TELESAT LOW EARTH ORBIT NON-GEOSTATIONARY SATELLITE SYSTEM

TECHNICAL INFORMATION SUPPLEMENT TO SCHEDULE S

A.1 SCOPE AND PURPOSE

On November 3, 2017, the Commission granted Telesat's petition (hereafter the "Grant"[1]) for an NGSO LEO constellation of 117 satellites (hereafter the "Constellation"). This document is the technical appendix to Telesat's application to modify the Grant in two phases: the first phase ("Phase 1") will modify the constellation from 117 satellites to 298 satellites (the "Modified Constellation"); and the second phase ("Phase 2") will add 1373 satellites to the Modified Constellation to bring the total to 1671 satellites (the "Final Constellation").

The technical information for both the Modified and Final Constellations, as required by paragraph (d) of Section §25.114[2] of the FCC rules, is addressed in this document. The information specified in paragraph (c) of that section has been provided in Schedule S and is not repeated here. The Modified Constellation is a subset of the Final Constellation. Section A.2, *Overall Description* below provides the necessary clarifications to identify which satellites in the Final Constellation belong to the Modified Constellation.

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[1] Order and Declaratory Ruling, *Telesat Canada Petition for Declaratory Ruling to Grant Access to the U.S. Market for Telesat's NGSO Constellation*, 32 FCC Rcd 9663 (2017).
[2] 47 C.F.R. §25.114

A.2 OVERALL DESCRIPTION

The design concept and frequencies used by the Modified and Final Constellations remain as described in Telesat's Petition for Declaratory Ruling[3] for the Constellation. The Modified and Final Constellations provide layer-2 Carrier Ethernet connectivity using highly secure and resilient low-latency links and employs a unique hybrid design combining polar orbits for global coverage (the "Polar Sub-Constellation") with inclined orbits for additional capacity over the highly-populated mid-latitude areas (the "Inclined Sub-Constellation").

The flexible satellite and network technologies efficiently provide power and spectrum only where and when needed. The network of satellites implements optical inter-satellite links and connects to the terrestrial internet through strategically located Landing Stations. Each satellite has four steerable spot beams to communicate with the Landing Stations, and a set of Direct Radiating Array ("DRA") antennas providing up to 24 fully independent, shapeable and steerable User beams. One of the User beams (the "Network Entry User Beam") generated by the DRA antennas is dedicated to the network entry process. The Network Entry User Beam is activated periodically and steered to cover the field of view of a satellite over a certain period of time. This feature replaces the role of the wide-area receive beam in the Constellation. An integrated Constellation Network Operating System ("CNOS") allocates resources (power,

[3] IBFS File No. SAT-PDR-20161115-00108.

bandwidth, beam size, etc.). Table A.2-1 provides a comparison of the Constellation, the Modified Constellation and the Final Constellation.

Table A.2-1 – Summary of orbit parameters for the constellations

Parameter		(Telesat Grant) Constellation	Modified Constellation	Final Constellation
Polar Sub-Constellation	Orbital planes	6	6	27
	Satellites per plane	12	13	13
	Inclination (deg)	99.5	98.98	98.98
	Altitude (km)	1000	1015	1015
	Total satellites	72	78	351
Inclined Sub-Constellation	Orbital planes	5	20	40
	Satellites per plane	9	11	33
	Inclination (deg)	37.4	50.88	50.88
	Altitude (km)	1248	1325	1325
	Total satellites	45	220	1320
Total satellites in constellation		117	298	1671

In the Modified Constellation, the Polar Sub-Constellation is essentially the same as it was in the Constellation, with the exception that in the Modified Constellation one satellite has been added to each plane. The 298 satellites comprising the Modified

Constellation are a subset of the 1671 satellites comprising the Final Constellation. For the Modified Constellation:

- The Right Ascension of the Ascending Node ("RAAN") angles of the six orbital planes of the Polar Sub-Constellation are equally spaced by 40 degrees between zero and 200 degrees (inclusive);
- The RAAN angles of the 20 orbital planes of the Inclined Sub-Constellation are equally spaced by 18 degrees between zero and 342 degrees (inclusive);
- There is no difference between the phase angles of the satellites belonging to those polar orbits that are common to the Modified Constellation and the Final Constellation;
- The 11 satellites in each of the 20 orbital planes of the Inclined Sub-constellation are equally spaced by 32.7 degrees in true anomaly, the first satellite of which has a true anomaly equal to an angle, in degrees, that can be calculated according to the following formula:

$$\left\{\left\lfloor\frac{n-1}{3}\right\rfloor \cdot 6.54\right\} + \{rem[(n-1), 3] \cdot 13.09\}$$

Where: n is the inclined orbital plane number, n= 1, 2 ,…, 20;

$\lfloor a \rfloor$ is the value of *a* rounded down to the nearest integer;

rem(*a*, *b*) is the remainder of *a* divided by *b*.

IBFS allows only one Schedule S per application. The Final Constellation of 1671 satellites is captured in Schedule S filed in IBFS. For reference purposes, a version of

Schedule S that includes only the 298 satellites of the Modified Constellation is included as an attachment to this application.

Ka-band frequencies are used for both User and Landing Station links. The frequency bands for the Modified and Final Constellations remain the same as those specified in the Grant and are provided in Table A.2-2. Telemetry, tracking and command ("TT&C") information for the Modified and Final Constellations remains unchanged from that of the Constellation.

Table A.2-2: Frequency bands

Direction	Lower Frequency Limit (GHz)	Upper Frequency Limit (GHz)
Downlink	17.8	18.3
	18.3	18.6
	18.8	19.3
	19.7	20.2
Uplink	27.5	28.35
	28.35	28.6
	28.6	29.1
	29.5	30.0

In the United States Table of Frequency Allocations[4] (the "U.S. Table") and the Commission's Ka-band Plan[5] there are restrictions that apply to the use of some of the frequency band segments identified in Table A.2-2 by a NGSO network in the fixed-satellite service ("FSS"). The applicable restrictions are described below.

17.8 – 18.3 GHz

In the U.S. Table, the frequency band 17.8-18.3 GHz is allocated to the fixed service ("FS") as well as to federal GSO and NGSO FSS on a primary basis and is allocated to the non-government FSS on a secondary basis. The sub-band 18.0-18.3 GHz is also allocated to the meteorological-satellite service (space-to-Earth) on a primary basis in accordance with footnote US519. The Commission's Ka-Band Plan designates the 17.8-18.3 GHz band for the use of the FS on a primary basis and the FSS on a secondary basis. Since satellites in the Modified and Final Constellations will be operating in a secondary service, they must not cause harmful interference to, nor can they claim protection from, stations in the primary services. Telesat's proposed use of the 17.8-18.3 GHz band satisfies this standard. Telesat will operate on a non-harmful interference basis with respect to the FS, meteorological-satellite service, and federal GSO and NGSO FSS, and will not seek protection from these services.

18.3-18.6 GHz

In the U.S. Table, the 18.3 - 18.6 GHz band is allocated to the FSS on a primary basis. The Commission's Ka-Band Plan designates this band for the use of the GSO FSS

[4] 47 C.F.R. § 2.106
[5] *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, Report and Order and Further Notice of Proposed Rulemaking, 32 FCC Rcd 7809 at Appendix B (2017).

on a primary basis and NGSO FSS on a secondary basis. Telesat will operate on a non-harmful interference basis with respect to the GSO FSS and will not seek protection from GSO FSS operations in this band.

18.8-19.3 GHz

In the U.S. Table and the Commission's Ka-Band Plan, the 18.8-19.3 GHz band is allocated to the NGSO FSS on a primary basis and to the GSO FSS on a secondary basis. Telesat notes there are GSO systems operating on a secondary basis in this band.

19.7-20.2 GHz

In the U.S. Table, the 19.7-20.2 GHz band is allocated to the FSS and the mobile-satellite service ("MSS"). The Commission's Ka-Band Plan designates this band for the use of the GSO FSS on a primary basis and NGSO FSS on a secondary basis. Telesat will operate in the 19.7-20.2 GHz band on a non-harmful interference basis to GSO FSS and will not seek protection from GSO FSS operations in this band.

27.5-28.35 GHz

In the U.S. Table, the frequency band 27.5-28.35 GHz is allocated to the FS, the FSS and the mobile service ("MS") on a co-primary basis. The Commission's Ka-Band Plan designates this band for the use of the Upper Microwave Flexible Use Service ("UMFUS") on a primary basis and to the FSS on a secondary basis. Telesat plans to use the 27.5-28.35 GHz band in the U.S. only for individually-licensed Landing Stations and will include with any Landing Station application filed with the Commission a demonstration that will (i) address protection of UMFUS stations and (ii) acknowledge the need to accept interference from UMFUS stations.

<u>28.35-28.6 GHz</u>

In the U.S. Table, the frequency band 28.35–29.1 GHz is allocated to the FSS on a primary basis. The Commission's Ka-band Plan designates the 28.35-28.6 GHz band to the GSO FSS on a primary basis and to the NGSO FSS on a secondary basis. Telesat will operate on a non-harmful interference basis to GSO FSS and will not seek protection from GSO FSS operations in this band.

<u>28.6-29.1 GHz</u>

In the U.S. Table, the frequency band 28.35–29.1 GHz is allocated to the FSS on a primary basis. Telesat acknowledges that Footnote NG62 gives priority over the FSS to some specific FS stations. Telesat will operate on a non-harmful interference basis to these FS stations and will not seek protection from operations of these stations in this band. The Commission's Ka-band Plan designates the 28.35-28.6 GHz band to the NGSO FSS on a primary basis and to the GSO FSS on a secondary basis. Telesat notes there are GSO systems operating on a secondary basis in this band.

<u>29.5-30.0 GHz</u>

In the U.S. Table, the frequency band 29.5-30.0 GHz is allocated to the FSS and the MSS on a primary basis. The Commission's Ka-band Plan designates the 29.5-30.0 GHz band to the GSO FSS on a primary basis and to the NGSO FSS on a secondary basis. Telesat will operate on a non-harmful interference basis to the GSO FSS and will not seek protection from GSO FSS operations in this band.

A.3 SPACE STATION ANTENNA GAIN CONTOURS

Space station antenna gain information applicable to both the Modified and Final Constellations is provided in a GIMS database attached to Schedule S. This section supplements Schedule S, in accordance with §25.114(c)(4)(vi).

Table A.3-1 provides a description of the linkage between the beams in the GIMS database and the beams in Schedule S. Table A.3-2 provides a description of the User and Landing Station beams specified in Schedule S. Since all User beams are technically identical and all Landing Station beams are technically identical, only one beam of each type is provided.

Table A.3-1: Linkage between beams in the GIMS database and Schedule S

Orbit type	Beam type	Direction	GIMS	Schedule S
Polar	User	Uplink	USRPOLRX	F1P1, F1P2, F2P1, F2P2
Inclined	User	Uplink	USRINCRX	F1P1, F1P2, F2P1, F2P2
Polar	Landing Station	Uplink	GWPOLRX	G1P1, G1P2, G2P1, G2P2
Inclined	Landing Station	Uplink	GWINCRX	G1P1, G1P2, G2P1, G2P2
Polar	User	Downlink	USRPOLTX	M1P1, M1P2, M2P1, M2P2, M3P1, M3P2
Inclined	User	Downlink	USRINCTX	M1P1, M1P2, M2P1, M2P2, M3P1, M3P2
Polar	Landing Station	Downlink	USRPOLTX	N1P1, N1P2, N2P1, N2P2, N3P1, N3P2
Inclined	Landing Station	Downlink	USRINCTX	N1P1, N1P2, N2P1, N2P2, N3P1, N3P2

Table A.3-2: Description of beam IDs in Schedule S

Beam Description	Beam ID	Notes
Uplink Landing Station RHCP polarization	G1P1 and G2P1	Beam ID G1P1 and G2P1, for 27.5-29.1 and 29.5-30.0 GHz, respectively
Uplink Landing Station LHCP polarization	G1P2 and G2P2	Beam ID G1P2 and G2P2, for 27.5-29.1 and 29.5-30.0 GHz, respectively
Downlink Landing Station RHCP polarization	N1P1, N2P1 and N3P1	Beam ID N1P1, N2P1 and N3P1, for 17.8-18.6, 18.8-19.3 and 19.7-20.2 GHz, respectively
Downlink Landing Station LHCP polarization	N1P2, N2P2 and N3P2	Beam ID N1P2, N2P2 and N3P2, for 17.8-18.6, 18.8-19.3 and 19.7-20.2 GHz, respectively
Uplink User beam RHCP polarization	F1P1 and F2P1	Beam ID F1P1 and F2P1, for 27.5-29.1 and 29.5-30.0 GHz, respectively
Uplink User beam LHCP polarization	F1P2 and F2P2	Beam ID F1P2 and F2P2, for 27.5-29.1 and 29.5-30.0 GHz, respectively
Downlink User beam RHCP polarization	M1P1, M2P1, and M3P1	Beam ID M1P1, M2P1 and M3P1, for 17.8-18.6, 18.8-19.3 and 19.7-20.2 GHz, respectively
Downlink User beam LHCP polarization	M1P2, M2P2, and M3P2	Beam ID M1P2, M2P2 and M3P3, for 17.8-18.6, 18.8-19.3 and 19.7-20.2 GHz, respectively

A.4 INTERFERENCE ANALYSIS

This section addresses compliance with power flux-density ("PFD") and equivalent power flux-density ("EPFD") limits for each of the Modified and Final Constellations. This section also provides an interference analysis for the Modified Constellation with respect to other NGSO systems in the first processing round. This latter analysis shows that, as compared to the Constellation, the Modified Constellation does not worsen the interference environment with respect to other NGSO systems in the first processing round. A similar analysis is not provided for the Final Constellation, as the satellites of the Final Constellation that are additional to those of the Modified Constellation are intended for consideration in the second processing round.

A.4.1 Compliance with Article 21 PFD limits

The Modified and Final Constellations will comply with applicable PFD limits in Section §25.208[6] of the FCC rules, as well as in Article **21** of the ITU Radio Regulations. The applicable limits are summarized in Table A.4.1-1.

Table A.4.1-1: Applicable PFD limits (reference bandwidth = 1 MHz)

Frequency Band (GHz)	Limit in $dB(W/m^2)$ for angles of arrival (δ) above the horizontal plane		
	0°-5°	5°-25°	25°-90°
17.7-19.3	-115-X	-115-X+ ((10+X)/20)(δ-5)	-105

The parameter X is a function of the number, n, of satellites:

$X = 0$	dB	for $n \leq 50$
$X = (5/119)\ (n - 50)$	dB	for $50 < n \leq 288$
$X = (1/69)\ (n + 402)$	dB	for $n > 288$

[6] 47 C.F.R. §25.208

Modified Constellation

The Modified Constellation is comprised of 298 satellites, resulting in a value of X = 10.14 dB. The applicable PFD limits and the calculated PFD at select angles of arrival, using the Modified Constellation maximum EIRP density of -50 dB(W/Hz), are shown in Table A.4.1-2. In all cases, the calculated PFD is lower than the applicable PFD limit. Therefore, the Modified Constellation is compliant with the limits stated in Section §25.208 of the Commission's rules.

Table A.4.1-2: Modified Constellation PFD

Angle of Arrival (deg)	PFD limit in dB(W/m^2/MHz)	Calculated PFD dB(W/m^2/MHz)
5	-125.1	-131.2
10	-120.1	-129.9
15	-115.1	-128.7
20	-110.0	-127.6
25	-105	-126.8
90	-105	-121.1

Final Constellation

The Final Constellation is comprised of 1671 satellites, resulting in a value of X = 30.04 dB. The applicable PFD limits and the calculated PFD at select angles of arrival, using the Final Constellation maximum EIRP density of -50 dB(W/Hz), are shown in Table A.4.1-3.

Table A.4.1-3: Final Constellation PFD

Angle of Arrival (deg)	PFD limit in dB(W/m^2/MHz)	Calculated PFD dB(W/m^2/MHz)
5	-145.0	-131.2
10	-135.0	-129.9
12	-131.0	-129.4
13	-129.0	-129.2
15	-127.0	-128.7
20	-115.0	-127.6
25	-105	-126.8
90	-105	-121.1

As evident from Table A.4.1-3, the PFD limits are not met for angles of arrival less than 13 degrees. This result is due to the fact the ITU methodology for establishing the Article **21** PFD limits were developed with the capability to scale up for application to dynamically controlled NGSO constellations of only 840 satellites[7]. Therefore, Telesat includes in Annex 1 a detailed technical showing to demonstrate that the Final Constellation will protect fixed service (FS) stations.

[7] The Commission already agreed with this principle, see *Space Exploration Holdings, LLC, Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System*, IBFS File Nos. SAT-LOA-20161115-00118, SAT−LOA−20170726−00110, 33 FCC Rcd 3391 (2018) at ¶ 35.

A.4.2 Compliance with Article 22 EPFD limits

Telesat will ensure compliance with the applicable EPFD limits set forth in Article **22** of the ITU Radio Regulations.[8] These limits apply in the Ka-band segments 17.8-18.6 GHz and 19.7-20.2 GHz in the space-to-Earth direction, 27.5-28.6 GHz and 29.5-30.0 GHz in the Earth-to-space direction, and 17.8-18.4 GHz in the space-to-space direction.[9] The Commission's rules and the Grant oblige Telesat to receive from the ITU Radiocommunication Bureau, prior to initiation of service, a favorable or "qualified favorable" finding in accordance with Resolution 85 (WRC-03). Telesat received from the ITU a favorable finding[10] for the Constellation, and expects to receive a favorable finding for each of the Modified and Final Constellations.

Modified Constellation

Although not required by the Commission's rules, Telesat provides herein an analysis to demonstrate that its Modified Constellation will comply with the applicable Ka-Band EPFD limits.

The latest version of the ITU-approved software developed by Agenium was used for determining compliance with the EPFD single-entry validation limits. The figures in Annex 2 present the results of this analysis with respect to the space-to-Earth direction ($EPFD_{down}$), the Earth-to-space direction ($EPFD_{up}$), and for the inter-satellite case ($EPFD_{is}$).

[8] 47 C.F.R. §25.146(a)(2)
[9] Telesat is also actively engaged in coordination discussions with relevant GSO FSS operators with respect to the18.8-19.3 GHz and 28.6-29.1 GHz bands.
[10] See CR/C/3313 MOD-3, published in BR IFIC 2863

In carrying out this analysis, Telesat has taken into account that the Modified Constellation will operate with a minimum elevation angle of 10 degrees and a minimum GSO arc exclusion angle of zero degrees. With respect to the parameter Nco, which is defined[11] as the "maximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location", in the Modified Constellation, only one satellite will transmit on a frequency at any one time with the intention of providing service to a given location. Nevertheless, a much higher value needs to be used when running the EPFD validation software in order to capture the contributions to the $EPFD_{down}$ from a larger number of satellites, whether or not they are intentionally transmitting to this given location. A conservative Nco value of 30 was used for all latitude ranges. The EPFD validation software will determine from the orbit geometry the actual maximum number of visible satellites up to the Nco number provided[12].

In Annex 2, the labeling of each diagram provides the relevant details for each analysis case generated by the Agenium software. For each diagram, the calculated EPFD level and the applicable EPFD limits are shown. As can be seen, in no case does the calculated EPFD level exceed the applicable limit. Therefore, it can be concluded that the Modified Constellation complies with the relevant EPFD limits as set forth in Article **22** of the ITU Radio Regulations.

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[11] See Item A.4.b.6.a.1 of Appendix 4 to the Radio Regulations (Edition of 2016)

[12] *See WorldVu Satellites Limited, Petition for a Declaratory Ruling Granting Access to the U.S. Market for the OneWeb System*, IBFS File No. SAT-LOI-20160428-00041 (Apr. 28, 2016) at Attachment A (Technical Information to Supplement Schedule S).

Final Constellation

In accordance with **§25.146** Telesat certifies it will meet all applicable equivalent power flux-density levels in Article **22**, Section II, and Resolution 76 of the ITU Radio Regulations (both incorporated by reference, §25.108) and will not commence operations prior to receiving a favorable or "qualified favorable" finding from the ITU BR.

A.4.3 Interference analysis with respect to other NGSO systems

The analysis in this section demonstrates that the Modified Constellation will not worsen, compared to the Constellation, the interference environment with respect to other NGSO systems in the first processing round. In fact, the analysis demonstrates that with the Modified Constellation not only is there not a worsening of the interference environment, there is a reduction in the probability that, absent coordination, band segmentation would be required based on the $\Delta T/T=6\%$ criterion[13]. These results are attributable to the following factors:

- There are more satellites to choose from at any given time in the Modified Constellation compared to the Constellation. This additional diversity offers the possibility of terminals selecting links that cause or suffer less interference;

[13] 47 C.F.R. §25.261

- Only one co-frequency satellite will offer service towards a given location in the Modified Constellation, while in the Constellation two co-frequency satellites could offer service simultaneously. This change will improve the interference environment with respect to other NGSO systems;
- The G/T for the satellites and earth station receivers in the Modified Constellation is lower than that for the Constellation, which will improve Modified Constellation resilience to interference caused by other NGSO systems.

Telesat analyzed four co-existence scenarios, as follows:

- **Scenario 1, Uplink, Telesat as Victim:** another NGSO system's earth station potentially interfering with a Telesat satellite receiver in the Earth-to-space direction;
- **Scenario 2, Uplink, Telesat as Interferer:** a Telesat earth station potentially interfering with another NGSO system's satellite receiver in the Earth-to-space direction;
- **Scenario 3, Downlink, Telesat as Victim:** another NGSO system's satellite transmitter potentially interfering with a Telesat earth station receiver in the space-to-Earth direction; and,
- **Scenario 4, Downlink, Telesat as Interferer:** a Telesat satellite transmitter potentially interfering with another NGSO system's earth station receiver in the space-to-Earth direction

In each of the scenarios, the interference environment is probabilistic and time varying, because the occurrence and magnitude of potential interference events are not constant but change as the NGSO systems move relative to each other. Therefore, for each of those scenarios, Telesat performed analyses that simulate its system operating together with another NGSO system, over a long enough time to produce meaningful results.

The analysis consisted of computing the cumulative distribution function ("CDF") of the I/N ratio measured at the input of the satellite or earth station receiver of the relevant victim system. For each of the considered cases, Telesat has computed the CDF curves for the Constellation and the Modified Constellation and compared them to verify that the modification will not worsen the interference environment with respect to other NGSO systems. For each of the four scenarios, by way of example, results are provided with respect to each of the SpaceX, OneWeb and O3b NGSO systems using the technical parameters for those systems contained in the technical showings on the public record.

Compared to the Constellation, in the interference-dominated environment (when I/N > 0 dB), in some cases, there is a small increase in interference due to the Modified Constellation. However, this result does not cause any adverse impact on the interference environment in which other constellations operate. In fact, a small increase in interference for a link subject to an interference-dominated environment has no impact on the interfered-with link because such a link would be unusable with or without the presence of the Modified Constellation. On the other hand, in the noise-dominated environment (when I/N ≤ 0 dB), where potential changes in the interference environment do matter, the Modified Constellation never causes an increase in interference, compared to the Constellation. In other words, the Modified Constellation does not worsen, and actually improves, the interference environment, causing no adverse impact on other constellations. In particular, it should be noted that since absent a coordination agreement two systems would implement band segmentation whenever the I/N ratio is greater than or equal to -12.2 dB (i.e. $\Delta T/T=6\%$, a level which falls well within the noise-dominated environment), the Modified Constellation reduces the requirement for band segmentation.

A.4.3.1 Analysis in the uplink direction (Scenario 1 and Scenario 2)

Telesat used the following assumptions:

1. The Telesat earth station is collocated with the earth station of the other NGSO system (the worst case);
2. Each earth station can communicate with any satellite in its own system following the rules applicable for that system (e.g. the GSO avoidance angle and/or minimum elevation angle);
3. For each interfering system, the maximum number, Nco, of satellites that can receive simultaneously from a given location is considered. In the case of the Telesat system, Nco is two for the Constellation and one for the Modified Constellation. The receiving satellites of the interfering system are randomly chosen in evaluating the I/N CDF;

4. All possible valid cases are considered in evaluating the CDF of the I/N ratio at the input of the victim satellite receiver.

Results are shown in figures A3-1 to A3-28 of Annex 3, for locations at 35°N and 65°N latitude[14]. Note that this simulation is conservative (i.e. it overestimates I/N), as it does not consider the effects of atmospheric attenuation.

A.4.3.2 Analysis in the downlink direction (Scenario 3 and Scenario 4)

Telesat used the following assumptions:

1. The Telesat earth station is collocated with the earth station of the other NGSO system (the worst case);
2. Each earth station can communicate with any satellite in its own system following the rules applicable for that system (e.g. the GSO avoidance angle and/or minimum elevation angle);
3. For each interfering system, the maximum number, Nco, of satellites that can transmit simultaneously towards a given location is considered. In the case of the Telesat system, Nco is two for the Constellation and one for the Modified Constellation. The transmitting satellites of the interfering system are randomly chosen in evaluating the I/N CDF;
4. All possible valid cases are considered in evaluating the CDF of the I/N ratio at the input of the victim earth station receiver.

[14] Results for two latitudes, which are representative of Telesat's primary service area and are located on U.S. territory, are included here. Simulations done at various latitudes showed similar results.

Results are shown in figures A3-29 to A3-47 of Annex 3, for locations at 35°N and 65°N latitude. Note that this simulation is conservative (i.e. it overestimates I/N), as it does not consider the effects of atmospheric attenuation.

A.5 ITU FILINGS

Telesat is licensed through the Canadian administration to the ITU networks COMMSTELLATION, CANSAT-LEO and TELSTAR-LEO. Telesat may submit to the ITU through Canada additional networks as necessary.

A.6 COMPLIANCE WITH COVERAGE REQUIREMENTS

For the Constellation, Telesat demonstrated compliance with the FCC's coverage requirements. The Modified and Final Constellations also will be capable of providing service consistent with these requirements, i.e. on a continuous basis throughout the fifty states, Puerto Rico, and the U.S. Virgin Islands.

CERTIFICATION OF PERSON RESPONSIBLE FOR PREPARING ENGINEERING INFORMATION

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/ Mario Neri
Mario Neri, M.Eng., M.Fin.
Director, International Coordination
Telesat International Ltd.

May 26, 2020

ANNEX 1

Final Constellation Interference Analysis

With Respect to the Fixed-Service Operating in the Ka-Band

This annex addresses the non-compliance of the Final Constellation with the limits in Article **21** for elevation angles less than 13 degrees. In a previous decision applicable to another NGSO applicant[15] where the Article **21** limits were not met for certain elevation angles, the Commission imposed a condition to file a technical showing demonstrating its operation would nevertheless protect Fixed-Service (FS) stations having characteristics as described in Recommendation ITU-R SF.1483. This annex presents a similar showing for the Final Constellation.

For the purposes of this analysis, Telesat used the following assumptions:

1) Characteristics of the victim FS links consistent with those specified in Recommendation ITU-R SF.1483, as summarized in Table A1-1.
2) Protection criteria for the victim FS links consistent with those specified in Recommendation ITU-R F.1495, as summarized below:
    a. Long-term: the Interference-to-Noise (I/N) ratio at the input of the FS victim receiver shall not exceed -10 dB for more than 20% of the time in any year;

[15] See Space Exploration Holdings, LLC 33 FCC Rcd. 3391 ¶ 35 (2018)

b. Short-term: the I/N ratio at the input of the FS victim receiver shall not exceed 14 dB for more than 0.01% of the time in any month, and the I/N ratio shall not exceed 18 dB for more than 0.0003% of the time in any month.

Table A1-1: FS link characteristics

Parameter	Value
Elevation Angles (degrees)	0 and 2.2
FS Antenna Height (m)	0
FS Antenna Gain (dBi)	32, 38, and 48
FS Antenna Pattern	As per Rec. ITU-R F.1245
Latitude (degrees)	25 N, 45 N, 60 N
Feeder Loss (dB)	3
Polarization Loss (dB)	0
Rx Thermal Noise (dB(W/MHz))	-139

To verify compliance with the protection criteria, Telesat carried out both a static and a dynamic analysis.

<u>Static Analysis</u>

The static analysis consists of computing the maximum possible I/N ratio in the worst-case geometry at the input of the receiver for each of the FS links described in Table A1-1. Since the maximum EIRP spectral density of each of the Telesat satellites is equal to -50 dB(W/Hz) and is assumed to be constant, the maximum I/N ratio depends on the receive gain of the victim FS antenna in the direction of the interfering Telesat polar[16] satellite *S* whose main beam is pointed towards the victim FS station, and the free-space loss reducing the power of the interfering signal when travelling from satellite *S* to the FS receiver. The worst-case geometry occurs when the gain of the victim FS station antenna is largest and the free-space loss is smallest. In other words, the worst-case geometry occurs when the angle θ between the boresight of the FS antenna and the line between the FS station and satellite *S* is smallest. Since the minimum elevation angle for the Telesat system is 10 degrees, the smallest angle θ is 10 - 2.2 = 7.8 degrees. This analysis makes also the worst-case assumption that a further 10 Telesat polar satellites S_{SL} are perfectly aligned with the boresight of the FS station antenna and interfere with it through their side-lobes[17].

The results of this static analysis are included in Table A1-2 and show that in no case is the I/N ratio at the input of the FS receiver greater than the strictest limit (I/N= -10 dB) derived from Recommendation ITU-R F.1495. It should be noted that this analysis is conservative as it does not take into account the effects of atmospheric attenuation.

[16] The altitude of the polar satellites orbits, and, consequently, the slant range to the FS station, are smaller than those of the inclined satellites. The polar satellites therefore are the worst-case interferers to the FS.
[17] The side-lobe EIRP spectral density from these satellites is assumed to be 30 dB lower on average than their corresponding maximum main beam EIRP spectral density.

Table A1-2: I/N ratio at the input of the FS receivers in the worst-case geometry

		FS Antenna Gain (dBi)		
		32	38	48
Telesat satellite S max. EIRP spectral density	dB(W/Hz)	-50.0	-50.0	-50.0
	dB(W/MHz)	10.0	10.0	10.0
FS receive off-axis gain at angle θ = 7.8 degrees	dBi	10.6	9.1	6.7
Free-space loss for satellite S	dB	186.7	186.7	186.7
Side-lobe EIRP sd for each of satellites S_{SL}	dB(W/MHz)	-20.0	-20.0	-20.0
Total interfering EIRPsd from all satellites S_{SL}	dB(W/MHz)	-10.0	-10.0	-10.0
Free-space loss between S_{SL} and FS station	dB	188.7	188.7	188.7
Feeder loss	dB	3.0	3.0	3.0
Interfering power from S at the input of the FS receiver	dB(W/MHz)	-169.1	-170.6	-173.0
Interfering power from S_{SL} at the input of the FS receiver	dB(W/MHz)	-169.7	-163.7	-153.7
Total Interfering power	dB(W/MHz)	-166.4	-162.9	-153.6
Receive Thermal Noise	dB(W/MHz)	-139.0	-139.0	-139.0
Max. I/N	dB	-27.4	-23.9	-14.6

Dynamic Analysis

The dynamic analysis consists of calculating the Cumulative Density Function (CDF) of the I/N ratio at the input of the receiver for each of the FS links described in

Table A1-1. This simulates the operation of the Telesat system for a period of time long enough to obtain statistically significant results. For each of the possible FS victim antenna gains, latitudes and elevations, the analysis considers the worst-case FS antenna pointing. In other words, the analysis assumes that, at every time-step, the beam from the Telesat satellite for which the I/N ratio at the input of the FS receiver is largest points directly at the victim FS station. Furthermore, the analysis includes the interference contribution from the side-lobes of all other Telesat satellites in view. This is a conservative analysis, because (i) it assumes that, at every time step, the most-interfering Telesat satellite interferes with the FS station through its main lobe, (ii) every other Telesat satellite in view is transmitting and interferes through its side-lobes, and (iii) it does not account for the mitigating effect of atmospheric attenuation. The results of the dynamic analysis, and the protection limits contained in Recommendation ITU-R F.1495, are shown in Figures A1-1 to A1-6 below. In all cases, the dynamic analysis aggregate I/N results are significantly lower than the long-term and short-term limits specified in Recommendation ITU-R F.1495.

The results of the static and dynamic analyses demonstrate that the Telesat Final Constellation protects FS stations having characteristics as described in Recommendation ITU-R SF.1483.

Figure A1-1. FS Station: Latitude 25°N, Elevation 0°

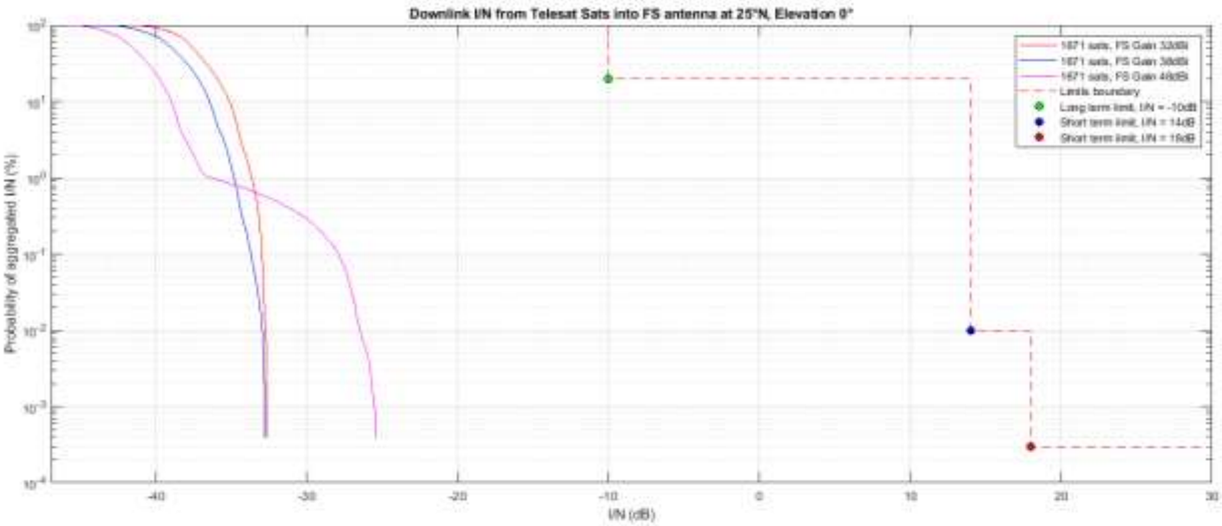


Figure A1-2. FS Station: Latitude 25°N, Elevation 2.2°

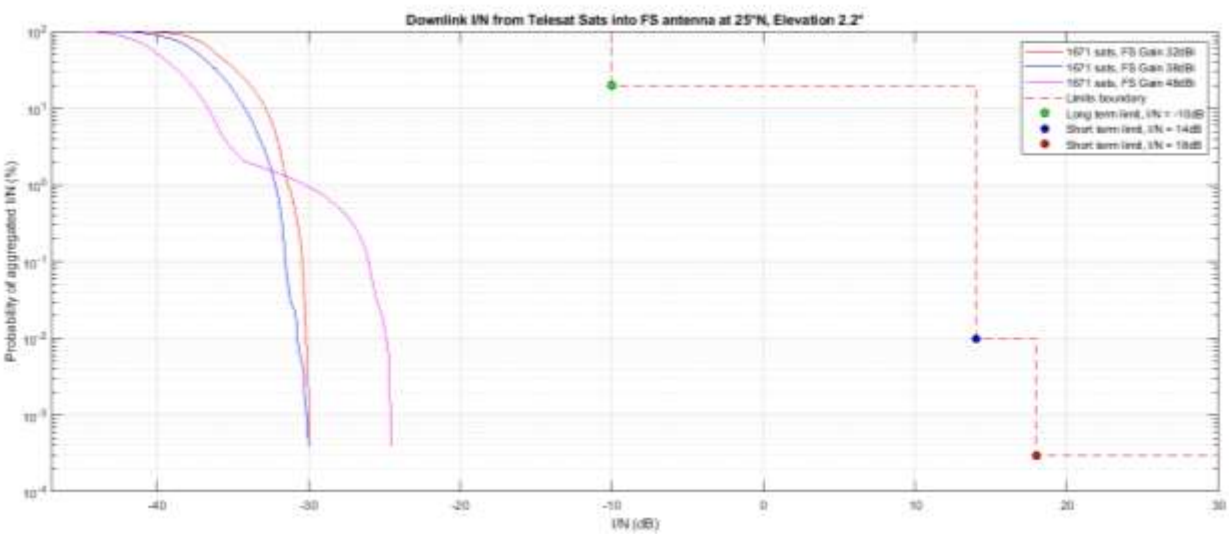


Figure A1-3. FS Station: Latitude 45°N, Elevation 0°

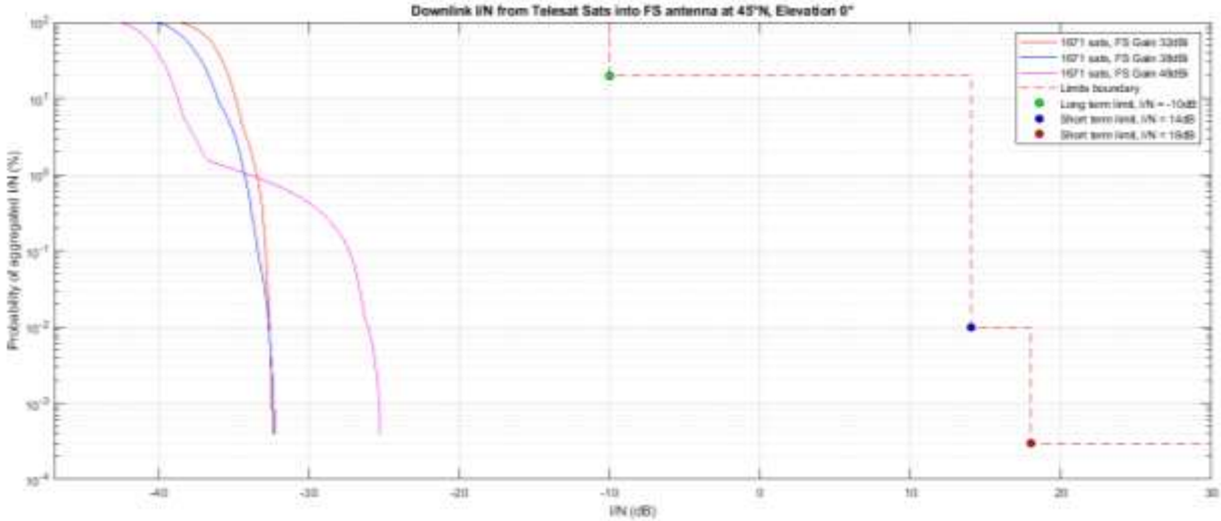


Figure A1-4. FS Station: Latitude 45°N, Elevation 2.2°

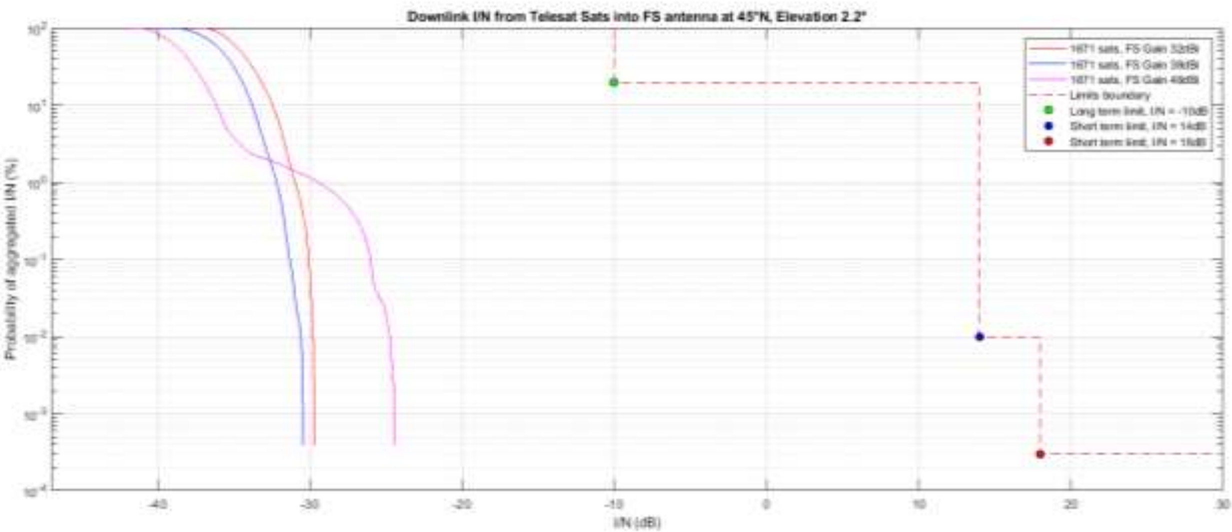


Figure A1-5. FS Station: Latitude 60°N, Elevation 0°

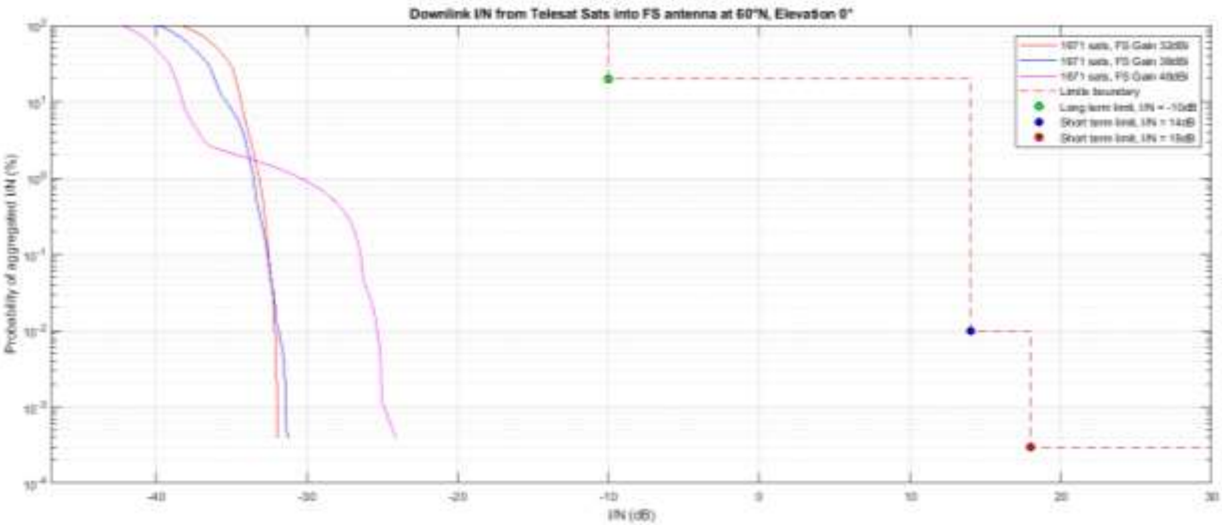
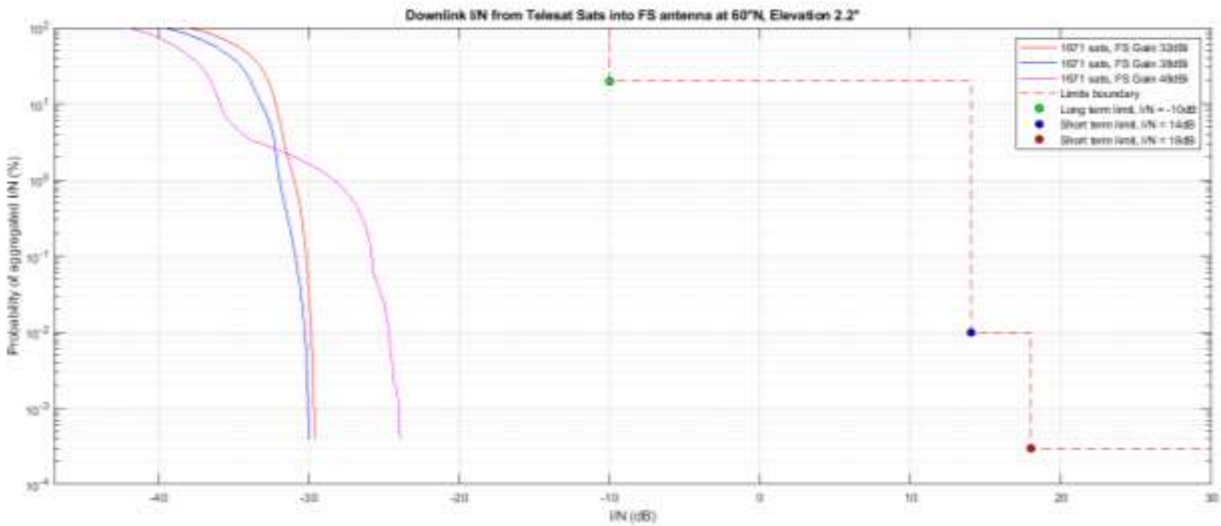


Figure A1-6. FS Station: Latitude 60°N, Elevation 2.2°



ANNEX 2

Results of the EPFD analysis for the Modified Constellation

Figure A2-1
EPFD$_{down}$, 17.8-18.6 GHz, Ref. BW= 40 kHz, reference antenna diameter 1m

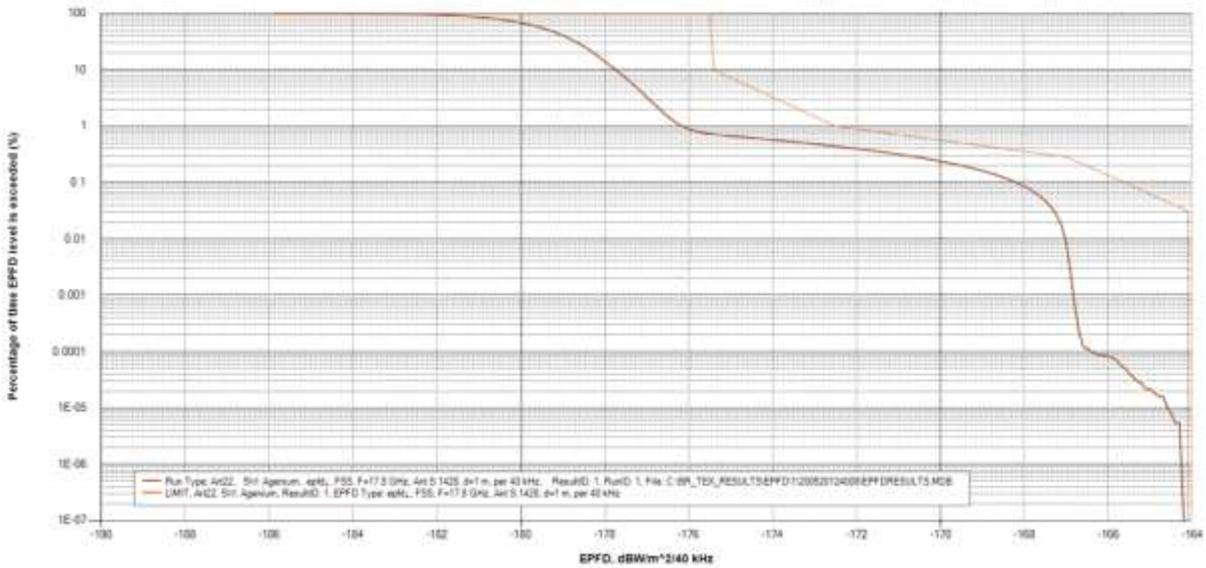


Figure A2-2
EPFD$_{down}$, 17.8-18.6 GHz, Ref. BW= 1000 kHz, reference antenna diameter 1m

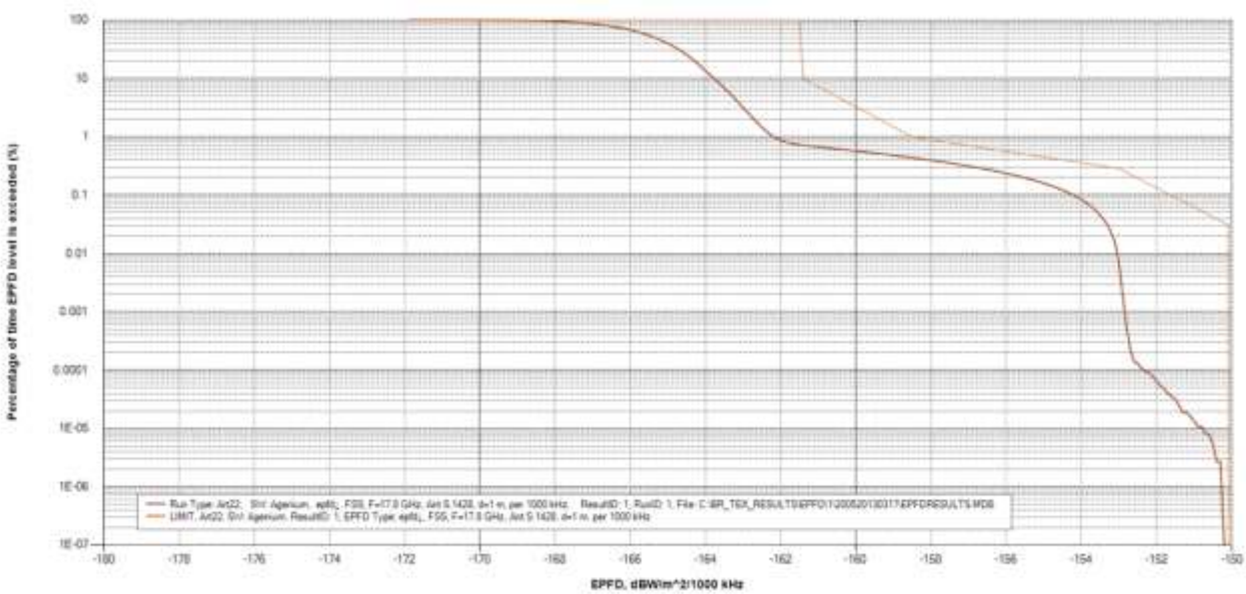


Figure A2-3
EPFD$_{down}$, 17.8-18.6 GHz, Ref. BW= 40 kHz, reference antenna diameter 2m

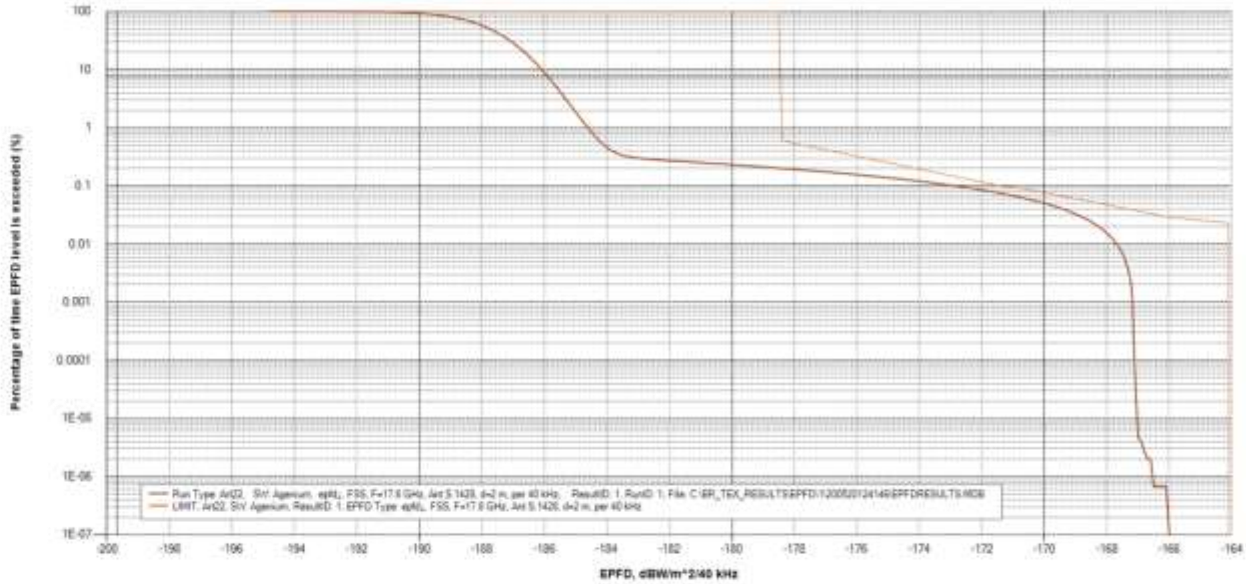


Figure A2-4
EPFD$_{down}$, 17.8-18.6 GHz, Ref. BW= 1000 kHz, reference antenna diameter 2m

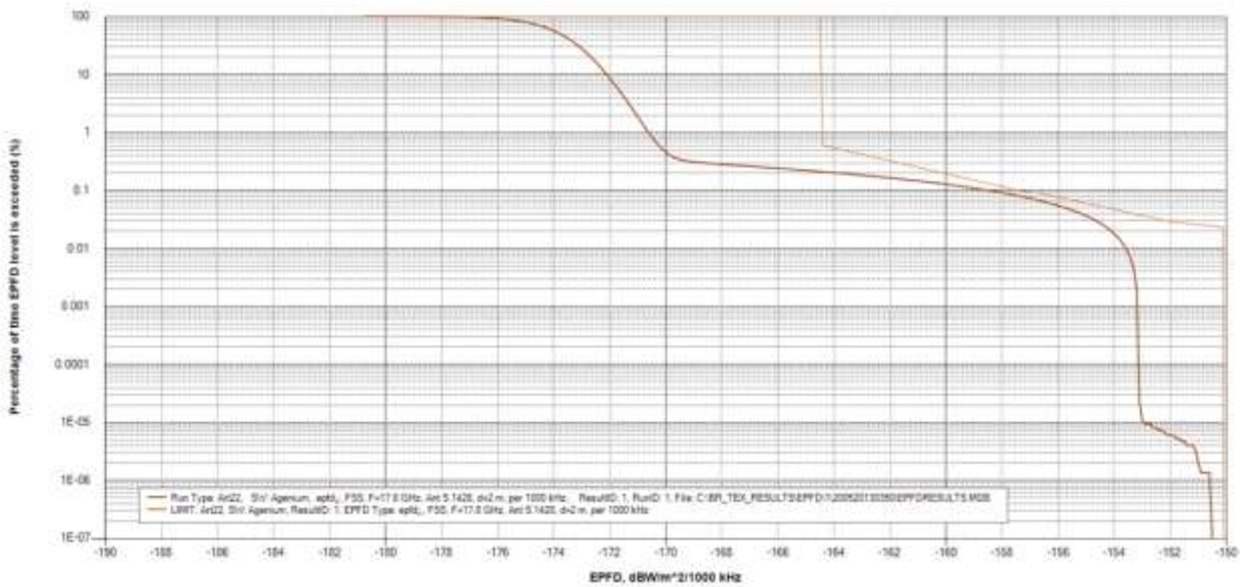


Figure A2-5
EPFD$_{down}$, 17.8-18.6 GHz, Ref. BW= 40 kHz, reference antenna diameter 5m

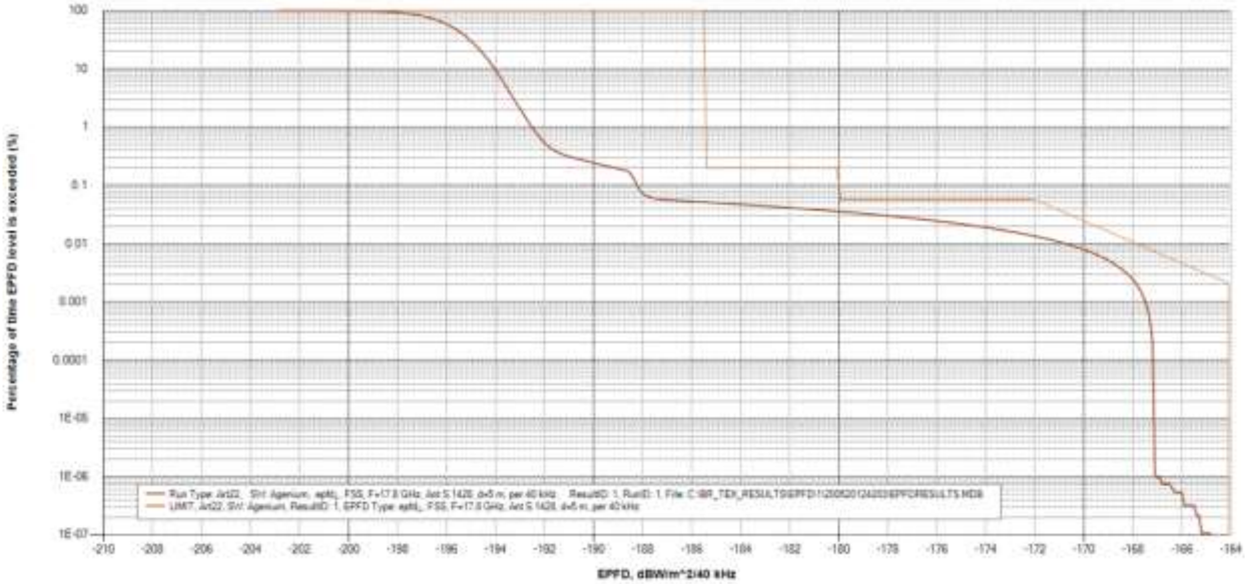


Figure A2-6
EPFD$_{down}$, 17.8-18.6 GHz, Ref. BW= 1000 kHz, reference antenna diameter 5m

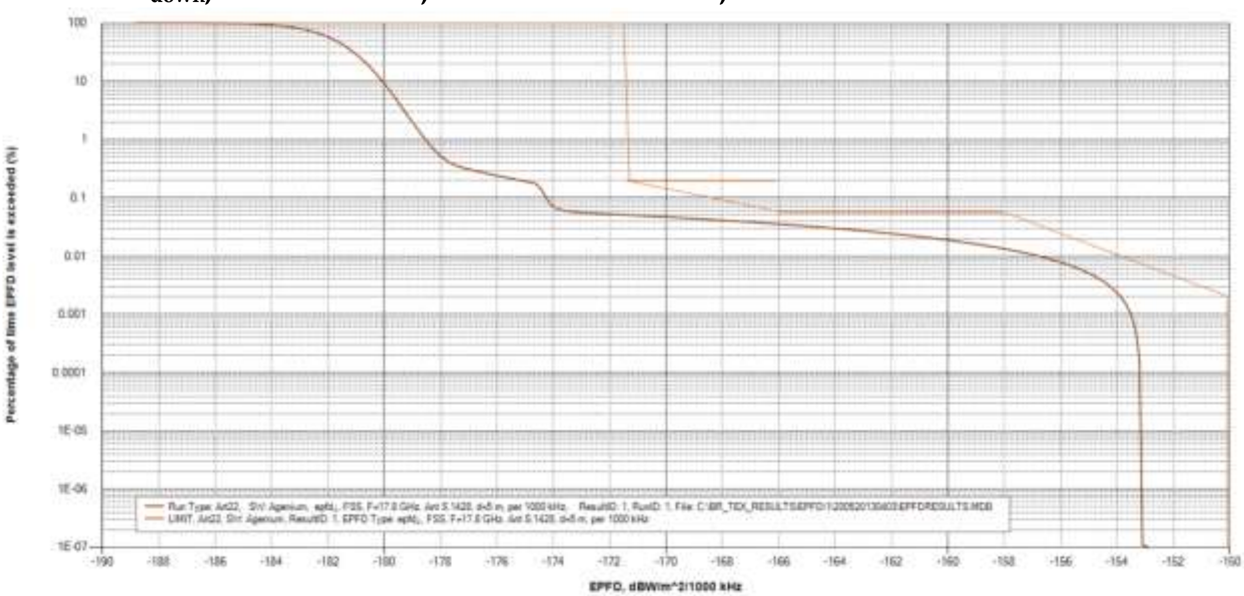


Figure A2-7
EPFD$_{down}$, 19.7-20.2 GHz, Ref. BW= 40 kHz, reference antenna diameter 0.7m

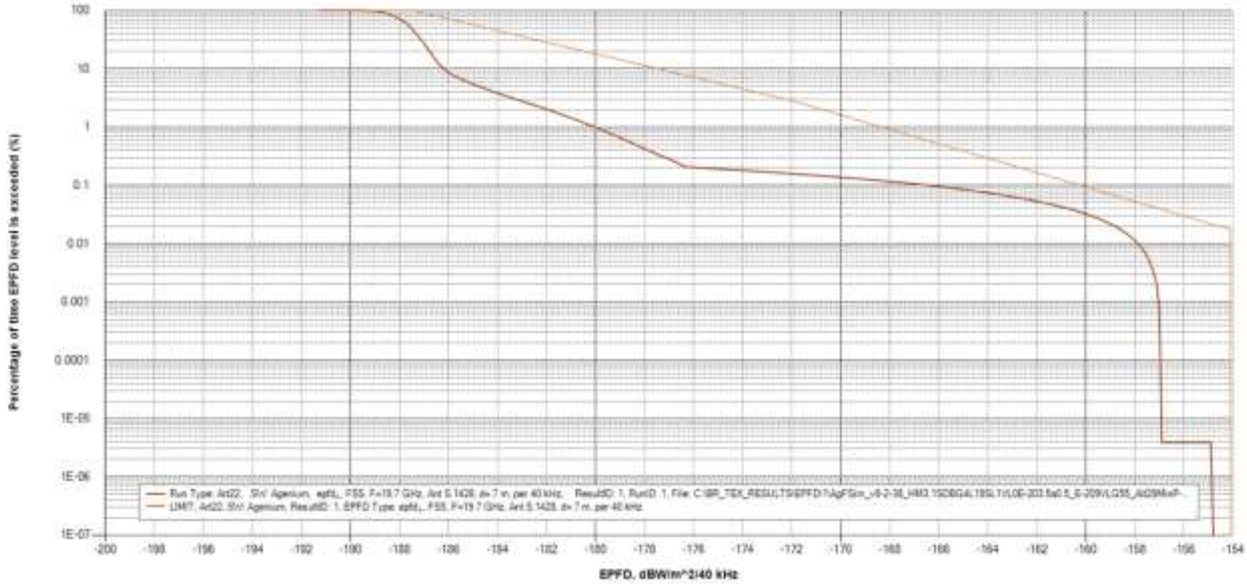


Figure A2-8
EPFD$_{down}$, 19.7-20.2 GHz, Ref. BW= 1000 kHz, reference antenna diameter 0.7m

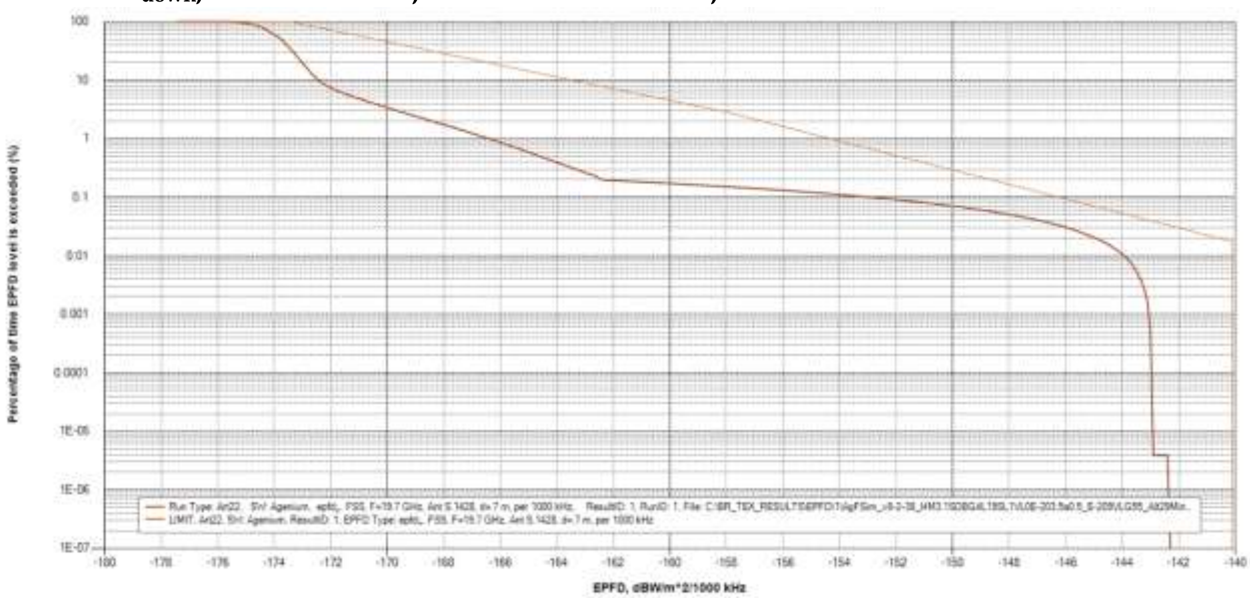


Figure A2-9
EPFD$_{down}$, 19.7-20.2 GHz, Ref. BW= 40 kHz, reference antenna diameter 0.9m

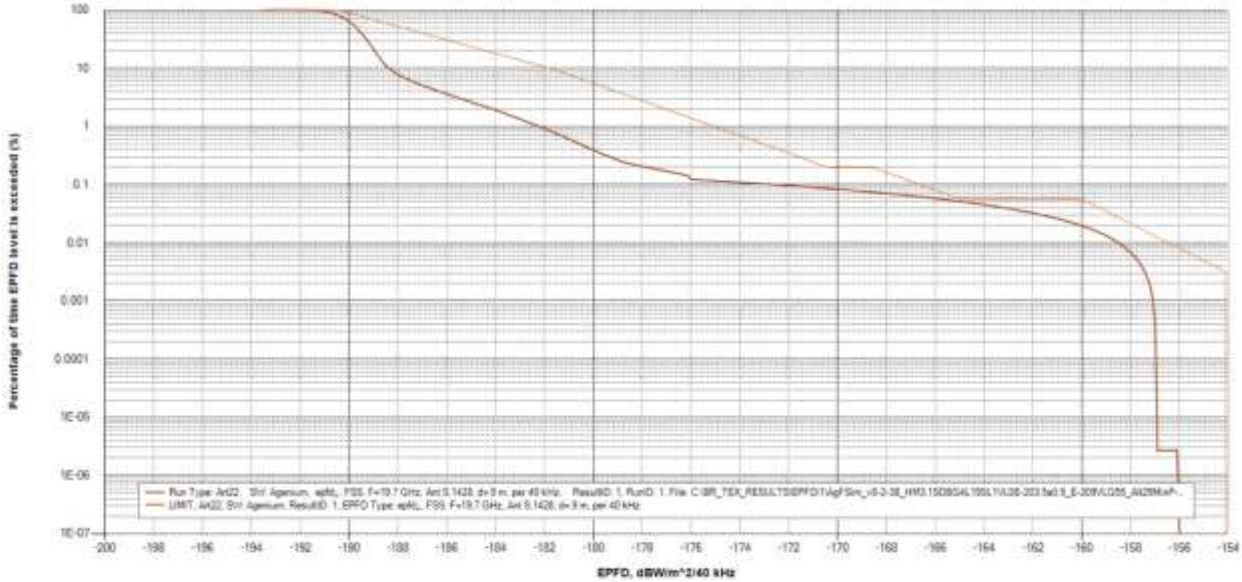


Figure A2-10
EPFD$_{down}$, 19.7-20.2 GHz, Ref. BW= 1000 kHz, reference antenna diameter 0.9m

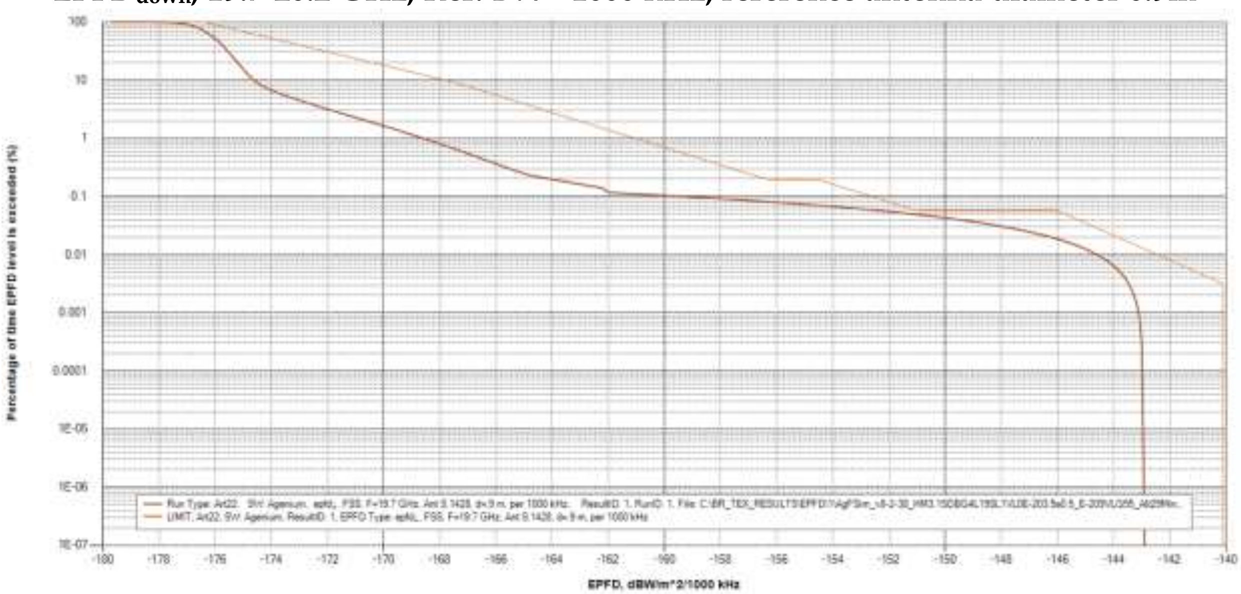


Figure A2-11
EPFD$_{down}$, 19.7-20.2 GHz, Ref. BW= 40 kHz, reference antenna diameter 2.5m

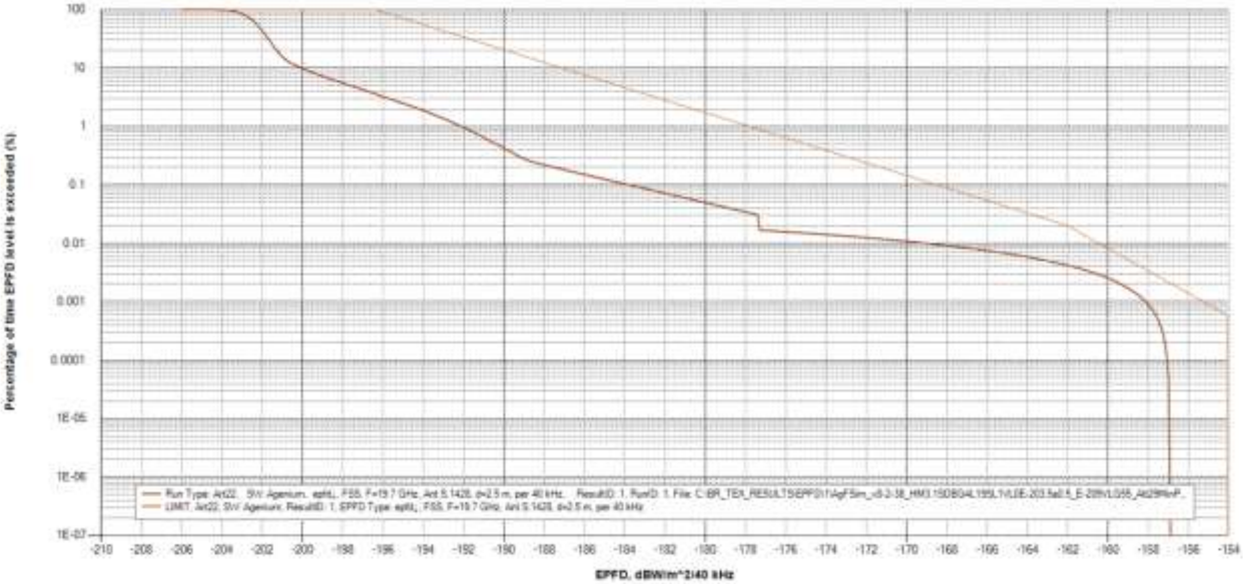


Figure A2-12
EPFD$_{down}$, 19.7-20.2 GHz, Ref. BW= 1000 kHz, reference antenna diameter 2.5m

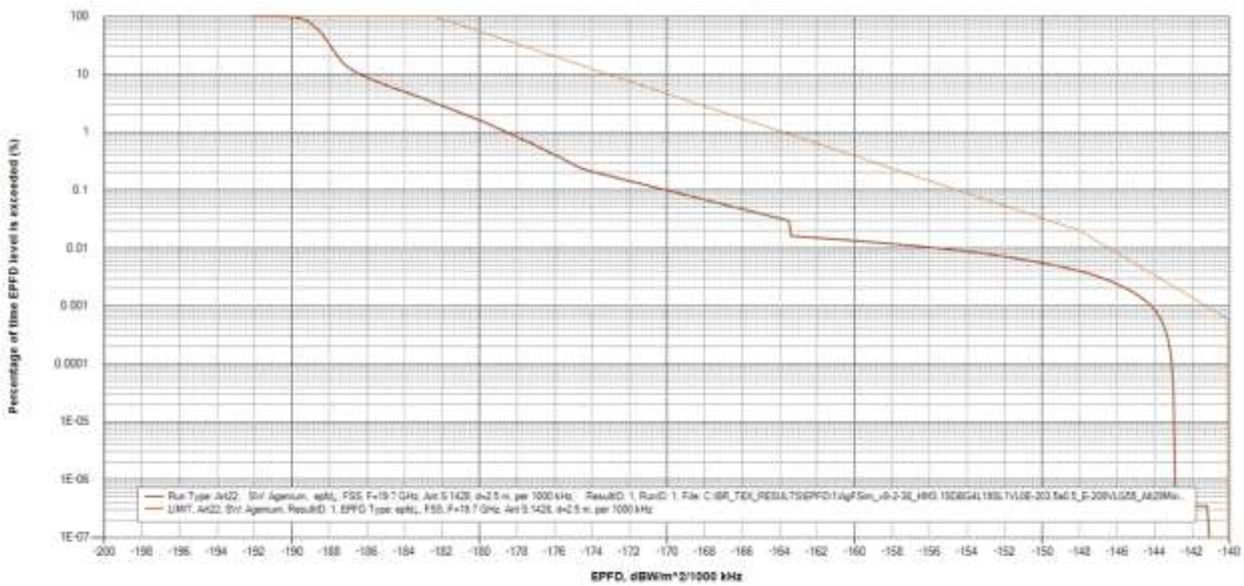


Figure A2-13
EPFD$_{down}$, 19.7-20.2 GHz, Ref. BW= 40 kHz, reference antenna diameter 5m

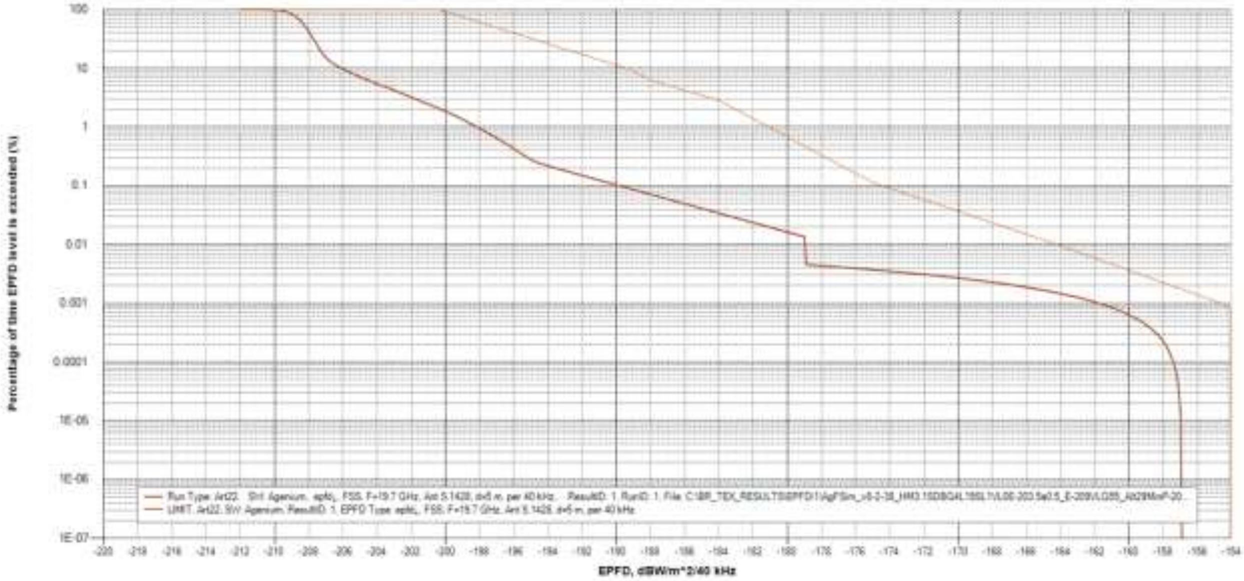


Figure A2-14
EPFD$_{down}$, 19.7-20.2 GHz, Ref. BW= 1000 kHz, reference antenna diameter 5m

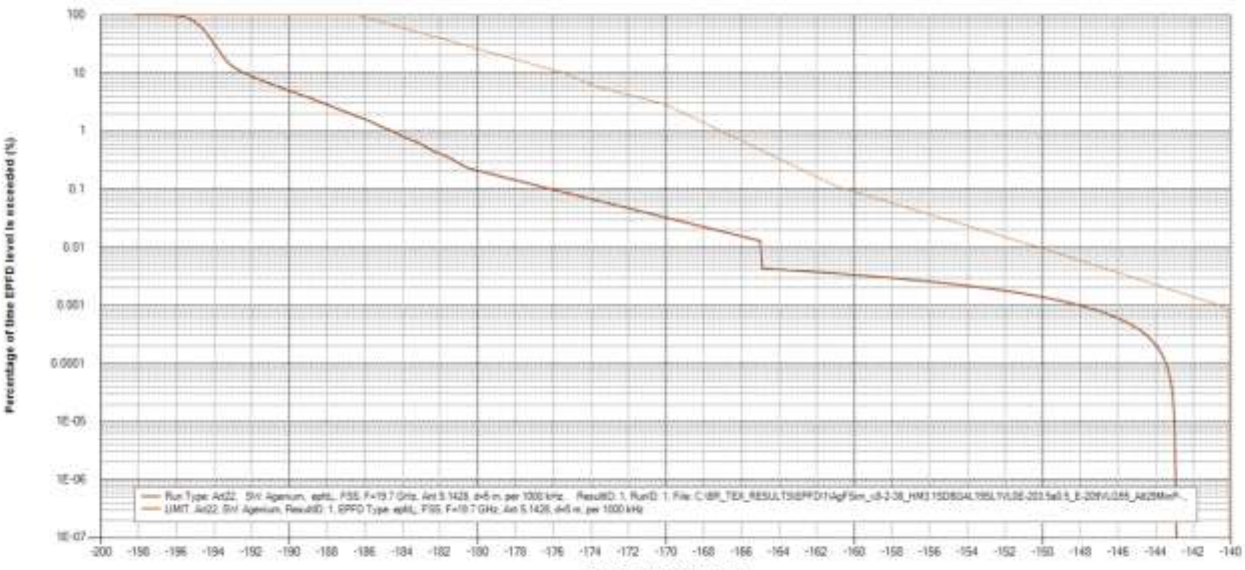


Figure A2-15
EPFD$_{up}$, 27.5-28.6 GHz, Ref. BW= 40 kHz, reference antenna beamwidth 1.55deg

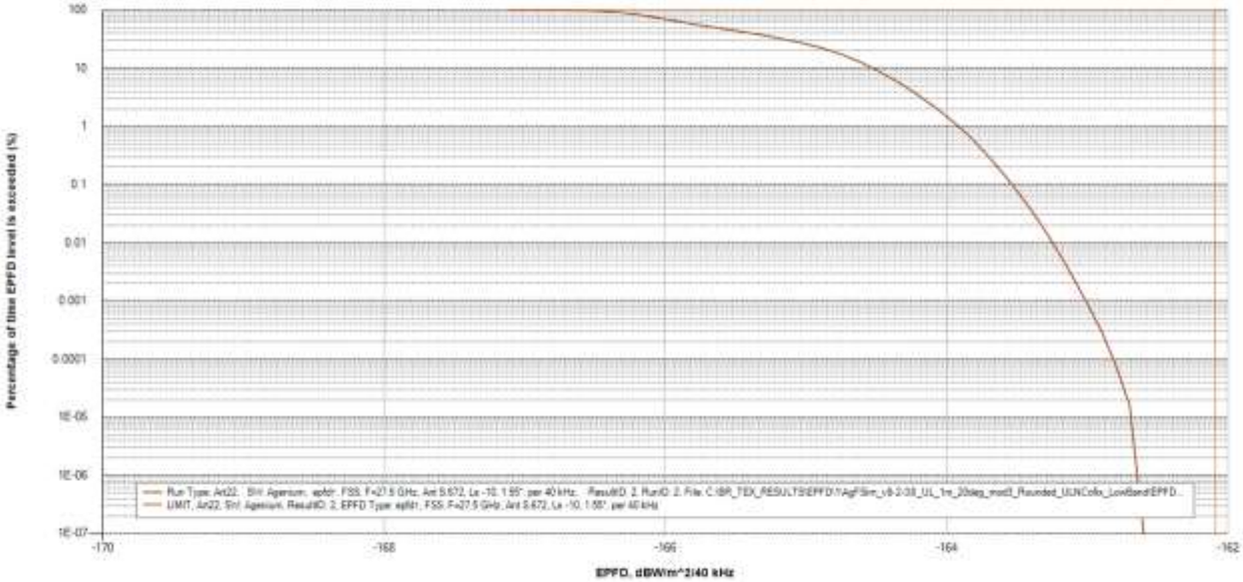


Figure A2-16
EPFD$_{up}$, 29.5-30.0 GHz, Ref. BW= 40 kHz, reference antenna beamwidth 1.55deg

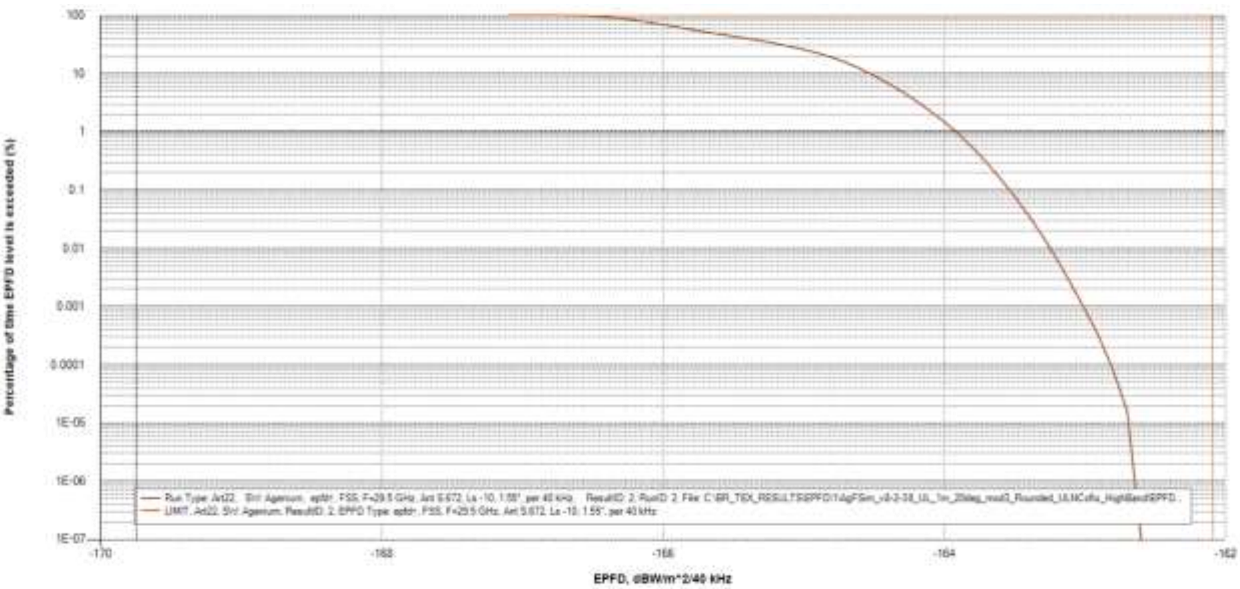
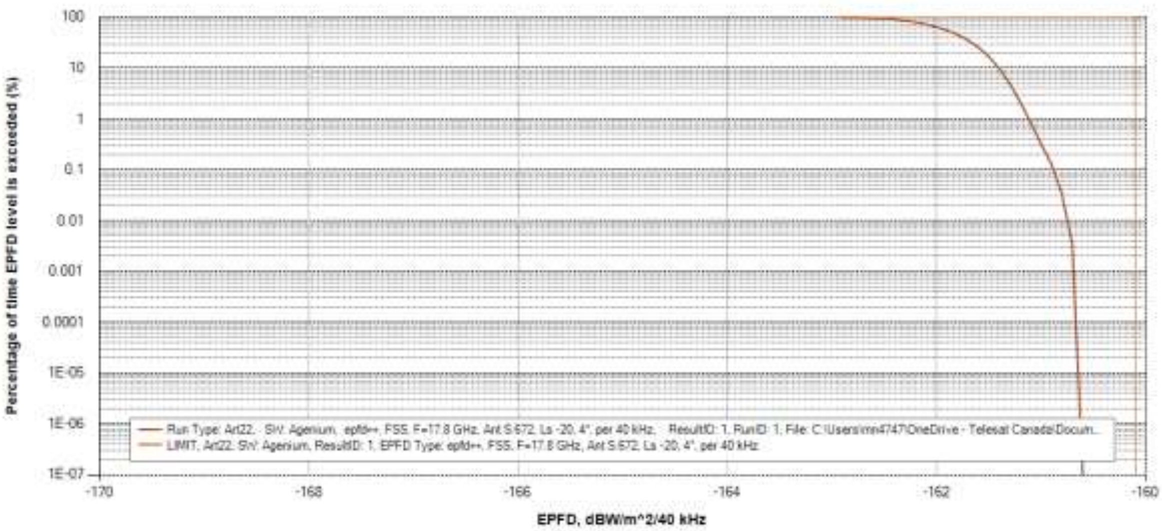


Figure A2-17
EPFD$_{is}$, 17.8-18.4 GHz, Ref. BW= 40 kHz, reference antenna beamwidth 4deg



ANNEX 3

Modified Constellation Interference Analysis

With Respect to other NGSO Systems

Figure A3-1
Scenario 1 (Uplink), Interferer: SpaceX, Victim: Telesat (User beam), Latitude: 35N

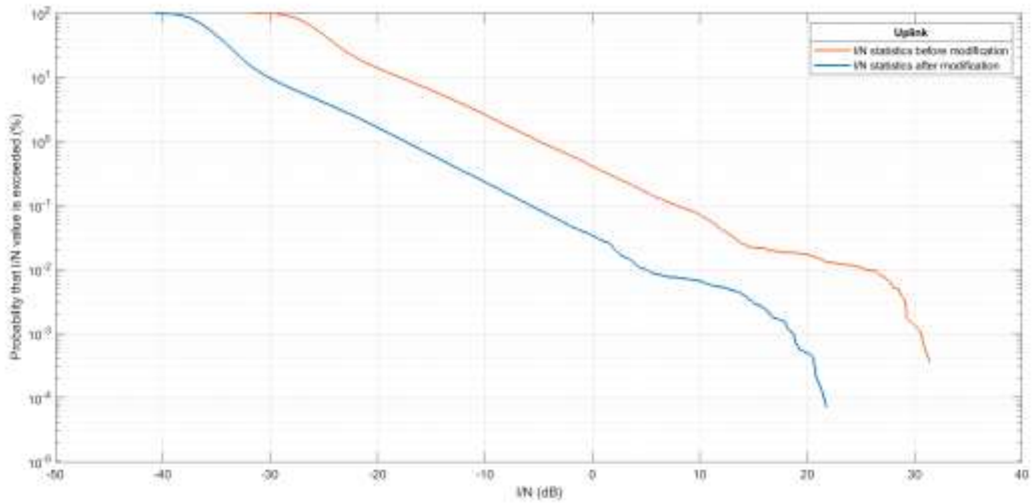


Figure A3-2
Scenario 1 (Uplink), Interferer: SpaceX, Victim: Telesat (User Beam), Latitude: 65N

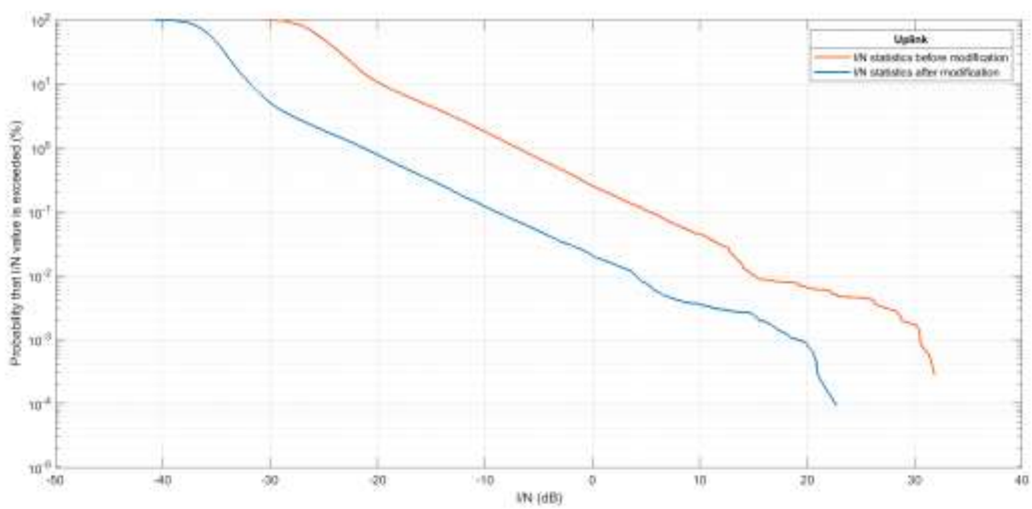


Figure A3-3
Scenario 1 (Uplink), Interferer: SpaceX, Victim: Telesat (Landing Station beam), Latitude: 35N

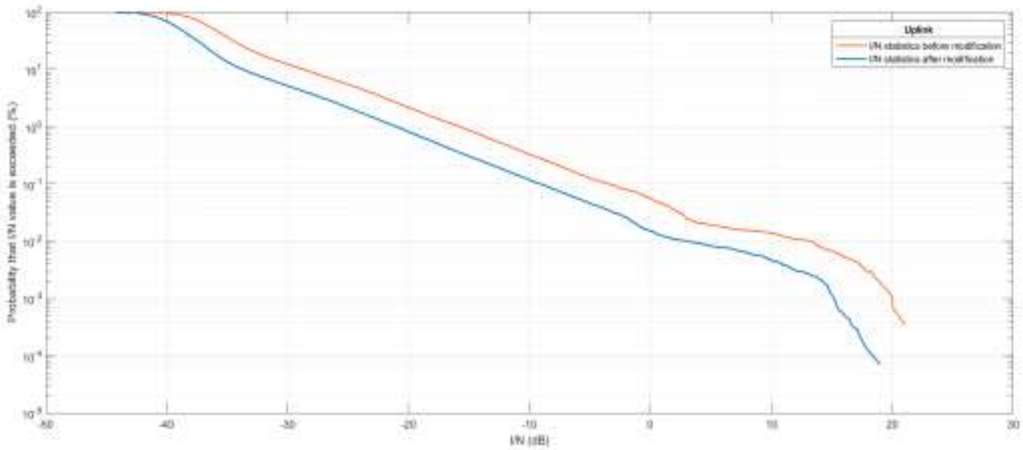


Figure A3-4
Scenario 1 (Uplink), Interferer: SpaceX, Victim: Telesat (Landing Station beam), Latitude: 65N

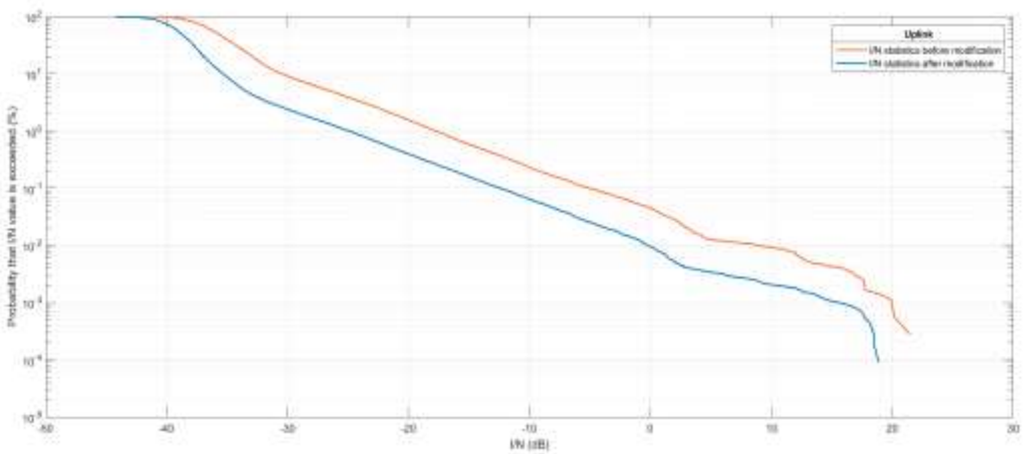


Figure A3-5
Scenario 1 (Uplink), Interferer: OneWeb, Victim: Telesat (User Beam), Latitude: 35N

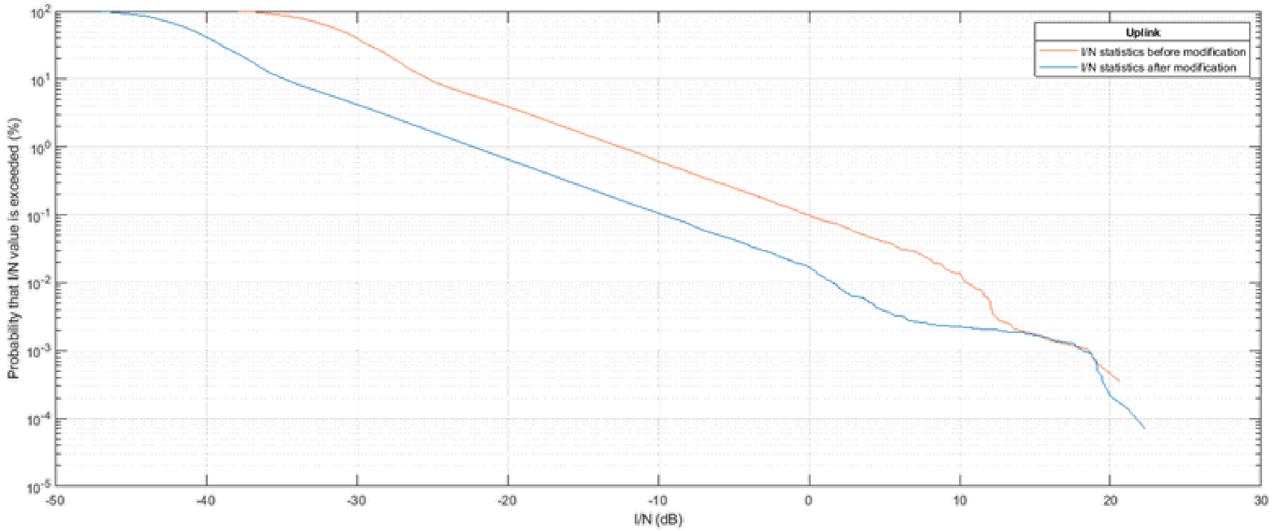


Figure A3-6
Scenario 1 (Uplink), Interferer: OneWeb, Victim: Telesat (User Beam), Latitude: 65N

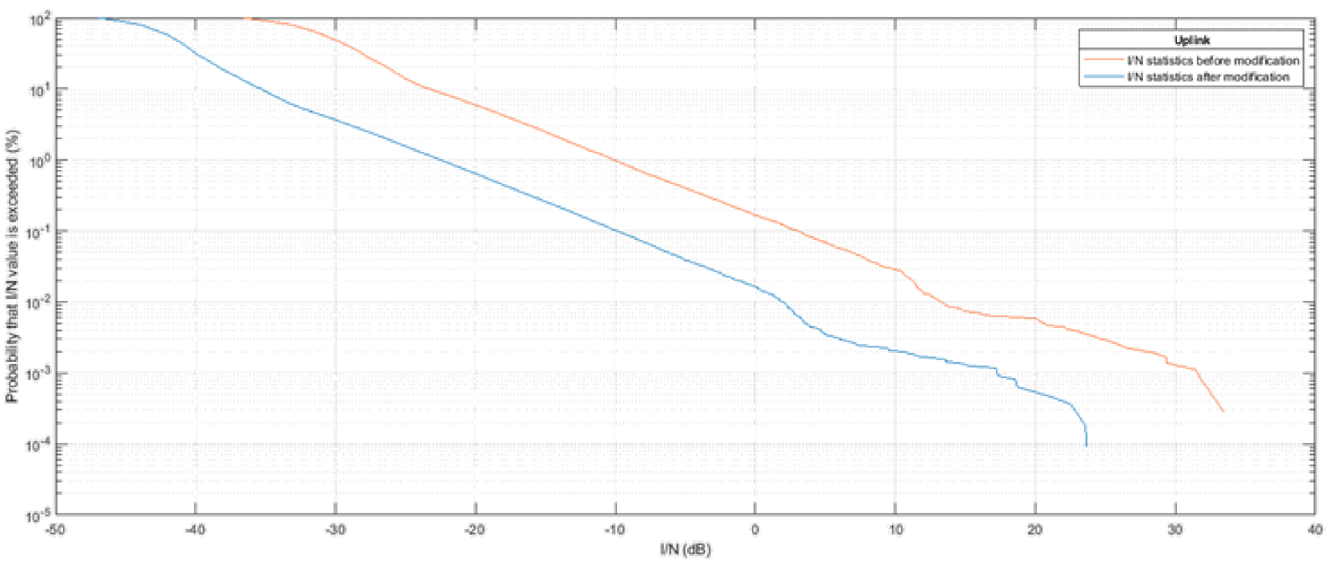


Figure A3-7
Scenario 1 (Uplink), Interferer: OneWeb, Victim: Telesat (Landing Station Beam), Latitude: 35N

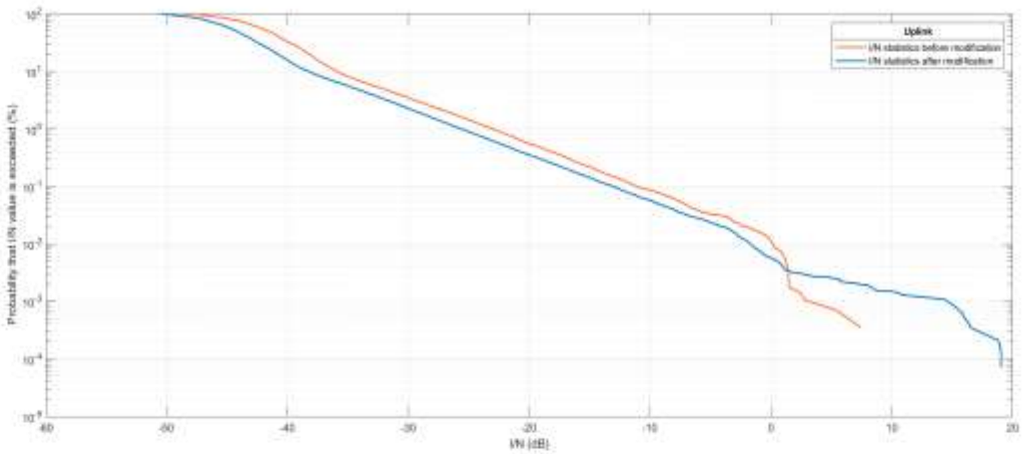


Figure A3-8
Scenario 1 (Uplink), Interferer: OneWeb, Victim: Telesat (Landing Station Beam), Latitude: 65N

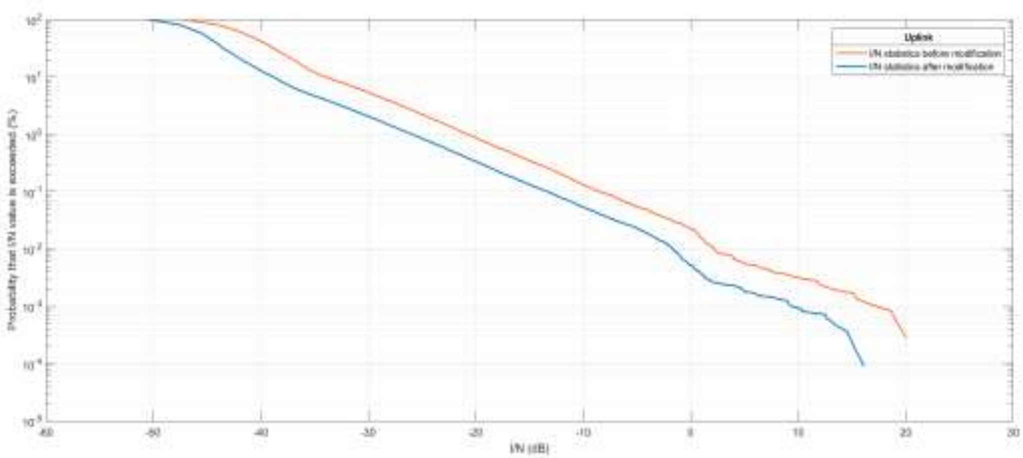


Figure A3-9
Scenario 1 (Uplink), Interferer: O3b (0.85m terminal), Victim: Telesat (User Beam), Latitude: 35N

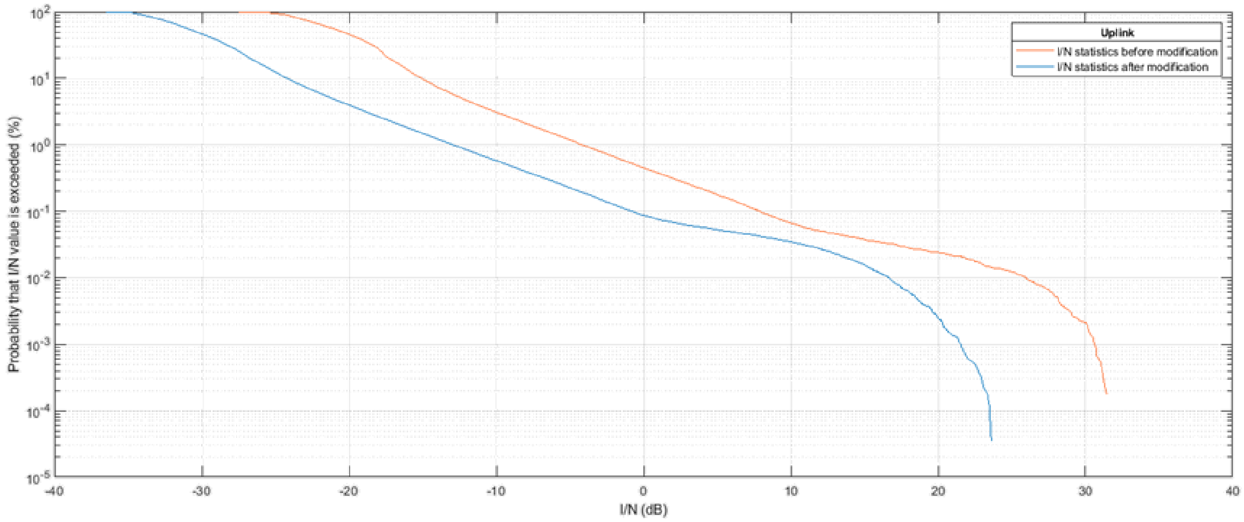


Figure A3-10
Scenario 1 (Uplink), Interferer: O3b (2.4m terminal), Victim: Telesat (User Beam), Latitude: 35N

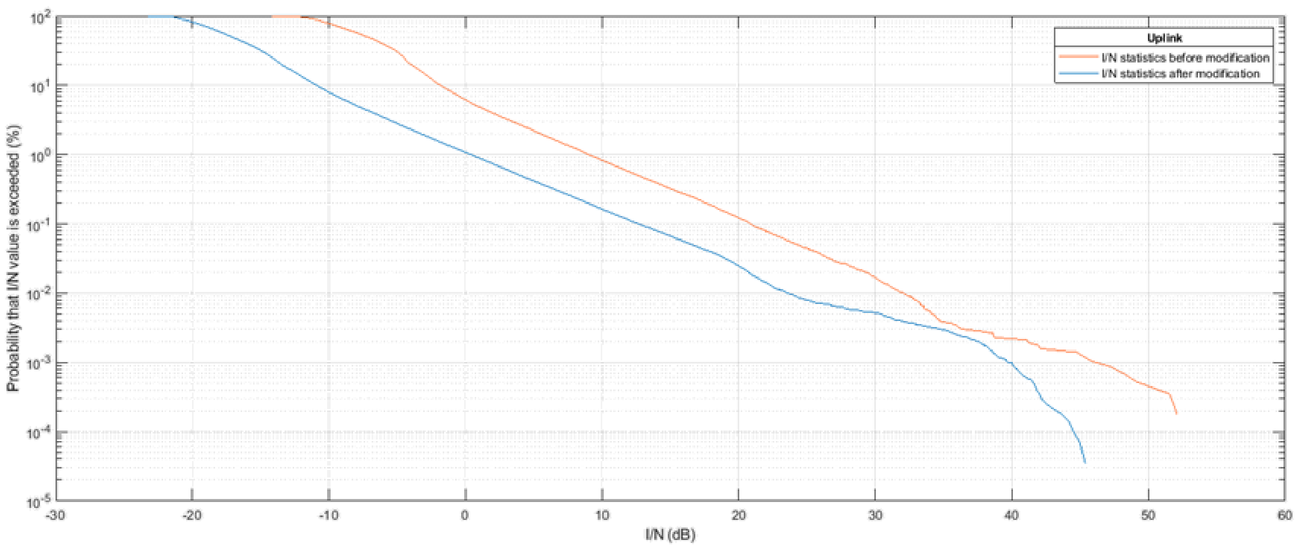


Figure A3-11
Scenario 1 (Uplink), Interferer: O3b (0.85m terminal), Victim: Telesat (User Beam), Latitude: 65N

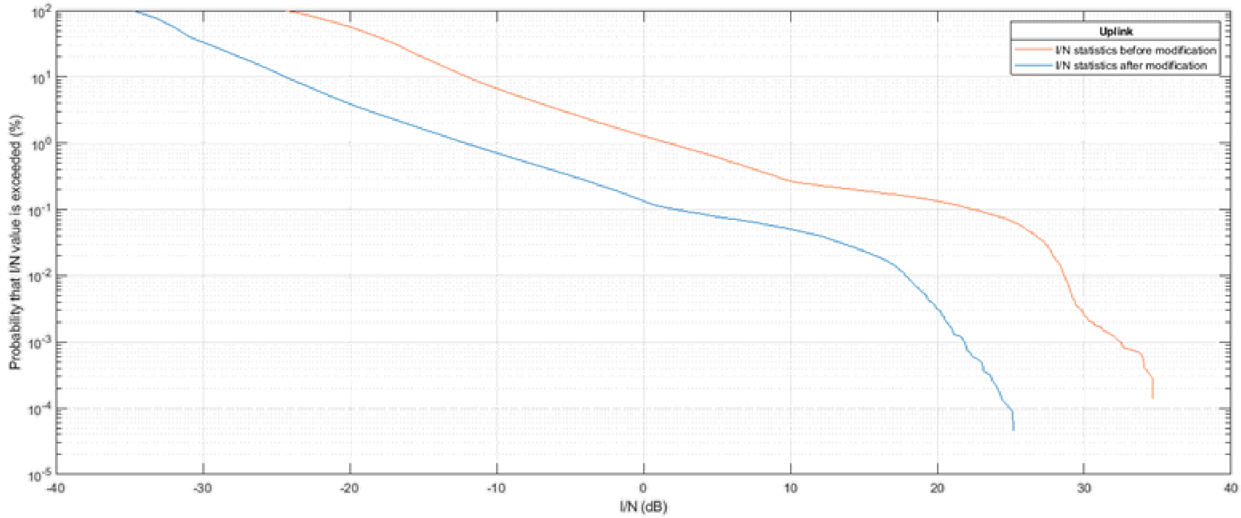


Figure A3-12
Scenario 1 (Uplink), Interferer: O3b (2.4m terminal), Victim: Telesat (User Beam), Latitude: 65N

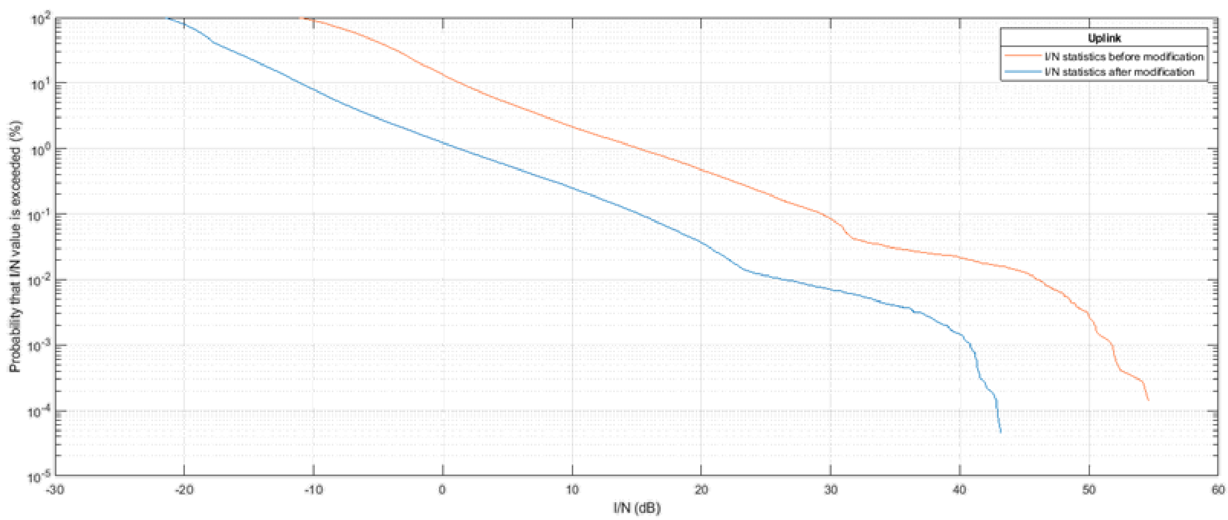


Figure A3-13
Scenario 1 (Uplink), Interferer: O3b (0.85m terminal), Victim: Telesat (Landing Station Beam), Latitude: 35N

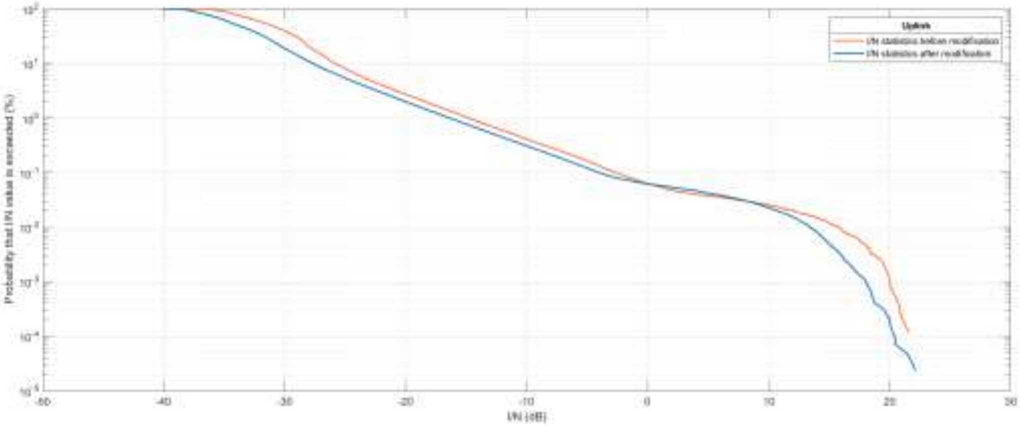


Figure A3-14
Scenario 1 (Uplink), Interferer: O3b (2.4m terminal), Victim: Telesat (Landing Station Beam), Latitude: 35N

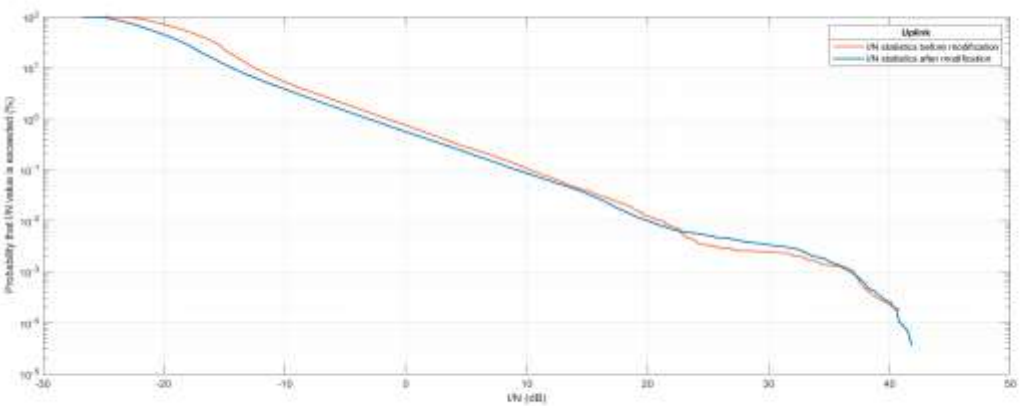


Figure A3-15
Scenario 1 (Uplink), Interferer: O3b (0.85m terminal), Victim: Telesat (Landing Station Beam), Latitude: 65N

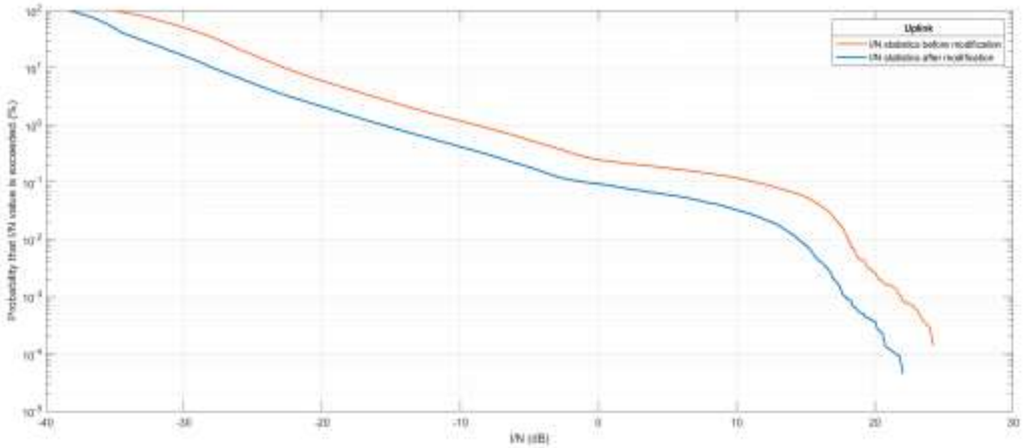


Figure A3-16
Scenario 1 (Uplink), Interferer: O3b (2.4m terminal), Victim: Telesat (Landing Station Beam), Latitude: 65N

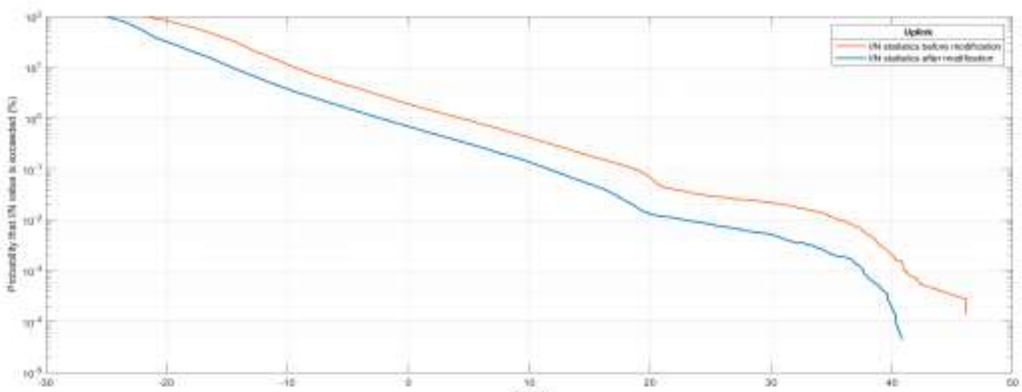


Figure A3-17
Scenario 2 (Uplink), Interferer: Telesat (1m terminal), Victim: SpaceX, Latitude: 35N

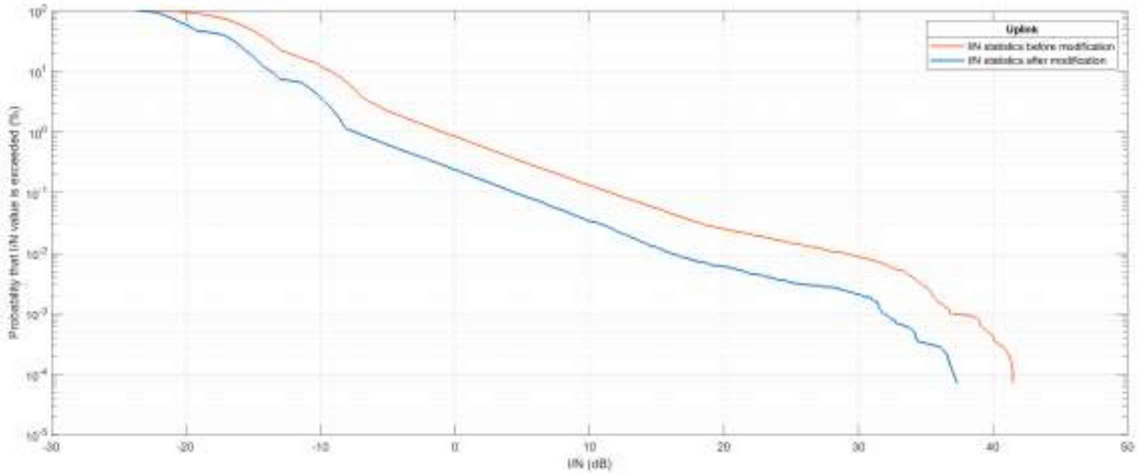


Figure A3-18
Scenario 2 (Uplink), Interferer: Telesat (3.5m terminal), Victim: SpaceX, Latitude: 35N

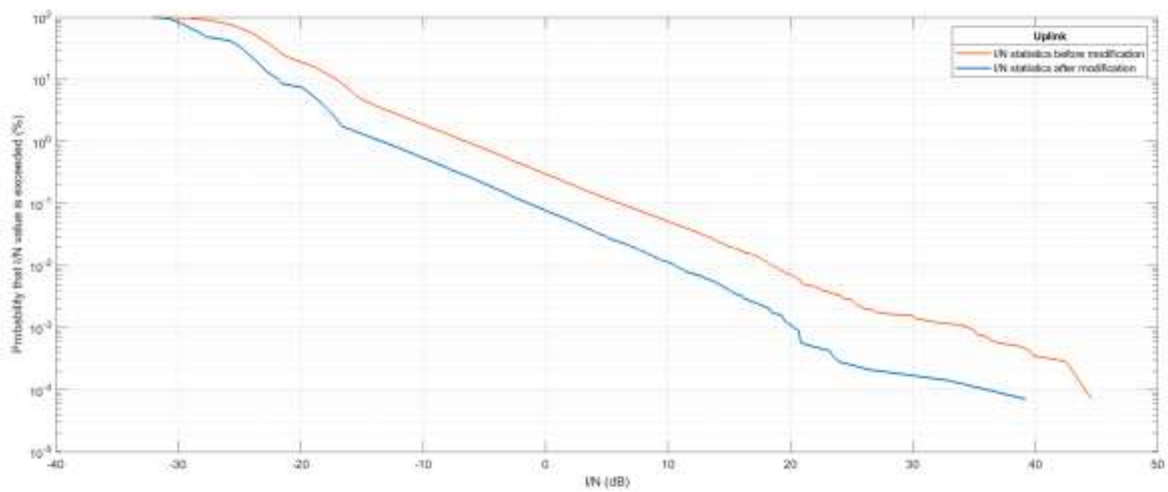


Figure A3-19
Scenario 2 (Uplink), Interferer: Telesat (1m terminal), Victim: SpaceX, Latitude: 65N

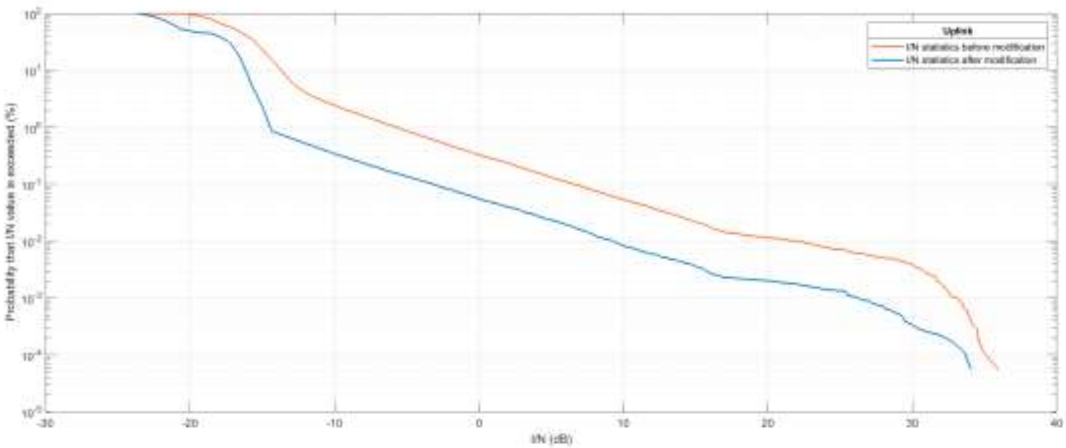


Figure A3-20
Scenario 2 (Uplink), Interferer: Telesat (3.5m terminal), Victim: SpaceX, Latitude: 65N

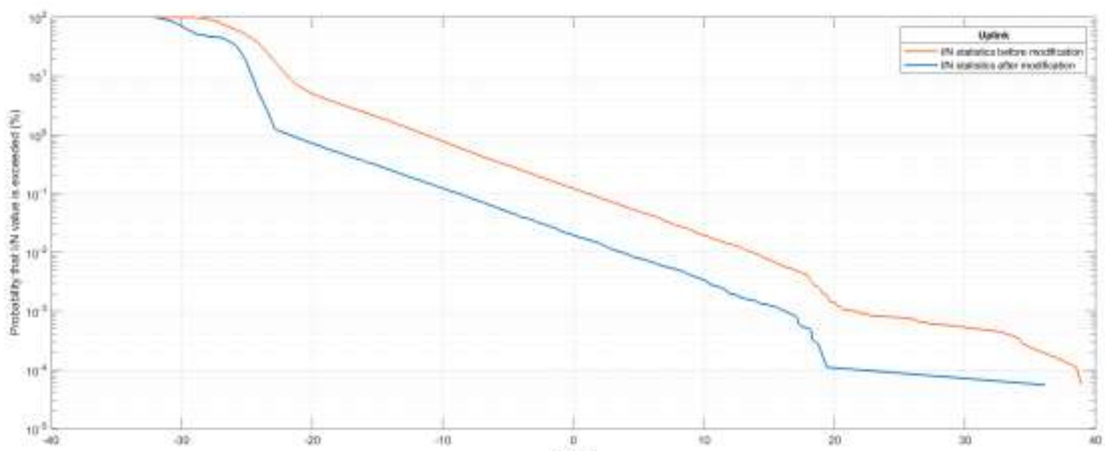


Figure A3-21
Scenario 2 (Uplink), Interferer: Telesat (1m terminal), Victim: OneWeb, Latitude: 35N

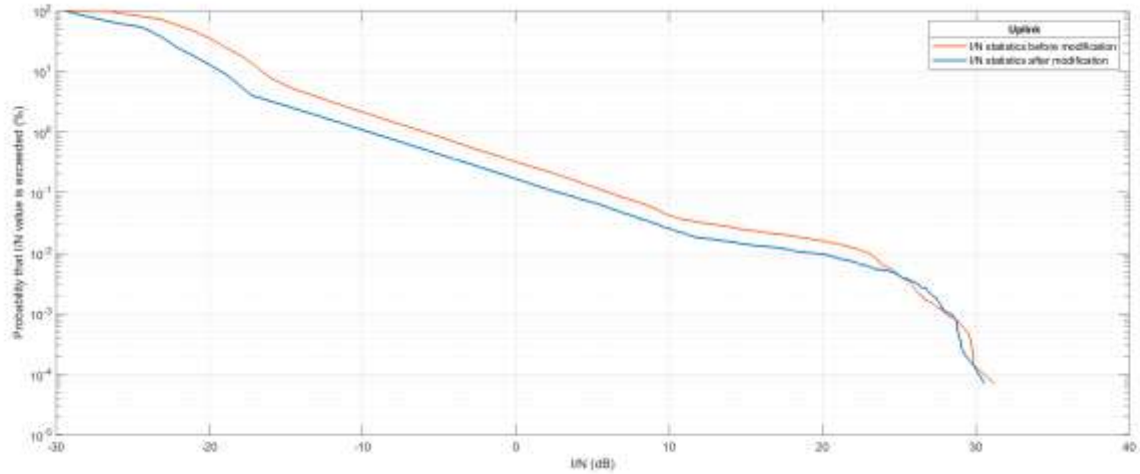


Figure A3-22
Scenario 2 (Uplink), Interferer: Telesat (3.5m terminal), Victim: OneWeb, Latitude: 35N

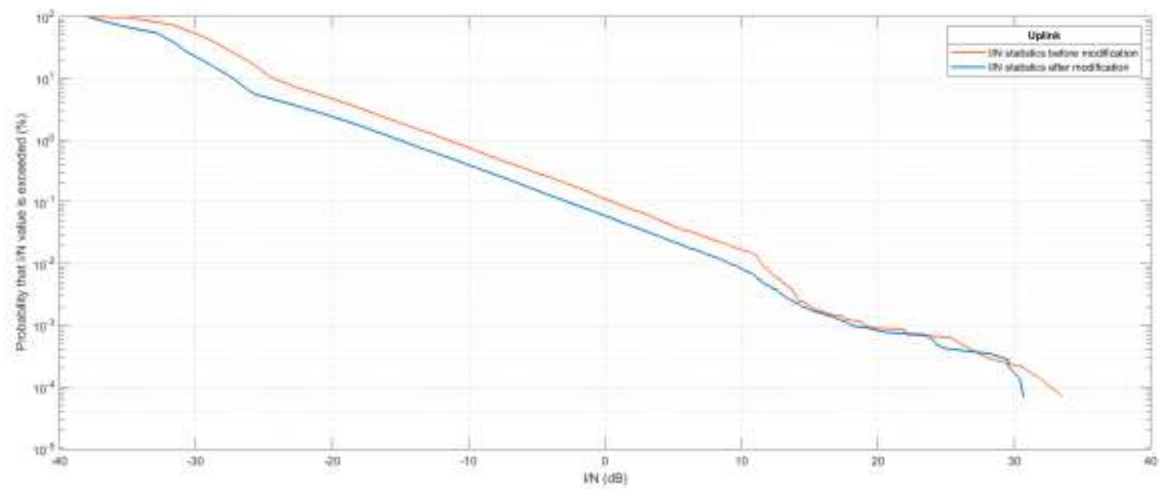


Figure A3-23
Scenario 2 (Uplink), Interferer: Telesat (1m terminal), Victim: OneWeb, Latitude: 65N

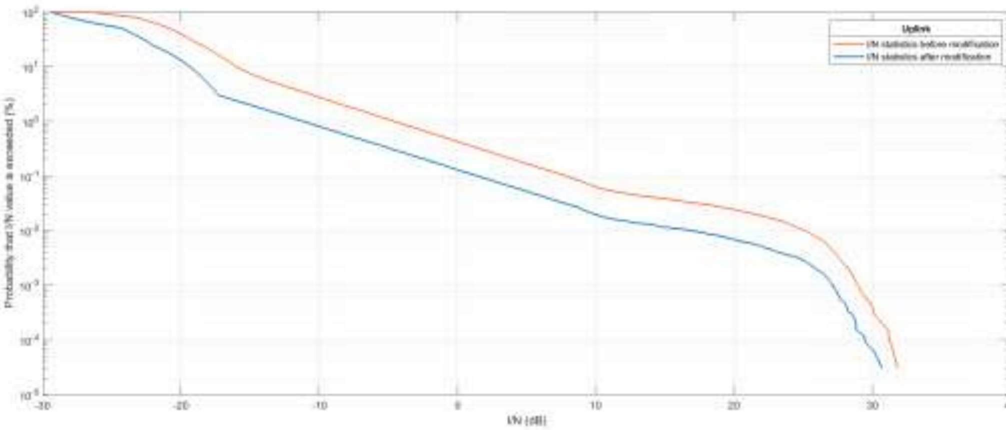


Figure A3-24
Scenario 2 (Uplink), Interferer: Telesat (3.5m terminal), Victim: OneWeb, Latitude: 65N

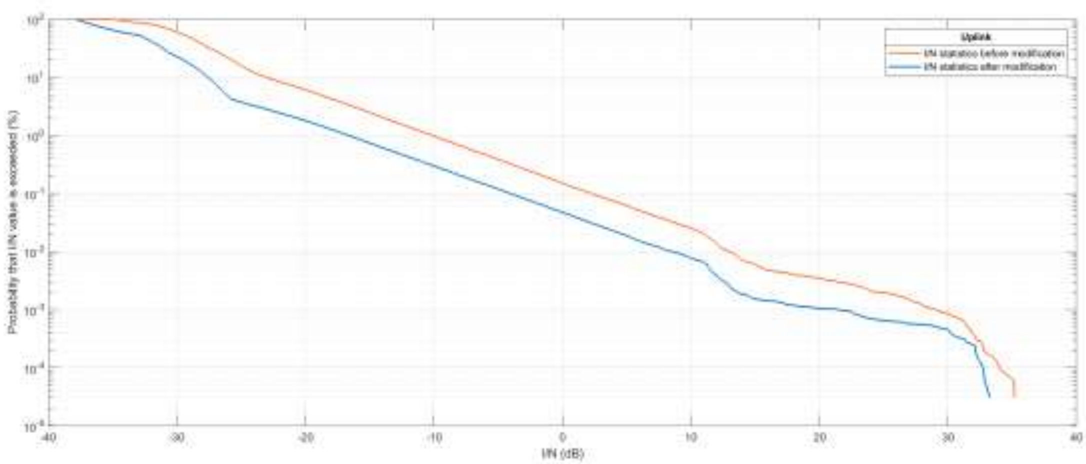


Figure A3-25
Scenario 2 (Uplink), Interferer: Telesat (1m terminal), Victim: O3b, Latitude: 35N

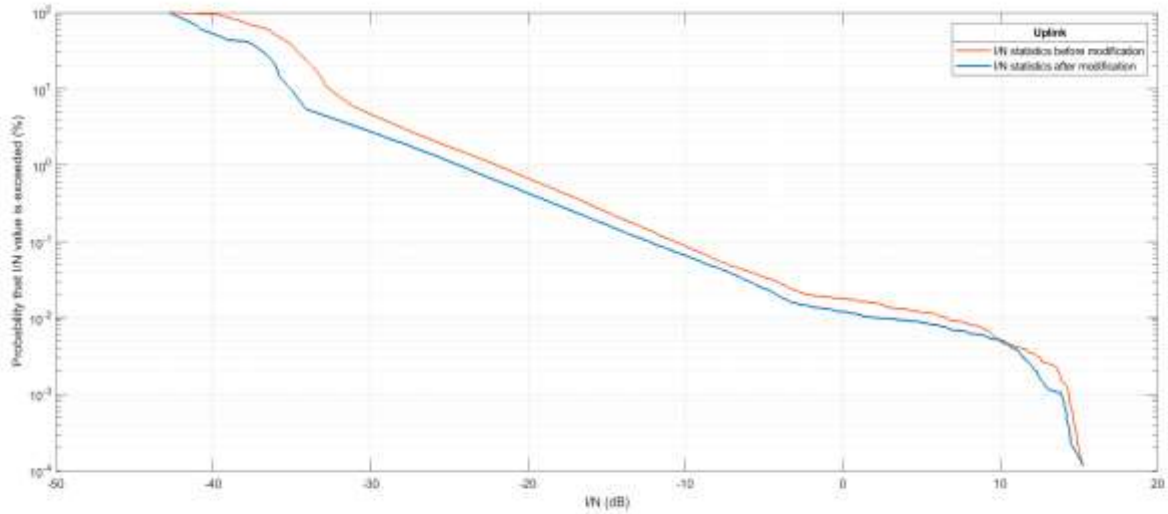


Figure A3-26
Scenario 2 (Uplink), Interferer: Telesat (3.5m terminal), Victim: O3b, Latitude: 35N

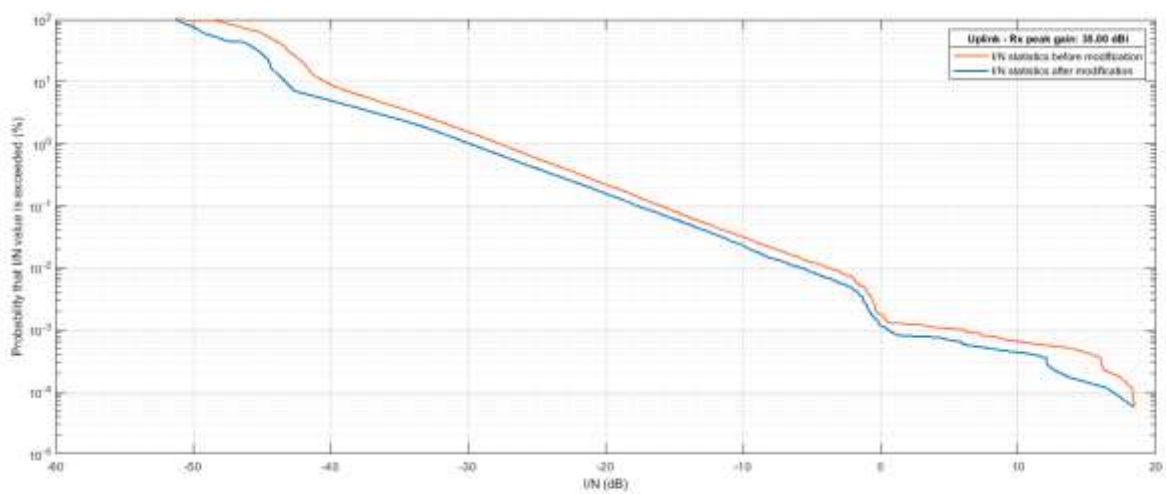


Figure A3-27
Scenario 2 (Uplink), Interferer: Telesat (1m terminal), Victim: O3b, Latitude: 65N

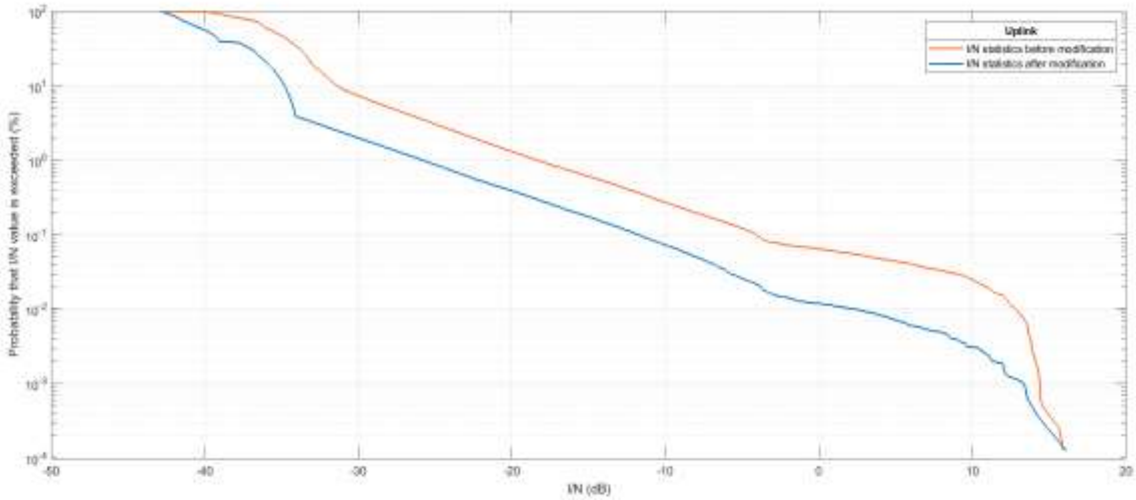


Figure A3-28
Scenario 2 (Uplink), Interferer: Telesat (3.5m terminal), Victim: O3b, Latitude: 65N

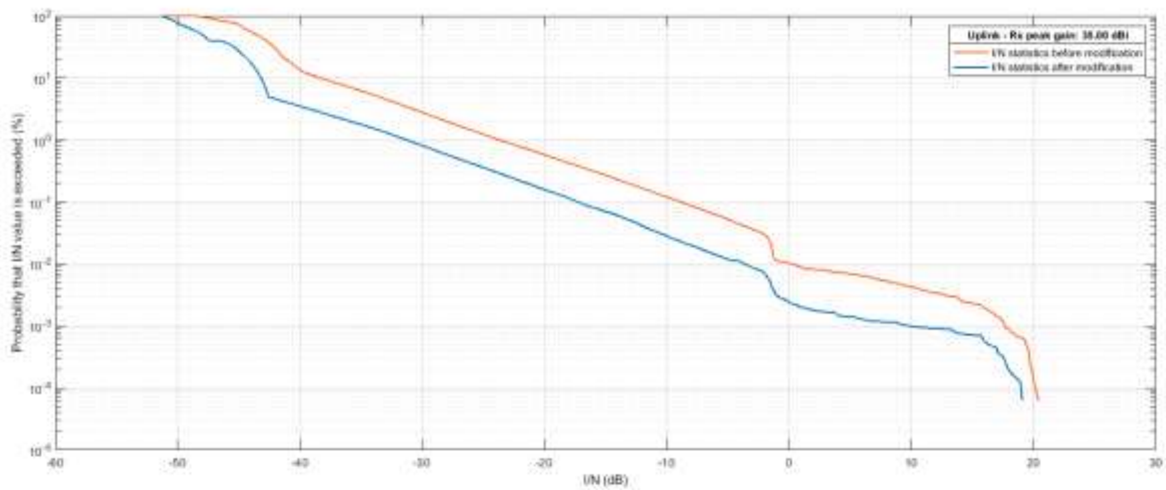


Figure A3-29
Scenario 3 (Downlink), Interferer: SpaceX, Victim: Telesat (1m terminal[18]),
Latitude: 35N

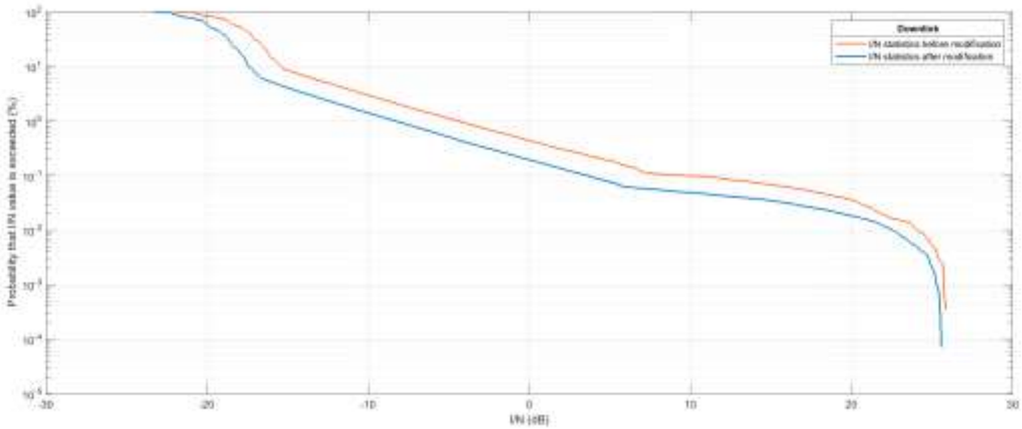
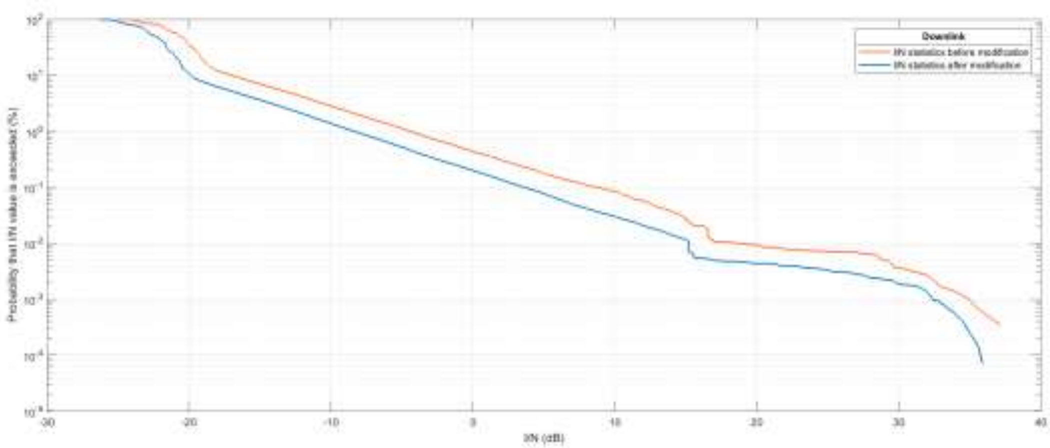


Figure A3-30
Scenario 3 (Downlink), Interferer: SpaceX, Victim: Telesat (3.5m terminal[19]),
Latitude: 35N



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[18] The G/T for the Telesat 1m terminal changes from 20.5 dB/K in the Constellation, to 20.1 dB/K in the Modified Constellation.

[19] The G/T for the Telesat 3.5m terminal changes from 32.1 dB/K in the Constellation, to 31.0 dB/K in the Modified Constellation.

Figure A3-31
Scenario 3 (Downlink), Interferer: SpaceX, Victim: Telesat (1m terminal), Latitude: 65N

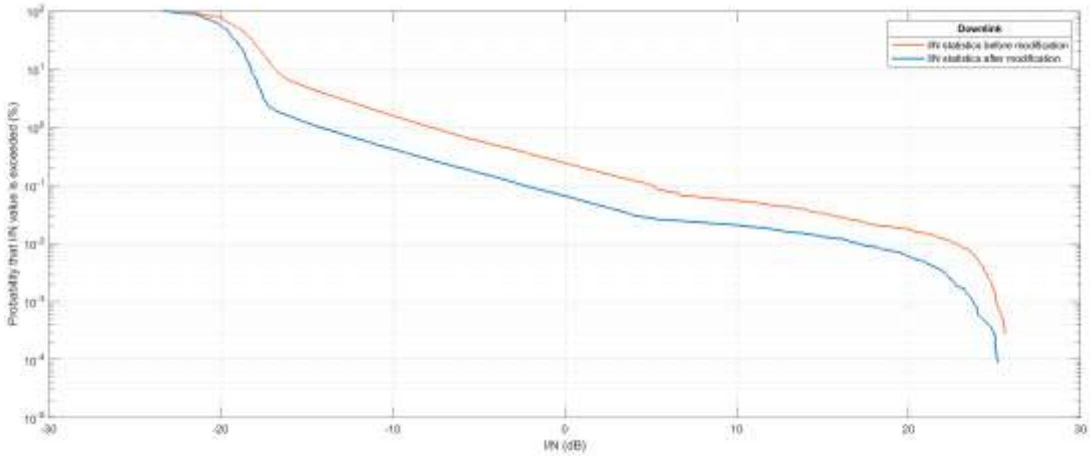

Figure A3-32
Scenario 3 (Downlink), Interferer: SpaceX, Victim: Telesat (3.5m terminal), Latitude: 65N

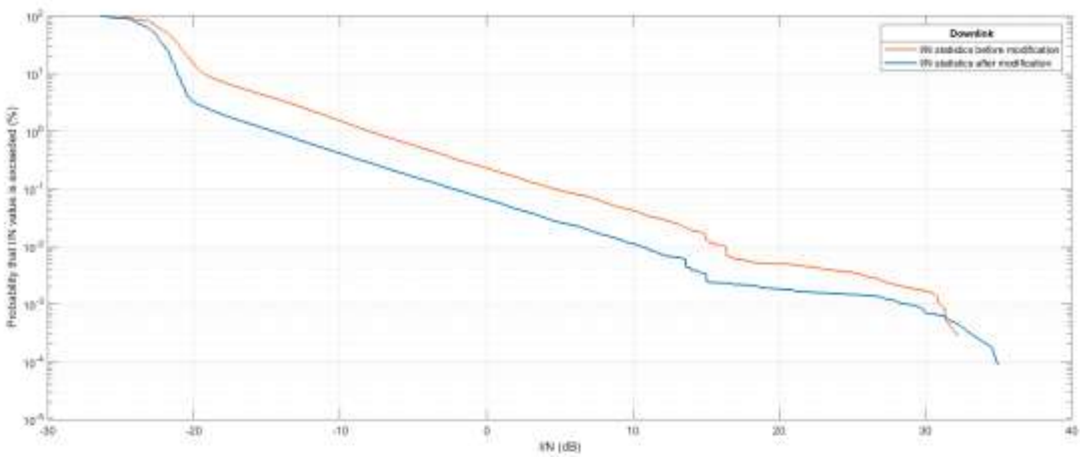

Figure A3-33
Scenario 3 (Downlink), Interferer: OneWeb, Victim: Telesat (1m terminal), Latitude: 35N

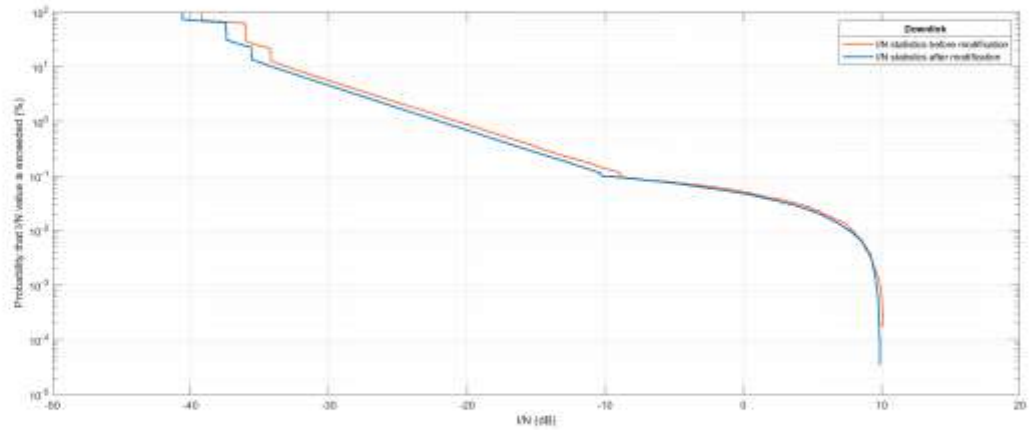

Figure A3-34
Scenario 3 (Downlink), Interferer: OneWeb, Victim: Telesat (3.5m terminal), Latitude: 35N

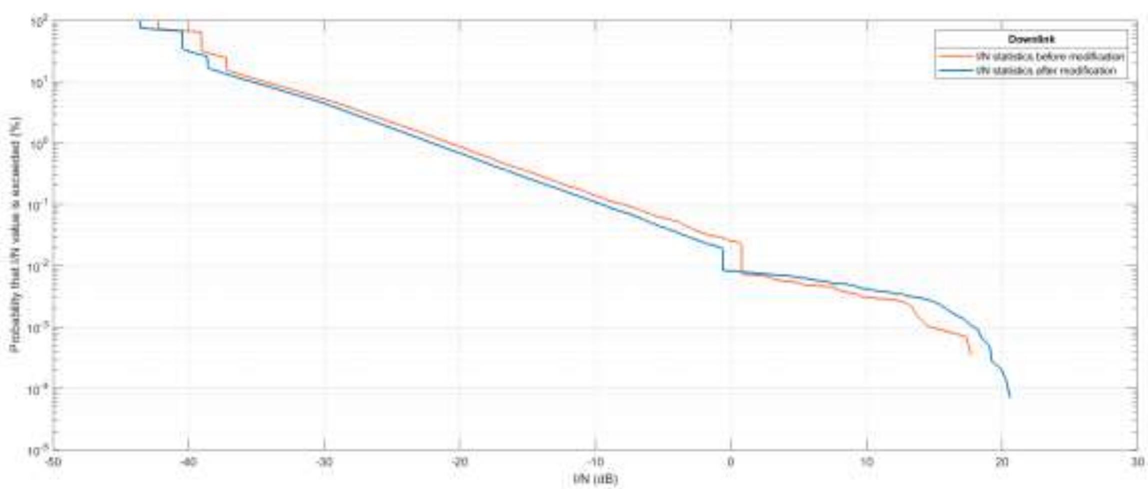

Figure A3-35
Scenario 3 (Downlink), Interferer: OneWeb, Victim: Telesat (1m terminal), Latitude: 65N

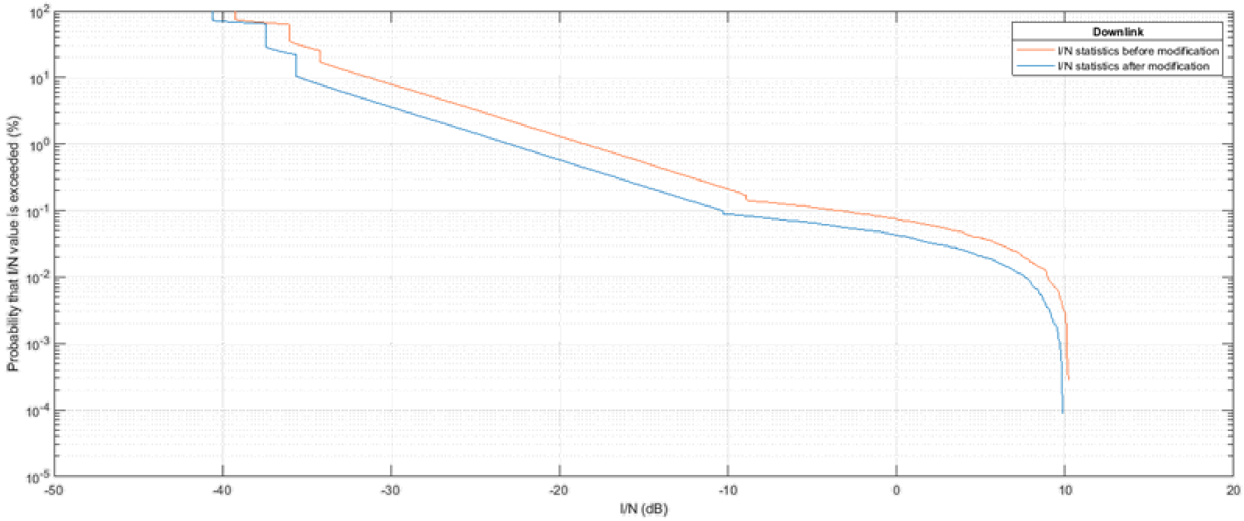

Figure A3-36
Scenario 3 (Downlink), Interferer: OneWeb, Victim: Telesat (3.5m terminal), Latitude: 65N

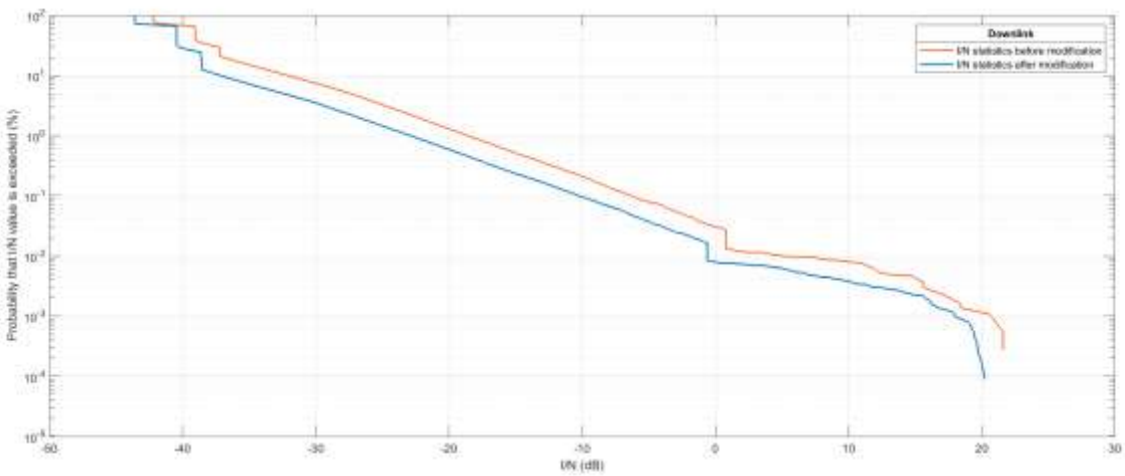

Figure A3-37
Scenario 3 (Downlink), Interferer: O3b, Victim: Telesat (1m terminal), Latitude: 35N

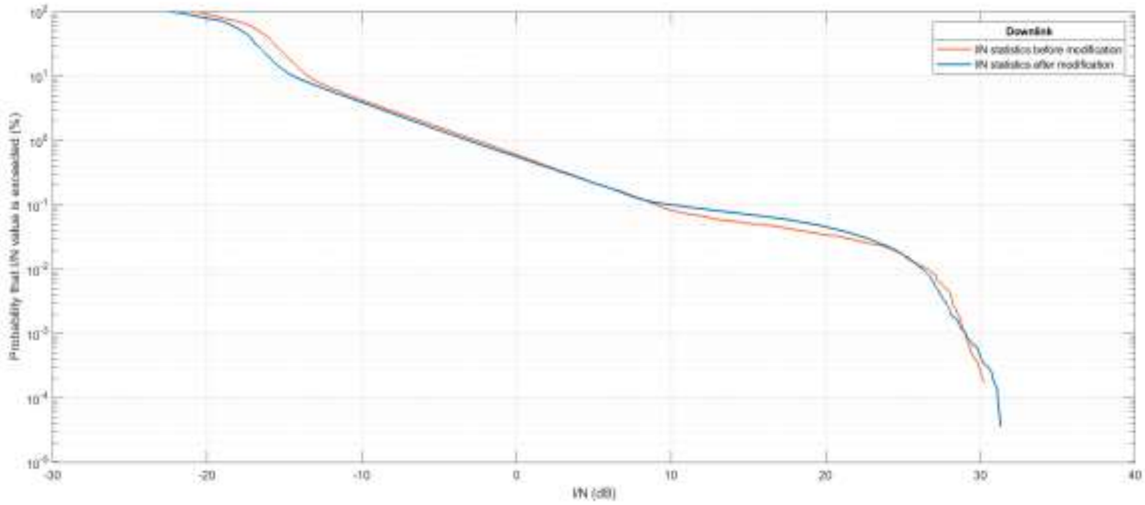

Figure A3-38
Scenario 3 (Downlink), Interferer: O3b, Victim: Telesat (3.5m terminal), Latitude: 35N

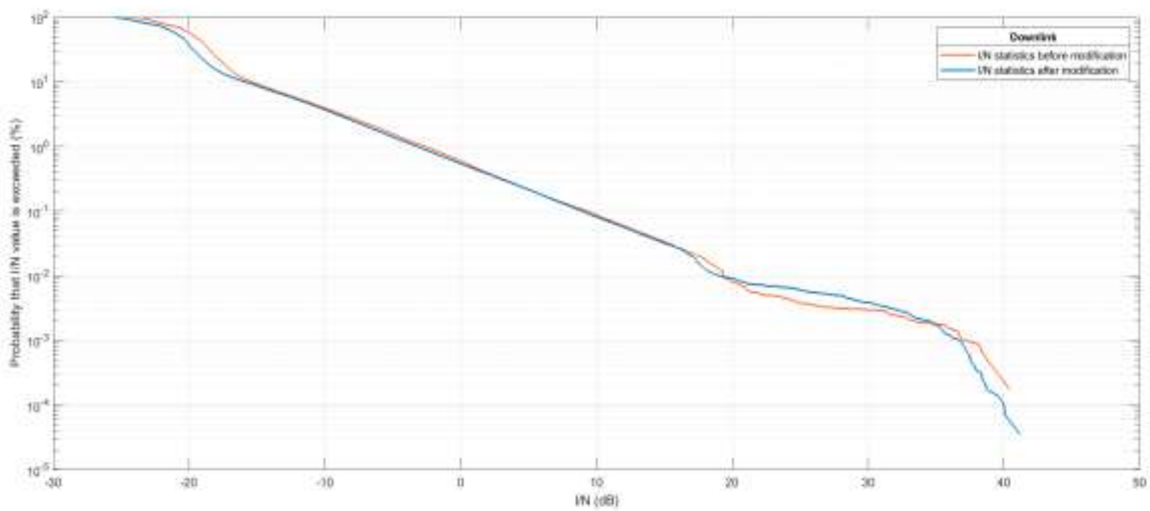

Figure A3-39
Scenario 3 (Downlink), Interferer: O3b, Victim: Telesat (1m terminal), Latitude: 65N

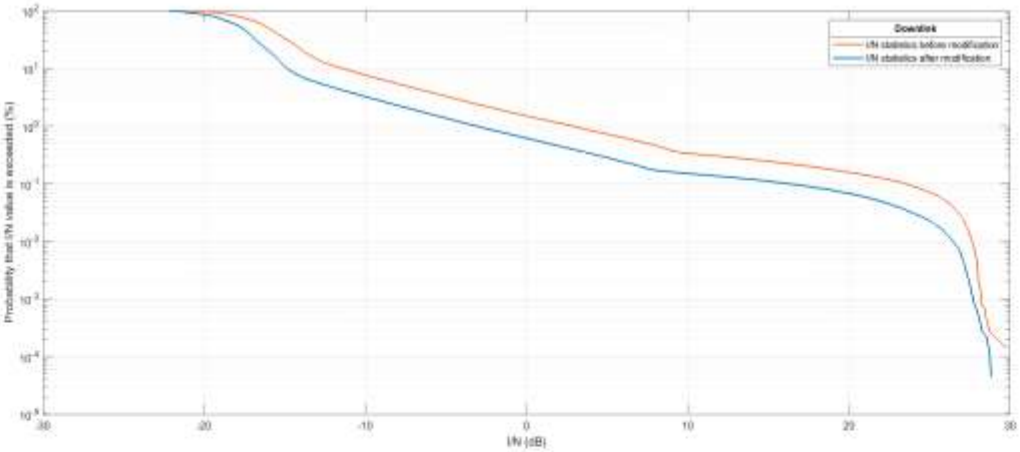

Figure A3-40
Scenario 3 (Downlink), Interferer: O3b, Victim: Telesat (3.5m terminal), Latitude: 65N

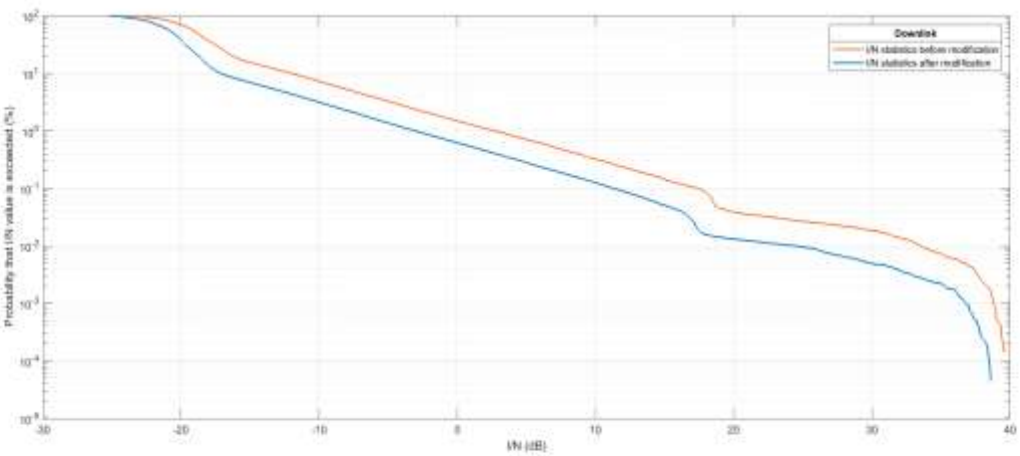

Figure A3-41
Scenario 4 (Downlink), Interferer: Telesat, Victim: SpaceX,
Latitude: 35N

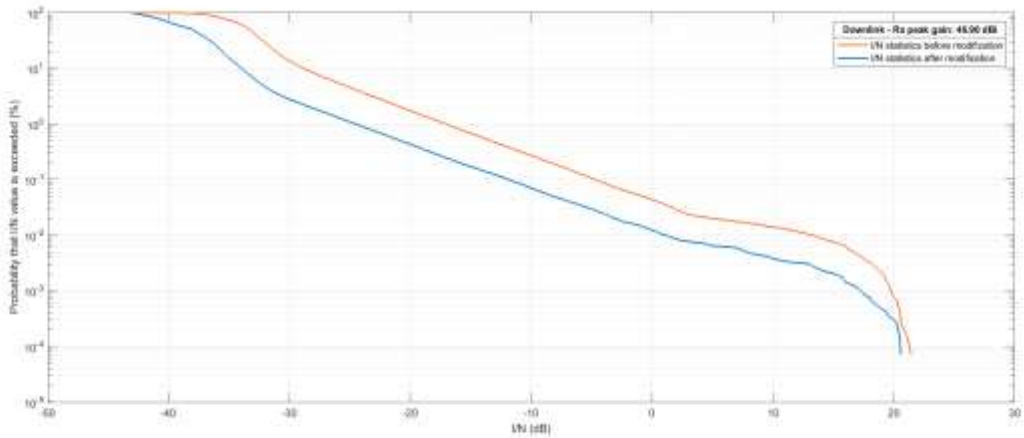

Figure A3-42
Scenario 4 (Downlink), Interferer: Telesat, Victim: SpaceX,
Latitude: 65N

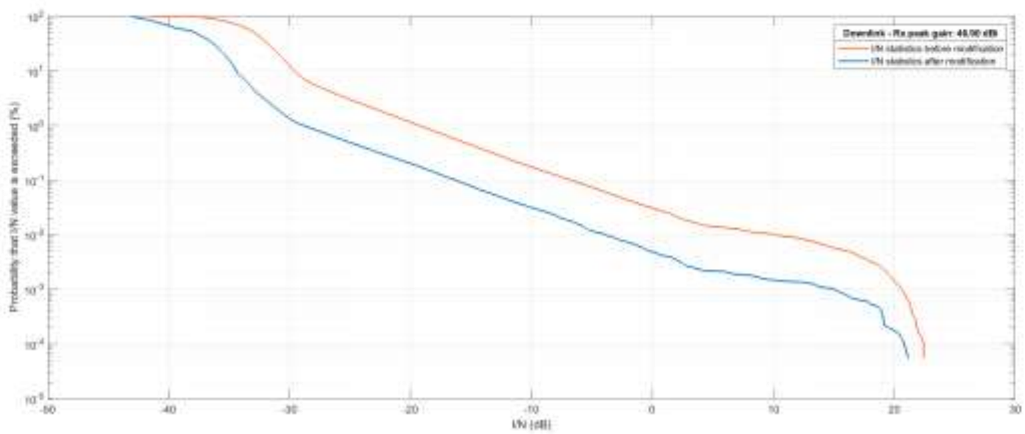

Figure A3-43
Scenario 4 (Downlink), Interferer: Telesat, Victim: OneWeb,
Latitude: 35N

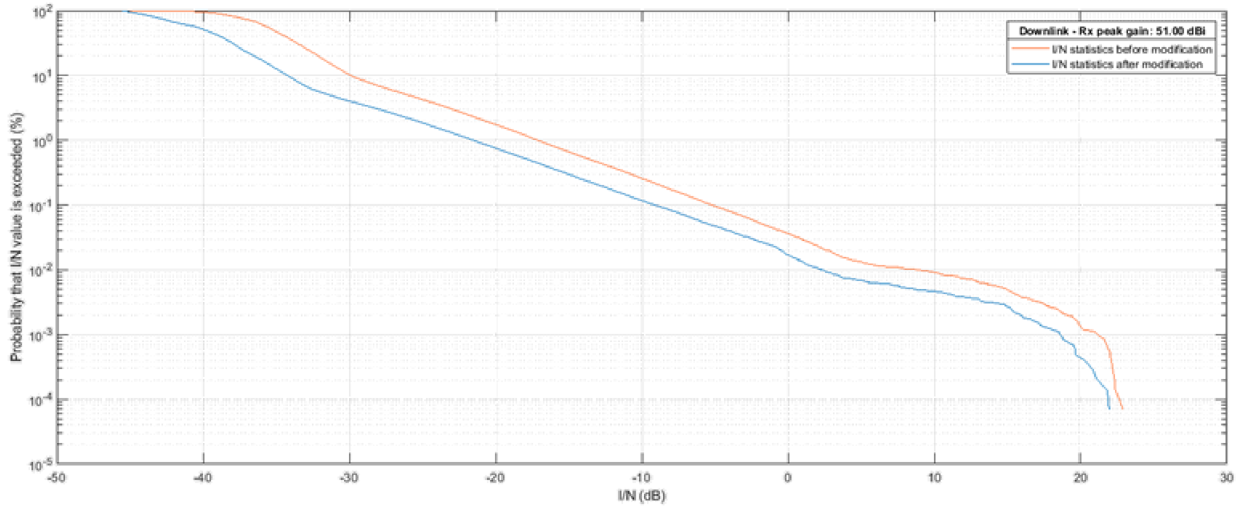

Figure A3-43
Scenario 4 (Downlink), Interferer: Telesat, Victim: OneWeb,
Latitude: 65N

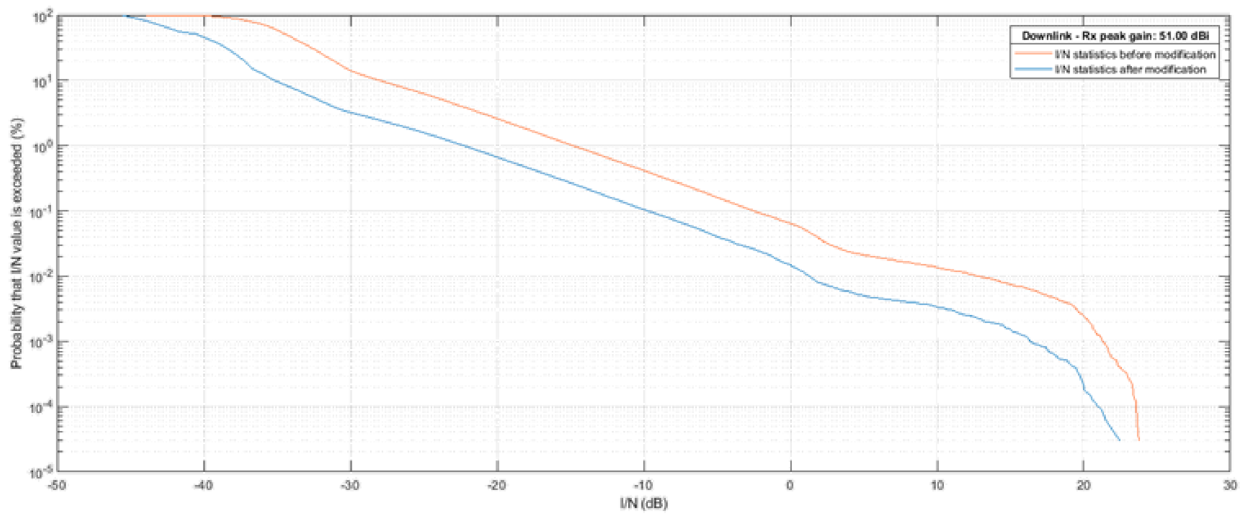

Figure A3-44
Scenario 4 (Downlink), Interferer: Telesat, Victim: O3b (0.85m terminal), Latitude: 35N

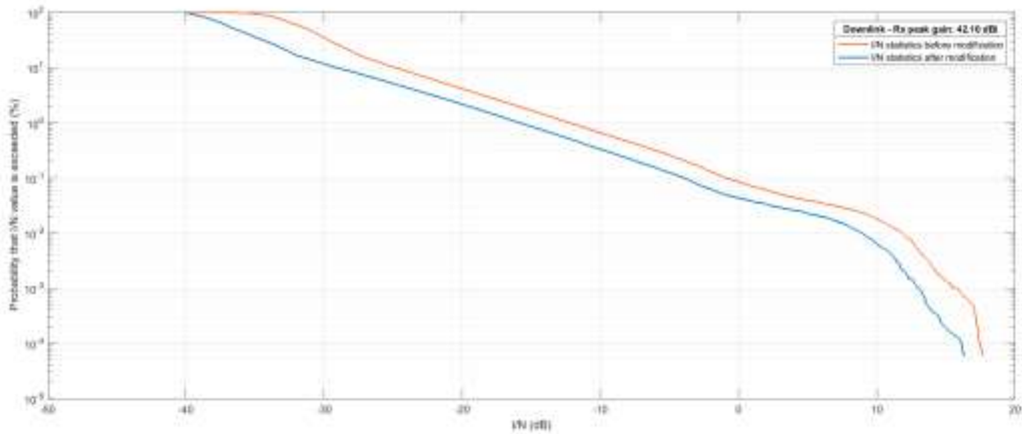

Figure A3-45
Scenario 4 (Downlink), Interferer: Telesat, Victim: O3b (2.4m terminal), Latitude: 35N

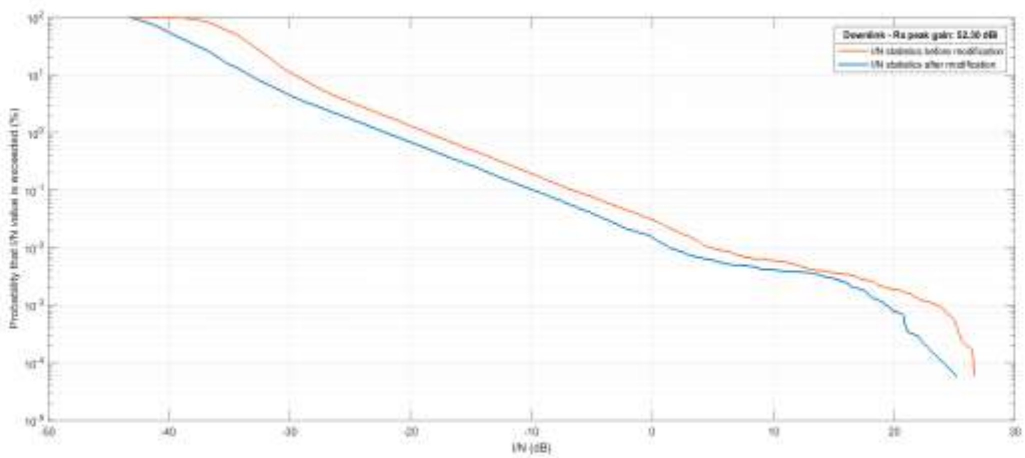

Figure A3-46
Scenario 4 (Downlink), Interferer: Telesat, Victim: O3b (0.85m terminal), Latitude: 65N

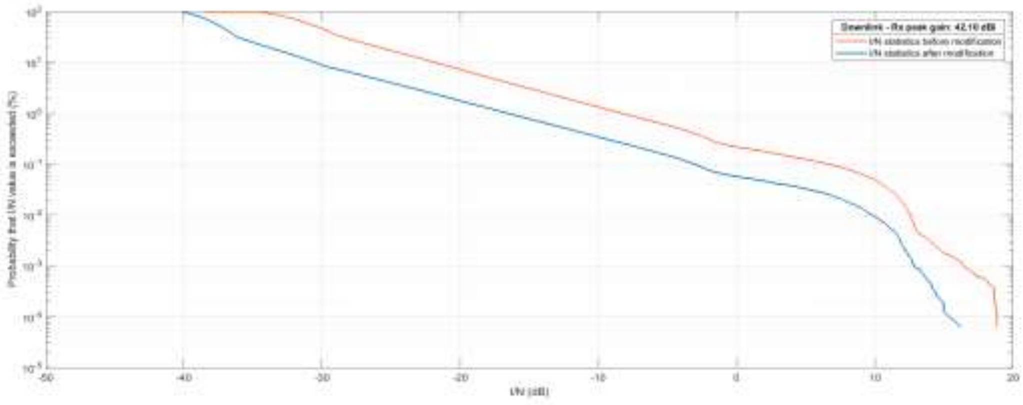

Figure A3-47
Scenario 4 (Downlink), Interferer: Telesat, Victim: O3b (2.4m terminal), Latitude: 65N