REVISED SPACEX GEN2 NON-GEOSTATIONARY SATELLITE SYSTEM

ATTACHMENT A
AMENDED TECHNICAL INFORMATION TO SUPPLEMENT SCHEDULE S

As part of the 2020 NGSO processing round initiated by the International Bureau, Space Exploration Holdings, LLC ("SpaceX") filed an application requesting authority to deploy and operate its next-generation non-geostationary orbit ("NGSO") satellite system in the Fixed-Satellite Service ("FSS") using Ku-band, Ka-band, and E-band frequencies (the "Gen2 System").[1] Using its unique iterative approach over the intervening months, SpaceX has unlocked a path to further optimization of its network in light of upgraded satellite and launch capabilities. With this application, SpaceX amends its pending application to implement the changes necessary to achieve those improvements under two scenarios—one to leverage the full capabilities of its new rocket, Starship, with significantly increased capability to deliver satellites to orbit, and the other assuming continued deployment on its established and tested Falcon 9 launch vehicle.

This attachment updates the technical information submitted with the Original Application as necessary to reflect the newly proposed operations under both scenarios that cannot be fully captured by the Schedule S software. It does not attempt to set forth everything covered in Attachment A to the Original Application, but only those areas where the proposed amendment would result in a material change. In addition, this attachment includes several analyses demonstrating that any impact of the proposed amendment on other spectrum users would be negligible, regardless of which scenario is chosen. Section 25.116 of the Commission's rules provides that an amendment to a pending NGSO application that does not request any additional

1 *See* Application for Approval of Orbital Deployment and Operating Authority for the SpaceX Gen2 NGSO Satellite System, IBFS File No. SAT-LOA-20200526-00055 (filed May 26, 2020) ("Original Application").

spectrum or result in a significant increase in the potential for interference will be treated as a minor amendment that does not affect the status of the pending application with respect to any applicable processing round cut-off date.[2] In this case, the revised orbital parameters and related adjustments proposed in this amendment qualify as a minor amendment, as they do not request additional spectrum and will not have any material impact on other users of the Ku- and Ka-band spectrum.[3]

For the Commission's convenience, SpaceX has included in the accompanying Schedule S, and the database of technical parameters attached thereto, the information filed as part of the pending application with revisions associated with this amendment for each proposed orbital configuration. The accompanying Schedule S, with its attached database of technical parameters, therefore reflects the full system as amended under each scenario.

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2 *See* 47 C.F.R. § 25.116(b) and (c).

3 The Commission has not established a processing round for E-band applications, so there is no applicable cut-off date with respect to that spectrum.

ORBITAL PARAMETERS AND RELATED CHANGES

The Gen2 System described in SpaceX's Original Application proposed the satellite configuration shown in Table 1.

Altitude (km)	Inclination (degrees)	Orbital Planes	Satellites per Plane	Total Satellites
328	30	1	7,178	7,178
334	40	1	7,178	7,178
345	53	1	7,178	7,178
360	96.9	50	40	2,000
373	75	1	1,998	1,998
499	53	1	4,000	4,000
604	148	12	12	144
614	115.7	18	18	324

Table 1. Original Gen2 System Orbital Parameters

In this amendment, SpaceX proposes to revise the Gen2 System orbital parameters in one of two ways. The first option (Configuration 1) leverages the full capabilities of the Starship launch vehicle to deploy satellites, and results in the constellation set forth in Table 2.

Altitude (km)	Inclination (degrees)	Orbital Planes	Satellites per Plane	Total Satellites
340	53	48	110	5,280
345	46	48	110	5,280
350	38	48	110	5,280
360	96.9	30	120	3,600
525	53	28	120	3,360
530	43	28	120	3,360
535	33	28	120	3,360
604	148	12	12	144
614	115.7	18	18	324

Table 2. Amended Gen2 System Orbital Parameters (Configuration 1)

This is SpaceX's preferred configuration. By targeting multiple inclinations, these revised orbital parameters will more evenly distribute capacity by latitude, ensuring better, more consistent global coverage. SpaceX will also nearly double the number of satellites deployed in a sun-synchronous orbit optimized for key throughput demand times and service to polar regions like Alaska, resulting in additional capacity for those chronically underserved areas. The revised orbital planes enable "direct to station" launch campaigns that capitalize on the ability of Starship to deliver satellites at a faster pace.

Yet SpaceX has also developed an alternative configuration (Configuration 2) based on the assumption that it can further accelerate deployment by taking advantage of its reliable Falcon 9 rocket. Configuration 2 would (like Configuration 1) target multiple inclinations to more evenly spread capacity by latitude, ensuring better, more consistent global coverage. In this scenario, SpaceX would deploy Constellation 2 as set forth in Table 3.

Altitude (km)	Inclination (degrees)	Orbital Planes	Satellites per Plane	Total Satellites
328	30	5,816	1	5,816
334	40	5,816	1	5,816
346	53	5,816	1	5,816
360	96.9	40	50	2,000
510	14	72	23	1,656
515	22	72	23	1,656
520	30	72	23	1,656
525	53	72	23	1,656
530	45	72	24	1,728
535	38	72	24	1,728
604	148	12	12	144
614	115.7	18	18	324

Table 3. Amended Gen2 System Orbital Parameters (Configuration 2)

Both Configurations 1 and 2 will operate within an expanded altitude range of -50 km to +70 km.

This increased altitude range provides the operational flexibility needed in light of the denser atmospheric conditions in which Starlink operates, helping to account for the significant impact of solar cycles. SpaceX will generally observe a minimum elevation angle as low as 25 degrees, although certain shells may use lower elevations in certain circumstances as discussed more fully in the Original Application.[4]

Antenna Gain Contours and EIRP Density

Regardless of orbital configuration, all satellites in the Gen2 System have been designed with transmit and receive antenna beams that fall within a defined range of minimum and maximum gain. In its Original Application, SpaceX generally provided the antenna gain contours for satellites at the lowest and highest relevant operating altitudes with the lowest and highest antenna gains to illustrate the full range of values. Because the lowest operating altitude in Configuration 1 is 340 km rather than 328 km, SpaceX provides contours for satellites at that altitude embedded in the associated Schedule S and the accompanying Technical Database. The discussion below also reflects this new lowest operating altitude for Configuration 1, as well as the other newly proposed altitudes where appropriate.

As explained in the Original Application, Figure 1 below illustrates the steerable service range of satellite beams using generalized parameters.

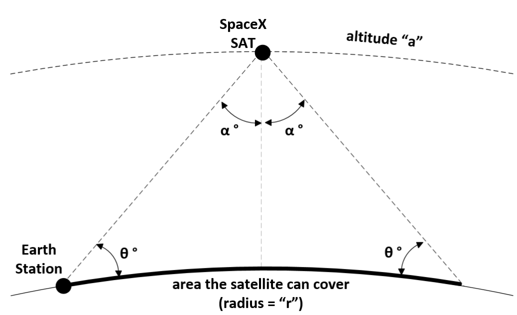

Figure 1: Steerable Service Range of Satellite Beams

[4] *See id.*, Attachment A at 6-15.

Table 4 provides the specific values for the parameters in Figure 1 for each of the new orbital altitudes proposed for Configurations 1 and 2 based on the minimum earth station elevation angle (θ) involved.

Altitude "a" [km]	340	346	350	510	515	520	525	530	535
Max steering angle α [deg]	59.4	59.3	59.2	57.1	57.0	56.9	56.9	56.8	56.7
Coverage radius "r" [km]	627.2	636.8	643.1	884.3	891.4	898.5	905.6	912.7	919.7

Table 4: Values for 25° Minimum Elevation Angle θ (New Configurations)

As illustrated in Figure 2 below with respect to Ku-band operations at the 340 km altitude, as the transmitting beam is steered, the power is adjusted to maintain a constant maximum power flux-density ("PFD") at the surface of the Earth, compensating for variations in antenna gain and path loss associated with the steering angle.

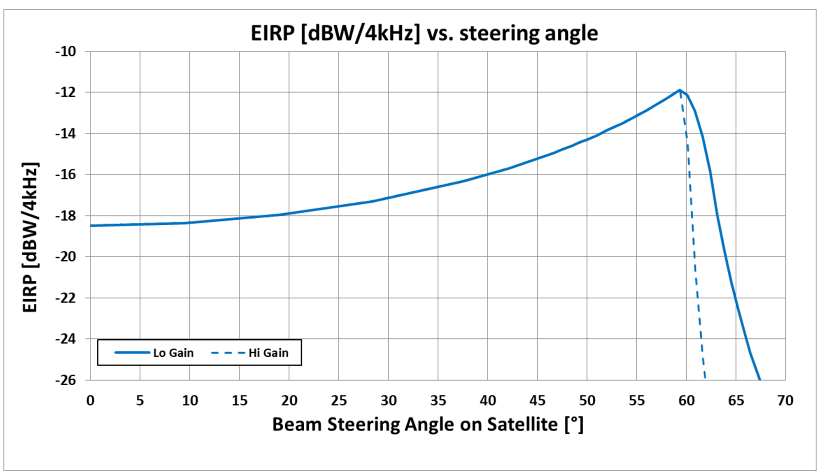

Figure 2. Ku-Band EIRP Density Variation by Beam Steering Angle (340 km)

Table 5 shows the maximum Ku-band equivalent isotropically radiated power ("EIRP") density at each proposed new operating altitude.

Altitude [km]	Max EIRP [dBW/4kHz]
340	-11.9
346	-11.7
350	-11.6
510	-8.7
515	-8.6
520	-8.5
525	-8.5
530	-8.4
535	-8.3

Table 5: Maximum Ku-Band EIRP Density at Various New Altitudes

The Ka-band antenna beam contours provided in Schedule S for Configuration 1 plot antenna gain contours (for both uplink and downlink beams used with gateways (parabolic) and user terminals (phased array) at the highest and lowest gain) for operations at the new lowest proposed altitude (i.e., 340 km rather than 328 km) at nadir and at 25°, 45°, and maximum slant away from nadir. As illustrated in Figures 3 and 4 below with respect to operations at 340 km altitude, as a satellite steers the Ka-band transmitting beam, it adjusts the power to maintain a constant PFD at the surface of the Earth.

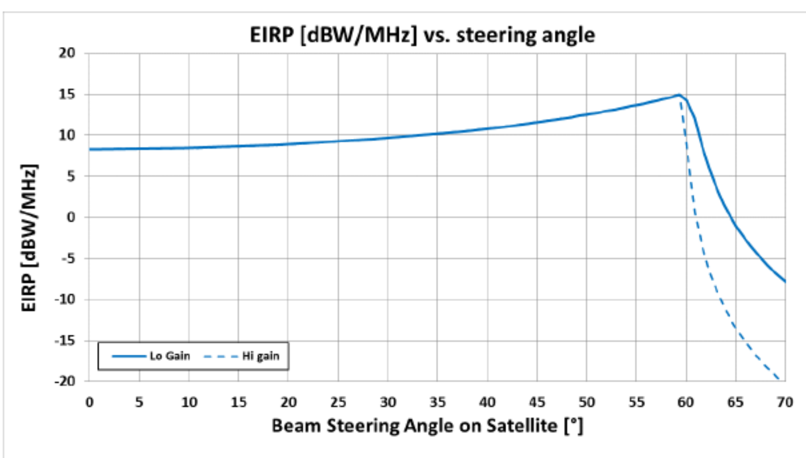

Figure 3: Ka-Band EIRP Density Variation by Gateway Beam Steering Angle (340 km, 25° min)

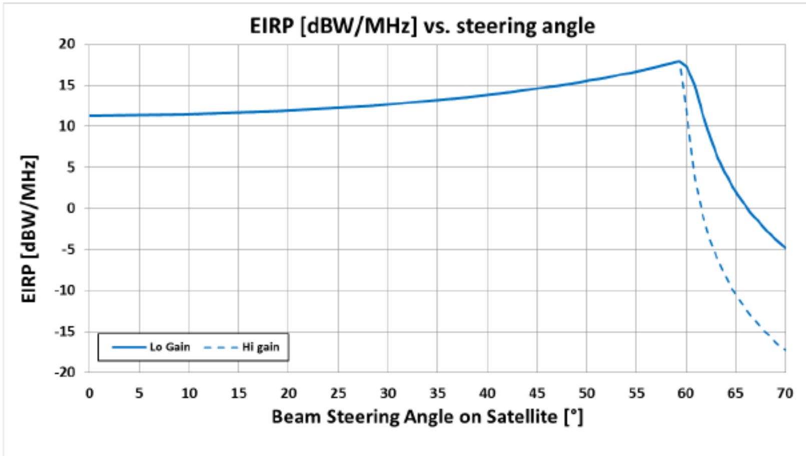

Figure 4: Ka-Band EIRP Density Variation by User Beam Steering Angle (340 km, 25° min)

Table 6 shows the maximum EIRP density at each proposed new operating altitude.

Altitude [km]	Max EIRP [dBW/MHz] (user beams)	Max EIRP [dBW/MHz] (gateway beams)
340	17.9	14.9
346	18.1	15.1
350	18.2	15.2
510	21.1	18.1
515	21.2	18.2
520	21.3	18.3
525	21.3	18.3
530	21.4	18.4
535	21.5	18.5

Table 6: Maximum Ka-Band EIRP Density at Various Altitudes

The Gen2 System will use E-band spectrum for communications with gateway earth stations only. The antenna beam contours provided in Schedule S for Configuration 1 plot contours (for both uplink and downlink beams with the highest and lowest gain) for operations at the new lowest proposed altitude (i.e., 340 km rather than 328 km) at nadir and at 25°, 45°, and maximum slant away from nadir. As illustrated in Figure 5 below with respect to operations at 340 km altitude, as a satellite steers the transmitting beam, it adjusts the power (in both polarizations) to maintain a constant PFD at the surface of the Earth.

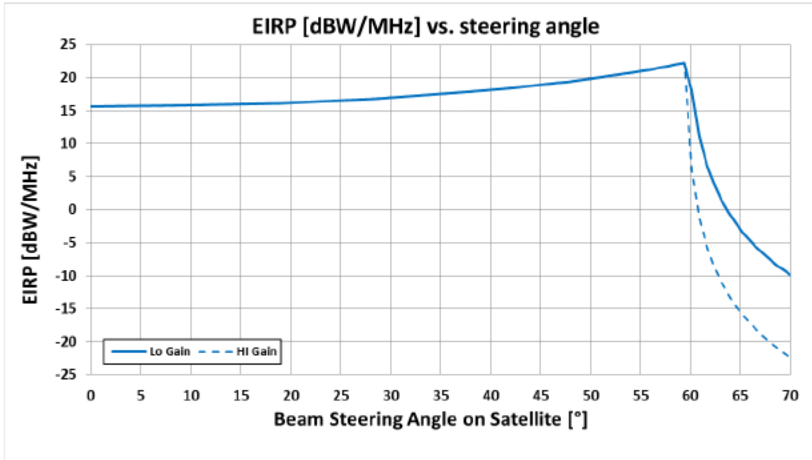

Figure 5: E-Band EIRP Density Variation by Beam Steering Angle (340 km, 25° min)

Table 7 shows the maximum EIRP density at each proposed new operating altitude.

Altitude [km]	Max EIRP [dBW/MHz]
340	22.2
346	22.4
350	22.5
510	25.4
515	25.5
520	25.6
525	25.6
530	25.7
535	25.8

Table 7: Maximum E-Band EIRP Density at Various Altitudes

The Gen2 System conducts its dedicated TT&C functions using omni-directional antennas on each satellite that are designed to communicate with earth stations at virtually any attitude (95% lowest of the 4 pi steradian antenna-gain sphere). The maximum transmit EIRP density, maximum and minimum G/T for receiving beams, and diagrams of the antenna gain contours for the new lowest altitude in Configuration 1 (340 km) are provided with the associated Schedule S.[5]

5 The one exception is the maximum transmit EIRP density for the Ku- and Ka-band TT&C downlink beams, which are -5.0 dBW and -3.0 dBW, respectively. Schedule S requires that the maximum transmit EIRP value for a beam be greater than 0 dBW. In order to accommodate this limitation, SpaceX has entered a value of "0" in Schedule S with respect to this parameter.

Power Flux-Density

The tables below show the PFD calculation for operations, both at maximum slant and at nadir, for Ku-band and Ka-band downlink beams from 340 km altitude (i.e., the lowest for Configuration 1). In each case, the table reflects operations at the lowest altitude and lowest gain—and, for the Ka-band, accounting for both polarizations—which presents a worst case, maximum PFD scenario without considering any of the operational constraints discussed above.

	Nadir	25° ES elev
EIRP density [dBW/Hz]	-54.5	-47.9
EIRP in 4kHz [dBW/4kHz]	-18.5	-11.9
EIRP in 1MHz [dBW/MHz]	5.5	12.1
Distance to Earth [km]	340.0	727.7
Spreading loss [dB]	121.6	128.2
PFD in 4 kHz [dB(W/m^2/4kHz)]	-140.1	-140.1
PFD in 1 MHz [dB(W/m^2/1MHz)]	-116.1	-116.1

Table 8. PFD at the Surface of the Earth Produced by Ku-band Downlink Transmissions (340 km)

	Nadir	25° ES elev
EIRP density [dBW/Hz]	-51.7	-45.1
EIRP in 1MHz [dBW/MHz]	8.3	14.9
Distance to Earth [km]	340.0	727.7
Spreading loss [dB]	121.6	128.2
PFD in 1 MHz [dB(W/m^2/1MHz)]	-113.3	-113.3

Table 9. PFD at the Surface of the Earth Produced by Ka-band Gateway Downlink Transmissions (340 km)

	Nadir	25° ES elev
EIRP density [dBW/Hz]	-48.7	-42.1
EIRP in 1MHz [dBW/MHz]	11.3	17.9
Distance to Earth [km]	340.0	727.7
Spreading loss [dB]	121.6	128.2
PFD in 1 MHz [dB(W/m^2/1MHz)]	-110.3	-110.3

Table 10. PFD at the Surface of the Earth Produced by Ka-band User Downlink Transmissions (340 km)

In addition, because the satellite downlink transmit power is adjustable on orbit, SpaceX has the ability to manage the satellites' PFD levels during all phases of the mission, as needed. Below, we plot these PFD values against the relevant PFD limits applicable in the various frequency bands used by the Gen2 System Configuration 1 for the 340 km altitude shell.[6]

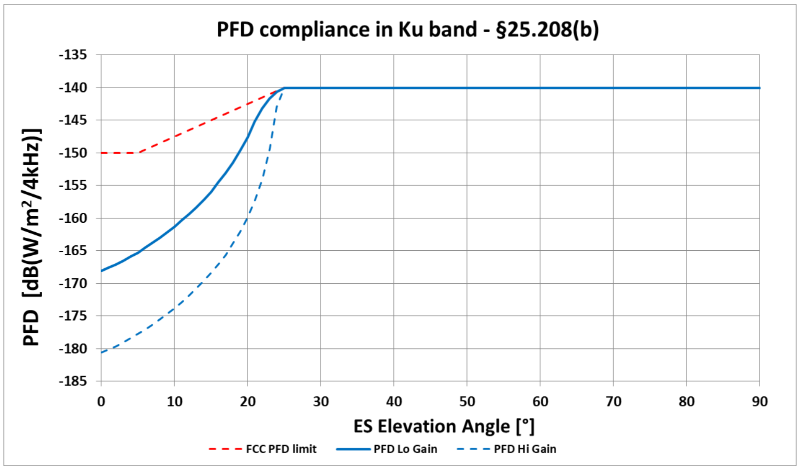

Figure 6. Compliance with Downlink PFD Limits in the 10.7-11.7 GHz Band (340 km)

The ITU Radio Regulations include PFD limits across the 11.7-12.7 GHz band that are effectively 2 dB higher than the PFD limits in the 10.7-11.7 GHz band plotted above.[7] Accordingly, given that the Gen2 System will comply with the lower limits applicable in the 10.7-11.7 GHz band, it will also comply with the limits applicable in the 11.7-12.7 GHz band.[8]

Section 25.208(o) of the Commission's rules specifies low elevation PFD limits that apply in the 12.2-12.7 GHz band to protect the Multichannel Video and Data Distribution Service ("MVDDS"). Figure 7 below shows that satellites in the proposed new 340 km shell of

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6 Neither the Commission nor the ITU has adopted PFD limits in the E-band.

7 *See* ITU Radio Regs., Table 21-4.

8 In the Ku-band, SpaceX will operate TT&C downlinks in the 12.15-12.25 GHz band. The maximum EIRP for the TT&C links is always below the minimum EIRP radiated in any direction by the user links in this band. As a result, the PFD created when TT&C links in this band are active falls significantly below the PFD created due to operational links in all cases. Because, as demonstrated above, the Ku-band operational links comply with the applicable PFD limits, the TT&C downlinks necessarily will do so as well. Moreover, SpaceX plans to deploy only two TT&C earth stations in the U.S. – one on the East Coast and one on the West Coast. Areas outside the immediate vicinity of those facilities would be unaffected by their operations. Accordingly, SpaceX's TT&C operations in this band should prompt no concern.

Configuration 1 will comply with these limits as well.

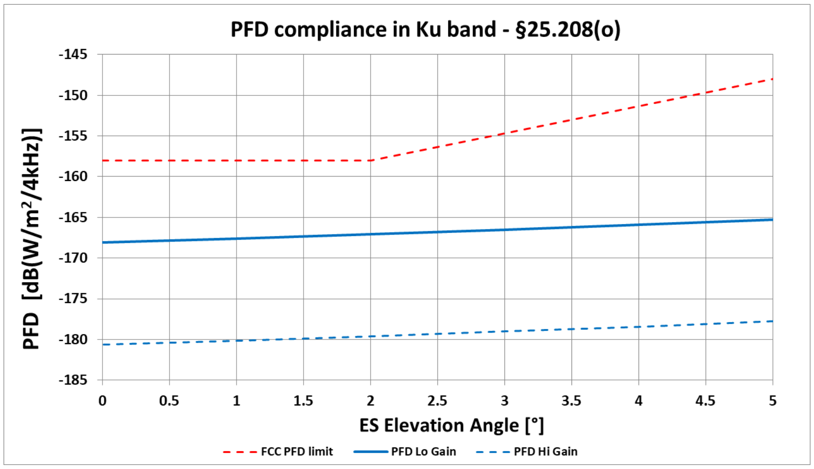

Figure 7. Compliance with Downlink PFD Limits in the 12.2-12.7 GHz Band (340 km)

Operations at this lowest shell of Configuration 1 provide a worst-case PFD scenario, yet still remain compliant over the full range of antenna gains. Accordingly, all Ku-band downlink transmissions from SpaceX satellites operating in the proposed Configuration 1 constellation will comply with all applicable Commission and ITU PFD limits in the Ku-band.

With respect to the Ka-band, the ITU has adopted a single set of PFD limits for NGSO systems across the entire 17.7-19.3 GHz band, which the Commission has incorporated by reference into its rules as well.[9] Unlike the limits applicable to the Ku-band, here the limits are expressed as a function of the number of satellites in the entire NGSO system, without any consideration to whether the satellites are in view of the terrestrial system or whether the satellites are turned on or off. As SpaceX explained in its Original Application, the ITU methodology for establishing the Ka-band PFD limits was not developed with capability to scale up for application to dynamically controlled NGSO constellations with more than 840 satellites.[10] As a result, the

9 *See* ITU Radio Regs., Table 21-4; 47 C.F.R. § 25.108(a)(2).

10 *See, e.g.,* Application, IBFS File No. SAT-LOA-20161115-00118, Attachment A at 29-32 (filed Nov. 15, 2016).

Gen2 System complies with the PFD limits specified by the Commission and the ITU at most elevation angles, but below about twenty-five degrees for communications links and twelve degrees for TT&C the flawed calculation technique appears to yield a result that exceeds the limit.

In granting SpaceX's *Initial Authorization*, the Commission agreed with several points raised by SpaceX, "in particular that the ITU limits were derived for constellations up to 840 satellites and under worst case assumptions."[11] Accordingly, in its Original Application, SpaceX requested a waiver of these PFD limits and also submitted a technical showing demonstrating that its operation will protect a fixed-service station with the characteristics described in Recommendation ITU-R SF.1483—i.e., the type of showing previously required for SpaceX's first-generation system.[12] Annexes 1A and 1B to this Technical Attachment present revised analyses demonstrating that Configurations 1 and 2 of the Gen2 System, respectively, will continue to protect terrestrial fixed services after taking the proposed amendment into account.

Spectrum Sharing Analyses

As discussed above, the revised orbital parameters and related adjustments proposed in this amendment qualify as a minor amendment, as they will not have any material impact on other users of the Ku- and Ka-band spectrum.[13] SpaceX demonstrated above that its amended Gen2 System under both Configurations 1 and 2 will continue to protect terrestrial systems by complying with the applicable Ku-band PFD limits.[14] To further demonstrate that this amendment will not increase interference, SpaceX has included in this Technical Attachment two analyses of the

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11 *See Space Exploration Holdings, LLC*, 33 FCC Rcd. 3391, ¶ 35 (2018) ("*Initial Authorization*").

12 *See id.*

13 *See* 47 C.F.R. § 25.116(b) and (c). The Commission has not established a processing round for E-band applications, so there is no applicable cut-off date with respect to that spectrum.

14 *See Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range*, 16 FCC Rcd. 4096, ¶ 42 (2000) (observing PFD limits should protect terrestrial systems in the band).

interaction between its system as amended for each configuration and other spectrum users, including proposed systems in the 2020 Processing Round. Annexes 1A and 1B, discussed above, present a revised analysis to demonstrate that SpaceX's operations will protect terrestrial fixed services operating in the Ka-band. Annexes 2A and 2B present analyses that consider the dynamic, time-varying interference between Configuration 1 and 2, respectively, and other NGSO systems proposed in the 2020 Processing Round expressed as a cumulative distribution function ("CDF") of the interference-to-noise ratio ("I/N"), for varying percentages of time. The I/N CDF is derived from a time-domain simulation of the two NGSO systems over a long enough time to produce meaningful statistics. Specifically, the analysis considers the effect of the proposed configurations on pending applications for two NGSO systems hypothetically operating in the Ku-band (OneWeb and Kepler) and five pending applications for hypothetical operations in the Ka-band (Amazon, O3b, OneWeb, Telesat, and Viasat). That analysis demonstrates that the amendment (regardless of configuration) would have a negligible effect on the interference environment of other NGSO systems proposed in the 2020 Processing Round.[15]

As these analyses confirm, the changes proposed in this amendment will not increase interference for other systems that share spectrum bands with the Gen2 System, no matter which configuration SpaceX deploys. In addition, pursuant to Section 25.146(a)(2) of the Commission's rules, SpaceX hereby certifies that its Gen2 System, as amended to either configuration, will comply with the applicable EPFD limits.

15 There is no need to provide an interference analysis with respect to NGSO systems authorized in prior processing rounds because all licensees in the 2020 Processing Round (including SpaceX) will be required to "coordinate to prevent harmful interference to operational systems licensed or granted U.S. market access in the previous NGSO FSS processing rounds." *Kuiper Systems LLC*, 35 FCC Rcd. 8324, ¶ 34 (2020) ("*Kuiper Authorization*").

ORBITAL DEBRIS MITIGATION

In its Original Application, SpaceX discussed the Gen2 System's orbital debris mitigation characteristics at length. Accordingly, this section discusses only those aspects that will change as a result of this amendment. The most significant change results from the new orbital parameters proposed in this application for the new configurations. Although all Gen2 satellites will be equipped with a propulsion system that can respond quickly and at high cadence, in case of an anomaly the new operational altitudes would affect the potential collision risk as well as the time it would take for a satellite to passively de-orbit. In addition, SpaceX has continued to refine the design of its Gen2 System satellites, which will be somewhat larger and generate more power than originally contemplated, enabling them to support expanded capabilities now and accommodate additional payloads in the future. As a result, this analysis assumes a larger and heavier satellite than assumed in the Original Application.

As the Commission has recognized, because SpaceX has invested in advanced propulsion capabilities for its satellites, collision risk with large objects is considered to be zero while the spacecraft are capable of maneuvering.[16] While SpaceX expects its satellites to perform nominally and deorbit actively, in the unlikely event a vehicle is unable to finish its planned disposal maneuver, the denser atmospheric conditions at the low altitudes proposed herein for use by the Gen2 System provide fully passive redundancy to SpaceX's active disposal procedures. Even assuming a worst-case scenario—i.e., the spacecraft loses maneuverability while in the operational orbit and has no attitude control—the longest demise time for either configuration is still less than

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[16] *See Space Exploration Holdings, LLC,* FCC 21-48, ¶ 58 (rel. Apr. 27, 2021) (finding that "the range in which this risk level falls appears to be sufficiently low to justify treating it as zero"). *See also Mitigation of Orbital Debris in the New Space Age*, 35 FCC Rcd. 4156, ¶ 35 (2020) ("*Orbital Debris Update Order*") (adopting the simplifying assumption that "the collision risk with large objects should be assumed zero or near zero during the period of the time when the space station is able to conduct collision avoidance maneuvers").

four years. These short demise times also significantly limit the risk of collision in the event that a satellite loses maneuverability while in operational orbit. Tables 11 and 12 below show the revised demise time and probability of collision between a space object larger than 10 cm in diameter and a Gen2 System satellite at each of the various operating altitudes proposed in Configurations 1 and 2, respectively, assuming that the satellite has lost all maneuver capability and attitude control (i.e., is tumbling).[17]

Altitude (km)	Demise Time (yrs)	Collision Risk
340	0.038	1.86E-06
345	0.042	2.06E-06
350	0.044	2.16E-06
360	0.056	4.33E-06
525	1.288	3.24E-04
530	1.374	3.31E-04
535	1.463	3.39E-04
604	2.780	1.25E-03
614	3.430	1.99E-03

Table 11. Revised Demise Time and Collision Risk Assuming No Maneuver Capability (Configuration 1)

Altitude (km)	Demise Time (yrs)	Collision Risk
328	0.028	1.13E-06
334	0.033	1.39E-06
346	0.043	2.21E-06
360	0.056	4.33E-06
510	0.984	1.97E-04
515	1.072	2.20E-04
520	1.167	2.51E-04
525	1.288	3.24E-04
530	1.335	3.31E-04
535	1.473	3.21E-04
604	2.780	1.25E-03
614	3.430	1.99E-03

Table 12. Revised Demise Time and Collision Risk Assuming No Maneuver Capability (Configuration 2)

[17] Although SpaceX previously provided information for satellites with and without sun shade panels, it now designs all satellites with sun shade panels and so assumes that configuration for all purposes.

Of course, even these collision risk calculations present an overly pessimistic picture since the vast majority of SpaceX satellites will not fail in orbit and will continue to maneuver to achieve an effective collision risk of zero.

Moreover, due to SpaceX's decision to minimize risk by using a low injection altitude when possible, in the unlikely event any satellites after the initial launch lose maneuverability immediately upon deployment, they would decay to the point of demise within a few months even under worst-case conditions. This short demise period significantly reduces the potential for collisions for such satellites. Table 13 below shows the revised demise time and probability of collision between a space object larger than 10 cm in diameter and a SpaceX satellite if rendered totally incapacitated immediately following orbital injection.

	Demise Time (yrs)	**Collision Risk**
Stowed Configuration	0.231	4.29E-07
Deployed Configuration	0.018	8.83E-07

Table 13. Revised Demise Time and Collision Risk Assuming Incapacitated Satellite at Injection

Here again, SpaceX satellites satisfy the Commission's safety standard by several orders of magnitude even assuming failure upon deployment.

Since SpaceX filed its original Gen2 System application, the Commission has granted one application and received two others for NGSO systems whose normal operation poses a risk of collision with the orbital altitudes requested in both the Original Application and in this amendment. Specifically, the Commission granted the application of Kuiper Systems LLC for an NGSO constellation operating at 590 km, 610 km, and 630 km.[18] It has also received applications

[18] *See Kuiper Authorization*, *supra* note 13.

in the 2020 Processing Round from (1) Kepler Communications, Inc. proposing to deploy satellites at 600 km altitude, and (2) O3b Limited proposing to deploy satellites at 507 km.[19] SpaceX continues to believe—and has demonstrated—that physical coordination is practicable, facilitated by the maneuverability of its system and its willingness to share information on the operations of its system.

SpaceX is also aware of the possibility that its system could become a source of debris in the unlikely case of a collision with small debris or meteoroids that could either create jetsam or cause loss of control of the spacecraft and prevent post-mission disposal. SpaceX has continued to explore ways to make its spacecraft even more resistant to such strikes. Although the design of these protective features is still being finalized, SpaceX has improved redundancy in the power and propulsion systems. As a result, SpaceX has maintained an overall probability of collision with small debris (down to one millimeter in diameter) sufficient to prevent compliance with post-mission disposal maneuvers of less than 0.01 for an individual Gen2 space station during its mission lifetime.

Although the latest design for Gen2 System spacecraft anticipates a slightly larger satellite, SpaceX has used internal software leveraging NASA's Debris Assessment Software to provide higher fidelity re-entry survivability analysis and has confirmed that all Gen2 satellites—whether deployed in Configuration 1 or Configuration 2—are fully demisable upon atmospheric re-entry. Accordingly, the calculated risk of human casualty remains zero.

[19] *See* IBFS File Nos. SAT-LOA-20200526-00059 and SAT-MOD-20200526-00058.

ENGINEERING CERTIFICATION

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

/s/ *Mihai Albulet*
Mihai Albulet, PhD
Principal RF Engineer
SPACE EXPLORATION TECHNOLOGIES CORP.

August 18, 2021
Date

ANNEX 1A

POTENTIAL INTERFERENCE TO KA-BAND FIXED SERVICE SYSTEMS—CONFIGURATION 1

As SpaceX demonstrates below, the SpaceX Gen2 constellation, as modified herein under Configuration 1, would continue to protect fixed-service ("FS") stations with the characteristics described in Recommendation ITU-R SF.1483. For purposes of this analysis, SpaceX used the following assumptions:

1. FS link characteristics per Recommendation ITU-R SF.1483

Parameters	Specifications
Elevation Angles	0° and 2.2°
FS Antenna Height (m)	0
FS Antenna Gain (dBi)	32, 38, and 48
FS Antenna Pattern	Per Rec. ITU-R F.1245
Latitude (degrees)	24° N, 45° N, 60° N
Atmospheric Attenuation	Not considered (conservative)
Feeder Loss (dB)	3
Polarization Loss	0, per Rec. ITU-R F.1245 (Note 7)
Rx Thermal Noise (dBW/MHz))	-139

2. SpaceX proposed modified constellation, Configuration 1

Altitude (km)	Inclination (degrees)	Orbital Planes	Satellites per Plane	Total Satellites
340	53	48	110	5,280
345	46	48	110	5,280
350	38	48	110	5,280
360	96.9	30	120	3,600
525	53	28	120	3,360
530	43	28	120	3,360
535	33	28	120	3,360
604	148	12	12	144
614	115.7	18	18	324

3. Protection criteria used in this analysis per Rec. ITU-R F.1495:

   a. Long-term: I/N should not exceed –10 dB for more than 20% of the time in any year.
   b. Short-term: I/N should not exceed +14 dB for more than 0.01% of the time in any month, and I/N should not exceed +18 dB for more than 0.0003% of the time in any month.

For a given FS victim antenna gain, latitude, and elevation, the analysis considers the worst-case antenna pointing. Because SpaceX operates with up to thirty-two co-frequency beams per spot in Ka-band, the analysis considers beams from the thirty-two satellites whose beams would be closest to boresight for the terrestrial antenna, and also includes the contribution of the sidelobes from all other SpaceX satellites in view. Note that this is a conservative analysis as it does not account for the mitigating effect of atmospheric attenuation.

The results are shown in Figures A1a-1 to A1a-6 below. In each case, the results are shown for the full proposed modified SpaceX constellation at a minimum elevation angle of 25 degrees. Note that in all cases, the aggregate I/N are lower than ITU-R F.1495 long-term and short-term limits.

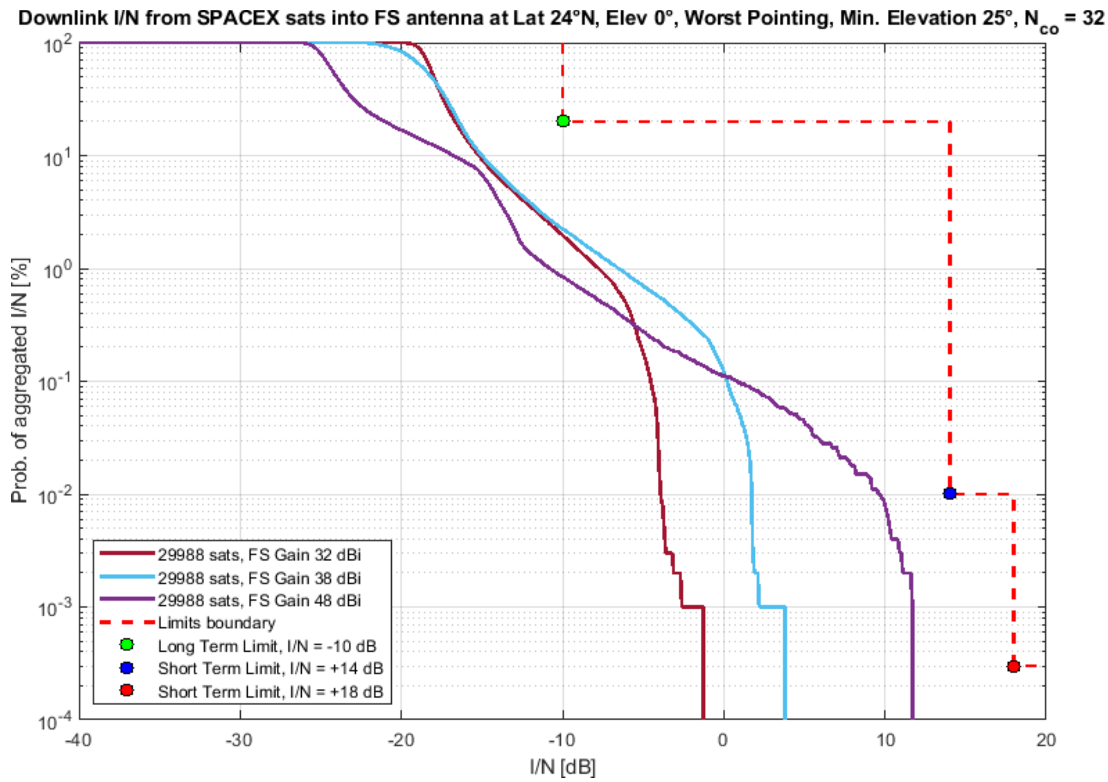

Figure A1a-1. FS Station: Lat. 24°, Elevation 0°

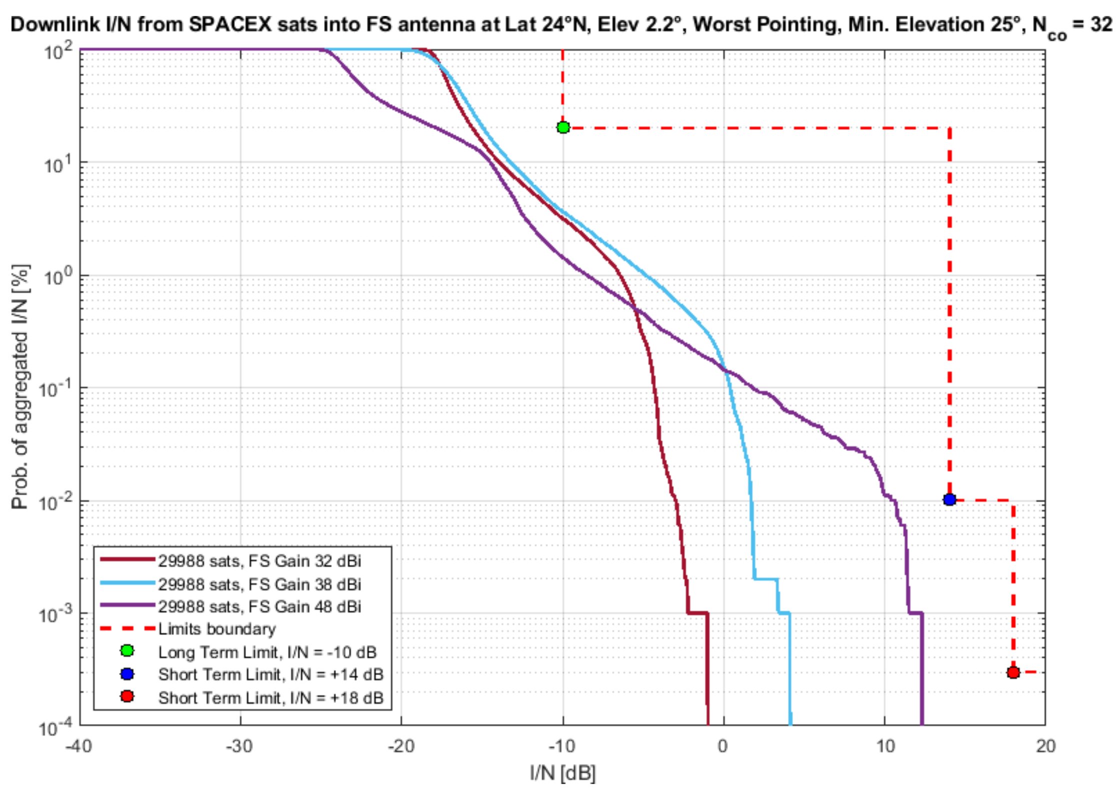

Figure A1a-2. FS Station: Lat. 24°, Elevation 2.2°

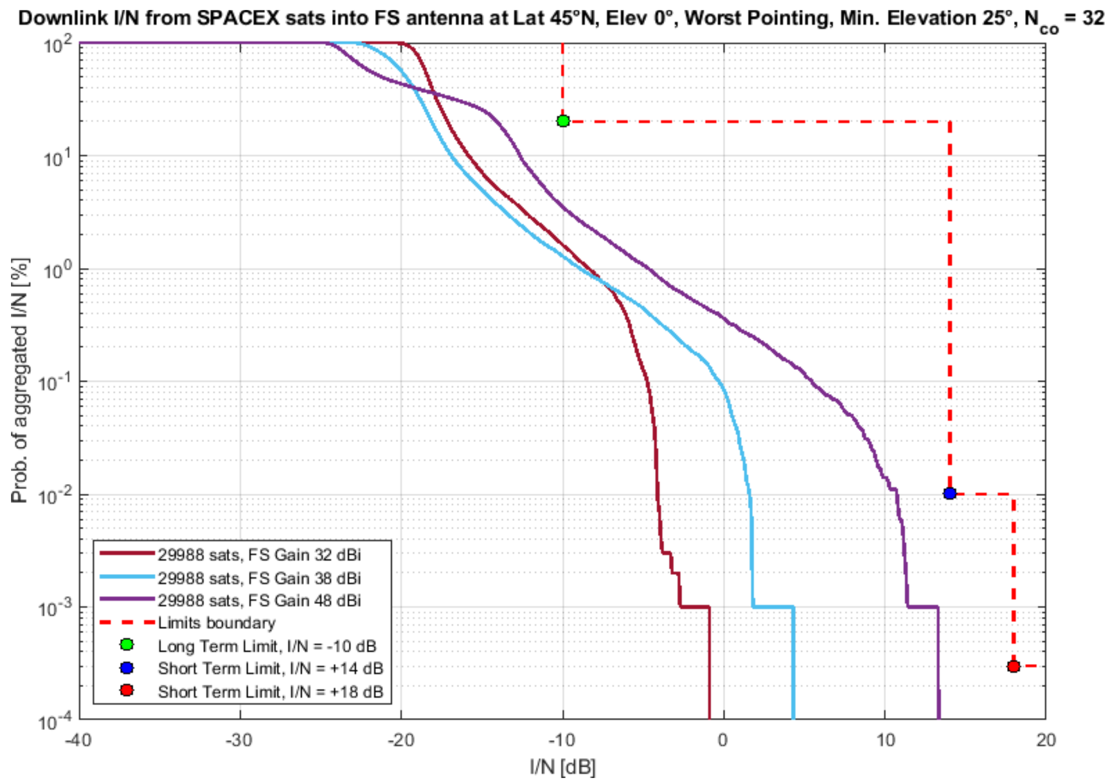

Figure A1a-3. FS Station: Lat. 45°, Elevation 0°

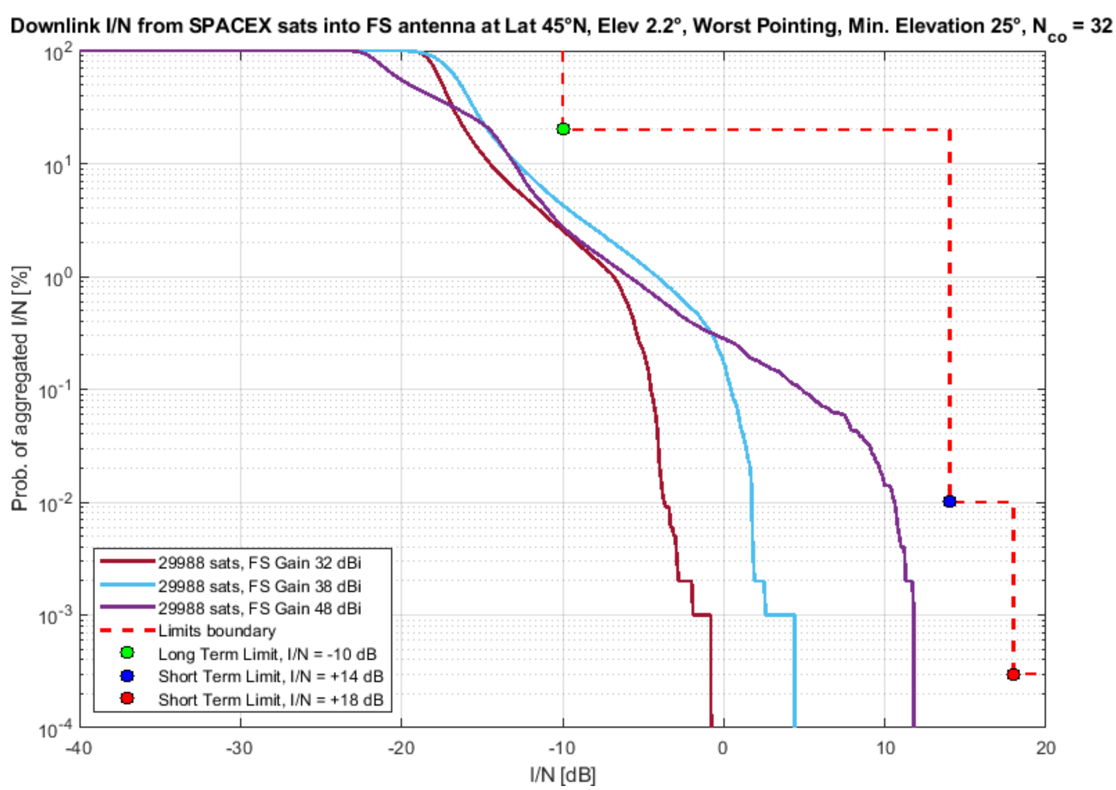

Figure A1a-4. FS Station: Lat. 45°, Elevation 2.2°

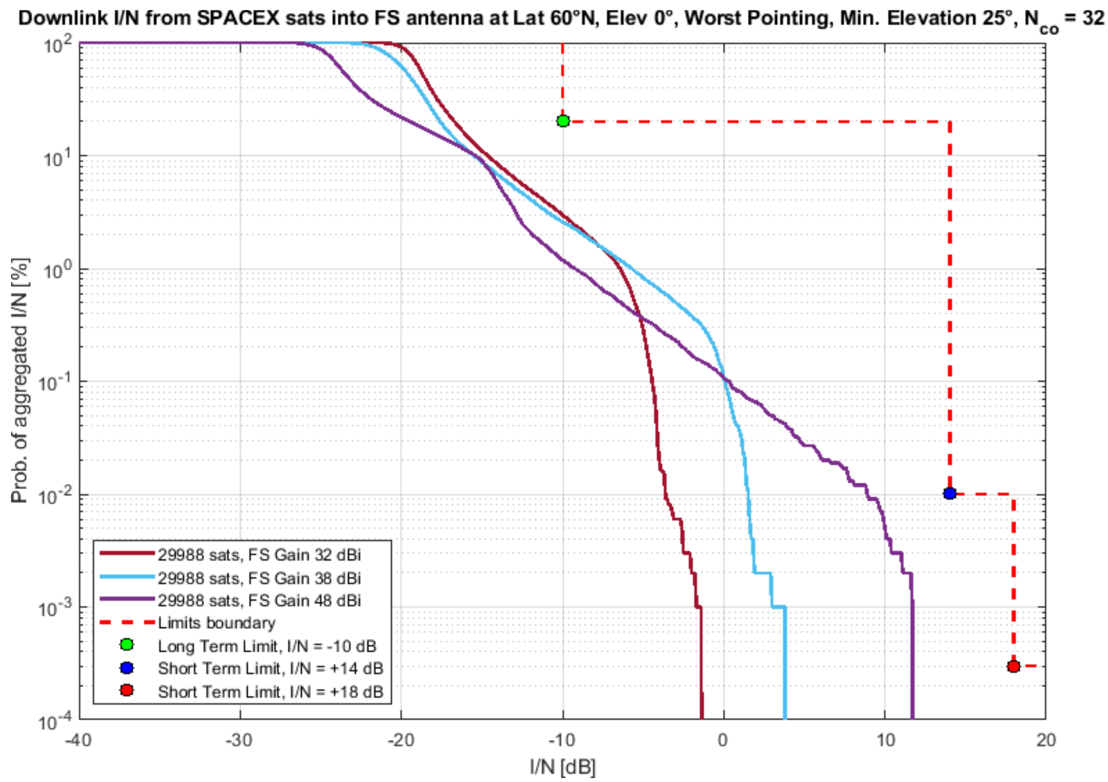

Figure A1a-5. FS Station: Lat. 60°, Elevation 0°

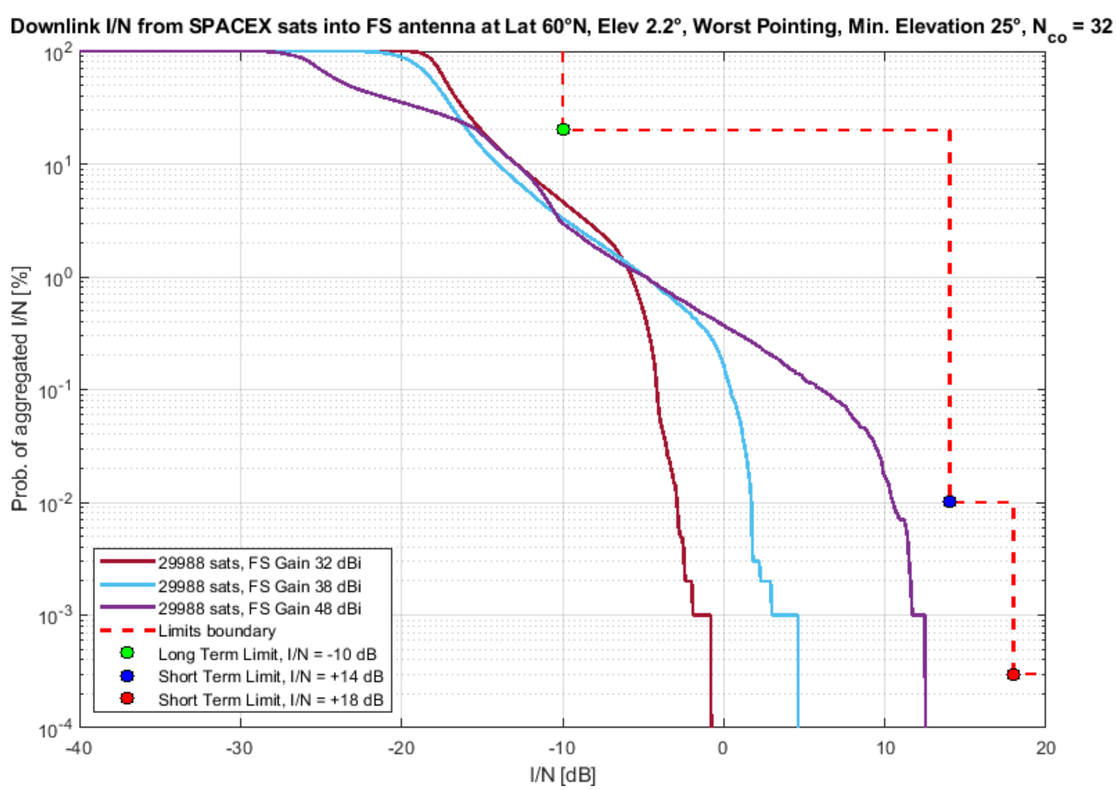

Figure A1a-6. FS Station: Lat. 60°, Elevation 2.2°

ANNEX 1B

Potential Interference to Ka-band Fixed Service Systems—Configuration 2

As SpaceX demonstrates below, the SpaceX Gen2 constellation, as modified herein under Configuration 2, would continue to protect fixed-service ("FS") stations with the characteristics described in Recommendation ITU-R SF.1483. For purposes of this analysis, SpaceX used the following assumptions:

1. FS link characteristics per Recommendation ITU-R SF.1483

Parameters	Specifications
Elevation Angles	0° and 2.2°
FS Antenna Height (m)	0
FS Antenna Gain (dBi)	32, 38, and 48
FS Antenna Pattern	Per Rec. ITU-R F.1245
Latitude (degrees)	24° N, 45° N, 60° N
Atmospheric Attenuation	Not considered (conservative)
Feeder Loss (dB)	3
Polarization Loss	0, per Rec. ITU-R F.1245 (Note 7)
Rx Thermal Noise (dBW/MHz))	-139

2. SpaceX proposed modified constellation, Configuration 2

Altitude (km)	Inclination (degrees)	Orbital Planes	Satellites per Plane	Total Satellites
328	30	5,816	1	5,816
334	40	5,816	1	5,816
346	53	5,816	1	5,816
360	96.9	40	50	2,000
510	14	72	23	1,656
515	22	72	23	1,656
520	30	72	23	1,656
525	53	72	23	1,656
530	45	72	24	1,728
535	38	72	24	1,728
604	148	12	12	144
614	115.7	18	18	324

3. Protection criteria used in this analysis per Rec. ITU-R F.1495:

    a. Long-term: I/N should not exceed –10 dB for more than 20% of the time in any year.
    b. Short-term: I/N should not exceed +14 dB for more than 0.01% of the time in any month, and I/N should not exceed +18 dB for more than 0.0003% of the time in any month.

For a given FS victim antenna gain, latitude, and elevation, the analysis considers the worst-case antenna pointing. Because SpaceX operates with up to thirty-two co-frequency beams per spot in Ka-band, the analysis considers beams from the thirty-two satellites whose beams would be closest to boresight for the terrestrial antenna, and also includes the contribution of the sidelobes from all other SpaceX satellites in view. Note that this is a conservative analysis as it does not account for the mitigating effect of atmospheric attenuation.

The results are shown in Figures A1b-1 to A1b-6 below. In each case, the results are shown for the full proposed modified SpaceX constellation at a minimum elevation angle of 25 degrees.

Note that in all cases, the aggregate I/N are lower than ITU-R F.1495 long-term and short-term limits.

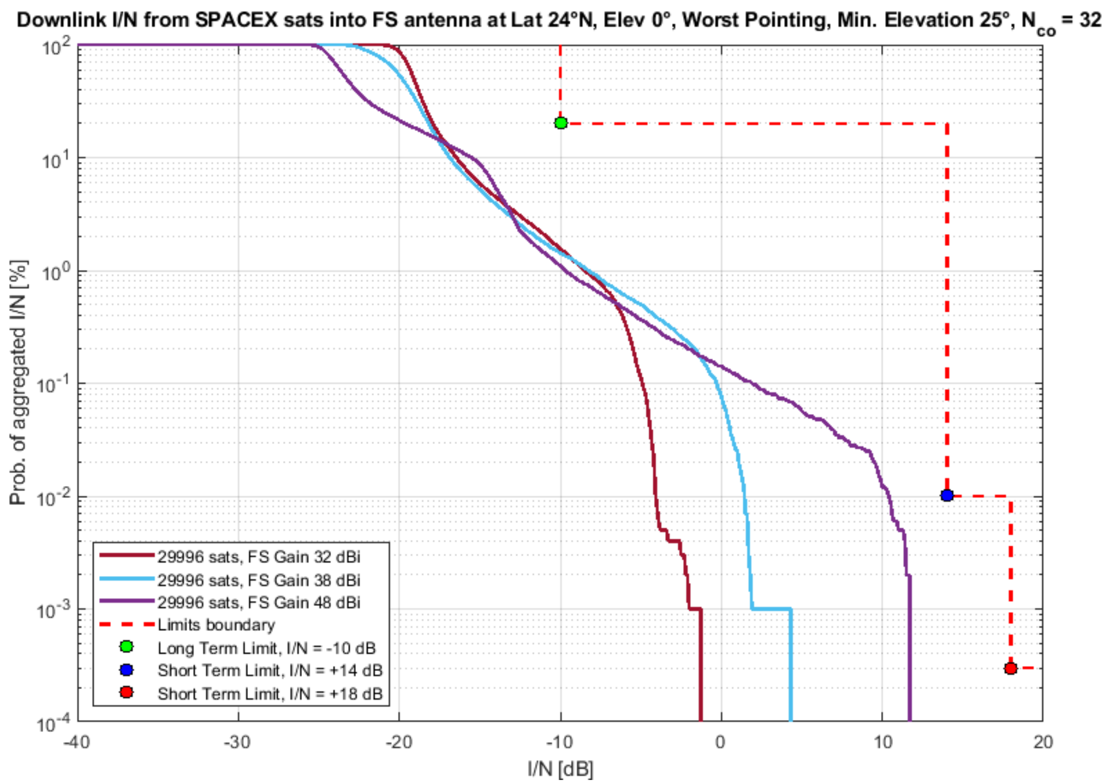

Figure A1b-1. FS Station: Lat. 24°, Elevation 0°

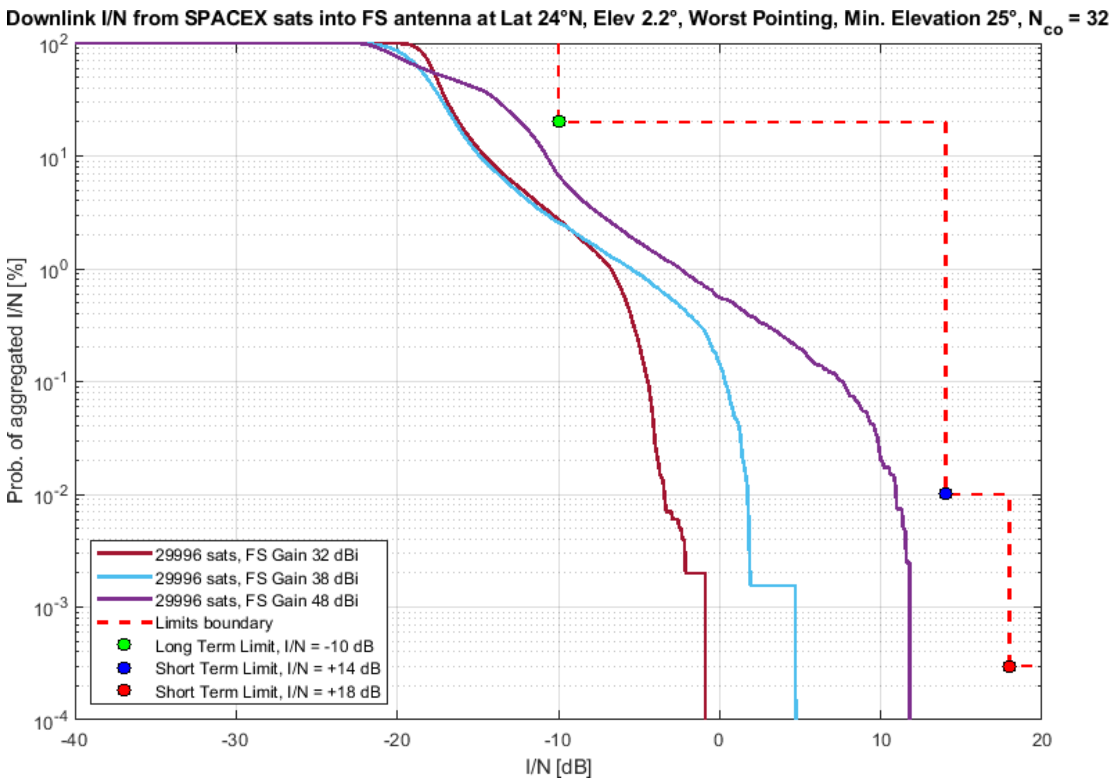

Figure A1b-2. FS Station: Lat. 24°, Elevation 2.2°

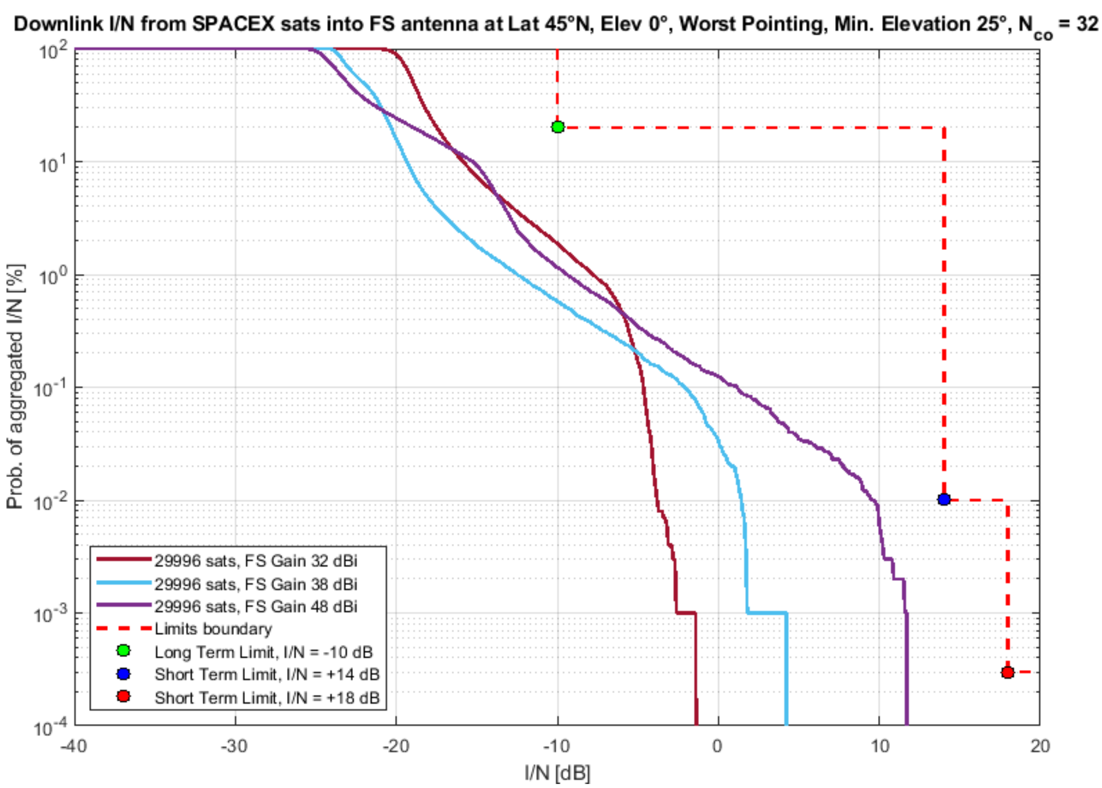

Figure A1b-3. FS Station: Lat. 45°, Elevation 0°

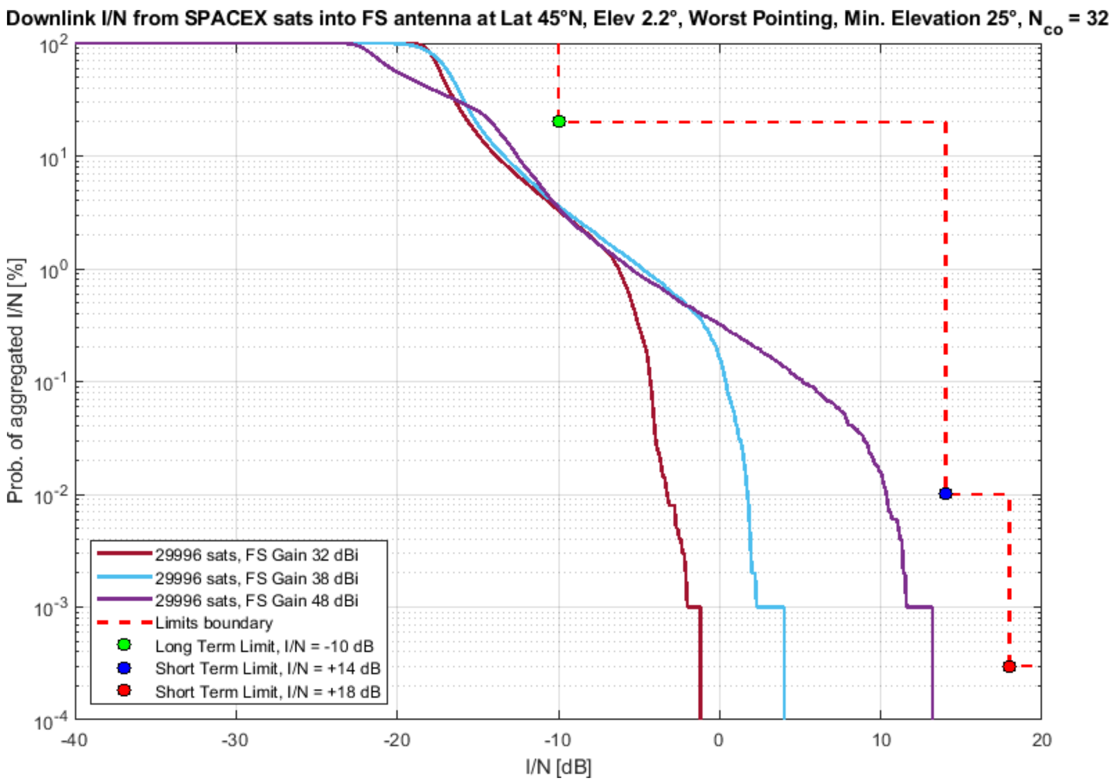

Figure A1b-4. FS Station: Lat. 45°, Elevation 2.2°

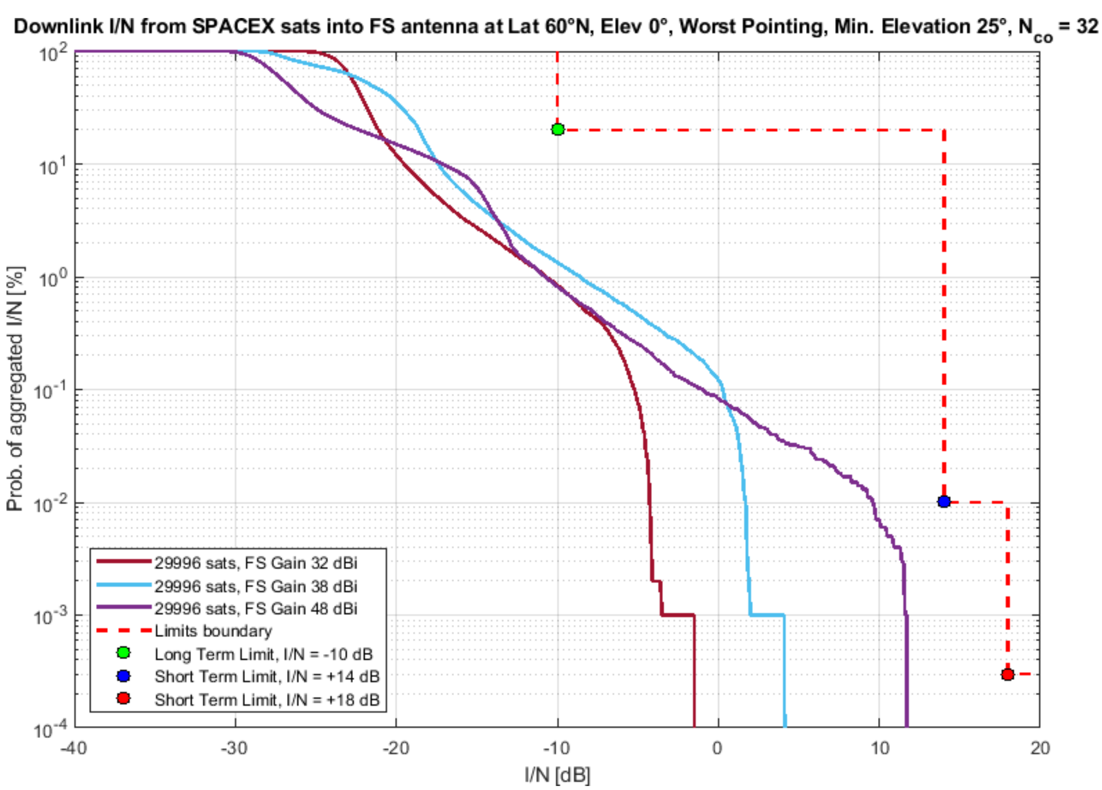

Figure A1b-5. FS Station: Lat. 60°, Elevation 0°

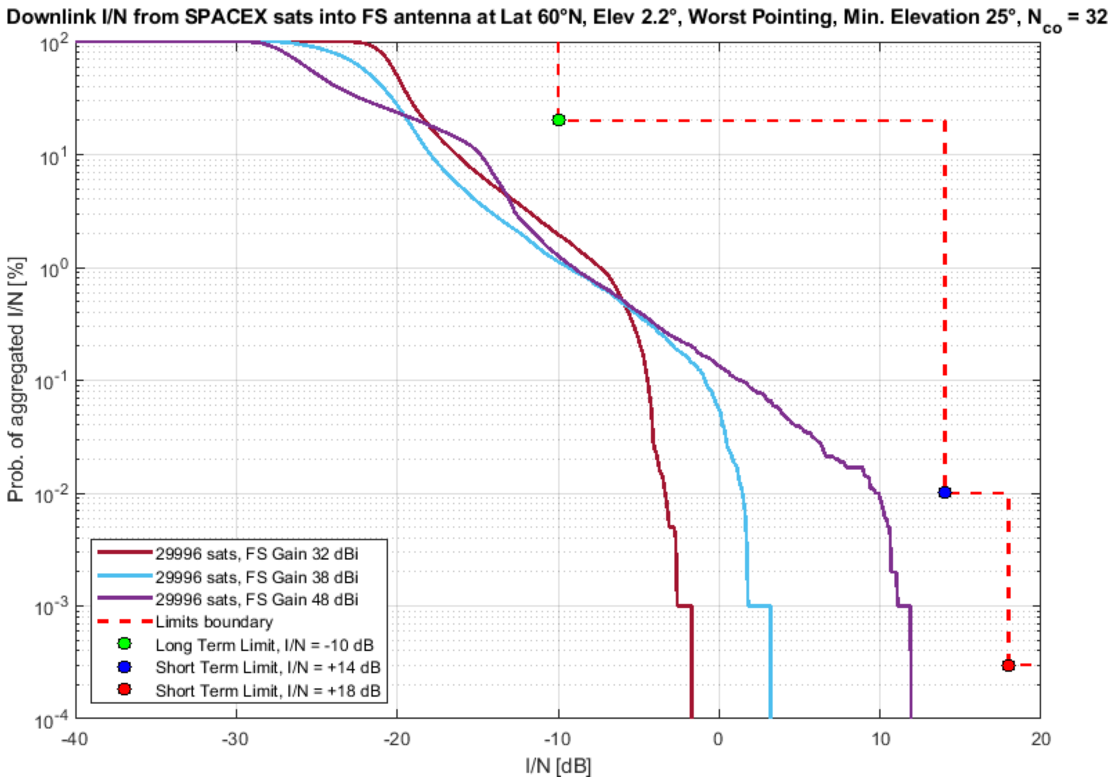

Figure A1b-6. FS Station: Lat. 60°, Elevation 2.2°

ANNEX 2A

POTENTIAL INTERFERENCE WITH RESPECT TO OTHER NGSO SATELLITE SYSTEMS PROPOSED IN THE 2020 PROCESSING ROUND—CONFIGURATION 1

SpaceX has engineered its Gen2 System with the technical flexibility that will facilitate the necessary coordination with other NGSO satellite systems and is committed to achieving mutually satisfactory agreements. Moreover, neither system configuration proposed herein will result in increased interference to other NGSO systems proposed in the 2020 Processing Round.

To demonstrate this point, SpaceX performed an analysis of the effect of the proposed amendment, under both configurations, on downlink and uplink interference using the characteristics of six NGSO systems participating in the 2020 Processing Round. This analysis considers the effect of Configuration 1 of the proposed amendment on two pending applications for hypothetical operations in the Ku-band (OneWeb and Kepler), which SpaceX proposes to use for communications with user terminals ("UTs"), and five pending applications for hypothetical operations in the Ka-band (Amazon, O3b, OneWeb, Telesat, and Viasat), which SpaceX proposes to use for communications with both UTs and gateways ("GWs").

The analysis considers the dynamic, time-varying interference expressed as a cumulative distribution function ("CDF") of the interference-to-noise ratio ("I/N"), for varying percentages of time. The I/N CDF is derived from a time-domain simulation of the two NGSO systems over a long enough time to produce meaningful statistics, using random antenna pointing. The corresponding interference levels before and after the amendment are calculated and plotted. To present a worst-case assessment of the interference environment, the analysis also assumes that the two systems do not implement any interference mitigation strategies. For these analyses, SpaceX used publicly available parameters for each NGSO system and, when relevant parameters were not available, conservative assumptions. The analysis considers both the lowest and highest gains relevant to the victim earth station (for downlink) and victim satellite receive antenna (for uplink) as relevant.

As demonstrated below, the new interference levels resulting from the amendment are mostly less than (and at worst comparable to) the interference levels that would have been experienced with the originally proposed constellation in the noise-dominated environment (i.e., I/N ≤ 0 dB). In the interference-dominated environment (i.e., I/N > 0 dB), the victim system already typically experiences at least 3 dB receiver de-sensitivity (if not 15 dB or more) and the two systems are not likely able to share the spectrum in a meaningful way outside of band segmentation both with and without the proposed amendment. Though some of the following plots show a theoretical increase in interference after the proposed amendment at fairly high I/N levels, in practice the two systems would need to implement band segmentation even before reaching such a highly interference-dominated environment. Hence, this amendment will not increase the potential interference into or from these NGSO systems operating in areas where true spectrum-sharing options may be available with the originally proposed system. It also will not increase the likelihood of exceeding the Commission's -12.2 dB (6% ΔT/T) threshold above which parties will be required to either split the spectrum or coordinate.[1]

In conducting the analysis, SpaceX used the following assumptions.

<u>For downlink interference between SpaceX satellites and another operator's earth station</u>:

1. The SpaceX earth station is collocated with the other operator's earth station at 40°N 100°W in this simulation.[2]
2. The victim earth station can communicate with any satellite in its own system

[1] 47 C.F.R. § 25.261(c).

[2] Note that SpaceX ran its simulation with multiple latitudes and achieved similar results for both the downlink and uplink analysis. Accordingly, it chose to provide results for one latitude that is centrally located in its U.S. service area.

following the rules applicable for that system (e.g., minimum elevation angle), except that no GSO avoidance angle is assumed for any system to ensure a conservative analysis. All possible valid cases are considered in evaluating the I/N CDF.

3. The SpaceX system places one co-frequency beam per Ku-band spot and either one (for UTs) or thirty-two (for GWs) co-frequency beams per Ka-band spot, and any satellite in view meeting the minimum elevation angle is eligible. SpaceX satellites are chosen randomly for consideration in evaluating the I/N CDF and operate at the power flux-density levels described in the Original Application and Configuration 1 of this amendment. The other operator's NGSO system operates as proposed in its 2020 Processing Round application.

4. The results are set forth for each NGSO system below. Note that this simulation is conservative (i.e., it overestimates I/N), as it does not consider the effects of atmospheric attenuation.

<u>For uplink interference between SpaceX earth stations and another operator's satellites</u>:

1. The SpaceX earth station is collocated with an earth station from the other system at 40°N 100°W in this simulation.

2. The other system's earth station can communicate with any satellite in its own system following the rules applicable for that system (e.g., minimum elevation angle), except that no GSO avoidance angle is assumed for any system to ensure a conservative analysis. All possible valid cases are considered in evaluating the I/N CDF.

3. In the SpaceX system, one co-frequency tracked satellite in Ku-band and one or thirty-two co-frequency tracked satellites in Ka-band (for UTs and GWs, respectively) can receive simultaneously from an earth station. Any satellite in view meeting the

minimum elevation angle is eligible. SpaceX satellites are randomly chosen for consideration in evaluating the I/N CDF. The other operator's NGSO system operates as proposed in its 2020 Processing Round application.

4. The results are set forth for each NGSO system below. Note that this simulation is conservative (i.e., it overestimates I/N), as it does not consider the effects of atmospheric attenuation.

KU-BAND SYSTEMS

The NGSO systems proposed by SpaceX, OneWeb, and Kepler in the 2020 Processing Round all use Ku-band spectrum for communications with users. Accordingly, the analysis below assesses the potential for interference between the user links. The results of the analysis for uplink and downlink interference simulations from and to each system are set forth below. In each case, the figure plots a CDF of aggregate I/N levels for the SpaceX constellation as originally proposed and as amended under Configuration 1.

I. OneWeb

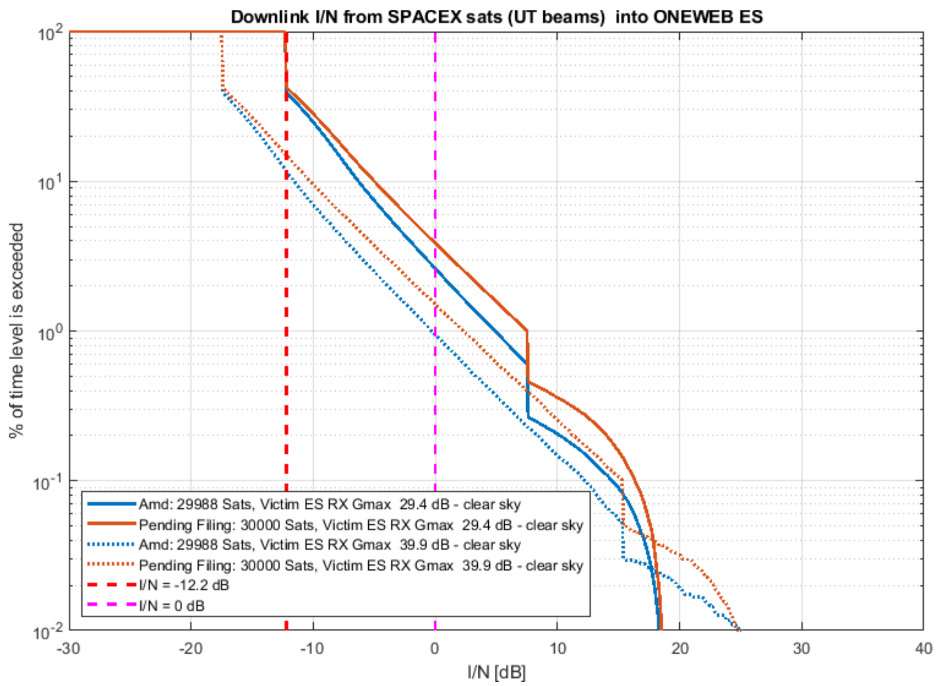

Figure A2a-I.1 — Downlink Interference from SpaceX to OneWeb UTs

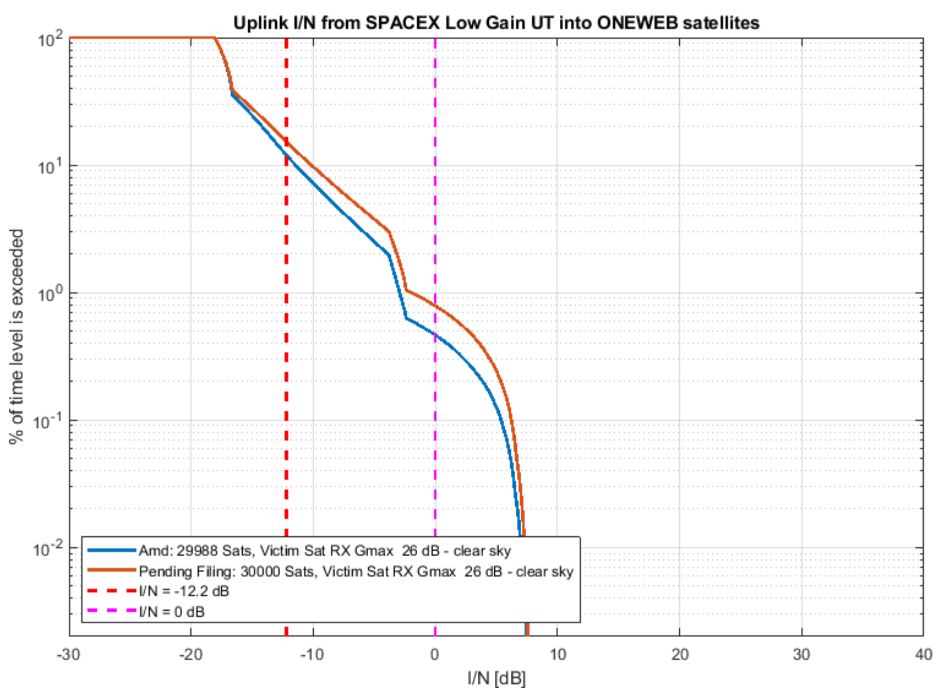

Figure A2a-I.2 — Uplink Interference from SpaceX Low Gain UTs to OneWeb

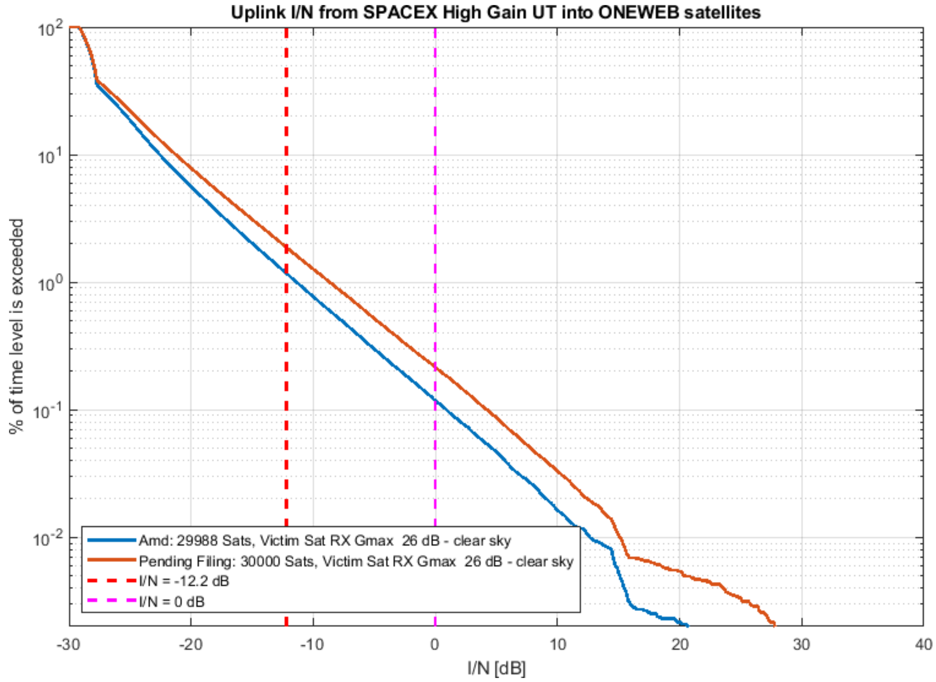

Figure A2a-I.3 — Uplink Interference from SpaceX High Gain UTs to OneWeb

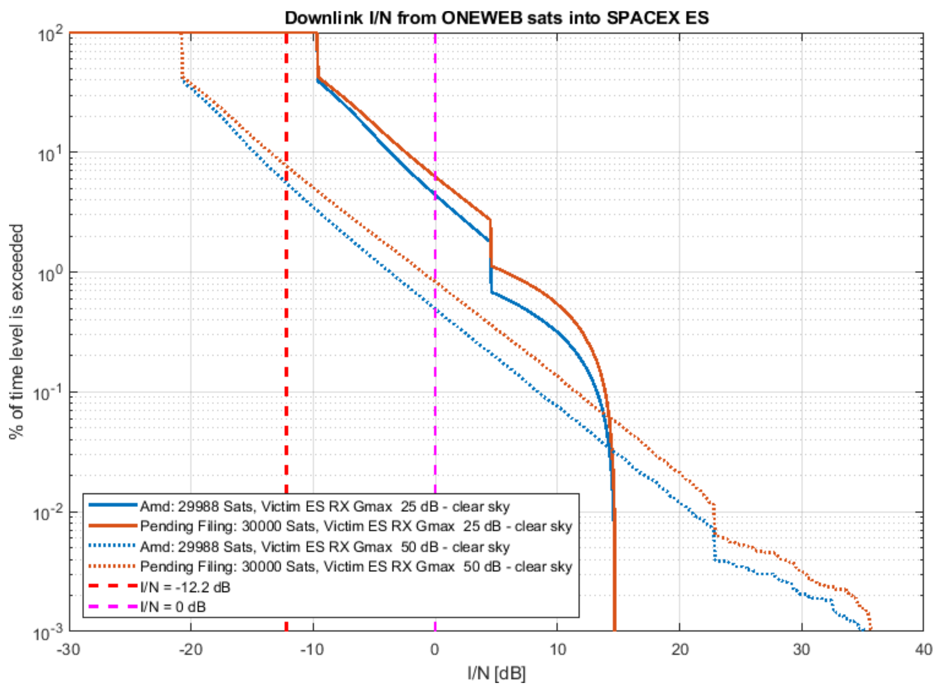

Figure A2a-I.4 — Downlink Interference from OneWeb to SpaceX ESs

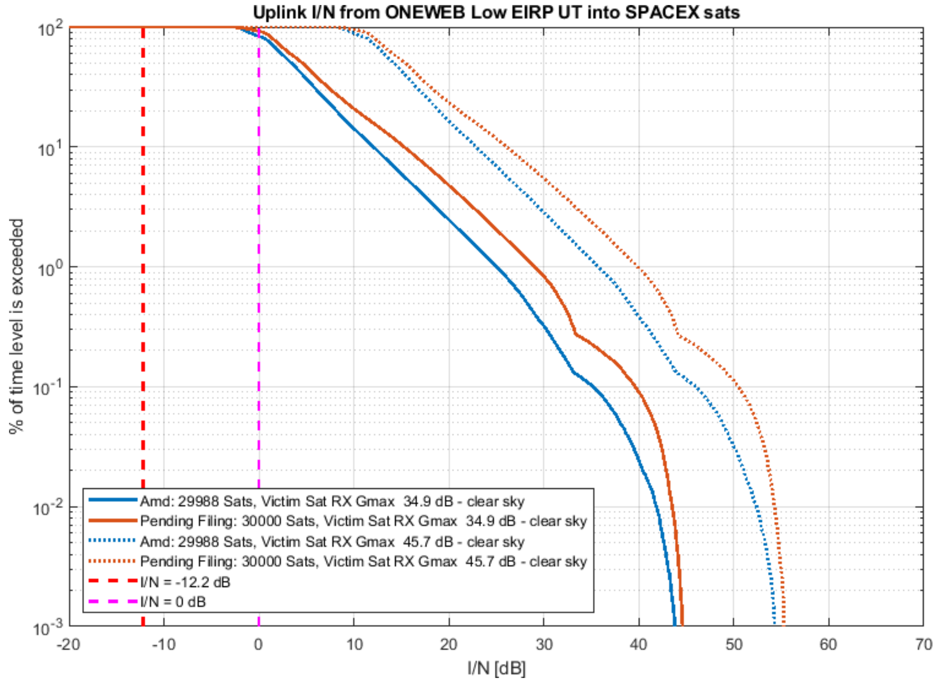

Figure A2a-I.5 — Uplink Interference from OneWeb Low EIRP UTs to SpaceX

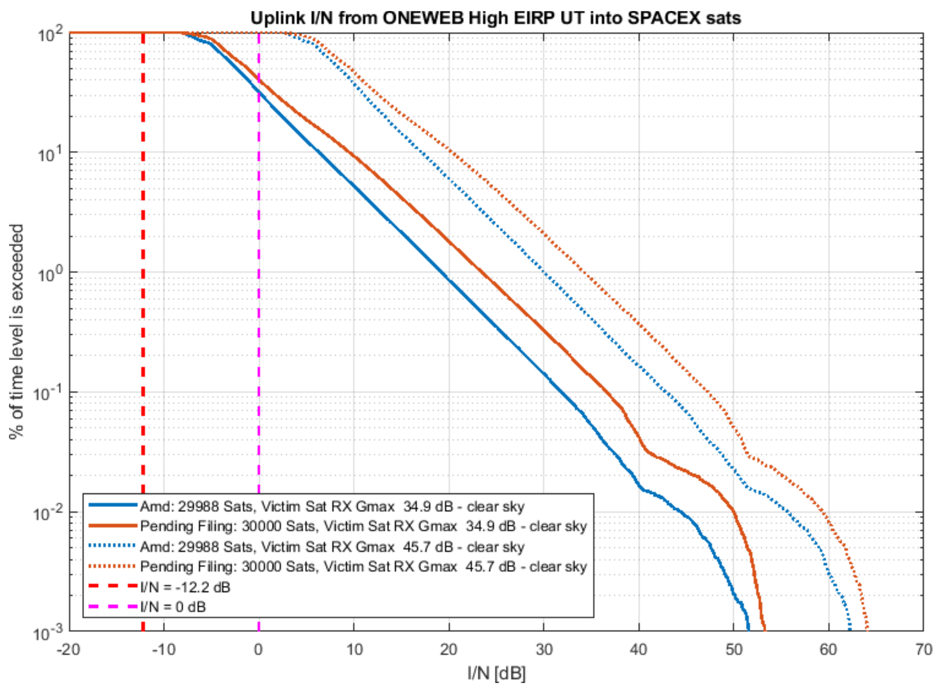

Figure A2a-I.6 — Uplink Interference from OneWeb High EIRP UTs to SpaceX

II. Kepler

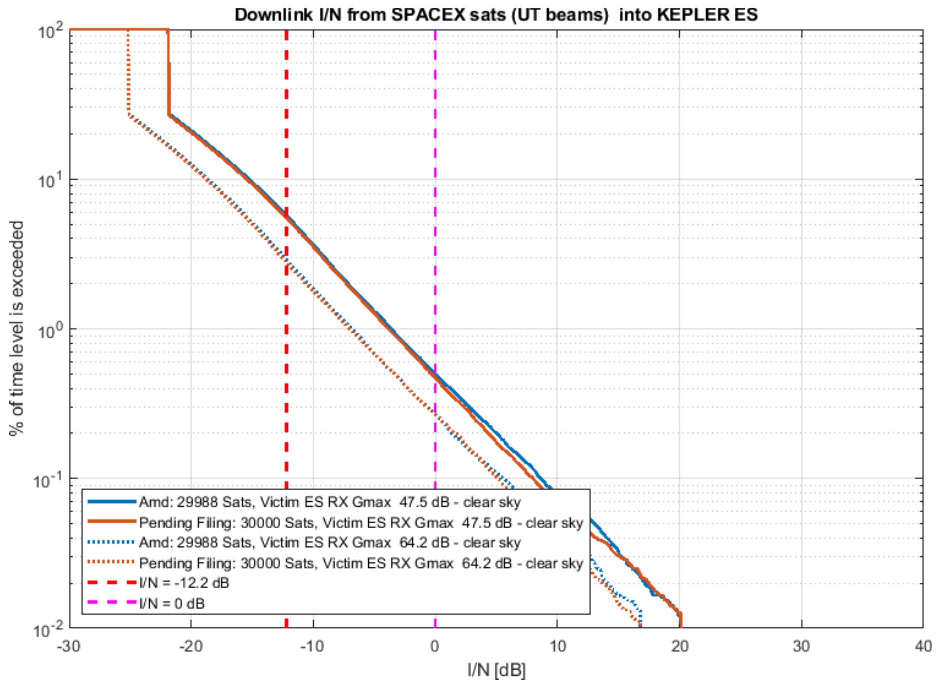

Figure A2a-II.1 — Downlink Interference from SpaceX to Kepler GWs

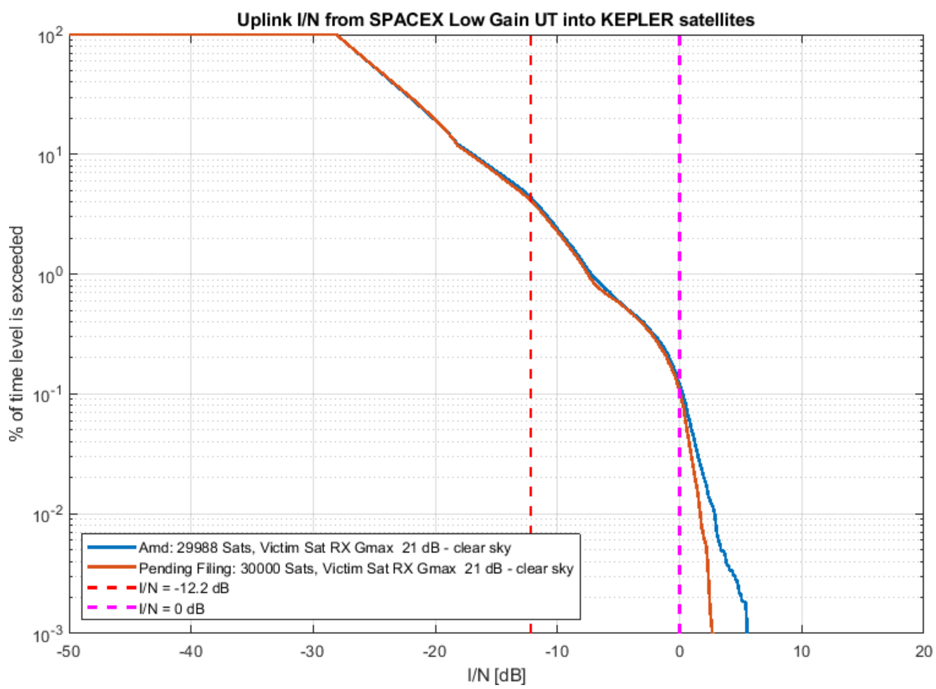

Figure A2a-II.2 — Uplink Interference from SpaceX Low Gain UTs to Kepler

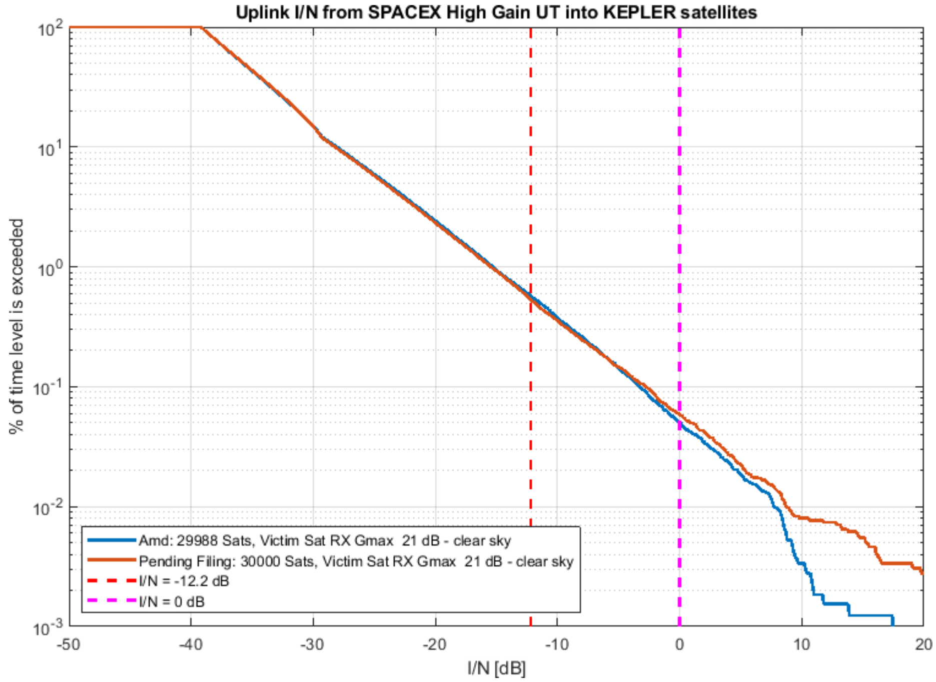

Figure A2a-II.3 — Uplink Interference from SpaceX High Gain UTs to Kepler

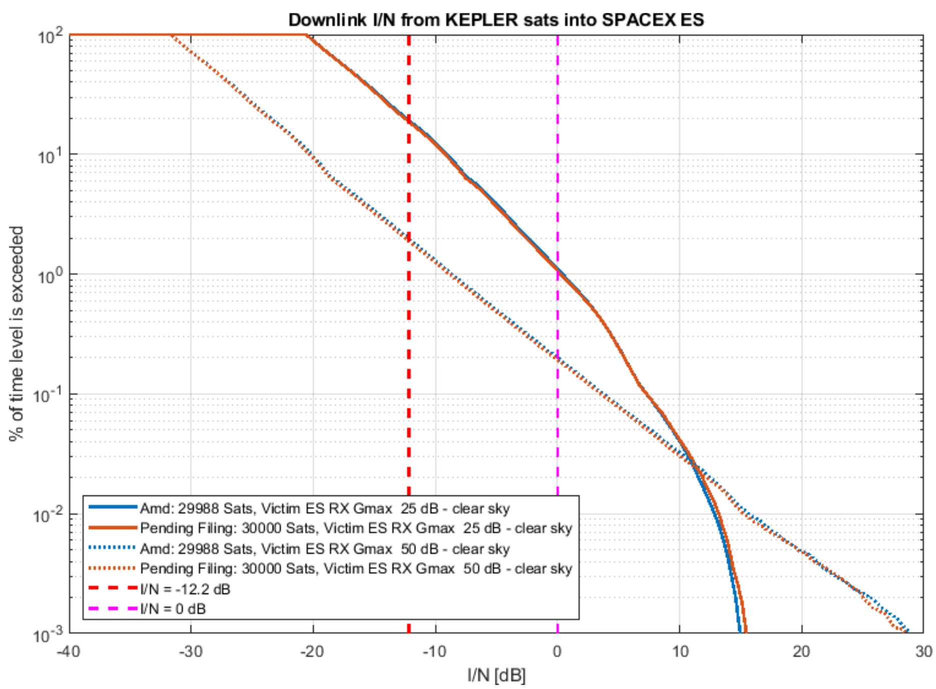

Figure A2a-II.4 — Downlink Interference from Kepler to SpaceX ESs

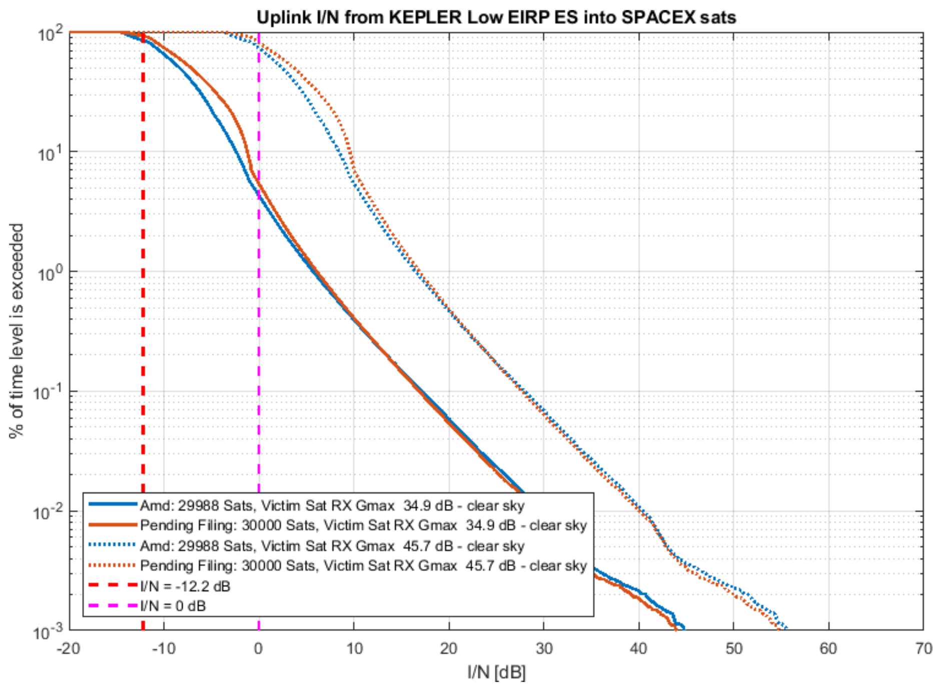

Figure A2a-II.5 — Uplink Interference from Kepler Low EIRP GWs to SpaceX

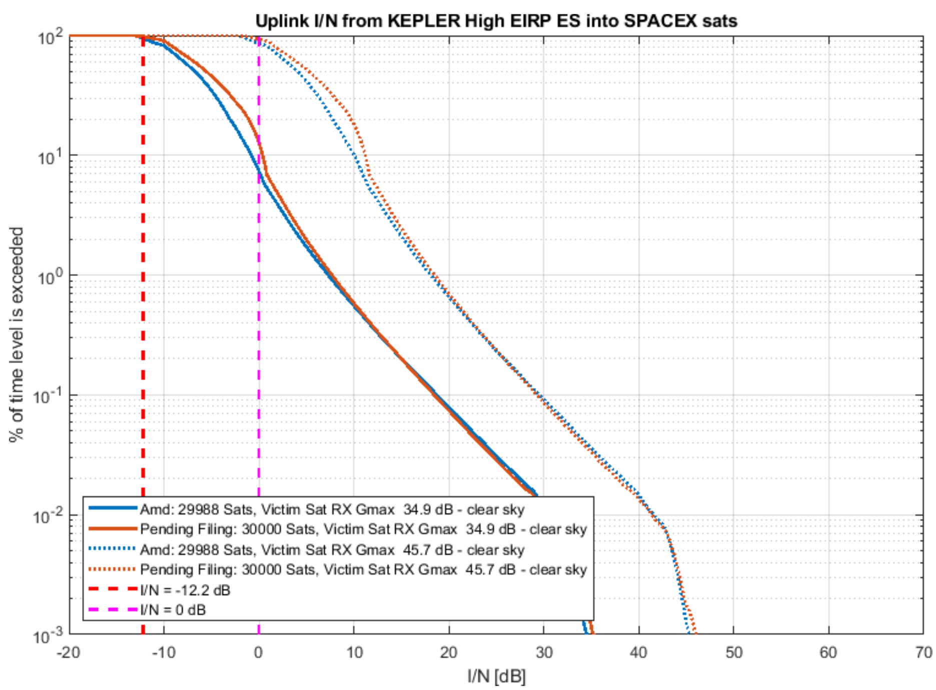

Figure A2a-II.6 — Uplink Interference from Kepler High EIRP GWs to SpaceX

KA-BAND SYSTEMS

The NGSO systems proposed by SpaceX, Amazon, O3b, Telesat, and Viasat in the 2020 Processing Round all use Ka-band spectrum for communications with both UTs and GWs. Accordingly, the analysis below with respect to those systems assesses the potential for interference between both user and gateway links. Because OneWeb proposes to use Ka-band spectrum for GWs only, the analysis for its system relates only to GW links. The results of the analysis for uplink and downlink interference simulations from and to each system are set forth below. In each case, the figure plots a CDF of aggregate I/N levels for the SpaceX constellation as originally proposed and as amended under Configuration 1.

III. Amazon

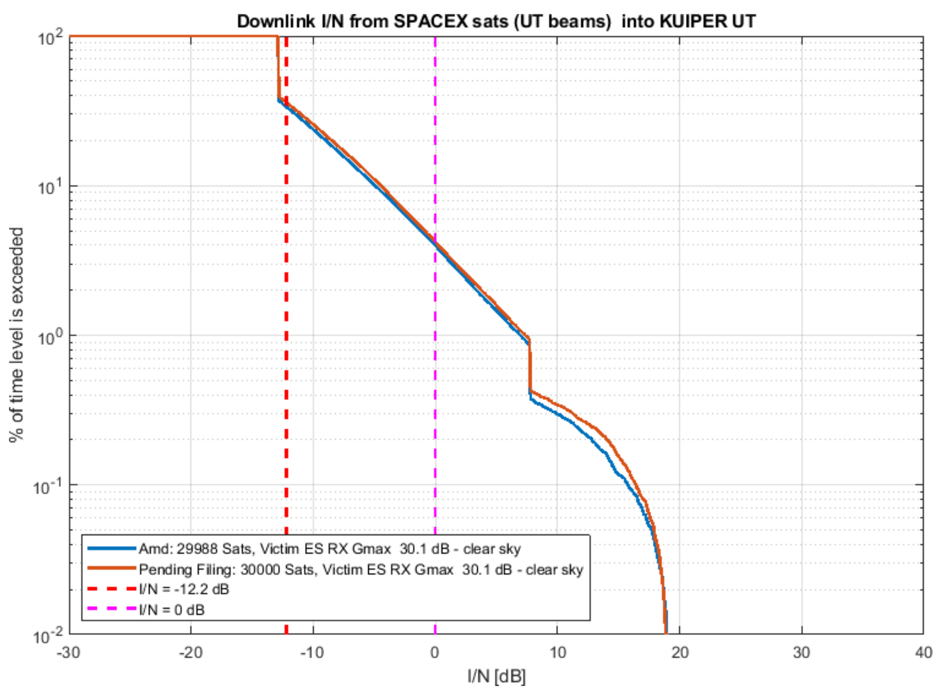

Figure A2a-III.1 — Downlink Interference from SpaceX UT Beam to Amazon UTs

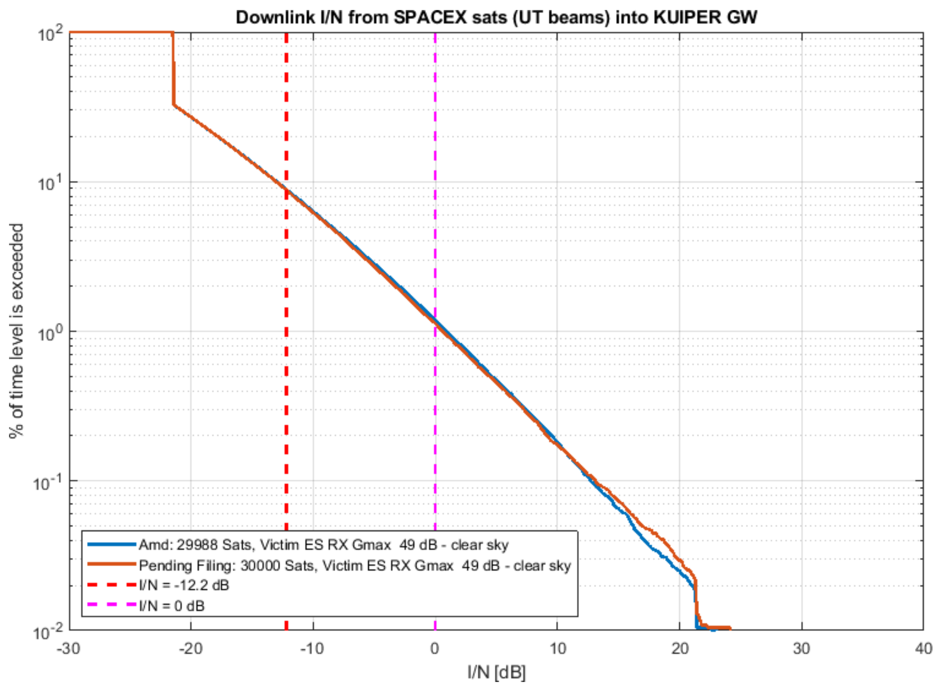

Figure A2a-III.2 — Downlink Interference from SpaceX UT Beam to Amazon GWs

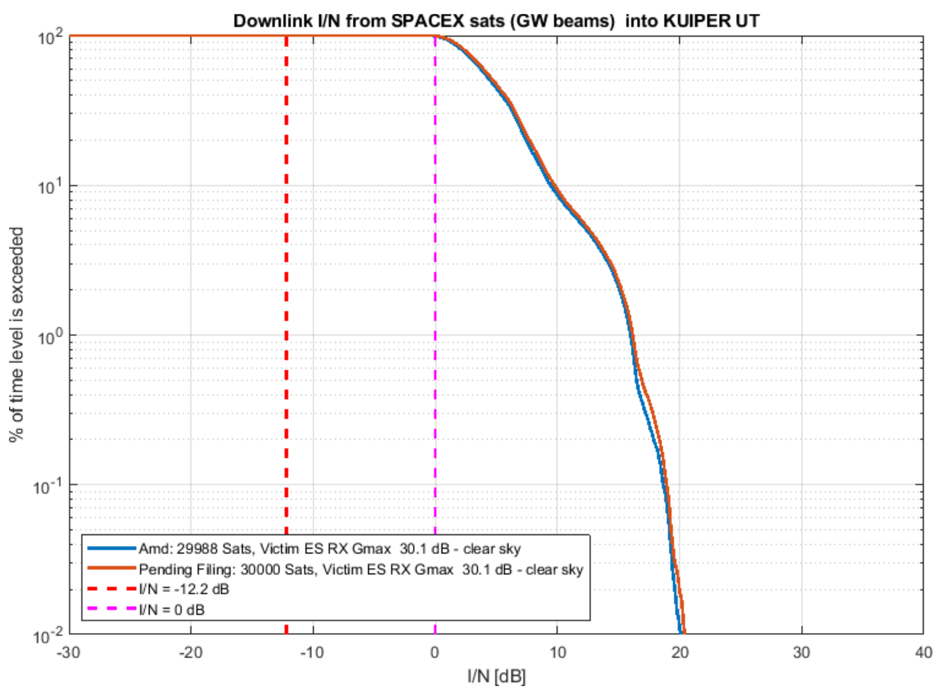

Figure A2a-III.3 — Downlink Interference from SpaceX GW Beam to Amazon UTs

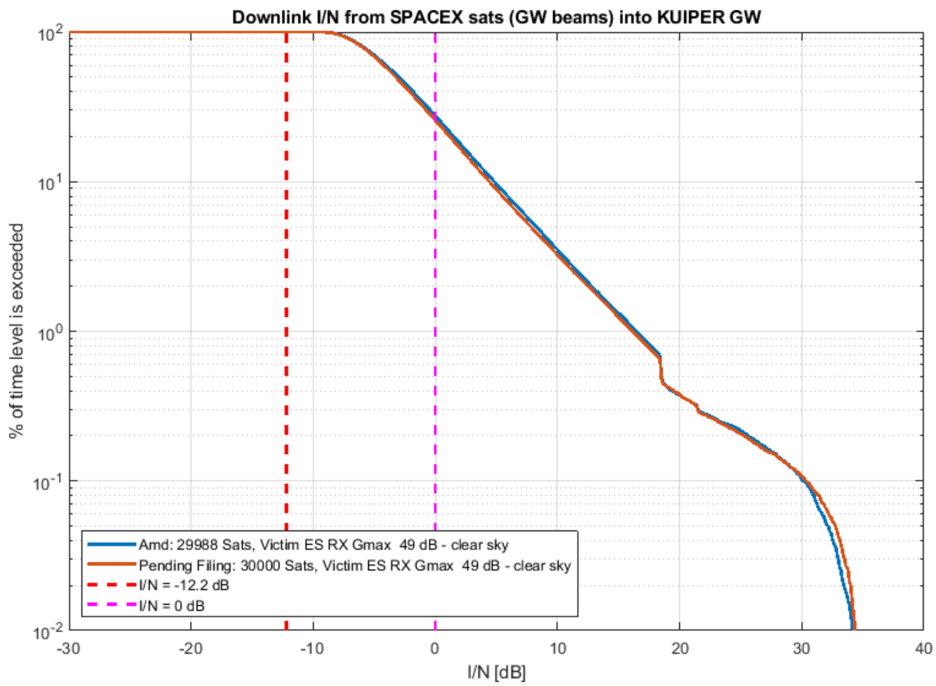

Figure A2a-III.4 — Downlink Interference from SpaceX GW Beam to Amazon GWs

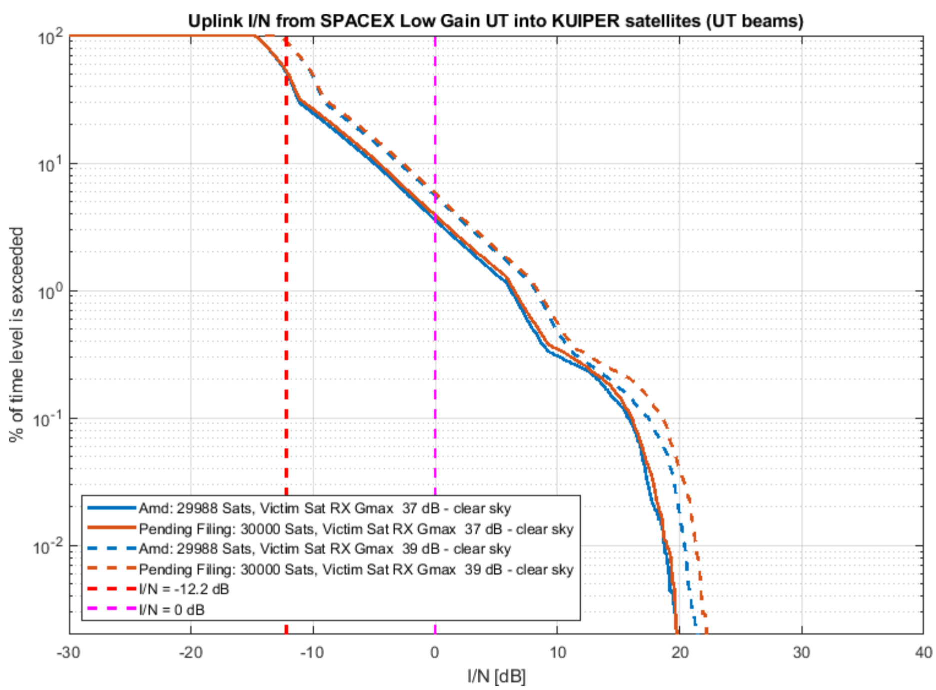

Figure A2a-III.5 — Uplink Interference from SpaceX Low Gain UTs to Amazon UT Receive Beam

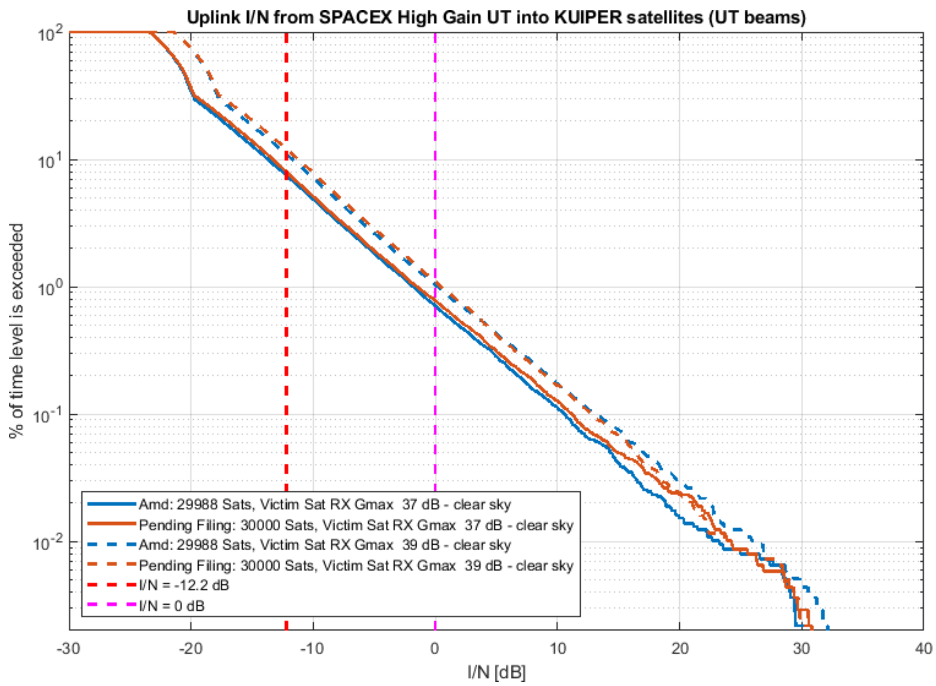

Figure A2a-III.6 — Uplink Interference from SpaceX High Gain UTs to Amazon UT Receive Beam

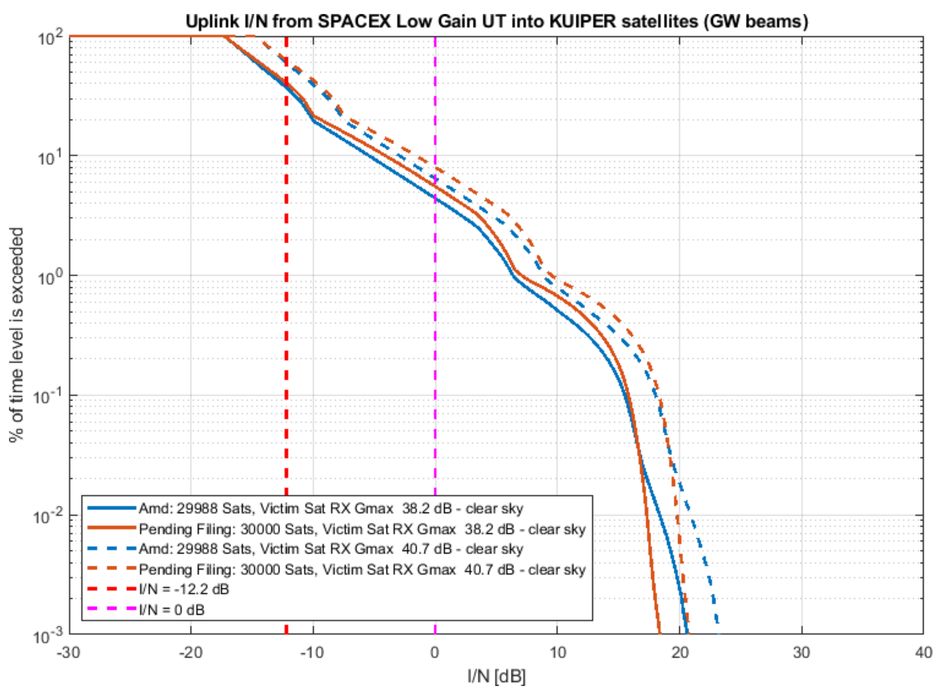

Figure A2a-III.7 — Uplink Interference from SpaceX Low Gain UTs to Amazon GW Receive Beam

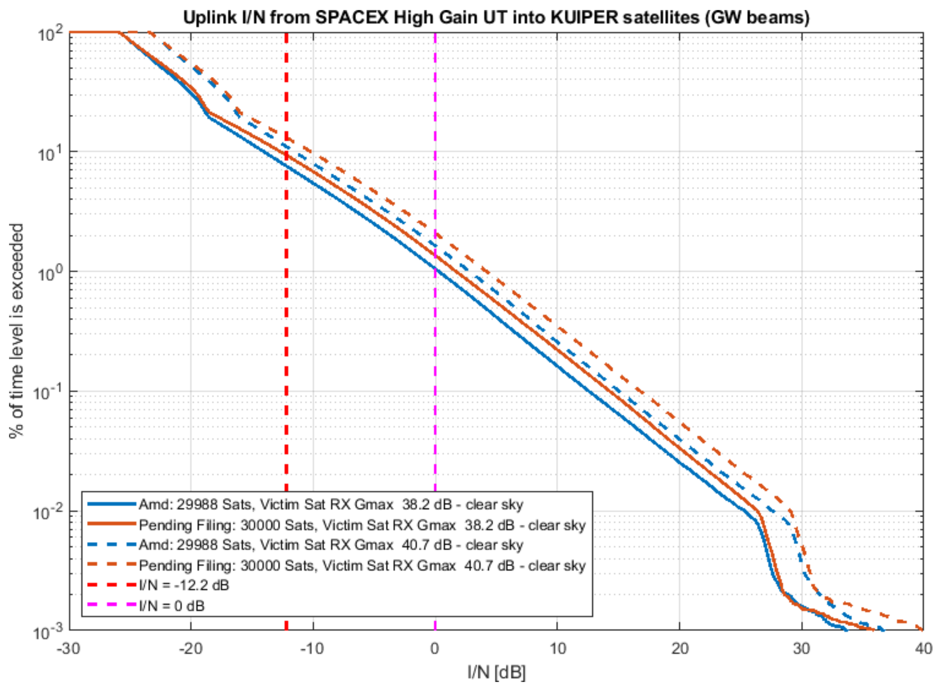

Figure A2a-III.8 — Uplink Interference from SpaceX High Gain UTs to Amazon GW Receive Beam

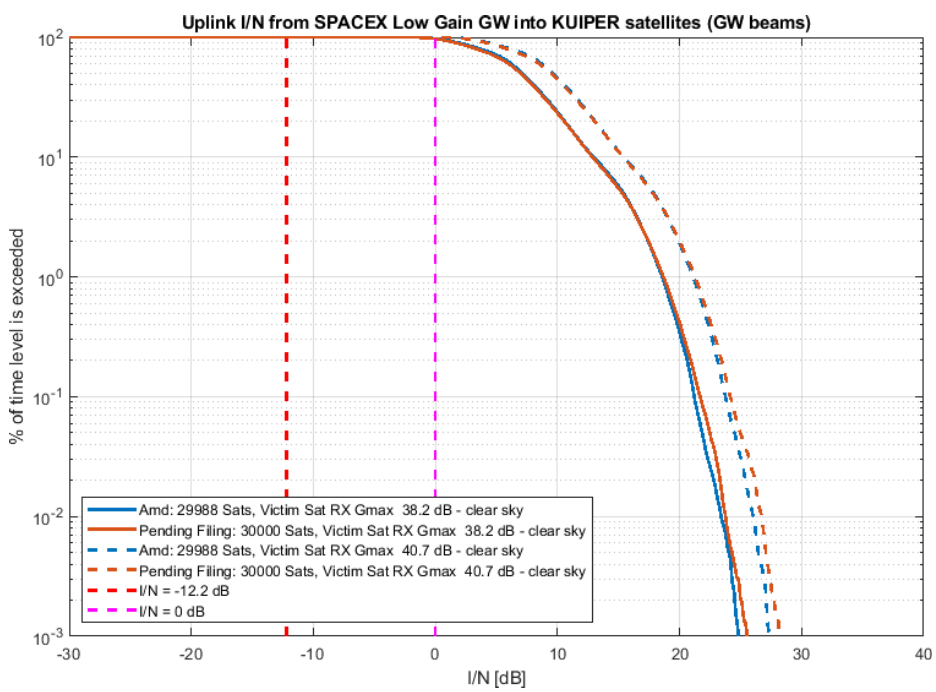

Figure A2a-III.9 — Uplink Interference from SpaceX Low Gain GW to Amazon GW Receive Beam

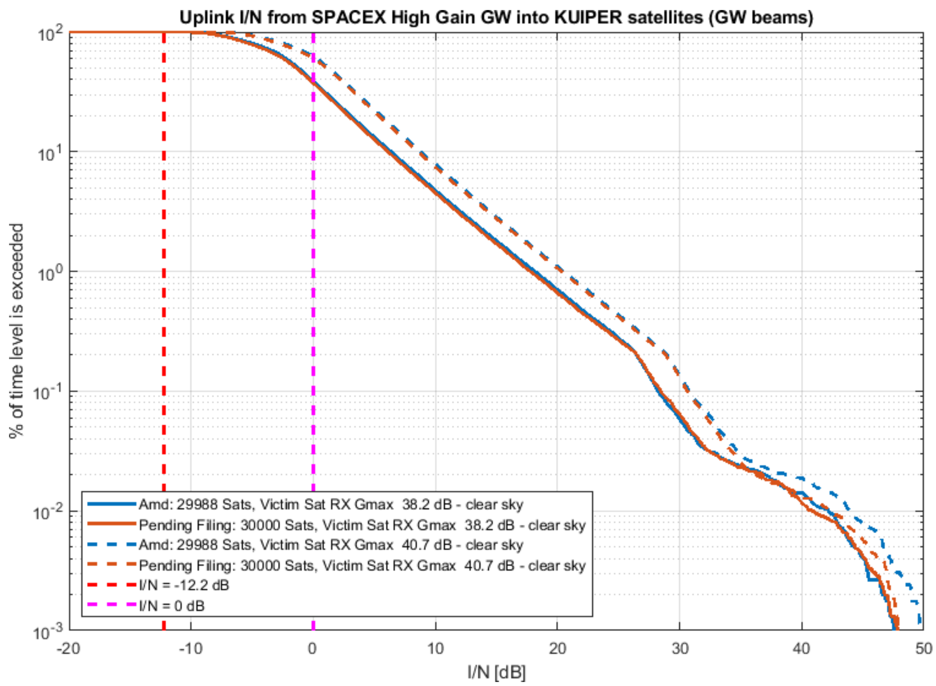

Figure A2a-III.10 — Uplink Interference from SpaceX High Gain GW to Amazon GW Receive Beam

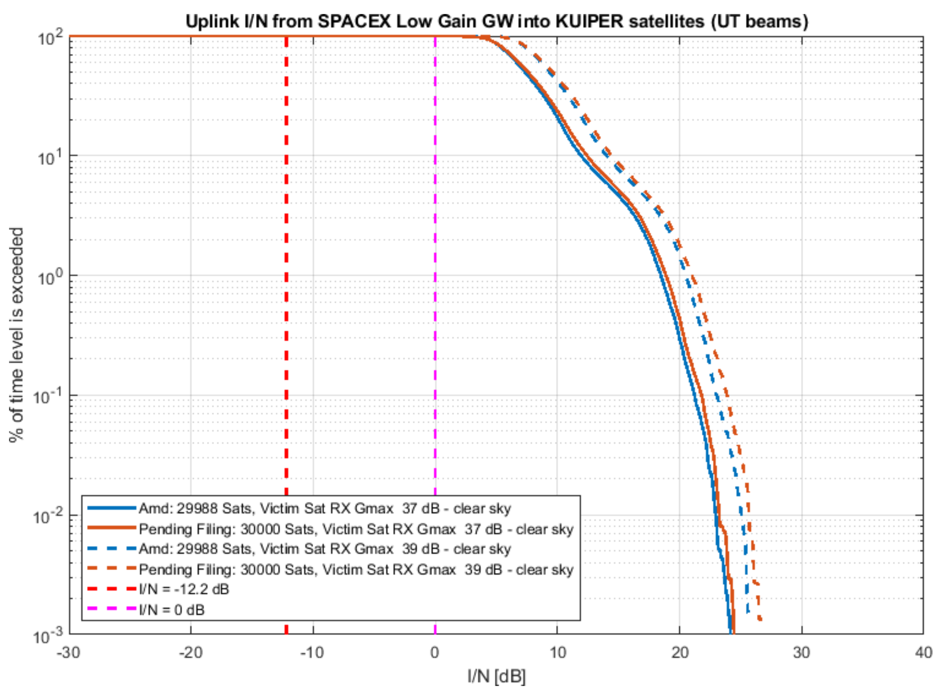

Figure A2a-III.11 — Uplink Interference from SpaceX Low Gain GW to Amazon UT

Receive Beam

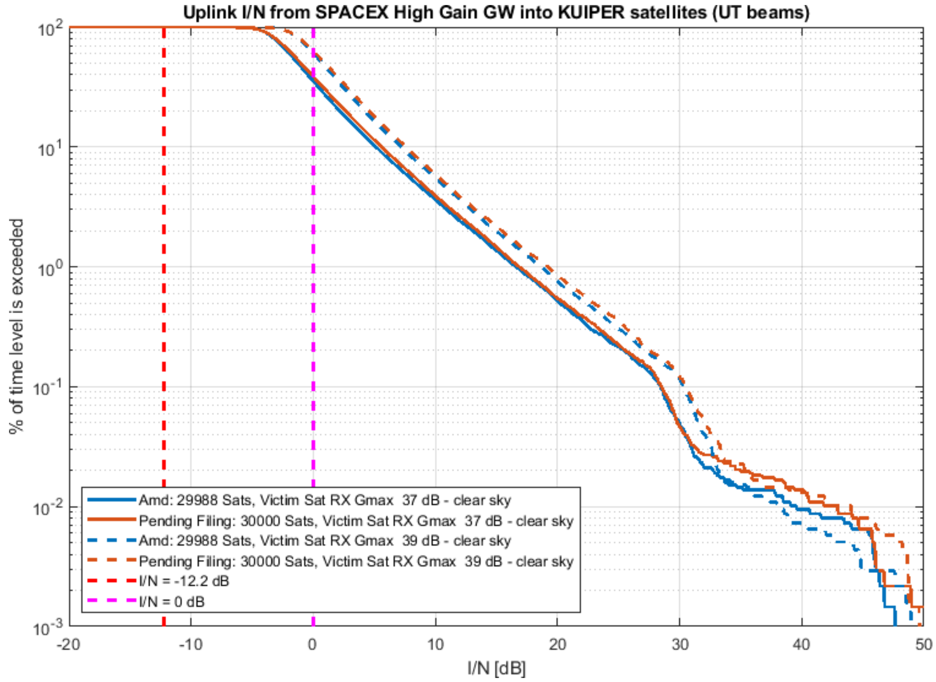

Figure A2a-III.12 — Uplink Interference from SpaceX High Gain GW to Amazon UT Receive Beam

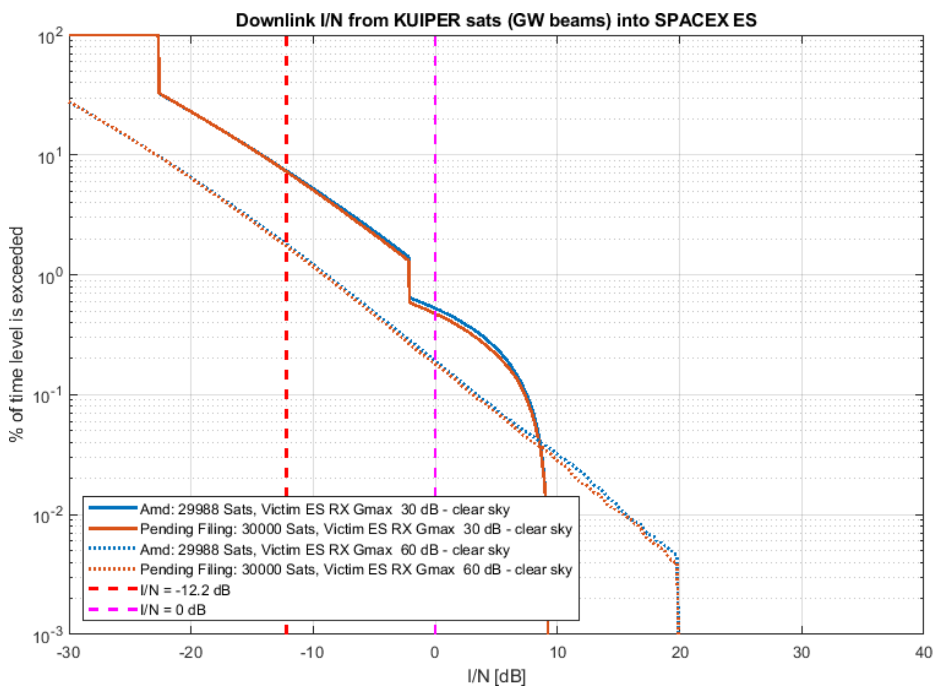

Figure A2a-III.13 — Downlink Interference from Amazon GW Beams to SpaceX ESs

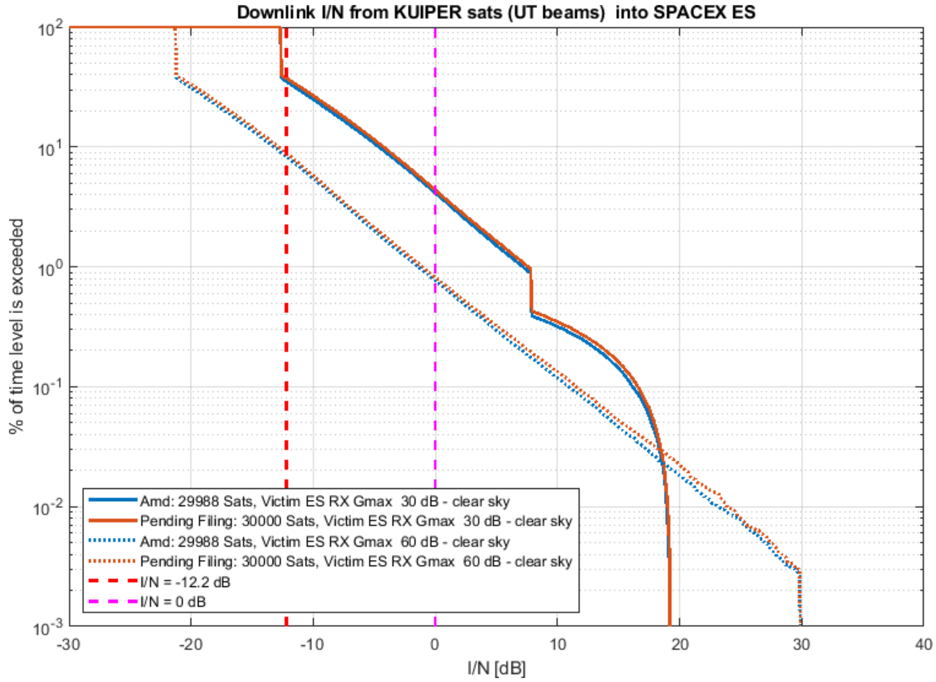

Figure A2a-III.14 — Downlink Interference from Amazon UT Beams to SpaceX ESs

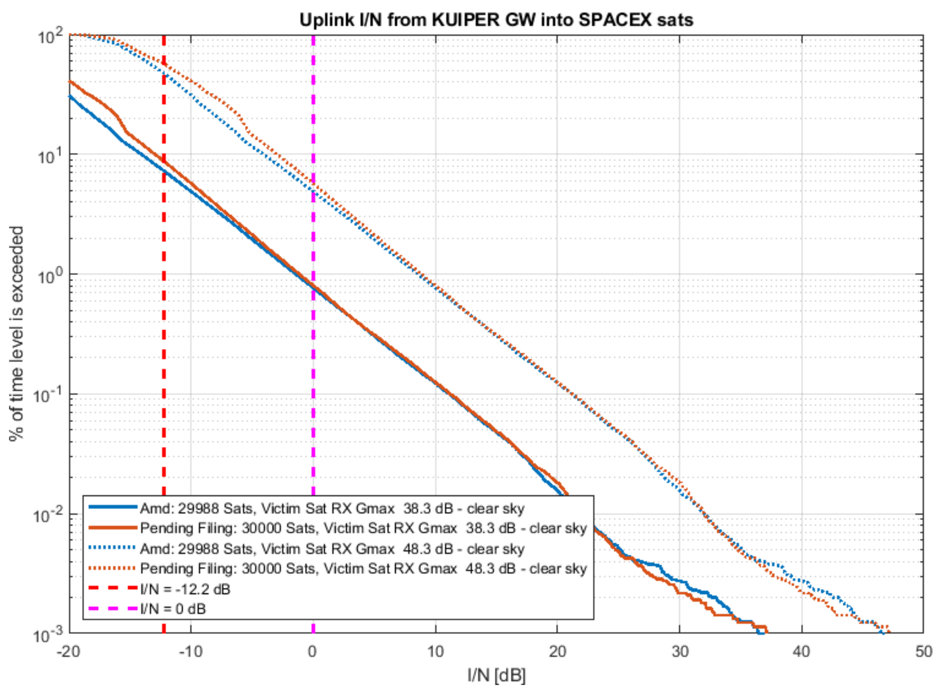

Figure A2a-III.15 — Uplink Interference from Amazon GWs to SpaceX

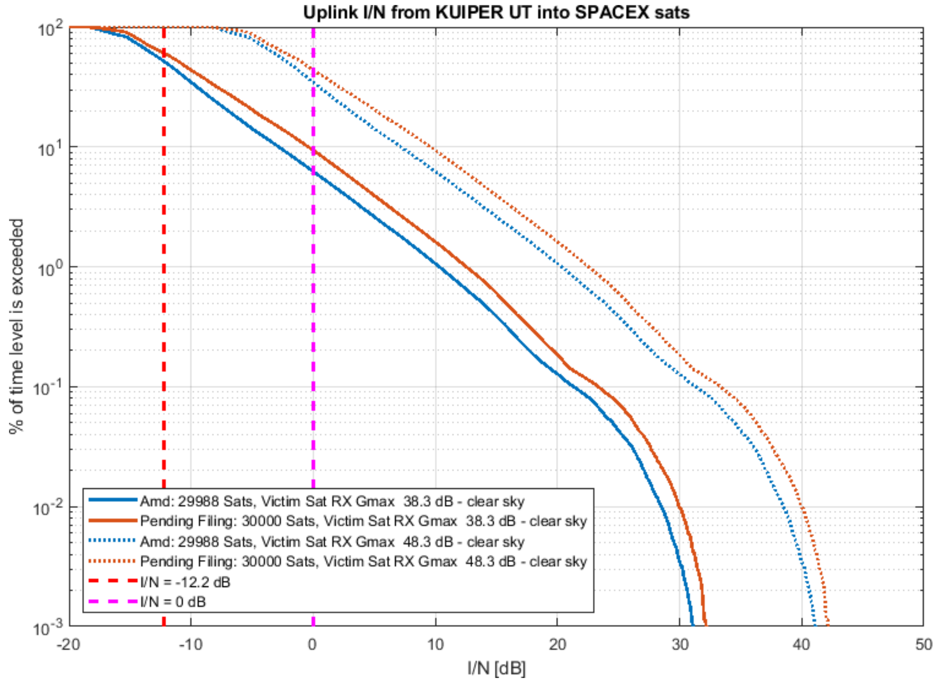

Figure A2a-III.16 — Uplink Interference from Amazon UTs to SpaceX

IV. O3b

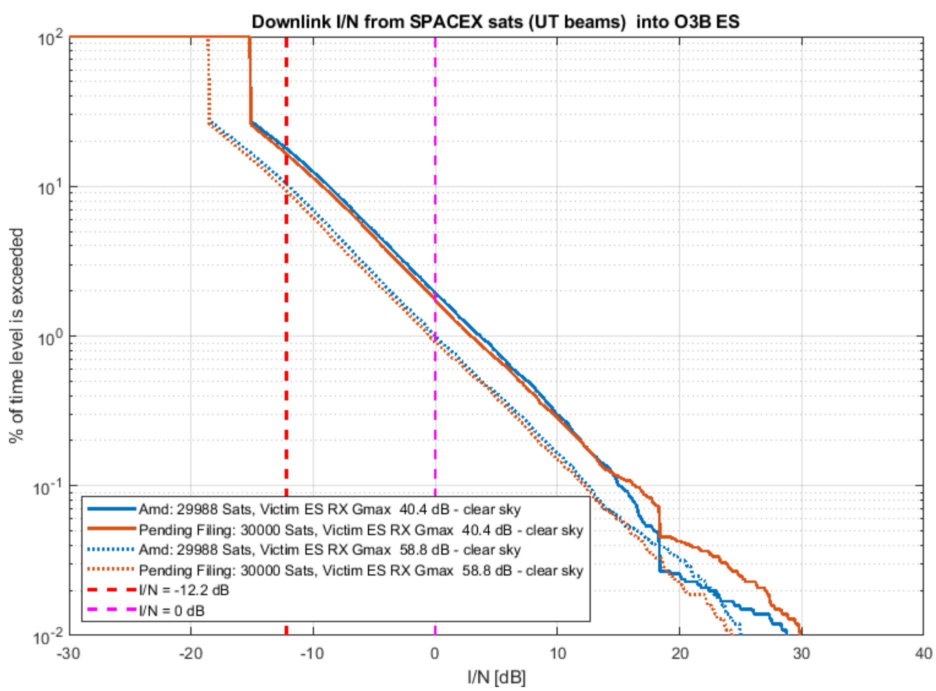

Figure A2a-IV.1 — Downlink Interference from SpaceX UT Beams to O3b ESs

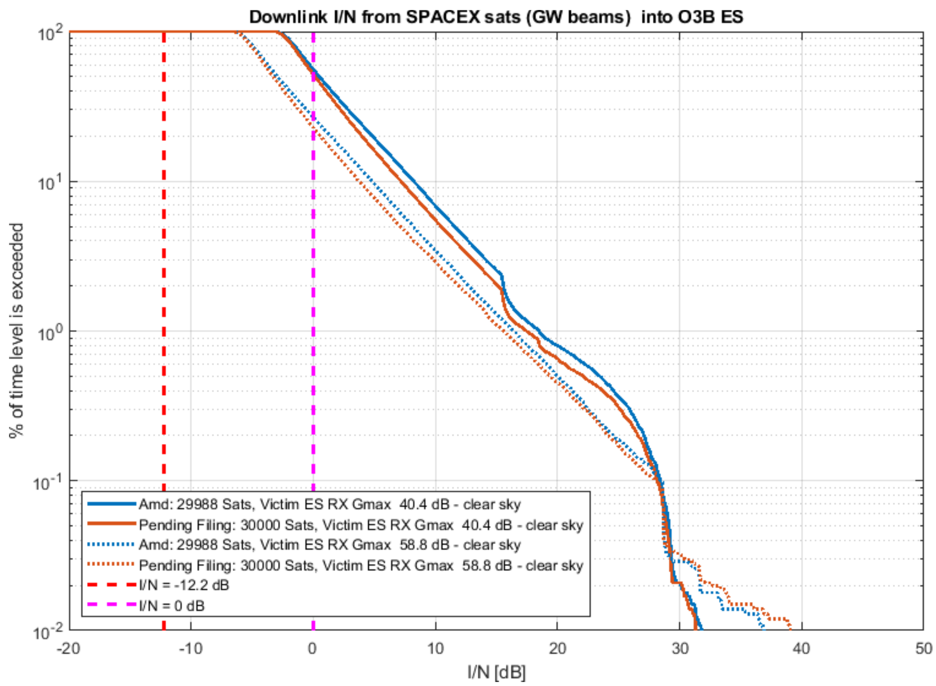

Figure A2a-IV.2 — Downlink Interference from SpaceX GW Beams to O3b ESs

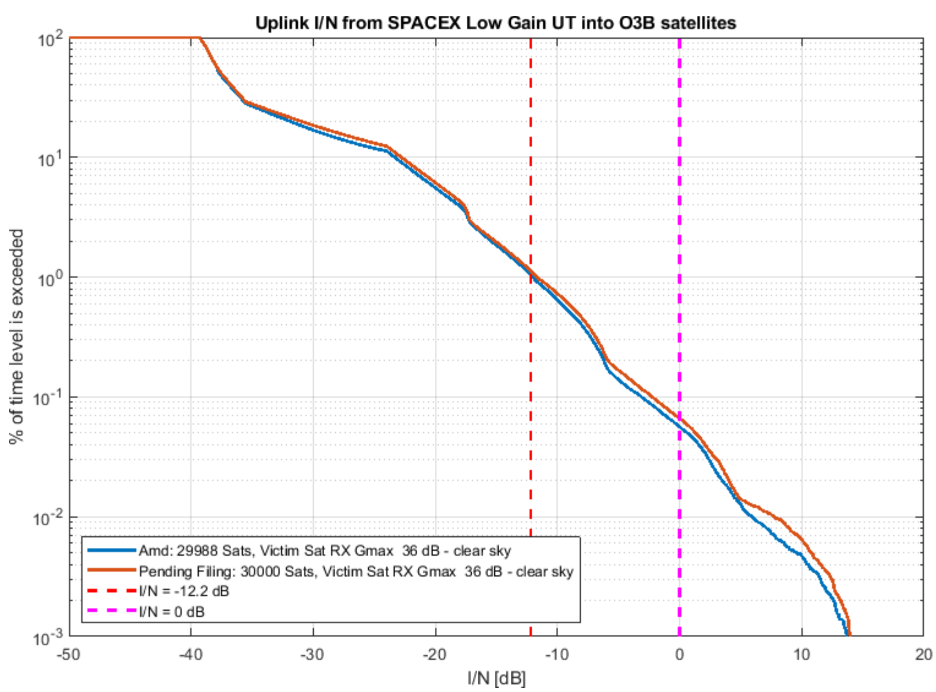

Figure A2a-IV.3 — Uplink Interference from SpaceX Low Gain UTs to O3b

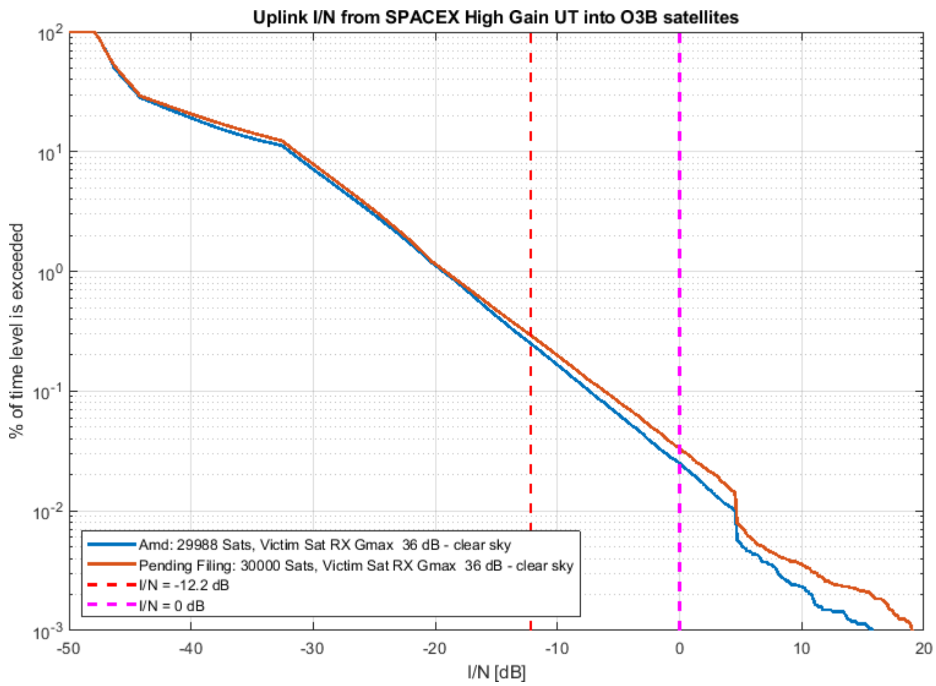

Figure A2a-IV.4 — Uplink Interference from SpaceX High Gain UTs to O3b

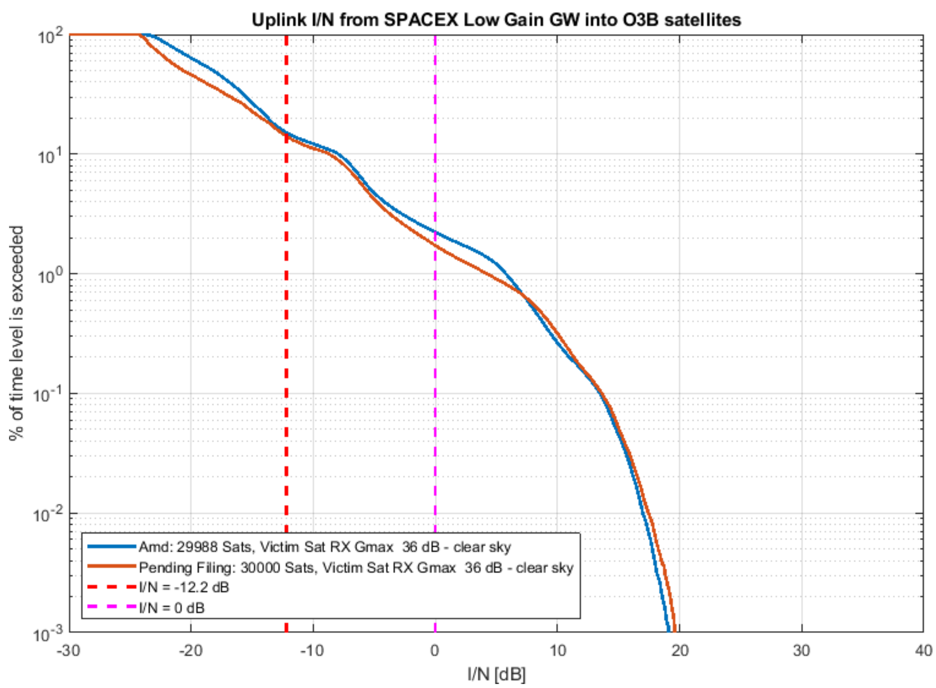

Figure A2a-IV.5 — Uplink Interference from SpaceX Low Gain GWs to O3b

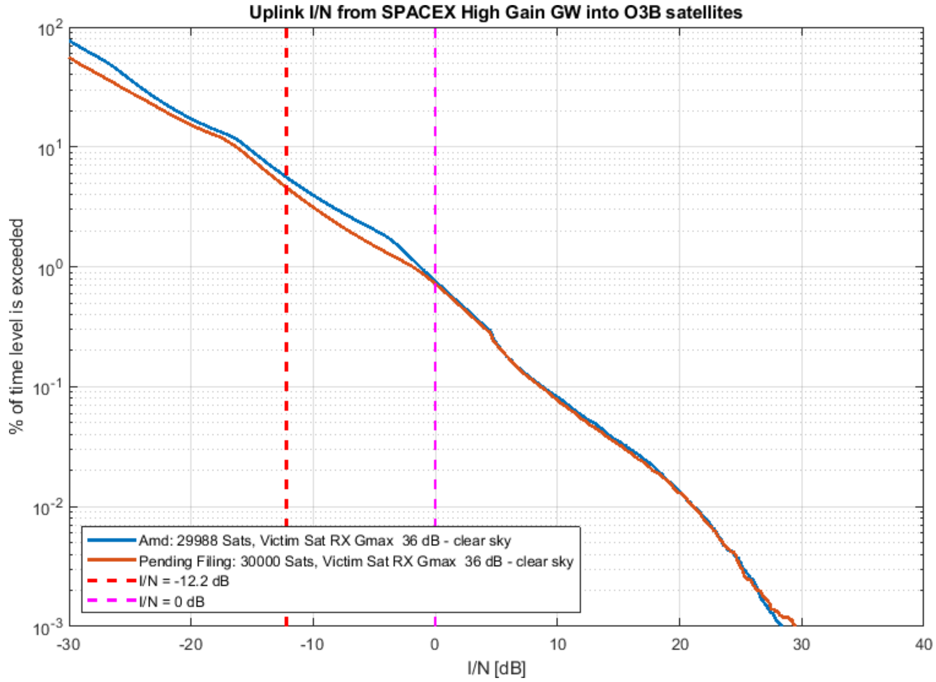

Figure A2a-IV.6 — Uplink Interference from SpaceX High Gain GWs to O3b

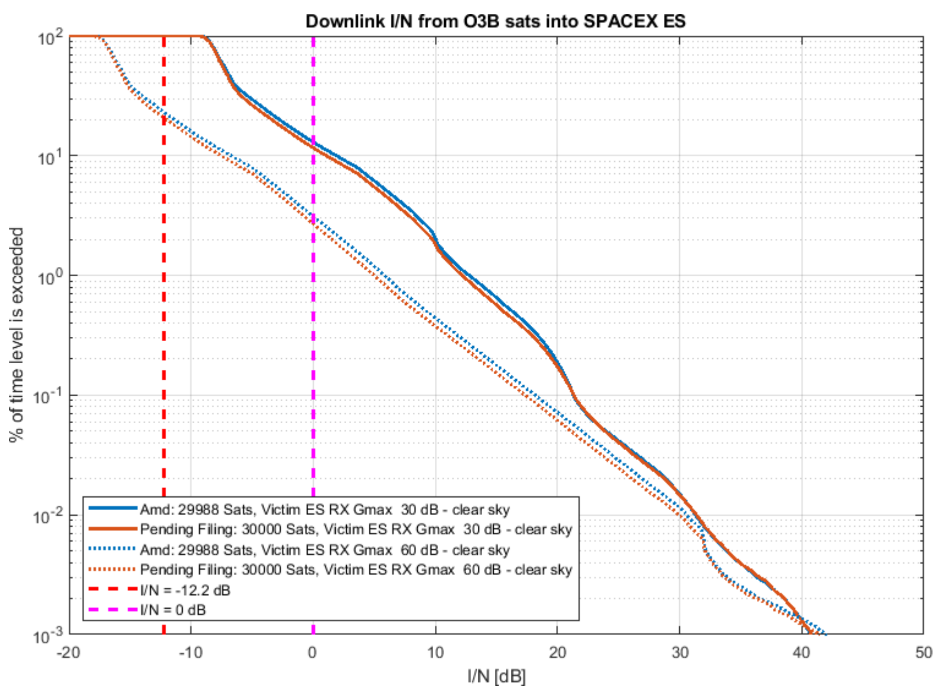

Figure A2a-IV.7 — Downlink Interference from O3b to SpaceX ESs

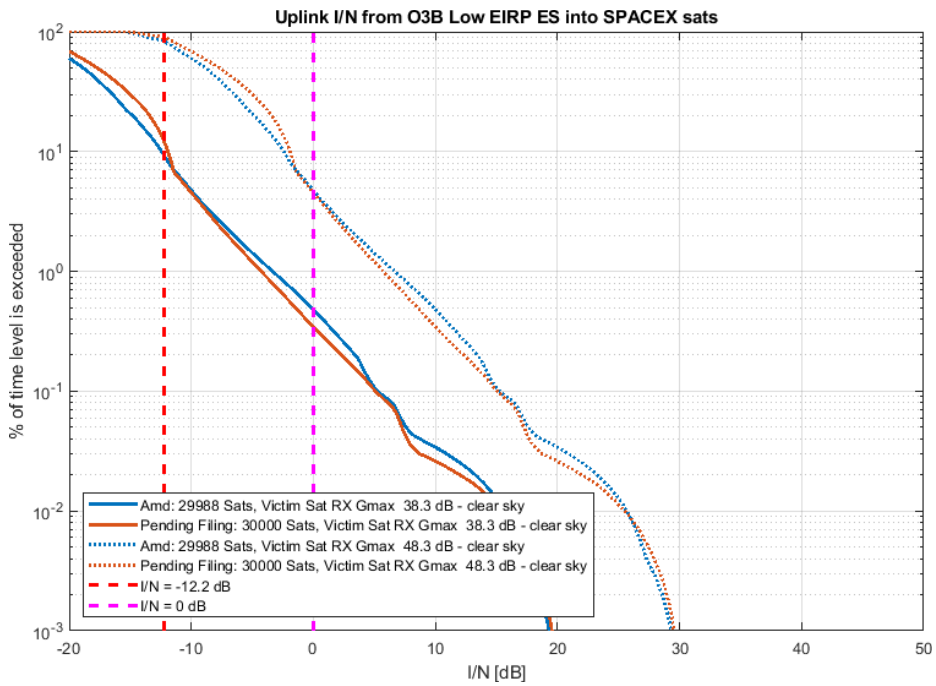

Figure A2a-IV.8 — Uplink Interference from O3b Low EIRP ESs to SpaceX

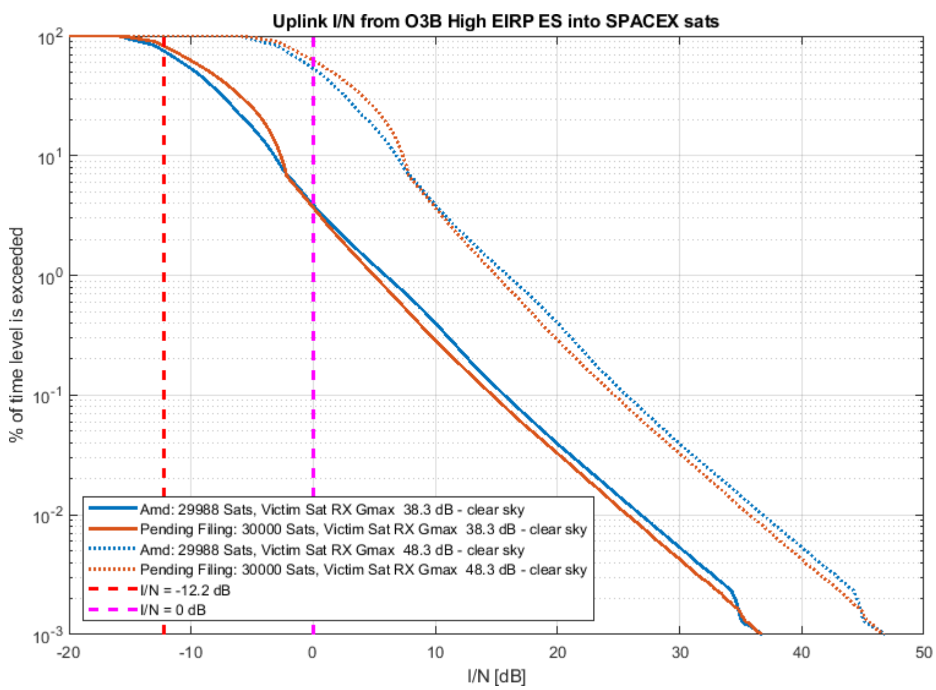

Figure A2a-IV.9 — Uplink Interference from O3b High EIRP ESs to SpaceX

V. OneWeb

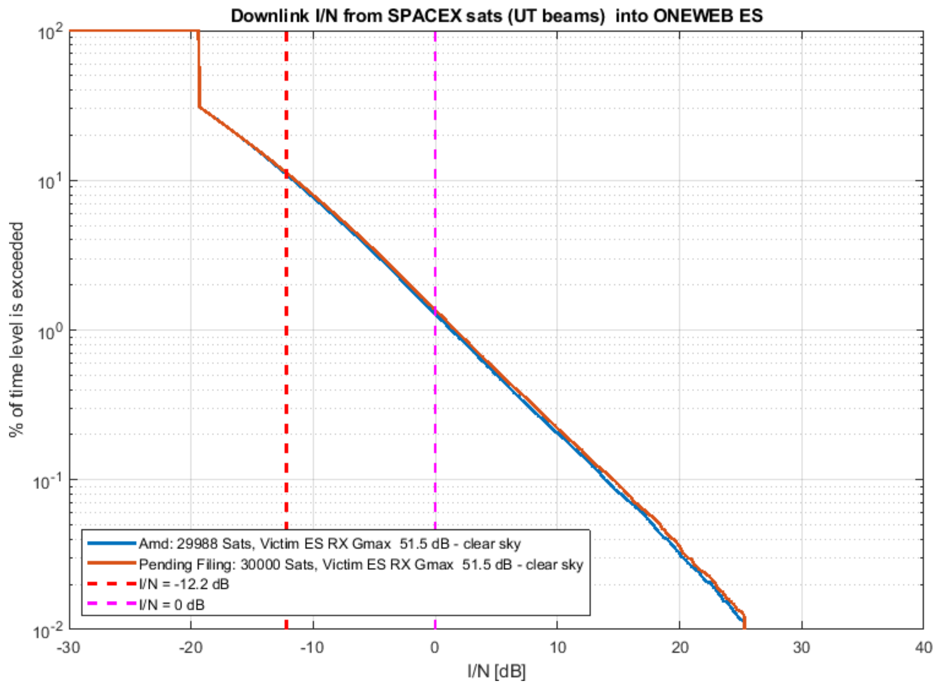

Figure A2a-V.1 — Downlink Interference from SpaceX UT Beam to OneWeb ESs

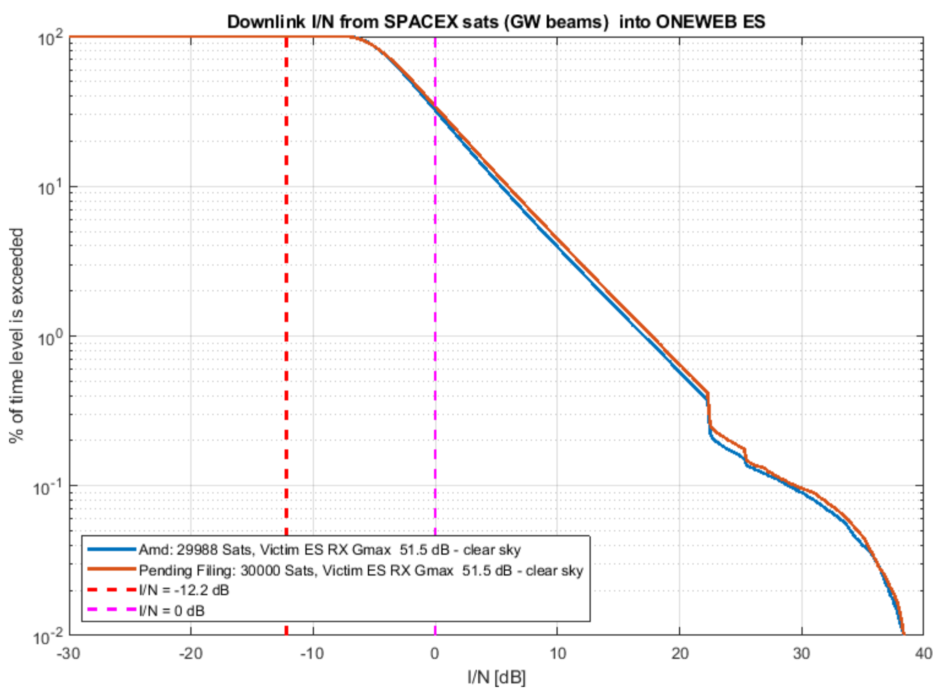

Figure A2a-V.2 — Downlink Interference from SpaceX GW Beam to OneWeb ESs

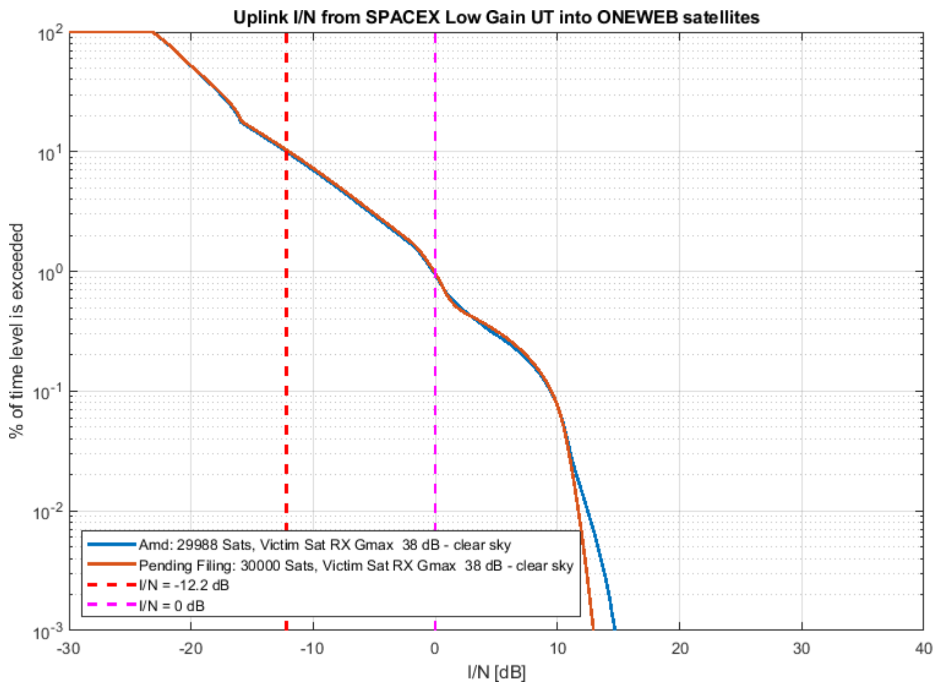

Figure A2a-V.3 — Uplink Interference from SpaceX Low Gain UTs to OneWeb

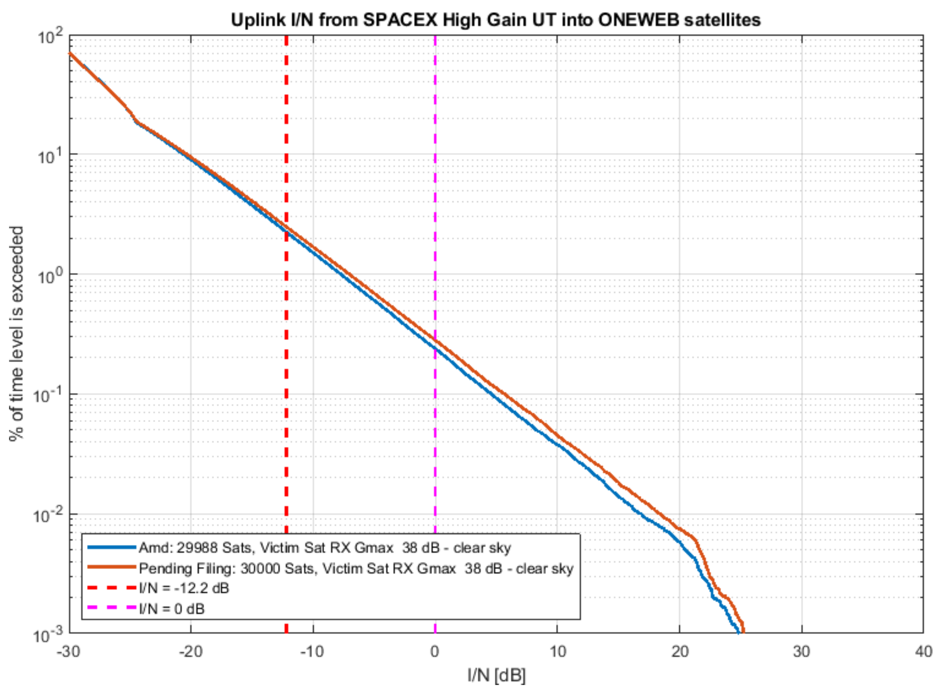

Figure A2a-V.4 — Uplink Interference from SpaceX High Gain UTs to OneWeb

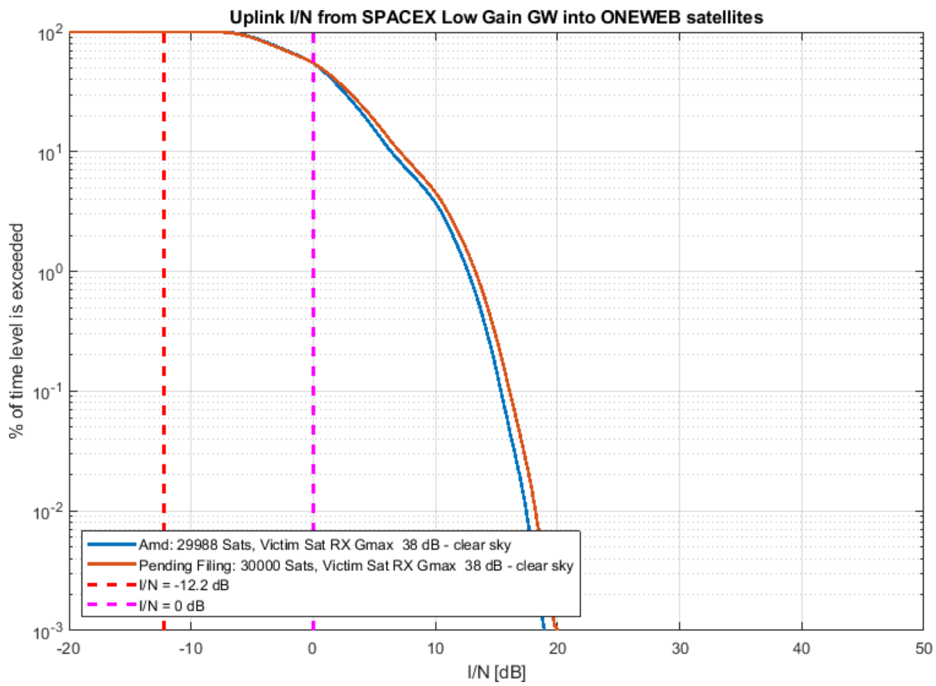

Figure A2a-V.5 — Uplink Interference from SpaceX Low Gain GWs to OneWeb

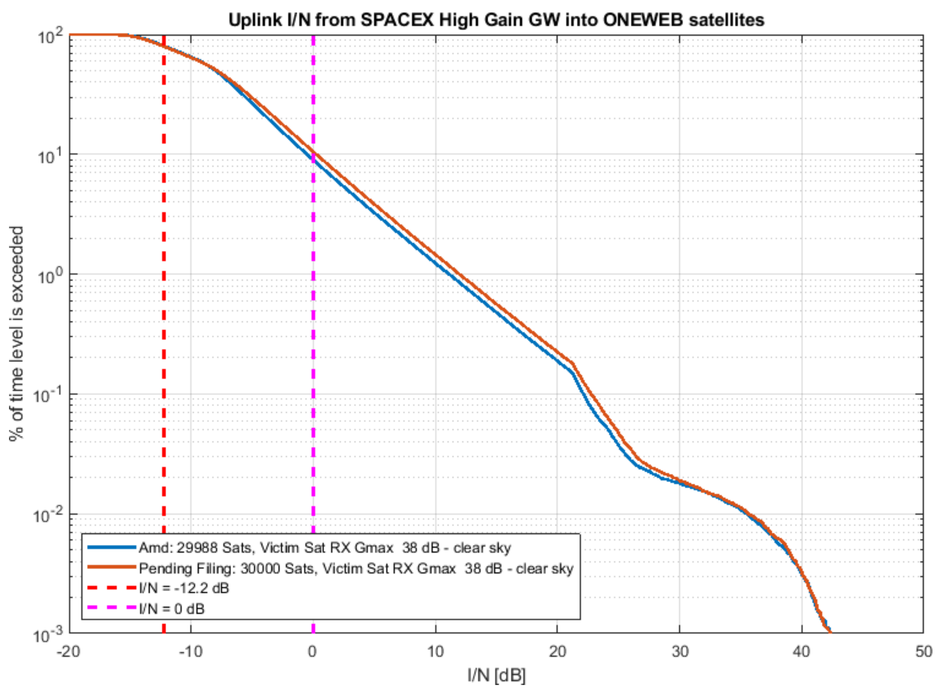

Figure A2a-V.6 — Uplink Interference from SpaceX High Gain GWs to OneWeb

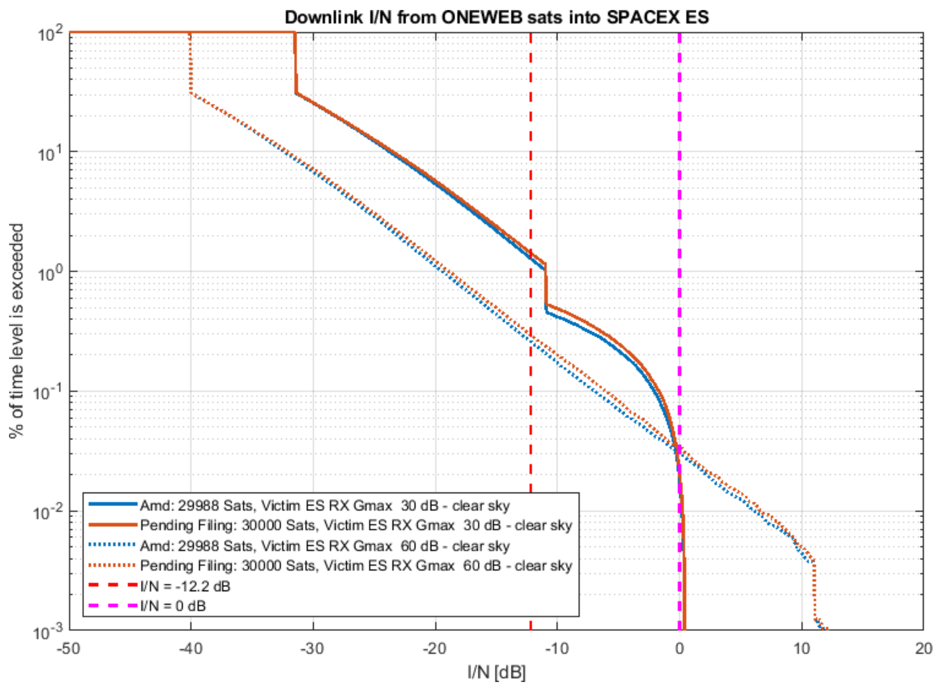

Figure A2a-V.7 — Downlink Interference from OneWeb to SpaceX ESs

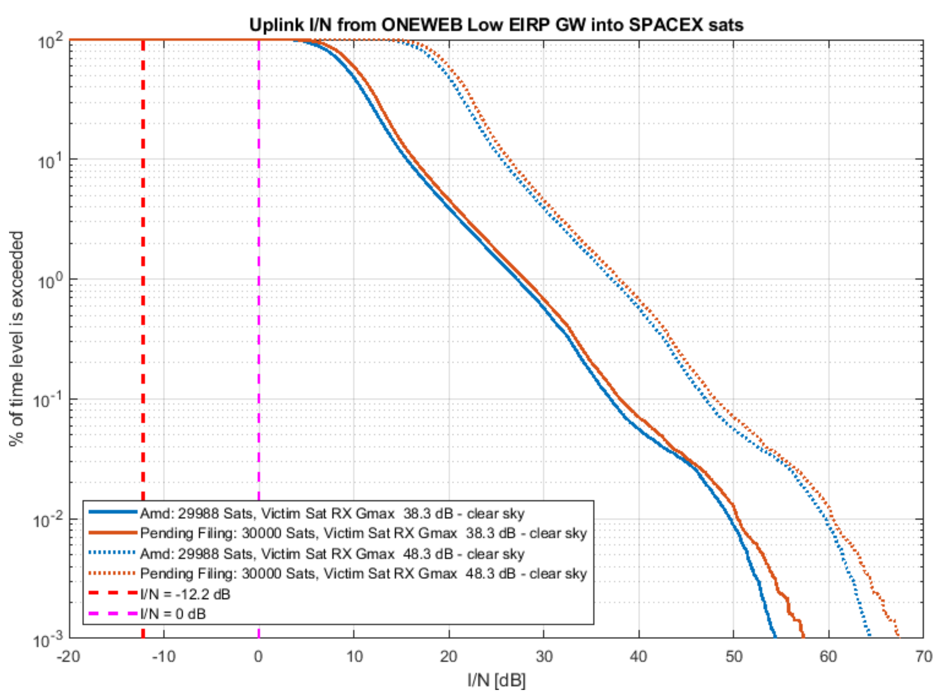

Figure A2a-V.8— Uplink Interference from OneWeb Low EIRP GWs to SpaceX ESs

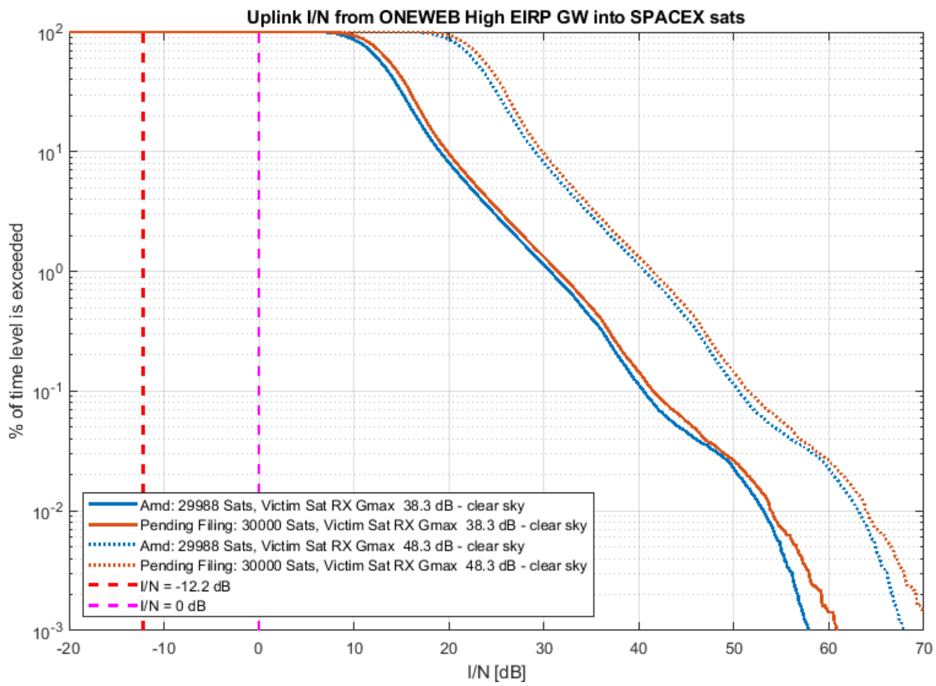

Figure A2a-V.9 — Uplink Interference from OneWeb High EIRP GWs to SpaceX

VI. Telesat

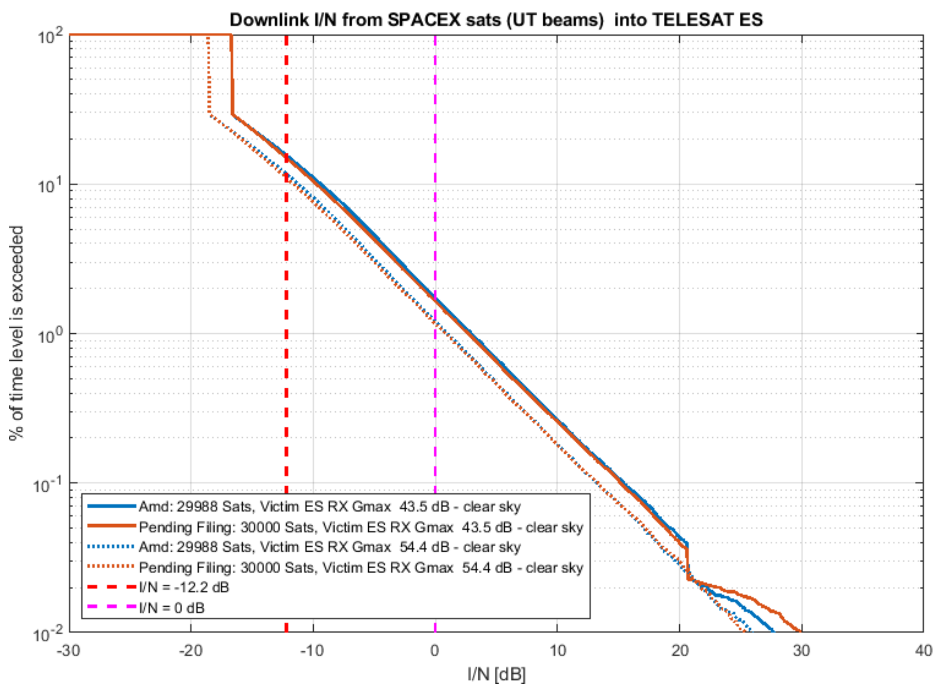

Figure A2a-VI.1 — Downlink Interference from SpaceX UT Beam to Telesat ESs

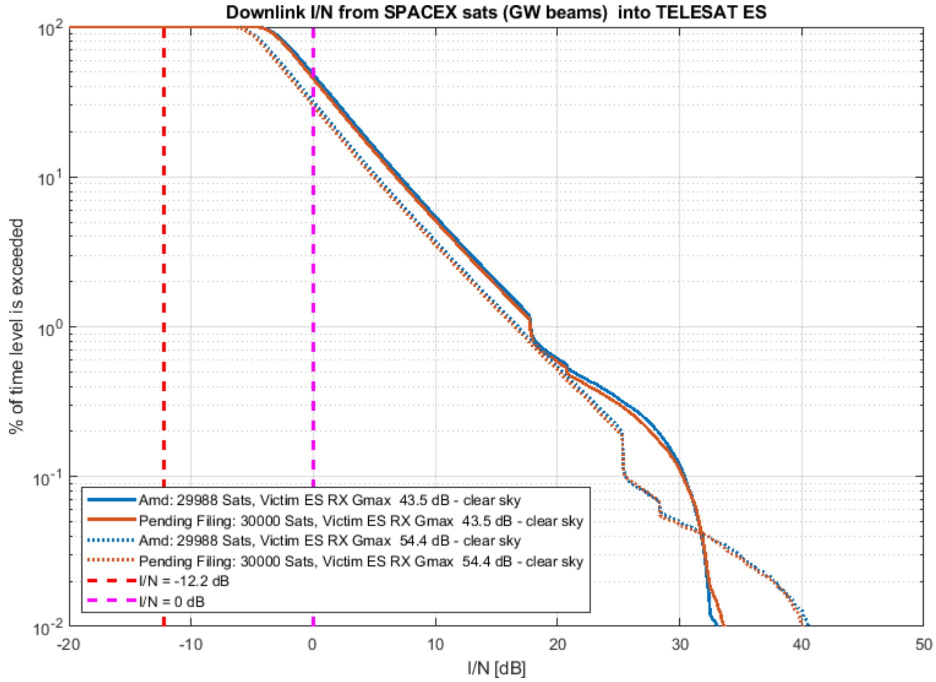

Figure A2a-VI.2 — Downlink Interference from SpaceX GW Beam to Telesat ESs

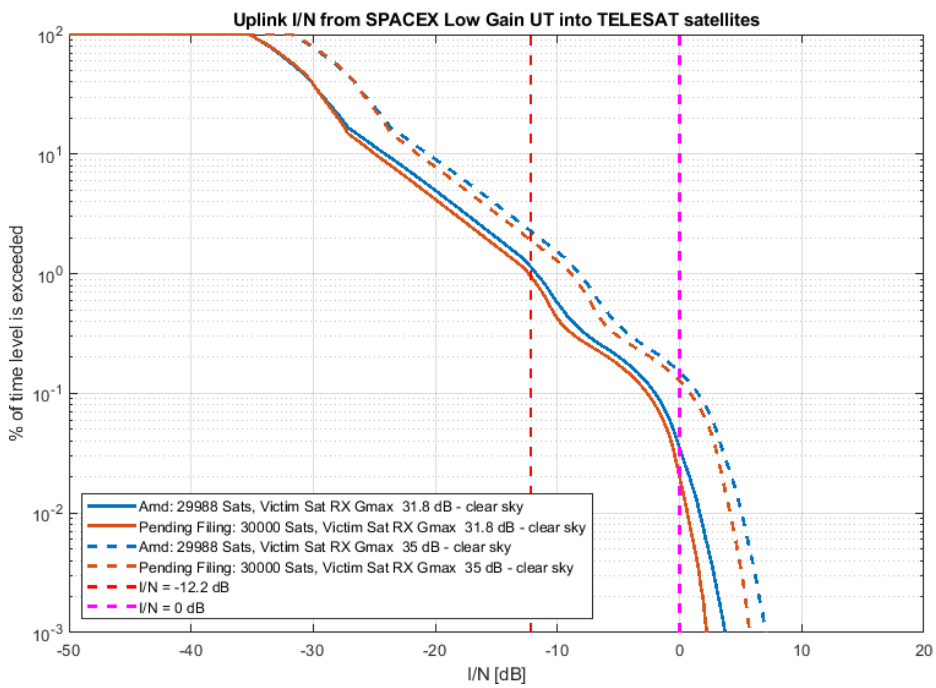

Figure A2a-VI.3 — Uplink Interference from SpaceX Low Gain UTs to Telesat

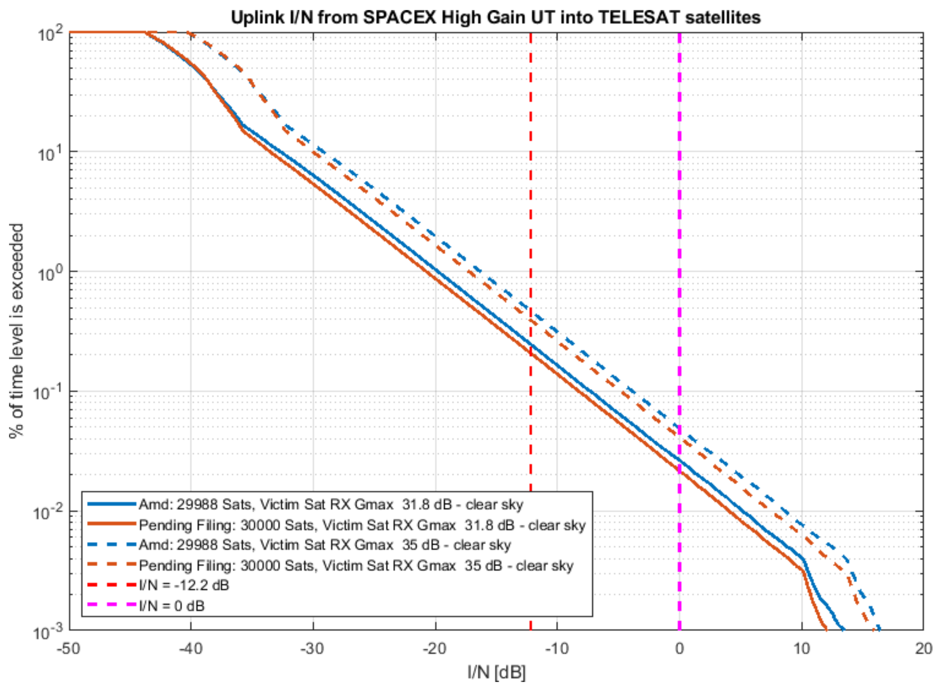

Figure A2a-VI.4 — Uplink Interference from SpaceX High Gain UTs to Telesat

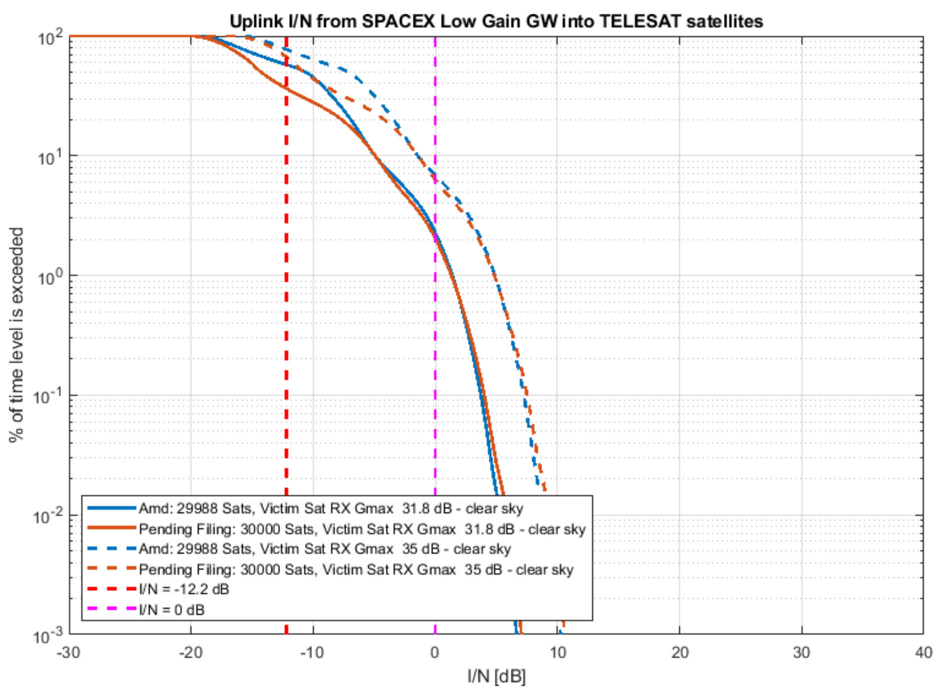

Figure A2a-VI.5 — Uplink Interference from SpaceX Low Gain GWs to Telesat

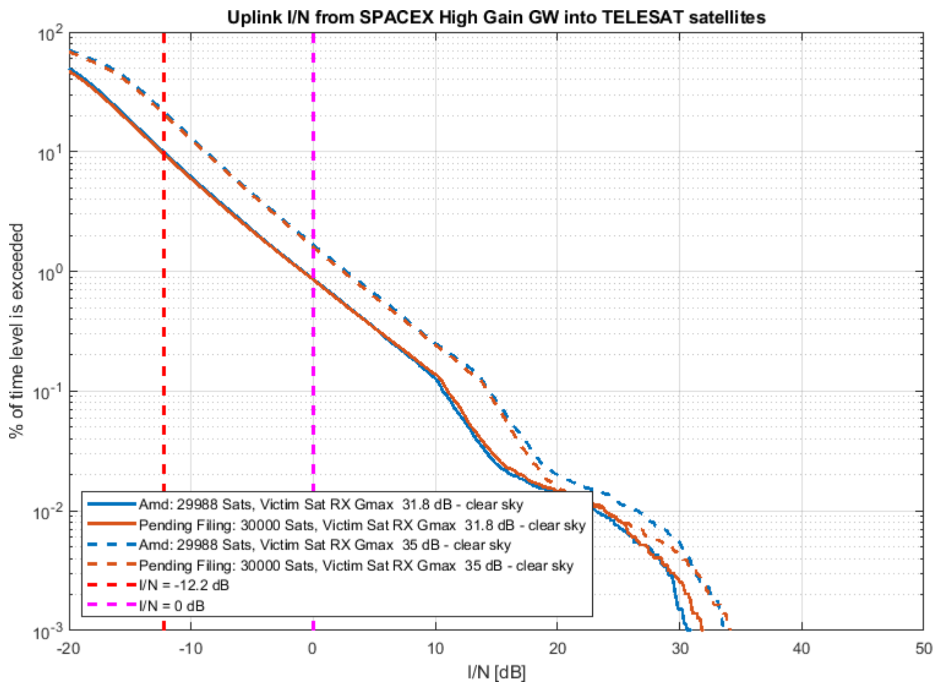

Figure A2a-VI.6 — Uplink Interference from SpaceX High Gain GWs to Telesat

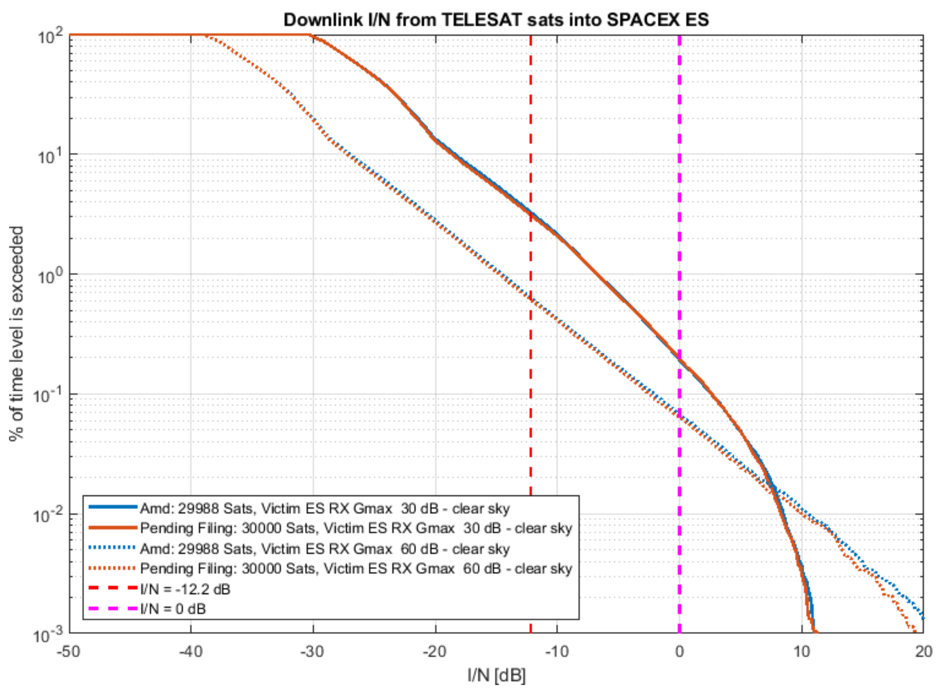

Figure A2a-VI.7 — Downlink Interference from Telesat to SpaceX ESs

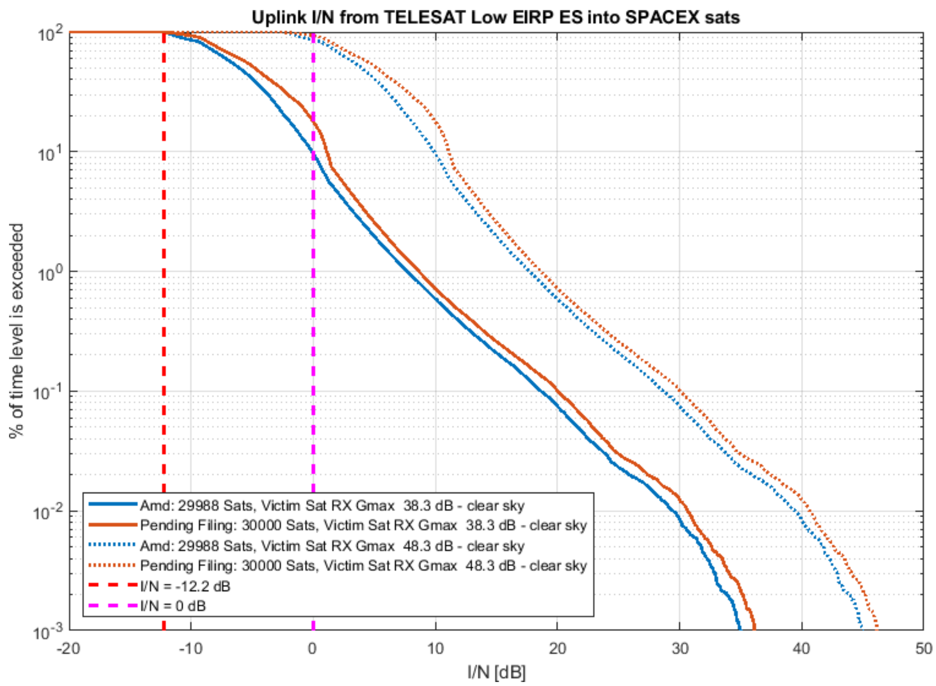

Figure A2a-VI.8 — Uplink Interference from Telesat Low EIRP ESs to SpaceX

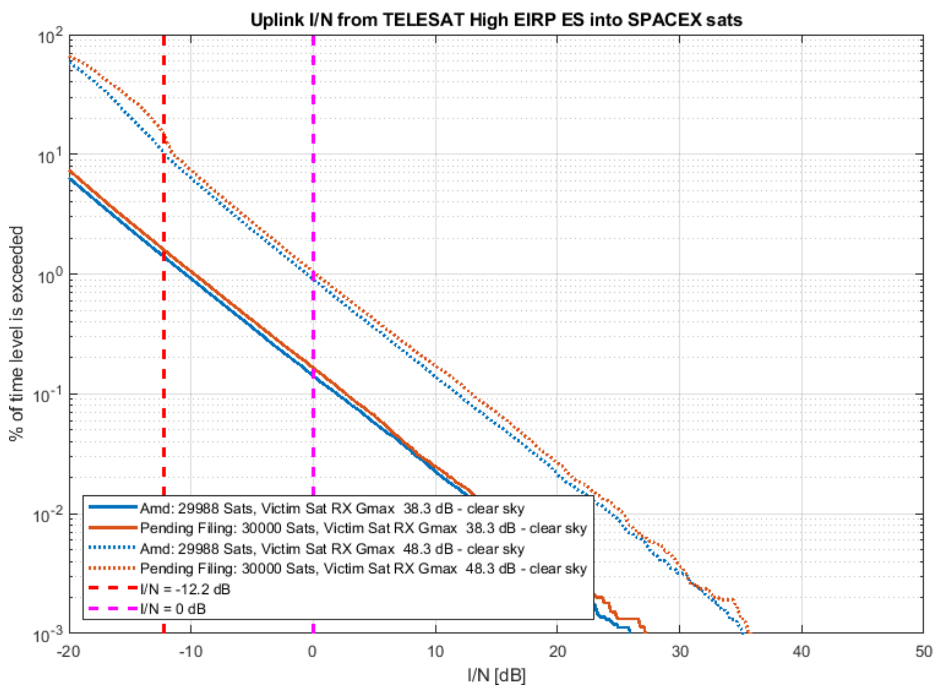

Figure A2a-VI.9 — Uplink Interference from Telesat High EIRP ESs to SpaceX

VII. Viasat

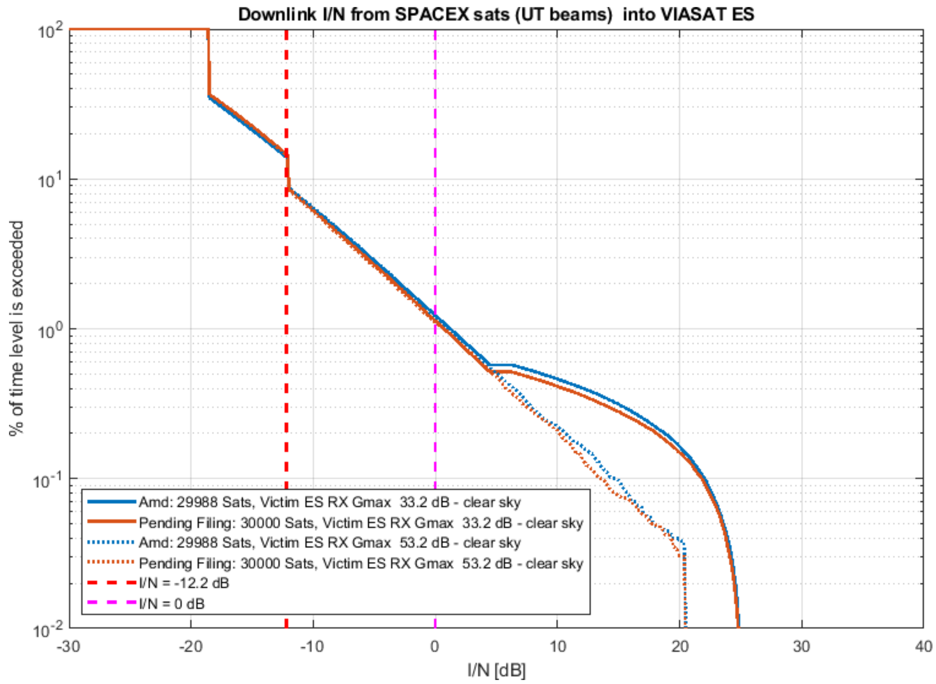

Figure A2a-VII.1 — Downlink Interference from SpaceX UT Beam to Viasat ESs

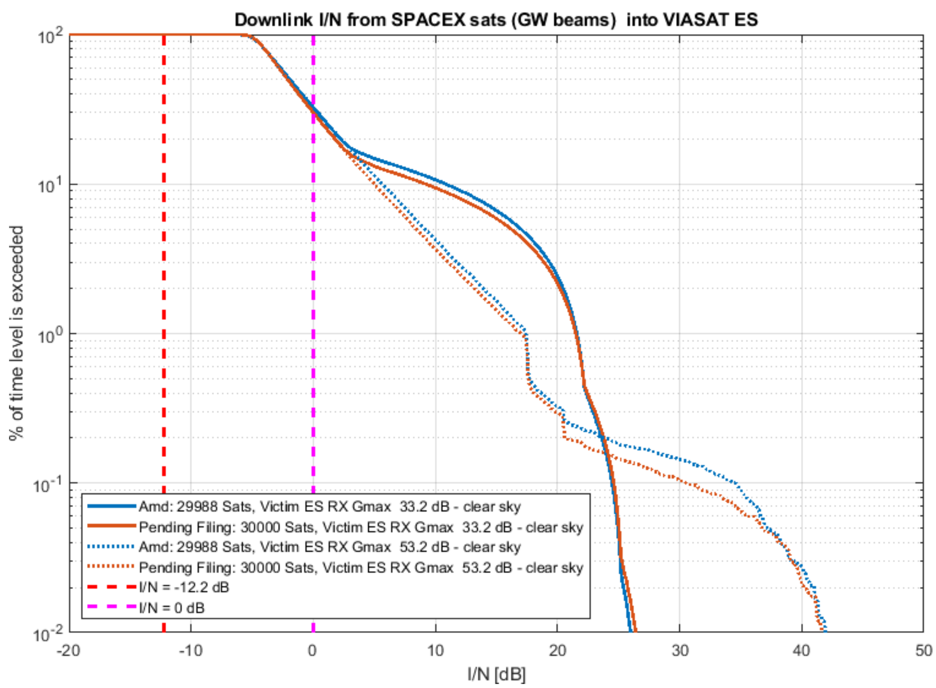

Figure A2a-VII.2 — Downlink Interference from SpaceX GW Beam to Viasat ESs

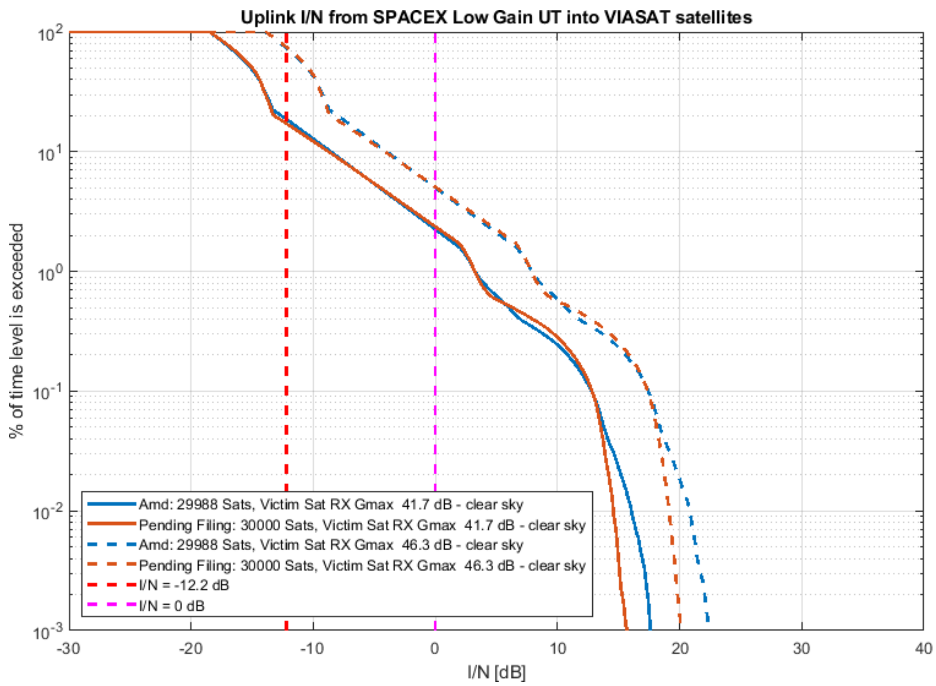

Figure A2a-VII.3 — Uplink Interference from SpaceX Low Gain UTs to Viasat

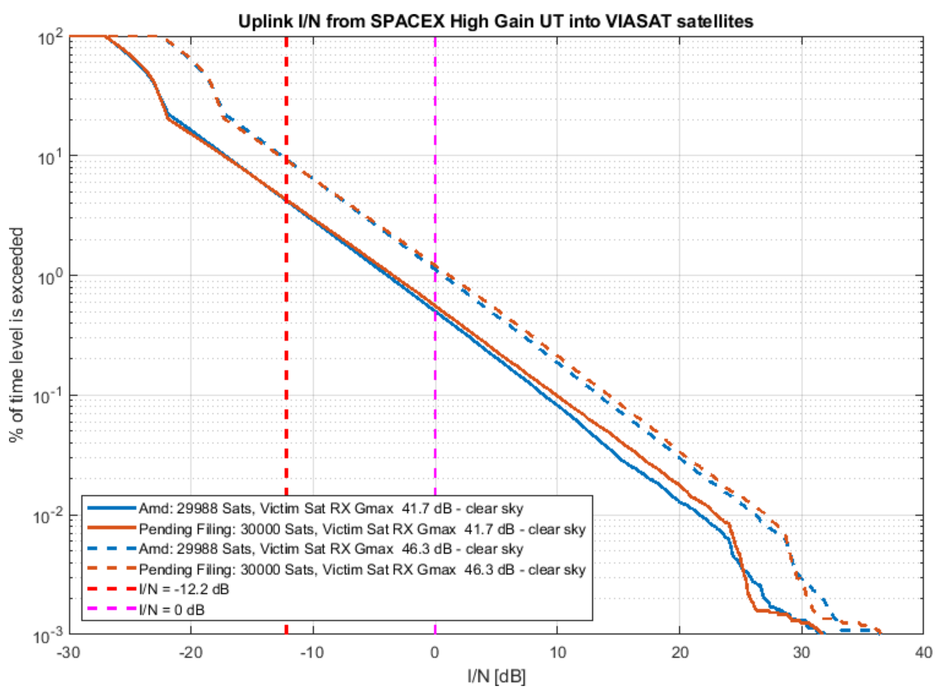

Figure A2a-VII.4 — Uplink Interference from SpaceX High Gain UTs to Viasat

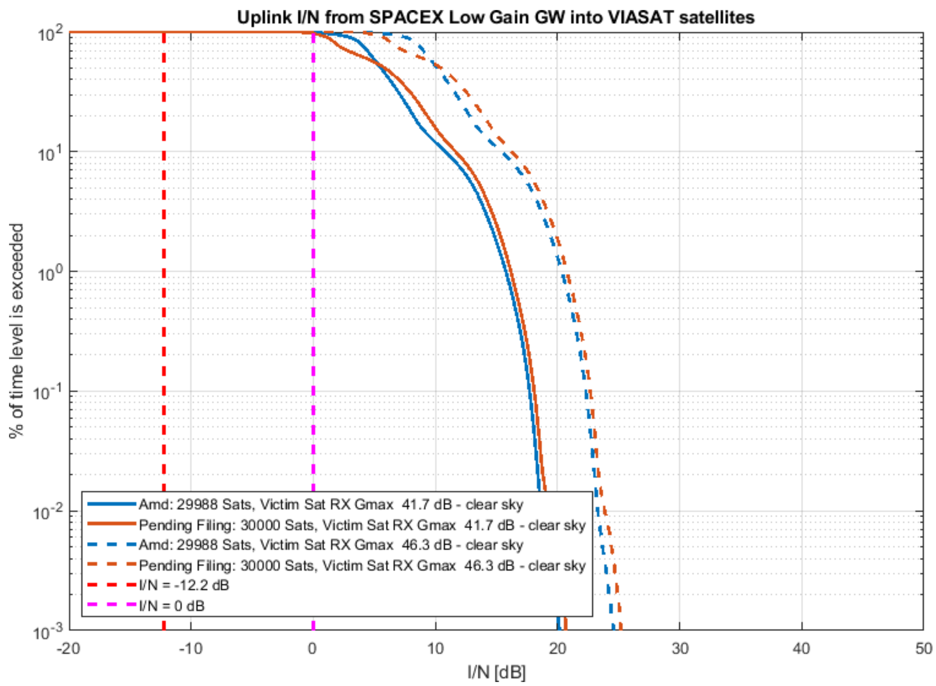

Figure A2a-VII.5 — Uplink Interference from SpaceX Low Gain GWs to Viasat

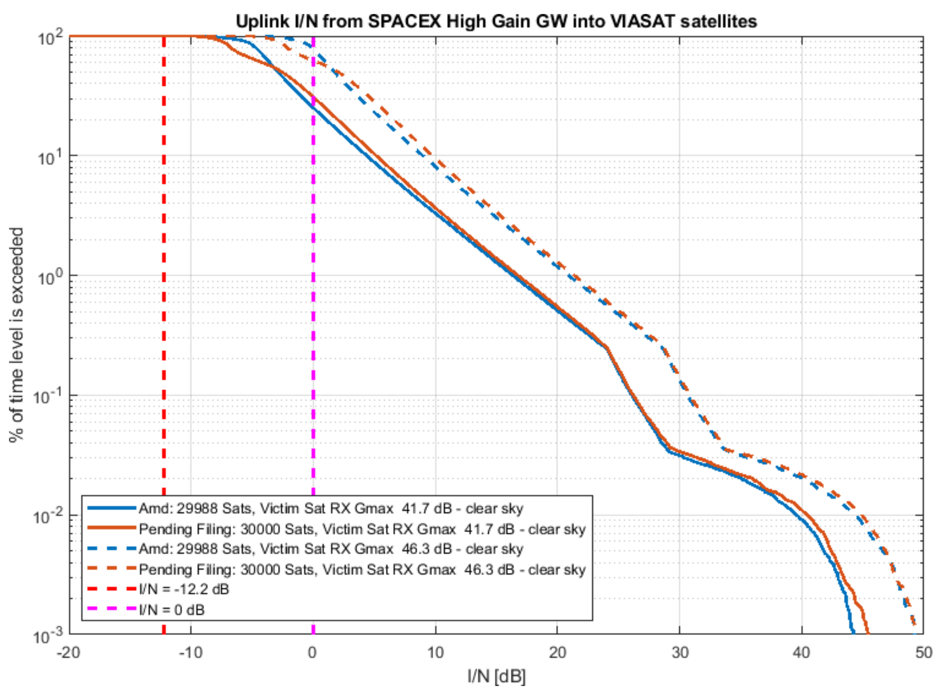

Figure A2a-VII.6 — Uplink Interference from SpaceX High Gain GWs to Viasat

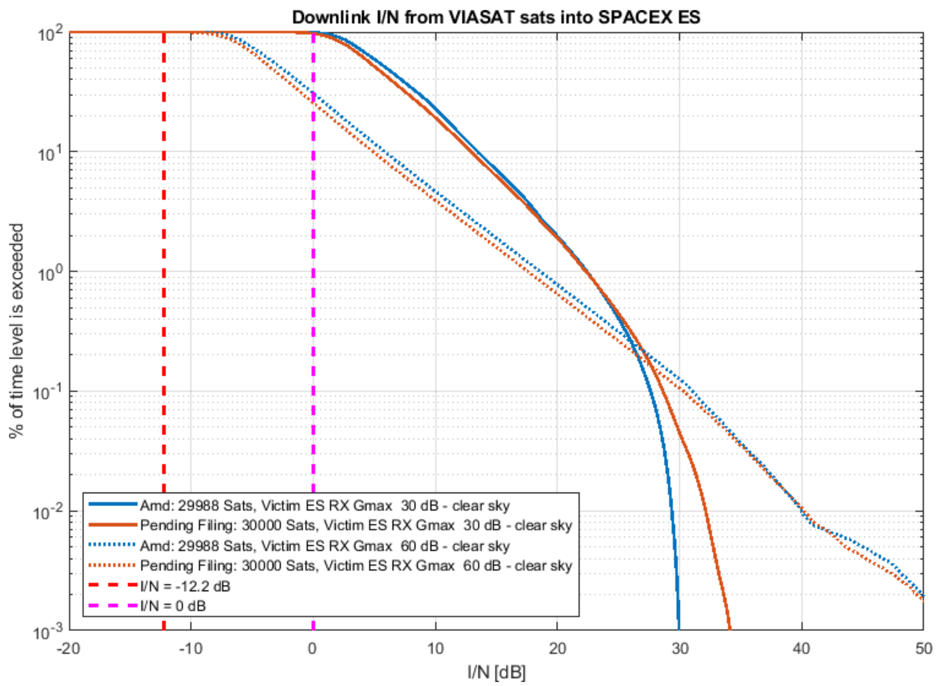

Figure A2a-VII.7 — Downlink Interference from Viasat to SpaceX ESs

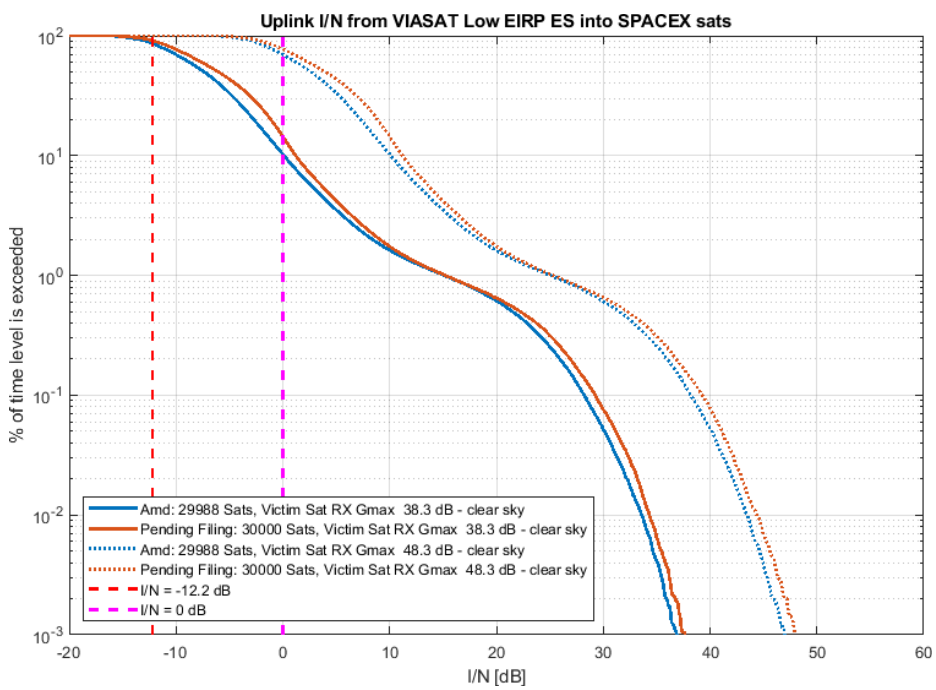

Figure A2a-VII.8 — Uplink Interference from Viasat Low EIRP ESs to SpaceX

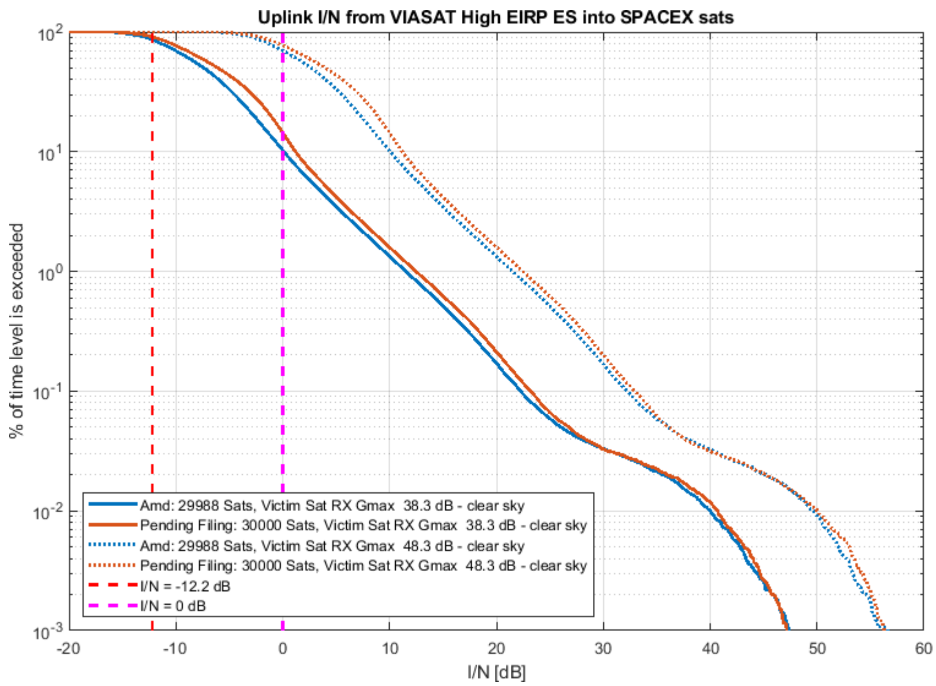

Figure A2a-VII.9 — Uplink Interference from Viasat High EIRP ESs to SpaceX

ANNEX 2B

POTENTIAL INTERFERENCE WITH RESPECT TO OTHER NGSO SATELLITE SYSTEMS PROPOSED IN THE 2020 PROCESSING ROUND—CONFIGURATION 2

SpaceX has engineered its Gen2 System with the technical flexibility that will facilitate the necessary coordination with other NGSO satellite systems and is committed to achieving mutually satisfactory agreements. Moreover, neither system configuration proposed herein will result in increased interference to other NGSO systems proposed in the 2020 Processing Round.

To demonstrate this point, SpaceX performed an analysis of the effect of the proposed amendment, under both configurations, on downlink and uplink interference using the characteristics of six NGSO systems participating in the 2020 Processing Round. This analysis considers the effect of Configuration 2 of the proposed amendment on two pending applications for hypothetical operations in the Ku-band (OneWeb and Kepler), which SpaceX proposes to use for communications with user terminals ("UTs"), and five pending applications for hypothetical operations in the Ka-band (Amazon, O3b, OneWeb, Telesat, and Viasat), which SpaceX proposes to use for communications with both UTs and gateways ("GWs").

The analysis considers the dynamic, time-varying interference expressed as a cumulative distribution function ("CDF") of the interference-to-noise ratio ("I/N"), for varying percentages of time. The I/N CDF is derived from a time-domain simulation of the two NGSO systems over a long enough time to produce meaningful statistics, using random antenna pointing. The corresponding interference levels before and after the amendment are calculated and plotted. To present a worst-case assessment of the interference environment, the analysis also assumes that the two systems do not implement any interference mitigation strategies. For these analyses, SpaceX used publicly available parameters for each NGSO system and, when relevant parameters were not available, conservative assumptions. The analysis considers both the lowest and highest gains relevant to the victim earth station (for downlink) and victim satellite receive antenna (for uplink) as relevant.

As demonstrated below, the new interference levels resulting from the amendment are mostly less than (and at worst comparable to) the interference levels that would have been experienced with the originally proposed constellation in the noise-dominated environment (i.e., I/N ≤ 0 dB). In the interference-dominated environment (i.e., I/N > 0 dB), the victim system already typically experiences at least 3 dB receiver de-sensitivity (if not 15 dB or more) and the two systems are not likely able to share the spectrum in a meaningful way outside of band segmentation both with and without the proposed amendment. Though some of the following plots show a theoretical increase in interference after the proposed amendment at fairly high I/N levels, in practice the two systems would need to implement band segmentation even before reaching such a highly interference-dominated environment. Hence, this amendment will not increase the potential interference into or from these NGSO systems operating in areas where true spectrum-sharing options may be available with the originally proposed system. It also will not increase the likelihood of exceeding the Commission's -12.2 dB (6% ΔT/T) threshold above which parties will be required to either split the spectrum or coordinate.[1]

In conducting the analysis, SpaceX used the following assumptions.

<u>For downlink interference between SpaceX satellites and another operator's earth station</u>:

1. The SpaceX earth station is collocated with the other operator's earth station at 40°N 100°W in this simulation.[2]

2. The victim earth station can communicate with any satellite in its own system

[1] 47 C.F.R. § 25.261(c).

[2] Note that SpaceX ran its simulation with multiple latitudes and achieved similar results for both the downlink and uplink analysis. Accordingly, it chose to provide results for one latitude that is centrally located in its U.S. service area.

following the rules applicable for that system (e.g., minimum elevation angle), except that no GSO avoidance angle is assumed for any system to ensure a conservative analysis. All possible valid cases are considered in evaluating the I/N CDF.

3. The SpaceX system places one co-frequency beam per Ku-band spot and either one (for UTs) or thirty-two (for GWs) co-frequency beams per Ka-band spot, and any satellite in view meeting the minimum elevation angle is eligible. SpaceX satellites are chosen randomly for consideration in evaluating the I/N CDF and operate at the power flux-density levels described in the Original Application and Configuration 2 of this amendment. The other operator's NGSO system operates as proposed in its 2020 Processing Round application.

4. The results are set forth for each NGSO system below. Note that this simulation is conservative (i.e., it overestimates I/N), as it does not consider the effects of atmospheric attenuation.

<u>For uplink interference between SpaceX earth stations and another operator's satellites</u>:

1. The SpaceX earth station is collocated with an earth station from the other system at 40°N 100°W in this simulation.

2. The other system's earth station can communicate with any satellite in its own system following the rules applicable for that system (e.g., minimum elevation angle), except that no GSO avoidance angle is assumed for any system to ensure a conservative analysis. All possible valid cases are considered in evaluating the I/N CDF.

3. In the SpaceX system, one co-frequency tracked satellite in Ku-band and one or thirty-two co-frequency tracked satellites in Ka-band (for UTs and GWs, respectively) can receive simultaneously from an earth station. Any satellite in view meeting the

minimum elevation angle is eligible. SpaceX satellites are randomly chosen for consideration in evaluating the I/N CDF. The other operator's NGSO system operates as proposed in its 2020 Processing Round application.

4. The results are set forth for each NGSO system below. Note that this simulation is conservative (i.e., it overestimates I/N), as it does not consider the effects of atmospheric attenuation.

KU-BAND SYSTEMS

The NGSO systems proposed by SpaceX, OneWeb, and Kepler in the 2020 Processing Round all use Ku-band spectrum for communications with users. Accordingly, the analysis below assesses the potential for interference between the user links. The results of the analysis for uplink and downlink interference simulations from and to each system are set forth below. In each case, the figure plots a CDF of aggregate I/N levels for the SpaceX constellation as originally proposed and as amended under Configuration 2.

I. OneWeb

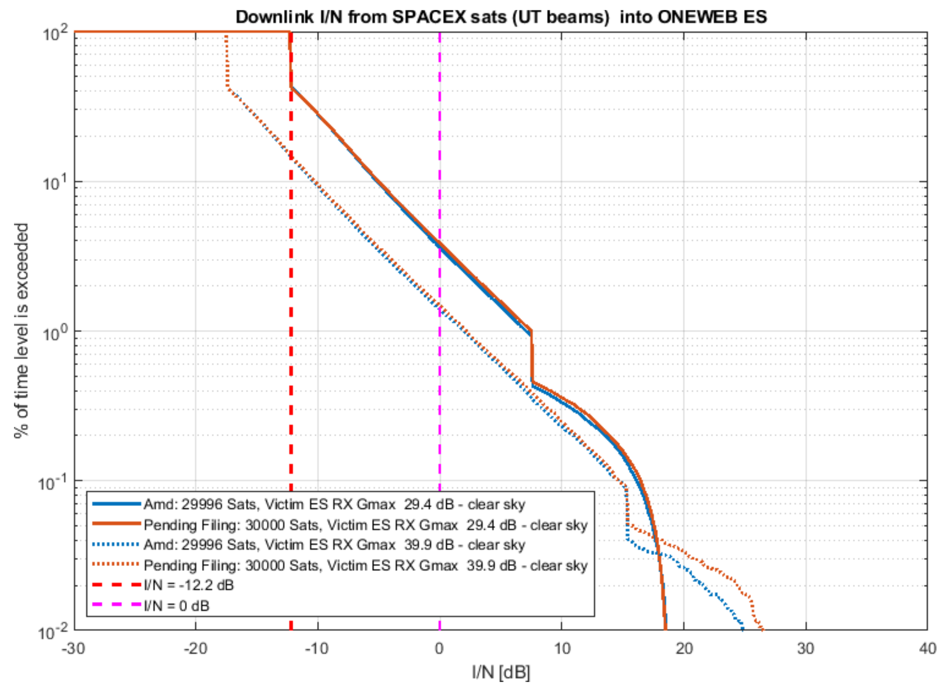

Figure A2b-I.1 — Downlink Interference from SpaceX to OneWeb UTs

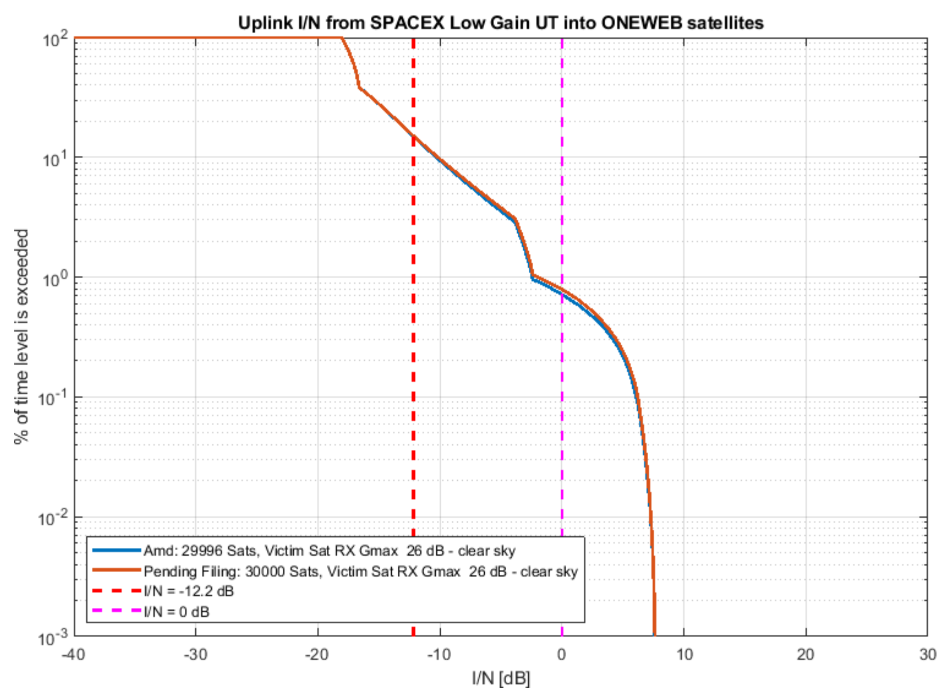

Figure A2b-I.2 — Uplink Interference from SpaceX Low Gain UTs to OneWeb

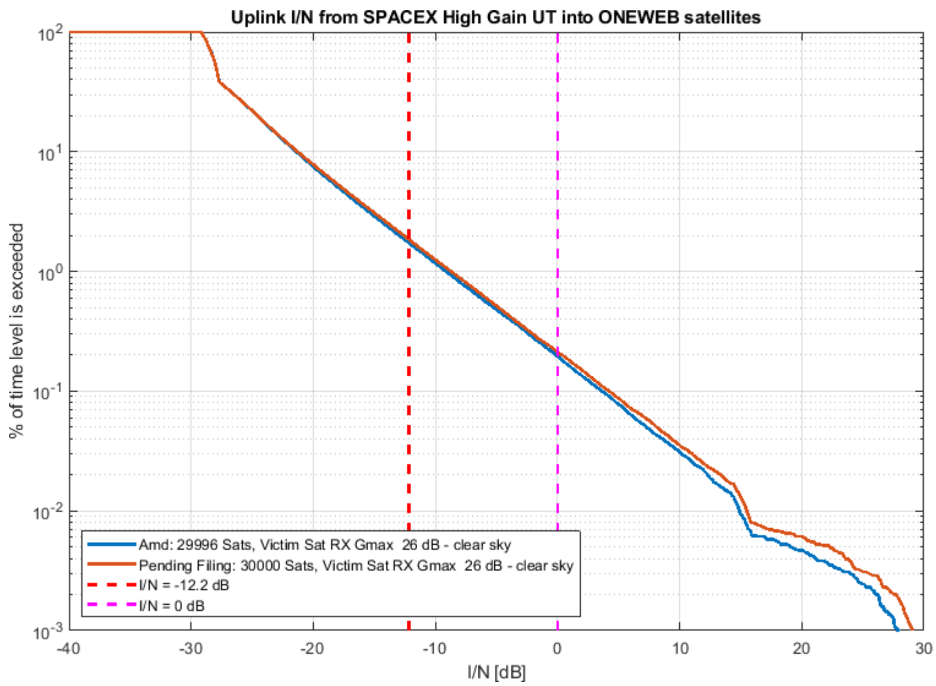

Figure A2b-I.3 — Uplink Interference from SpaceX High Gain UTs to OneWeb

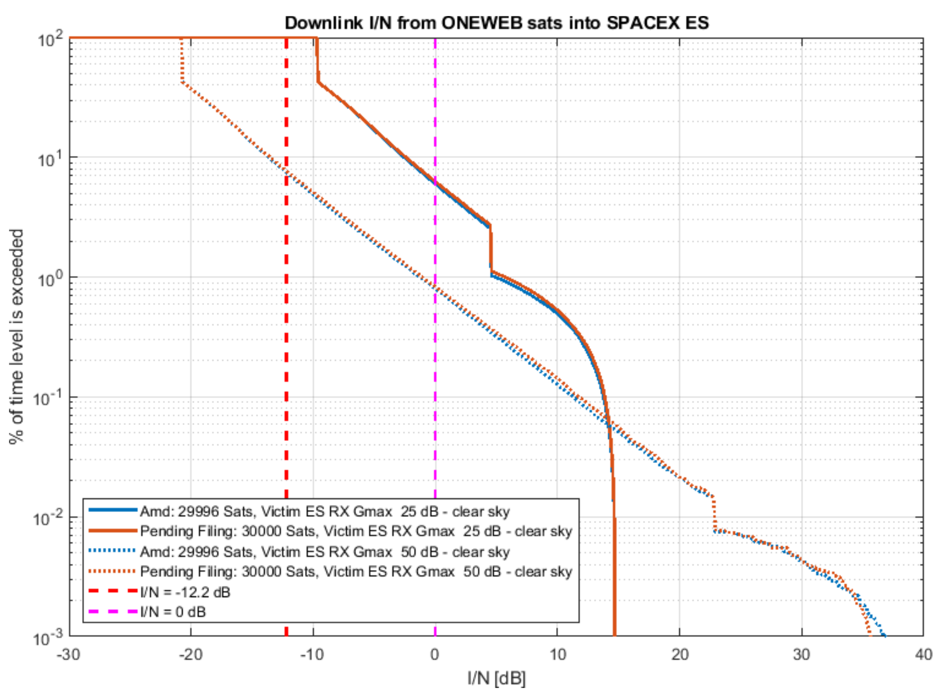

Figure A2b-I.4 — Downlink Interference from OneWeb to SpaceX ESs

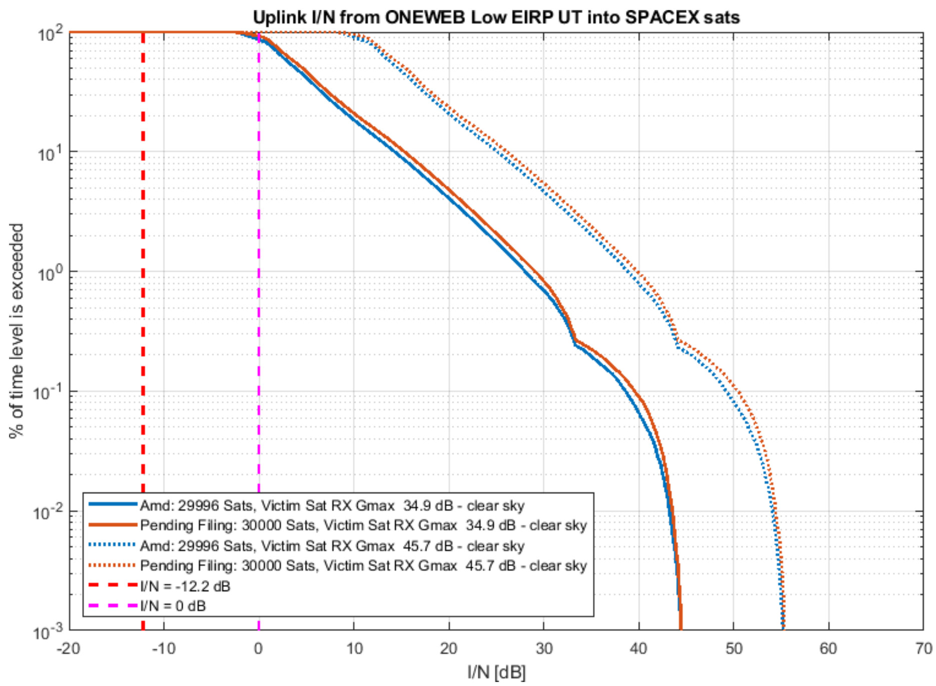

Figure A2b-I.5 — Uplink Interference from OneWeb Low EIRP UTs to SpaceX

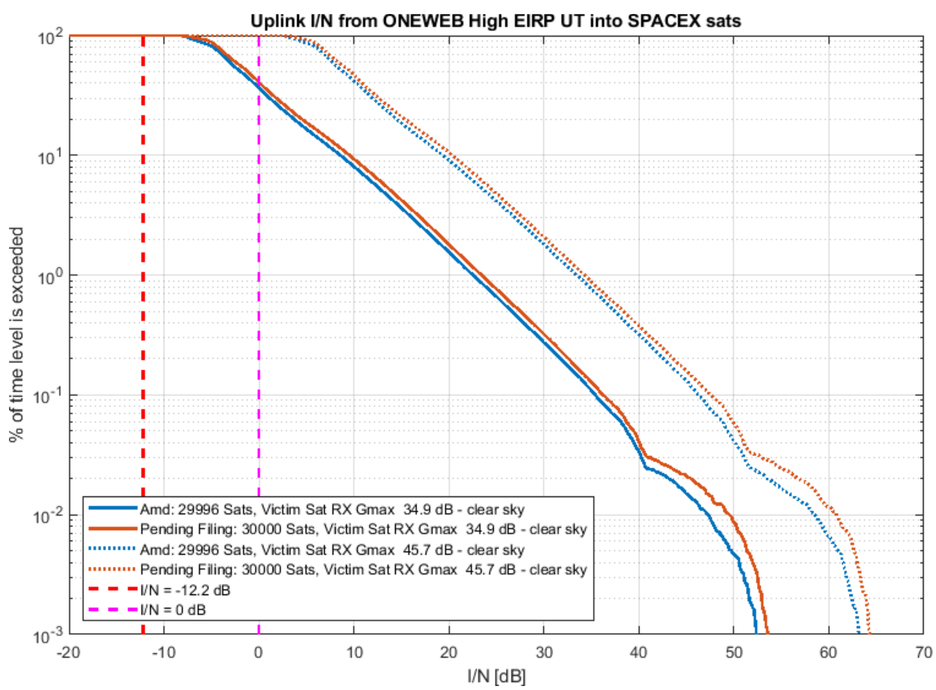

Figure A2b-I.6 — Uplink Interference from OneWeb High EIRP UTs to SpaceX

II. Kepler

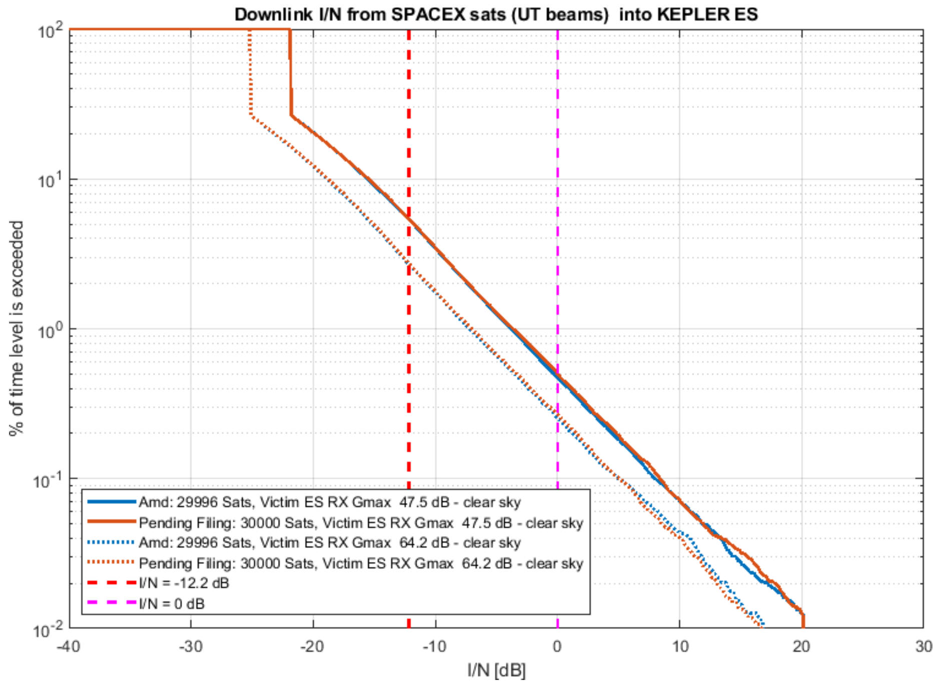

Figure A2b-II.1 — Downlink Interference from SpaceX to Kepler GWs

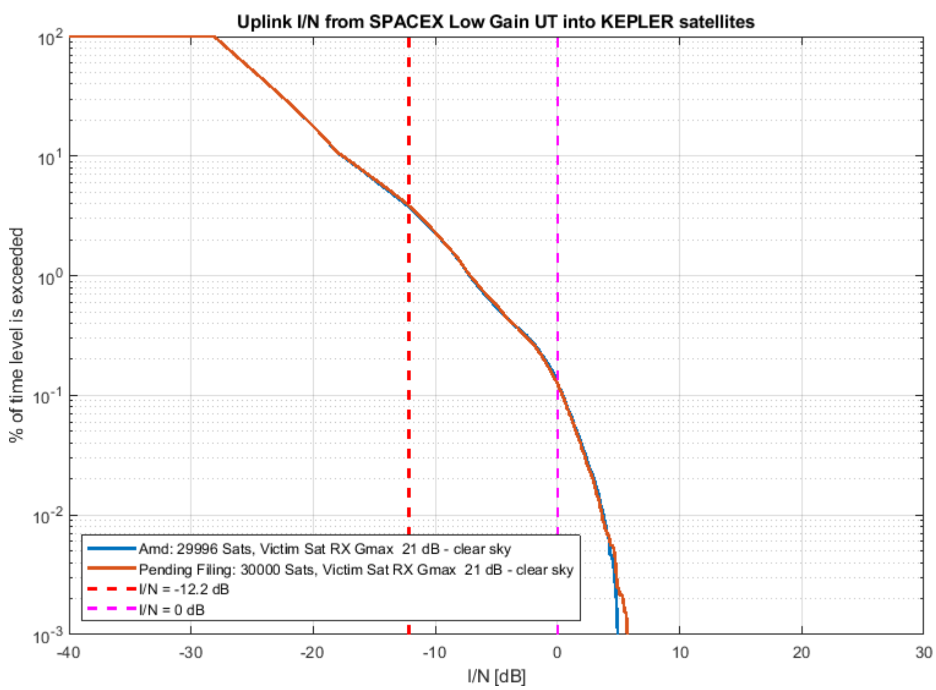

Figure A2b-II.2 — Uplink Interference from SpaceX Low Gain UTs to Kepler

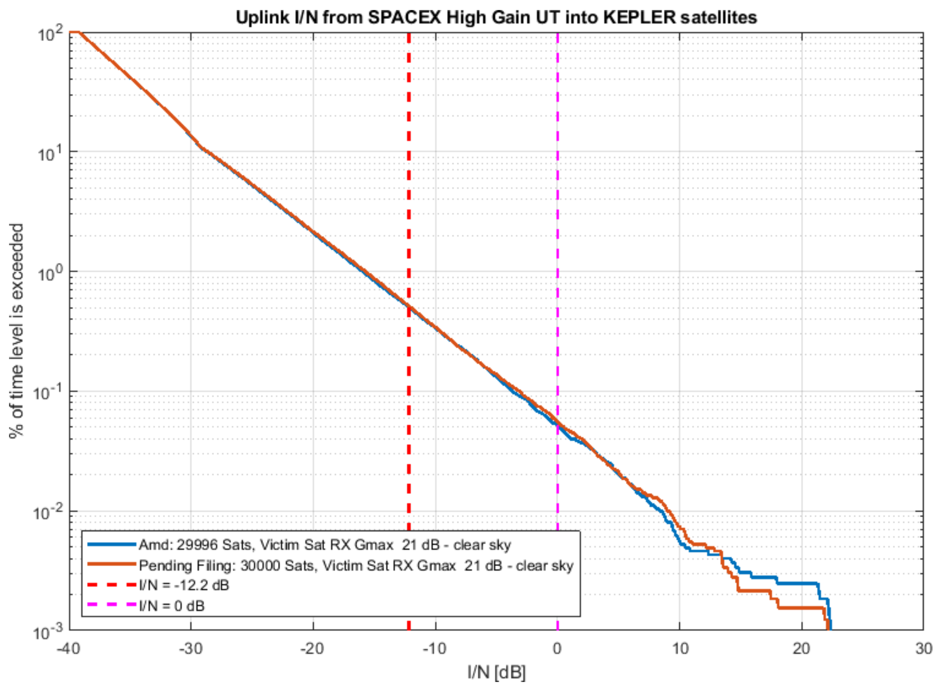

Figure A2b-II.3 — Uplink Interference from SpaceX High Gain UTs to Kepler

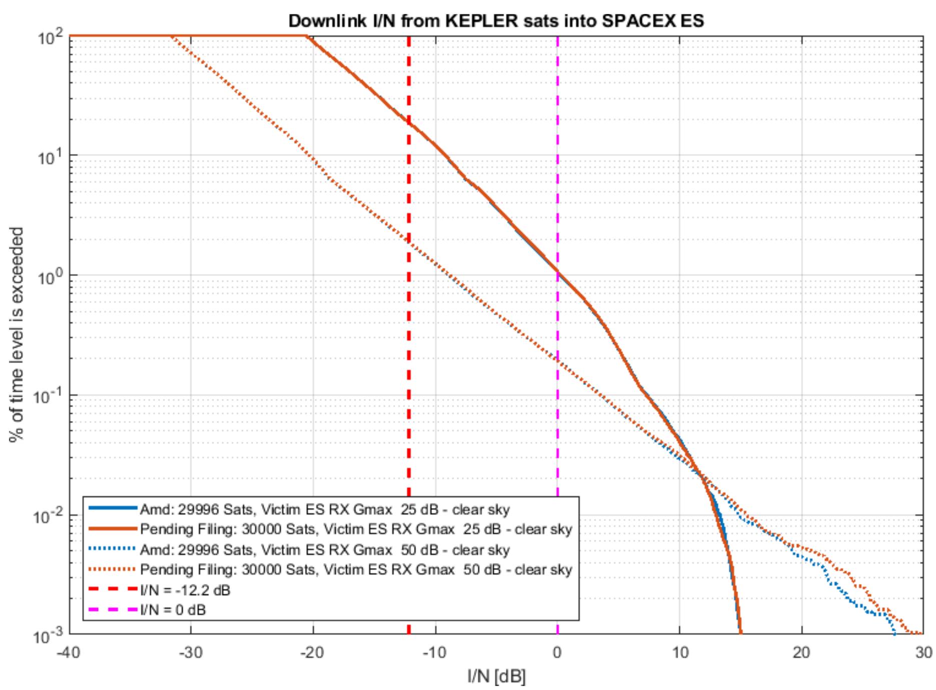

Figure A2b-II.4 — Downlink Interference from Kepler to SpaceX ESs

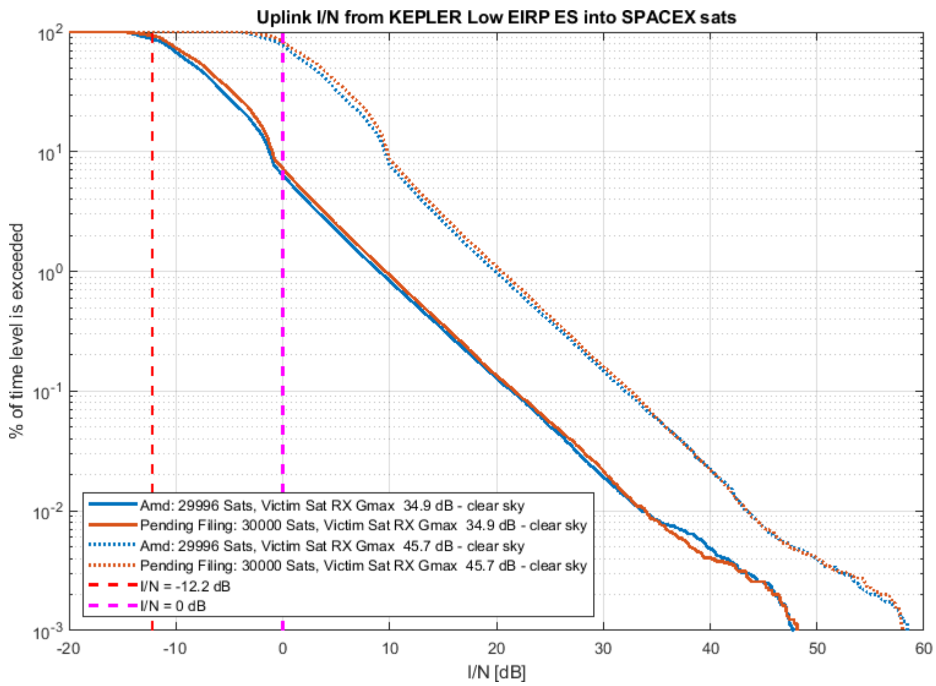

Figure A2b-II.5 — Uplink Interference from Kepler Low EIRP GWs to SpaceX

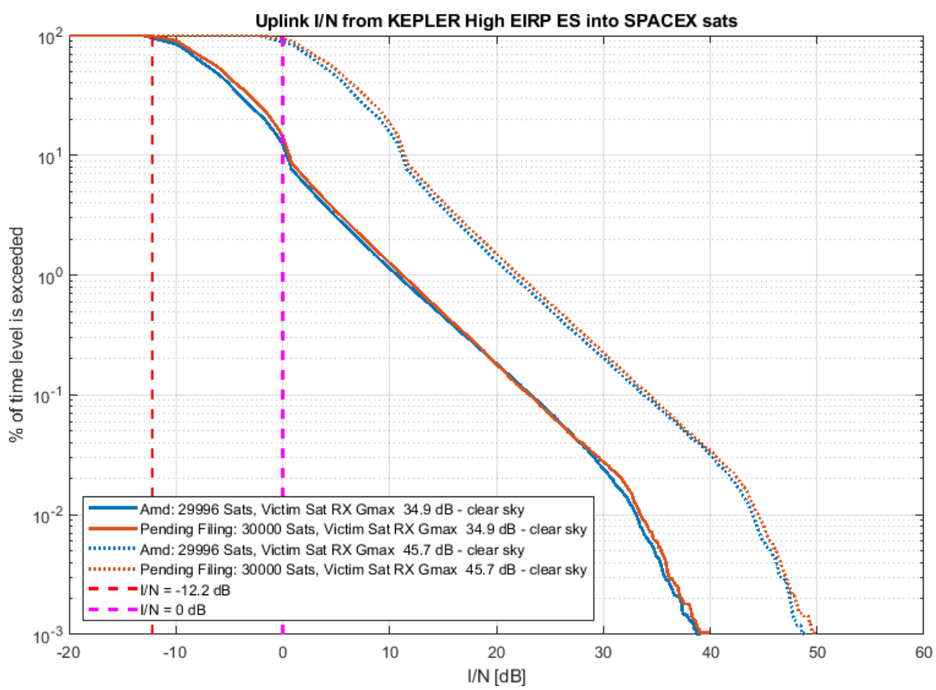

Figure A2b-II.6 — Uplink Interference from Kepler High EIRP GWs to SpaceX

KA-BAND SYSTEMS

The NGSO systems proposed by SpaceX, Amazon, O3b, Telesat, and Viasat in the 2020 Processing Round all use Ka-band spectrum for communications with both UTs and GWs. Accordingly, the analysis below with respect to those systems assesses the potential for interference between both user and gateway links. Because OneWeb proposes to use Ka-band spectrum for GWs only, the analysis for its system relates only to GW links. The results of the analysis for uplink and downlink interference simulations from and to each system are set forth below. In each case, the figure plots a CDF of aggregate I/N levels for the SpaceX constellation as originally proposed and as amended under Configuration 2.

III. Amazon

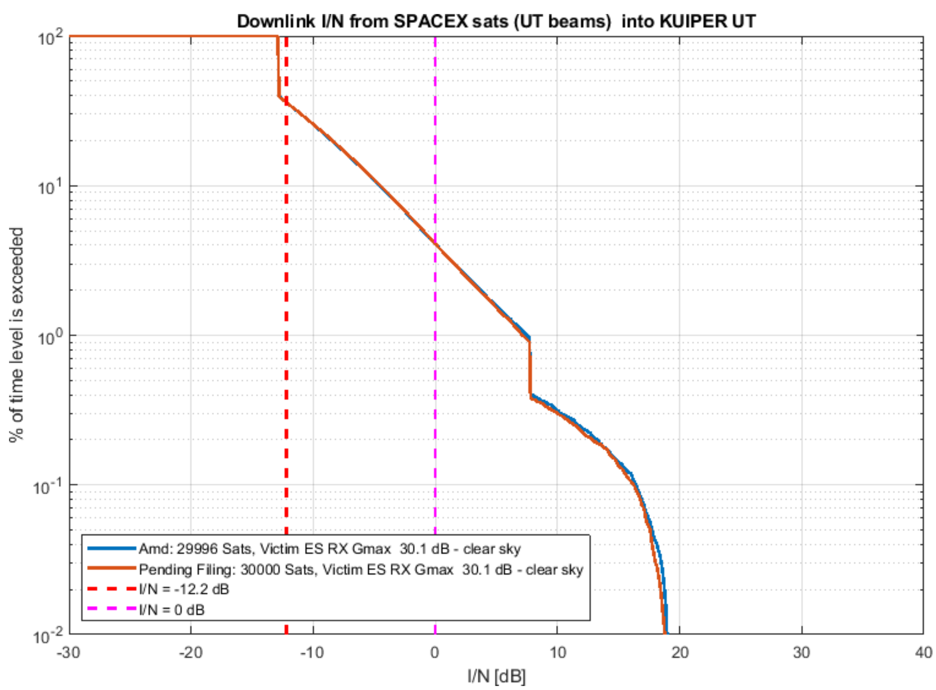

Figure A2b-III.1 — Downlink Interference from SpaceX UT Beam to Amazon UTs

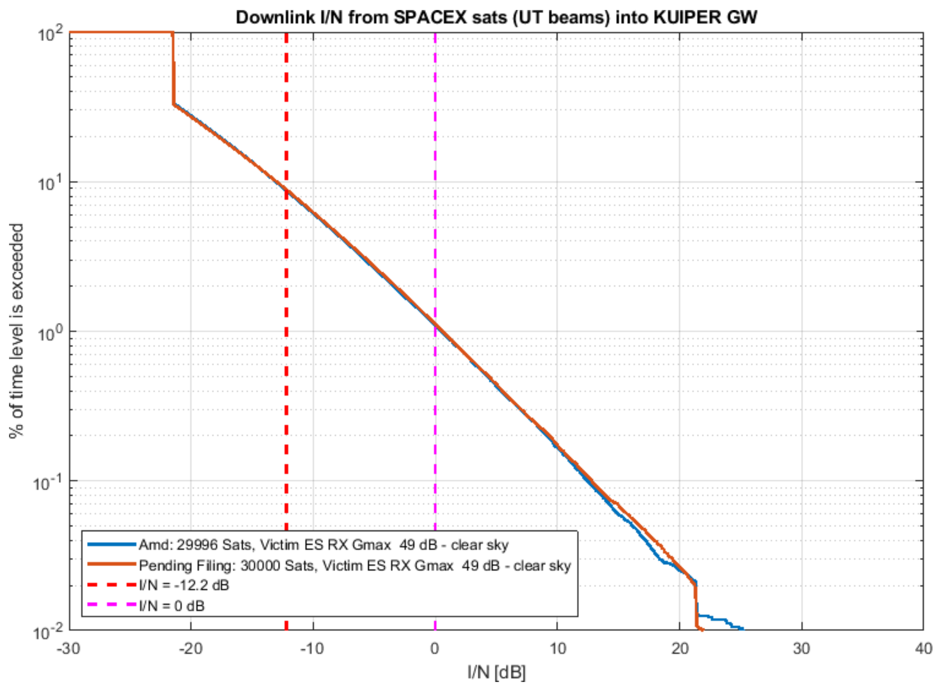

Figure A2b-III.2 — Downlink Interference from SpaceX UT Beam to Amazon GWs

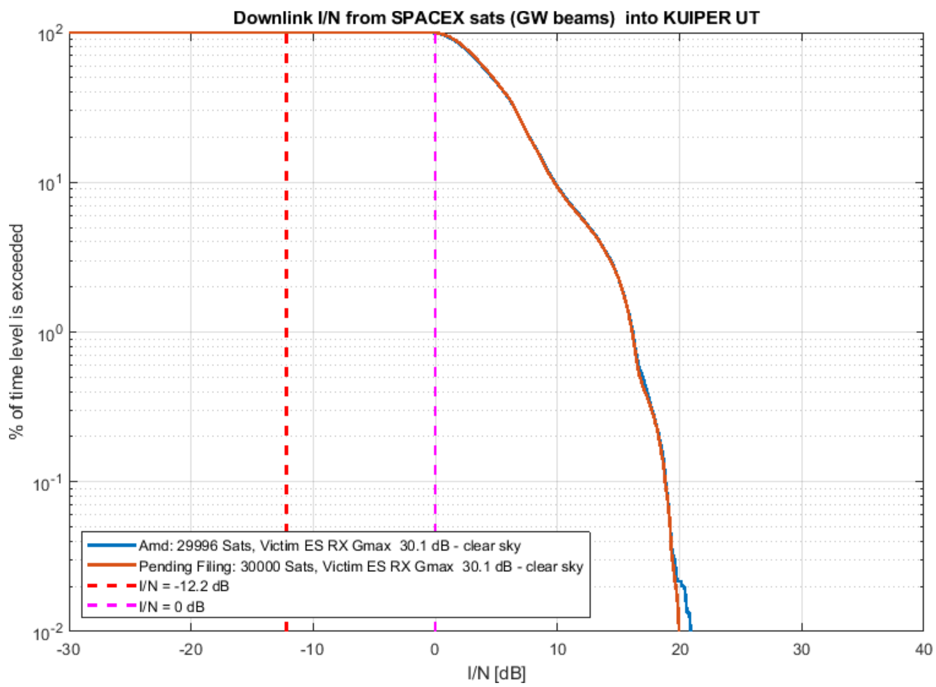

Figure A2b-III.3 — Downlink Interference from SpaceX GW Beam to Amazon UTs

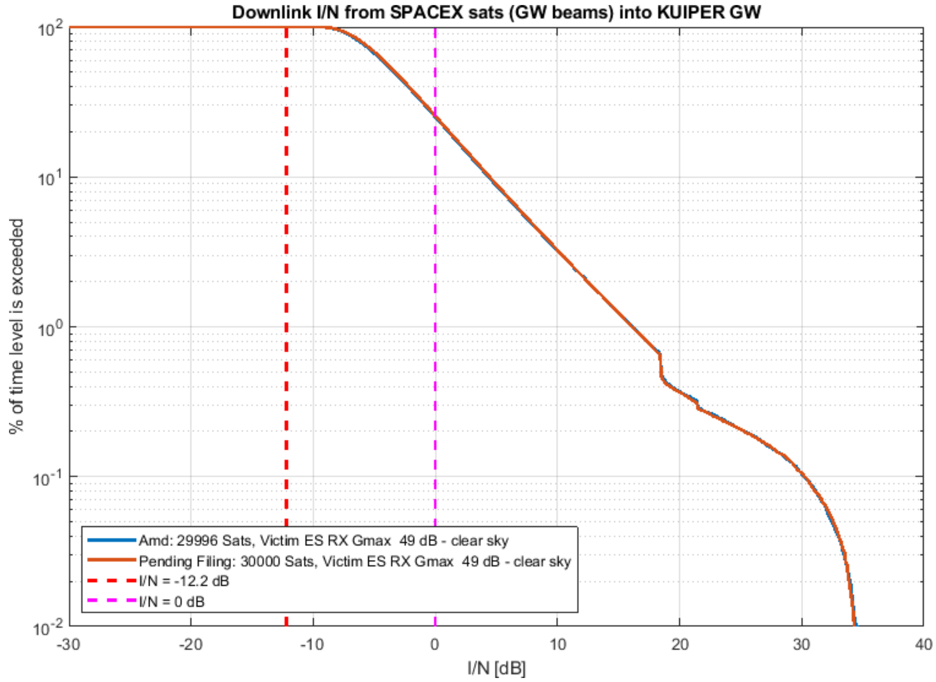

Figure A2b-III.4 — Downlink Interference from SpaceX GW Beam to Amazon GWs

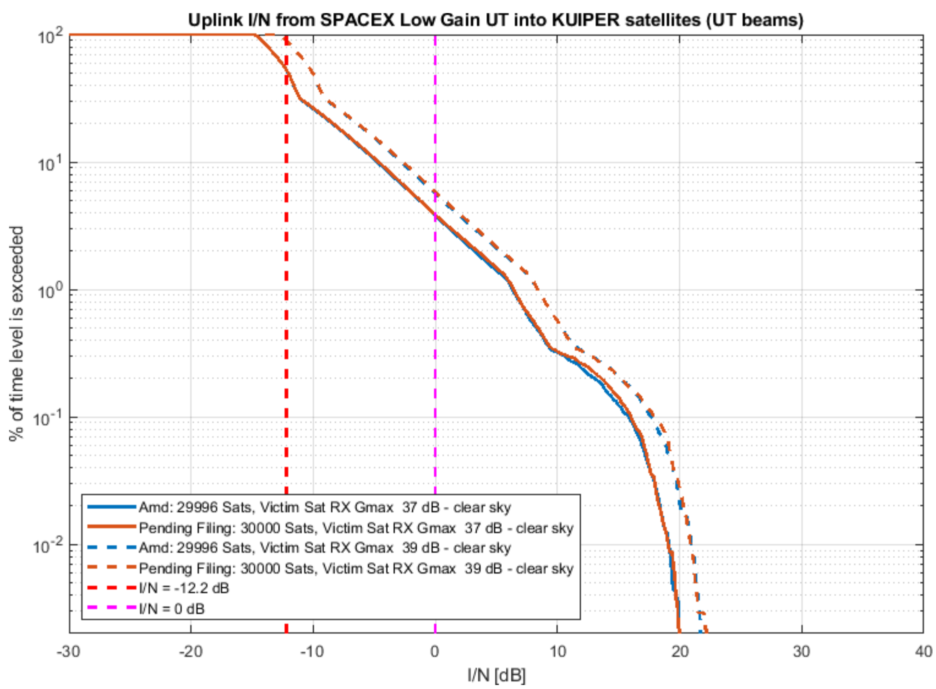

Figure A2b-III.5 — Uplink Interference from SpaceX Low Gain UTs to Amazon UT Receive Beam

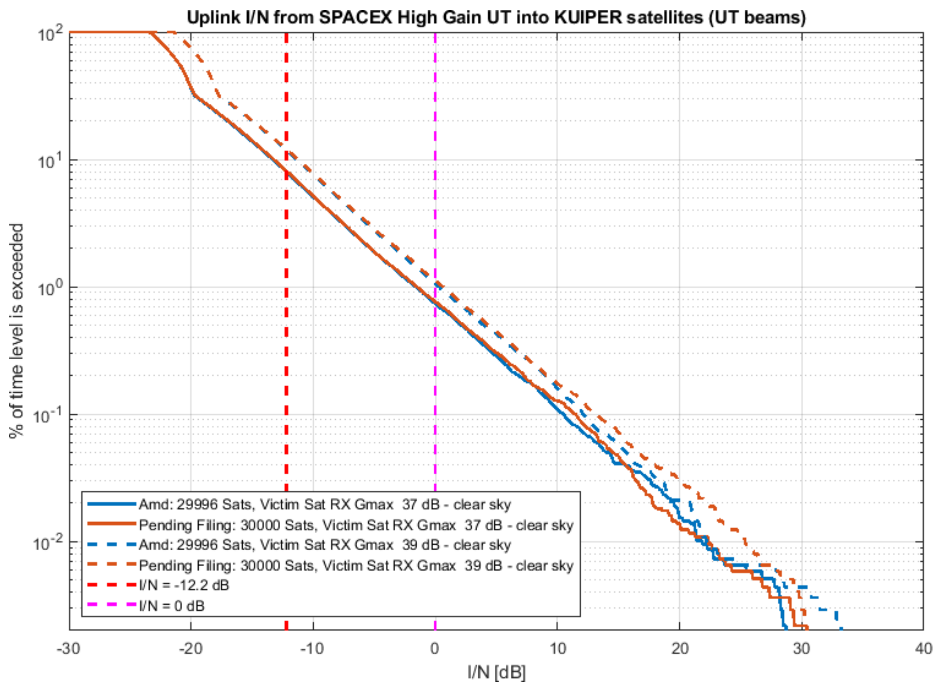

Figure A2b-III.6 — Uplink Interference from SpaceX High Gain UTs to Amazon UT Receive Beam

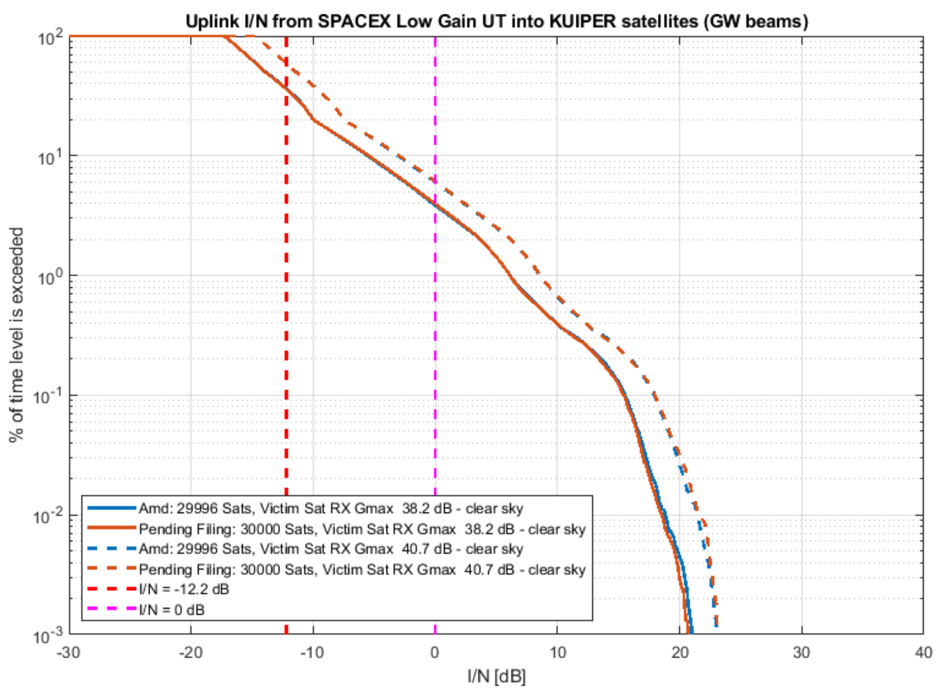

Figure A2b-III.7 — Uplink Interference from SpaceX Low Gain UTs to Amazon GW Receive Beam

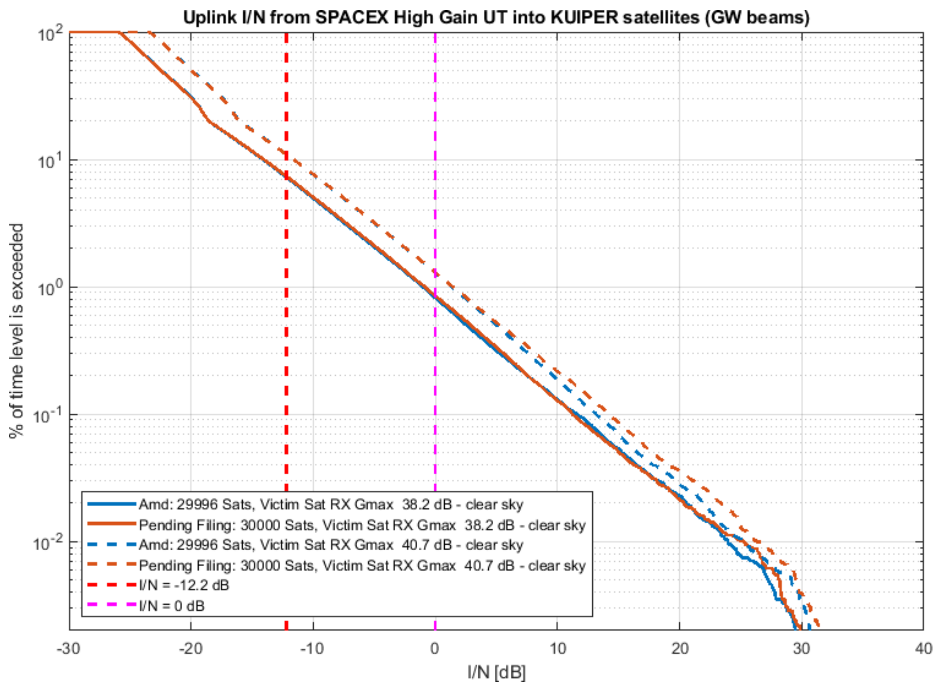

Figure A2b-III.8 — Uplink Interference from SpaceX High Gain UTs to Amazon GW Receive Beam

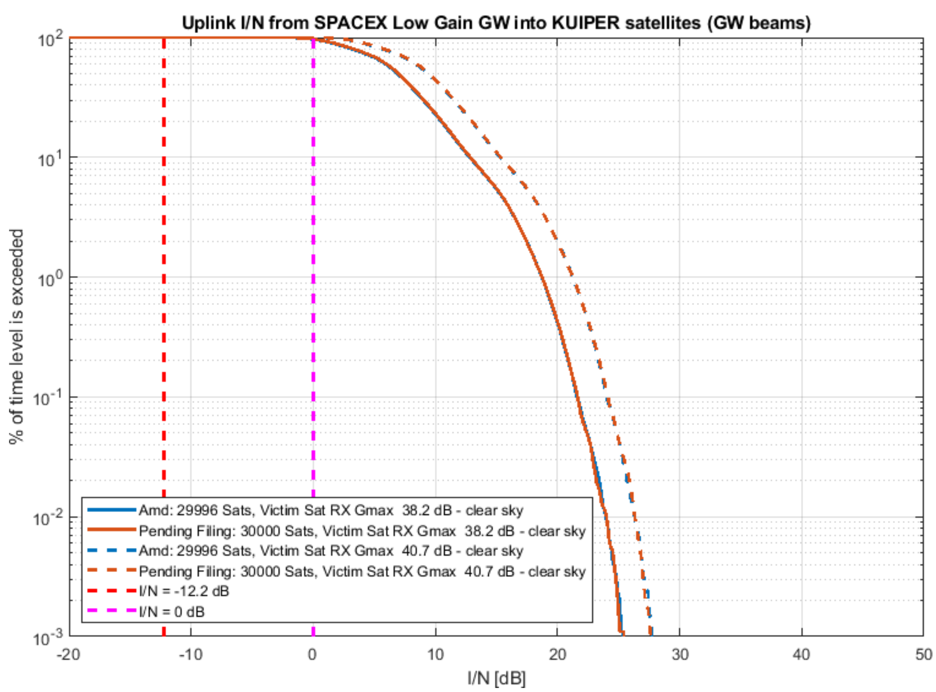

Figure A2b-III.9 — Uplink Interference from SpaceX Low Gain GW to Amazon GW Receive Beam

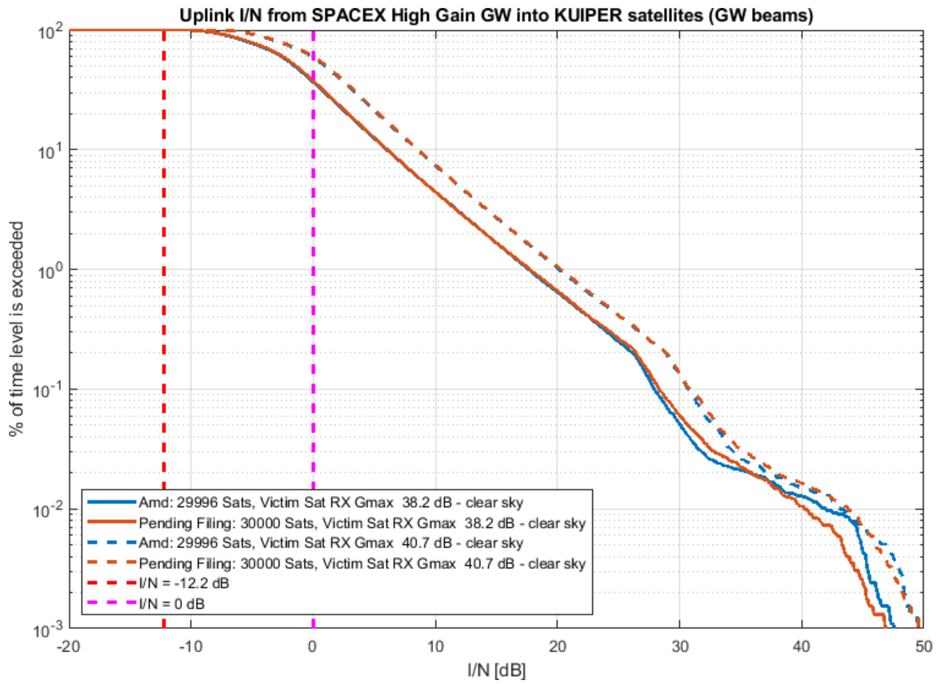

Figure A2b-III.10 — Uplink Interference from SpaceX High Gain GW to Amazon GW Receive Beam

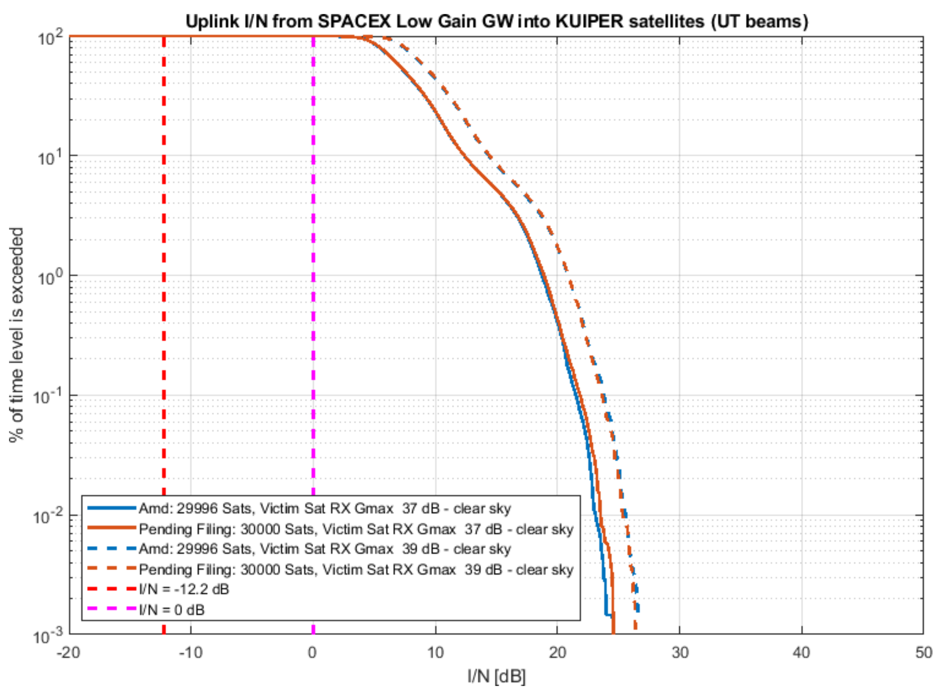

Figure A2b-III.11 — Uplink Interference from SpaceX Low Gain GW to Amazon UT

Receive Beam

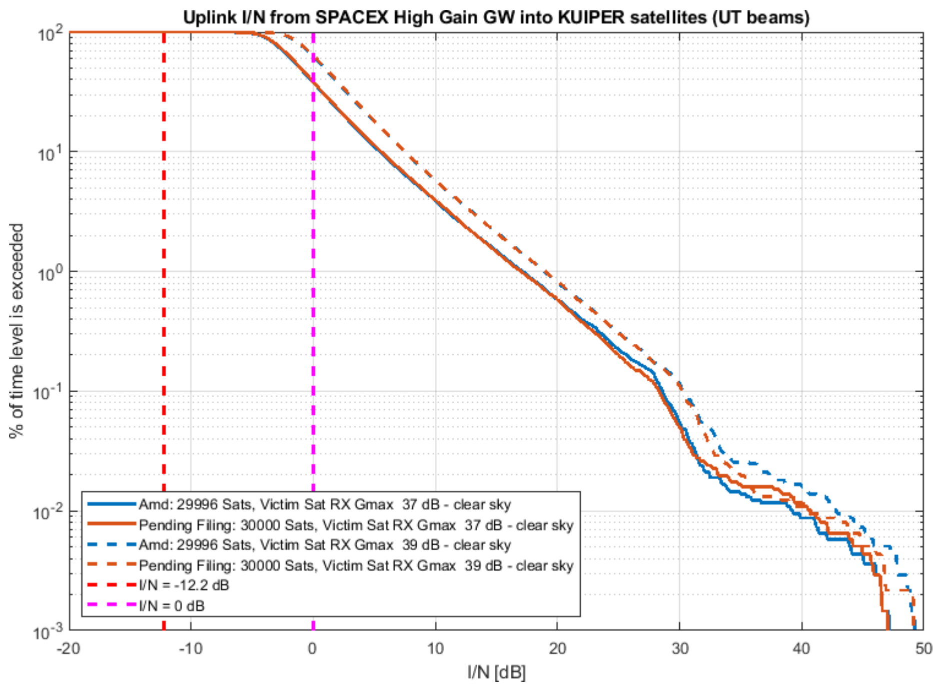

Figure A2b-III.12 — Uplink Interference from SpaceX High Gain GW to Amazon UT Receive Beam

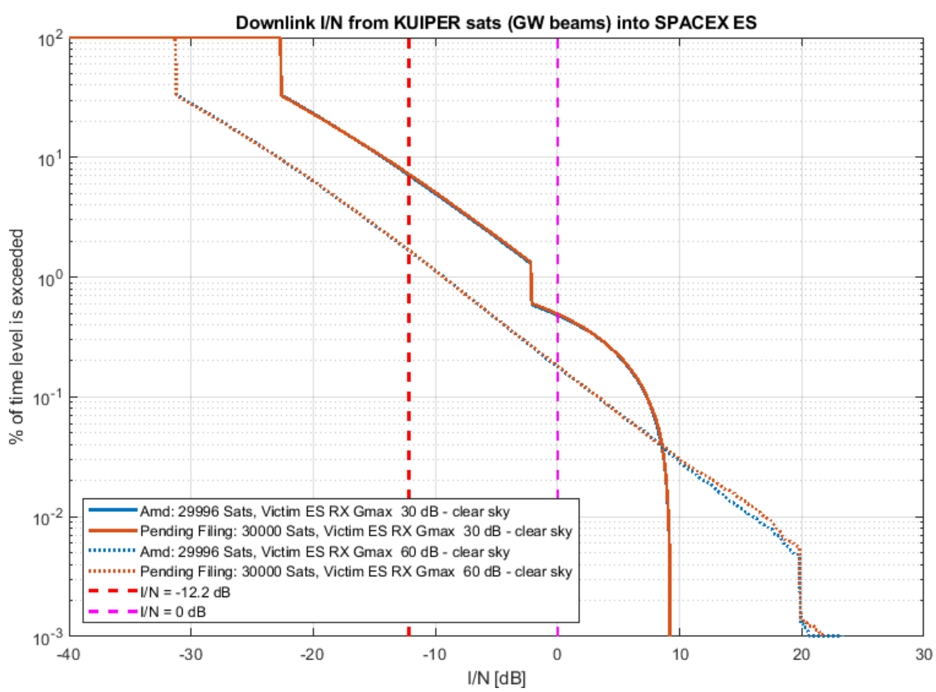

Figure A2b-III.13 — Downlink Interference from Amazon GW Beams to SpaceX ESs

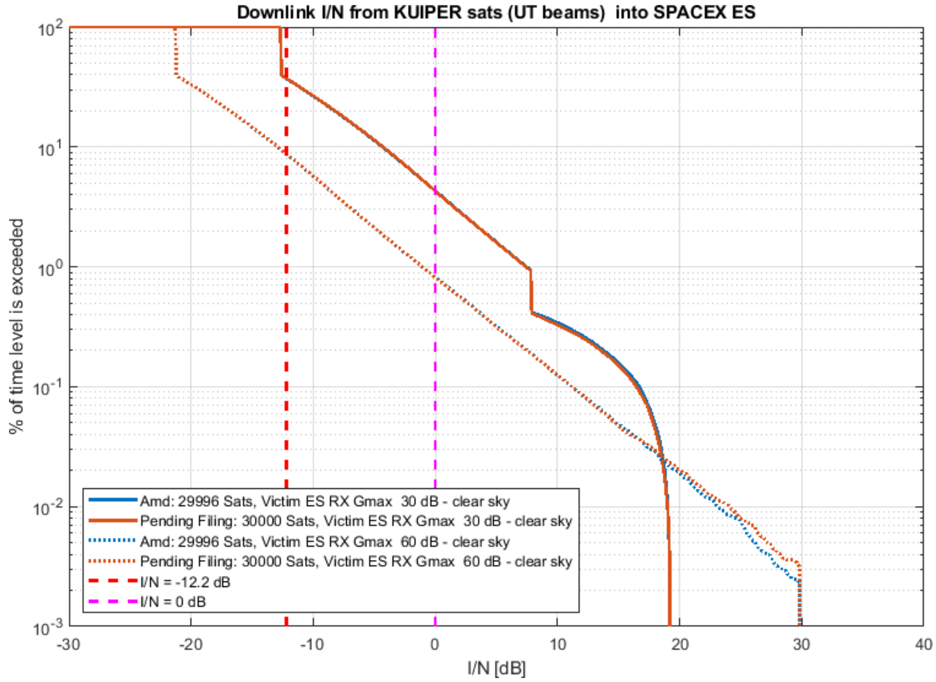

Figure A2b-III.14 — Downlink Interference from Amazon UT Beams to SpaceX ESs

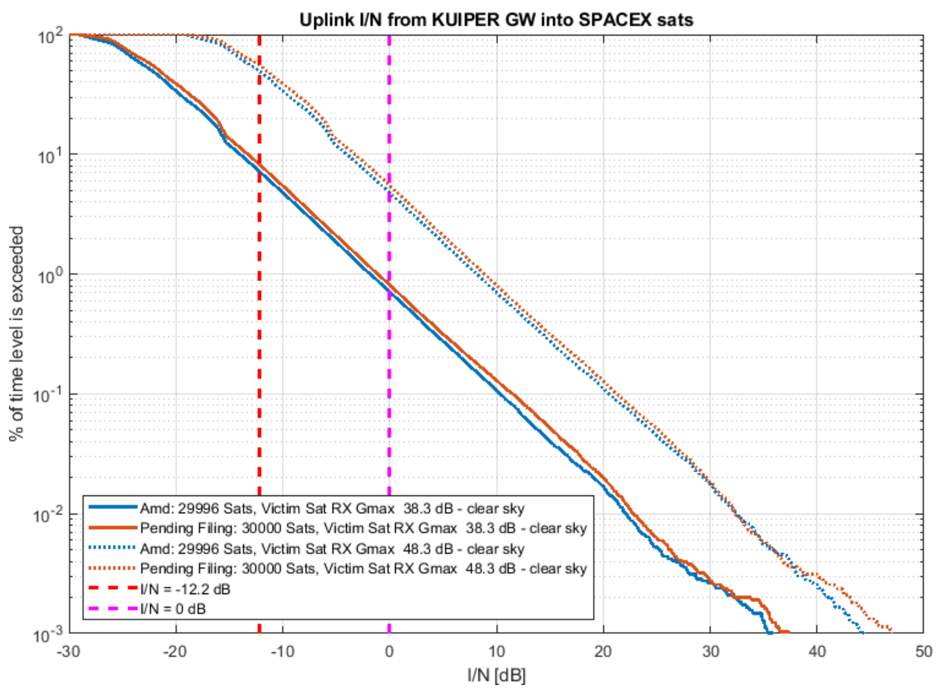

Figure A2b-III.15 — Uplink Interference from Amazon GWs to SpaceX

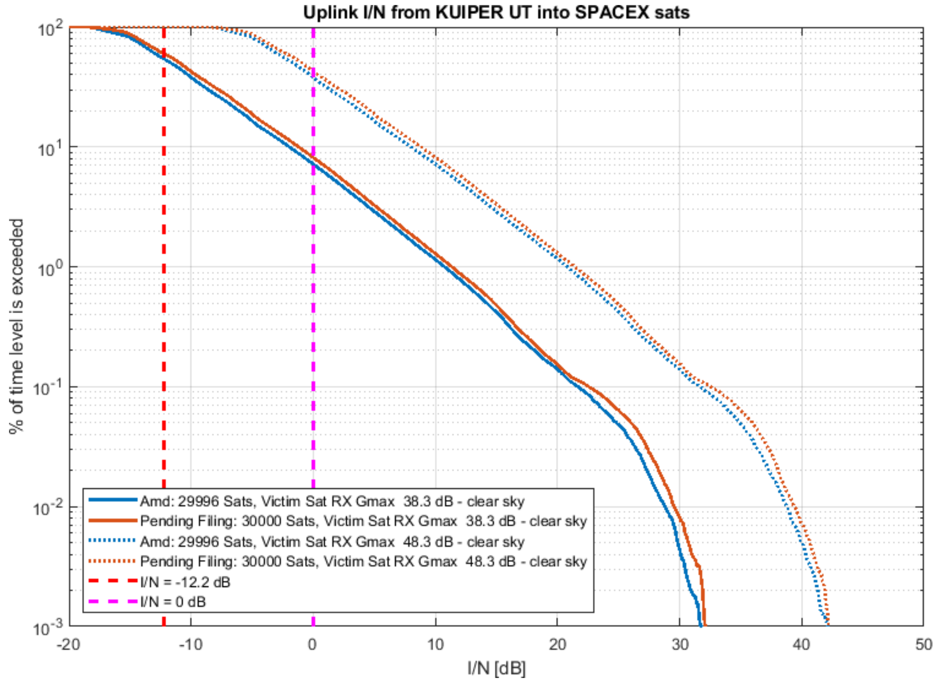

Figure A2b-III.16 — Uplink Interference from Amazon UTs to SpaceX

IV. O3b

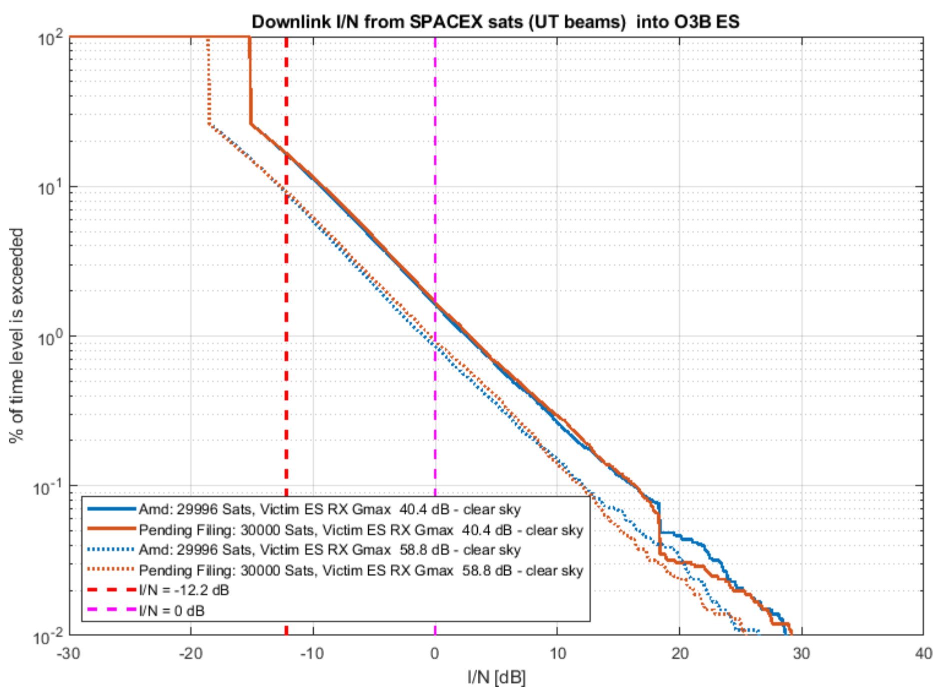

Figure A2b-IV.1 — Downlink Interference from SpaceX UT Beams to O3b ESs

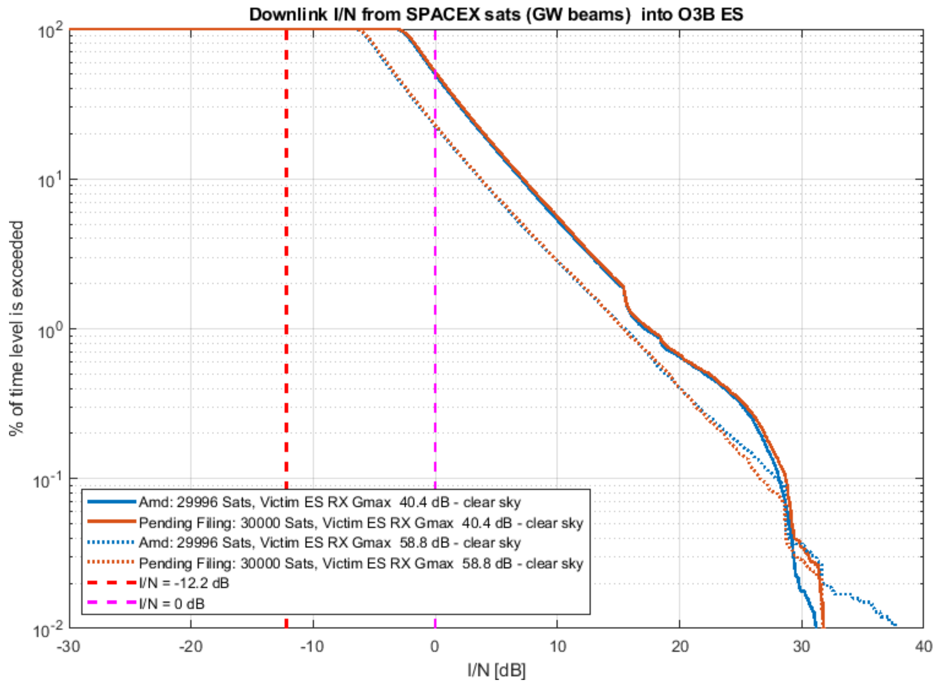

Figure A2b-IV.2 — Downlink Interference from SpaceX GW Beams to O3b ESs

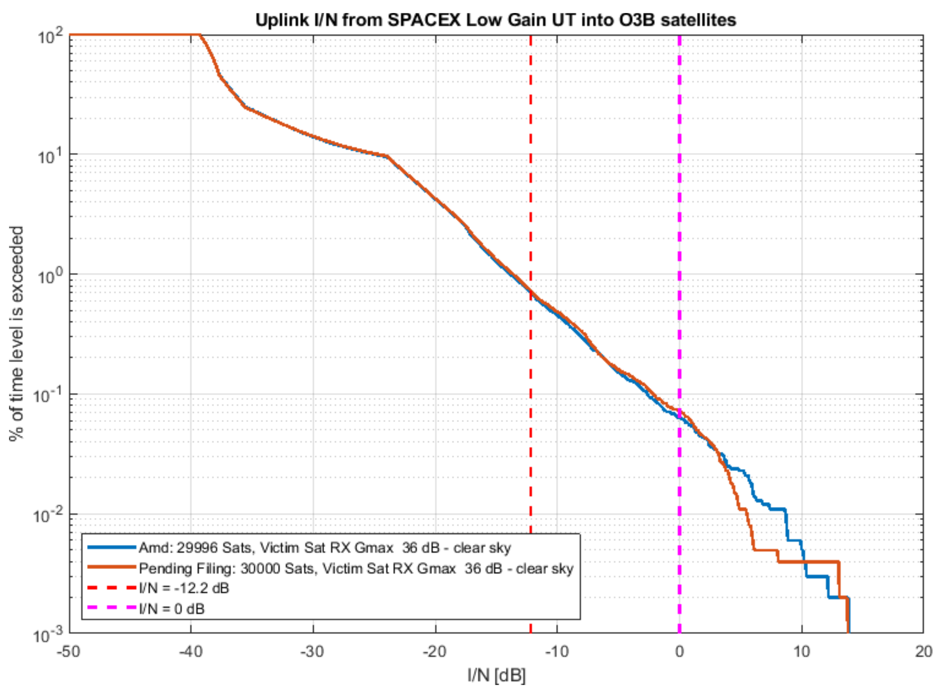

Figure A2b-IV.3 — Uplink Interference from SpaceX Low Gain UTs to O3b

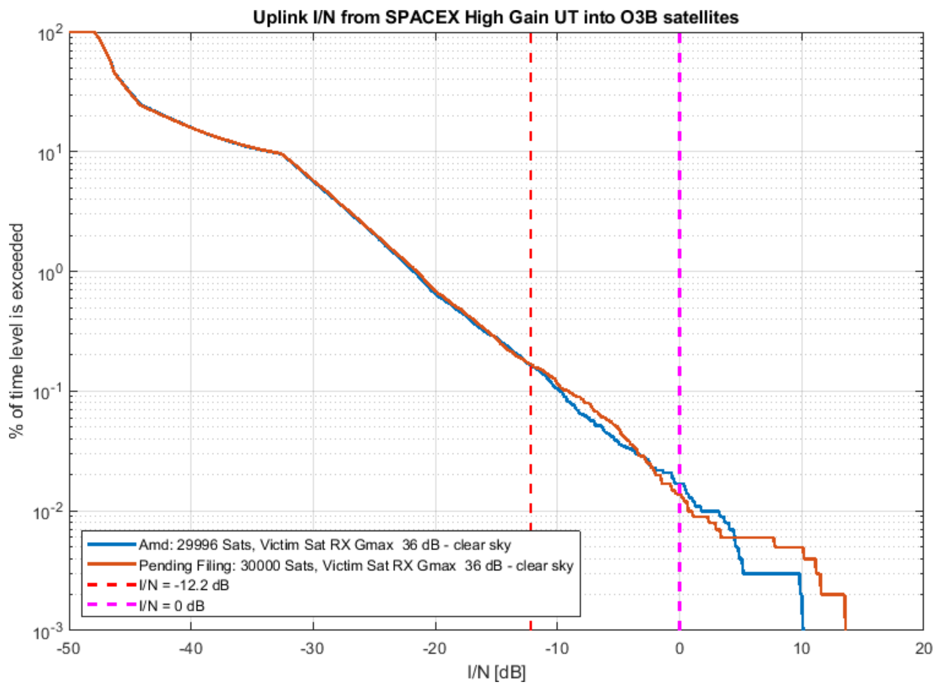

Figure A2b-IV.4 — Uplink Interference from SpaceX High Gain UTs to O3b

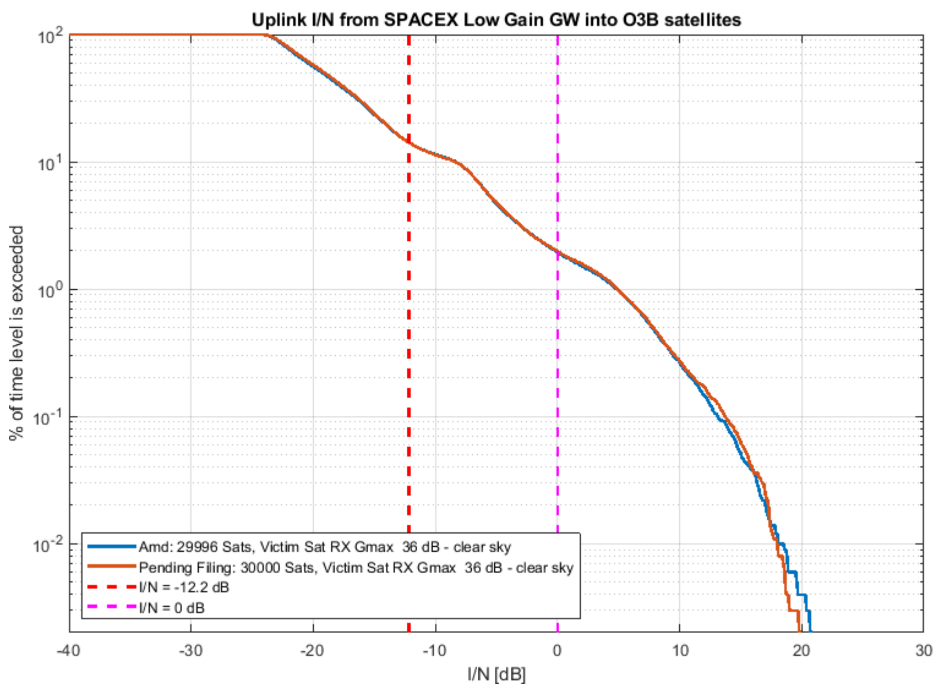

Figure A2b-IV.5 — Uplink Interference from SpaceX Low Gain GWs to O3b

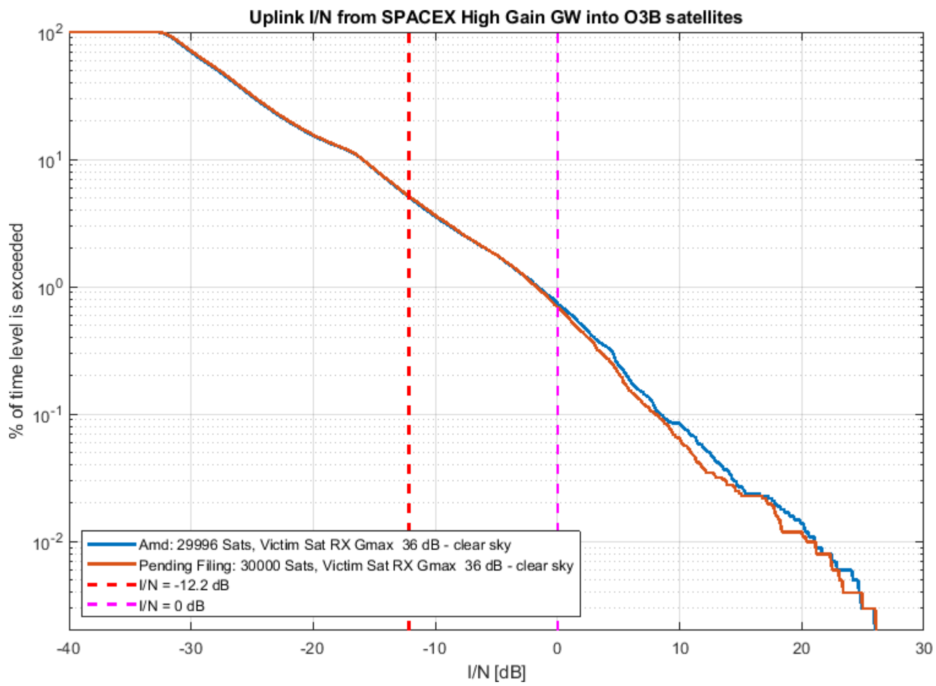

Figure A2b-IV.6 — Uplink Interference from SpaceX High Gain GWs to O3b

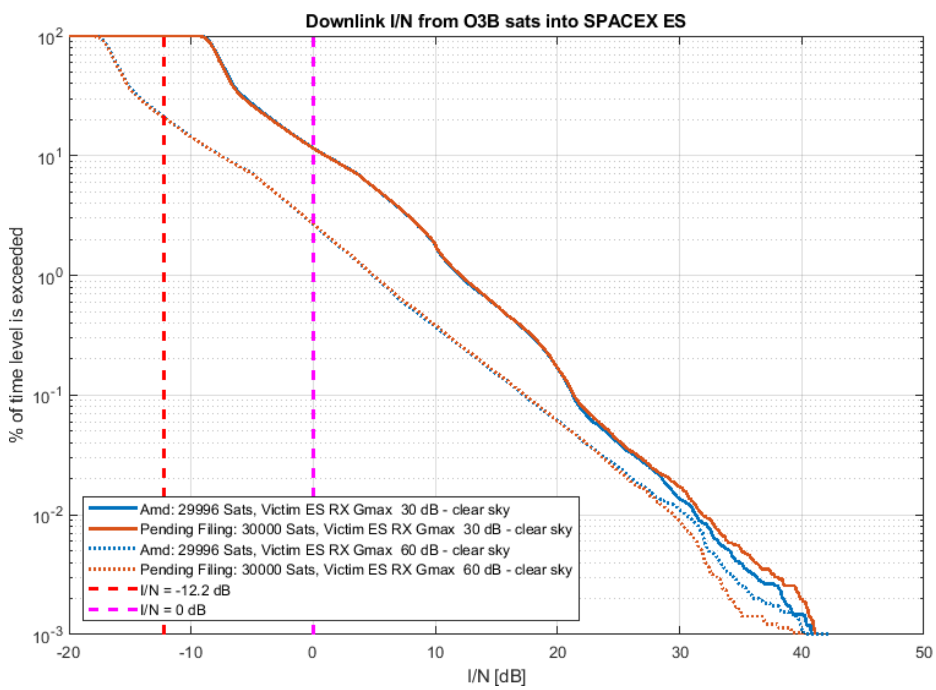

Figure A2b-IV.7 — Downlink Interference from O3b to SpaceX ESs

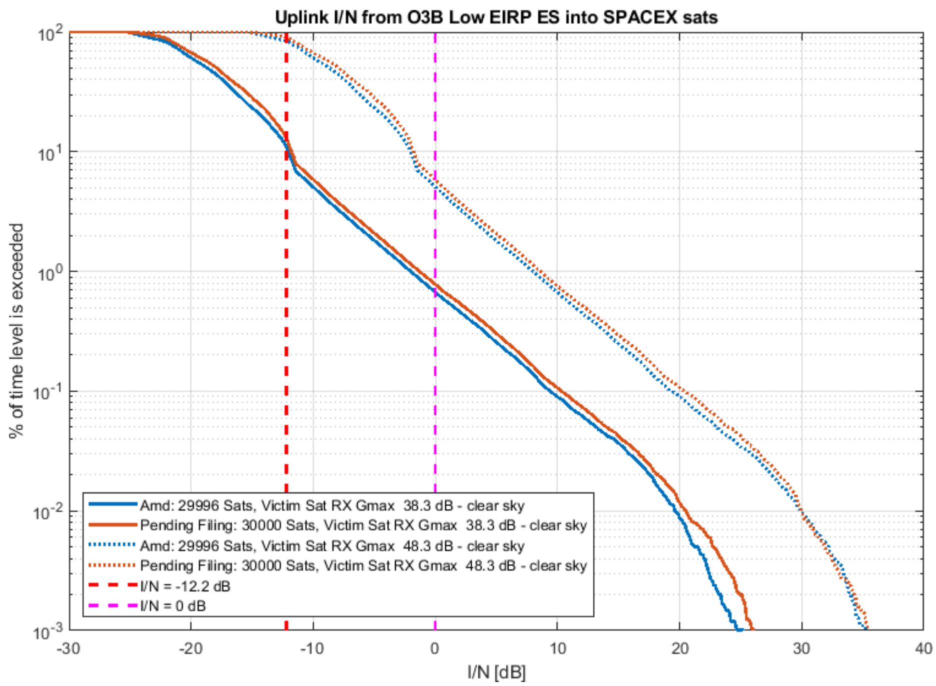

Figure A2b-IV.8 — Uplink Interference from O3b Low EIRP ESs to SpaceX

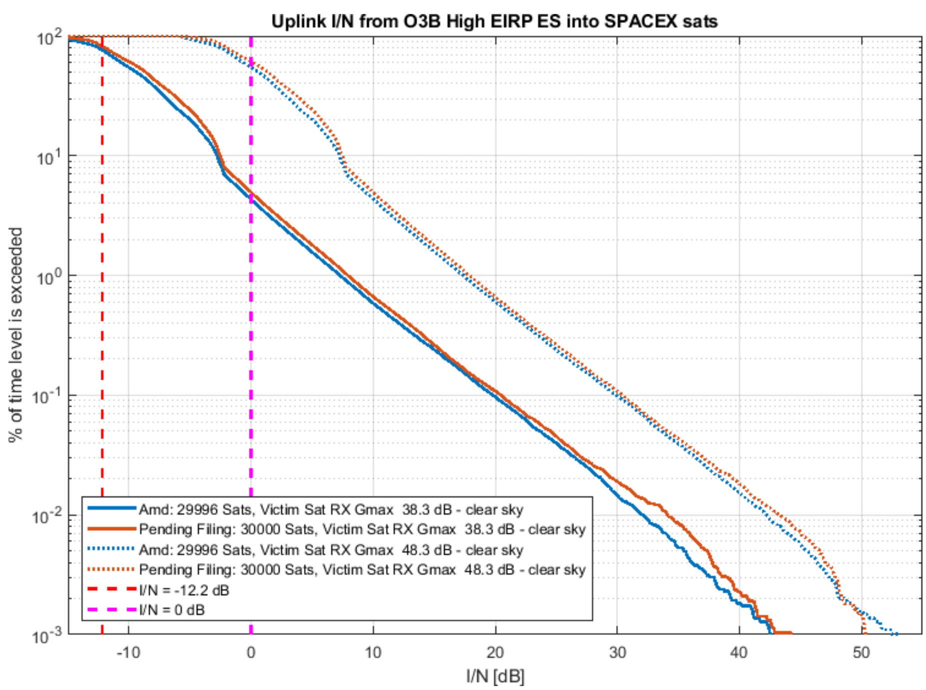

Figure A2b-IV.9 — Uplink Interference from O3b High EIRP ESs to SpaceX

V. OneWeb

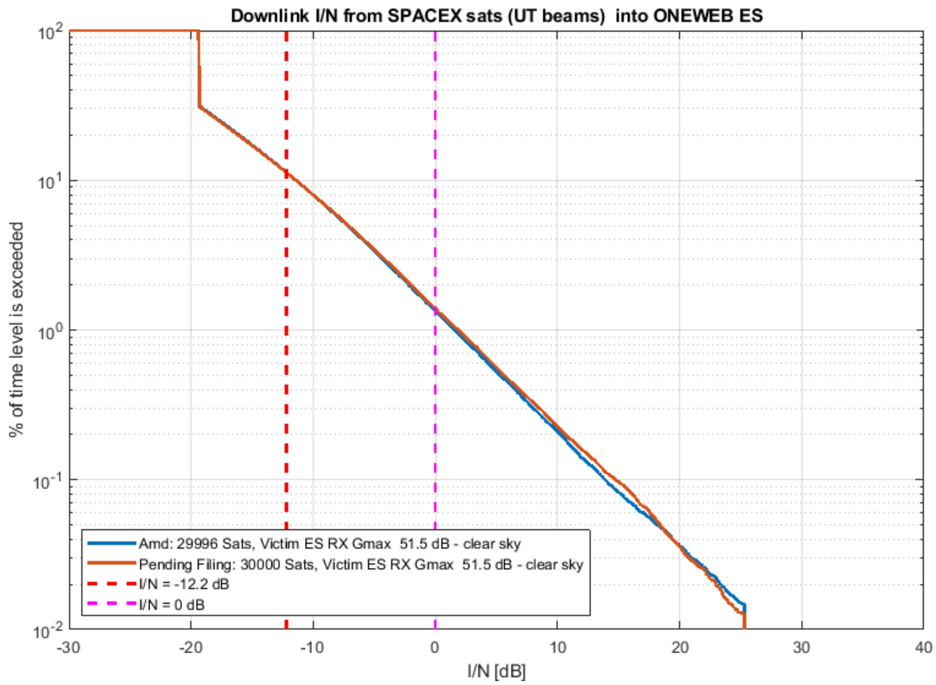

Figure A2b-V.1 — Downlink Interference from SpaceX UT Beam to OneWeb ESs

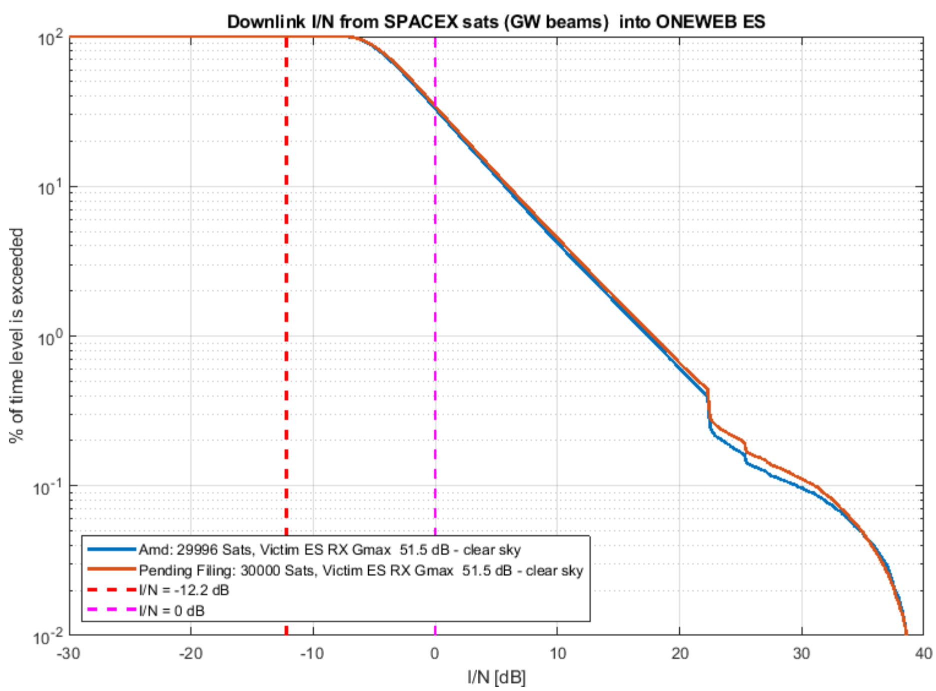

Figure A2b-V.2 — Downlink Interference from SpaceX GW Beam to OneWeb ESs

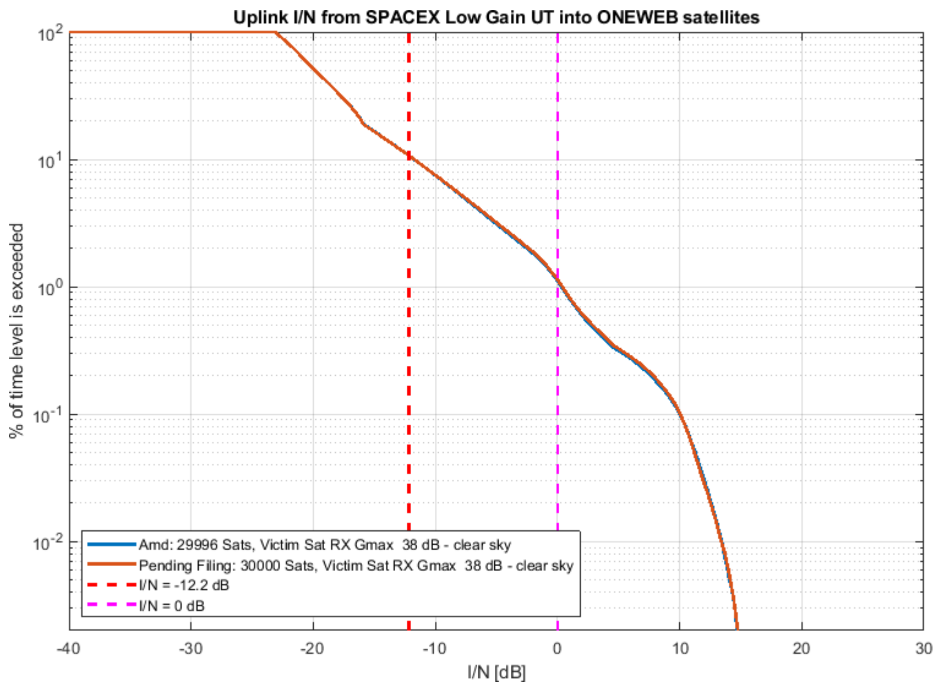

Figure A2b-V.3 — Uplink Interference from SpaceX Low Gain UTs to OneWeb

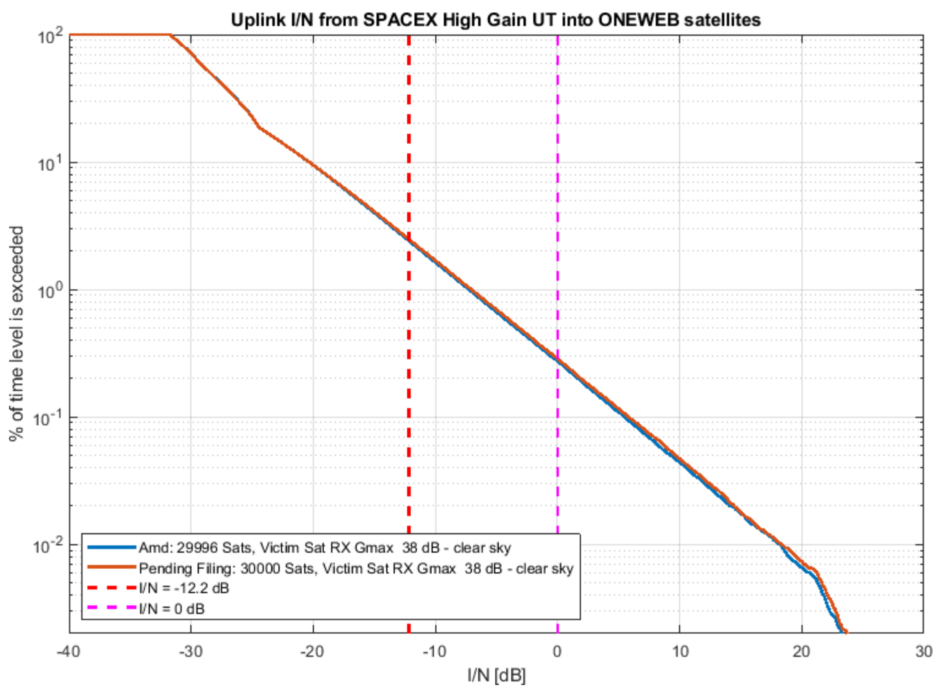

Figure A2b-V.4 — Uplink Interference from SpaceX High Gain UTs to OneWeb

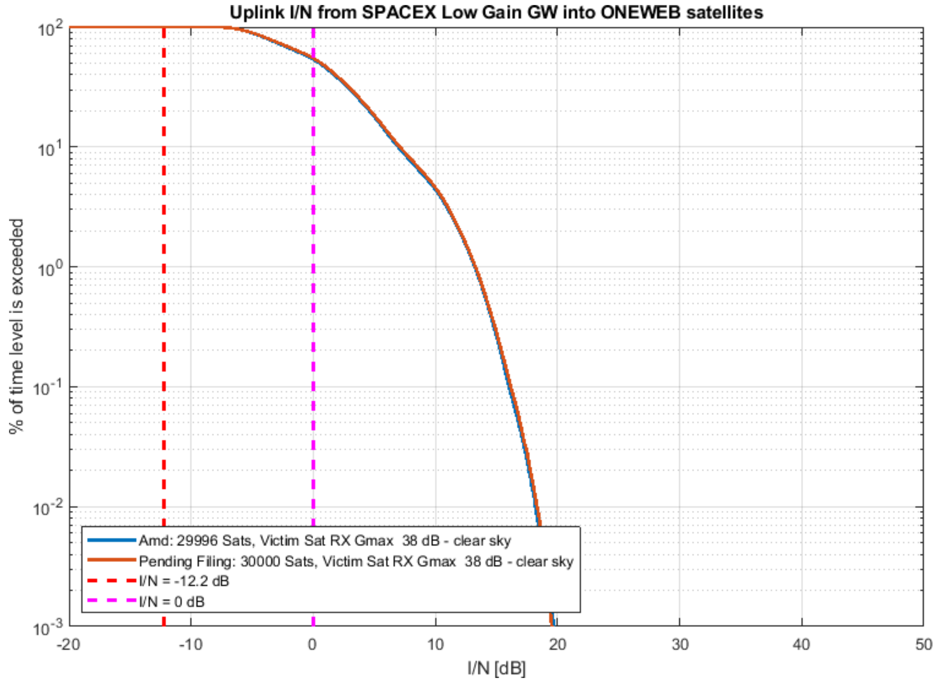

Figure A2b-V.5 — Uplink Interference from SpaceX Low Gain GWs to OneWeb

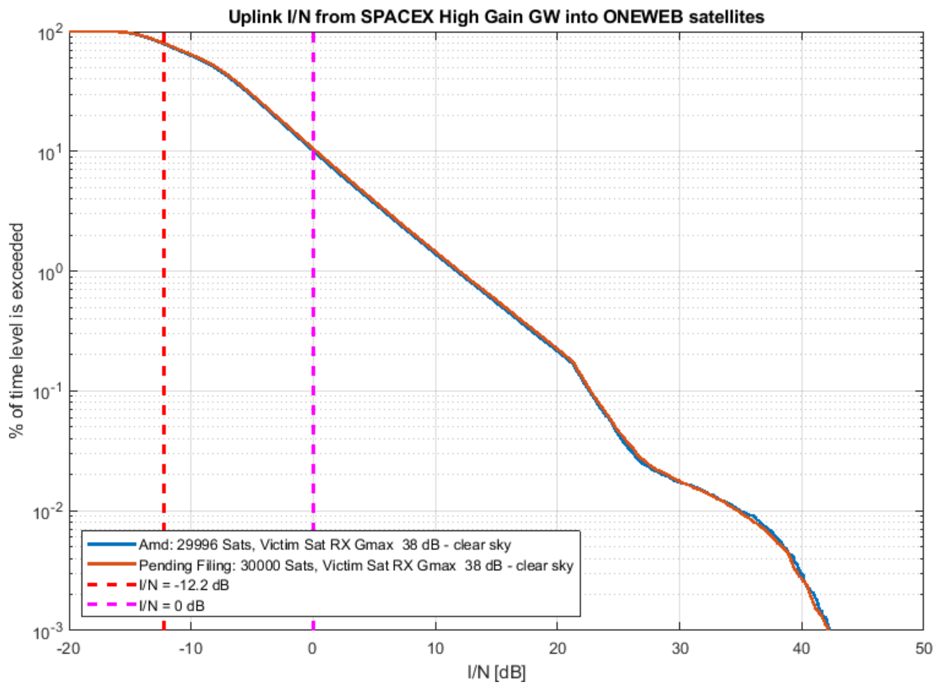

Figure A2b-V.6 — Uplink Interference from SpaceX High Gain GWs to OneWeb

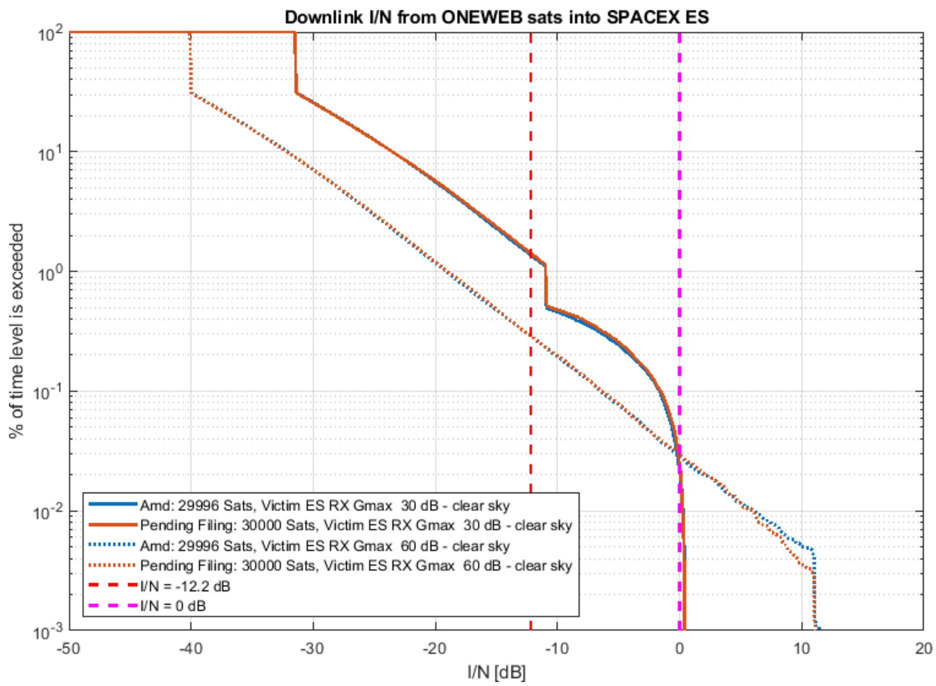

Figure A2b-V.7 — Downlink Interference from OneWeb to SpaceX ESs

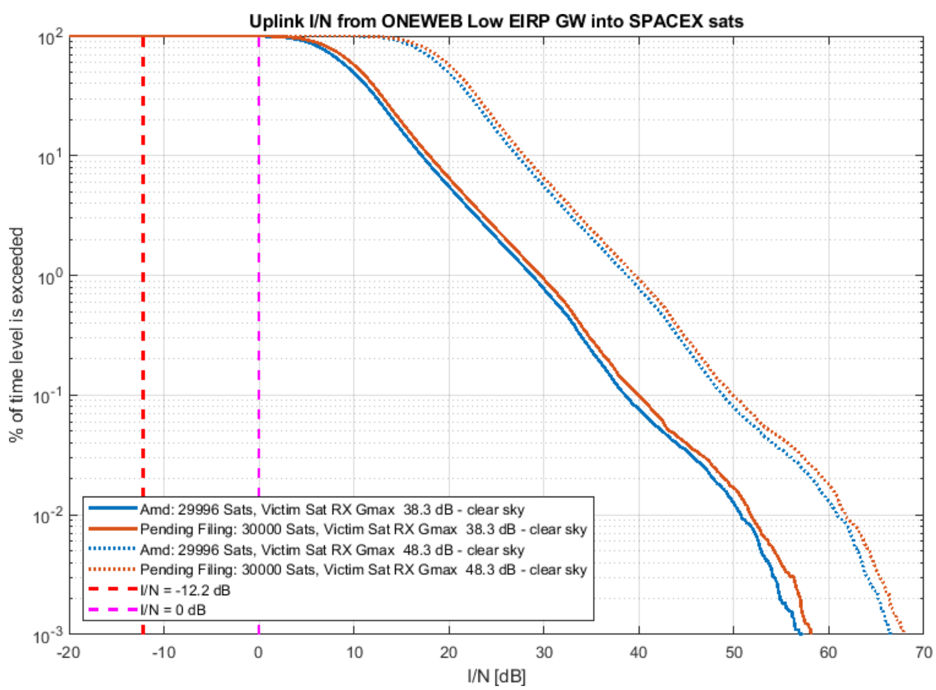

Figure A2b-V.8— Uplink Interference from OneWeb Low EIRP GWs to SpaceX ESs

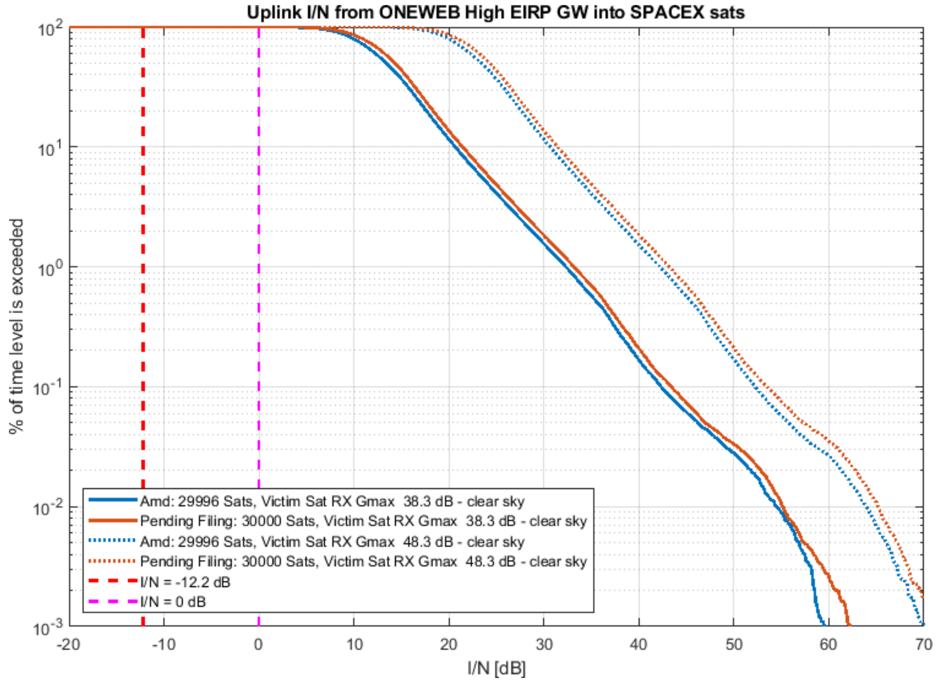

Figure A2b-V.9 — Uplink Interference from OneWeb High EIRP GWs to SpaceX

VI. Telesat

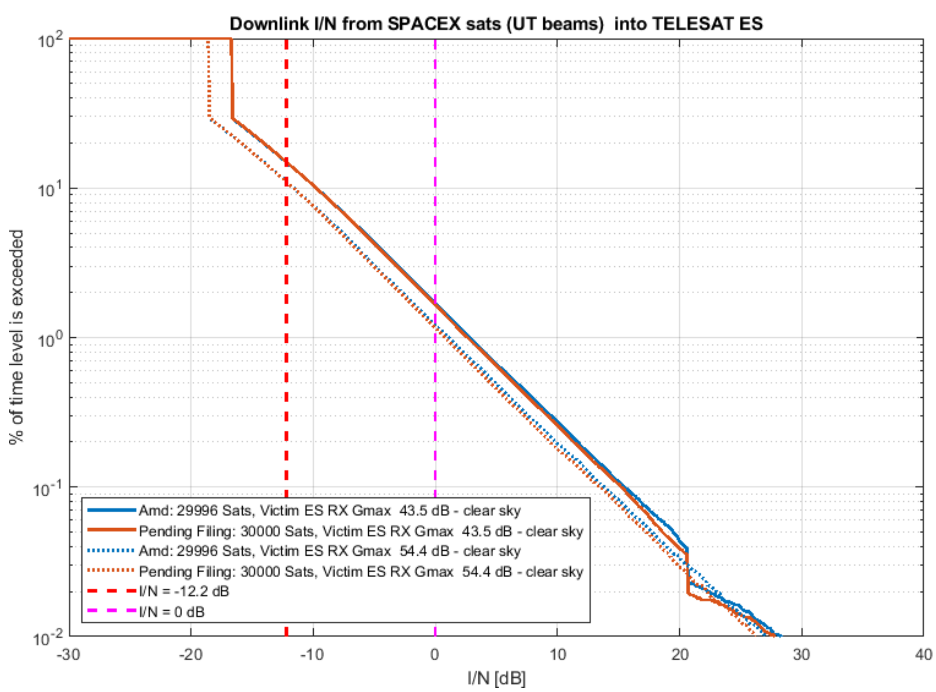

Figure A2b-VI.1 — Downlink Interference from SpaceX UT Beam to Telesat ESs

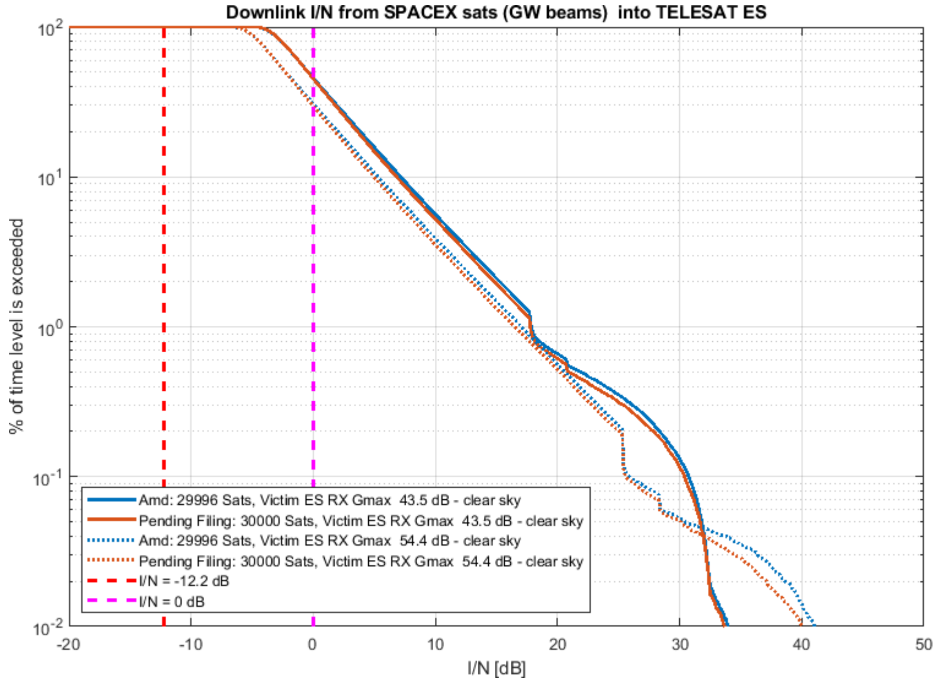

Figure A2b-VI.2 — Downlink Interference from SpaceX GW Beam to Telesat ESs

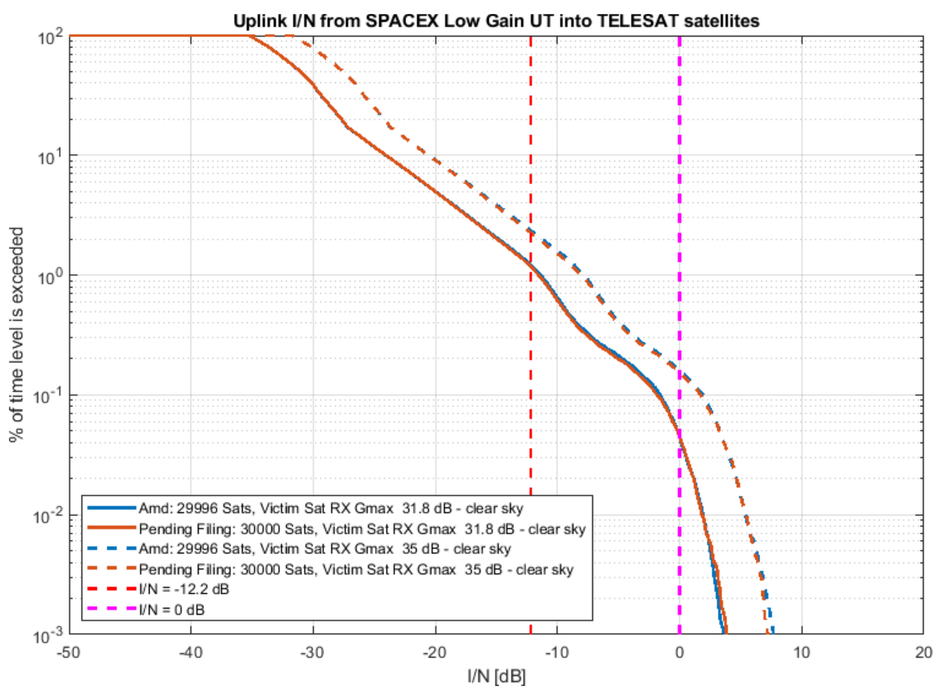

Figure A2b-VI.3 — Uplink Interference from SpaceX Low Gain UTs to Telesat

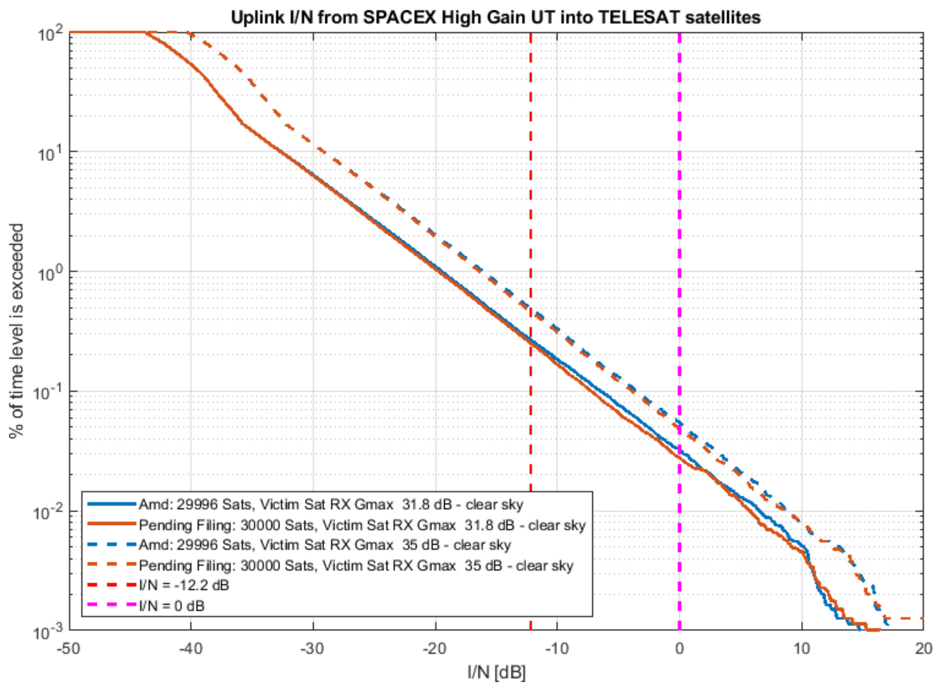

Figure A2b-VI.4 — Uplink Interference from SpaceX High Gain UTs to Telesat

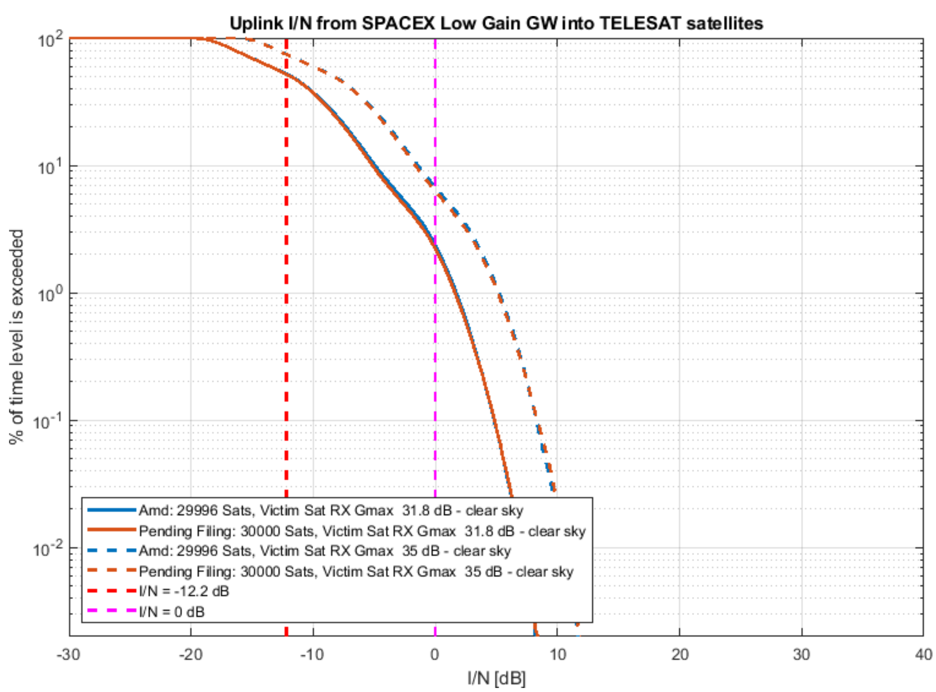

Figure A2b-VI.5 — Uplink Interference from SpaceX Low Gain GWs to Telesat

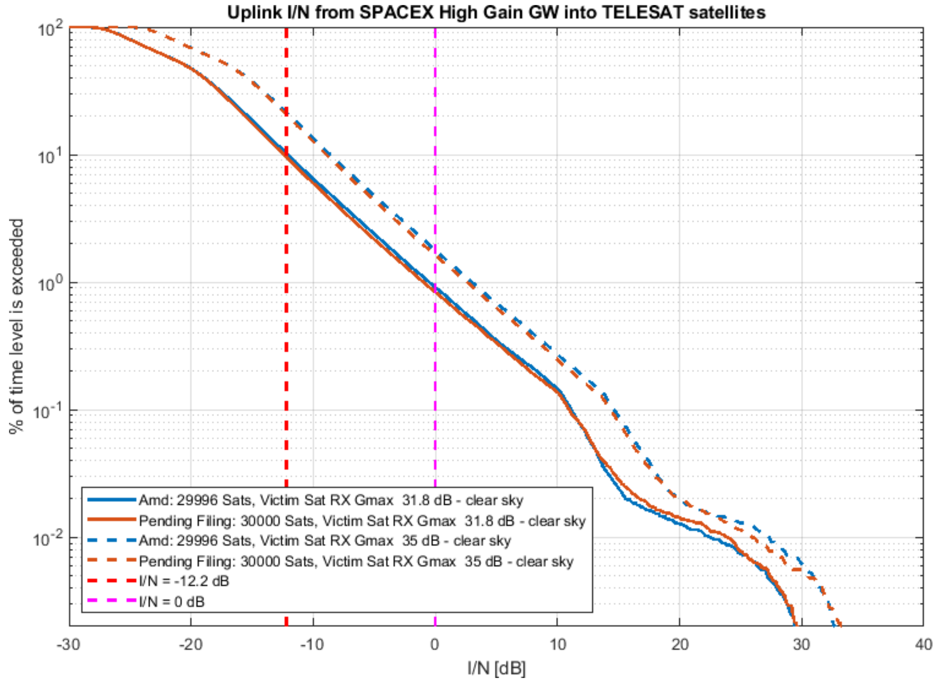

Figure A2b-VI.6 — Uplink Interference from SpaceX High Gain GWs to Telesat

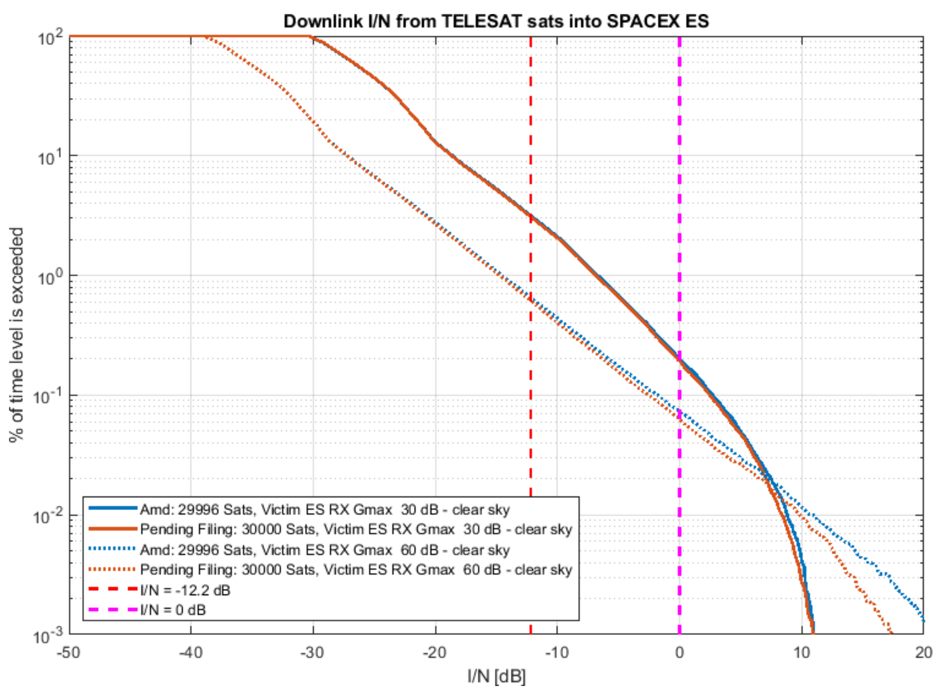

Figure A2b-VI.7 — Downlink Interference from Telesat to SpaceX ESs

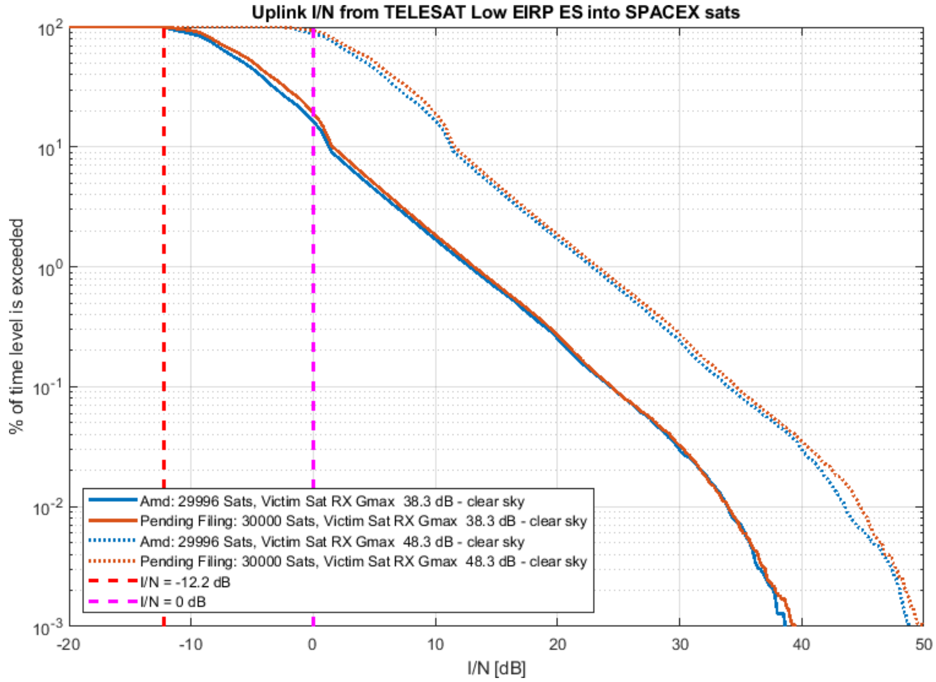

Figure A2b-VI.8 — Uplink Interference from Telesat Low EIRP ESs to SpaceX

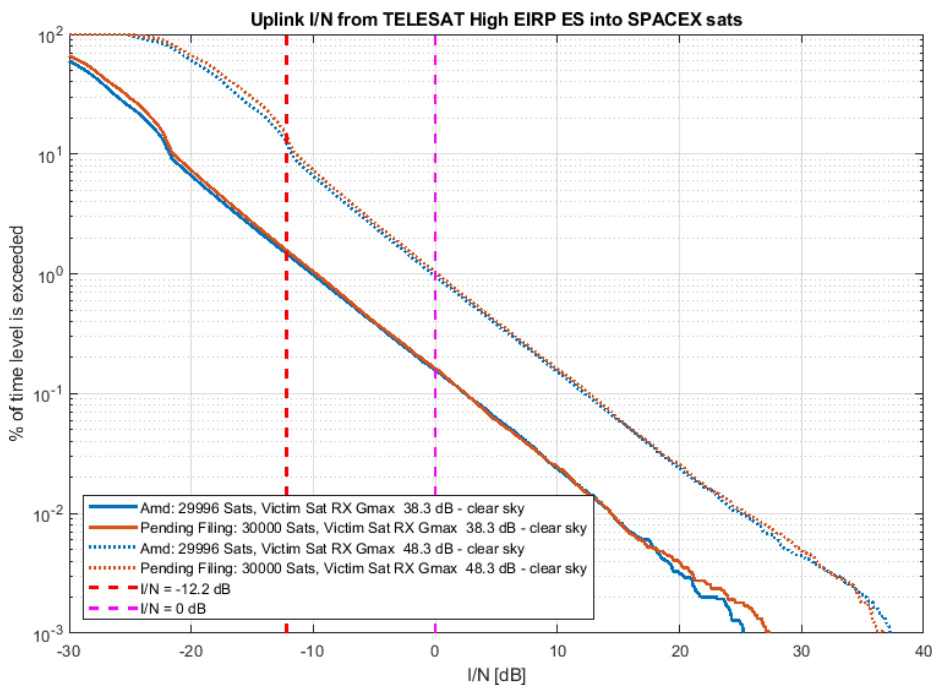

Figure A2b-VI.9 — Uplink Interference from Telesat High EIRP ESs to SpaceX

VII. Viasat

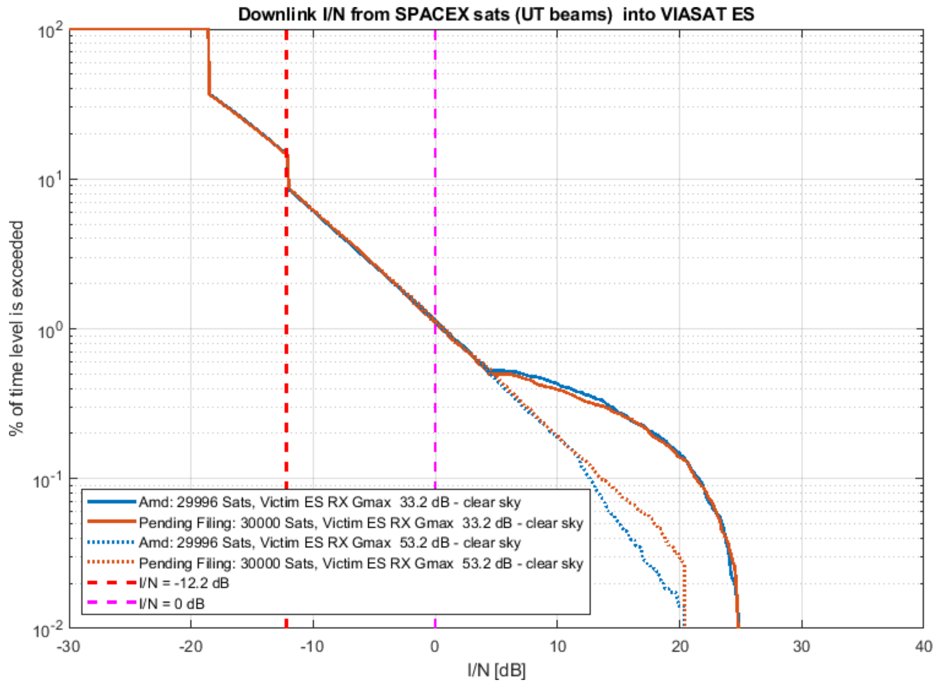

Figure A2b-VII.1 — Downlink Interference from SpaceX UT Beam to Viasat ESs

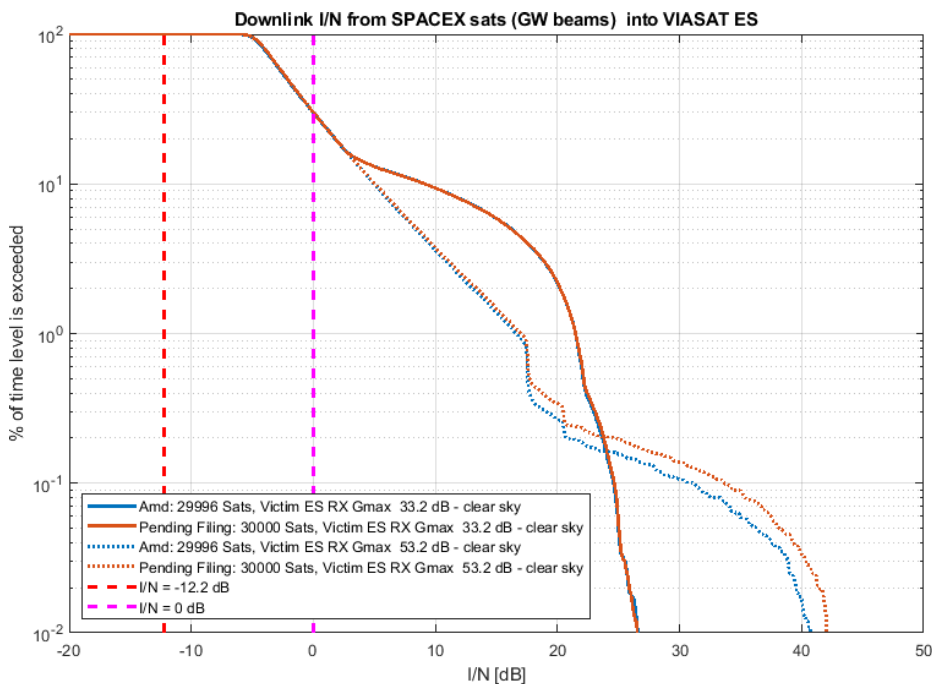

Figure A2b-VII.2 — Downlink Interference from SpaceX GW Beam to Viasat ESs

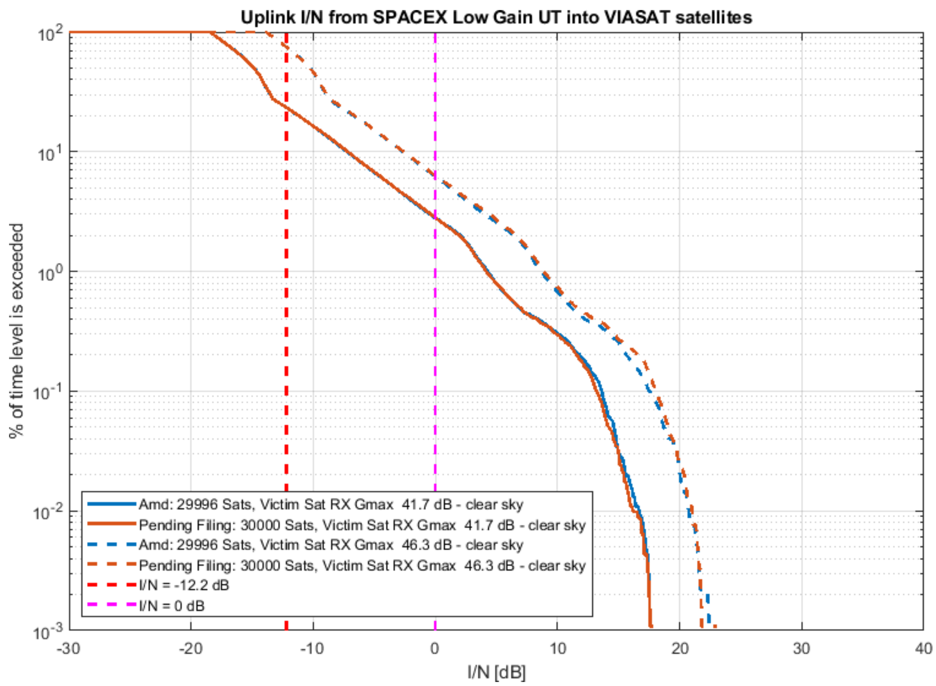

Figure A2b-VII.3 — Uplink Interference from SpaceX Low Gain UTs to Viasat

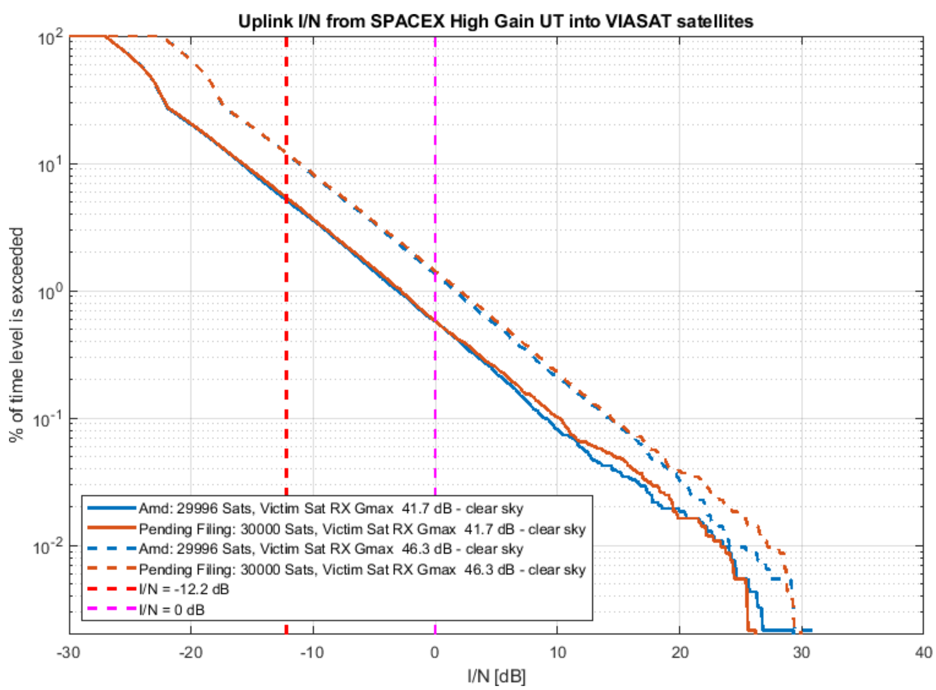

Figure A2b-VII.4 — Uplink Interference from SpaceX High Gain UTs to Viasat

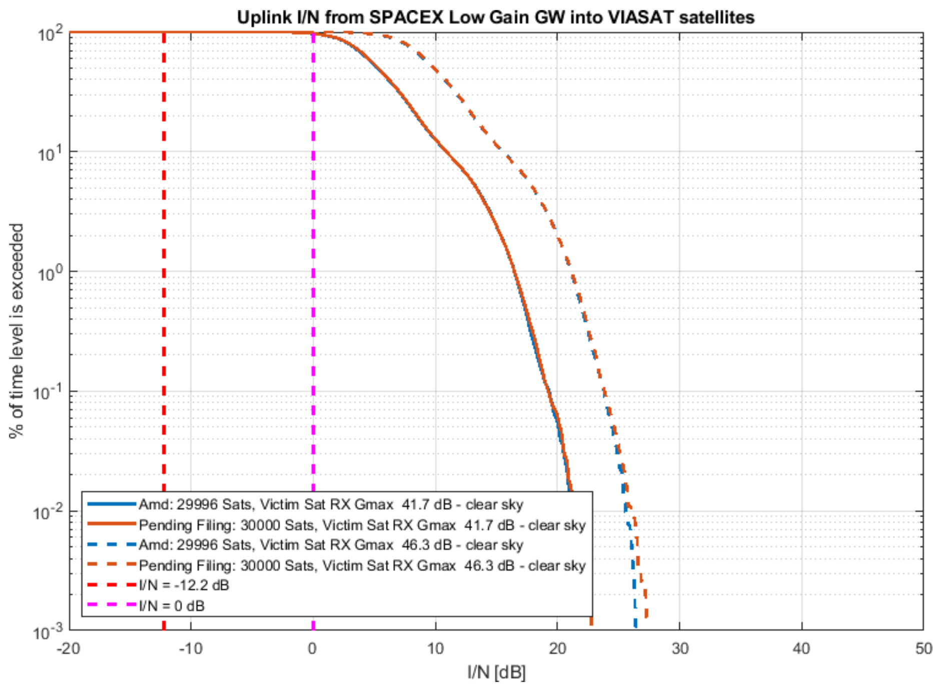

Figure A2b-VII.5 — Uplink Interference from SpaceX Low Gain GWs to Viasat

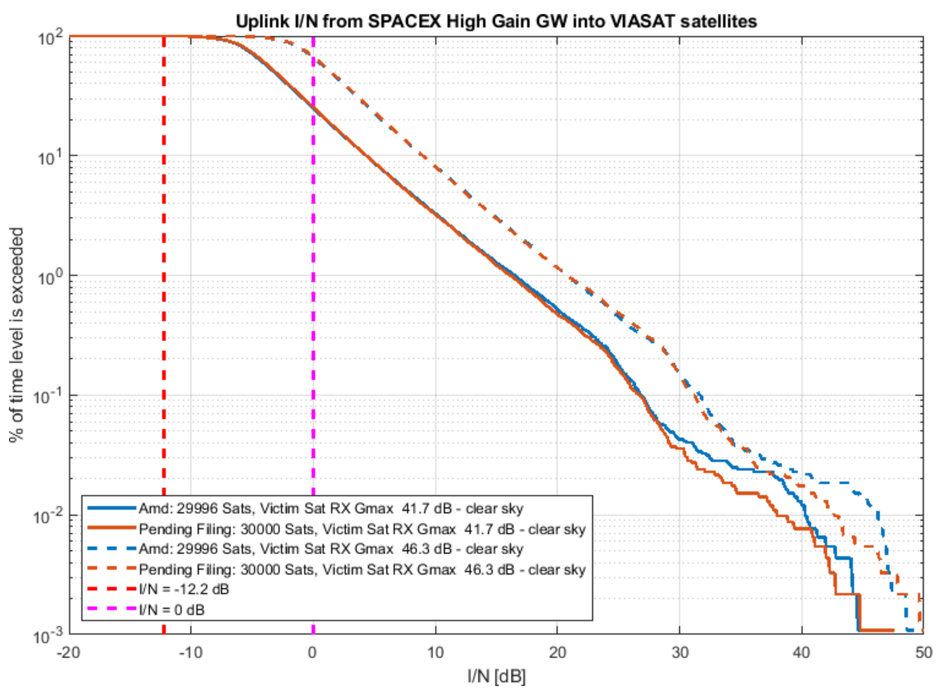

Figure A2b-VII.6 — Uplink Interference from SpaceX High Gain GWs to Viasat

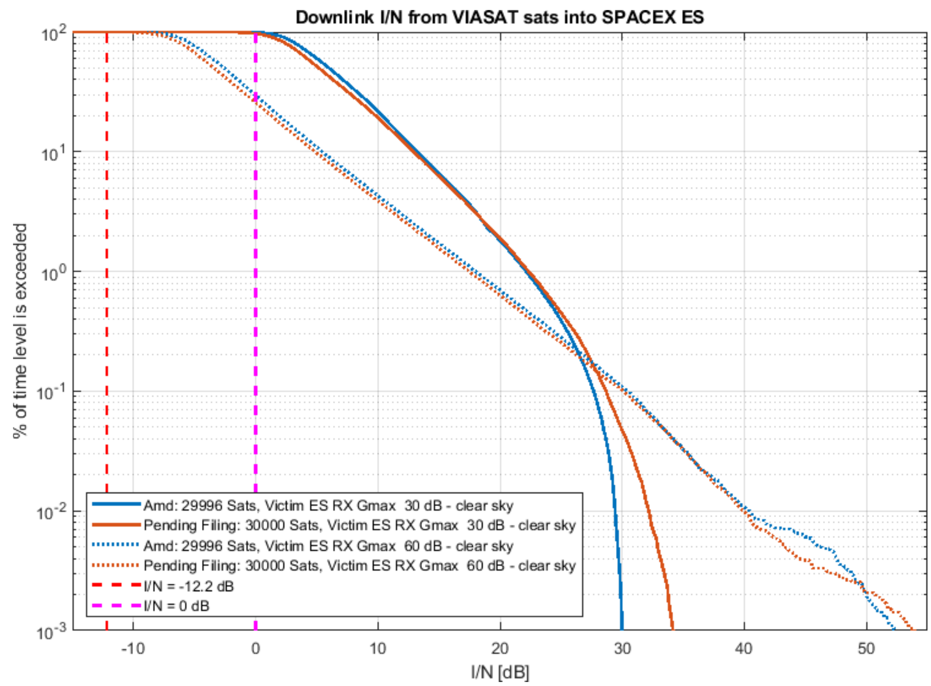

Figure A2b-VII.7 — Downlink Interference from Viasat to SpaceX ESs

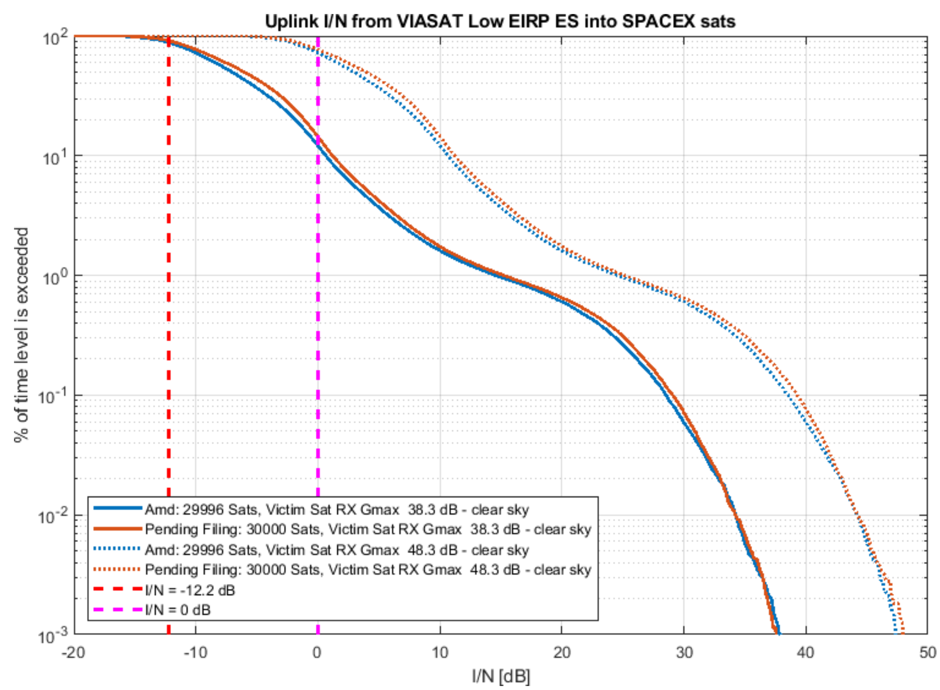

Figure A2b-VII.8 — Uplink Interference from Viasat Low EIRP ESs to SpaceX

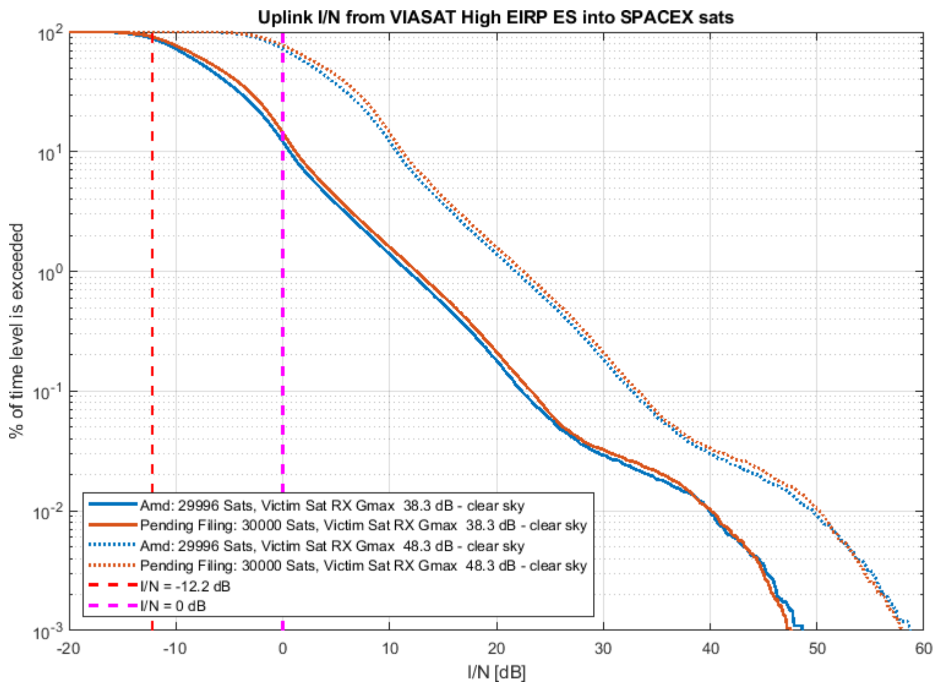

Figure A2b-VII.9 — Uplink Interference from Viasat High EIRP ESs to SpaceX