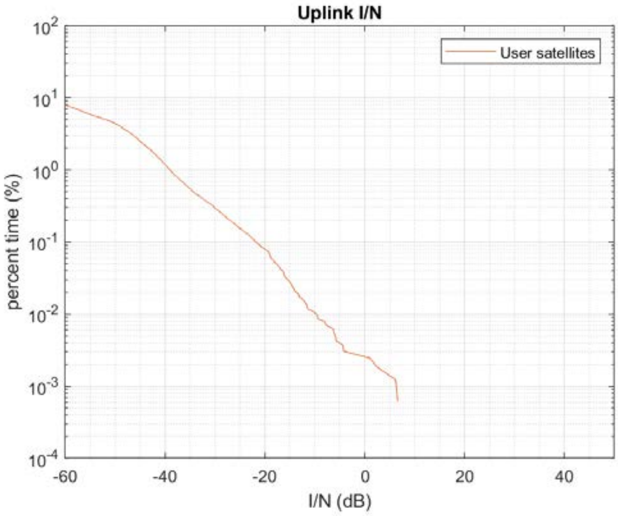


Figure 9: O3B MEO service provider, OneWeb victim

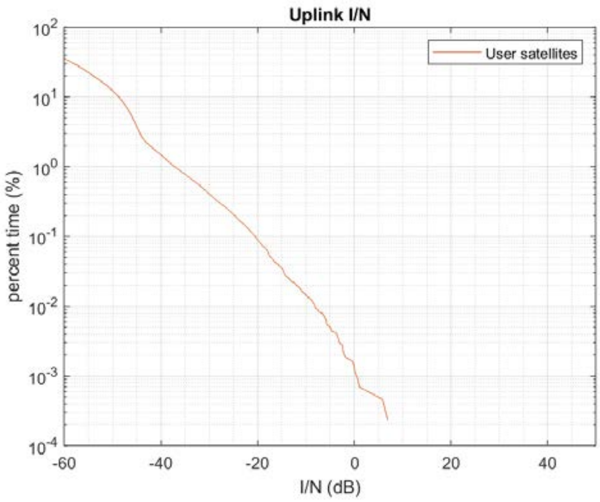


Figure 10: O3B MEO service provider, Telesat victim

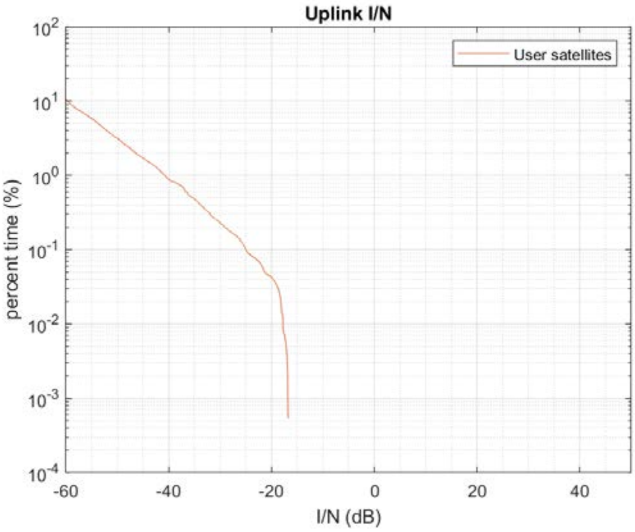


Figure 11: O3B MEO service provider, Viasat victim

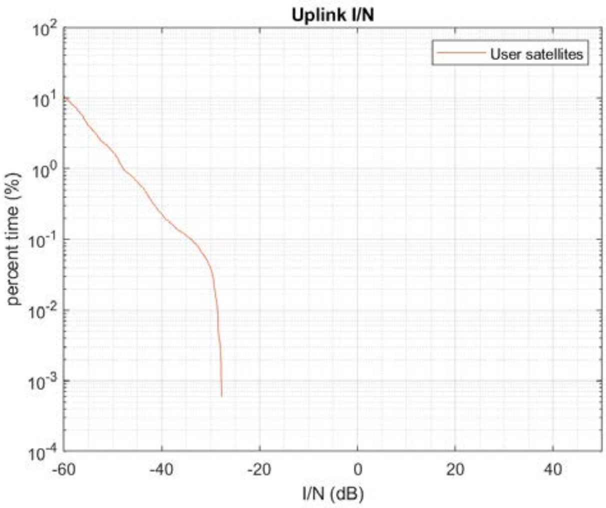


Figure 12: O3B MEO service provider, SpaceNorway victim

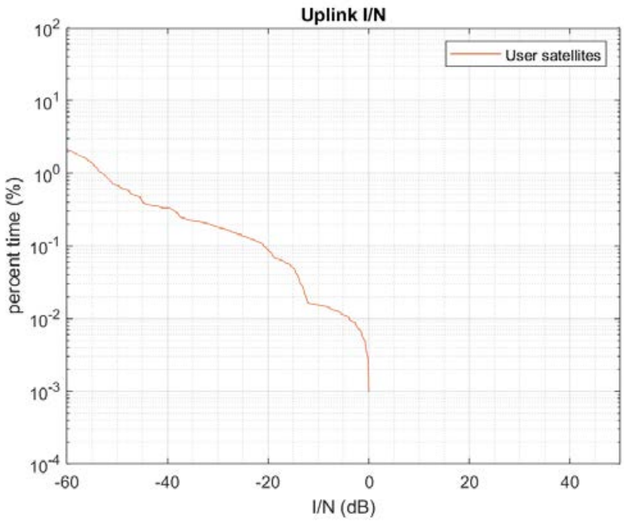


Figure 13: O3B MEO service provider, Theia victim

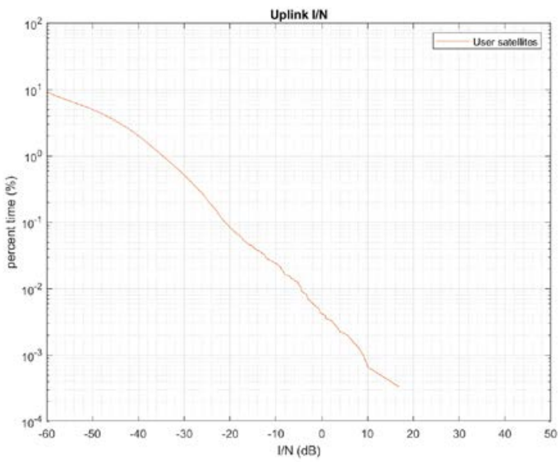


Figure 14: O3B MEO service provider, Kuiper victim

Annex B: Response to Orbital Debris Matters, Question 6

6) Please provide the following additional information concerning O3b's plans for orbital debris mitigation and additional supporting material with respect to United Kingdom regulation:

> *a. Please indicate whether the United Kingdom has reviewed and approved specifically the satellites covered by the application referenced above. If so, please provide copies of the authorization and the supporting materials submitted by O3b to obtain such authorization. If not, please provide the status of any such review and provide copies of any materials submitted for review.*

Because the design of the satellites covered by the Modification has not been finalized, O3b has not yet submitted information regarding the satellites to the United Kingdom to obtain authorization for the spacecraft.

> *b. Please provide references to and/or copies of any published criteria utilized by the United Kingdom for evaluation of the debris mitigation plans of satellites operating in MEO and LEO.*

The United Kingdom's Civil Aviation Authority (CAA), which recently assumed primary responsibility for regulating space activities in the United Kingdom, has published guidance for applicants seeking licenses under the United Kingdom's Outer Space Act 1986 and Space Industry Act 2018. In particular, Annex A of the CAA's "Guidance for Orbital Operator licence applicants and Orbital Operator Licensees" (July 2021)[1] provides a long, non-exhaustive list of "Best Practice Standards" applicable to various space activities, including (for example) the IADC Guidelines (IADC 02-0-1, 04-06), European Code of Conduct (European CoC), and ISO 24113:2019 (space systems-space debris mitigation requirements). As explained by the CAA, "Applicants are expected, as part of their licence application, to demonstrate to the regulator how they have adopted industry best practice/standards or, if they have chosen to use an alternative approach, to explain this and demonstrate why it is appropriate."[2]

> *c. To the extent not specifically addressed by the materials provided in response to items a and b above, please provide the information specified in 25.114(d)(14)(i)-(iv) of the Commission's rules.*

As noted above, O3b has not yet finalized the satellites' design or selected a manufacturer and therefore cannot yet provide complete information in response to these Commission rule provisions. However, compliance with the standards of the CAA and the Commission's rules on orbital debris mitigation, as well as with international standards on Space Debris including ISO 24113:2019, will be a design requirement and criteria to select the manufacturer of the O3b satellites. The relevant United Kingdom standards cover debris release, collision avoidance, prevention of explosions, and post-mission disposal.

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[1] Guidance for Orbital licence applications and Orbital Operator Licensees, available at: https://publicapps.caa.co.uk/docs/33/Guidance%20for%20Orbital%20Operator%20licence%20applicants%20and%20Orbital%20Operator%20Licensees%20(CAP2210).pdf.

[2] *Id*. at 33.

d. Please provide an estimate of the per satellite collision risk for any satellites that lose propulsion capability, using a representative sampling of orbits in which the satellite will operate (injection orbit, intermediate orbits reflecting the orbit raising process, main operational orbit, and failure prior to completion of re-orbiting at end of life).

The probability of collision (PoC) with large objects for any satellite that loses propulsion capability has been estimated using NASA DAS 3.2.1 and is summarized in the table below.

For the circular MEO equatorial and inclined MEO satellites, O3b performed the calculation using the largest area-to-mass ratio of the current O3b satellites, 12 m^2 area and 675 kg, giving 0.018 m^2/kg. O3b also assumed that propulsion is lost at the start of the ten-year lifetime.

The launcher selection and corresponding injection orbit and possible orbit raising have not yet been determined, so O3b has only analyzed the PoC for the satellites' mission lifetime and disposal phase.

Circular MEO Equatorial	Launch year	Altitude	Inclination	Area-to-Mass ratio	PoC per satellite over 10-year lifetime
Operational Orbit	2024	8062 km	0°	0.018	1.17E-06
Operational Orbit	2029	8062 km	0°	0.018	1.41E-06

Circular MEO Inclined	Launch year	Altitude	Inclination	Area-to-Mass ratio	PoC per satellite over 10-year lifetime
Operational Orbit	2024	8062 km	90°	0.018	5.59E-07
Operational Orbit	2029	8062 km	90°°	0.018	6.21E-07

For the LEO satellites in sun-synchronous orbits at 507 km altitude and 97.4 degree inclination, the planned dimensions are 100 mm x 100 mm x 300 mm. O3b used the largest area or high drag orientation of 0.03 m^2 for the estimate. With a mass of 3 kg this results in an area-to-mass ratio of 0.01 m^2/kg. O3b also assumed loss of maneuverability at the start of the operational lifetime. For the analysis O3b used launch years of 2024, around the Solar maximum in 2025, and 2029, around the solar minimum anticipated in 2032.

LEO sun-synchronous at 507 km	Launch year	Altitude	Inclination	Area-to-Mass ratio	PoC per satellite over lifetime including disposal
Operational Orbit including disposal	2024	507 km	97.4°	0.01	2.15E-07
Operational Orbit including disposal	2029	507 km	97.4°	0.01	4.19E-07

e. Please provide an estimate of the number of O3b satellites that will be launched over a 15-year period, including replacement satellites. We ask that you describe the basis for this estimate, including the criteria for replacing spacecraft and for estimating launch rates for the purposes of replenishing the constellation. Please consider in your estimate the anticipated rate of satellite failure that would require replacement of satellites prior to the end of their design life.

O3b estimates that it will launch up to 232 satellites over a 15-year period based on the calculations below.

O3b plans to launch the initial deployment of satellites proposed under the Modification within the first 3 to 4 years following authorization. The O3b MEO satellites will be designed with a lifetime of 10 years and will likely need to be replaced before the end of the 15-year period. Because there has not been a need to replace any of the 20 in-orbit MEO satellites, no failures are anticipated prior to the end of design life.

The O3b LEO satellites will have an orbital life between 2 years and 12 years, 6 years on average, depending on the launch date and the time spent in high or low drag attitude. We anticipate two replacement cycles of the LEO satellites over a 15-year period, up to 64 satellites.

These calculations produce a total estimate during 15 years of up to 168 satellites covered by this filling and up to 44 mPOWER satellites previously authorized.

	Initial Deployment	Lifetime	Anticipated replacement during 15 years	Total for 15 years
O3b MEO Equatorial	10		10	20
O3b MEO Inclined	24	10 years	24	48
O3b LEO	36	Min: 2 years Max: 12 years Average: 6 years	64	100
O3b mPOWER	22	10 years	22	44
Total O3b	112		120	232

f. Please identify any periods during the disposal phase for both LEO and MEO satellites where O3b satellites will not be capable of executing collision avoidance maneuvers, and if there are any such periods provide an estimated per satellite collision risk during that period.

The O3b MEO satellites in both equatorial and inclined orbits will be fully capable of executing collision avoidance maneuvers during the disposal phase until the final passivation of the propulsion system.

The O3b LEO satellites will be capable of executing collision avoidance maneuvers during the disposal phase until after transition to below the ISS altitude of 400 km. Further maneuverability below 400 km is still to be assessed. The remaining probability of collision with large objects during the passive disposal from 400 km is estimated below.

LEO sun-synchronous	Launch year	Altitude	Inclination	Area-to-Mass ratio	PoC per satellite over lifetime including disposal
Passive disposal from 400 km	2024	400 km	97.4°	0.01	4.65E-08
Passive disposal from 400 km	2029	400 km	97.4°	0.01	2.79E-08

g. Please provide a description of the process O3b uses and will use for responding to Conjunction Data Messages (CDMs), and more generally for collision avoidance. Please indicate if are any risk thresholds or lead time limits that inform whether and when an action will be required, the sequence of events from when a CDM is received to the time a collision avoidance maneuver is executed, etc. Please provide an analysis, considering an array of typical conjunctions in the O3b operational orbits, of whether high-risk events will be mitigated by at least one and one-half orders of magnitude below the mitigation action threshold. If O3b has not adopted a specific threshold, please use a 1E-5 threshold.

The collision avoidance process for the O3b satellites covered by the Modification will be fully integrated into the process used for all current O3b and other SES satellites. The process starts with an automated orbit determination and predicted ephemeris generation, including planned future maneuvers. This predicted ephemeris is uploaded to Space-track.org, the SatCen portal of the European Union Space Surveillance and Tracking system (SatCen), and the Space Data Association.

Upon reception of a Conjunction Data Message, the orbit of the secondary object is compared with the latest orbit and covariance prediction at time of closest approach (TCA). For the current and future O3b satellites in MEO equatorial and inclined orbits, if the probability of collision is larger than 10-6 at TCA, using a scaling of the covariance of the secondary object between 0.25 and 4, a maneuver is planned to reduce the PoC to below 1E-9.

A miss distance threshold of 4 km and PoC of 1E-8 are used as warning thresholds.

For the current O3b satellites the maneuver is typically planned more than 24 hours or 5 revolutions prior to TCA, to have backup maneuver opportunities. However, in case of an emergency, the 24/7 satellite controllers on shift can respond to a CDM, and a maneuver can be planned and executed in less than 4 hours.

The current planned design for the O3b LEO satellites does not include propulsion, but by re-orienting the attitude of the satellite from the low drag area (0.01 m^2) to the high drag area (0.03 m^2), changes can be made in the predicted position at TCA to respond to a predicted conjunction. An in-track separation of 1.5 km after 1 day at solar maxima and after 3 days at solar minima can be achieved in the event of a predicted conjunction. For the O3b LEO satellites an action threshold of PoC of 1E-5 and warning at threshold of 1E-6 will be used.

h. Please provide an estimate and description of the estimation method for the number of actionable conjunctions for the O3b satellite system, considering all operational orbits. Please also state, for the O3b MEO spacecraft already in orbit, how many CDMs have been received for such spacecraft, and any significant actions taken in response, including contacting other operators or executing a maneuver.

For the 20 current O3b MEO satellites in orbit, a total of 979 CDMs were received from April 2021 to March 2022. Of these, 20 CDMs pertaining to 8 individual conjunctions met the warning criteria, PoC > 1E-8 or miss distance < 4 km. No avoidance maneuvers were required during this period.

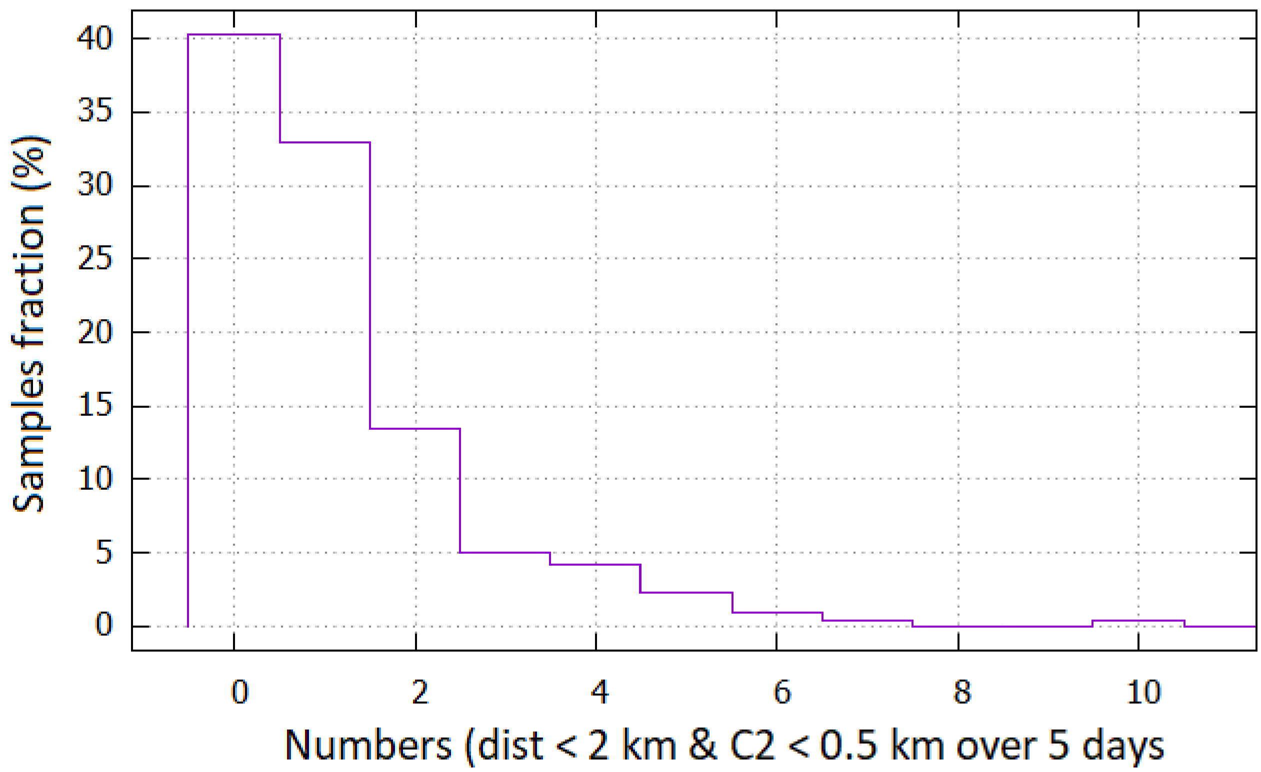
A total of 7 avoidance maneuvers have been performance to date since 2016, where the PoC was initially above the 1E-6 action threshold.

Using this historical data of 7 actionable conjunctions for the 20 satellites launched between June 2013 and April 2019 produces an average of one event for every 6.3 years of orbit time. That rate translates to an average of less than one (0.56) actionable conjunction event per satellite during its 10-year lifetime.

Comparing the PoC over a ten-year period between the O3b MEO inclined and equatorial spacecraft, the probability for the O3b inclined satellites is less than half that of O3b equatorial satellites, meaning on average 0.28 actionable conjunctions per O3b inclined satellite during its 10-year lifetime.

In order to estimate the number of actionable conjunctions for the O3b LEO satellites, we used the database of objects currently in orbit maintained by the 18th Space Control Squadron to assess, during a 5-day period, all objects that pass within 2 km in-track and 0.5 km cross-track of the O3b LEO orbit of 507 km altitude, 97.4° inclination, at various combinations of Right Ascension of the Ascending node (RAAN) and mean anomaly to simulate a range of O3b LEO operational orbits.

As shown in the plot below, in 40% of the all the simulated orbits there are no conjunctions during the 5-day period and for 87% of the orbits there are two or fewer conjunctions during a 5-day period, or 426 per year on average.



i. Please state whether O3b spacecraft will at any time after initial deployment transit the International Space Station (ISS) and Chinese space station altitudes, and, if so, please describe the design and operational strategies that will be used to minimize the risk of collisions with or operational impacts to the inhabitable spacecraft. Please indicate whether O3b spacecraft will be capable of maneuvering effectively in order to resolve conjunctions with inhabitable spacecraft at all times when transiting those altitudes. Please include in your response a discussion of any coordination with the operators of the ISS as well as an assessment of how many conjunctions and/or collision avoidance maneuvers might be required of the ISS, assuming it is in operation throughout the period in which O3b satellites would transit the ISS altitude.

The operational and disposal orbits of the O3b MEO satellites will remain above the ISS and Chinese space stations. The launcher selection, corresponding injection orbit, and orbit raising plans have not yet been determined. If the perigee of the injection orbit will be below the ISS and Chinese space station altitudes, the launch trajectory and initial orbit raising will be determined to avoid the space stations. During any possible orbit raising phase the ephemeris will be uploaded to Space-track.org and SatCen and screened for conjunction, and the orbit raising maneuver sequence will be adjusted to create separation at the predicted conjunction.

The O3b LEO satellites will be required to actively maneuver, using differential drag, during the disposal phase until after the transition to below the ISS altitude of 400 km.